

**Efficacy Improvisation of Wastewater Treatment System
and Effluent Management of Indian Permanent Research
Station “Maitri” in Polar Environment in Antarctica**

Ph.D. Thesis

By

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Statement

As required under the University ordinance OB.9.9 (iv), I state that the present thesis entitled “Efficacy Improvisation of Wastewater Treatment System and Effluent Management of Indian Permanent Research Station “Maitri” in Polar Environment in Antarctica” is my original contribution and the same has not been submitted on any previous occasion. To the best of my knowledge the present study is the first comprehensive work of its kind from the area mentioned.

The literature related to the problem investigated has been cited. Due acknowledgement have been made wherever facilities and suggestions have been availed of.

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Certificate

This is to certify that the thesis entitled, "Efficacy Improvisation of Wastewater Treatment System and Effluent Management of Indian Permanent Research Station "Maitri" in Polar Environment in Antarctica", submitted by Mr. Anoop Kumar Tiwari for the award of the degree of Doctor of Philosophy in Marine Science is based on his original studies carried out by him under my supervision. The thesis or any part thereof has not been previously submitted for any other degree or diploma in any universities or institute



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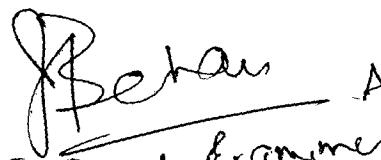
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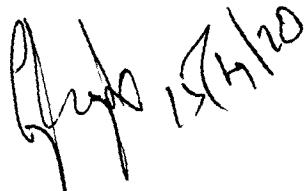
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Chapter 1

Introduction

1.1 Antarctica the “Seventh Continent”

Antarctica is the seventh continent of the world which is driest, coldest, windiest and most inaccessible place on the earth. Lowest minimum temperature ever recorded in Antarctica is -89°C (NOAA, 2009). Wind speed seldom attains the limit of 250 km per hour. This place is known as white desert as 98% of the area is covered with thick ice ranging from 800 m to 4.5 km in depth. The average depth of the ice is around 1.8 km, which covers an area of approximately 13.9 million sq. km i. e., one tenth of the Earth's land surface. The present volume of ice in Antarctica is around 30,000 km³, which is equivalent to 60 m of global sea-level (Siegert, 2000). The Antarctic ice contains about 70 percent of world's fresh water.

Antarctica is a critical component of global climate system and geodynamics. The separation of Antarctica from Gondwanaland took place about 180 million years ago (Reading, 2006) and the events that took place about 90 million years ago and also 25 million years ago are landmarks in geological history (Clarke et al., 2005). Actually the birth of Southern Ocean and Antarctic Polar Front (APF) took place after opening the Drake Passage (Rintoul, 2009; Carter et al., 2008) about 30 million years ago. Today Antarctica and Southern Ocean are unique places to conduct study on ozone hole, atmospheric chemistry and dynamics, palaeoclimatic research from ice core and marine sediments (Edwards et al., 1998; Moody et al., 2005), sun earth relationship, global climate change and genome research from cold regions. Antarctica is a continent with a difference. Its vast ice sheet, remote location and inhospitable conditions make it a challenging place for scientific research. Being a critical component of earth climate and ocean circulation system, Antarctica offers a unique platform for addressing global scientific issues such as climate change, ozone hole, sea level rise etc; and regional issues

like katabatic winds and Antarctic sub-glacial lakes. These lakes are drawing attention of scientists across disciplines of geosciences, physical, environment and life sciences and are challenges to technologists and environmentalists for developing appropriate techniques to carry out the research work without disturbing the pristine lakes and complying with the Antarctic Treaty System (*Bonner, 1987*).

Antarctic Ocean supports biological communities of a few species which have large populations and short food chain processes. It is among the richest biological provinces on the earth. The important organism regulating the simple food chain (*Clarke, 2003*) in the Antarctic waters is "krill"(like shrimp).The Indian, Atlantic and the Pacific Oceans meet around Antarctica forming a distinct body of water which girdles the earth and is uninterrupted by any landmass. The mixing process between cold and warm water in this body of water demarcates the area of Antarctic convergence which has great importance to biologists and chemists.

Antarctica by acting as a global heat sink helps to control Earth's climate and weather and influences global ocean. Cold, dense, oxygen-rich waters originate in Antarctica and replenish the ocean's supply of bottom water, helping to drive ocean circulation. The sea surrounding Antarctica supports marine life from tiny ice-dwelling algae to the great whales. Through investigations of Antarctica it will be possible to develop a better understanding of how this vast, ice-covered continent responds to environmental change. This knowledge will enable further to predict the response of all of Earth's systems to future environmental change.

For environmental study, Antarctica provides a unique, unpolluted and stable environment for carrying out scientific observations. It is far away from all sources of environmental contamination and thus remains an unpolluted datum point from which global changes due to pollution could be monitored, thus it is very important place to carry out significant study on environmental changes (*Pandey and Tiwari, 2005*).

1.1.1 Antarctica Treaty System

Antarctic Treaty, signed on 1st of December 1959 by twelve nations and entered into force on 23rd June 1961, establishes the legal framework for the management of Antarctica (*Department of States, 2002*). At present there are 47 treaty member nations including India in which 30 nations have consultative status and few more countries are in the process to join for consultative status (*Grant, 2005*).

The Governments of Argentina, Australia, Belgium, Chile, the French Republic, Japan, New Zealand, Norway, the Union of South Africa, the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland and the United States of America, were original signatories of Antarctica and

- ↳ recognizing that it is in the interest of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord;
- ↳ acknowledging the substantial contributions to scientific knowledge resulting from international co-operation in scientific investigation in Antarctica; Convinced that the establishment of a firm foundation for the continuation and development of such co-operation on the basis of freedom of scientific investigation in Antarctica as applied during the International Geophysical Year accords with the interests of science and the progress of all mankind;
- ↳ convinced also that a treaty ensuring the use of Antarctica for peaceful purposes only and the continuance of international harmony in Antarctica will further the purposes and principles embodied in the Charter of the United Nations.
- ↳ have agreed on the ATS which consists altogether 14 articles on various aspects of scientific, logistics, international cooperation and preservation of continent flora and fauna.

1.1.2 The Madrid Protocol

Environmental Protocol, which is also known as “Madrid Protocol” (*Environment Protocol, 1991*) was adopted in 1991 in response to proposals that the wide range of

provisions relating to protection of the Antarctic environment should be harmonized in a comprehensive and legally binding form. Recognizing the importance of Antarctica and its pristine environment and at the same time the growing scientific interest in understanding climate, environment biology etc, stemmed the Environmental Protocol, which can safeguard the Antarctic unpolluted area (*Harris and Meadows, 1992*). It draws on and updates the Agreed Measures as well as subsequent Treaty meeting recommendations relating to protection of the environment Protocol as part of the Antarctic Treaty System. It provides for comprehensive protection of the Antarctic environment and dependent and associated ecosystems. The Protocol on Environmental Protection to Antarctic Treaty and more commonly referred as Environmental Protocol or Madrid Protocol came into force in 1998. It prohibits the mineral resource activities and amongst other things stipulates, that;

“The protection of the Antarctic environment and development and associated ecosystems and the intrinsic value of Antarctica, including its wilderness and aesthetic values and its value as an area for the conduct of scientific research essential to understanding the global environment, shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty Area”

The Protocol on Environmental Protection of the Antarctic Treaty, which was ratified in 1998, does commit Treaty Parties to the comprehensive protection of the Antarctic environment and dependent and associated ecosystems, and designates Antarctica as a natural reserve devoted to peace and science. Annex III to the protocol (Waste Disposal and Management) established that past and present work sites shall be cleaned up unless they are designated as a historic site or monument, or removal by any practical option would result in greater adverse environmental impact than leaving in its existing location or condition.

It opened for signature on October 4, 1991 and entered into force seven years later on January 14, 1998. Till date 30, nations have become party to it. India signed the

Protocol in 1992, which came into force in 1998. This protocol consists, 27 articles and 6 annexes:

- ↳ Annex 1: Environmental Impact Assessment
- ↳ Annex 2: Conservation of Antarctic Fauna and Flora
- ↳ Annex 3: Waste Disposal and Waste Management
- ↳ Annex 4: Prevention of Marine Pollution
- ↳ Annex 5: Area Protection and Management
- ↳ Annex 6: Liability

The Annex 3 and 4, which are directly linked to the present research are defined in Appendix 1.

Articles on above Annex, related with studies are;

Article 4 (Other Waste disposal on Land)

1. Wastes not removed or disposed of in accordance with Articles 2 and 3 shall not be disposed of onto ice-free areas or into fresh water systems.
2. Sewage, domestic liquid wastes and other liquid wastes not removed from the Antarctic Treaty Area in accordance with Article 2, shall, to the maximum extent practicable, not be disposed of onto sea ice, ice shelves or the grounded ice-sheet, provided that such wastes which are generated by stations located inland on ice shelves or on the grounded ice-sheet may be disposed of in deep ice pits where such disposal is the only practicable option. Such pits shall not be located on known ice-flow lines which terminate at ice-free areas or in areas of high ablation.
3. Wastes generated at field camps shall, to the maximum extent practicable, be removed by the generator of such wastes to supporting stations or ships for disposal in accordance with this Annex.

Article 5 (Disposal of Waste in the Sea)

1. Sewage and domestic liquid wastes may be discharged directly into the sea, taking into account the assimilative capacity of the receiving marine environment and provided that:
 - (a) Such discharge is located, wherever practicable, where conditions exist for initial dilution and rapid dispersal; and
 - (b) Large quantities of such wastes (generated in a station where the average weekly occupancy over the austral summer is approximately 30 individuals or more) shall be treated at least by maceration.
2. The by-product of sewage treatment by the Rotary Biological Contactor process or similar processes may be disposed of into the sea provided that such disposal does not adversely affect the local environment, and provided also that any such disposal at sea shall be in accordance with Annex IV to the Protocol.

Annex IV (article 6) to the Protocol (Prevention of Marine Pollution) states that

- (a) Each party shall eliminate all discharge into the sea of untreated sewage "sewage" being defined in Annex IV of MARPOL 73/78) within 12 nautical miles of land or ice shelves;
- (b) Beyond such distance, sewage stored in a holding tank shall not be discharged instantaneously but at a moderate rate and, where practicable, while the ship is enroute at a speed of no less than 4 knots.

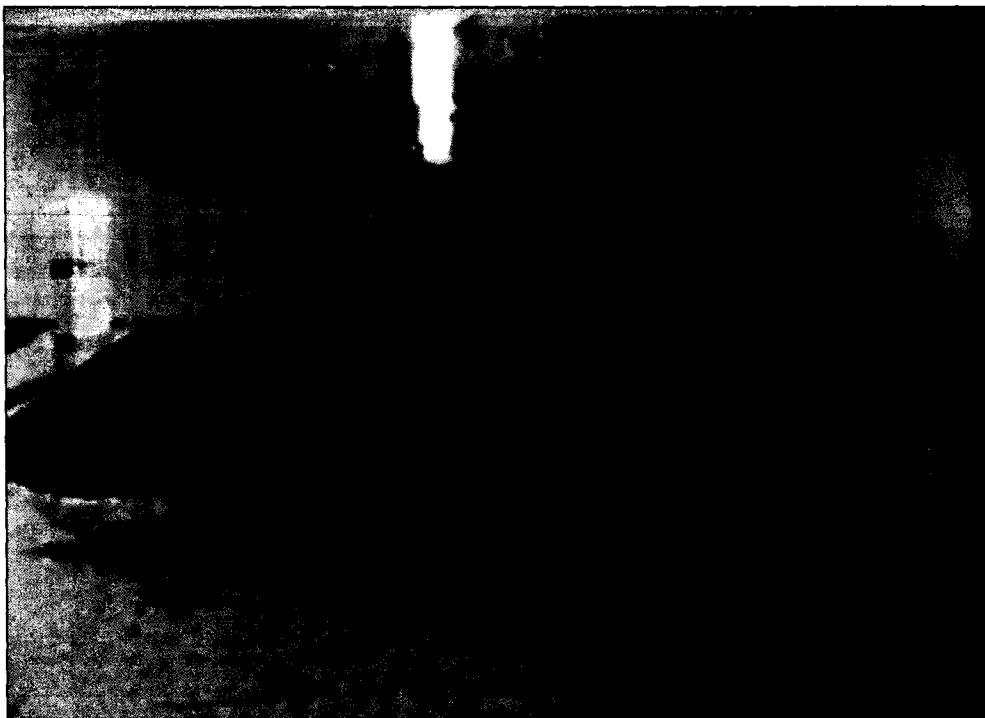
1.2 India in Antarctica

1.2.1 Dakshin Gangotri

India made its first achievement when it established first permanent station "Dakshin Gangotri" ($70^{\circ}05'37"S$ Latitude, $12^{\circ}00'00"E$ Longitude) on ice-shelf and along Princess Astrid Coast (Figure 1.1). First wintering expedition conducted the various scientific experiments from permanent station Dakshin Gangotri (DG) that was built in the year 1983. Number of occupants in DG remains 12-15 and the treatment process adopted was chemical treatment. In subsequent years, due to internal heat stress, weight and external snow accumulation around the station, structure buried under the snow, which

was abandoned in 1989, finally when the second permanent station “Maitri” was commissioned (*Sengupta and Quasim, 1983; Pandey and Tiwari, 2005*).

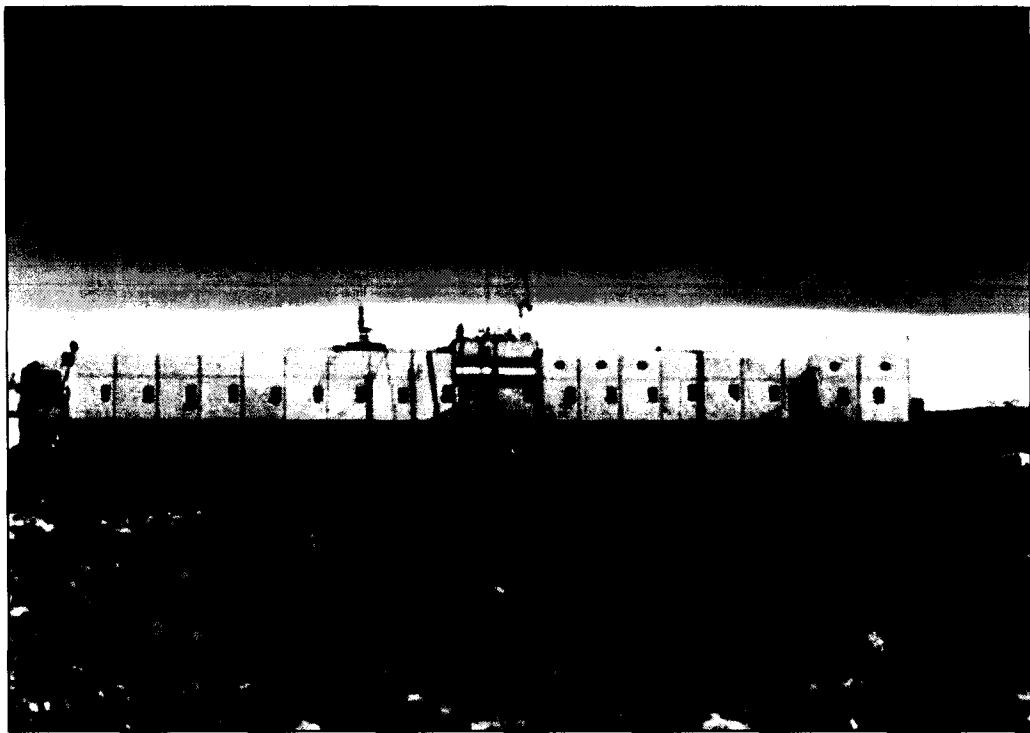
Figure - 1. 1: Dakshin Gangotri Station in Antarctica



1.2.2 Indian Permanent Research Station “Maitri”

India built its second indigenous station Maitri at Schirmacher oasis at $70^{\circ}45'53''$ S latitude and $11^{\circ}44'03''$ E longitude, which is well equipped and facilitated to accommodate scientists, round the year and allow them to conduct their scientific experiments (Figure 1.2). Maitri station is situated on the Nunatak Vassfjellet, Dronning Maud Land, around 80 km from the ice shelf edge. Maitri station is situated in an area of base rock and surrounded by a number of small lakes. It is built on an ice-free rocky moraine at an elevation of 117 m above mean sea level. A glacier to the south of the station covers parts of the Nunatak and ends about 400 m from the main building. Maitri can accommodate around 25 people during winter and around 45 additional scientists during summer season in summer huts, built in front of Maitri.

Figure - 1. 2 : Maitri Station in Antarctica



1.3 Environmental Impact in Antarctica

The end of the 19th and early 20th century brought construction of first station in Antarctica. The sustained presence and human activities started a new era of development and legacy of environmental pollution. This process accelerated by the scientific efforts since International Geophysical Year i.e 1957/58. Regardless the nature of activity, survival in Antarctica necessitates the use of fossil fuels, imported construction material and production of waste. The conduction of scientific experiments involves human footprints and definitely it leads to contamination in cold regions which has only recently become a widely recognized problem (SCAR, 1996; SCAR and COMNAP, 2002; Tiwari, 2008; COMNAP, 2006). Pollution associated with infrastructure support of scientific research has all been sources of contamination in the ground in cold regions (*Walton et al.*, 2001). Once in the ground, contaminants typically become mobile in the summer months and are readily dispersed from their immediate sources, where they then cause environmental impacts or pose risks to human health. However, the ways in

which contaminants in freezing ground disperse and interact with associated ecosystems is a new and challenging field of applied research. Such research needs to underpin the design and optimization of techniques for site management and assessment, particularly since remediation in cold regions is inherently more difficult and expensive than elsewhere.

1.3.1 Contamination from Sewage

Disposal of the sewage waste generated by the estimated 4000 summer and 1000 wintering personnel in the 37 permanent and 16 summer-only active stations is a challenge for Antarctic Treaty nations (Grondahl *et al.*, 2008). Annex III to the Environmental Protocol recommends that, to the maximum extent possible, sewage should not be disposed on to sea ice, ice shelves or grounded ice sheet, unless in deep ice pits when this is the only practicable option. It further requires that sewage from coastal stations housing more than 30 people is to be treated before being disposed of into the sea. The inland stations (including those on permanent ice shelves) face significant additional technical challenges for sewage disposal. Connor (2008) reported that, the level of sewage treatment applied at stations varied considerably, since adoption of the Environmental Protocol.

Many countries are treating the waste as required under Madrid Protocol whereas others have taken the decision to treat their sewage to levels that exceed their own national standards. Sewage waste and ‘gray water’ originated from station toilets, laundry facilities, accommodation and cooking areas may contain faeces, urine and associated nutrients, microorganisms (including potential pathogens), organic material viz. toilet paper and food waste (Bunch *et al.*, 1961), detergents, heavy metals, hydrocarbons and desalination plant brine. Fishing, tourist, research and re-supply vessels also generate sewage, but this should be discharged into water more than 12 nautical miles from the coast according to Article 6 of Annex IV of the Environmental Protocol, and is unlikely to have a significant environmental impact. Breaching the provision on sewage discharge location by ships could be a concern. Nevertheless, with the exception of McMurdo Station, which has a peak capacity of well over 1000 people, shipping represents the

most common, large local density of people in Antarctica, as individual ships carry typically hundreds but sometimes as many as 3000 people.

Sewage contamination levels around outfalls depend upon the biological and physical environmental characteristics also based on the volume of sewage released and the degree of treatment. The extents of several Antarctic station sewage plumes were published before the implementation of the Environmental Protocol (*Hughes*, 2004). However, since 1998, sewage plume extents, measured using faecal microorganisms, have been published for McMurdo (*Edwards et al.*, 1998), and Casey (*Morris et al.*, 2000).

1.4 Ecological Effect of Sewage Discharge in Marine Environment in Antarctica

The Protocol on Environmental Protection to the Antarctic Treaty sets out clear environmental goals and commitments for all countries operating in Antarctica (*Joyner*, 1996). Specifically, countries are committed to effective monitoring in order to detect and reduce environmental impacts. Despite Antarctica being the largest pristine wilderness on Earth, many coastal Antarctic research stations release untreated sewage waste into the marine environment, which may have negative effects on local wildlife (*Hughes and Blenham*, 2003). Madrid Protocol also deals with “Marine Pollution” which is to be implemented in furtherance of the environmental protection of Antarctica. One of the Annex IV of “Prevention of Marine Pollution” specifically covers the circumpolar marine environment. This annex prohibits through article 3 “any discharge of oil or oily mixture”, permitted only in circumstances defined under MARPOL 73/78. Article 4 of annex prohibits the discharge of any noxious liquid substances and any other chemicals or other substance in quantities or concentration that is harmful to the marine environment. In addition parties (countries) are also obligate in article 6 to eliminate all discharge of untreated sewage within 12 nautical miles of land or ice shelves (Appendix 2).

Several studies have described the extent of sewage pollution released from Antarctic stations (*Cripps*, 1992; *Howington et al.*, 1992; *McFeters et al.*, 1993; *Bruni et al.*, 1997;

Delille and Delille, 2000; Powell et al., 2003) and their ecological effects (*Edwards et al., 1998; Smith et al., 1994; Hughes and Nobbs, 2004*) on Marine environment (*Chou et al., 2003; Parnell, 2003*). Lenihan et al. (1995) showed that sewage effluent from McMurdo station in the Ross Sea influenced marine benthic communities close to the sewage outfall. Sewage is a source of human-derived bacteria, yeasts and viruses that are not native to the Antarctic. Once released, enteric bacteria can remain viable in low temperature Antarctic waters ($^{\circ}\text{C}$) for prolonged periods (*Smith et al., 1994; Statham and McMeekin, 1994*) and untreated sewage can affect biological oxygen demand (*Howington et al., 1994*). It has the potential to infect and cause disease, or become part of the gut flora of local sea mammal and bird populations as well as fish and marine invertebrates (*Lenihan et al., 1995; Gardner et al., 1997; Edwards et al., 1998*). Several authors have recommended that sewage be fully treated before discharge into the polar environment (*Hughes, 2004*). However, logistic constraints force release of untreated sewage into the marine environment is often the only option available—especially at smaller Antarctic stations.

The effect of the low Antarctic seawater temperatures has been quantified by Howington et al. (1994) who showed that at -1.8°C the extent of BOD (biochemical oxygen demand; a measure of a wastewater's content of biodegradable organic compounds) removal was only one third of that at 20°C . The fate of pathogens under Antarctic conditions has also been explored and Parker and Martel (2002) concluded that some bacteria, viruses and helminth ova could survive for long periods in a frozen state.

Concerns about the impacts of coastal sewage discharges have led to the mapping of sewage plumes around outfalls from a number of research stations. Around Dumont d'Urville station relatively high densities of bacteria (up to 1000 cfu/100 ml) were found in the immediate vicinity of the outfall but bacterial indicators dropped to very low levels within 2 km of the outfall (*Delille and Delille, 2000*). Not surprisingly, given the large numbers (over 1000) of people working at the U.S. McMurdo Station, this station's outfall has a large plume, 200–300 m wide and 1 km long, with coliform bacteria densities up to 105/100 ml (*McFeters et al., 1993*).

Certainly the levels of faecal coliforms in the vicinity of outfalls can be markedly reduced, as was demonstrated at the British Rothera station (*Hughes, 2004*). However, what this means for local ecosystems remains uncertain. Despite these uncertainties, it is expected that increasing numbers of countries will embrace the precautionary principle and decide to install treatment plants at their Antarctic bases. Most will adopt technologies similar to those currently in use but, at inland stations particularly, innovative uses of high-tech membrane and thermal evaporative techniques are to be expected. Not all innovation needs to involve high-tech processes however; for example, Hughes and Blenkham (*2003*) have shown that replacement of intermittent effluent tank discharging by continuous cold water flushing can bring about a 90% reduction in faecal coliform concentrations around outfalls.

So far these plumes have not been shown to cause other than localized changes but there remain concerns about the possible transmission of diseases to wildlife. This issue was dealt in a paper prepared by a SCAR and COMNAP Working Party (*SCAR and CONMAP, 2000*). It states that no disease outbreak in Antarctica positively linked to human activities has yet been identified but recommends taking precautions to obviate such occurrences.

It is realized by a number of countries that sewage discharges of the magnitude and nature of those at their research stations would require more extensive treatment if they occurred at home given regulatory requirements in their respective countries. In other words they elected to regard their Antarctic bases as coming under the same requirements as would equivalent sized populations within their countries. Halton and Nehlsen (*1968*) recommended that sewage should receive full treatment before being released into the polar environment.

With this back ground an effort has been made in the present study to improvise efficacy of the wastewater treatment system at Maitri.

1.5 Why Wastewater Treatment and Management is Critical in Antarctica

The wastewater treatment and waste management are very critical aspects in Antarctica because of cold climatic conditions, energy availability and Environmental Protocol and since adhere to be stringent measures due to pristine continent. In retrospect, the following issue must be considered while designing the waste treatment plant in Antarctica:

- ◆ Size of the plant to accommodate long-term trends in population and flexibility of design to accommodate fluctuating waste loading within and between seasons.
- ◆ Power consumption and energy efficiencies and
- ◆ Ease of operation, maintenance and process control.

The challenges in the wastewater treatment always existed because of the problems in technical expertise, logistics and operation support available in Antarctica compared to the rest of the part of the world. The need for developing strategies is important in this environment for follow-up, technical assistance and pilot tests to produce better effluent quality. Chemical contamination associated with on-going sewage disposal is of growing concern. Hale et al. (2008) found that contemporary sewage management practices at some stations are insufficient to prevent the local dispersal and accumulation of waste.

1.5.1 Problems for Waste Treatment and Management in Antarctica

As mentioned earlier, Antarctica is known for its coldest, driest and most inaccessible place on earth. Since this place is serene and unpolluted, Madrid Protocol has made stringent guidelines to protect the environment of the Antarctica. Therefore, waste treatment, management and disposal has become the most challenging task. There are 82 stations which have been established and are operating scientific activities including 47 winter stations. They are spread over in various geographical locations of East and West Antarctica and more conglomerations are in peninsula. The high costs, logistic difficulties, environmental risks and political sensitivities make bulk earth extraction, transport and disposal (dig-and-haul), an unattractive proposition. The challenge for research scientists and engineers is to develop robust low-cost alternatives that can be

applied on site. A range of techniques have recently been investigated, including multistage water treatment systems, permeable reactive barriers, and bioremediation of petroleum hydrocarbons (*Snape et al., 2001; Northcott et al., 2005; Filler et al., 2008*).

The problems associated with the stations are:

- ◆ Operation of reliable wastewater treatment system mainly because yearly average temperature remains sub zero which poses problem in waste treatment.
- ◆ Disposal of treated waste as according to Environmental protocol the treated waste only can be disposed either in an ice pit or into the seawater.
- ◆ Waste management and its disposal.

1.6 Significance of Present Study

India is a developing country and it has added a feather in the success story when it setup the first permanent research station at Antarctica and in extension to that, established second station "Maitri". Antarctica is no man's land. According to Antarctica Treaty the participating country can continue its scientific research programme on various disciplines by strictly abiding to the Environmental Protocol. Many countries have remained content to comply with the minimum requirements for sewage disposal. However, for a number of countries, the Madrid Protocol has provided a strong stimulus to introduce more advanced sewage treatment methods (*Connor, 2008*). Council of Managers of National Antarctic Programmes (CONMAP) mentions instances in which sewage was still being discharged to ice-free land, in contravention of the protocol's stipulations (*CONMAP, 2002*).

Under the present research study a defined solution shall be the outcome, to resolve the emerging problem of the wastewater treatment and effluent management system at "Maitri" station in polar environment. This will boost the Indian Scientific Expedition to Antarctica for longer duration, which is very important, as Antarctica's pristine environment is benchmark for various scientific activities and governs the global climate.

1.7 Criterion for Selection of Wastewater Treatment System

The contaminants are removed from wastewater by physical, chemical and biological means. There may be combination of various units to treat the waste of desired quality. There may be preliminary and/or primary (physical unit), secondary (chemical or biological) or advanced tertiary (combination of all three) processes to treat the waste water. The various combinations of unit operations and processes in a treatment plant work as a system. Important factors that must be considered when evaluating and selecting unit operations and processes are presented in Table 1.1.

Table - 1. 1: Important factors for Consideration of Evaluation and Selection of Unit Operation and Process (Metcalfe and Eddy, 1995)

S.No.	Factor	Comment
1.	Process applicability	The applicability of a process is evaluated on the basis of past experience, published data, data from full-scale plants, and from pilot plant studies. If new or unusual conditions are encountered, pilot plant/Lab Scale studies are essential.
2.	Applicable flow range	The process should be matched to the expected range of flow rates. For example, stabilization ponds are not suitable for extremely large flow rates.
3.	Applicable flow variation	Most unit operations and processes have to be designed to operate over a wide range of flow rates. Most processes work best at a relatively constant flow rate. If the flow variation is too great, flow equalization may be necessary.
4.	Influent-wastewater characteristics	The characteristics of the influent wastewater affect the types of processes to be used (e.g., chemicals or biological) and the requirements for their proper operation.
5.	Inhibiting and unaffected constituents	What constituents are present and may be inhibitory to the treatment processes? What constituents are not affected during treatment?
6.	Climatic constraints	Temperature affects the rate of reaction of most chemical and biological processes. Temperature may also affect the physical operation of the facilities. Warm temperatures may accelerate odor generation and also limit atmospheric dispersion.
7.	Reaction kinetics and reactor selection	Reactor sizing is based on the governing reaction kinetics. Data for kinetic expressions usually are derived from experience, published literature, and the results of pilot plant studies.
8.	Performance	Performance is usually measured in terms of effluent quality, which must be consistent with the effluent-discharge requirements.
9.	Treatment residuals	The types and amounts of solid, liquid, and gaseous residuals produced must be known or estimated. Often, pilot plant studies are used to identify and quantify residuals.
10.	Sludge-processing	Are there any constraints that would make sludge processing and disposal infeasible or expensive? How might recycle loads from sludge processing affect the liquid unit operations or processes? The selection of the sludge-processing system should go hand-in-hand

Cont .

Cont. Table 1.1

S.No.	Factor	Comment
		with the selection of the liquid treatment system.
11.	Environmental constraints	Environmental factors, such as prevailing winds, wind directions and proximity to residential area, may restrict or affect the use of certain processes, especially where odors may be produced. Noise and traffic may affect selection of a plant site. Receiving waters may have special limitations, requiring the removal of specific constituents such as nutrients.
12.	Chemical requirements	What resources and what amounts must be committed for a long period of time for the successful operation of the unit operation or process? What effects might the addition of chemicals have on the characteristics of the treatment residuals and the cost of treatment?
13.	Energy requirements	The energy requirements, as well as probable future energy cost, must be known if cost-effective treatment systems are to be designed.
14.	Other resource requirements	What, if any, additional resources must be committed to the successful implementation of the proposed treatment system using the unit operation or the process under consideration?
15.	Personnel requirements	How many people and what levels of skills are needed to operate the unit operation or process? Are these skills readily available? How much training will be required?
16.	Operating and maintenance requirements	What special operating or maintenance requirements will need to be provided? What spare parts will be required and what will be their availability and cost?
17.	Ancillary processes	What support processes are required? How do they affect the effluent quality, especially when they become inoperative?
18.	Reliability	What is the long-term reliability of the unit operation or process under consideration? Is the operation or process easily upset? Can it stand periodic shock loadings? If so, how do such occurrences affect the quality of the effluent?
19.	Complexity	How complex is the process to operate under routine or emergency conditions? What levels of training must the operators have to operate the process?
20.	Compatibility	Can the unit operation or process be used successfully with existing facilities? Can plant expansion be accomplished easily?
21.	Space availability	Is there sufficient space to accommodate not only the facilities currently under consideration but possible future expansion? How much of a buffer zone is available to provide landscaping to minimize visual and other impacts?

1.8 Wastewater Treatment Systems

One of the most important tasks of waste treatment is removal of dissolved organic matter (*Hiras et al., 2004*) and which is very difficult too. These solids are usually oxidized rapidly by the microorganisms, resulting in loss of dissolved oxygen. Biological method have proved most effective of organic waste treatment since bacteria are adept at devouring organic matter in the wastes, and greater the bacterial efficiency the greater the reduction of organic waste. Microorganisms are quite temperamental and sensitive

to changes in environmental conditions such as temperature, pH, dissolved oxygen, mixing and toxic elements or compounds and character and quantity of food (organic matter).

There are many varieties of biological treatment each adapted to certain type of wastewater and local environmental conditions. Some specific processes (Nemerow, 1991) in practice to treat the organic matter are:

- ◆ Lagooning in oxidation pond
- ◆ Activated Sludge treatment
- ◆ Modified aeration
- ◆ Dispersed growth aeration
- ◆ Contact stabilization
- ◆ High rate anaerobic treatment
- ◆ Trickling filtration
- ◆ Spray irrigation
- ◆ Wet combustion
- ◆ Anaerobic digestion
- ◆ Mechanical aeration
- ◆ Deep well injection
- ◆ Bio disc system

1.8.1 Lagooning in Oxidation Pond

Lagooning in oxidation pond is a common means of removing and oxidizing organic matter. Stabilization or oxidation of waste in ponds depends on several by self purification phenomena. Decomposition of organic material takes place either aerobic, anaerobic or by facultative bacteria.

1.8.2 Activated Sludge Treatment

This method is well proved for treatment of domestic sewage. In this process biologically active growths are created, which are able to adsorb organic matter from the wastes and convert it by oxidation-enzyme system to simple end product like CO_2 , H_2O , NO_3 and SO_4 . The flock (zoogelous masses) is living masses of organisms, food and slime material and are highly active centers of biological life, hence the term "activated sludge". The desired concentration of active flock is maintained by recirculating a specific volume of

secondary settled sludge, normally about 20%. This method also has some limitations as it involves long detention time, sludge bulking and high initial oxygen demand.

1.8.3 Modified Aeration

Modified aeration is the variation of the activated sludge treatment. The objective is to supply maximum air to sludge when it is in the optimum condition to oxidize the adsorbed organic matter. Lower amount of the air and shorter detention times are claimed for this processes. The chief advantage of this process is flexibility it offers the operator.

1.8.4 Dispersed Growth Aeration

It is a process for oxidizing dissolved organic matter in the absence of flocculent growth. Dispersed growth aeration requires more air to achieve the same BOD reduction as the activated sludge process. A portion of the supernatant liquid is retained for seeding incoming waste, while the settled sludge from the secondary settling tank is digested or treated by other sludge treatment methods. The effluent obtained with this process has higher turbidity than the raw waste and color is not removed. The process can be used as pretreatment to the conventional biological treatment process.

1.8.5 Contact Stabilization

In the contact stabilization process, raw waste is mixed with aeration with previously formed activated sludge from a stabilization-oxidation tank, or digester, for a short period of time. This activated sludge-raw waste mixture is then clarified by settling for about two hours, after which the settled sludge goes through intense biological oxidation in the stabilization-oxidation basin for an aeration period. It then returns to the mixing tank and is again mixed with raw waste, so that it can absorb and adsorb added organic matter. Studies shows that it requires less aeration tank capacity than other processes, since the real aeration or reactivation takes place in the settled and concentrated sludge.

1.8.6 High Rate Aerobic Treatment

High rate aerobic treatment (total oxidation) consists of combinations of waste, long period aeration, final settling of sludge and return of the settled sludge to the aeration tank. There is no need of primary settling or sludge digestion, but the aeration system must be large, to provide the required aeration period. The total oxidation process is particularly useful in small installations. Little difficulty occurs with bulking on the sludge. The high rate of aerobic treatment, though it produces little waste sludge, has the disadvantages of requiring about three times as much air as conventional activated sludge plants.

1.8.7 Trickling Filtration

Trickling filter is the process by which biological units are coated with slime growths from the bacteria in the wastes. These growths adsorb and oxidize dissolved and colloidal organic matter from the waste applied to them. Crushed stone, such as trap rock, granite and limestone usually forms the surface material in the filter. In this process an active surface film grows on the stone or contact surface followed by concentration of colloidal material and gelatinous matter occurs. These adsorbed substances are attacked by bacteria and enzymes and reduced to simpler compounds, so that NH_3 , is liberated and oxidized by chemical and bacterial means, giving a gradual reduction of NH_3 and an increase of NO_2 and NO_3 . A flocculent is humus like residue or sludge. Trickling filter acts as both strainers and oxidizers.

1.8.8 Spray Irrigation

Spray irrigation is an adaptation of the familiar method of watering agriculture crops by portable sprinkling-irrigation system. Waste is applied as a rain to the surface of the soil, with the objective of applying the maximum amount that can be absorbed without surface runoff or damage to the cover crops. The process is generally limited to spring, summer and autumn.

1.8.9 Wet Combustion

Wet combustion is the process of pumping organic laden wastewater and air into a

reactor vessel at elevated pressure. The organic fractions undergo rapid oxidation. The rapid oxidation gives off heat to the water by direct convection and the water flashes into steam. The wet combustion process can maintain itself only when the waste has high percentage of organic material (usually about 5% solids and 70% organic).

1.8.10 Anaerobic Digestion

Anaerobic digestion is a process for oxidizing organic matter in closed vessels in the absence of air. The process has been highly successful in conditioning sewage sludge for final disposal. Generally anaerobic processes are less effective than aerobic processes, mainly because of the small amount of energy that results when anaerobic bacteria oxidize organic matter. Anaerobic process is slow and therefore requires low daily loadings or long detention time. However little power is needed and operating cost is low. The pH in digesters must be controlled near to the neutral point, which requires attention in comparison to aerobic treatment.

1.8.11 Mechanical Aeration

Cavitations are typical processes for mechanical aeration of waste. In this system rotor connected with vertical pipe withdraw air from the atmosphere. The rotor creates a zone of cavitations in its turbulent trail and air moves into fill the areas of rarefied under pressure. This system promises to be the most economical one for secondary treatment of wastes with a highly dissolved organic content.

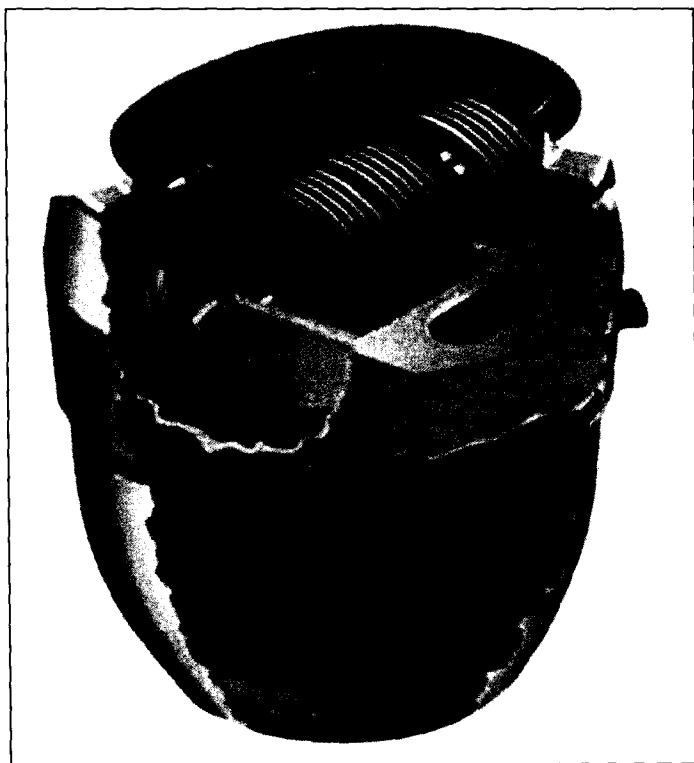
1.8.12 Deep Well Injection

Disposal of waste containing dissolved organic matter by injecting them into deep wells has been a successful one in areas of low or nonexistence of stream flow. For effective disposal, the waste must be placed in a geological formation which prevents the migration of the wastes to the surface or ground water supplies. The rock types most frequently used are the more porous ones such as limestone, sandstones and dolomites. Pretreatment of the waste is required prior to injecting into well depending upon the nature of the source of waste.

1.8.13 The Bio Disc System

It consists of a series of flat, parallel discs which are rotated while partially immersed in the waste being treated (Figure 1.3). Biological slime covers the surface of the discs and adsorbs and absorbs colloidal and dissolved organic matter present in the wastewater. Excess slime generated by synthesis of the waste material is sloughed off gradually into the mixed liquor and subsequently separated by settling. The rotating disc carry a film of the waste water into the air where it absorbs the oxygen necessary for aerobic biological activity of the slime (Boumansour and Vasel, 1998). Use of closely spaced parallel discs achieves a high concentration of active biological surface area. Because a buoyant plastic material is used for the discs and negligible heat loss is encountered through the RBC itself, the power consumption for this process is very low. Its simplicity of construction and operation has demonstrated that minimal unskilled maintenance is all that is required for efficient operation.

Figure - 1. 3: Rotating Biological Contactor



1.9 Wastewater Systems in Practice in Various Stations in Antarctica

Many countries active in Antarctica have still made no move to take sewage treatment beyond the minimum standards prescribed by the Madrid Protocol (*Hughes, 2004*). However, some have elected to install more advanced treatment systems, usually incorporating biological treatment and sludge dewatering processes. According to Heaton and Paterson (2003), Australia was the first country to decide to introduce secondary treatment at its Antarctic stations. This decision was taken well before the Madrid Protocol was drafted, with Rotating Biological Contactors (RBCs) being installed at Australia's Mawson, Casey and Davis stations in 1985, 1989 and 1991 respectively. During this period several other countries also introduced biological treatment plants, all based on RBCs. The Italians installed their plant at their Terra Nova base in 1987–1988. This base is not permanently occupied and problems were experienced due to the time taken to get the RBC system functioning properly at the start of each summer season (*Lori et al., 1992*). India also introduced two RBC systems at this time, one in 1988 and another in 1989. These were installed at their permanent research station, Maitri (*Ghosh et al., 1997*). The discs used on these plants were rather unusual, being mostly square in shape.

There are total 82 stations exists in Antarctica including 47 winter stations. Mostly the conglomeration of the stations is at the Antarctic Peninsula. The population of each station varies in summer and winter which also affect the wastewater treatment load on the system. Many of the stations are using biological wastewater treatment plant i.e Rotating Biological Contactor (RBC) and mostly the stations situated near the seashore discharge the treated/untreated waste into the marine environment (*Connor, 2008*). Table 1.2 shows the present wastewater treatment data in few of the stations which are currently in practice (*Thomsen, 2005; COMNAP, 2006*).

Table - 1. 2 : Present Wastewater Treatment data of Various Stations in Antarctica

Sr. No.	Station Name	Country	Location		No. of occupants		Water Requirement	Waste Treatment Method	Discharge Method and Effluent Quantity
			Latitude	Longitude	Winter	Summer			
1	Aboa	Finland	73°03'S	013°25'W	n/a	20	-	Grey water is not treated	Discharged on ice covered area which ultimately drains into sea
2	Amundsen-Scott	USA	89°59.85'S	139°16.37'E	55-60	260	95 litres/person/day	Nil	Sewage is discharged in abandoned wells
3	Bellingshausen	Russia	62°11.78'S	058°57.65'W	25	38	-	Septic sewage treatment system	Discharged untreated sewage into nearby stream
4	Casey	Australia	66°17.00'S	110°31.18'E	20	70	1,598,700	Rotating Biological Contactor and UV filtration	Discharged into Marine Environment
5	Comandante Ferraz	Brazil	62°05.00'S	058°23.47'W	12	40	-	Three stage passive filtration system	Discharged inshore to Martel Inlet below the low tide line
6	Concordia (2)	France & Italy	75°06.12'S	123°23.72'E	14	50	83 liters/person/day	1) UV filtration 2) Nano filtration 3) Reverse Osmosis 75% is recycled except for drinking	In well in Polar Ice Sheet
7	Davis	Australia	68°34.63'S	077°58.35'E	22	70	10,000-14,000 litres per day	Rotating Biological Contactor	Discharged into Marine Environment
8	Dumont d'Urville	France	66°39.77'S	140°00.08'E	26	100	-		Sewage and domestic liquid waste is deposited into the sea, with toilet and food first being ground

Cont .

Cont. Table 1.2

Sr. No.	Station Name	Country	Location		No. of occupants		Water Requirement	Waste Treatment Method	Discharge Method and Effluent Quantity
9	Enigma Lake	Italy	74°42.81'S	164°02.49'E			-	Biological sewage treatment plant and with chlorine disinfection	Discharged into marine environment
10	Great Wall	China	62°12.98'S	058°57.73'W	12	30	-	Processed through sewage treatment plant	Discharged treated/untreated into tidal basin
11	Halley	United Kingdom	75°34.90'S	026°32.47'W	15	65	-	Sewage macerated	Discharged to ice pit
12	Law – Racovita	Australia & România	69°23'S	076°23'E	n/a	13	-	Grey water is collected in 200-L drums and returned to Australia	
13	Mawson	Australia	67°36.28'S	062°52.25'E	20	60	1,063,000	Rotating Biological Contactor	Discharged into Marine Environment
14	McMurdo	USA	77°50.88'S	166°40.10'E	250	1000	-	An anoxic zone, an aerobic zone, clarification and disinfection	
15	Neumayer	Germany	70°38.00'S	008°15.80'W	6	43	90-110 litres/person/day	Grey and black water is cleaned with filter and UV radiation system	
16	O'Higgins	Chile	63°19.25'S	057°54.02'W	17	50	-	Sate-of-the-art sewage treatment plant	Discharged into marine environment
17	Progress 2	Russia	69°23'S	076°23'E	20	77	-		Discharged to the ocean
18	Rothera	United Kingdom	67°34.17'S	068°07.20'W	22	110	110 litres/person/day	Type pack 3 sewage treatment plant with UV filtration	Discharged into Bay
19	SANAE IV (3)	South Africa	71°40.42'S	002°49.73'W	10	80	-	Filtration through biological treatment and then UV filtration	Discharged into ice

Cont. Table 1.2

Sr. No.	Station Name	Country	Location		No. of occupants		Water Requirement	Waste Treatment Method	Discharge Method and Effluent Quantity
20	Scott Base	New Zealand	77°51.00'S	166°45.77'E	10	85	-	Aerated submerged media process system Sludge generation is low at 0.65L/person/day (at 1.5% solids)	
21	Signy	United Kingdom	60°43'S	045°36'W	n/a	10	-		Discharged directly to sea
22	Syowa	Japan	69°00.37'S	039°35.40'E	40	110	-	Liquid wastes such as medicines and used oil, to be brought back to Japan	
23	Troll (4)	Norway	72°00.12'S	002°32.03'E	nil	18	-	Grey water is treated through three chamber filtration systems and then UV filtration. Incinerators are used to burn excreta	Discharged on open land
24	Wasa	Sweden	73°03'S	013°25'W	nil	9	-	Grey water is not treated	Discharged on ice covered area which ultimately drains into sea
25	Zhongshan	China	69°22.27'S	076°23.22'E	15	30	-	-	Disposed after treatment to the ocean

- data not available

1.10 Treatment System at Maitri

Rotating Biological Contactor (RBC) units installed at Maitri to treat the grey water generated in station are made of Glass fiber Reinforced Polyester (GRP) which is extremely robust and easy to transport and install. The RBC units are located in separate rooms that are not exposed to sunlight to prevent the growth of algae, which could intervene with microbial attachment (*Ayoub and Saikaly, 2004*) and at times overburden the discs with extra mass. The RBC comprises main components: primary settling zone, biozone and secondary settling zone. The direction of disc rotation was selected to be opposite to the direction of wastewater flow in order to reduce short circuiting (Figure 1.4). Both the systems are kept outside the main building in a separate wooden chamber and connected with trace heated inlet and outlet discharge pipe.

Figure - 1. 4: RBC at Maitri



Gray water is collected separately from kitchen which is treated through B1 RBC and from other sources like bathroom, laundry, urinal and washbasin is treated from B3 RBC. The treated effluent is collected in a collection pond. Once in a year the treated waste water is discharged further 350 m away on the open ground.

1.11 Review of Literature

1.11.1 RBC Experiment

The Rotating Biological Contactors (RBC) originated in Europe in 1960 and thereafter introduced in United States. Many plants which were installed experienced variation in high hydraulic and low organic loading. Initially the RBC was applied to treat the industrial waste and later applied to treat the municipal waste. The RBC is designed based on the hydraulic and organic loading which has influence on the effluent quality. The fractional removal of substrate per stage is strongly dependent on the hydraulic loading rate per unit disc area but independent of feed substrate concentration. It is also evaluated that constant removal independent of disc size provided the hydraulic loading per unit area is kept constant (*Hansford et al., 1978; Cortez et al., 2008*). The rotational speed has only a slight predicted effect on the rate of substrate removal. Fixed-film systems have been successfully used for organic matter stabilization and nutrient control. Rotating biological contactors (RBC) have been employed in recent years for the treatment of various types of substrates, including municipal wastewater (*Grady, 1983; Akunna and Jefferies, 2000; Griffin and Findlay, 2000; Nowak, 2000*), and studies have been conducted to ascertain the effect on RBC performance of factors such as disc rotation speed (*Friedman et al., 1979*), recirculation (*Klees and Silverstein, 1992*), temperature (*Pano and Middlebrooks, 1983*), presence of organic particulate matter (*Figueroa and Silverstein, 1992*), hydraulic conditions (*Kugaprasatham et al., 1991*), use of supplemental air (*Surampalli and Baumann, 1992*) and scale-up (*Wilson et al., 1980*).

Castillo et al. (1999) studied the kinetics of a combined anaerobic (UASB)-aerobic (RBC) system for treatment of domestic sewage, concludes, first order model provides a very good kinetic description of the processes involved in USAB and in RBC. A study by *Allerman et al. (1982)* stated that the texture of biofilm varies in season. They have observed color and texture of the biofilm varied only slightly between winters, spring and summer periods. The characterization of the biofilm of RBC by a new technique to evaluate geometric irregularities of biofilm surface has been studied by *Zahid and Ganczarczy (1994)*, which revealed that surface irregularities decreased as RBC biofilms (*Allerman et al., 1982*) decreased in thickness from one stage to another. As biofilms grew

thicker, their fractal dimensions increased. The performance of RBC also depends upon the flow rate and influent organic strength. The system performance of an anaerobic rotating biological contactor (AnRBC) for the treatment of high-strength synthetic wastewater was investigated under different flow rates and influent organic strengths.

In the steady-state condition, the removal efficiencies of COD and BOD increases as the hydraulic retention time (HRT) increases or the influent organic strength decreases (Yeh et al., 1997). Most organic compounds are removed in the first two stages of the AnRBC indicating that a two-stage reactor may be sufficient in practical applications. Increasing the organic loading (Al-Ahmady, 2005) and reducing the hydraulic retention time negatively affect the treatment efficiency. In the two stage RBC system most of the COD is removed in the first stage with additional removal in second stage. The hydraulic shock loading does not affect COD levels but E coli and nitrification efficiency declines (Tawfik et al., 2002). The influence of the HRT on metal accumulation (cadmium, copper and zinc) was studied by Costley and Wallis (1999; 2000). They found longer HRT (>12 h) were associated with greater metal removal than short HRT.

There is a relationship between population dynamics of nitrifiers in biofilm and reactor performance at various C: N ratios. The microbial structure and activity in the biofilms vary greatly with time and are strongly depends on changes in the environment (i.e. water quality). The higher organic load (C: N ratio) retard accumulation of nitrifiers, resulting in a considerably long start up period for complete nitrification. The desired biofilm population dynamics can be controlled to maximize the nitrification efficiency (Okabe et al., 1996). The type of surface material also affects the initial biofilm development in RBC. The initial phase in the biofilm development involves the adsorption of organic compounds over the material which will be colonized (Trulear and Characklis, 1982; Vinage and Rohr, 2003). This initial organic layer is a prerequisite for the later microbial attachment (Baier, 1972; Fletcher, 1980).

Apilanez et al. (1998) studied the effect of surface material on initial biofilm development in RBC. Various surface materials (activated carbon sand disc etc.) were used to observe the growth of the biofilm on the disc. The carbon coated disc indicated that they were

best for biofilm growth. The biofilm growth was found to be independent of bioreactor seed. The disk rotational speed in RBC to remove the soluble carbonaceous substrate and different organic load contributes significantly. The rotational speed is a parameter which affects the oxygen transfer in the biofilm (*Palma et al., 2003*). Effect of disk rotational speed on heavy metal accumulation by RBC biofilm was studied by Cosetly and Wallis (1999). They concluded that rate and overall extent of accumulation was not influenced by disk rotational speed up to 25 RPM in RBC model, but higher speeds caused detachment of pre-established biofilm, probably because of greater shear forces experienced. The optimum disc area for the removal of the soluble organic carbon can be modeled through Monod kinetics or first order kinetics. Due to oxygen transfer limitation active disc area can be increased during the stage of overloading of soluble organic carbon (*Buchanan and Leduc, 1994*)

Several studies have employed rotating biological contactors (RBCs) for nitrogen removal (*Chiu and Chang, 2003; Welander and Mattiasson, 2003; Wyffels et al., 2003; Windey et al., 2005*) where partially submerged disks are used for nitrification, while completely submerged disks are used for denitrification. Effect of disk submergence (*Banergee, 1997a; Teixeira and Oliveira, 2001*) in the performance of rotating biological contactors, in terms of the denitrification process also contributes. Two RBCs, one with completely submerged disks (100% submergence) and the other with partially submerged disks (64.5%), were operated under the same conditions. Their performance was evaluated in terms of denitrification efficiency as well as biofilm characteristics, composition and activity. As far as the denitrification process is concerned, the RBC with a completely submerged biofilm was more efficient than the other but had a longer delay in start-up (*Rosario et al., 2003*). Biofilm activity seems to be directly dependent on the biofilm structure, namely on the degree of hydration. The RBC reactor with the completely submerged disks proved to be more efficient in terms of the denitrification process. Nevertheless, it had a longer startup, which delayed the attainment of maximum efficiency. An increase in hydraulic loading resulting from higher recirculation, had limited negative effect on organic removal but improved nitrogen removal, and in terms of Total-N removal efficiency. *Hiras et al. (2004)* experimented in a laboratory scale

rotating biological contactor (RBC) pre-denitrification system incorporating anoxic and aerobic for the treatment of settled high-strength municipal wastewater. The average removal efficiency in terms of chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total suspended solids (TSS) and total nitrogen (Total-N) was 82%, 86%, 63% and 54%; settling of the RBC effluent increased COD and TSS removal to 94% and 97% respectively.

Kubsad et al. (2004) investigated the rate of oxygen transfer from air to water in the RBC, designing the Lab scale model (Laopaiboon et al., 2002; 2003; 2006; 2008). Bioaugmentation of nitrifying bacteria for short solids retention time nitrification is an attractive alternative for wastewater treatment plants in cold climates. The possible source of ammonia for the production of nitrifying bacteria may be from liquor generated during the dewatering of anaerobically digested sludges. Nitrification rated drops as the temperature drops from $20^{\circ} C$ to $10^{\circ} C$ considerably (Head and Oleszkiewicz, 2004). There is correlation between the presence of different microorganisms and the values of physico-chemical parameter. Galvan and Castro (2007) investigated the relationship among filamentous microorganisms in RBC. Tawfik et al. (2004) studied physico-chemical factors affecting the *E.coli* removal in a RBC treating UASB effluent, which concluded that removal of *E.coli* under aerobic conditions is significantly higher than under anaerobic conditions.

The incorporation of particular bacteria has effect on the removal of carbon and nitrogen. A novel biofilm in a 3-stage lab-scale rotating biological contactor (RBC) incorporated by a sulfur oxidizing bacterium *Thiosphaera pantotropha*, which exhibits high simultaneous removal of carbon and nitrogen in fully aerobic conditions (Gupta and Gupta, 2001) of synthetic high strength domestic waste. The ratio of carbon to nitrogen, removed was close to 12. The RBC is also used as a post treatment unit to treat effluent of Up-flow Anaerobic Sludge Blanket (UASB). The removal efficiencies of Chemical Oxygen Demand (COD) increases at a higher hydraulic retention time (HRT) and a lower influent organic loading. However two stage RBC system operated on same total loading gives improved water quality (Tawfik et al., 2002). Total Organic Carbon (TOC) loading removal rate is a function of the hydraulic loading rate as well as inlet

substrate concentration. A high correlation was found between Total Organic Carbon (TOC) and Biochemical Oxygen Demand (BOD) while treating the high organic waste, which justified the use of TOC in the investigation (Wilson, 1993). Step-feed and recycling affects the efficiency of treatment in rotating biological contactors while hydraulic loading rates were maintained constant and the COD concentrations were variable. The improvements in the treatment efficiencies of RBC systems may be attained by operating the system in a step feed mode as compared to a single point feed mode. Further improvements may also be obtained by inducing effluent recirculation to the inlet stage which can be as high as 26% for COD removals (Ayoub and Saikaly, 2004).

In a study implying vertical moving biofilm to treat the municipal waste concluded that clogging commonly found in other biofilm systems did not occur in this system. The new biofilm system offers potential for reduced reactor volumes, energy saving, simple construction and easy operation (Rodgers *et al.*, 2003). In RBC systems, the adsorption is the main mechanism to remove E coli followed by sedimentation which is not influenced by the pH in a range of 6.5-9.4 (Tawfik *et al.*, 2004). Die-off has a relatively minor role for E coli removal and it is higher in aerobic condition rather than the anaerobic condition.

Kargi (2002) revealed in his experiment to treat the saline wastewater in RBC under different operating conditions such as A/Q (Area/Volume) ratio, feed COD, COD loading and salt concentrations. These results indicate that the percentage COD removal increased with increasing A/Q ratio and decreasing feed COD and salt content. The system performance was more sensitive to changes in variations in A/Q ratio and feed COD compared to salt content. COD removal efficiency was more sensitive to changes in A/Q, feed COD and salt content at low values of these variables. Large A/Q ratios ($A/Q > 3000 \text{ m}^2.\text{h/m}^3$) should be used for treatment of high strength ($\text{COD}=5 \text{ kg/m}^3$) and high salinity ($T=5\%$) wastewaters in order to obtain high COD removal efficiencies ($E>90\%$).

1.11.2 Chemical Treatment and Tertiary Unit

Whilst almost all treatment plants proposed for use in Antarctica have employed biological processes, the unsuitability of these processes for use at seasonally occupied bases prompted the Italians to try out a physicochemical plant at their Terra Nova base (*Lori et al.*, 1992). This plant comprised a wastewater storage tank, a chemical reactant preparation and storage section, a flocculation reactor, a dissolved air flotation (DAF) unit, a final effluent receiver and a sludge processing unit. The process required sequential injection of a pH corrector, a primary coagulant and a polyelectrolyte (*Lori et al.*, 1992). Difficulties were experienced when trying to commission this process and later the decision was taken to combine it with the RBC system that was designed to replace. The resulting hybrid plant comprises newly added screening equipment, the flocculation and DAF units from the physico-chemical plant, followed by the RBC unit from the earliest plant. To these were added an activated carbon filter and a UV disinfection unit. The sludge drying unit from the physico-chemical plant was also retained. This hybrid plant was reported to be performing well; inclusion of the physico-chemical section was noted as having helped to improve treatment efficiencies when the plant was started up (*Lori et al.*, 1996). No matter what type of process has been selected, all recent plants have opted to disinfect their effluent prior to discharge. In all cases UV radiation has been the process of choice since it leaves no potentially harmful residuals. As Heaton and Paterson (2003) point out, UV lamps of medium-strength or stronger are required for the cooler temperatures found in Antarctic treatment plants. Because the presence of suspended particles in the effluent can lead to inefficient disinfection, they recommend the use of multiple pass systems preceded by a filter.

Alum is a coagulant used extensively in wastewater treatment. Omoike and Vanloon (1999) studied removal of phosphorus and organic matter removal by alum during wastewater treatment. They found that the phosphorus and organic matter removal is a complex process but study supported the experiment. In similar study, Demirci et al. (1998) used coagulants and Turkish clay to treat the wastewater of petroleum refinery. Their results showed that local clays with optimum values of 100 mg/l accompanied with 100 mg/l coagulant can give a sufficient decrease in COD and NTU values (about 90%).

However, some studies (Koivunen et al., 2003; Haberkamp et al., 2007) used the coagulant and activated carbon as tertiary treatment to the secondary wastewater effluent. Koivunen's study concluded that Finnish municipal wastewater contained high numbers of enteric bacteria after conventional wastewater treatment. Tertiary filtration units removed microorganism (Ausland et al., 2002) and other pollutants from secondary treated wastewater. Haberkamp et al. (2007) concluded, coagulation removes predominantly macromolecular substances from secondary effluent, whereas low molecular-weight organic compounds are eliminated to a minor extent. Activated carbon adsorbs organic compounds of a wide range of molecular weight and a combination of coagulation and adsorption applying technically appropriate dosages can largely enhance the removal of biopolymers from secondary effluent.

Granular activated carbon (GAC) is used for wastewater treatment and removal of dissolved organic carbon (Quesnel and Nakhla, 2005). Razvigorova et al. (1998) studied use of activated carbons for purification of water. He found that activated carbon from apricot stones and oxidized anthracite are appropriate for purification of water from metal ions.

1.11.3 Operational condition of Wastewater Treatment Plant at Various Antarctic Stations

The Australian plants comprise a flow equalization tank, a primary sedimentation tank, an RBC with six banks of discs in series (to help cope with the widely varying seasonal loads), a clarifier and an effluent holding tank (Heaton and Paterson, 2003). All three are still in use and those at Mawson and Casey appear still to be working satisfactorily, though no detailed analysis of their performance appears to be available. Some problems have been reported at Davis where the RBC was not constructed in its own building as was the case at Casey and Mawson. According to Heaton and Paterson (2003), this resulted in access difficulties over winter and a consequent inability to carry out maintenance activities. Poor ventilation, resulting in the system becoming anaerobic was also noted as a problem. These problems provided the stimulus for the design of a new plant at Davis, as described by Heaton and Paterson (2003). Experience at the Italian and Indian plants was also not very encouraging. Lori et al. (1992) noted that the

BOD removal efficiency achieved by the Terra Nova plant was low, but this could well be due to the plant's lengthy start-up time. As Lori et al. (1992) recognized, the time needed to re-start biological treatment plants casts serious doubt on their suitability for use at seasonally occupied stations. Low BOD removal efficiencies, of 25 to 40%, were also reported for the Maitri plant and these were associated with significant falls in effluent pH (Ghosh et al., 1997). Reasons for this poor performance were not known but observations noted that at times the discs were not rotating suggests that the plant was experiencing mechanical problems, resulting perhaps in the development of anaerobic conditions in the RBC tank. Whilst biofilm-based plants have predominated at Antarctic research stations, a suspended growth design was introduced in the late 1990s at the German Neumayer station and the Argentine Jubany base.

Despite the success of the German design, all recent plants appear to have continued with biofilm-based systems. No documented discussion of the reasons why RBCs were chosen for the early plants appears to be available. However, detailed analyses of possible technologies and their respective advantages and disadvantages have been provided for the planned new plant at Davis (Heaton and Paterson, 2003), the recently commissioned plant at Scott base (New Zealand, 2002), and, to a lesser extent, for the Japanese Syowa station plant (Umezawa et al., 2000). What is interesting is that in all the three cases RBCs and contact aeration systems employing submerged aerated fixed media were selected as the two most suitable technologies. New Zealand opted to go for contact aeration as they had concerns about drive shaft problems and the height requirements of the RBCs. The latter would make it hard to construct the plant within a standard container while still retaining easy access to all parts of it (New Zealand, 2002). The Japanese made a similar choice, as that of Americans at their McMurdo station and the British at Rothera (Umezawa et al., 2000; Hughes, 2004). The Australians, however, elected to continue with RBCs for Davis, although they planned to introduce some significant modifications: discs are to be replaced by cylindrical drums containing spiral media while the contactors are to be made from buoyant material so as to overcome some of the mechanical problems that have afflicted past RBCs. The plant dimensions will be 8.2 m long, 2.27 m wide and 2.9 m high (Heaton and Paterson, 2003),

precluding its construction within a standard container.

1.11.4 Water Quality Models

The development of computer-based water quality models (Kuo *et al.*, 2005) has closely followed water pollution (Eckenfelder, 1970) control in the United States. Before 1970 the focus of water pollution control was directed towards achieving the ambient water quality standards. These standards were extremely hard to administer due to the fact that current biochemical oxygen demand (BOD) and dissolved oxygen (DO) models were not prepared for the challenge of transforming the ambient standards to effluent discharge limits. A large number of water quality models have been developed from simple methods such as the water quality analytical model (WQAM), to complex ones such as the Water Quality Analysis Simulation Program (WASP) (USEPA, 1985; Ambrose *et al.*, 1993). WQAM is not a true computer model, but a set of simple methods and procedures which are suitable for estimating the water quality effects of individual industrial plants (Zeng *et al.*, 2001).

WASP is a complex model that is capable to deal with a range of water bodies and water quality management analyses. Other existing complex water-quality models include the QUAL2E, HEC-5Q and CE-QUAL-RIV1 (Cerco and Cole, 1994, 1995; Cole and Wells, 2002; McAvoy *et al.*, 2003). The QUAL2E a steady state model, was developed by the US EPA for simulating well-mixed rivers and streams. QUAL2E has been widely applied in many parts of the world (Brown and Barnwell, 1987). While the former has primarily been used for analyzing water flows and water quality in reservoirs and associated downstream river reaches, the latter has been effectively applied in simulating the dynamics of highly unsteady stream flows, such as those occurring during flood events (US ACE, 1986; 1995).

One water quality model developed and refined throughout the process is USEPA's Water Quality Analysis Simulation Program (WASP). Di Toro *et al.* (1971; 1983), Di Toro and Connolly (1980), Di Toro and Matystic (1980), Di Toro (1985), developed the first complete version of USEPA's Water Quality Analysis Simulation Program. Connolly and Winfield (1984) enhanced the modelling software the following year. Ambrose

(1988) updated the software once again and it became known as WASP4. Ambrose (1987; 1988), Ambrose et al. (1993), refined the modelling software, therefore, effectively producing WASP5. The current release is WASP7 and is distributed and maintained by USEPA's Watershed and Water Quality Modelling Technical Support Center located in Athens, Georgia. In addition to WASP, there are a significant number of computer-based water quality models that have been developed over the past three decades (Table 1.3). The risk minimization model is developed to minimize the fuzzy risk of low water quality along a river in the face of conflict among various stake holders. The result of the model was compared with the result of FWLAM, when the methodology was applied to the case study of Tunga-Bhadra River in southern India. (Ghosh and Majumdar, 2006)

Table - 1. 3: Abbreviated List of Water Quality Models with References

Model	References
Enhanced Stream Water Quality Model (QUAL 2E)	Brown and Barnwell, 1987
Three-Dimensional Hydrodynamic-Eutrophication Model (HEM-3D)	Park et al., 1995; Sisson et al., 1997
Tidal Prism water Quality Model (TPWQM)	Shen et al., 2002

WASP is a dynamic compartment-based model for aquatic systems that allows for one-, two- and three- dimensional investigations. Nikolaidis et al., (2006) analyzed and modeled salinity, nutrient and chlorophyll-a data collected in the gulf. The model has been used extensively to simulate nutrients, PCBs, organic compounds and heavy metals in many lakes and coastal systems such as the Great Lakes, and the estuaries of Potomac, James, Delaware, and Deep Rivers (Rygwelski et al., 1999; Wool et al., 2001; Stansbury and Admiraal, 2004). The model consists of two main sub-programs viz. DYNHYD and WASP. The first deals with the hydrodynamic motion of the system and the second with pollutant transport and reactions. WASP also consists of two different

sub-models EUTRO and TOXI. EUTRO simulates conventional eutrophication parameters and TOXI simulates toxic pollutants.

The Central Pollution Control Board, New Delhi, has taken up a project to review the mathematical models for water quality management in lakes and ponds. Under the project, six identified models are - CE-QUAL-R1, CE-QUAL-W2, WASP-5, BATHTUB, DYRESM and AQUATOX. Among these six models, CE-QUAL-R1 has been selected for validation with respect to lakes and ponds. Rabindra Sarovar Lake and Jadavpur University Pond have been selected for model validation. This is a dynamic uni-dimensional model to stimulate vertical profiles of water quality in ponds and lakes. This model is not applicable to flowing water bodies. This model is recommended for regulatory purposes after thorough scrutiny of applicability for the water quality parameters, in different zones of India.

1.11.5 Sewage Discharge in Antarctica

In the last decade, most sewage impact studies have focused on benthic invertebrates, particularly near Stations. Before sewage treatment started at stations, long-term release of untreated sewage led to significantly reduced benthic community abundance around the location of the outfall. Conlan et al. (2004) reported that at all but the most contaminated sites, biodiversity was equal or greater than at control sites. Reduced assimilation of organic sewage material near the outfall was caused by the formation of an anaerobic microbial biofilm (Lazarova and Manem, 1995; 2000) that caused avoidance by megafauna scavengers (Kim et al., 2007). Using a technique that examined carbon- and nitrogen isotope ratios in sewage, sediments and invertebrates, Conlan et al. (2004) suggested that generalist benthic feeders could be used as biomonitor for sewage contamination at sites across Antarctica. Studies at Casey Station showed that even comparatively low volumes of sewage could affect the near-shore marine environment, with impacted sites generally having lower species richness, biodiversity and variability compared with control sites (Stark et al., 2003a). Evidence suggests that sewage derived heavy metals may impact upon soft-sediment assemblages in Casey station (Stark et al., 2003b), *Laternula elliptica* station (King and Riddle, 2001), Rothera research station (Lohan et al., 2001). Comparatively little work has been done

on the effects of sewage on other biological groups. In experiments, it has been shown that sewage may cause genotoxic effects and pathological anomalies in Antarctic fish (Van et al., 2007). Whilst a comparison of heavy metal effects between Winter Quarters Bay and an almost pristine site suggests that levels of heavy metals found in sewage may have little direct effect on fish (Evans et al., 2000). A recent report of *E. coli* from two fur seal pups suggest that pathogenic microbes can be ingested by marine mammals but it is not yet clear what the pathway might be (Hernandez et al., 2007). Effects upon indigenous marine microorganisms are little understood, although George (2002) showed that Antarctic marine microorganisms could break down detergents commonly found in sewage but at a lower rate than in temperate locations.

Few coastal Antarctic stations discharge untreated waste into the near shore environment (Thompson et al., 2003) . The bacterial population (El-Zanfaly and El-Abagy, 1987) growth in a sewage holding tank can inhibit the microbial reproduction and decreases the numbers of bacteria subsequently released into sea water by >90%. The widespread use of this simple method could significantly reduce the numbers of faecal coliform and other non-native microorganisms introduced into the Antarctic marine environment (Hughes and Blenkharn, 2003). The wastewater discharged to subsurface of the ocean at 11 m depth from McMurdo station in Antarctica was studied for the special distribution of the sewage plume. Coliform bacterial study concluded to use bacterial indicators as means to map the distribution and movement of recent sewage contamination in cold (-1.8⁰ C) seawater and provides evidence that the disposal and movement of domestic wastes in coastal polar environments deserves attention (Howington et al., 1992). Santos et al. (2005) found elevated metal concentrations in marine sediments only in the immediate vicinity of Comandante Ferraz Station sewage outfall. Ensuring optimal operational performance of wastewater facilities is notoriously difficult, particularly if sewage treatment plants are installed, making on-going sewage impact monitoring essential (Hughes and Blenkharn 2003; Grondahl et al., 2008). Not all human activities are located along the coast. Inland, sewage is generally disposed of either in "sewage bulbs" in ice beneath stations, while field parties may bury faecal waste in shallow snow pits, crevasses, or dispose it directly into the sea when in coastal

locations. Sjoling and Cowan (2000) detected that the legacy of sewage disposal can be long-term. Using molecular techniques, bacterial genetic material from sewage organisms was detected many years after deposition.

1.12 Objectives of Present Study

- ↳ To assess the water quality of the Priyadarshini lake (drinking water source to Maitri station) and other interconnected lakes, which is being affected by the seepage from effluent collection pond
- ↳ To improve the efficacy (*Burkhard et al., 2000*) of present wastewater treatment system to meet the growing need
- ↳ To evaluate the design parameters of the existing treatment plant
- ↳ To assess, monitor and analyze the practicability of introduction of tertiary wastewater treatment system i.e. application of alum dose and activated carbon.
- ↳ To manage the effluent discharge system

Chapter 2

Methodology, Simulation and Prediction

2.1 Methodology

As a pre requisite the problems of the station were identified and cause-effect relationship was established to reach to the solution. Manipulative experiments were particularly useful in demonstrating cause and effect of chemical contamination (Stark *et al.*, 2003a; Thompson *et al.*, 2007). In this regard following basic steps were selected to define methodology;

- ↳ Identification of sources of the problem
- ↳ Selection of the parameter to evaluate and quantify the pollution indicators
- ↳ Designing of the sample points and cycle of collection
- ↳ Establishment of Environmental Laboratory at Maitri
- ↳ Selection of standard methods and procedure for analysis
- ↳ Application of the tertiary treatment at Maitri station
- ↳ Laboratory-scale experiment opting tertiary treatment
- ↳ Prediction of wastewater impact by mathematical modelling software
- ↳ Designing of ancillary treatment units for “Maitri”
- ↳ Suggestions for advance treatment units

2.2 Approach to Identify Problems

Being cold climatic conditions at Maitri in Antarctica, biological wastewater treatment

system (Rotating Biological Contactor) has to be assessed frequently for its efficacy while it operates for long, so that effective decision can be taken if improvisation is required. At Maitri station the drinking water source is Priyadarshini Lake (Zub Ozero) which remains in melted form only for around two months and rest of the year it freezes. However, below three meters of ice water remains unfreezed at lower layer so it caters the water requirement of the station throughout the year. It is also interconnected with glacial lakes and intermixing of gray water through chain contamination has to be considered. In this regard water quality of lakes is required to be assessed.

2.3 Assessment of Water Abundance at Priyadarshini Lake

Priyadarshini Lake covers an area of 0.29 Km² and forms the major source of water supply to the Maitri station (*Ingole and Parulekar, 1990*). The lake is situated about 150 m away from the Indian permanent research station “Maitri” towards north. The volume of the water fluctuates between 1.7 m³/day, in winter and 5.7 m³/day, in summer. The consumption of water at Maitri is relatively more in austral summer compared to the rest of the year. The number of consumers is more during summer as total strength reaches to around 65-75 in a day (*Tiwari and Nayak, 2007*). It is during the austral summer that most of the scientific activities are carried out.

2.3.1 Area Measurement

Ingole and Parulekar (1990) estimated the area of the Priyadarshini Lake as 0.297 km². In January 2000 Global Positioning System (GPS) of make Corvallis Microtechnology Inc. version 2.4 was used as a mapping tool without differential correction (MC-GPS, 1996) to mark the boundary of the lake. The accuracy of this instrument was quoted 10-30 meters. In the last week of January when the ambient temperature was around -4 to -2 °C and there was no inflow of water, instrument (GPS) was calibrated with necessary inputs and it was set to record the position of the point for every five second. Holding the GPS handheld positions of the points were recorded moving on foot close to edge of the water around the lake keeping the instrument vertically above the water except few points where easy approach was not possible. After getting all the coordinates it was converted into graphical data and with the application of GPS and SURFER total area

was computed.

2.3.2 Depth Measurement and Volume of Lake

Before feeding of glacial melt water the depth of water at various places were recorded using the marked string with around 2 kg weights which was attached at bottom to keep the string vertically over the point. Using the inflatable boat and GPS wherever depth was measured, coordinates were recorded above those points at 55 locations within the lake. Care was taken to lower the string gradually into water so as to avoid penetration into algal mats which was present at the bottom of the lake. As soon as the string was slack the depth was recorded. Maximum depth recorded was 7.2 m at middle of the lake.

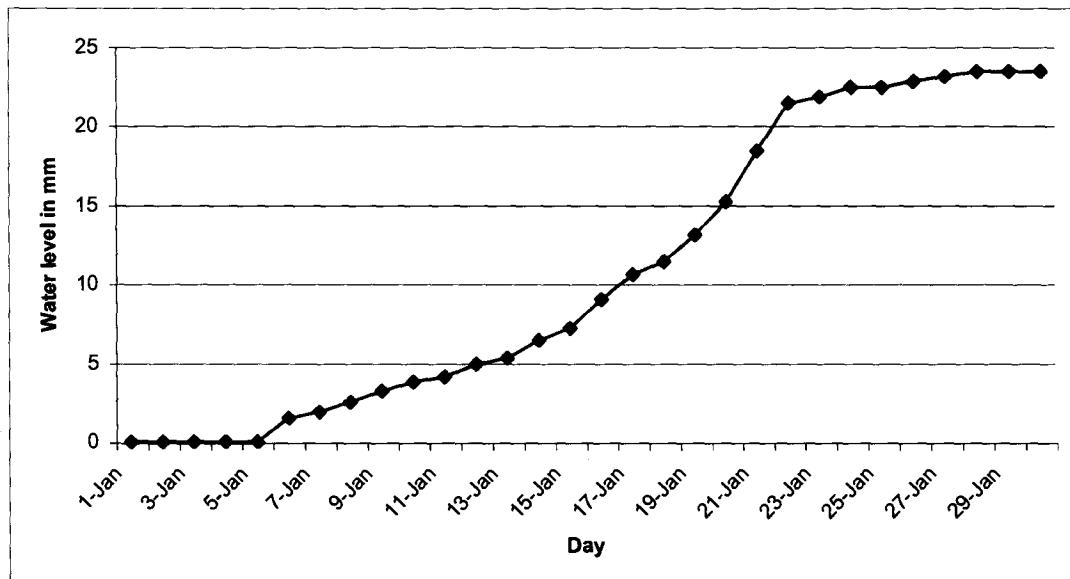
2.3.3 Additional Feed Water Measurement

The volume of water of Priyadarshini lake never remains the same because of the Schirmacher glacier which is around 1200 m away from the lake and melts when ambient temperature reach as to +1 to +5 °C for couple of days. This melted water joins glacial lakes formed adjacent to glacier and from these lakes ultimately it joins Priyadarshini Lake. After reaching certain level, the water outflows from Priyadarshini Lake into adjacent lake. To measure the inflow into the lake two iron rods at the bank of the lake were fixed at two feet distance. A cotton string was tightened in between the iron rods and leveled with the help of spirit level, keeping in view that it just touches to the water surface level when there was no inflow into the lake when the ambient temperature recorded was -2 °C. After a few days when temperature starts raising the glacier starts melting and the melt water starts feeding into Priyadarshini Lake through connecting glacial lake, daily at the evening increment in height of water level of the lake water was measured over the string using a scale.

From 2nd January to 29th January 2000 (Figure 2.1) the water level recorded continuously showed an increase in water level till 21st January, there after that it slightly increased till 27th January and remained constant for 3 days . It was noted that the excess water started diverting to a connecting lake situated downward side of the Priyadarshini Lake and after three days temperature went down and glacier melting

stopped which barrier feeding of water into the lake. Maximum air temperature recorded on 9th and 20th January, was +4.4 °C. This lake has also got an outlet through which access water passes to a channel and ultimately joins other lake at lower level, this happens when water level raises close to 23 cm.

Figure - 2. 1 : Daily water increment in Priyadarshini Lake



2.4 Waste Generation

2.4.1 Sources of Gray Water in Maitri

The Indian research station Maitri is situated at higher elevation (117 m above msl) in comparison to the Priyadarshini Lake (113 m above msl), which is drinking water source for Maitri (Ghosh and Ramteke, 1997; Tiwari *et al.*, 2006). This is the only source of drinking water which can cater the water requirement throughout the year, even in the winter condition. This water is used at various utilities of station i.e. boilers, drinking purpose, bathroom, washbasin, sink, kitchen, laboratory etc. which ultimately generates gray water. There is no black water generated as wet toilets are not in use at Maitri.

2.4.2 Liquid Waste Disposal and it's Consequences

Liquid waste obtained from bathroom, laundry room, washbasin, urinal and kitchen is sent into two different Rotating Biological contactors (RBC), made in UK by Klärgester

Company, popularly known in Maitri as Klargeter (Kee, 2004). These two RBC's are kept separately outside Maitri in a closed wooden chamber. Effluent obtained from these RBC's is discharged into a collection pond, dug adjacent to these chambers. Effluent disposal pipes are enclosed with heat tracing element to avoid freezing during subzero temperature. The fate of liquid discharge is summarized below;

- ↳ Treated waste from the pond is disposed and discharged on open land around 320 m away from the pond. Further down to discharge point, lakes are situated and they get inter-connected during summer once the glacier melted water feed these glacial lakes, they overflow and join each other. There is a probability of contamination of Priyadarshini Lake through this chain.
- ↳ Priyadarshini Lake is situated 150 m away in front of wastewater collection pond at lower level. During summer period when frozen effluent melts it seeps from pond and joins Priyadarshini Lake.
- ↳ Therefore, final discharge point of the effluent is not fulfilling the criterion of the environmental protocol

2.4.3 Solid Waste Contamination in Lake

During summer period around 60-70 persons stay at Maitri and in the adjoining summer huts (Figure 2.2) which are built in front of the Maitri, and during winter round 25 people live in Maitri station. Solid waste mainly generates from the kitchen waste which is semi solid food waste and organic in character. Other sources include packing material in the form of wood, cartoons tetra packs etc. Fuel operated incinerator based toilet modules are used to burn excreta, which are used during summer camps and placed around 150m away in northern side of the station and few are placed at western side of the main building. Incineration process emits particulate matters and gases. Sometimes it is noticed that excreta is not burnt properly and during ash collection and disposal it creates threat to mix (suspended particles) with lake water due to high wind. Similarly, packing material not kept in closed area, are threats to disperse around Maitri in a large area as well as submerging into surrounding lake water (Ghosh et al., 1997).

Figure - 2. 2 : summer Huts at Maitri



2.5 Establishment of Environmental Laboratory at Maitri

It is felt necessary to establish an environmental laboratory at Maitri with the capacity to analyze physico-chemical parameters of water and wastewater sample. To set-up an environmental laboratory a suitable place was needed, where permanent equipments could be installed to carry out continuous environmental monitoring and its analysis to take effective decision and for waste management in and around the Maitri. For this purpose the old Green House room was selected at Maitri. Before placing the instruments the infrastructure assessment was carried out and provided with water arrangements, electricity connections, proper ventilation, heating of the lab etc. Various new chemicals, glassware's and plastic wares were placed which were required to carryout the in-situ physico-chemicals, demand analysis and nutrient analysis of water and wastewater. Laboratory was strengthen to analyze i.e. pH, temperature, Dissolved Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand, chlorides, sulfate, ammonia, nitrate, phosphate, conductivity, turbidity and chlorides, according to Standard Methods of Water and Waste Water Analysis (APHA, 1995). Following instruments are calibrated and placed in proper working condition (Figure 2.3):

- ◆ Distilled Water Unit: Quartz make with capacity 3 litre/hr, electrically operated.

- ➔ Soxlet Extraction Mantle with Digestion Unit: Six mantel type (100 °C).
- ➔ B.O.D. Incubator: Digitally controlled, with temperature range 5°C to 60°C and accuracy + 0.5°C.
- ➔ Hot air Oven: Range 5°C to 450°C, digitally Controlled.
- ➔ Muffle furnace: Digitally Controlled, maximum temperature 1150°C.
- ➔ Magnetic Stirrer with Hot Plate: 2 litre capacity with energy regulator.
- ➔ Turbidity Meter: Range 0 to 100 NTU with 0.1 NTU resolutions and with tungsten lamp.
- ➔ Conductivity Meter: Digital display with automatic temperature compensation.
- ➔ pH Meter : Range 0 to 14, digital display with automatic temperature compensation.
- ➔ Digital Spectrophotometer: Range 340 – 960 nm, with resolution 1 nm.
- ➔ Analytical Balance: Sartorius make maximum capacity 200 grams, 4 digits auto calibrate with 1 mg accuracy.
- ➔ Heating Mantle: Maximum surface temperature of 450° C, controlled by a built - in energy regulator.

Figure - 2. 3: Environmental Laboratory at Maitri

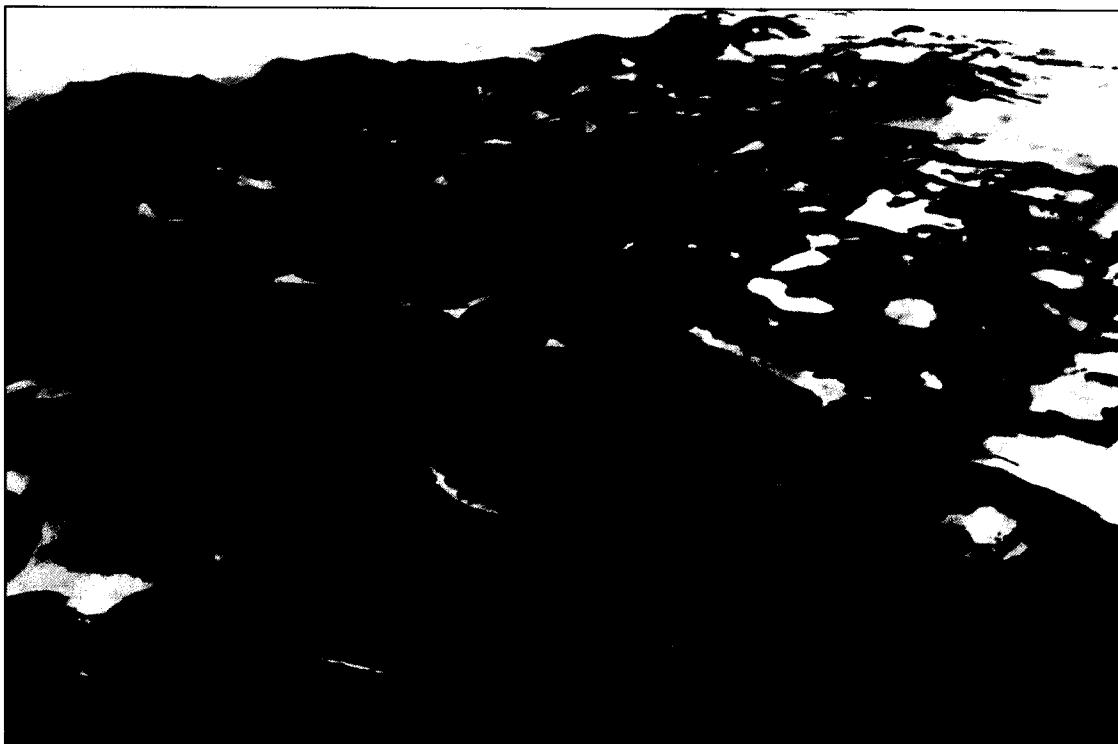


2.6 Sample collection Locations

2.6.1 Water Sample

Around the station several glacial and fresh water lakes exists (Figure 2.4). The main lake used for the potable water is in front of the station which is feed by interconnected glacial lakes. In this lake 10 locations were selected for water sampling, taking into account its importance i.e., feeding inlet, outlets of lake, center point, seepage point through wastewater system nearness to summer huts and toilets. Samples were collected in the year 2000 and 2004. In January 2004 out of 10 stations only seven locations could be sampled due to high wind logistics support sailing inside the lake could not be materialized. Few locations in the glacial lakes were also selected which exists near to the station.

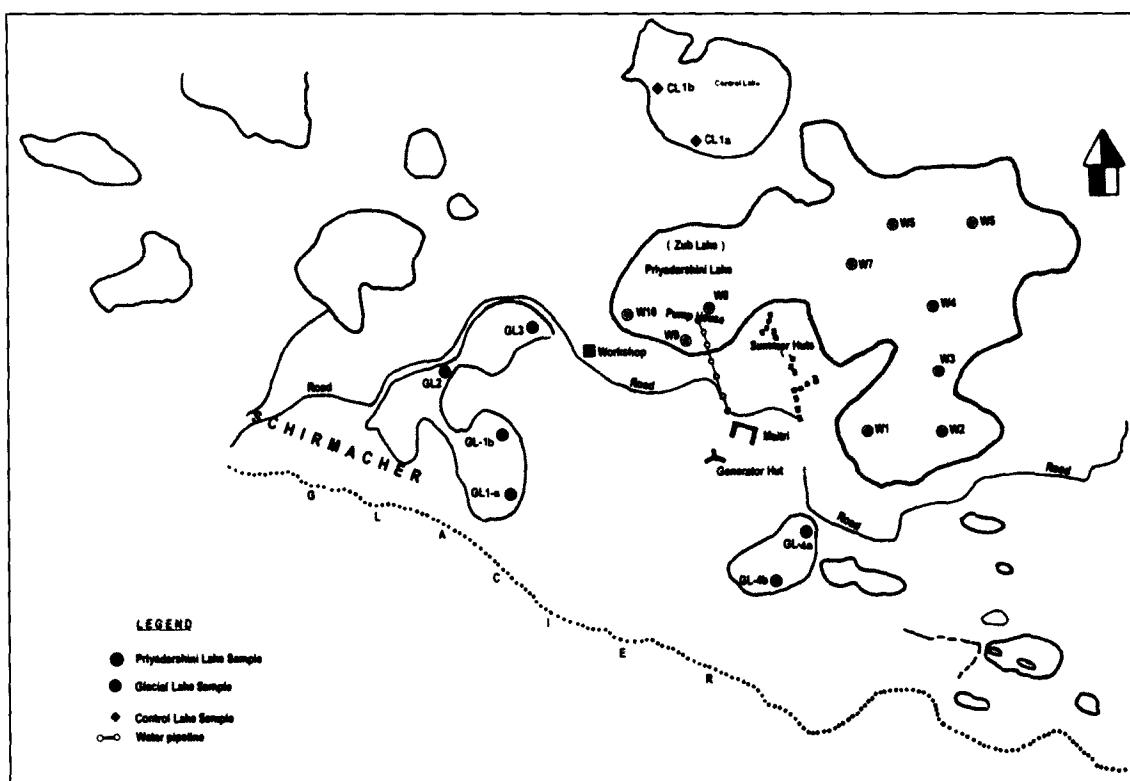
Figure - 2. 4 : Maitri Station, Priyadarshini Lake and Summer Camp



Four Glacial Lakes and two Control Lakes (1 and 2 km away from Priyadarshini Lake) were selected for assessing the water quality and comparison purpose. Ten sampling locations denoted as W1 to W10 were selected from different locations within the

Priyadarshini Lake for a proper assessment of its water quality. Six locations denoted as GL1a, GL1b, GL2, GL3, GL4a and GL4b were identified in the four glacial lakes located on the western side of the station. Three additional locations denoted as CL1a, CL1b and CL2 included two freshwater lakes and are referred as Control Lakes (Figure 2.5). These samples from Control Lakes were used to obtain the background concentrations since the lakes were situated some distance away from the Maitri station and assumed to be not affected by the prevailing activities.

Figure - 2. 5: Schematic diagram of Maitri Station and Sampling Location



2.6.2 Wastewater Sample Points at RBC

RBC's installed at Maitri are made of Glass fiber Reinforced Polyester (GRP) which is extremely robust and easy for transport and install. The RBC units are located in separate rooms that are not exposed to sunlight to prevent the growth of algae, which could intervene with microbial attachment (Ayoub and Saikaly, 2004) and at times overburden the discs with extra mass. B1 RBC treat waste obtained from kitchen and B3

RBC treat the waste obtained from bathroom, washbasins, laundry and urinal.

Treatment systems are installed and operate to filter and convert organic matter into stabilized unharmed material and gases. For the present study all the places where waste generates and further process takes place, efforts are made to collect the samples i.e. inlet points, primary and secondary settling tank and biozone. However few locations were also identified to collect samples i.e. collection pond,, final discharge point and from connecting lakes to Priyadarshini.

2.7 Water Balance at Maitri

Efficacy of wastewater depends upon the designed load and surrounding environmental conditions of wastewater that feed into the system. To assess the actual average quantity of wastewater generated and fed into RBC's, water balance of station is developed through water intake assessment and its distribution, losses and conversion into wastewater. Water is supplied to Maitri through a submersible pump from Priyadarshini Lake which is collected in two tanks of 5 m^3 volume, inside the station. In the month of January 2000 and 2003, on a particular day when the strength in the station was noticed maximum, 24 hourly assessments of wastewater generation and measurement was carried out to derive water balance (*Tiwari and Kulkarni, 2005*).

Water was collected in a main tank where from it is distributed into kitchen, boiler, bathroom, and washbasin and summer huts. Daily total water consumption was measured through the changes in water level of main tank, before and after pumping. Boiler was used at Maitri to circulate heated water through radiators, in each room. An expansion tank was placed to make up evaporated water, lost during circulation through boiler. Water loss was measured through change in the water level in 24 hours. However, variation in water demand is noticed during winter and summer months.

The inlet quantity of wastewater to B1 was measured from inside kitchen through a closet which joins to kitchen RBC. Water was collected in bucket before releasing into RBC and volume was measured every hour. At the outlet of RBC 220 litres capacity barrels were kept to collect the treated wastewater before releasing into pond.

Wastewater generated at laundry was assessed through daily consumption of water that was required by the washing machines based on number of persons using it.

Inlet measurement of B3 RBC which mainly receives waste water from laundry, urinal, washbasin and bathroom is assessed through back calculation because all the pipe line were concealed and no suitable place was found to measure the flow. Effluent quantity flow was measured by collecting effluent in 220 litre barrel for 24 hours. At summer huts water was collected in a tank where from it is distributed to other places like tea room (Annapurna hut), and bathrooms. The level of water on filling and after consumption was measured to calculate water consumption in summer huts.

2.8 Sample collection and Preservation

Samples (water and wastewater) were collected in the month of January-February, 2000, 2001 and 2004. Pre acid washed Nalgene; High Density Poly Ethylene (HDPE) bottles were used for water and wastewater sample collection. The bottles were soaked with 10% HCL for 24 hours and then thoroughly cleaned and rinsed with distilled water. All the borosilicate glass bottles and polyethylene container were rinsed with chromic acid solution followed with tap and distilled water and then inverted them to dry. Trace metal analysis container were rinsed with 20% HNO_3 followed by distilled water. The above procedure was followed at Maitri as well as for RBC model analysis.

In the years 1994 and 1995 samples were collected from the influent and effluent of both B1 and B3 RBC. These four sets of sample were considered as reference analysis to pursue further study. During the study period in the year 2000, composite samples were collected from influent as well as effluent of B1 and B3 RBC. Samples were also analysed for tertiary treatment. For this effluents collected after alum dose and further passing through activated carbon were analysed. Eight sets of samples were collected and analysed for performance study. In the year 2004 six sets of samples were collected and analysed from influent, effluent and bio-disk chambers of B1 and B3 RBC. Additional set of sample were collected from the wastewater collection pond in the year 2004.

Water sampling in lakes was carried out with the help of Niskin water sampler from different depths. Each sample was collected in one litre bottle for nutrient, oil and grease, physico-chemical parameters and half litre bottles were used for sample collection for trace metal analysis. A part of water, from collected sample was used to analyze the essential parameters in Environmental laboratory at Maitri. Utmost care was taken to bring the samples collected from the Lakes to laboratory within an hour to measure the essential parameters. Ambient temperature during sample collection varied from -5°C to +3 °C and water temperature from -2 °C to +1 °C.

An inflatable boat was used to collect the samples from middle of the Priyadarshini Lake. In each of the heavy metal bottles one ml of HNO₃ was added to acidify the sample. Oil and Grease and nutrient samples were preserved with H₂SO₄ by mixing one ml of acid and making pH to 2. All the samples were preserved in near temperature range of +4 °C, for further analysis at the laboratory in Maitri and in India.

2.9 Performance Evaluation and Tertiary Treatment at Maitri in Lab Scale

Wastewater treatment system should ‘work at design load and give desired effluent quality. To evaluate the performance of RBC’s 24 hourly composite samples were collected at various points, during summer period in the year 2000, and 2003. Composite samples were collected from inlets, primary settling chamber, biozone and secondary settling chambers of both the RBC’s. Sample was also collected from effluent collection pond. Having assessed the performance of RBC which gave its running efficiency at 25-60%, it was decided to seek the option to understand the effect of tertiary treatment at laboratory-scale/bench-scale (*Banerjee, 1997a; Laopaiboon et al., 2002*) at environmental laboratory of Maitri.

An attempt was made at the laboratory to observe the effect of tertiary treatment on the effluents of RBC. In this regard the effluent was primarily treated through the optimum dose of alum (*Malhotra and Lee, 1964*) which is widely used as a coagulant (*Chu, 1999*) and then treated through granular activated carbon. The influent waste from both the RBC’s and effluent after optimum dosing of alum and effluent from the activated carbon

column was further analyzed for physico chemical parameters viz. pH, turbidity, total suspended solids (TSS), total dissolved solids (TDS), conductivity, total alkalinity, chlorides, sulfate, temperature, COD, BOD, ammonia, total phosphates, oil and grease, hydrocarbons, nitrogen nitrite, nitrogen nitrate, phenol and heavy metals viz. nickel, cadmium, chromium (Ayub et al., 2003), copper, lead, iron, manganese, zinc, cobalt.

2.9.1 Tuning of RBC

While through performance evaluation it was assessed that the RBC's are not working at designed efficacy, both the systems were tuned for its disc rotational speed (RPM) and biozone temperature to develop the bacterial growth properly and DO transfer and then its performance evaluation was done again collecting the sample and analyzing at environmental laboratory at Maitri.

2.10 Transportation of Samples

All the samples were kept in plastic crate and transported from Maitri to Ship by helicopter and kept in +4 °C containers in the ship and after reaching Cape Town it was transported by flight keeping in icebox with dry ice to maintain the temperature and brought to the laboratory at NCAOR for further analysis.

2.11 Lab Scale Modelling

At Polar environmental Laboratory of NCAOR two RBC's simulating to the RBC's of Maitri were designed keeping the physical aspect ratio 1: 200. The resident time of waste was kept similar to RBC at Maitri, rest of the parameters were designed according to dimensional analysis of RBC at Maitri and working model of RBC. These model were kept running for about four months and during this period various experiments were conducted at ambient temperature 25-30 °C taking into consideration that RBC at Maitri will perform in the same temperature. The performance evaluation is carried out on the working model i.e.

- ➔ Considering both the RBC running separately with independent waste load
- ➔ Kitchen RBC (B1) effluent diverted into influent of laundry, urinal RBC (B3)

- ◆ Tertiary treatment implying alum dose and activated carbon treatment

This laboratory-scale model may be particularly useful in predicting the organic loading rate. Such information is very useful in the scale-up process of constructing a treatment plant, as a pilot plant of intermediate size (*Palma et al., 2003*).

2.11.1 Collection and Analysis of Wastewater Samples from RBC Model

Composite samples were collected at influent, effluent and biozone and were analyzed for physico chemical parameters viz. suspended solids (SS), volatile suspended solids (VSS), volatile dissolved solids (VDS), pH, conductivity, turbidity, total suspended solids (TDS), dissolved solids, BOD, COD, nitrate, ammonia, phosphate, sodium, potassium, calcium and trace metals (chromium, manganese, cobalt, nickel, copper, zinc, cadmium, lead and iron), using, Inductively Coupled Plasma Mass Spectrophotometer (IC-PMS) of Thermo make.

All analytical procedures were performed according to Standard Methods (APHA, 2000). Chemical oxygen demand (COD) was measured by the closed reflux method using Hach DRB 200 COD reactor; biochemical oxygen demand (BOD_5) was measured by the 5-d BOD test using Orion 810 + and Thermo electron DO meter; temperature was measured through Cole Parmer thermo couple digital thermometer; sodium, potassium and calcium were measured through Elico CL 361 make flame photometer; nitrate, ammonia and phosphate were measured by colorimetric method using Thermo Genesys 20 spectrometer; conductivity, pH, and TDS were measured through Oakton pH/Con 510 Series make bench top meter; total suspended solids (TSS), dissolved solids, volatile dissolved and suspended solids were measured by the gravimetric method and for filtration a PALL make filtration unit and Nalgene filter paper 0.45 um were used. For all the analysis purpose in India Millipore type II water from Elix 3 was used and chemical balance Sartorius CP 224 S was used for general weighing purpose. Trace metal analysis, was carried out after filtering the sample through 0.45 um membrane filter on Thermo make ICP-MS.

2.12 Analysis of Samples in Laboratory

Basic parameters of water and wastewater i.e. pH, temperature, conductivity, turbidity, DO, BOD, COD, alkalinity acidity, TDS, ammonia, nitrite and nitrate were analysed in Environmental laboratory at Maitri. The preserved samples were sealed properly and brought to India for further analysis in the laboratory. Samples were filtered before analysis with 0.45 μm Whatman filter papers. All the samples were analyzed using standard methods of water and waste water analysis (APHA, 2000) for, total hardness, calcium hardness, sulfate, sodium, potassium, oil and grease, hydrocarbons, phenol and heavy metals (nickel, cadmium, chromium, copper, lead, iron, manganese, zinc, and cobalt). The samples were analyzed through following the standard method of water and wastewater analysis as follows.

Turbidity by Nephelometric method, acidity by titrametric method, alkalinity by titrimetric method, hardness by EDTA titrametric method, conductivity by conductivity meter, solids by gravimetric and oven dried method, sulfate by turbiditric method, temperature by mercury filled certified Celsius thermometer and thermocouple, metals by atomic absorption spectrometry, chlorides by argentometric method, fluoride by SPADNS method, pH by electrometric method, nitrogen (ammonia, nitrate and nitrite) by colorimetric method, phosphorus by colorimetric method, BOD by 5 day BOD test, COD by closed reflux colorimetric and open reflux titrimetric (at Maitri) method, oil and grease by partition gravimetric method.

2.12.1.1 Turbidity

Turbidity of the sample was measured by digital turbidity meter with range of 1000 NTU and 0.1 NTU resolution. Stock hydrazine sulfate and hexamethylenetetramine solution was prepared to make standard turbidity suspension and instrument was calibrated using different dilution solution from the standard solution.

2.12.1.2 Oil and Grease

To assess the concentration of oil and grease, Trichlorotrifluoroethane-soluble floatable oil and grease method is used. For the extraction, dry filter (1 μm Pall) was used. After 30

minutes settling time, soluble floatable oil and grease were estimated for the samples.

2.12.1.3 Total Dissolved and Volatile Solids

Total solids were estimated evaporating the known volume of sample at 105°C, in silica glass. The initial and final weight difference of known volume of sample produced the total solids. For total suspended solids a known volume of the sample was filtered through the glass fiber filter paper which was dried at 105° C. The weight difference of initial and final reading corresponding to known volume of sample which passes through the filter paper (1 μ m Pall) gave the amount of total suspended solids. The filtrate was evaporated to dryness in a weighted dish at 180°C, thus increase in weight of the dish represents the total dissolved solids. A sample volume 100 ml was filtered in all solid determination using Nalgene filtration unit and PALL filtration pump. The residue of the total solids, suspended solids and dissolved solids was ignited at 550 °C in muffle furnace and weight loss of the known weight and volume of the sample represented fixed total volatile, suspended volatile solids and dissolved volatile solids respectively.

2.12.1.4 Dissolved Oxygen (DO)

At Maitri DO was measured through Winkler method. Sample collected from the source, was soon put into 300 ml BOD bottle. DO was fixed with reagents at the site and then precipitated sample was titrated in the laboratory with standard sodium thiosulphate solution (0.025 N) putting starch as indicator. While experimented on RBC model, DO was measured through Thermo Orion 810+, DO meter which was calibrated against zero and saturated DO.

2.12.1.5 Biochemical Oxygen Demand (BOD)

At Maitri BOD was estimated by measurement of initial and final DO of the sample by Winkler method which was kept for 5 days in BOD incubator at 20 °C. Dilution of water samples were prepared depending on the need and strength of sample. The lake water samples were kept for test with 25% dilution water without addition of seed. Initial and final DO of diluted water samples was measured after 5 days of incubation and average BOD estimated based on these two measurements. The waste water samples were

diluted to, 0.5%, 1%, 3% and 5%, with dilution water, according to the expected strength of wastewater sample, and kept for incubation for 5 days and initial and final DO measurement of sample as well as dilution water used, in preparation of sample were recorded. Accordingly using formulae BOD was estimated.

2.12.1.6 Chemical Oxygen Demand (COD)

The COD analysis is carried out at Maitri by open reflux method. Samples digested in 500 ml flask using 0.25 N potassium dichromate and sulfuric acid was then titrated with 0.1 ferrous ammonium sulfate solution. The samples of model experiment were analyzed by closed reflux colorimetric method using Hack DRB 200 COD reactor and setting Thermo Genesis 20 spectrometer at 600 nm. The value of COD is then estimated through calibration curve of COD prepared with standard solutions. The samples were diluted to measure the strength in line with calibration curve.

2.12.1.7 Ammonia

Ammonia was estimated by colorimetric method (*Ramteke and Moghe, 1988*). The pH of the filtered sample (0.45 um) is maintained by adding ZnSO₄, then mixing with Rochelle salt solution, and nessler reagent then absorbance was measured at 410 nm. Calibration curve was drawn through standard ammonium solution.

2.12.1.8 Nitrate

Nitrate in the samples (filtered through 0.45 um membrane filter) were measured through phenol disulfonic acid (PDA) method (*Ramteke and Moghe, 1988*). Evaporated sample to dryness by water bath was mixed with phenol disulfonic acid reagent and then NaOH was added. Color developed solution was then put for absorbance in the spectrometer at 410 nm. Calibration curve was developed using standard nitrate solution.

2.12.1.9 Total Phosphate

To determine the total phosphate, colorimetric method was used, adding phenolphthalein indicator and sulfuric acid solution and then color was developed

through adding hydroxide after boiling the sample for 90 minutes. Further, mixing the reagents, absorbance was measured in spectrometer at 690 nm. Calibration curve was prepared by phosphate standard solution and its absorbance.

2.12.1.10 Acidity

In the water sample acidity was measured by titration using standard sodium hydroxide 0.02 N solution and phenolphthalein and methyl orange indicator

2.12.1.11 Alkalinity

Alkalinity in the water sample was determined by volumetric analysis using Standard sulfuric acid 0.02 N as titrate and phenolphthalein and methyl orange indicator.

2.12.1.12 Hardness

Total hardness in water sample was determined by mixing sample with buffer solution followed by Erichrome black T and titration with standard EDTA. Further calcium hardness was measured by titrating sample with EDTA after adding NaOH and murexide indicator. Magnesium hardness was obtained by deducting calcium hardness from total hardness.

2.12.1.13 Chloride

Chloride in the water samples was estimated by titrating it with standard silver nitrate solution 0.0141 N. Silver nitrate was also standardize against NaCl solution.

2.12.1.14 Sulfate

In the water sample sulfate was measured by colorimetric method. Samples were mixed with conditioning reagent and BaCl₂ and the absorbance was measured at 420 nm. Standard calibration curve was drawn using standard sulfate solution.

2.12.1.15 Trace Metal Analysis

Trace metal analysis of water as well as wastewater sample was determined using GBC –

AAS (F) and also by Thermo 100 -ICP-MS.

2.13 Alternative Selection for Waste Disposal

The present method of disposal of treated wastewater at Maitri is being followed as to discharge treated effluent on open ground around 320 m away from the collection pond, which seeps further and join the glacial lake and joins another lake as these lakes are interconnected and ultimately joins the Priyadarshini lake. This leads to threat of chain contamination of the lakes. An alternate solution suggested is the treated wastewater may be further treated with tertiary treatment units and thereafter Reverse Osmosis (RO) can be implemented to further filter the impurities and trace metals. The effluent from RO can be either evaporated or sprinkled over the open land.

2.14 Application of WASP7

The Water Quality Analysis Simulation Program (WASP7), an enhancement of the original WASP (*Di Toro et al., 1983; Connolly and Winfield, 1984; Ambrose, 1988*) is proposed. This model helps users to interpret and predict water quality responses to natural phenomena and manmade pollution for various pollution management decisions. WASP is a dynamic compartment-modelling program for aquatic systems, including both the water column and the underlying benthos. WASP allows the user to investigate 1, 2, and 3 dimensional systems, and a variety of pollutant types. The time varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are represented in the model. WASP also can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity and sediment fluxes. This water quality prediction model was employed to assess the effect of wastewater seepage from the collection pond to Priyadarshini Lake in terms of pollution and eutrofication.

Chapter 3

Water Characterization it's Prediction and Efficacy Improvisation of RBC

3.1 Lake System around Maitri Station

Priyadarshini Lake is one of the biggest glacial melt water lakes among 105 lakes of various sizes exist in the Schirmacher oasis. Around the Maitri station many glacial lakes are present which receives direct melt water from the glacier. The region is completely free from rain fall but during summer small tributaries from the glacial area flow which pass over moraine deposits and boulders generate and are the potential of chemical weathering. In addition, rates of carbon dioxide uptake in cold climate, introduction of trace metals and nutrients in the streams makes the system dynamic to study. Many lakes are not affected by the human impact in the past and also present which opens a window to designate as control lakes to act as datum for impacted lakes from the human interference and pollution in future.

3.1.1 Significance of Earlier Study

Water is withdrawn from Priyadarshini Lake to meet the daily demand of Maitri for various purposes. Water characteristics have direct relationship to the effluent characteristics which affects the treatment system after converting into wastewater (Nemerow, 1991; Ozaki and Li, 2002; Ellen et al., 2005). It is also assessed that there are chances of direct and indirect contamination to the Priyadarshini Lake which may affect its the water quality. So it becomes imperative to analyze water quality of the lakes around the station. The environmental monitoring of the Maitri station started in around 15 the years ago in 1994 by Ghosh (Ghosh et al., 1997) and in 1995 by Nair (1998). Few studies are also available on sample analysis of Schirmacher Oasis (Pradeep et al., 2002) and heavy metals of a few sediment samples of lakes (Kureishy et al.,

1993). These studies being very preliminary and locations of the interest varied could not be considered to compare with latest results. Sample collection of water and wastewater and analysis carried out by earlier expedition members are defined in section-A, whereas Section-B deals with water and wastewater sample characterization of the present research work. To understand the long term variability in the concentrations of various constituents in the water and effect of RBC installation, wastewater results of earlier workers were considered.

SECTION “A” – Earlier Study

3.2 Water and Wastewater Sample Analysis during Various Expeditions by Expedition Member (1994 and 1995)

During 1994 summer, water samples were collected from Priyadarshini Lake, Control Lake and glacial lake. Each sample was collected between 50 m and 100 m from the bank of each site. Two samples were also collected from the seepage channel which originates from wastewater collection pond which ultimately joins Priyadarshini Lake following a steep gradient (*Ghosh and Ramteke, 1997*). Water samples were collected by means of clean polyethylene bucket and transferred into different clean polyethylene bottles. Samples were collected from four locations of Priyadarshini Lake one from Control Lake and two from glacial lake (Figure 3.1). Field parameters like pH, temperature, conductivity, turbidity and dissolved oxygen were estimated immediately after collecting the samples. Results of the water analysis carried out during 1994 are presented in Table 3.1. Influent and effluent wastewater samples collected from RBCs B1 and B3, in the year 1994 are presented in Table 3.2 and 3.3.

The water samples were also collected in the summer period of 1995 by Nair (1998) from various locations of Priyadarshini Lake, Control and Glacial Lakes, depicted in Figure 3.1. During this period samples were collected from eighteen different locations viz. nine from Priyadarshini lake, three from control lake and six from glacial lake and characterized for different parameters like physical, inorganic, nutrient, demand and organic parameters (Table 3.4 and 3.5). These include pH, temperature, conductivity, turbidity, alkalinity, total hardness, chloride, sulfate, sodium, potassium, nitrate, nitrite, ammonical nitrogen, total phosphate, dissolved oxygen (DO), biochemical oxygen

demand (BOD), chemical oxygen demand (COD), oil and grease, hydrocarbons and trace metals like cadmium, copper, chromium, lead, iron and zinc. Field parameters like pH, temperature, conductivity, turbidity, DO and BOD were analyzed at Maitri station immediately after collecting the samples while samples for other parameters were preserved and brought to India for further analysis. The results of wastewater sample analysis carried out during the year 1995 are presented in Table 3.6 and 3.7.

Figure - 3. 1: Water Sample Location 1994 and 1995

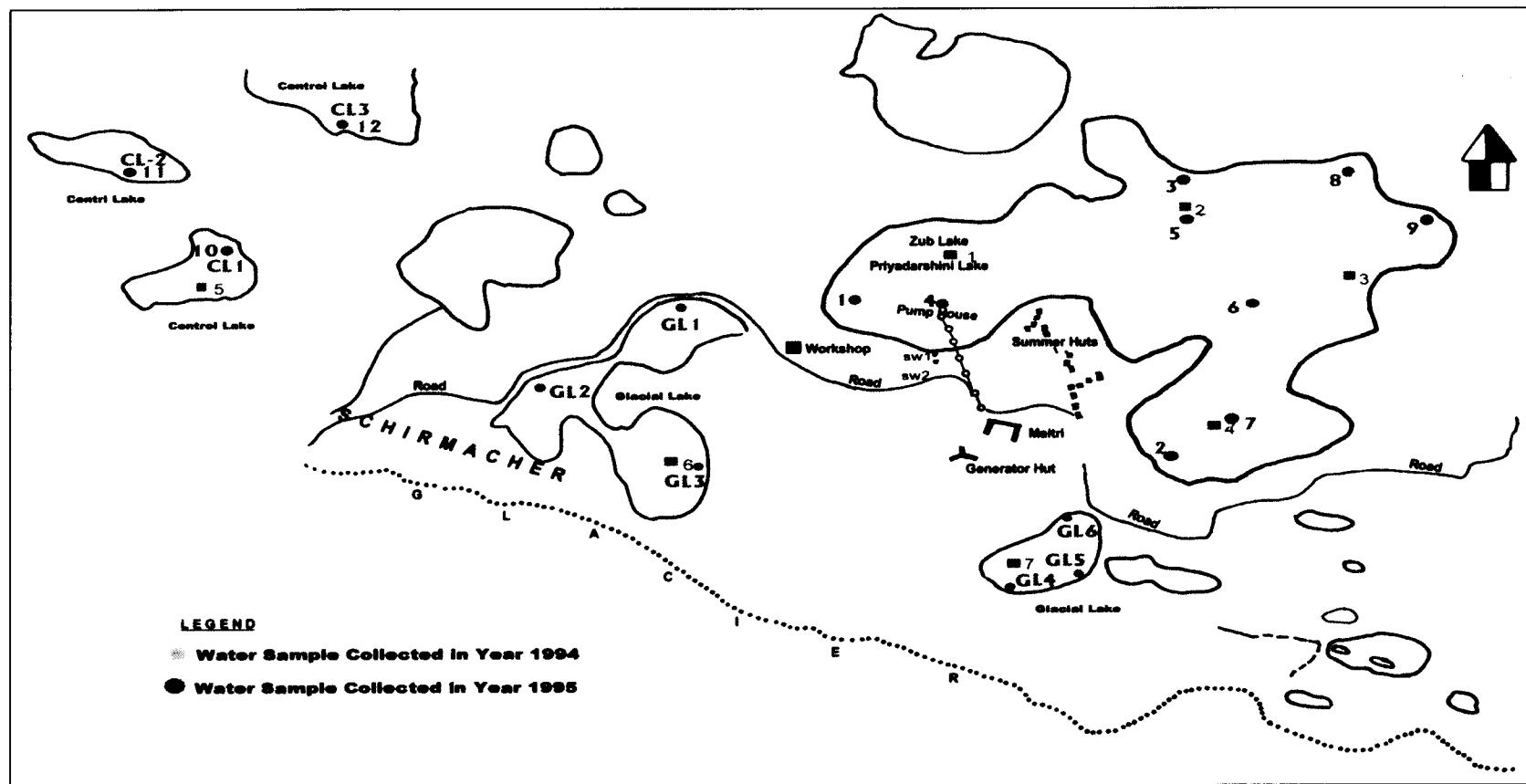


Table - 3. 1: Abiotic Characteristics of Water Samples from Priyadarshini Lake, Control Lake, Glacier Lakes and Seepage Channel (Year 1994)

S.No	Parameter	Unit	Concentration levels							
			Priyadarshini Lake				Control Lake		Glacier Lake	
			1	2	3	4	5	6	7	
A. Physical										
Turbidity	NTU	3.4	3.3	3.0	2.4	4.6	4.6	4.6	4.6	
pH	-	5.8	5.7	5.1	6.0	6.7	4.6	4.6	4.6	
Conductivity	us/cm	21.3	18.6	24.04	20.06	10.6	9.3	8.2		
Total dissolved solids	mg/l	12.9	11.2	10.3	9.4	3.0	10.0	6.0		
Suspended solids	mg/l	4.0	2.0	5.0	3.0	2.0	10.0	6.0		
B. Inorganic										
Chloride	mg/l	23.0	24.0	29.0	23.0	11.0	11.0	10.0		
Sulphate	mg/l	4.0	1.0	4.0	4.0	9.0	9.0	8.0		
C. Nutrient & Demand										
Nitrate	mg/l	0.07	0.01	0.02	0.06	0.05	0.08	0.05		
Nitrite	mg/l	ND	ND	ND	ND	ND	ND	ND		
Phosphate	mg/l	ND	ND	0.08	ND	ND	0.1	ND		
Dissolved Oxygen	mg/l	8.5	8.2	8.6	8.4	8.7	8.4	8.4		
D. Organic										
Total Organic Carbon	mg/l	10.0	15.0	10.0	8.5	ND	ND	ND		
Hydrocarbon	µg/l	0.03	0.03	0.03	0.03	0.01	0.01	0.01		
E. Heavy Metals										
Cadmium	µg/l	7.0	15.0	6.0	13.0	6.0	3.0	3.0		
Copper	µg/l	ND	2.0	2.0	32.0	4.0	9.0	3.0		
Chromium	µg/l	14.0	22.0	ND	4.0	ND	14.0	ND		
Lead	µg/l	8.0	27.0	ND	58.0	53.0	64.0	58.0		
Iron	µg/l	256.0	251.0	140.0	343.0	200.0	70.0	98.0		
Manganese	µg/l	2.0	41.0	ND	199.0	ND	43.0	22.0		
Zinc	µg/l	77.0	113.0	39.0	99.0	47.0	129.0	102.0		

**Table - 3. 2 : Physico-chemical Characteristics of Wastewater Sample
(Year 1994)**

S. No.	Parameter	RBC (B1)		RBC (B3)	
		Influent	Effluent	Influent	Effluent
1.	pH	7.98	5.50	8.11	6.5
2.	Suspended solids	646.06	124.00	68.00	30.00
3.	Chloride	63.00	52.00	110.00	85.00
4.	Sulphate	18.5	10.6	55.05	97.32
5.	Phosphate	0.52	0.73	4.2	5.2
6.	Nitrate	8.3	6.4	24.3	16.8
7.	Chemical oxygen demand	1510.0	920.0	1650.0	1100.0
8.	Biochemical oxygen demand	490.0	310.0	540.0	400.0

(Except pH, all values are expressed in mg/l)

Table - 3. 3 : Levels of Heavy Metals in Wastewaters of RBCs (Year 1994)

S. No.	Sampling Location	Waste	Cadmium	Copper	Chromium	Lead	Iron	Zinc
		mg/l						
1.	RBC (B1) sample collected at time t1	I E	0.01 ND	0.06 1.52	0.24 0.27	0.26 0.02	16.74 21.46	2.31 11.26
2.	RBC (B1) sample collected at time t2	I E	ND ND	0.03 0.05	0.12 0.12	0.01 0.02	13.57 11.25	9.84 6.32
3.	RBC (B1) Composite sample	I E	ND ND	0.33 0.65	0.11 0.14	0.09 0.01	4.02 6.25	10.36 8.35
4.	RBC (B3) sample collected at time t1	I E	ND ND	0.18 0.28	0.27 0.06	ND 0.09	3.34 4.02	1.05 0.01
5.	RBC (B3) sample collected at time t2	I E	ND 0.01	0.84 0.06	0.30 0.24	0.03 0.26	4.53 6.11	14.72 0.35
6.	RBC (B3) Composite sample	I E	ND ND	0.84 0.16	0.19 0.12	0.09 0.09	4.01 4.16	10.36 0.10

I – Influent, E- Effluent

Table - 3. 4 : Surface Water Quality – Priyadarshini Lake, Control Lake Physical Parameters and Inorganic Parameters (Year 1995)

S. No.	Sampling Location	Temperature (°C)	pH	Conductivity (µs/cm)	Turbidity (NTU)	Alkalinity	Total Hardness	Calcium Hardness	Chloride	Sulfate	Sodium	Potassium
						as CaCO ₃ (mg/l)	mg/l					
Priyadarshini Lake												
1.	Western side of the lake (100 m from the bank)	6.5	6.0	22.5	1.5	5.1	12.0	4.8	2.2	4.2	ND	ND
2.	Southern side of the lake (100 m from the bank)	4.5	6.1	18.0	1.0	4.7	12.0	2.4	3.3	4.2	ND	ND
3.	Northern side of the lake (100 m from the lake)	4.5	6.1	15.0	1.5	3.1	10.2	2.4	8.0	4.2	ND	ND
4.	Western side of the lake (200 m from the lake)	4.5	5.9	19.5	1.0	3.2	9.6	2.4	2.0	4.3	ND	ND
5.	Northern side of the lake (200 m from the lake)	4.5	5.8	18.5	1.0	3.2	9.6	2.4	2.0	4.3	ND	ND
6.	Centre of the lake	4.5	5.9	16.5	1.0	4.9	9.6	2.4	8.0	4.9	ND	ND
7.	South-East side of the lake (200 m from the lake)	4.5	5.4	20.5	1.0	5.1	12.0	2.4	6.0	4.3	ND	ND
8.	North-East side of the lake (100 m from the lake)	4.5	6.4	19.0	1.0	4.8	12.0	2.4	6.0	4.6	ND	ND
9.	Eastern side of the lake (100 m from the lake)	4.5	6.2	13.0	1.0	5.1	9.2	2.4	8.0	4.6	ND	ND

Cont. .

Cont. Table 3.4

S. No.	Sampling Location	Temperature (°C)	pH	Conductivity (µs/cm)	Turbidity (NTU)	Alkalinity	Total Hardness	Calcium Hardness	Chloride	Sulfate	Sodium	Potassium
Control Lake												
10.	Control lake No. 1 (North-West side of Maitri Station)	5.5	6.4	23.0	1.0	5.2	9.6	2.4	8.0	4.9	ND	ND
11.	Control lake No. 2 (North-West side of Maitri Station)	4.0	6.3	34.5	1.0	10.7	12.0	4.8	8.0	5.4	ND	ND
12.	Control lake No. 3 (North-West side of Maitri Station)	5.5	6.7	33.7	1.0	20.6	18.4	19.2	7.2	5.8	ND	ND
Glacial Lake												
13	Northern side of Glacier lake towards West of Maitri Station	3.0	6.2	15.0	16.0	9.0	12.0	2.4	8	2.4	ND	ND
14	Western side of Glacier lake towards West of Maitri Station	3.0	6.0	17.0	4.0	6.4	12.0	2.4	6	4.7	ND	ND
15	Southern side of Glacier lake towards West of Maitri Station	3.0	6.0	14.5	3.0	6.4	9.6	2.4	10	4.7	ND	ND
16	Western side of Glacier lake towards South-East of Maitri Station	0.5	5.9	17.0	4.0	6.4	9.6	2.4	6	4.7	ND	ND
17	Eastern side of Glacier lake towards South-East of Maitri Station	1.0	5.9	15.0	6.5	6.4	12.0	2.4	6	4.7	ND	ND
18	Northern side of Glacier lake towards South-East of Maitri Station	1.0	5.8	14.0	7.5	6.5	7.2	2.4	8	4.7	ND	ND

ND: Not Detected

Table - 3. 5 : Surface Water Quality – Priyadarshini Lake, Control Lake, Nutrient and Organic Parameters and Heavy Metals (Year 1995)

S. No	Sampling Location	Nitrate NO ₃ -N	Nitrite NO ₂ -N	Ammonia as NH ₃ -N	Total phosphate	Dissolved Oxygen	BOD	COD	Oil & Grease	Hydrocarbon	Cadmium	Copper	Chromium	Lead	Iron	Zinc
		(mg/l)								(µg/l)	(mg/l)					
Priyadarshini Lake																
1.	Western side of the lake (100 m from the bank)	ND	ND	ND	3.2	10.2	2.1	8.7	ND	ND	ND	ND	ND	ND	0.07	0.04
2.	Southern side of the lake (100 m from the bank)	2.7	ND	ND	3.9	10.5	2.3	4.0	ND	ND	ND	ND	ND	ND	ND	ND
3.	Northern side of the lake (100 m from the lake)	0.4	ND	ND	4.7	11.0	2.2	6.2	ND	ND	ND	ND	ND	ND	ND	ND
4.	Western side of the lake (200 m from the lake)	0.4	ND	ND	1.3	10.8	2.2	6.9	ND	ND	ND	ND	ND	ND	ND	ND
5.	Northern side of the lake (200 m from the lake)	2.1	ND	ND	0.6	10.5	2.7	6.2	ND	ND	ND	ND	ND	ND	ND	ND
6.	Centre of the lake	1.2	ND	ND	0.8	10.9	3.9	5.3	0.8	0.14	ND	0.01	ND	ND	ND	ND
7.	South-East side of the lake (200 m from the lake)	0.2	ND	ND	1.7	13.5	3.0	5.8	ND	ND	ND	0.01	ND	ND	ND	ND

Cont.

Cont. Table 3.5

S. No	Sampling Location	Nitrate NO ₃ -N	Nitrite NO ₂ -N	Ammonia as NH ₃ -N	Total phosphate	Dissolved Oxygen	BOD	COD	Oil & Grease	Hydrocarbon	Cadmium	Copper	Chromium	Lead	Iron	Zinc
8.	North-East side of the lake (100 m from the lake)	0.2	ND	ND	2.9	13.5	3.0	7.0	ND	ND	ND	0.01	ND	ND	ND	ND
9.	Eastern side of the lake (100 m from the lake)	1.4	ND	ND	4.2	10.7	1.4	4.0	ND	ND	ND	ND	ND	ND	ND	ND
Control Lake																
10.	Control lake No. 1 (North-West side of Maitri Station)	1.4	ND	ND	4.0	9.5	1.0	6.2	ND	ND	ND	ND	ND	ND	ND	ND
11.	Control lake No. 2 (North-West side of Maitri Station)	1.4	ND	ND	0.5	9.4	1.6	2.8	ND	ND	ND	ND	ND	ND	ND	ND
12.	Control lake No. 3 (North-West side of Maitri Station)	0.6	ND	ND	4.3	9.9	2.7	10.0	ND	ND	ND	ND	ND	ND	ND	ND
Glacial Lake																
13	Northern side of Glacier lake towards West of Maitri Station	0.5 10	0.0	ND	1.2	8.5	ND	2.0	4.8	0.01	ND	0.01	ND	ND	ND	ND
14	Western side of Glacier lake towards West of Maitri Station	ND 03	0.0	ND	1.1	8.1	ND	3.6	6.2	ND	ND	ND	ND	ND	ND	ND
15	Southern side of Glacier lake towards West of Maitri Station	0.5	ND	ND	1.3	8.7	ND	1.1	3.6	0.09	ND	ND	ND	ND	ND	ND
16	West of Glacier of Glacier lake towards west of Maitri Station	0.9	ND	ND	4.7	12.5	6.5	1.5	4.6	ND	ND	0.01	ND	ND	0.03	0.09
17	East of Glacier of Glacier lake towards west of Maitri Station	0.2	ND	ND	0.8	10.8	4.1	4.8	4.4	ND	ND	0.01	ND	ND	0.06	0.11

Cont. Table 3.5

S. No	Sampling Location	Nitrate NO ₃ -N	Nitrite NO ₂ -N	Ammonia as NH ₃ -N	Total phosphate	Dissolved Oxygen	BOD	COD	Oil & Grease	Hydrocarbon	Cadmium	Copper	Chromium	Lead	Iron	Zinc
18	North of Glacier of Glacier lake towards west of Maitri Station	ND 03	0.0 03	ND	3.1	13.1	ND	2.3	8.8	ND	ND	0.01	ND	ND	0.03	0.02

ND: Not Detected, BOD: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand

Table - 3. 6 : Physico-chemical Characteristics of Wastewater (Year 1995)

S. No.	Parameters	Biodisc (B1) influent			Biodisc(B1) effluent			Biodisc (B3) influent			Biodisc(B3) effluent		
		Time t1	Time t2	Composite	Time t1	Time t2	Composite	Time t1	Time t2	Composite	Time t1	Time t2	Composite
1.	pH	4.4	4.3	4.4	4.2	4.2	4.3	7.8	7.9	7.9	7.6	7.9	7.9
2.	Suspended solids (mg/l)	120	269	148	151	99	112	68	61	53	63	46	53
3.	Nitrate (mg/l)	10.2	9.4	9.3	13.0	11.6	10.6	35.5	25.5	23.0	28.5	14.4	22.5
4.	Nitrite (mg/l)	0.010	0.010	0.008	0.014	0.002	0.010	0.04	0.01	0.01	0.06	0.03	0.03
5.	Ammonia (mg/l)	2.5	2.5	2.5	2.5	2.5	2.5	100	100	100	100	100	100
6.	BOD (mg/l)	860	-	-	444	-	-	620	-	-	430	-	-
7.	COD (mg/l)	2586	-	-	1332	-	-	1832	-	-	1296	-	-
8.	Oil & Grease (mg/l)	1.4	0.8	ND	ND	ND	ND	14.2	0.8	12.8	2.0	2.0	5.2
9.	Hydrocarbon (μ g/l)	0.12	ND	ND	ND	ND	ND	1.3	1.9	3.0	1.9	2.9	1.8

ND: Not Detected

Table - 3. 7 : Biodisc Influent and Effluent Wastewater Heavy Metals (Year 1995)

S. No	Sampling Location	Cadmium	Copper	Chromium	Lead	Iron	Zinc
		(mg/l)					
1.	Biodisc sample collected at time t1 B11(I)	ND	0.01	ND	ND	0.02	0.01
2.	Biodisc sample collected at time t2 B12(I)	ND	0.03	ND	ND	0.03	0.01
3.	Biodisc sample composite B1C(I)	ND	0.02	ND	0.01	1.40	0.23
4.	Biodisc sample collected at time t1 B31(I)	ND	0.03	ND	0.07	0.19	0.12
5.	Biodisc sample collected at time t2 B32(I)	ND	0.04	ND	0.01	0.37	0.16
6.	Biodisc sample composite B3C(I)	ND	0.01	ND	0.01	0.36	0.16
7.	Biodisc sample collected at time t1 B11(O)	ND	0.02	ND	0.01	5.09	0.15
8.	Biodisc sample collected at time t2 B12(O)	ND	0.07	ND	0.03	6.17	0.30
9.	Biodisc sample composite B1C(O)	ND	0.03	ND	0.01	0.06	0.01
10.	Biodisc sample collected at time t1 B31(O)	ND	0.03	ND	0.01	0.39	0.13
11.	Biodisc sample collected at time t2 B32(O)	ND	0.18	ND	ND	0.01	ND
12.	Biodisc sample composite B3C(O)	ND	0.05	ND	0.02	0.24	0.12

ND: Not Detected

3.3 Results

3.3.1 Water Characteristics of Priyadarshini Lake, Glacial and Control Lakes around Maitri Station

Location and number of water samples collected by different expedition members from the Priyadarshini Lake, Glacial Lake and Control Lake during the years 1994 and 1995 are varied. As in the year 1994 water samples were collected from four locations from Priyadarshini Lake, one from Control Lake and two from glacial lakes one each situated at South-East and South-West to Maitri station. In the year 1995 water samples were collected from nine locations in Priyadarshini Lake, three different control lakes (other than control lakes considered in the year 1994) and three each from the glacial lakes locations situated at South-East and South-West to Maitri station.

3.3.1.1 pH

Samples collected in the year 1994 shows pH variation from 5.1 to 6.0 in Priyadarshini Lake; in control Lake pH recorded was little higher than 6.7, whereas in glacial lake pH recorded was acidic side 4.6. During 1995 in Priyadarshini Lake pH measured nearly the same i.e. 5.4 to 6.4 with temperature recorded 4.5 to 6.5 °C. In the control lakes pH was measured 6.3-6.7 (temperature, 4 to 5.5 °C), whereas in glacial lake pH varied from 5.8 to 6.2 with temperature ranging from 0.5 to 3 °C. The pH does not vary drastically in the lakes with time except for glacial lake which indicated almost acidic in 1994. If the temperature is near freezing point as it would absorb more CO₂ can contribute to lower pH (Sawyer *et al.*, 2003).

3.3.1.2 Turbidity

Turbidity in Priyadarshini Lake varied in the range of 2.4 to 3.4 NTU in the year 1994 whereas it reduced in all locations to 1.0-1.5 NTU in the year 1995. In the glacial lake it recorded 4.6 NTU in the year 1994 and in the year 1995 very high turbidity was recorded 3-16 NTU. Turbidity in the control lakes measured was 4.6 NTU in 1994. During the year 1995 it recorded 1.0 at all locations. Slightly higher range of turbidity recorded in all locations in glacial lake in the year 1995 may be due to the effect of

glacier melt water which aggravates the abrasion of flowing snow water over the rock, accumulated near conjunction of Glacier and glacial lake. Phytoplankton in shallow lakes is easily exposed to stronger solar radiation during ice-free summer period due to wind-induced vertical mixing, heat convection, and such situation together with oligotrophic condition may induce photo-inhibition, and phytoplankton biomass cannot be increased in summer (*Tanabe et al., 2008*). Therefore benthic algal production increased toward summer, while phytoplankton production in the same lake diminished.

3.3.1.3 Temperature

Temperature could not be recorded in the year 1994. In the Priyadarshini Lake variation in temperature recorded was 4.5 to 6.5°C. In the Control Lake it varied from 4-5.5°C. In glacial lake it varied from 0.5 °C to 3°C in the year 1995.

3.3.1.4 Conductivity

Conductivity does not show much variation in the lakes when compared between different the years. In Priyadarshini lake in 1994 it is found in the range of 19 μ S/cm to 28 μ S/cm whereas in Control Lake and glacial lake it was recorded in range of 10.6 μ S/cm and 8.2-9.3 μ S/cm respectively. In the year 1995 in Priyadarshini Lake it varied from 13.0 to 22.5 μ S/cm, whereas in control lake and glacial lakes conductivity measured from 23.0 to 34.5 μ S/cm and 14.0-17.0 μ S/cm respectively. Relatively higher conductivity values were recorded in Priyadarshini Lake in the year 1995. This is due to glacial lake water which itself carried conductivity 14-17.0 μ S/cm. This effect may be due to melting of glacier, which abrades rocks and mineral and mix with water.

3.3.1.5 Alkalinity

The alkalinity analysis is not available for the year 1994. Alkalinity measured for glacial lake and Control Lake in the year 1995, was found in the range of 5.2 to 10.7 mg/l. In Priyadarshini Lake it is recorded in the range of 3.1 mg/l to 5.1 mg/l. Alkalinity in the lake water measured in the lower side indicated that all the lakes around Maitri were devoid of HCO₃, CO₃ and OH anions.

3.3.1.6 Total Hardness

The total hardness analysis is not available for lake waters for the year 1994. During 1995 that the values for Priyadarshini Lake varied from 9.2 to 12.0 mg/l; in glacial lake it ranges from 7.2-12.0 mg/l and in control Lake 9.6 to 18.4 mg/l. It shows that some minerals in small amount dissolved in glacial water and same water feeds to Priyadarshini Lake.

3.3.1.7 Calcium Hardness

Calcium is one of the principles hardness causing element in water, other are magnesium, strontium and ferrous ion. In Priyadarshini Lake the calcium hardness in the year 1995, recorded was in range of 2.4 mg/l to 4.8 mg/l whereas for glacial lake and Control Lake it was found in the range from 2.4 mg/l to 2.4-19.2 mg/l, respectively. This shows that calcium hardness is not only one which governs the total hardness in the lakes around Maitri station.

3.3.1.8 Total Dissolved Solids (TDS)

Total Dissolved Solids are contributed in the water by the presence of anions and cations. In 1995, TDS measured is in the range of 9.4-12.9 mg/l in Priyadarshini Lake. Highest values were obtained at the confluence point of glacial lake, situated at south-east side of Maitri. The value for glacial lake recorded is 6-10.0 mg/l whereas in Control Lake it is 3.0 mg/l. It shows that the TDS is comparatively higher side in Priyadarshini lake water. The probable reasons are (1) mixing of seepage water from wastewater collection pond and (2) sediment re-suspension during sample collection.

3.3.1.9 Total Suspended Solids

In the year 1995, the total suspended solids measured in Priyadarshini Lake and glacial lakes vary from 2.0-5.0 mg/l and 6.0-10.0 mg/l, respectively. In the Control Lake, it is recorded 10 mg/l.

3.3.1.10 Chloride

The water samples collected in the year 1994 shows that chloride concentration in Priyadarshini, glacial are found in the range of 10.0 mg/l to 29.0 mg/l and in Control Lake it is found to be 11.0 mg/l. While, in 1995 the level of concentration decreased. In Priyadarshini Lake it is recorded 2.0-8.0 mg/l. In the glacial lake chloride concentration was recorded in range of 6.0 to 10.0 mg/l and in Control Lake it is recorded in the range of 7.2-8.0 mg/l. Higher concentration in the Priyadarshini Lake may be due to the seepage water channel which joins the lake.

3.3.1.11 Sulfate

The measured of Sulfate concentration in 1994 for glacial lake, control lake and Priyadarshini lake is in the range of 1.0 mg/l to 9.0 mg/l, while in the year 1995 the sulfate concentration in glacial lake, control lake and Priyadarshini lake is in range of 4.2 mg/l to 5.8 mg/l.

3.3.1.12 Nitrate

The concentration of nitrate in Priyadarshini Lake, Control Lake and glacial lake in the year 1994 is in the range of 0.01mg/l to 0.08mg/l whereas in the 1995 the concentration is found to be in the range of 0.0 mg/l to 2.7 mg/l. At few locations in Priyadarshini Lake higher values were recorded. Conversion of ammonia into nitrate in due course of time, which was being contributed from urinal, laundry to wastewater treatment system, and treated water, must be responsible for higher values. Nitrate concentration in glacial and Control Lake is negligible. Presence of nitrate in Priyadarshini Lake is the effect of intermixing of glacial feed water with seepage water. Nitrate in the lake water may derive from stratospheric sources (Green et. al., 2005). In the control and glacial lake the presence of nitrate is may be due to melting of glacier snow. Nitrate is believed to be a product of long-range transport and local sources are not expected to be significant and over snow nitrification and denitrification takes place (Mayewski and Legrand, 1990).

3.3.1.13 Ammonia and Nitrite

Ammonia was not analyzed in water samples collected from different lakes in the year 1994. Water sample analysis in the year 1995 shows that ammonia is not present in the water samples.

In the year 1994 nitrite was not detected in any of the water samples collected for Priyadarshini, Control and glacial lake. During the year 1995 nitrite was not detected in the Priyadarshini lake and control lake water samples. However, in the glacial lakes it was detected only at two locations and the concentrations recorded are 0.003 mg/l and 0.01 mg/l, in the lake situated south-west direction of the Maitri. It may be the effect of the partially treated effluent close to the lake which contributed the nitrite to the lake water.

3.3.1.14 Total Phosphate

Water samples collected, in the year 1994 shows that the total phosphate (inorganic and organic) in Priyadarshini Lake is detectable for only one location with concentration of 0.08 mg/l. In Control Lake it was not detected whereas in the glacial lake it was measured as 0.1 mg/l from a location. During the year 1995 total phosphate concentration was relatively increased in Priyadarshini Lake which varied from 0.6 to 4.7 mg/l. In Control Lake it varied from 0.5 to 4.3 mg/l and in glacial lake it is recorded as 0.8 to 4.7 mg/l. Comparatively higher concentration was recorded in the glacial lake situated at south-west of Maitri. Higher concentration of the phosphate may be the effect of the partially treated waste discharged near the glacial lake situated at south-west of the Maitri. Further phosphorus must have been contributed by the algae which were grown at the bank of confluence point of both the lakes. Chemical weathering rates are unexpectedly high during severe Antarctic winter. Phosphate is the result of chemical weathering of rocks and soil (Green et al., 2005)

3.3.1.15 Dissolved Oxygen

In Antarctic lake water temperature is very low during austral summer due to glacier melts. Water samples were collected from lakes, which have almost negligible salinity. In

the year 1994 DO measured was in the range of 8.2-8.7 mg/l in Priyadarshini, control and glacial lakes. The lower concentration recorded may be due to longer time period between collection and analysis. In the year 1995, DO recorded was 9.4-13.5 mg/l in Priyadarshini Lake, 9.4-9.9 mg/l in Control Lake and 8.1-13.1 mg/l in glacial lake water.

3.3.1.16 Biochemical Oxygen Demand (BOD)

BOD was not measured in the year 1994 for any of the sample from the lakes. It was measured for Priyadarshini Lake in the year 1995 and was in the range of 1.4 to 8.7 mg/l. In Control Lake it varied from 1.0-2.7 mg/l. In the glacial lake it is recorded only in the lake situated south-east of the Maitri at two locations and it varied from 4.1 and 6.5 mg/l.

3.3.1.17 Chemical Oxygen Demand (COD)

COD was not measured in any of the locations from the Priyadarshini, Control and glacial lakes during 1994. The COD in the water samples collected in the year 1995 was found in the range of 4.0-8.7 mg/l in Priyadarshini Lake. In the Control Lake it was measured as 2.8-10.0 mg/l, whereas in glacial lake it was recorded as 1.1 to 4.8 mg/l. COD in Control Lake was almost equal to other lakes which indicate that these lakes are naturally containing some organic matter.

3.3.1.18 Total Organic Carbon (TOC)

TOC measured in the year 1994 showed that in Priyadarshini Lake it varied from 8.5-10.0 mg/l, whereas in the control and glacial lake it was not detected. TOC was not analyzed during the year 1995.

3.3.1.19 Oil and Grease and Hydrocarbon

Oil and grease was not analyzed for the water sample collected from the lakes in the year 1994. In the samples collected in 1995 it was not detected in the Priyadarshini Lake and Control Lake. However in the glacial lake it varied from 3.6 to 8.8 mg/l. Glacial may be contaminated due to the windblown drums which would be containing the lubrication oil left outside the Maitri unattended.

In the year 1994, hydrocarbon detected in the Priyadarshini Lake, Control Lake and the glacial lake, varied from 0.01 to 0.03 mg/l. During the analysis of the water samples collected in the year 1995, hydrocarbon detected from the centre of the lake was with concentration of 0.14 $\mu\text{g/l}$. But in the control lake it was not detected, whereas in the glacial lake it was detected at two locations with concentration of 0.01 $\mu\text{g/l}$ and 0.09 $\mu\text{g/l}$. Presence of the vehicle garage just near by the Priyadarshini Lake, situated at higher elevation must be responsible for the concentration.

3.3.1.20 Sodium and Potassium

Sodium and Potassium was not measured in any of the water samples collected in the year 1994. The water sample collected during 1995 from the Priyadarshini, control and glacial lake water did not show presence of Sodium and Potassium.

3.3.1.21 Cadmium

Cadmium was detected in the Priyadarshini control and glacial lakes' water which varied as 6.0-15.0 $\mu\text{g/l}$, 6.0 $\mu\text{g/l}$ and 3.0 $\mu\text{g/l}$, respectively. In the year 1995, the concentration of the cadmium was not detected from any of the lake water samples.

3.3.1.22 Copper

Copper was found in the range of 2-32 $\mu\text{g/l}$ in Priyadarshini Lake in the year 1994. In Control Lake it was measured as 4 $\mu\text{g/l}$ and in glacial lake it was measured between 3 and 9 $\mu\text{g/l}$. However in the year 1995, in Priyadarshini Lake it was detected 0.01 mg/l at only one location and at rest of the locations it was found below detectable limit. In Control Lake it was found below detection limit whereas in the glacial lake it was measured 0.01 mg/l in four locations.

3.3.1.23 Chromium

Chromium was detected in the range of 4-22 $\mu\text{g/l}$ in Priyadarshini Lake in the year 1994 and in glacial lake it was detected as 14 $\mu\text{g/l}$ at one location, however it was not detected in Control Lake. In the year 1995 it was not detected from any of the water samples collected from the in Priyadarshini Lake Control Lake and glacial lake. In the

Priyadarshini Lake it was observed that various windblown metallic sheets and other metallic material were submerged at various locations during the year 1994. They may be possible source of chromium in the lake.

3.3.1.24 Lead

In the year 1994 lead was detected 8-58 $\mu\text{g/l}$, in Priyadarshini, 53 $\mu\text{g/l}$ in, Control Lake and 58 and 64 $\mu\text{g/l}$ in the glacial Lake. In the year 1995 it was not detected in any of the water samples collected from Priyadarshini, Control and glacial lakes. During 1994 the presence of the lead even though in small quantity showed that lake was mixed with external matter i.e. batteries, lubricants, and welding material in the Priyadarshini Lake.

3.3.1.25 Iron

The iron concentration in the Priyadarshini Lake in the year 1994 was in the range of 140-343 $\mu\text{g/l}$, in Control Lake it was detected as 200 $\mu\text{g/l}$, whereas in the glacial lake it was detected 70 and 98 $\mu\text{g/l}$. In the year 1995, iron was detected only at one location with concentration of 0.07 $\mu\text{g/l}$ in Priyadarshini Lake, in control lake it was not detected whereas in the glacial lake it was recorded at three locations with concentration between 0.03-0.06 mg/l. Iron does not impart any harmful effect on human, but if contains more than 0.03 mg/l and it interferes with laundry operation. This effect is observed at Maitri station.

3.3.1.26 Manganese

The manganese concentration was 41.0 to 199.0 $\mu\text{g/l}$ in Priyadarshini Lake, in glacial lake it was recorded 22.0 and 43.0 $\mu\text{g/l}$ but in Control Lake it was not measured during 1994. While, in the year 1995 concentration of manganese was not detected in any of the lake water samples.

3.3.1.27 Zinc

Zinc was recorded in the range of 39.0 to 113 $\mu\text{g/l}$ in Priyadarshini Lake, 47.0 $\mu\text{g/l}$ in Control Lake and 102.0 and 129.0 $\mu\text{g/l}$ in glacial lake water in the samples collected in the year 1994. In the year the 1995, zinc concentration was detected only at one

location in Priyadarshini Lake with the concentration of 0.04 mg/l; however it was not detected in control lake water, whereas in one glacial lake it was detected 0.02 to 0.11 mg/l. In the lakes, the probable source of zinc was due to the mixing of metal, battery scrap from garage or metals, lubricant and welding material, which must have mixed during the blizzard condition in the lake water.

Heavy metal in Antarctic lake water was attributed to airborne pollution which deposited on snow which melts and mixes with lake water. Polar snow contamination has played an important role in elevating crustal enrichment factors (EFs) of the heavy metals (*Landy and Peel, 1981; Wolff and Peel, 1985, Ikegawa et al., 1999, Planchon et al., 2001*)

3.3.2 Wastewater Analysis of RBC at Maitri Station

Wastewater generated from the Maitri station are separated into two different streams and treated separately into RBCs. These units are located in separate wooden enclosed rooms outside the Maitri station. After the treatment, effluent is discharged in wastewater collection pond. Pond is situated at higher elevation south of Priyadarshini Lake. During summer period for couple of days while ice cover melts wastewater seeps through pond and a narrow stripe joins the Priyadarshini Lake. Grab as well as partially-composite samples were collected from the wastewater treatment system. The parameters analysed are presented below.

3.3.2.1 pH

In the year 1994 the pH of influent of laundry RBC (B3) measured 8.11, effluent pH was lower (6.5) than influent. In the year 1995, pH of influent and effluent of RBC- B3 is observed as 7.9. The pH of the system is well within the limit to support the growth of bacteria. pH of kitchen RBC (B1) in the year 1994 measured 7.98 for influent and 5.5 for effluent. While in the year 1995 pH of influent was 4.4 and that of effluent was 4.3. Kitchen RBC' is acidic in nature. This range of pH does not provide comfortable environment for the growth of bacteria on Biodisc.

3.3.2.2 Suspended Solids

Suspended solids measured were 68 mg/l in influent and 30 mg/l in the effluent of B3 RBC in the year 1994 (56% removal). However suspended solids measured in the year 1995 was same amount of 53 mg/l in the influent and effluent of B3 RBC. During the year 1995 suspended solids recorded 646.0 mg/l in influent of B1 RBC which reduced to 124.0 mg/l in the effluent, showing 81% reduction. Whereas, in the year 1995, it was recorded as 148 mg/l in the influent and 112 mg/l in the effluent i.e. 24% reduction. In the B1 RBC the value of suspended solids varied considerably because the influent generation depends on the food habits of the Maitri as well as summer hut residents. However, it was noticed that during the year 1995 B1 RBC has not proved well in reduction of the suspended solids.

3.3.2.3 Chloride

In the year 1994 chloride measured in B3 RBC, in influent was 110.0 mg/l and in the effluent 85.0 mg/l i.e. around 23% reduction. In the B1 RBC, chloride recorded was 63.0 mg/l and 52.0 mg/l in influent and effluent respectively indicating 17% reduction. B3 RBC carries more chloride due to urine-waste. During the year 1995 samples were not analyzed to assess the concentration of chloride in the wastewater.

3.3.2.4 Sulfate

In the year 1994, sulfate measured was 55.0 mg/l in the influent of B3 RBC whereas in the effluent the value increased to 97.3 mg/l. In B1 RBC it was 18.5 mg/l in the influent and 10.6 mg/l in the effluent. Sulfate concentration was not very high, but reduction in sulfate through the sulfate conversion into hydrogen sulfide in the anaerobic condition with the production of methane and carbon dioxide will lead to corrosion and odor problem. Thick sludge accumulated in the secondary settling tank may create anaerobic condition.

3.3.2.5 Phosphate

In wastewater the phosphate concentration in the year 1994 recorded was 4.2 mg/l in

influent and 5.2 mg/l in the effluent of B3 RBC, which is higher than influent value. Phosphate concentration in the B1 RBC recorded was 0.52 mg/l in influent sample and 0.73 mg/l in effluent sample of B1 RBC. During 1995, phosphate concentration was not measured in the wastewater samples. Nutrients like nitrogen, phosphorus are essential for bacterial growth in the ratio BOD_5 : N: P, as 100: 5: 1 (Duncan, 1976). The source of phosphorus in both the RBC was found appropriate in comparison to BOD for bacterial growth. In B3 RBC nitrogen was present in excess amount for required growth of bacteria, whereas in B1 RBC concentration was poor.

3.3.2.6 Ammonia

Urea is the principal form in which the human body excretes excess nitrogen; it is rapidly hydrolyzed to ammonia. In the year 1994, ammonia in wastewater was not measured. The results of 1995 show that in influent and effluent of RBC- B3, ammonia was present in same amount with the value of 100.0 mg/l. In the wastewater ammonia source was from the laundry, urinal and bathroom. In influent and effluent of B1 RBC the value was 2.5 mg/l and 4.3mg/l respectively. Same concentration of ammonia in the influent and effluent indicates nitrification process was poor in RBC.

3.3.2.7 Nitrite

Nitrite concentrations were not measured in the wastewater samples in the year 1994. Sample collected in the year 1995 shows nitrite in B3 RBC influent 0.01 mg/l and in effluent it was 0.03 mg/l. In B1 RBC it was measured 0.008 mg/l in influent and 0.010 mg/l in the effluent. Nitrite forms from ammonia during the nitrification process. In the effluent the concentrations are marginally higher than the influent which indicates biodegradation of ammonia.

3.3.2.8 Nitrate

Nitrate is the end product of conversion of ammonia by nitrification. The nitrate concentration in the year 1994 was 24.3 mg/l in influent, 16.8 mg/l in the effluent of B3 RBC, whereas in the influent and effluent of B1 RBC, nitrate was 8.3 and 6.4 mg/l. In the year 1995 nitrate showed almost same level of concentration in the influent and

effluent of B3 RBC i.e. 23.0 mg/l and 22.5 mg/l respectively. B1 RBC carried the concentration 9.3 mg/l in influent and 10.6 mg/l in effluent. Results indicate that nitrification process was not complete.

3.3.2.9 Biochemical Oxygen Demand

The biochemical oxygen demand in the year 1994 for influent and effluent of B3 RBC was observed as 540.0 and 400.0 mg/l i.e. with 26% removal. While in the influent and effluent of B1 RBC it was recorded as 490 and 310 mg/l i.e. with 37% removal. During subsequent year in 1995 the value in influent of B3 RBC was 620.0 mg/l and in effluent 430.0 mg/l i.e. with 30% removal. Similarly in B1 RBC in the influent it was 860.0 mg/l and in the effluent 444.0 mg/l i.e. with 48% removal. Results obtained indicated that both the RBCs were functioning poorly as compared to their designed standards.

3.3.2.10 Chemical Oxygen Demand

In the year 1994 the concentration of chemical oxygen demand in influent of B3 RBC was 1650 mg/l while in effluent it is recorded as 1100 mg/l with total reduction in COD was around 33%. In influent of B1 RBC, COD recorded 1510 mg/l in influent and 920.0 mg/l in effluent which shows COD reduction around 39% which is higher compared to B3 RBC. In the year 1995 COD measured in the influent and effluent at B3 RBC was 1832 and 1296 mg/l respectively with 29% reduction. In the B1 RBC the COD measured 2586 mg/l in influent and 1332 mg/l in the effluent with 48% reduction. Overall efficacy of the RBC is very low as compared to the design efficacy at 90%.

3.3.2.11 Oil and Grease

During the year 1994 samples were not analyzed for oil and grease. In the year 1995, the concentration of oil and grease in the influent of B3 RBC was 12.8 mg/l and in the effluent 5.2 mg/l. In B1 RBC (kitchen wastewater) oil and grease was not detected in the composite sample.

3.3.2.12 Hydrocarbon

Hydrocarbon was not measured in any wastewater sample during the year 1994. The

hydrocarbon concentration in the year 1995 in samples collected from wastewater of B3 RBC in influent was $3.0\mu\text{g/l}$ and in effluent $1.8\mu\text{g/l}$. In B1 RBC it was not detected in the composite sample of influent and effluent.

3.3.2.13 Cadmium

Cadmium in the samples of wastewater collected in the year 1994 and 1995 was found to be below detectable limit in the samples collected from both the RBCs.

3.3.2.14 Copper

The copper concentration in the year 1994 in the samples of wastewater was 0.84 mg/l in influent and 0.16 mg/l in the effluent of B3 RBC. In the influent of B1 RBC it was 0.33 mg/l and in the effluent it was 0.65 mg/l . In the year 1995 it was recorded 0.01 mg/l in influent and 0.05 mg/l in effluent of B3 RBC, whereas copper in B1 RBC was 0.02 mg/l in influent and 0.03 mg/l in effluent. It indicated that Biofilm of the RBC has high metal sorption capacity (*Cabaniss and Shuman, 1988*) and can be used as a tool to remove and recover metals from wastewater (*Costley and Wallis, 2001*).

3.3.2.15 Chromium

In the year 1994 chromium presence was detected 0.19 mg/l in the influent of B3 RBC, whereas in the effluent it was 0.12 mg/l . In B1 RBC it was detected 0.11 mg/l in the influent and 0.14 mg/l in the effluent. Higher concentration in the effluent was most probably from the dead cell of microorganism. In the sample collected in the year 1995, chromium in influent and effluent of both the RBCs was not detected.

3.3.2.16 Lead

Lead was measured 0.09 mg/l in the influent as well as in the effluent of B3 RBC in the year 1994, and in B1 RBC it was detected 0.09 mg/l in the influent and 0.01 mg/l in the effluent. It indicated that despite the poor function of B1 RBC, in the consortium of bacteria few species were capable of consuming lead. In the year 1995 lead was detected in the influent and effluent of B3 RBC with concentration of 0.01 mg/l and 0.02 mg/l respectively. In the B1 RBC it was 0.01 mg/l in the influent as well as effluent. The

results indicated poor trace metal removing capacity of RBCs.

3.3.2.17 Iron

In the year 1994 the iron concentration in wastewater was 4.01 mg/l in the influent of B3 RBC, while in the effluent it was 4.16 mg/l. In influent of B1 RBC it was 4.02 mg/l and in effluent it was 6.25mg/l. Sample collected in the year 1995 showed that iron concentration in the B3 RBC as 0.36 mg/l, and 0.24 mg/l in the influent and effluent respectively, whereas in the B1 RBC it was 1.4 mg/l in influent and 0.06 mg/l in the effluent.

3.3.2.18 Zinc

The concentration of zinc during 1994 in the influent of B3 RBC was 10.36 mg/l, in the effluent it was 0.10 mg/l. In the B1 RBC it was recorded 10.36 mg/l in the influent and 8.35 mg/l in the effluent. Sample collected in the year 1995 showed that in B3 RBC, zinc concentration was 0.16 mg/l in the influent and 0.12 mg/l in the effluent. It was 0.23 mg/l in influent, and 0.01 mg/l in the effluent of the B1 RBC. The source of zinc in the RBC was waste from edible oil, use of cosmetic products (cream, facial etc.) and wastewater generated from washing the face.

SECTION “B” – Present Study

3.4 Rotating Biological Contactor at Maitri

The Bio-discs (RBC) are a range of complete self-contained sewage treatment plants which are designed for small communities and manufactured in different range of sizes (*Connor, 2008; Cortez et al., 2008*). These units are ideal for single house, small housing developments, hotels, public houses and small commercial developments. The units are compact, self-contained, single-piece treatment plants that utilize natural biological processes to effectively break down domestic and commercial waste water (*Banerjee, 1997b; Grady, 1983; Akunna and Jefferies, 2000; Griffin and Findlay, 2000; Nowak, 2000; Hiras et al., 2004*). RBCs are one of the standard methods of biological wastewater treatment in which degradation and bio-oxidation are predominantly achieved by a biofilm which is attached to the rotating discs (*Casey, 1997; Alemzadeh and Vossoughi, 2001*). There are many evidences showing that biofilms have higher resistance to toxic compounds than free cell systems (*Lazarova and Manem, 2000; Laopaiboon et al., 2002; Saravia and Mele, 2005; Laopaiboon et al., 2006*). Other advantages of the RBCs over other biological wastewater treatment systems are simplicity in construction and maintenance, stable operation and relatively low cost.

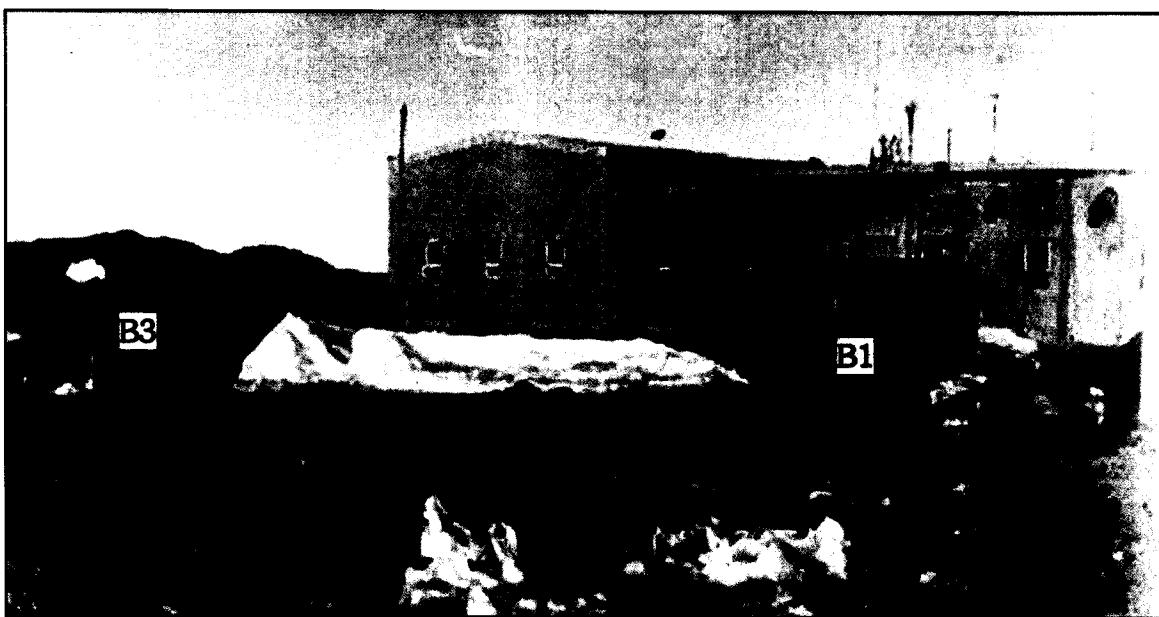
The units constructed are of glass reinforced polyester (*Kee, 2004*). A low-energy electric motor rotates the rotating biological contactor to separate solids and produce an effluent sufficiently clean to be discharged into or near a water course. In the year 1988, when Maitri station was inaugurated these two RBCs were procured from Klärgester Company, UK to treat the wastewater of the station, B1 installed in 1988 and B3 installed in 1989. At Maitri two RBC's are installed to treat the waste (Figure 3.2). Since in design no provision was made to install the wastewater treatment plant they were placed in two separate wooden enclosures, outside, adjacent to the station each measuring of size 6.5x2.4x3.25 m and 4.5x2x3 m.

Provisions were made to connect the outlet of the kitchen conduit which receives discharge from the wash basins of kitchen and connects the wash basins, to B1 RBC. High Density Poly Ethylene (HDPE) pipe, used as carrier of wastewater, exposed to low

ambient temperature from outside of station wall to RBC and from RBC to the effluent collection pond. But HDPE are kept warm by encasing with trace heating element to avoid freezing wastewater flow. Treated wastewater from B1 RBC (Biodisc) is discharged into a collection pond.

The outlets of the washbasins, bathrooms, laundry and the urinals are connected through a single common copper pipe inside the station which joins to HDPE pipe outside the station while it connects to B3 RBC. Similar to B1 RBC arrangements HDPE pipes are encased with trace heating element to avoid freezing of wastewater flow. The effluent from B3 RBC is also discharged to a common collection pond (*Ghosh et al., 1997; Nair, 1998; Tiwari and Kulkarni, 2005*).

Figure - 3. 2 : Location of B1 and B3 RBC Room at Maitri



3.4.1 Design Features of RBC – Installed at Maitri

Klargester Bio Discs are manufactured with Glass Fiber Reinforced Polyester (GRP). These RBC are light in weight, easy to transport and install. GRP is extremely robust, but susceptible to damage by sharp objects and from point loads (*Kee, 2004*).

3.4.1.1 Primary Settlement, Sludge Storage and Digestion Zone

Raw gray water enters the Primary Settlement Tank (PST) of the Bio-disc through

baffled inlet pipe and through the side wall of the unit. The flow passes through the primary zone, where solid matter get settled and retained. The settled or partially clarified liquor then passes into the biozone. The primary zone is designed to have sufficient capacity to accept high flows within the unit over short intervals of time.

3.4.1.2 Biozone

The biozone is semi-circular in cross section and rectangular in plan. Clarified liquor from the settling zone enters the first stage of the biozone, which contains the first stage that is ‘roughing’ media bank, through a submerged transfer pipe in the base of the biozone. This stage is within the flow balancing regime and is subject to the variations in water level of the balancing volume. The second stage of the biozone is hydraulically sealed from the first stage and maintains a constant water level. The second stage is fed via a bucket lift transfer (Managed Flow) system contained in the first stage of the biozone.

3.4.1.3 Discs and Drive

The RBC consists of banks of polypropylene media attached to a central shaft and is supported by two bearings, which are mounted on the rear bearing support bracket and the drive platform steelwork. The main operational features of the rotor unit are outlined below;

- ◆ The RBC is divided into three stages by means of a fixed baffle attached to the biozone and rotating baffles fixed to the shaft. The media is split into stages designed to promote effective and efficient growth of bio-culture to effect treatment.
- ◆ The RBC is rotated slowly through a reduction gearbox and peripheral drive gear and is arranged so that a proportion of its surface area is submerged in the effluent at any given time. As the RBC rotates, the surface of the media is subjected alternately to sewage and air, encouraging an aerobic, biologically active film (*Pause and Switzenbaum, 1984*) of micro-organisms (biomass) to become established on each side of the media sheets (*Hammer and Hammer, 2005*). This biologically active film grows in size, self regulating and oxidizes the pollutants in the sewage. The micro organisms use the untreated waste as a substrate (food) and as they do so, multiply in number, maintaining a specific

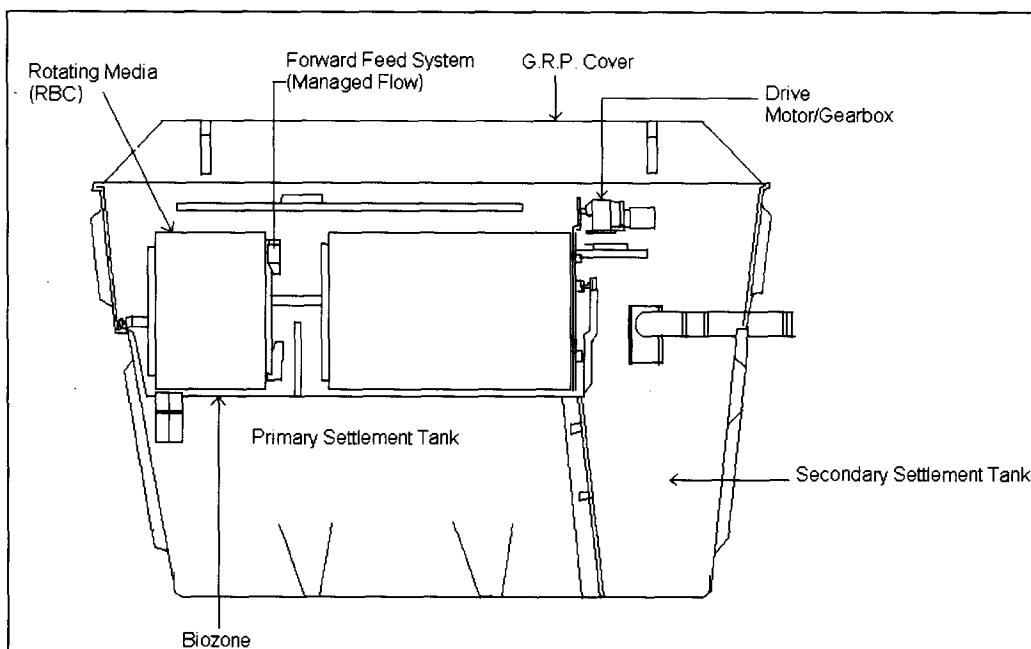
biomass thickness to ensure optimum process efficiency. Material from the first stage of the RBC falls into the Primary Settlement Tank (PST) through the pipe in the biozone casing, whereas material from the remaining stages of the RBC is kept in suspension and carried forward into the Final Settlement Tank (FST).

- ◆ In order to ensure a balanced and constant flow and, therefore, a stable environment, dosing buckets fitted to the first stage of the RBC shaft lift and transfer the partially clarified liquor to the final stages of the RBC at a constant rate, irrespective of changes to incoming flow rates and water level.
- ◆ The B1 RBC comprises 47 square discs each of 490 cm^2 , and three circular discs each of 95 cm diameter, made of GRP sheets. The size of B3 discs are comparatively larger, it carries 71 square (1 m^2 each) and three circular (each 1. m diameter) discs.

3.4.1.4 Secondary Settlement and Sludge Storage Zone

The Final Settlement Tank (FST) comprises the secondary settlement or final zone, which is situated under the drive motor. It is formed by a full depth GRP baffle across the width of the unit and it is in this final zone that any biological culture, which falls from the latter stages of the RBC, is allowed to settle out. The treated effluent enters this zone from the biozone. Sludge storage volume of B1 RBC is kept 300 litres and desludging period is 180 days, whereas for B3 RBC sludge storage volume is kept 1530 litres and dislodging period is 91 days (Figure 3.3).

Figure - 3. 3 : Schematic diagram of RBC installed at Maitri



All sludge storage periods assume that primary sludge is retained at 3% solids content and 100% plant utilization

3.5 Present Operational Conditions

The B1- RBC is designed for maximum hydraulic load of $1.2\text{m}^3/\text{day}$ and Biochemical Oxygen Demand (BOD) load is 0.36 kg/day and B3-RBC is designed to take maximum hydraulic load of $5.0 \text{ m}^3/\text{day}$ and BOD load is 1.5 kg/day . The equipment is designed to achieve an effluent discharge standard of not more than 20 mg/l of BOD and 30 mg/l suspended solids and 20 mg/l of ammonia nitrogen assuming that ambient temperature within the plant is 5°C . The direction of disc rotation was selected to be opposite to the direction of wastewater flow in order to reduce on short circuiting (*Gupta and Gupta, 2001; Vinage and Rohr, 2003*). The ambient temperature under which sample collection and analysis performed ranged between -12°C and $+3^\circ \text{C}$. In a day for 24 hours, flow variation at the inlet of systems was observed. Production of the waste depends on the living and food habits of the occupants. Since the systems are kept outside in a wooden room which is not heated from inside, heaters were immersed in the biozone to keep the

temperature 10-12 °C.

3.5.1 Collection and Storage Pond

The treated effluent from both the RBC is discharged through a HDPE pipe which is insulated with trace heating element into a pond of size approximately 25x45 m with depth of 1.5 m. This pond is partially separated with a soil divider. Another small pond is dig in front of the pond of size with approximate size of 23x16 m and depth 1.2 m. This pond collects the seepage from the main pond, being situated at lower elevation (Figure 3.4).

Figure - 3. 4: Effluent Discharge Pond



3.5.2 Effluent Discharge and Priyadarshini Lake Contamination

Treated effluent from the system is discharged into collection pond. This pond is exposed to ambient temperature. Once in a year during the summer period stored wastewater (treated) is discharged through centrifugal pump and pipe attached to pump, around 320 m away from the pond in the open ground (Figure 3.5).

Figure - 3. 5 : Final Effluent Discharge Point



Final treated effluent discharge point is full of moraine deposits in the form of crushed rock fragments. Discharged water find its way and seeps in few cm in the ground until level of permafrost soil and then joins the lake in the downstream side. A volume of the water also evaporates due to high wind and low humidity in the region. The three sub-glacial lakes present at lower elevation are interconnected to each other. Excess melt-water from the lake flows over into other lakes. The third lake is situated around 150 m away from west bank of the Priyadarshini Lake. The excess water from these lakes ultimately joins Priyadarshini Lake. Once lake receives the discharge of treated effluent it gets diluted many folds and then joins Priyadarshini Lake back again.

The elevations of ponds pumping site and nearest Glacier Lake's water level stand at higher elevations than the level of Priyadarshini Lake water. The distance between waste collecting ponds and nearest Priyadarshini Lake Boundary is 175 m. In view of lower elevation, a surface seepage channel was observed flowing towards the Lake. Flow rate of this seepage which supports thick algal growth becomes maximum during the months of December and January, then gradually reduces and finally freezes in the middle of February.

3.6 Water Balance at “Maitri” Station

3.6.1 Water Intake System

Water supply to Maitri station is catered by pumping water from Priyadarshini lake situated in front of it about 150 m away in the northern side. Water is pumped by means of a centrifugal pump having a capacity of 3000 litre/hr. Additionally, one submersible pump, enclosed in stainless steel jacket for electrical heating, has been lowered in the lake at a distance of 80 m from its edge.

The entire copper pipeline carrying water to Maitri is electrically heated and well insulated from the ambient temperatures. Heating ensures a continuous flow of water even at temperature of -40°C during austral winter. In summer camp water is distributed at the rate of around 800-1000 litres per day. This water is used for bathroom and wash basins. A small quantity of water is also used for tea preparation etc at Annapurna hut (*Ghosh et al., 1997; Nair, 1998; Tiwari and Kulkarni, 2005*).

3.6.2 Distribution of Water

The consumption of water at Maitri is relatively more in austral summer compared to the rest of the year and it fluctuates between 1.70 m³/day in winter and 5.7 m³/day in summer (Table 3.8). Water balance diagram is prepared by estimating the inlet and outlet measurement at various distribution points. The evaporation loss is also estimated from the boiler room and RBC. Pumped water in the Maitri is stored in two 5000 litre tanks and then distribute to drinking, kitchen, laundry, bathroom, washbasins, boilers for circulating into radiators and summer camp. In summer camp further it is distributed into bathroom, washbasins and Annpurna hut.

The rooms of the Maitri are kept warm by means of water radiators. The hot water is circulated through boilers into radiators; whereas returned water is collected in expansion tank to make the water loss up, in evaporation. It is estimated that around 55 litres is evaporation loss from the expansion tank. Similarly evaporation loss at laundry is estimated around 50 litres/day.

Table - 3. 8: Monthly water consumption at Maitri

Month	Maximum Water Supply in a day (m ³ /day)	Minimum Water Supply in a day (m ³ /day)	Total Water Supply in a month (m ³)	Average Water Supply (m ³ /day)	Summer Camp Consumption (m ³)
January	9.0	2.5	121.8	3.92	24.8
February	7.0	5.0	164.5	5.67	23.8
March	4.0	1.5	66.3	2.21	4.0
April	4.5	2.5	50.4	1.68	0.0
May	4.2	3.1	56.6	1.82	0.0
June	4.0	3.0	53.1	1.77	0.0
July	7.5	3.0	58.9	1.9	0.0
August	5.0	3.2	63.5	2.04	0.0
September	5.0	3.0	67.7	2.25	0.0
October	5.0	3.5	52.3	1.69	0.0
November	5.0	3.0	57.2	1.9	0.0
December	5.5	1.8	62.3	2.09	0.0

3.6.3 Wastewater Production

A study was carried out to assess the water consumption, its use, loss and conversion into wastewater. The average water intake for particular day estimated to be 3900 litres. Around 3100 litres of water is supplied to Maitri and rest 800 litres of water is supplied to summer huts. At Maitri it is estimated that there is loss of 345 litres of water from kitchen, which includes tea and food preparation, drinking water and evaporation losses around 25 litres from B1 RBC and 50 litres from B3 RBC. Effluent discharge from the both RBCs is measured on hourly basis for 24 hrs which represent the fluctuation in the effluent discharge corresponding to the consumption. The figure below shows the fluctuation in the effluent discharge of the RBCs (Figure 3.6 and 3.7). The cumulative average discharge from B1 is estimated around 700 litres in a day whereas from B3 it is measured around 1950 litres in a day.

In summer camp, 660 litres of wastewater (gray water) is discharged from bathroom on open ground considering 80 litres as evaporation loss. At Annapurna hut, 40 litres

wastewater (gray water) is collected in a barrel, considering 20 litres as water use for tea etc. Approximately 2575 litres of wastewater is collected in a pond, maximum in a day, whereas 700 litres of wastewater is discharged in open ground. Water balance diagram is depicted in Figure 3.8.

Figure - 3. 6: Effluent Discharge of B1 RBC

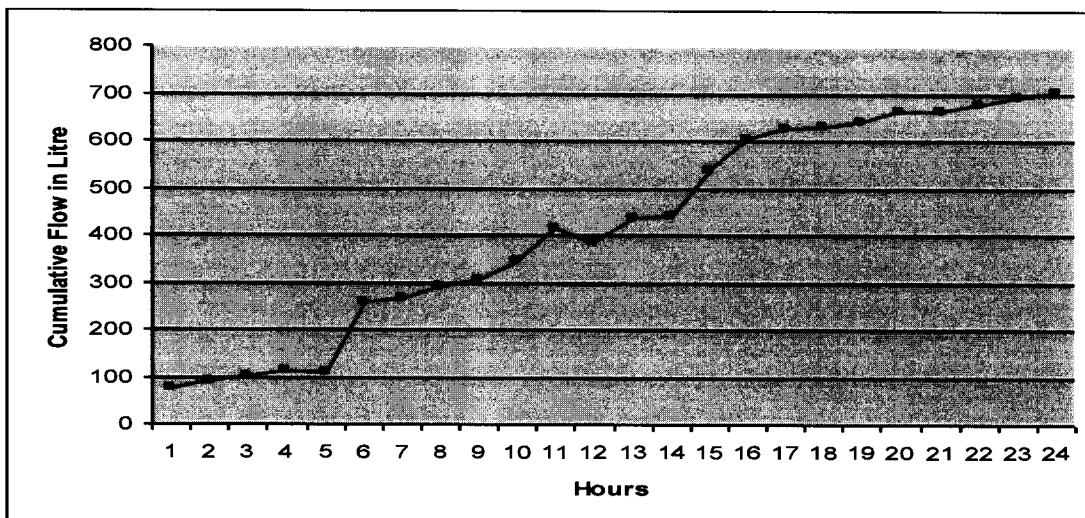


Figure - 3. 7: Effluent Discharge of B3 RBC

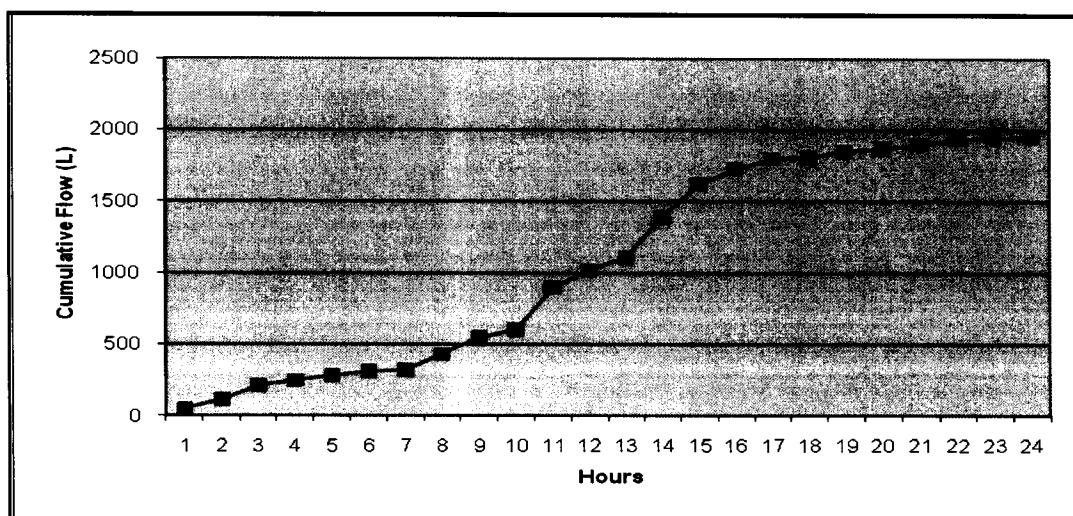
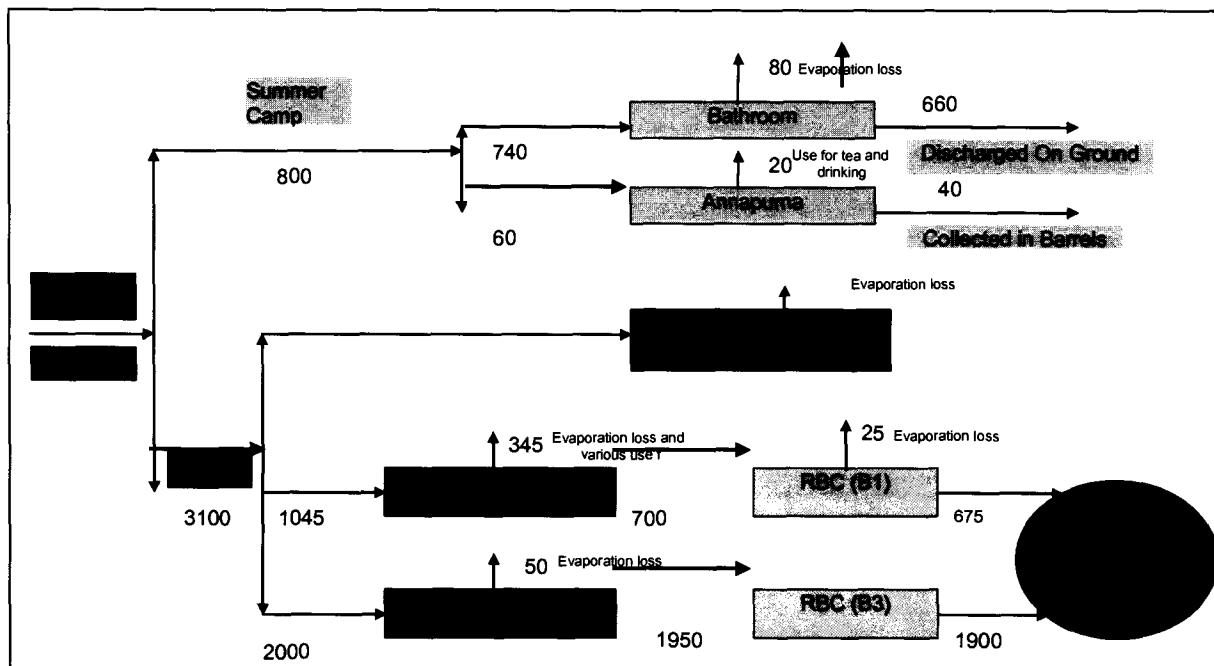


Figure - 3. 8: Water Balance at Maitri



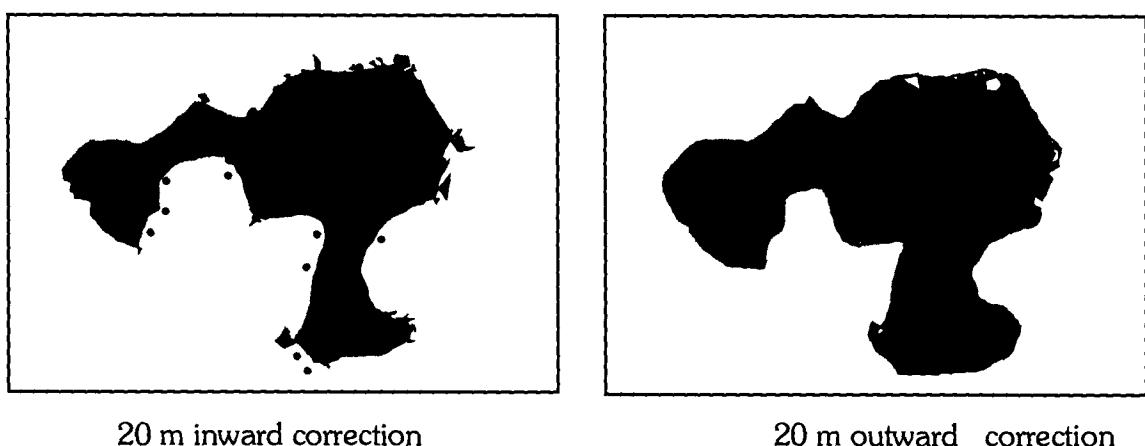
3.7 Priyadarshini Lake Water Assessment

It is felt necessary to assess the water abundance of Priyadarshini Lake which is the only water source for Maitri station and summer camp. The volume assessment will also help in characterization of water as well as in water quality prediction modeling and also to understand potential of contamination.

Total demand of water estimated based on the average consumption of water is approximately 353 m^3 (total four months) during summer and 522 m^3 (total eight months) during winter. During summer in the month of January, lake water melts and water is available for intake. From mid February onwards the water starts freezing. So the water from the bottom of the lake is drawn using the submersible pump and with the help of heating coils. However, it is necessary to estimate quantity of water available at the lake becomes imperative for avoiding the risk associated during a very harsh climate in the winter season. Total area of the lake estimated through GPS (Figure 3.9) is around $2,89,972 \text{ m}^2$. This is validated with the results of the study carried out by Ingole

and Parulekar (1990). However, the contour maps drawn using the SURFER-7 of the same coordinate shows that the total area is $2,76,944 \text{ m}^2$, which is 4.49% less than the GPS monitored area. The range of the accuracy of the GPS used is between 10 to 30 m (MC-GPS, 1996) without differential correction. The deviation from accurate position may be in any direction. For this purpose this is assumed that the deviation is on an average of 20 m and may be either in or off side. Considering both these options it is estimated that 20 m off side gives (Figure 3.9) total area approximately $3,60,802 \text{ m}^2$ (24.4% more) and considering 20 m inside points from present recorded points (Figure 3.9) gives area around $2,23,070 \text{ m}^2$ (23.0% less).

Figure - 3. 9: Area of Priyadarshini Lake

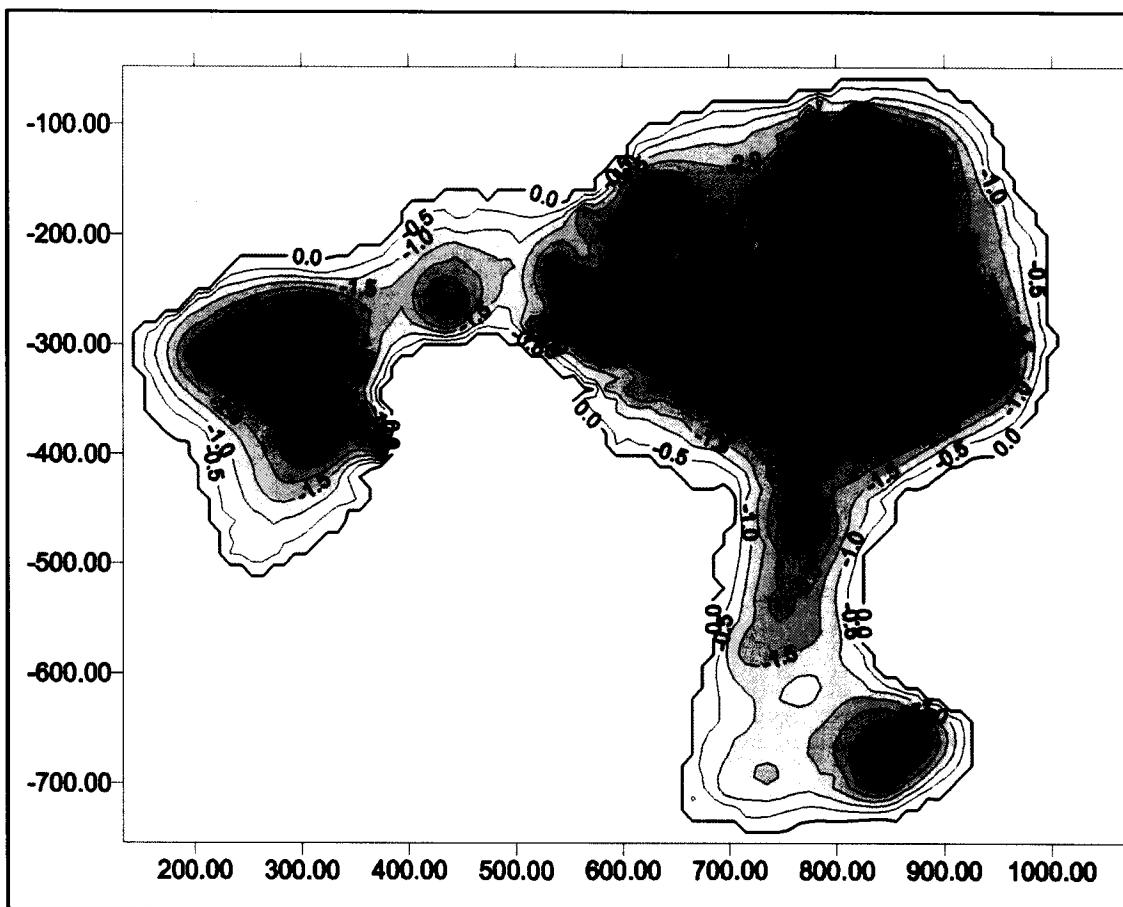


3.7.1 Volume of the Lake

Considering the same coordinates, contour mapping and GPS data gives average depth which ranges from 2.34 m to 2.24 m. Based on this the volume of water using SURFER 7 (Goktepe and Hilmi, 2003; Yilmaz and Yakar, 2008) by Simpson's rule, estimated is $6,50,358 \text{ m}^3$. Considering the area of lake of 20 m offside the, volume would be $8,08,197 \text{ m}^3$ and if 20 m inside, the volume would be $4,99,695 \text{ m}^3$. For more realistic approach to facilitate the calculation of volume within the envelope, the area of lake is considered $2,76,944 \text{ m}^2$ and volume calculated is $6,50,358 \text{ m}^3$. The recorded rise in the water level was 23 cm, so volume before the water inflow into the lake was estimated to be $5,89,226 \text{ m}^3$ (Figure 3.10). This shows that due to the glacial melt the total inflow of

water into the Priyadarshini Lake is around $61,132 \text{ m}^3$. The average consumption of water at Maitri is about 900 m^3 per year. Except Maitri there is no other user who draws the water from the lake and no seepage was observed (Tiwari and Nayak, 2007).

Figure - 3. 10 : Contour Map of Priyadarshini Lake



Further, in this area due to high wind velocity and dry atmosphere the relative humidity is varies from 5-35%. Therefore the water evaporation rate is quite high which $217.5 \text{ litre/m}^2/\text{year}$. During the winter period when upper 3 m of the lake water freezes, the water available below in the lake is estimated as $1,24,429 \text{ m}^3$. This reveals that this lake possesses an inverse thermal stratification, with a minimum temperature of -2 to 0°C at the surface and a positive temperature beneath the ice stratification in the lake.

3.8 Water Sample Collection and Analysis around Maitri (Year 2000 and 2004)

Since the Priyadarshini Lake is the main source of water for Maitri and probability is noticed to get protuberated by the ancillary sources it is decide to collect the samples from various pre decided points in and around the bank of the lake. Input streams which joins through glacial lake and ultimately meets Priyadarshini lake also becomes imperative to study after a gap of many years especially to study the changes in the nutrient, trace metals and other physico-chemical parameter to derive conclusions. This will also facilitate as background study to understand the wastewater treatment system. Various locations of the water sample collection from Priyadarshini Lake, glacial Lake and Control Lakes are shown in Figure 3.11.

3.8.1 Water Sample Analysis in the Year 2000

In Priyadarshini, control and Glacial lakes samples were collected from different depths and immediately temperature was recorded. DO, pH, conductivity, TDS was recorded within an hour of collection of samples taking the samples to Maitri Environmental Laboratory. Basic parameters were than analyzed in the laboratory and rests of the parameters like trace metals, hydrocarbon, oil and grease were analyzed in India, taking care of preservation and transportation of the samples in proper temperature. The results of the analysis are shown in following Table 3.9 and 3.10.

Figure - 3. 11: Water Sample Location around Maitri in the year 2000 and 2004

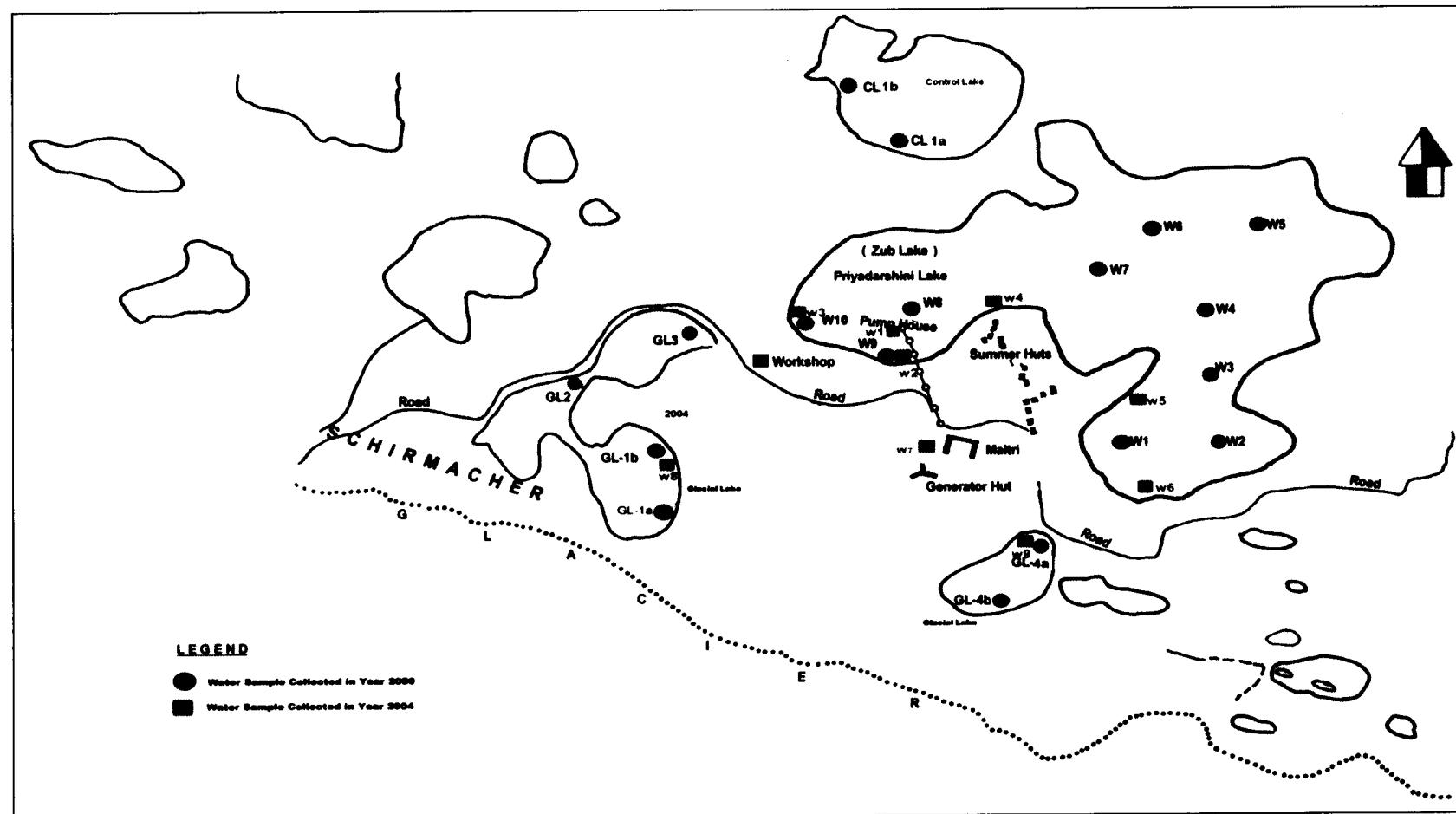


Table - 3. 9 : Surface Water Quality - Physico-Chemical Characteristics and Inorganic Characteristics (Year 2000)

Particulars of Sample	Denoted as	Temperature °C	pH	Conductivity $\mu\text{S}/\text{cm}$	Turbidity	Alkalinity	Total Hardness	Ca Hardness	Chloride	Sulfate	Sodium	Potassium
West side of Control Lake 2	CL2	12	6.0	19	0.5	5.8	8.1	5.6	1.9	1.3	1.3	0.5
Northeast (NE) side of Glacial Lake 4	GL4 (A)	11	6.01	10	1.4	5.3	10.1	7.6	2.8	1.5	1.4	0.4
Southeast side of Glacial Lake 4	GL4 (B)	11	6.3	15	1.0	6.2	10.0	8.5	3.4	1.7	1.4	0.4
Control Lake 1 located north of Maitri station	CL1 (A)	11	6.46	22	1.0	4.0	6.8	4.8	2.5	1.5	1.6	0.5
Northern side of Control Lake 1	CL1 (B)	11	6.47	21	0.6	3.8	6.0	4.3	2.7	1.3	1.4	0.5
Glacial Lake 1 located southwest of Maitri station	GL1 (A)	11	6.0	15	0.4	3.0	5.0	3.8	1.8	0.6	1.1	0.3
Glacial Lake 1, Sampling point near joining Glacial Lake 2	GL1 (B)	11	6.1	16	1.5	3.9	6.2	4.8	2.9	1.1	1.2	0.3
Glacial Lake 2 located west of Maitri station	GL2	11	5.8	11	1.4	3.4	6.1	4.9	2.8	1.1	1.3	0.2
Glacial Lake 3 located northwest of Maitri station	GL3	11	6.3	36	1.0	4.5	6.4	4.7	2.5	1.2	1.4	0.5
South-southeast (SSE) side of P. Lake 50m away from western bank	W1	11	6.4	28	1.0	4.2	8.3	6.3	2.9	1.8	1.5	0.8

Cont .

Cont. Table 3.9

Particulars of Sample	Denoted as	Temperature °C	pH	Conductivity $\mu\text{S}/\text{cm}$	Turbidity	Alkalinity	Total Hardness	Ca Hardness	Chloride	Sulfate	Sodium	Potassium
Southeast side of P. Lake 75m away from eastern bank	W2	10	6.4	23	0.6	5.3	9.5	7.0	2.9	1.7	1.5	0.6
East-southeast side of P. Lake 50m away from west bank	W3	10	6.4	20	0.5	5.0	8.0	6.8	3.1	1.2	1.5	0.7
SSE of P. Lake 60m away from west bank	W4	11	6.4	21	1.1	4.0	8.6	7.0	2.5	1.3	1.7	0.8
Eastern side of P. Lake	W5	11	6.4	23	1.0	4.8	8.5	6.9	3.2	1.8	1.8	0.6
NE side of P. Lake	W6	11	6.3	23	1.1	4.8	9.4	6.2	2.5	1.7	1.4	0.7
Centre of P. Lake	W7	11	6.4	26	1.0	4.3	7.5	5.5	2.6	1.7	1.5	0.5
Near pump house in P. Lake	W8	11	6.3	19	1.2	4.0	6.5	4.5	2.8	1.2	1.6	0.4
SW side of P. Lake 3m from seepage channel	W9	11	6.4	22	1.0	4.8	8.4	6.2	2.4	1.2	1.5	0.8
West-southwest side of P. Lake 5m away from bank	W10	11	6.5	19	1.7	4.8	7.4	5.0	2.8	1.6	1.5	0.4

Conductivity expressed in $\mu\text{S}/\text{cm}$, Turbidity in NTU; P stands for Priyadarshini; CL is Control Lake; GL is Glacial Lake; Glacial and Control lakes are freshwater lakes besides Priyadarshini Lake present in the region.

Table - 3. 10: Surface water Quality - Organic & Nutrient Characteristics and Concentration of Selected Heavy Metals

(Year 2000)

Particulars of Sample	Denoted as	Dissolved Oxygen	Nitrate	Total Phosphate	Bio Chemical Oxygen	Chemical Oxygen Demand	Cadmium	Chromium	Copper	Iron	Manganese	Lead	Zinc
West side of Control Lake 2	CL2	10.2	0.14	BDL	1.1	12.4	BDL	BDL	BDL	0.59	0.39	BDL	0.029
Northeast (NE) side of Glacial Lake 4	GL4 (A)	13.4	0.09	0.4	2.1	10.8	BDL	BDL	BDL	0.601	0.04	BDL	0.119
Southeast side of Glacial Lake 4	GL4 (B)	13.8	0.18	0.2	2.7	12.8	BDL	BDL	BDL	0.472	0.184	BDL	0.033
Control Lake 1 located north of Maitri station	CL1 (A)	13.4	0.1	0.3	1.4	16.0	BDL	BDL	BDL	1.01	0.005	BDL	0.063
Northern side of Control Lake 1	CL1 (B)	13.6	0.05	1.2	1.8	7.2	BDL	BDL	BDL	0.365	0.018	BDL	BDL
Glacial Lake 1 located southwest of Maitri station	GL1 (A)	12.5	0.1	0.6	1.9	4.4	BDL	BDL	BDL	0.646	0.050	BDL	0.227
Glacial Lake 1, sampling point near joining Glacial Lake 2	GL1 (B)	11.8	0.05	1.8	2.2	5.6	BDL	BDL	BDL	1.655	0.175	BDL	0.15
Glacial Lake 2 located west of Maitri station	GL2	12.4	0.04	0.9	1.9	4.7	BDL	BDL	BDL	1.025	0.054	BDL	0.015
Glacial Lake 3 located northwest of Maitri station	GL3	13.4	0.2	0.2	1.9	15.2	BDL	BDL	BDL	1.265	0.077	BDL	0.111
South-southeast (SSE) side of P. Lake 50m away from western bank	W1	14.0	0.3	BDL	3.1	8.0	BDL	BDL	BDL	0.574	0.017	BDL	0.072
Southeast side of P. Lake 75m away from eastern bank	W2	14.0	0.4	0.2	3.3	12.0	BDL	BDL	BDL	0.379	0.011	BDL	0.033

Cont .

Cont. Table 3.10

Particulars of Sample	Denoted as	Dissolved Oxygen	Nitrate	Total Phosphate	Bio Chemical Oxygen	Chemical Oxygen Demand	Cadmium	Chromium	Copper	Iron	Manganese	Lead	Zinc
East-southeast side of P. Lake 50m away from west bank	W3	14.1	0.4	1.4	3.0	12.4	BDL	BDL	BDL	0.191	0.037	BDL	0.024
SSE of P. Lake 60m away from west bank	W4	14.1	0.3	0.7	3.2	14.0	BDL	BDL	BDL	0.306	0.02	BDL	0.02
Eastern side of P. Lake	W5	13.5	0.5	1.1	3.2	18.8	BDL	BDL	BDL	0.248	0.029	BDL	0.038
NE side of P. Lake	W6	13.5	0.4	0.3	3.0	16.8	BDL	BDL	BDL	0.985	0.021	BDL	0.348
Centre of P. Lake	W7	13.7	0.2	0.8	3.8	21.4	BDL	BDL	BDL	0.615	0.071	BDL	0.132
Near pump house in P. Lake	W8	14.0	0.1	0.4	3.9	12.4	BDL	BDL	BDL	0.568	0.011	BDL	0.001
SW side of P. Lake 3m from seepage channel	W9	12.8	1.2	0.8	4.2	19.6	BDL	BDL	BDL	0.129	0.02	BDL	BDL
West-southwest side of P. Lake 5m away from bank	W10	13.7	0.2	0.5	3.6	12.0	BDL	BDL	BDL	0.995	0.03	BDL	0.047

All values expressed in mg/L. BDL is below detectable limit; P stands for Priyadarshini; BOD5 is biochemical oxygen demand measured as difference in dissolved oxygen over a 5-day period; COD is chemical oxygen demand

3.8.2 Water Sample Analysis in the Year 2004

In order to evaluate the variations in physico- chemical parameters in the lakes over a period of time from the year 2000, the water samples were collected from Priyadarshini Lake, and Glacial Lake. The samples were collected in the year 2000 from Control Lakes but samples could not be collected as lakes were in frozen state during 2004. The distribution of inorganic, nutrient, demand and trace metal analysis showed good temporal variation in relation to physical and biological process.

Locations of the water samples are shown in the Figure 3.11. It was noted that the concentrations in the surface are mainly affected by the dynamics of ice melting. Sample collection from deeper part of lake could not be repeated during 2004 due to logistics reasons. Temperature measurement was carried out instantly at the site whereas for DO, pH, conductivity, BOD, alkalinity, nutrient measurements were carried out at the EIA laboratory. Trace metal, oil and grease and hydrocarbon analysis were carried out in India.

Many of lakes are remnants of larger glacial water bodies. During the freezing conditions while it covers with ice, these lakes, minimize the wind-driven currents and, to a limited extent, the exchange of gases between the water column and the atmosphere (*Raymond et al., 2000*). Priyadarshini Lake remains in complete epilimnion state. The physico-chemical parameters measured during 2004 are presented in the Table 3.11 and 3.12.

Table - 3. 11: Surface Water Quality - Physico-Chemical Characteristics and Inorganic Characteristics (Year 2004)

Sampling Location	Denoted as	pH	Temperature °C	Turbidity (NTU)	Total Suspended Solids (mg/l)	Total dissolved Solids (mg/l)	Conductivity (µS/cm)	Total alkalinity (mg/l as CaCO ₃)	Acidity (mg/l)	Total Hardness (mg/l as CaCO ₃)	Calcium Hardness (mg/l as CaCO ₃)	Chloride (mg/l)	Sulphate (mg/l)	Sodium (mg/l)	Potassium (mg/l)
Pump House	W1	5.6	1.6	2.0	<1	53.2	12.2	4	2	12	6	39.3	2	3	1
Confluence point of seepage & lake	W2	4.6	-1	1.0	<1	55.3	16.6	72	16	8	5	43.5	3	3	1
Confluence point of upper lake & P. Lake	W3	5.3	-1	2.5	<1	15.7	23.6	32	10	7	5	5.85	1	3	1
Behind Vindhya Hut	W4	5.3 7	-2	0.8	<1	19.6	8	36	10	7	5	10.0	2	3	0
Behind Summer Bathroom	W5	6.5 8	-2	2.0	<1	30.1	6.1	28	32	11	4	20.0	2	2	1
Confluence point of Glacial lake and Priyadarshini	W6	5.3 7	-1	1.4	<1	27.0	6.5	40	16	13	12	14.2	1	3	1
Drinking water of Priyadarshini	W7	5.3 7 5	10. 5	1.0	<1	26.8	7.2	40	16	13	6	16.7	1	3	1
Glacial Lake (R.H.S.)	W8	5.4 6	-1	6.0	<1	27.7	23.2	28	35	10	8	16.7	1	3	1
Glacial Lake (L.H.S.)	W9	5.4 5	-1	5.0	<1	28.2	26.1	4	20	11	5	18.4	1	2	1

Table - 3. 12 : Surface water Quality - Organic & Nutrient Characteristics and Concentration of Selected Heavy Metals
(Year 2004)

Sampling Location	Denoted as	Dissolved Oxygen (mg/l)	Nitrate as N	Total Phosphates	Chemical oxygen demand	Bio-chemical oxygen demand	Oil and grease	Hydro carbons (µg/l)	NO₂-N	NH₃-Nitrogen	Phenol	Nickel	Cadmium	Chromium	Copper	Lead	Iron	Manganese	Zinc	Cobalt
Pump House	W1	14.4	ND	2.30	<5	5.9	ND	ND	-	-	-	ND	ND	0.01	ND	ND	0.07	ND	0.02	ND
Confluence point of seepage & lake	W2	14.2	24.5	2.0	<5	8.6	ND	ND	-	-	-	ND	ND	0.01	0.01	0.03	0.14	0.01	0.01	0.01
Confluence point of upper lake & P. Lake	W3	14.0	ND	2.50	<5	9.7	ND	ND	-	-	-	ND	ND	0.01	ND	ND	0.17	0.01	ND	ND
Behind Vindhya Hut	W4	14.8	ND	4.20	<5	5.9	ND	ND	-	-	-	ND	ND	0.01	0.01	0.03	0.06	0.01	ND	0.01
Behind Summer Bathroom	W5	14.8	ND	1.4	<5	8.1	ND	ND	-	-	-	ND	ND	0.01	ND	ND	0.18	ND	ND	ND
Confluence point of Glacial lake and Priyadarshini	W6	14.8	ND	6.30	<5	6.5	ND	ND	-	-	-	ND	ND	0.01	0.01	ND	0.09	ND	ND	ND
Drinking water of Priyadarshini	W7	12.4	ND	0.04	<5	2.1	ND	ND	-	-	-	0.03	ND	ND	0.39	ND	0.08	ND	0.03	ND
Glacial Lake (R.H.S.)	W8	14.8	ND	1.80	<5	3.3	ND	ND	-	-	-	ND	ND	0.01	ND	ND	0.20	0.01	ND	0.01
Glacial Lake (L.H.S.)	W9	14.8	ND	6.30	<5	8.9	ND	ND	-	-	-	ND	ND	ND	ND	ND	0.19	ND	ND	ND

Not Detected

3.9 Characteristics of Wastewater Generation at Maitri

The wastewater produced in the station except toilet waste (urine and faeces) is called gray water. The largest part of residential gray water comes from laundry, showers, sinks and washing dishes. The amount of gray water produced per day and person varies from 20- 30 litres in some regions and up to several hundred litres in rich parts of the world. At Maitri it varies from 60-80 litres per day depending upon the season and requirement. Characteristic ingredients in gray water are fat, oil and other organic substances from cooking, residues from soap and surfactant from detergents. All these reflect the lifestyle in the household and the choice of chemicals used during washing, laundry and in the shower. It is estimated that total detergent consumption during the assessment year was around 250 kg at Maitri, apart from the soap used for bathing purpose.

The content of pathogens in gray water is generally low, because pathogens are primarily added to waste water through faeces. However gray water can be seen as a health hazard because all the indicator bacteria are found in it. It has been shown that gray water can contain pathogens especially in bath/shower and laundry water. Metals in gray water come from different leaching sources in dishes and laundry. It could also come from leaching of pipes, wires, machines and similar products. The levels of nutrients in gray water are normally low compared with normal waste water. In some gray water high concentration of phosphorous are found. This originates from washing and dishwashing powder, where it is used for softening the water. Sewage is a source of human-derived bacteria, yeasts and viruses that are not native to the Antarctic. Once released, bacteria can remain viable in low temperature Antarctic waters ($\sim 0^{\circ}\text{C}$) for prolonged periods (Smith *et al.*, 1994; Statham and McMeekin, 1994) and untreated sewage can affect biological oxygen demand (Howington *et al.*, 1992).

One way to get cleaner and less dangerous gray water starts with investigating what is put into the system. This can be done by considering all the chemicals used in the system, and effort to change to more environmental friendly ones. Today more and more of our efforts are focused on green electricity, environment friendly food,

renewable fuel and sorting garbage. But at the same time the number of cosmetics is increasing. It has been shown that the cosmetics and hair products contains dangerous and environment hazards. Many substances that are forbidden exist in hair products. In one investigation carried out in Stockholm it was reported from 73 examined products, 438 different compounds present and 21 of them were considered or classified as dangerous for the environment.

Many of the products contained several substances with the same qualities but with different toxicity for the environment. Triclosan is a chemical used for its antibacterial properties in many detergents, dishwashing liquids, soaps, deodorants, cosmetics, lotions, anti-microbial creams, various toothpastes, and an additive in various plastics and textiles (*Thomsen, 2005*). It has been showed that it does not break down in purification plants and becomes bio accumulated in fish. It is classified as a toxic substance that immediately kills water living organisms. It can also transform into dioxins by combustion.

3.10 Wastewater flow Rates and Composition

In the station flow rate depends upon the per capita presence. For example at the German Neumayer and the Argentine Jubany stations, flow rates of 145 and 133 litre/day/capita were used (*Ahammer et al., 2000*). Almost similar values of 164 and 160 litre/day/capita respectively were employed for New Zealand's new Scott base plant (*New Zealand, 2002*) and that planned for Australia's Davis station (*Heaton and Paterson, 2003*), while for the Japanese Syowa station plant, the corresponding figure was 150 litre/day/capita (*Umezawa et al., 2000*). These authors point out that the latter figure is only 60% of the flow rate used in Japan itself; this reflects the high energy costs associated with water production at Antarctic research stations and the resulting emphasis on water conservation. At "Maitri" the water demand fluctuates from 68 to 76 litre /capita/day during winter and summer. A key design consideration at all plants is the marked seasonal variation in hydraulic loading rates. The number of people overwintering on bases can be as few as 10% of the peak number present during the summer resupply period. Actual or projected minimum and maximum numbers for various bases are: Davis (Australia): 20 and 150 (*Heaton and Paterson, 2003*); Scott (New Zealand):

12 and 120 (*New Zealand*, 2002); and Rothera (U.K.): 20–25 and 100+ (*Hughes and Blenkharn*, 2003). It is recognized that per capita BOD loads in Antarctica tend to be high. Lori et al. (1996) cite a figure of 100–120 g BOD per person, contrasting this with the figure of 60 g BOD per person often quoted in textbooks. This high per capita BOD level can be attributed to the fact that people working in Antarctica are well fed and have a high calorific value food rich in fats; there is also a predominance of males, who produce more wastes than females (*Heaton and Paterson*, 2003). It is also possible that the higher per capita BOD at research stations might be caused by a more concentrated waste stream.

The gray water may be diluted by infiltrating ground water which would result in a lower per capita BOD measured in the influent at a wastewater treatment facility (*Burkhard et al.*, 2000). It would be expected that the wastewater stream in most research stations in Antarctica is concentrated with little dilution from wash water since water use is restricted. Although per capita BOD outputs would not be expected to differ much between bases, design BOD levels show substantial variations, and this is true also of suspended solids (SS) levels; for example in designing the Scott base plant SS and BOD levels of 700 mg/l were used (*New Zealand*, 2002) while in the design of the Japanese Syowa station SS and BOD levels of 320 mg/l were assumed (*Umezawa et al.*, 2000). An additional complication at coastal stations using seawater for toilet flushing is the high salt content of the wastewater: at Scott base up to 28% of the sewage is seawater (*New Zealand*, 2002). Many studies have shown that the importance of DOM in controlling the speciation and toxicity of trace metals in aquatic environment). It also plays a significant biochemical and geochemical role in aquatic ecosystems. The characterization of dissolved organic matter in effluents from waste water treatment plants (*Imai et al.*, 2002) using resin adsorbents showed that the averaged molecular weight of DOM increased as the UV: DOC ratio of total DOM increased. High strength municipal waste is treated by RBC pre-nitrification system (*Hiras et al.*, 2004). The simultaneous carbon and nitrogen removal from high strength domestic wastewater (*Gupta and Gupta*, 2001) help to achieve over 43% removal of influent nitrogen from two concentration of high strength synthetic wastewater along with over 90% COD

removal and 60% nitrification. A combined anaerobic and aerobic system is used to treat domestic sewage (*Hodgson, 2000*) in coastal areas (*Castillo et al., 1996*). It is observed that the COD removal efficiencies are similar for summer and winter because temperature balances the excess of the summer load. The physical and chemical characteristic of the biomass in three lab-scale sequencing batch reactors treating a wastewater investigated the highest specific ammonium oxidation rates in the aerobic SBR. All the reactors had very good COD removal. The empirical models for biological treatment of saline wastewater in RBC (*Kargi, 2002*) is observed under different operating condition and it is found that the COD removal increased with increasing A/Q ratio and decreasing feed COD and salt content. The study of sulfate reducing and methane producing bacteria in aerobic wastewater treatment systems (*Lens et al., 1995*) show that methane producing bacteria (MPB) and sulfate reducing bacteria (SRB) appear to be present in a broad range of aerobic biofilm and activated sludge reactors. The treatability and kinetics studies of mesophilic aerobic biodegradation (*Brar and Gupta, 2000*) of high oil and grease pet food wastewater (*Liu et al., 2004*) high oil and grease wastes can be treated aerobically with favorable kinetics in conventional activated sludge systems. More than 90% COD removal efficiency can be achieved at oil and grease concentrations as high as 660mg/L. the removal mechanism of *E. coli* from UASB effluent using RBC (*Tawfik et al., 2004*). It indicates that the most important removal process mechanism of *E. coli* is the adsorption process followed by sedimentation. High removal of *E. coli* is found in aerobic compared to anaerobic biofilm system.

3.11 Wastewater Sample Analysis of RBC

The Madrid Protocol of 1991 designated Antarctica as a natural reserve, devoted to peace and science (*Connor, 2008*). The Protocol sets out environmental principles, incorporates a conditional prohibition on mineral resources activities, and defines requirement of conduct of Environmental Impact Assessments (EIAs) for proposed activities on the continent. Also, signatory nations have agreed to elaborate rules and procedures relating to legal and practical responsibility for environmental damage arising from their activities.

"Minor and transitory" are terms used in the Madrid Protocol to describe levels of effects of proposed activities. These terms are not well defined in the Protocol, yet it is important to evaluate the potential impacts of activities in Antarctica even in the absence of specific definitions. Present study is prompted by concerns regarding the environmental impact through the RBC operation on the Antarctic lake. To investigate the efficacy of the RBC and its potential impact on the surrounding environment, composite samples were collected and analyzed on 23 January 2000 while the maximum population present in the Maitri station (Table 3.13 and 3.14). In the year 2004 wastewater sample were collected from influent and effluent of both B1 and B3 RBC and wastewater collection pond and data obtained are presented in Table 3.15 and 3.16.

Table - 3. 13: Wastewater Characteristics of Influent and Effluent Streams of the RBC (Year 2000)

Particulars of Sample	pH	Dissolved Oxygen	Temperature °C	Conductivity (ms/cm)	Suspended Solids	Chemical Oxygen Demand	Biochemical Oxygen Demand	Ammonia	Nitrate	Phosphate	Oil & Grease	Hydrocarbon
Influent of RBC-B3 (Bathroom & Urinal wastewater from Maitri)	7.2	0.4	8.0	23.8	41	522	123.6	122.5	3.18	0.3	5.8	0.35
Effluent of RBC-B3	6.96	4.3	6.0	1.807	26	306	108.2	47.5	2.45	1.5	4.2	0.27
Influent of RBC-B1 (Kitchen wastewater)	5.08	0.0	8.0	0.741	97	2664	1363.6	4.8	BDL	1.8	20.6	0.53
Effluent of RBC-B1	5.1	0.7	6.0	0.447	20	828	391.8	4.3	BDL	2.8	2.8	0.47

All values except pH are expressed in mg/L

Table - 3. 14: Wastewater Characteristics of Influent and Effluent Streams of RBC: Heavy Metal Content (Year 2000)

Particulars of Sample	Cadmium	Copper	Chromium	Lead	Iron	Zinc	Manganese
Influent of RBC-B3 (Bathroom & Urinal wastewater from Maitri)	BDL	0.231	BDL	BDL	3.79	0.49	0.025
Effluent of RBC-B3	BDL	0.126	BDL	BDL	4.71	0.241	0.006
Influent of RBC-B1 (Kitchen wastewater)	BDL	3.17	BDL	BDL	4.63	30.6	0.113
Effluent of RBC-B1	BDL	0.012	BDL	BDL	2.97	0.691	0.074

All values are expressed in mg/L. BDL is below detectable limit.

Table - 3. 15: Wastewater Characteristics of Influent and Effluent Streams of the RBC (Year 2004)

Particulars of Sample	pH	Dissolved Oxygen	Temperature °C	Turbidity (NTU)	Conductivity (ms/cm)	Total Solids	Volatile solids	Chemical Oxygen Demand	Biochemical Oxygen Demand	Alkalinity	Acidity	Chloride	Ammonia	Nitrate	Phosphate	Oil & Grease	Hydrocarbon(µg/l)	Phenol
Influent of RBC-B3 (Bathroom & Urinal wastewater from Maitri)	6.98	0.54	21	55	0.849	299.4	35.2	280	120	96	76	87	9.8	0.12	17.4	2.6	0.3041	0.16
Effluent of RBC-B3	7.28	4.6	21	42	0.941	52.7	0.0	208	100	64	92	95.3	21.8	0.13	12.4	4.0	0.2719	0.15
Disk Chamber of RBC-B3	6.87	3.2	13.5	-	-	1843.4	1664.4	-	-	-	-	97.0	-	0.15	14.4	1.8	0.2106	0.32
Influent of RBC-B1 (Kitchen wastewater)	4.99	0.53	22	200	0.207	1223.8	1186.8	728	620	20	52	20.0	2.85	0.10	2.1	3.9	0.4449	0.13
Effluent of RBC-B1	4.54	1.0	21	190	0.202	135.3	0.0	548	320	20	36	28.4	3.54	0.13	11.1	2.1	0.3075	0.25
Disk Chamber of RBC-B1	3.78	4.2	21	-	-	1920.9	1636.8	-	-	-	-	25.0	-	0.14	13.8	1.3	0.1692	0.46
RBC effluent collection pond	7.67	4.67	15	85	1.053	682.0	170.7	452	277.9	72	92	128.8	15.25	0.17	17.2	5.2	0.2819	0.0

All values except pH are expressed in mg/L

Table - 3. 16: Wastewater Characteristics of Influent and Effluent Streams of RBC – Heavy Metal Content (Year 2004)

Particulars of Sample	Cadmium	Copper	Chromium	Lead	Iron	Zinc	Manganese	Nickel	Cobalt
Influent of RBC-B3 (Bathroom & Urinal wastewater from Maitri)	ND	0.12	ND	0.05	0.17	0.10	0.01	0.14	0.01
Effluent of RBC-B3	0.12	0.24	ND	0.05	0.13	0.09	0.01	0.04	ND
Disk Chamber of RBC-B3	ND	0.13	0.01	0.05	0.38	0.13	0.01	0.20	0.01
Influent of RBC-B1 (Kitchen wastewater)	ND	0.02	ND	ND	0.14	0.05	0.01	ND	ND
Effluent of RBC-B1	ND	0.05	ND	0.06	0.84	0.09	0.02	ND	0.02
Disk Chamber of RBC-B1	ND	0.26	0.01	0.07	1.70	0.63	0.05	0.16	0.04
RBC effluent collection pond	ND	0.03	ND	0.06	0.39	0.04	0.10	0.03	0.01

All values are expressed in mg/L. ND- Not Detected (is below detectable limit).

3.12 Efficacy Improvisation at Site

The major objective of RBC is to remove soluble organic matter by converting it to insoluble microbial cells, which can be removed by sedimentation, thereby providing an effluent of high quality. The maximum capacity of B3 RBC is 5 kl/day and B1 RBC is having capacity of 1 kl/day (Kee, 2004). These systems were installed during the IX-Indian Antarctic Scientific Expedition (IASE) in the year 1989-90. During the summer period the lowest temperature recorded was around -15°C and highest +4°C. During winter lowest temperature recorded was around -38 °C. The treatment systems are installed in enclosed room outside of Maitri, which is in operation throughout the year irrespective of seasonal variation.

The performance of RBC is evaluated in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and Ammonia nitrogen ($\text{NH}_3\text{-N}$). The analysis of the data of the year 2000 (Table 3.13 and 3.14) depicts that both the RBC's were running much below the desired efficiency according to designed criterion. It was noticed that the treatment efficiency of B3 RBC was 27.8% in terms of BOD and 41.3 % in terms of COD. Whereas, B1 RBC was working with efficiency of 66.7% in terms of BOD and 68.9% in terms of COD.

3.12.1 Tertiary Treatment of Wastewater at Site

An attempt is made at the laboratory (Blutstein and Exton, 1983) to observe the effect of tertiary treatment on the effluents of RBC through alum and activated carbon. Alum, $[\text{Al}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}]$ is a coagulant used extensively in wastewater treatment (Nihalani *et al.*, 2004; Jagtap *et al.*, 2003). When alum is added to water, it dissociates to give trivalent Al^{3+} ions, which hydrate to form hexaaquoaluminum or bicarbonate species as a source of alkalinity (Omoike and Vanloon, 1999), the aquo aluminum ion, $\text{Al}(\text{H}_2\text{O})_6^{3+}$ undergoes a series of rapid hydrolytic reactions to form soluble mono-meric and polymeric species as well as solid $\text{Al}(\text{OH})_3$. Removal of nitrogen (Lee *et al.*, 2006) from wastewater has become an important part of the overall treatment process due to significance of nitrogen compounds on the environment and more stringent legislation on wastewater discharges (Windey *et al.*, 2005). Similarly removal of phosphorus

(Rybicki, 1998; Banu et al., 2008) is also equally important to overall treatment process. Alum treatment has been proven to achieve significant results in eliminating the nitrogen, phosphorus and other substances from treatment process (Omoike and Vanloon, 1999).

Activated carbons are successfully applied for the purification or supplementary purification of potable and wastewater. It's highly developed porous structure and large specific surface area exhibits a considerable adsorption capacity towards various pollutants, both organic and inorganic (Razvigorova et al., 1998; Vreysen et al., 2008). Granulated activated carbon has been proposed by the Environmental Protection Agency (EPA) USA to eliminate or reduce potentially carcinogenic organics substances in public supply; especially Trihalomethanes (THM). Activated carbon adsorbs organic compounds of a wide range of molecular weights. (Razvigorova et al., 1998; Vreysen et al., 2008) A combination of coagulation and adsorption applying technically appropriate dosage can largely enhance the removal from secondary effluent (Haberkamp et al., 2007).

In this regard the effluent is primarily treated through the alum dose by flocculation and obtained supernatant liquid was passed through the vertical column of 9 cm diameter and 16.5 cm height consists of activated carbon of total weight of 700 gm. Influent before introduction of alum and effluent through activated carbon treatment was analyzed for temperature, pH BOD, COD, conductivity and DO at Maitri laboratory and later heavy metals at the NCAOR laboratory. One gram of alum was mixed well in 500 ml of distilled water to prepare stock solution of alum. This consists of 2 mg/ml of alum dose. In a series of four one litre volumetric jars- 1, 2, 4 and 8 ml of the stock solution of alum was mixed in each of four jars filled with one litre of B3 and B1 RBC effluent. This series consists 2, 4, 8 and 16 mg of alum per litre of effluent. The aqueous solution mixed and flocculated well in a litre of series of waste obtained from inlet of B3 and B1 RBC. An optimum dose of alum solution, which gave the maximum settlement of the suspended particles, was selected to pass through the activated carbon column. For this purpose alum dose of 16 mg/l was selected for B3 RBC influent and 8 mg/l for B1 RBC to mix with effluent. After alum dose mixing and settling of the maximum flocculated matter, supernatant liquid of total volume of 1450 ml of the effluents was passed through

activated carbon flask, which took around 25 minutes to collect 680 ml of the B3 effluent treated sample passed through activated carbon column and 25 minutes to collect 495 ml of sample of B1 RBC effluent treated sample. The influent waste from both the RBC's and effluent after optimum dosing of alum and effluent from the activated carbon column was further analyzed for physico chemical parameters and trace metals. The results are presented in Table 3.17 to 3.20.

**Table - 3. 17: Physico-Chemical Characteristics of Wastewater of B3 RBC
(Urinal, Bathroom, and Laundry)**

S. No.	Parameters	Composite Sample			Tertiary Treatment (Effluent)			Overall % Removal
		Influent	Effluent	% Removal	Alum	Activated Carbon	% Removal	
1.	pH	7.2	6.9	-	7.0	7.8	-	-
2	DO (mg/l)	0.4	4.3	-	-	-	-	-
2.	Temperature (°C)	8.0	6.0	-	11.0	11.0	-	-
3.	Suspended Solids (mg/l)	41.0	26.0	36.6	78.0	48.0	38.5	6.2
4.	Nitrates (mg/l)	3.18	2.45	23.0	0.44	0.14	68.2	95.5
5.	Phosphates (mg/l)	0.3	1.5	-	1.6	1.8	-	-
6.	Ammonia (mg/l)	122.5	47.5	61.2	42.0	22.0	47.6	61.1
7.	Chemical Oxygen Demand (mg/l)	522.0	306.0	41.4	180.0	126.0	30.0	94.3
8.	Biochemical Oxygen Demand (mg/l)	158.6	108.0	31.9	55.2	43.9	20.4	72.3
9.	Oil & Grease (mg/l)	5.8	4.2	27.6	ND	ND	-	100
10.	Hydrocarbons (µg/l)	0.35	0.27	22.9	ND	ND	-	100

Table - 3. 18: Trace Metal Analysis –B3 RBC

S. No.	Parameters	Influent	Effluent	% Removal	Tertiary Treatment (Effluent)			Overall % Removal
					Alum	Activated Carbon	% Removal	
1.	Cadmium	ND	ND	-	ND	ND	-	-
2.	Chromium	ND	ND	-	ND	ND	-	-
3.	Copper	0.231	0.126	45.5	ND	ND	-	100
4.	Iron	3.79	4.71	-	1.13	1.00	11.5	73.6
5.	Manganese	0.025	0.006	76.0	ND	ND	-	100
6.	Lead	ND	ND	-	ND	ND	-	-
7.	Zinc	0.490	0.241	50.8	0.079	ND	-	100

Units are in mg/l, ND - Not Detectable

Table - 3. 19: Physico-Chemical Characteristics of Wastewater of B 1 RBC (Kitchen)

S. No.	Parameters	Composite Sample			Tertiary Treatment (Effluent)			Overall % Removal
		Influent	Effluent	% Removal	Alum	Activated Carbon	% Removal	
1.	pH	5.1	5.1	-	5.0	7.5	-	
2	DO (mg/l)	0.0	0.7	-	-	-	-	-
2.	Temperature (oC)	8.0	6.0	-	11.0	11.0	-	
3.	Suspended Solids (mg/l)	97.0	20.0	79.4	13	8.0	38.5	91.8
4.	Nitrates (mg/l)	ND	ND	-	ND	ND	-	--
5.	Phosphates (mg/l)	1.8	2.8	-	1.2	0.3	75.0	83.3
6.	Ammonia (mg/l)	4.8	4.3	10.4	3.8	3.7	2.6	22.9
7.	Chemical Oxygen Demand (mg/l)	2664.0	828.0	68.9	576.0	450.0	21.9	83.1
8.	Biochemical Oxygen Demand (mg/l)	1363.0	392.0	71.2	437.8	402.1	35.7	70.4
9.	Oil & Grease (mg/l)	20.6	2.8	86.4	0.0	0.0	-	100.0
10.	Hydrocarbons (µg/l)	0.53	0.47	11.3	0.0	0.0	-	100.0

Table - 3. 20: Trace Metal Analysis -B1 RBC

S. No.	Parameters	Influent	Effluent	% Removal	Tertiary Treatment (Effluent)			Overall % removal
					Alum	Activated Carbon	% Removal	
1.	Cadmium	ND	ND	-	ND	ND	-	-
2.	Chromium	ND	ND	-	ND	ND	-	-
3.	Copper	3.17	0.012	99.6	ND	ND	100	100
4.	Iron	4.63	2.97	35.9	2.16	1.71	20.8	63.1
5.	Manganese	0.113	0.074	34.5	0.025	ND	100	100
6.	Lead	ND	ND	-	ND	ND	-	-
7.	Zinc	30.6	0.691	99.6	0.187	ND	100	100

Units are in mg/l, ND - Not Detectable

3.13 Results

3.13.1 Priyadarshini Lake Water Assessment

Priyadarshini Lake situated near Maitri is the source of water for Maitri. The average water consumption by Maitri is around 900 m³ per year. Inflow of water to the Priyadarshini Lake due to glacial melt, estimated around 61,132 m³ per year. Even during winter sufficient water is available to consume by Maitri. The water abundance available through Priyadarshini Lake will sustain for many more the years to come even if there is no inflow of water and even if the water evaporation rate is high. The water quality of the lake has not changed by the intrusion of small quantity of wastewater through seepage water channel possibly due to maintained high dilution ratio and also due to replenish of water from the glacial melt. However in the interest of maintaining quality of water in the Priyadarshini Lake it is essential to take steps to control seepage of wastewater to the lake by carpeting the pond liner and permeable reactive seepage barrier(EPA, 1998; Woinarski et al., 2003).

3.13.2 Water Characteristics of Lakes around Maitri Station

The main surface water bodies identified in the region were Priyadarshini Lake, its feeding glacial waters and other lakes referred as Control Lakes. The treated effluent is collected in pond. A seepage channel observed for short period arising from near the treated effluent collection pond and apparently joining Priyadarshini Lake was also considered for the study. The water from these different sources was assessed for their physical, inorganic, nutrient and organic parameters. Additionally, the prevailing levels of some selected heavy metals were also quantified. The important factors that are likely to affect the water quality in the region, especially Priyadarshini Lake, are the closeness of summer camp to it and the emergence of above-referred seepage channel at higher elevation. In the year 2000 during austral summer, water samples were collected from nineteen locations wherein during the year 2004 it could be collected from only nine locations owing to limitations of logistics support as well as freezing condition of Lakes (Table 3.9 to 3.12).

3.13.2.1 Turbidity

Turbidity in Priyadarshini Lake varied in the range of 1.0 to 1.7 NTU in the year 2000 whereas it reduced in all the locations less than one NTU in the year 2004. In the glacial lake it was 0.4 to 1.4 NTU in the year 2000. Turbidity in the control lakes was 0.4 and 0.5 NTU in 2000. Slightly higher range of turbidity recorded in all the locations in the year 2000 may be due to the effect of glacier melt water which aggravates the abrasion of flowing snow water over the rock. Glacial lakes feed water to Priyadarshini Lake so the effect was observed. While in 2004 results are at lower side, because samples were collected while flow in glacial lake stopped so in the Priyadarshini Lake the suspended particles were less owing to settlement.

3.13.2.2 Temperature

Temperature in the Priyadarshini Lake, glacial lake and control lake was varied from -1°C to +4°C in the year 2000, while sample analysis and physico-chemical measurement carried out at Maitri laboratory showed that the temperature of sample varied from, 10-12 °C . In the year 2004 the temperature of all lakes varied in the range

of -2 to 1.6 °C, except drinking water sample which was collected inside the Maitri and measured 10.5 °C.

3.13.2.3 Conductivity

Conductivity does not show much variation in the lakes when compared between different years. In the Priyadarshini lake in 2000 it was found in the range of 19 μ S/cm to 28 μ S/cm whereas in the Control Lake and glacial lake it was recorded in range of 10 μ S/cm to 22 μ S/cm. In the year 2004 in Priyadarshini Lake it varied from 6.1 to 23.6 μ S/cm. whereas in glacial lakes conductivity was 23.2 to 26.1 μ S/cm. Relatively higher conductivity in Priyadarshini Lake was recorded near confluence point with glacial lake. This is due to glacial lake water which itself carried conductivity 23.6-26.1 μ S/cm. This effect may be due to melting of glacier, which abrades rocks and mineral in very low concentration and mix with water.

3.13.2.4 Alkalinity

Alkalinity is defined as measure of water's ability to absorb hydrogen ions without significant pH change, or it is a measure of water capacity to neutralize the acids. This was measured in glacial lake and Control Lake in the year 2000 and is in the range of 3 to 6.2 mg/l. In Priyadarshini Lake it is recorded in the range of 4.0 mg/l to 5.3 mg/l. In 2004 it is found in the range of 4 mg/l to 72mg/l for all lakes. It shows that in 2000 all the lakes around Maitri are devoid of HCO₃, CO₃ and OH anions. But in the year 2004 presence of algae at the confluence point of glacial and Priyadarshini Lake must have contributed carbonate and hydroxide to alkalinity (Sawyer et al., 2003). Therefore relatively it was on higher side as compared to other locations in Priyadarshini Lake. Highest was recorded at the confluence point of wastewater seepage to Priyadarshini Lake. It is a clear indication that seepage water is mixing with Priyadarshini Lake. However, alkalinity in the glacial lake was recorded as 4 mg/l. Drinking water contains relatively higher alkalinity, might be the iron pipe which was corroded and contributing to alkalinity.

3.13.2.5 Total Hardness

Hardness which is defined as the concentration of all multivalent metallic cations in solution requires considerable amount of soap to produce foam or lather. The total hardness in 2000 in Priyadarshini lake varied from 6.5 to 9.5 mg/l, in glacial lake it ranges from 5-10.1 mg/l and in control lake 6 to 8.1 mg/l. Higher concentration in comparison to other locations were recorded in glacial lake situated SE to Maitri and near the confluence point of glacial lake and Priyadarshini lake (CL4-A and W2). It indicates that minerals in small amount are being dissolved in glacial water by rocks and same flux of water feeds the Priyadarshini Lake. However, other glacial lake which feeds water to Priyadarshini Lake has lower hardness as compared to glacial lake present SE of Maitri. So by mixing two sources of different hardness of water, average concentration is recorded in Priyadarshini Lake. In the year 2004 total hardness measured was 7.0-13 mg/l in Priyadarshini Lake, and 10-11 mg/l in glacial lake. Samples could not be collected from Control Lakes during 2004. Higher concentration has been recorded at the confluence point of glacial lake (SE to Maitri) and Priyadarshini Lake (W6). The hardness of glacial lake was lower when compared to 2000 but, in Priyadarshini Lake it was measured higher than that recorded in the year 2000. One possible reason may be seepage of bathroom water which contains large amount of soap. The summer hut bathroom modules were kept around 100 m from the bank of the lake. Since in the year 2000 at all the locations alkalinity was less than total hardness so carbonate hardness can be designated to alkalinity . Whereas in the year 2004 in Priyadarshini Lake, total hardness being less than alkalinity, carbonate hardness was designated to total hardness. As a qualitative check all the locations show hardness less than 50 mg/l and are considered soft water.

3.13.2.6 Calcium Hardness

Calcium is one of the principle elements causing hardness in water in addition to magnesium, strontium, ferrous ion and magnesium ions. It is also referred as temporary hardness as it can be removed simply by boiling water. In Priyadarshini Lake the calcium hardness in the year 2000, recorded was in range of 4.5 mg/l to 7.0 mg/l, whereas for

glacial lake and Control Lake it was found in the range of 3.8-8.5 mg/l and 4.3-5.6 mg/l, respectively. In 2004, the calcium hardness was found in the range of 4-12 mg/l in Priyadarshini Lake. In glacial lake it is measured in the range of 5-8 mg/l. It depicts that calcium hardness also increased in the year 2004 as compared to 2000 mostly in all locations. This also shows that calcium hardness governs the total hardness in lakes around Maitri station.

3.13.2.7 Chloride

Chloride occurs in all natural waters in widely varying concentration. Chloride in reasonable concentration is not harmful to humans. The water sample collected in the year 2000 shows that chloride concentration in Priyadarshini, glacial and control lakes are found in the range of 1.8 mg/l to 3.4 mg/l, while in 2004 the level of concentration increased. In Priyadarshini Lake it is recorded as 10-43.5 mg/l. Maximum concentration of 43.5 mg/l was recorded at location where seepage channel water intermixes with Priyadarshini Lake, and second lowest was near pump house. It is clearly an indication of chloride present in the urine joining the Lake through seepage and effect is seen up to pump house. However, at other locations reduces by dilution of glacial melt water. In glacial lake, chloride concentration was recorded in the range of 16.7 to 18.4 mg/l. In the year 2000, samples were collected immediately after melting of glacial lakes while wastewater pond was also frozen, so seepage effect observed in the lake was considerably less.

3.13.2.8 Total Dissolved Solids (TDS)

Total Dissolved Solids include all anions and cations. In 2000 the total dissolved solids was not measured in any lakes. While in 2004, TDS was measured and was in the range of 19.6-55.3 mg/l in Priyadarshini Lake. Highest was measured at the confluence point of seepage channel and Priyadarshini Lake (55.3 mg/l). In glacial lake it was recorded as 27.7 to 28.2 mg/l. It shows that the TDS is comparatively high at lower side in all lakes. The study of effect of TDS on aquatic organism (*Phyllis et al., 2007*) shows that there is effect on fertilization and egg development of aquatic organism.

3.13.2.9 Total Suspended Solids

In the year 2004, in Priyadarshini Lake and glacial lakes the total suspended solids were measured less than one milligram in a litre of sample. During 2000 total suspended solids were not measured in any of the lakes.

3.13.2.10 Sulfate

Sulfate is concern in water and wastewater because of its odor and corrosion problem. It is also known for “cathartic effect” on human being, so it should be below 250 mg/l in the drinking water. The observation of Sulfate concentration in 2000 for glacial lake, control lake and Priyadarshini lake was observed in the range of 0.6 mg/l to 1.8 mg/l, while in 2004 the sulfate concentration in Priyadarshini lake was found to be in the range of 1 mg/l to 3 mg/l, at seepage channel and Priyadarshini lake confluence point, whereas in glacial lakes it was almost same as 1 mg/l. It can be concluded that sulfate concentration in all the lakes present in almost negligible amount.

3.13.2.11 Nitrate

The concentration of nitrate in Priyadarshini Lake in the year 2000 was in the range of 0.1mg/l to 1.2mg/l, whereas in 2004 the concentration in lake was found to be in the range of 0.31mg/l to 0.50mg/l only at few locations. Highest was recorded near pump house which was around 50 m away from the confluence point of seepage water and Priyadarshini Lake. It may be the conversion of ammonia into nitrate in due course of time, which was being contributed from urinal, laundry to wastewater treatment system, and as treated water seeps towards the lake. At other locations it was not detected. In glacial and Control Lake in the year 2000 it varied from 0.04 to 0.18 mg/l, in one glacial lake it was recorded as 0.4 mg/l i.e. situated RSH of Maitri which receives treated effluent discharge from RBC and in other glacial lake it was not detected. The presence of nitrate in the glacial and control lakes was noticed, even though in the negligible concentration during 2004. In Priyadarshini Lake, presence of nitrate was due to the effect of self intermixing, glacial feed of glacial melt water as well as at few locations due to seepage channel contribution. In glacial and Control Lake the presence of nitrate

indicates existence of blue - green algae which obtain nitrogen directly from atmosphere. It cannot also be ruled out that during electrical storm, Antarctica is known for this phenomenon nitrogen-fixation occurs and certain bacteria and blue-green algae convert atmospheric nitrogen into nitrate and ammonia for their use (*Masters, 2001*). The biomass burning by humans (*Mayewski and Legrand, 1990*) also contributes to nitrate conversion, from continents to remote area like Antarctica which deposits over snow and mixes in lakes.

3.13.2.12 Total Phosphate

Phosphate is another important element apart from nitrate in growth of algae (observed near lakes) and also it contributes to corrosion prevention. Water samples collected in the year 2000 shows concentration of total phosphate (inorganic and organic) in Priyadarshini Lake as below detection level (BDL) to 1.4 mg/l. In the glacial and Control Lake it varied from BDL to 1.8 mg/l. During the year 2004 total phosphate concentration relatively increased in Priyadarshini Lake which varies from 1.4 to 6.3 mg/l. In drinking water phosphate value recorded was 0.04 mg/l, whereas in glacial lakes concentration measured was 1.8 and 6.3 mg/l. Higher concentration recorded at in the glacial lake situated at LHS of Maitri and at confluence point of glacial lake and Priyadarshini lake. It indicates that phosphorus is being contributed by the algae which had grown at the bank of confluence point of both the lakes. To the Priyadarshini Lake and the RSH glacial lake phosphate was contributed by inorganic phosphate by breakdown of proteins and elimination of the librated phosphates in the urine. So the wastewater treatment plant which was not functioning properly during the time of observation and the partially treated effluent which was being discharged nearby RSH glacial lake was contributing phosphate to the Priyadarshini and glacial lake water. In the lakes phytoplankton and zooplankton were also identified (*Tiwari et al., 2006*). These floating organisms can survive while nutrient like nitrate and phosphate are present in the water which is essential for their growth. Presence of phosphate in the control and glacial lakes even in low concentration requires further study to identify the source.

3.13.2.13 Dissolved Oxygen

Dissolved Oxygen in water is governed by, solubility of gas, partial pressure, temperature and salinity. In Antarctic lake water temperature is very low during austral summer while glacier melts. Water samples were collected from lakes, which has almost negligible salinity. In the year 2000, DO measured was in the range of 12.8-14.1 mg/l. In glacial and Control Lake it varied from 10.2-13.8 mg/l. During 2004, DO measured was in the range of 14.0-14.8 mg/l in Priyadarshini Lake, and 14.8 mg/l in glacial lakes. In the drinking water it measured slightly less i.e. 12.4 mg/l, possibly because the temperature was high (12°C) while DO was measured. In the year 2000 while DO was measured temperature of all the samples were in the range of $2\text{-}4^{\circ}\text{C}$, while in the year 2004 when DO was measured temperature was near to 0°C . So the Do level shows marginally higher concentration in the year 2004.

3.13.2.14 Biochemical Oxygen (BOD) Demand

Biochemical Oxygen Demand is an indicator of decomposable organic pollution in the water. It was measured in Priyadarshini Lake in the year 2000 and was in the range of 3.0 to 4.2 mg/l. In glacial and Control Lake it varied from 1.1-2.7 mg/l. In the year 2004, BOD measured was in the range of 2.1-9.7 mg/l in Priyadarshini Lake, whereas in glacial lake it was 2.7 - 3.5 mg/l. In Priyadarshini Lake during 2004, concentration found to be relatively higher than in the year 2000. The sample collected was just before freezing of the lake when seepage water completely mixed with lake water may be the possible reason. It was showing relatively higher concentration near the confluence point of wastewater seepage channel and behind summer hut where wastewater from bathroom was discharged openly, ultimately mixed with lake water.

3.13.2.15 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand is an indicator of pollution strength, measured by oxidizing almost all organic matter present in water or wastewater, using high strength oxidizing agent, rather utilizing bacteria. COD test is helpful in indicating toxic conditions and the presence of biologically resistant organic substances (Sawyer *et al.*, 2003). The COD in

the year 2000 found to be in the range of 8.0 mg/l to 21.4mg/l in Priyadarshini Lake. Higher value was obtained (21.4 mg/l) at the centre of the lake. In Control and glacial lake it varied from 4.4-16.0 mg/l. Highest value was obtained for Control Lake (16.0 mg/l) situated at north direction few hundred meters away from the Priyadarshini Lake. In the year 2004 COD value was below 5 mg/l at all locations in Priyadarshini, Control and glacial lake. When the sample was collected lake was almost below the freezing point. In this case the productivity of phyto and zooplankton might have reduced, which might have contributed to higher COD. The treatment of anaerobically pretreated domestic sewage (*Tawfik et al., 2002*) helps in removing most of the COD.

3.13.2.16 Oil and Grease and Hydrocarbon

In the year 2000 oil and grease and hydrocarbon were not measured. However in the year 2004 these parameters were not detected in the water samples of all lakes.

3.13.2.17 Heavy Metals

Heavy metals may often be defined as any metal which have atomic number greater than that of Iron (*Wolff and Peel, 1985*). These elements are emitted industrially and dispersed widely in the environment, and are potentially harmful through in small concentration.

3.13.2.18 Sodium

In Priyadarshini lake the concentration of sodium observed in the year 2000 is in the range of 1.4-1.8 mg/l. In Control Lake and glacial lake it varied from 1.1-1.6 mg/l. The sodium presence in the lakes in the year 2004 is in the range of 2-3 mg/l for Priyadarshini and other lakes. It shows that the concentration of sodium in the year 2004 is relatively higher.

3.13.2.19 Potassium

The potassium concentration in the year 2000 in Priyadarshini Lake was in the range of 0.4mg/l to 0.8mg/l and in glacial lake and Control Lake it measured in the range of 0.2mg/l to 0.5mg/l. During 2004, potassium measured was in the range of 0-1 mg/l, in

Priyadarshini and glacial Lake. Sodium and Potassium are necessary inorganic ions for the growth of most of the organisms. The concentration in the Priyadarshini Lake increased marginally in subsequent the year 2004, though the overall concentration at all locations was very less.

3.13.2.20 Iron

The measured iron concentration in the Priyadarshini Lake in the year 2000 was in range of 0.129mg/l to 0.995mg/l, in glacial and control lake it varied in range of 0.472-1.655 mg/l. Higher concentration was recorded in the glacial lake which receives the treated effluent discharge. It shows that the partially treated effluent mixing with glacial water is contributing to iron accumulation in the water. Higher concentration was also recorded in the confluence point of glacial lakes and Priyadarshini Lake, which is the highest concentration in the lake water sample. In the year 2004, iron concentration recorded was in range of 0.06-0.18 mg/l in Priyadarshini Lake, and 0.19-0.20 mg/l in glacial lake. In drinking water it was recorded as 0.08 mg/l. Priyadarshini Lake and effluent discharge was not noticed near glacial lake situated RSH of Maitri. Iron does not impart any harmful effect on human, but if contains more than 0.03 mg/l it interfere with laundry operation. This effect was observed at Maitri station, even though alkalinity of water was found low. Higher concentration recorded in the year 2000 in Priyadarshini Lake is due to mixing of glacial melt water. Glacial melt water flows over soil which may contain insoluble ferric oxide and iron sulfide or ferrous carbonate. In water containing high carbon dioxide, ferrous carbonate may dissolve and react with CO₂ can forms iron ions. Another possible reason of higher concentration of iron in the RSH glacial lake is because of mixing of partially treated effluent which contains iron in higher amount.

3.13.2.21 Manganese

The manganese concentration in the year 2000 in Priyadarshini Lake was in the range of 0.011mg/l to 0.037mg/l in most of the location except at centre of lake wherein it was found to be 0.071mg/l, which is quite high compared to other locations. In glacial and Control Lake, it measured in the range of 0.04-0.184 mg/l and .005-.039 mg/l, respectively. In the year 2004, in Priyadarshini Lake the concentration of manganese

was not detected at seven locations but at two locations it was recorded as 0.01 mg/l. In RSH glacial lake it recorded 0.01 mg/l and in other glacial lake it was not detected. Manganese in drinking water if more than 0.05 mg/l then it interfere with laundry operation as iron imparts this characteristic. In the year 2000 the concentration recorded was higher because of the glacial melting water mixed. Also glacier flow over soil which may contain manganese dioxide, though it is very insoluble in water containing carbon dioxide, but under reduced environmental conditions as a result of biological reactions, it may dissolve. This may be true in the case of partially treated effluent is discharged over moraine which contains partially converted soil, and would develop anaerobic conditions to mix manganese oxide into water. This ultimately joins glacial lake. In Priyadarshini Lake at the centre higher concentration, may be due to stratification of layers. The depth measured was around seven meter (*Tiwari and Nayak, 2007*) at the centre, develops hypolimnion, so bottom sediment releases soluble manganese (iron as well), and reaches the surface.

3.13.2.22 Lead

In the year 2000 lead was not detected in any of the sample collected from Priyadarshini, glacial or Control Lake. In the year 2004 it was detected only at two locations in Priyadarshini Lake with concentration of 0.03 mg/l at the confluence point of seepage channel to the lake and another near location W4. It was clear that lead is being introduced from the seepage of partially treated effluent into lake. However the amount is very less and not observed at all the location.

3.13.2.23 Zinc

Zinc is also important trace metal in drinking water. It is recorded in the range from BDL to .047 mg/l in Priyadarshini Lake and from BDL to 0.15 in glacial and Control Lake. Highest concentration is recorded 0.15 mg/l in glacial lake nearby location where partially treated effluent is discharged. In the year 2004 zinc concentration is detected only at three location out of six locations in Priyadarshini lake ranging from 0.01 to 0.03 mg/l In glacial lake it is not detected.

3.13.2.24 Cadmium

Cadmium measured was found to be below detectable limit in the year 2000 as well as 2004 in all the lakes

3.13.2.25 Copper

Copper was below detectable limit in all the locations in Priyadarshini, Control and glacial lake, in the year 2000. However in the year 2004, in Priyadarshini Lake it was detected as 0.01 mg/l at two locations and at rest of the four locations it was not detected. In drinking water the concentration measured was 0.39 mg/l. A portion of drinking water pipeline made of copper may be the reason, which adding ions in drinking water supply. In Priyadarshini Lake it was recorded at confluence point of partially treated effluent seepage channel, which would have contributed to the lake. In glacial lake, copper concentration was not detected.

3.13.2.26 Chromium

Chromium was found below detectable limit in the year 2000 in all the lakes. In the year 2004 it was measured 0.01 mg/l at all six locations in Priyadarshini lake, and a glacial lake, whereas in glacial lake it was not detected. Hexavalent chromium compounds tend to be more mobile and toxic than trivalent chromium compounds (Calder, 1988). Exposure of the hexavalent compounds has been found to cause ulceration of the skin, perforation of nasal septum, inflammation of the larynx and damage to the kidney's and lungs. On the other hand, trivalent chromium has been found to be an essential trace element in the human diet, and deficiency in trivalent chromium has been linked with poor sugar metabolism (Katz, 1991). In the Priyadarshini Lake it was observed that, various windblown metallic sheets and other metallic material are submerged at various locations. They may be possible source of chromium presence in the lake.

3.13.2.27 Nickel

Nickel was not measured in the year 2000 in any lake. In the year 2004 at all the locations in Priyadarshini Lake and glacial it was not detected, but in drinking water it

measured 0.03 mg/l. It might be imparting due to use of nickel coated iron pipe for intake and distribution of drinking water.

3.13.2.28 Cobalt

In the year 2000 cobalt concentration was not measured in any lake. In the year 2004 only two locations in Priyadarshini Lake showed the concentration of 0.01 mg/l, which is due to mixing of partially treated wastewater into Priyadarshini Lake. In a location of glacial lake situated RSH to Maitri concentration of cobalt was measured 0.01 mg/l. It is due to mixing of partially treated effluent into lake water, which is discharged near this glacial lake, as it seeps through moraine and soil and ultimately joins glacial lake.

3.13.3 Wastewater Analysis of RBC at Maitri Station

The RBC units are located in separate rooms. The treated effluent is collected in the pond. A seepage channel arising from near the treated effluent collection pond and apparently joining Priyadarshini Lake was also considered for the study (Table 3.13- Table 3.16).

3.13.3.1 pH

pH was measured immediately after collection of composite samples for all the locations in RBC and effluent collection pond. In the year 2000 influent of laundry RBC (B3) measured 7.2, effluent pH measured slightly lower than influent i.e. 6.9, while temperature of influent and effluent recorded 8 °C and 6°C at primary sediment tank (PST) and secondary sediment tank (SST). It may be attributed to the presence of less number of inorganic consuming bacteria which otherwise had consumed CO₂ produced by the oxidation of organic matter. In the biodisk-chamber of B3-RBC it measured 6.87 at 13.5°C. In the year 2004, pH was measured in influent and effluent of RBC- B3, as 6.98 and 7.28 at 21°C, respectively. Effluent pH found slightly higher than influent. The pH of the system is well within the limit to support growth of the bacteria. pH of kitchen RBC (B1) in the year 2000 measured 5.08 of influent at 8°C and 5.1 at 6°C of effluent. While in the year 2004 pH of influent measured 4.99 at 22°C (PST) and of effluent measured 4.54 pH at 21°C,(SST), while pH of biodisk-chamber measured 3.78 at 21°C.

Kitchen influent's pH was lower than Kitchen effluent, so the pH of biodisk-chamber also, shows acidic state. This range of pH does not provide comfortable environment to support the growth of bacteria on biodisk. Influent and Effluent pipes of RBC's are enclosed with heat tracing element, which keeps warm to liquid till it is discharged into effluent collection pond and pH measured was 7.67 in the year 2004. In the year 2000 trace heating encased pipe was not functioning properly so temperature measured lower than during 2004.

In the SST of B3 and B1 RBC (thicker) anaerobic condition formed and may be acid forming bacteria working to convert the organic matter into acidic acid. But methane forming bacteria may not be able to function as they need $pH > 7$ and alkalinity require 1000 mg/l for their growth. So the pH of the effluent is acidic.

3.13.3.2 *Dissolved Oxygen (DO)*

The dissolved oxygen in the B3 RBC remains almost same in the influent and effluent. In 2000 it measured 0.4 and in 2004 it recorded 0.54 mg/l in the influent. In the effluent it measured 4.3 and 4.6 mg/l in the year 2000 and 2004 respectively. It shows that the characteristics of laundry waste remain same and RBC effluent quality also remains unchanged. In biodisk-chamber, DO measured was 3.2 mg/l during sample collection in the year 2004. Similar condition was observed in the influent and effluent of B1 RBC. Influent shows concentration of DO as 0.53 mg/l, which is septic condition, whereas in the effluent it measured 0.7 and 1.0 mg/l in the year 2000 and 2004, respectively. Biodisk-chamber shows DO of 4.2 mg/l. It indicated that oxygen was being transferred in through the biodisk for treatment but another part of BOD was counteracting to reduce the DO of effluent. Minimum DO needed was 1-2 mg/l for proper growth of bacteria in aerobic condition. The effluent DO was very low, which is not a good sign of desirable treatment of the kitchen waste. DO of wastewater collecting pond which is open to air, measured 4.67 mg/l in the year 2004.

3.13.3.3 *Turbidity*

Turbidity was not measured in the year 2000 in any of the samples. In the year 2004 it

measured 55 NTU in influent of B3 RBC. In the effluent, turbidity reduced marginally by 24% measured 42 NTU. Influent of B1 RBC, shows turbidity 200 NTU whereas, effluent shows 190 NTU. There is slight decrease in the turbidity of the effluent. It may not be ignored that, if biodisk is working properly, which would reduce further turbidity in the effluent but at PST, suspended/dissolved or colloidal particles are again mixing with the effluent. While effluent from both the RBC was collected in the wastewater collection pond, it had shown turbidity of 85 mg/l, which indicates settling of the suspended particle resulting reduction in turbidity.

3.13.3.4 Conductivity

Conductivity measured for the sample collected in 2000 shows for B3 RBC influent 23.8 ms/cm, whereas effluent's conductivity reduced considerably to 1.807 ms/cm. It reduced almost by 92.5%. The conductivity of B1 RBC of influent and effluent recorded 0.741 and 0.447 ms/cm i.e. 40% reduction in the dissolved and colloidal particles. In the year 2004 conductivity of B1 RBC recorded 0.849 ms/cm and 0.941 ms/cm for influent and effluent respectively. So it indicates there is remixing of the particles in the effluent from some source. Conductivity in the B3 RBC shows in the influent 0.207 ms/cm and in effluent it recorded 0.202 ms/cm. There is marginal decrease in conductivity in the effluent. It indicated either biodisk is not functioning properly or if functioning, particles are being introduced to the effluent of the RBC from some source and it may be from the PST. Conductivity of the wastewater pond i.e. 1.053 ms/cm shows almost equal to adding to effluent of both the RBCs, indicating that the effluent consists of a major portion of colloidal and dissolved particles, which do not conglomerate and settle down.

3.13.3.5 Total and Suspended Solids

Total solids were not measured in the year 2000. However, suspended solids measured in the year 2004 shows that in B3 RBC it was 41 mg/l and 26 mg/l in the influent and effluent and 97 and 20 mg/l in the influent and effluent of B1 RBC. In 2004, suspended solids were not measured but total solids were recorded as 299.4 mg/l and 52.7 mg/l for influent and effluent of B3 RBC (82% reduction). In biodisk-chamber it was measured as 1843.4 mg/l, which is Mixed Liquor Suspended Solids (MLSS) contribution. Influent and

effluent of B1 RBC shows high solid content compared to B3 RBC as 1223.8 and 135.3 mg/l (89% reduction). Whereas due to MLSS contribution, total solids measured in biodisk-chamber was 1920.9 mg/l. Total solid was measured 682.0 mg/l in the wastewater pond, during 2004. It is higher than the combining both the RBC's effluent measurement for total solids.

3.13.3.6 Volatile Solids

Volatile solids were not measured in the year 2000. In the year 2004 volatile solids in the influent of B3 RBC measured was 35.2 mg/l and in effluent it recorded zero milligram per litre. In the biodisk-chamber of B3 RBC it was 1664.4 mg/l. The microorganism which were grown on the disk upon death, mixes with liquid and contributing to high organic content. Presence of the algae was also noticed in the biodisk of the laundry RBC (B3-RBC), which can contribute to the higher organic content of volatile solids. It is quantified in influent of B1 RBC as 1186.8 mg/l and zero milligrams per litre in the effluent. Whereas in the biodisk-chamber it measured 1636.8 mg/l. Wastewater collection pond shown volatile solids as 170.7 mg/l concentration of volatile solids. Kitchen waste contains high organic content in the influent. Higher concentration in the biodisk- chamber and then in the influent imparted because of MLSS. In the effluent of both the RBC the concentration was found nil, indicated that either organic matter gets converted into gas or settling down in the secondary settling chamber. In the pond generation of the algae may be contributing due to volatile solids.

3.13.3.7 Chemical Oxygen Demand

Since sewage is complex in nature for which theoretical oxygen demand (ThOD) which is defined as theoretical amount of oxygen required to oxidize the organic fraction of the waste completely to carbon dioxide and water, cannot be calculated but in practice it is approximated by the chemical oxygen demand (*Duncan, 1976*). In the year 2000 the concentration of chemical oxygen demand in influent of RBC- B3 is observed to be 522 mg/l while in effluent of RBC- B3 it is recorded as 306mg/l, i.e. total reduction in COD was around 41%. Whereas in influent of B1 RBC carried 2664 mg/l and effluent, 828 mg/l, shows COD reduction around 69%. This is higher compared to B3 RBC. In the

year 2004 COD measured in the influent and effluent of composite sample of B3 RBC was 280 and 208 mg/l respectively (26% removal). Effluent COD measured higher than the influent indicated- nonfunctional state of B3-RBC. In the B1 RBC the COD measured was 728 mg/l in influent and 1760 mg/l in the effluent (25% removal). This also indicate that B1 RBC was not functioning, on the contrary in the effluent organic matter was contributing higher COD than influent In the collection pond the COD recorded was 452 mg/l. In the year 2000 COD load was higher than during 2004 in B3 and B1 RBC but still it was functioning compared to the condition in the year 2004. Overall efficacy of the RBC was very low as compared to the design efficacy (90%).

3.13.3.8 Biochemical Oxygen Demand

The biochemical oxygen demand in the year 2000 for influent and effluent of B3 RBC was observed as 158.6 and 108.0 mg/l with 32% removal. While in influent and effluent of B1 RBC it recorded as 1363.0 and 392.0 mg/l with 71% removal. BOD concentration in B1 RBC measured around 859% higher than B3 RBC. However, composite samples were collected when maximum members were present on particular day and generated higher quantity of wastewater as compared to normal average wastewater production. So considering the flow of 1900 litre in B3 RBC and 675 litres per day in B1 RBC the maximum BOD load in the year 2000 estimated as 0.30 kg/day on B3 RBC and 0.92 kg/day on B1 RBC. Whereas, design load of the B3 RBC is 1.5 kg/day and B1 RBC is 0.36 kg/day. It is clear that B3 RBC was working under load and B1 RBC is overloaded. The BOD in the year 2004 was measured on the normal average occupancy of the Maitri station. It recorded in influent of B3 RBC as 123 mg/l and in effluent (253.0 mg/l) higher than influent. Similarly in B1 RBC in the influent it measured as 142 mg/l and in effluent 263 mg/l which is higher than the influent. It is because de-sludge is not proper which created the anaerobic condition and which releases the gases like methane and hydrogen sulfide along with settled particles thus increases the BOD. In the wastewater collection pond BOD measured was 277.9 mg/l, which is mainly contributed by dissolved organic matter. On observation it is found that excessive growth of the biofilm which might be causing clogging (*Vinage and Rohr, 2003*) for effective surface area for oxygen transfer.

3.13.3.9 Alkalinity

Alkalinity was not measured in the year 2000 in the wastewater samples. Sample collected during 2004 shows 96 mg/l in the influent and 4 mg/l in the effluent of B1 RBC. Since alkalinity was reduced, so the pH of the effluent of B3 RBC. In the B1 RBC it measured as 20 mg/l in both influent as well as effluent of the RBC. In the wastewater collection pond it measured as 72 mg/l. Higher alkalinity helps in the removal of the trace metals from the water and wastewater as they get precipitated (*Jagtap et al., 2003*) because of their corresponding insoluble complex salts.

3.13.3.10 Acidity

Normally in the water if pH is less than 8.5 it is said to be acidic. In the year 2000 acidity was not measured in the samples collected from the RBC. The influent and effluent of B3 RBC shows 76 mg/l and 92 mg/l. Whereas, B1 RBC shows 52 and 36 mg/l acidity presence. Wastewater collection pond shows higher acidity concentration of 92 mg/l. Acidity may be due to the production of the CO₂ and due to biological oxidation of the organic matter. It may not be of great concern because effluent pipes are not made of iron otherwise they would have corroded.

3.13.3.11 Chloride

During the year 2000, samples were not analyzed to assess the concentration of chloride in the wastewater. In the year 2004, chloride measured in B3 RBC, in influent was 87 mg/k, effluent, 95.3 mg/l and in the biodisk-chamber as 97 mg/l. In the B1 RBC chloride recorded was 20.0 mg/l, 28.4 mg/l and 25.0 mg/l in influent, effluent and in biodisk-chamber respectively. B1 RBC carried more chloride due to incursion of urine-waste.

3.13.3.12 Ammonia

Urea is the principal form in which the human body excretes excess nitrogen which is rapidly hydrolyzed to ammonia. The observation of the year 2000 on ammonia in wastewater shows that in the influent of B3 RBC it is 122.5 mg/l and in the effluent of B3 RBC it is recorded as 47.5 mg/l. Mostly the wastewater receive from the laundry, urinal

and bathroom so ammonia concentration on higher side. While in influent and effluent of B1 RBC it is measured as 4.8mg/l to 4.3mg/l respectively. In both the RBC the ammonia concentration reduced. In the year 2004 results shows ammonia concentration as 9.8 mg/l in the influent of RBC and 21.8 mg/l in the effluent of B3 RBC. Influent and effluent concentration of B1 RBC shows 2.85 mg/l and 3.54 mg/l respectively. In the wastewater pond the concentration of ammonia measured was 15.25 mg/l.

3.13.3.13 *Nitrate*

Nitrate is the end product of conversion of ammonia by nitrification. The nitrate concentration measured in the year 2000 for wastewater is 3.18mg/l in influent, 2.45mg/l in the effluent of B3 RBC, whereas, in the influent and effluent of B1 RBC, nitrate found below detection limit. In the year 2004 nitrate shows decrease level of concentration in the influent, effluent and biodisk-chamber of B3 RBC i.e. 0.12 mg/l, 0.13 mg/l and 0.15 mg/l, respectively. B1 RBC carried the concentration 0.1 mg/l in influent, 0.13 mg/l in effluent and 0.14 mg/l in the biodisk-chamber. Wastewater pond shows the nitrate concentration as 0.17 mg/l.

3.13.3.14 *Phosphate*

In wastewater the phosphate concentration in the year 2000 recorded as 0.3 mg/l in influent and 1.5 mg/l in the effluent of B3 RBC, which is higher than influent value. Phosphate concentration in the B1 RBC recorded as 1.8 mg/l in influent sample and 2.8 mg/l in effluent sample. Sample of wastewater collection pond shows 17.2 mg/l of phosphate. Nutrients like nitrogen, phosphorus are essential for bacterial growth in the ratio BOD5: N: P, 100: 5: 1(Duncan, 1976). But the source of phosphorus in both the RBC is found to be less in comparison to BOD, which might be affecting bacterial growth in the biodisk chamber of RBCs.

3.13.3.15 *Oil and Grease*

In the year 2000 the concentration of oil and grease in the influent of B3 RBC was found to be 5.8 mg/l in influent and 4.2 mg/l in the effluent. In B1 RBC (kitchen wastewater) it measured as 20.6 mg/l in the influent sample and 2.8 mg/l in the effluent of RBC.

Afterwards in the year 2004 in B3 RBC it is recorded as 2.6mg/l in influent, 4.0 mg/l in the effluent and 1.8 mg/l in the biodisk-chamber. However in the B1 RBC the result shows concentrations of 3.9 mg/l, 2.1 mg/l and 1.3 mg/l in influent, effluent and biodisk-chamber respectively. In effluent collection pond it shows presence of oil and grease as 5.2 mg/l. This may be explained as after vehicle repairing person use to wash hands in the wash basin and cleans the dirty cloth in the laundry, which is the prime source of oil and grease in B1 RBC. In B3 RBC source is cleaning of utensils which contains edible oil stick on the surface.

3.13.3.16 Hydrocarbon

In the year 2000, the hydrocarbon concentration in the samples collected from wastewater of influent is 0.35 mg/l and in effluent 0.27 mg/l in B3 RBC. In B1 RBC it was recorded as 0.53 mg/l in influent and 0.47 mg/l in the effluent. During 2004 hydrocarbon recorded as 0.2179 $\mu\text{g/l}$ in influent, 0.2819 $\mu\text{g/l}$ in effluent and 0.2106 $\mu\text{g/l}$ in the biodisk-chamber in B3 RBC. It was measured, 0.4449 $\mu\text{g/l}$, in influent, 0.3075 $\mu\text{g/l}$ in effluent and 0.1692 $\mu\text{g/l}$ in the biodisk-chamber of B1 RBC. Wastewater collection pond shows presence of 0.2819 $\mu\text{g/l}$ of hydrocarbon. The removal of surfactant solublized PAH by phanerochaete chrysosporium in RBC (*Zheng and Obbard, 2002*) is found to be a first order reaction. However, this study clearly demonstrates the effectiveness of RBC reactor treatment of PAH contaminated solution medium in the presence of the immobilized white rot fungus.

3.13.3.17 Phenol

Phenol was not measured during the year 2000 in the wastewater sample. During the year 2004 presence of phenol was recorded as 0.16 mg/l in influent, 0.15 mg/l in the effluent and 0.32 mg/l in the biodisk-chamber of B3 RBC. However in B1 RBC concentration of phenol measured in influent 0.13 mg/l, in effluent 0.25 mg/l and in biodisk-chamber 0.46 mg/l. In the wastewater collection pond presence of phenol was not recorded.

3.13.3.18 Cadmium

Cadmium in the samples of wastewater collected in the year 2000 found below detectable limit. During the year 2004 only it is detected only in the effluent of B3 RBC, as 0.12 mg/l. Cadmium has no known metabolic function (*Ting et al., 1991*) and is known to be toxic at very low concentrations (*Tervors, et al., 1986*).

3.13.3.19 Copper

The copper concentration in the year 2000 for wastewater was observed as 0.231 mg/l in influent of B3 RBC and 0.126 mg/l in the effluent. In the influent of B1 RBC it was recorded 3.17 mg/l and in the effluent it was recorded as 0.012 mg/l. In the year 2004 it was recorded as 0.12 mg/l in influent, 0.24 mg/l in effluent and 0.13 mg/l in the biodisk-chamber of B3 RBC. Whereas, copper measured in B1 RBC was 0.02 mg/l in influent 0.05 mg/l in effluent and 0.26 mg/l in the biodisk-chamber of RBC. In the wastewater collection pond it is recorded 0.03 mg/l. It indicated that Biofilm of the RBC has high metal sorption capacity and can be used as a tool to remove and recover metals from wastewater (*Costley and Wallis, 2001*).

3.13.3.20 Chromium

In the year 2000 chromium presence was not detected in any of the wastewater samples. In the sample collected in the year 2004 it was not detected in the influent and effluent of the B3 RBC but in the biodisk-chamber of B3 RBC it was measured 0.01 mg/l. Similarly in the influent and effluent of the B1 RBC it was not measured but in the biodisk-chamber of B1 RBC it was recorded as 0.01 mg/l. In wastewater collection pond presence of chromium was not detected.

3.13.3.21 Lead

Lead was not detected in influent and effluent of either RBC's in sample collected during the year 2000. In the year 2004 lead was detected in the influent, effluent and biodisk-chamber of B3 RBC with concentrations 0.05 mg/l. In the B1 RBC it was not detected in the influent but in the effluent it was measured as 0.06 mg/l and in biodisk-chamber it

was measured as 0.06 mg/l. In the pond it was measured as 0.06 mg/l.

3.13.3.22 Iron

In the year 2000 the iron concentration in wastewater was observed as 3.79 mg/l in the influent of B3 RBC, while in the effluent it was observed as 4.71mg/l. In influent of B1 RBC it was detected as 4.63 mg/l and in the effluent it was observed 2.97mg/l. Sample collected in the year 2004 shows that iron concentration in the B3 RBC is 0.17 mg/l, 0.13 mg/l and 0.38 mg/l in the influent, effluent and in the biodisk-chamber respectively. Whereas, in the B1 RBC it was measured as 0.84 mg/l in influent, 1.7 mg/l in the effluent and 0.39 mg/l in the biodisk-chamber. In the waste water collection pond it was measured as 0.39 mg/l.

3.13.3.23 Zinc

The measurement of the year 2000 shows that the concentration of zinc in the influent of B3 RBC was 0.49 mg/l, in the effluent it was 0.241 mg/l and in the B1 RBC it was recorded as .30.6 mg/l in the influent and 0.691 mg/l in the effluent. Sample collected in the year 2004 shows that in B3 RBC zinc concentration measured was 0.1 mg/l in the influent, 0.09 mg/l in the effluent and 0.2 mg/l in the biodisk-chamber, whereas it was recorded as 0.01 mg/l in influent, 0.02 mg/l in the effluent and 0.05 mg/l in the biodisk-chamber of the B1 RBC. In the wastewater collection pond concentration was measured as 0.1 mg/l.

3.13.3.24 Manganese

The manganese concentration in the year 2000 is 0.025mg/l in the influent of B3 RBC, while in the effluent of B3 RBC it was 0.006mg/l. In the B1 RBC manganese concentration recorded as 0.113 mg/l in the influent, 0.074 mg/l in the effluent. Sample of 2004 shows concentration of manganese in the influent, effluent and in the biodisk-chamber as 0.01 mg/l in B3 RBC. B1 RBC sample shows concentration of manganese in the influent 0.01 mg/l, in the effluent as 0.02 mg/l and in the biodisk-chamber it was 0.05 mg/l. In the pond it measured as 0.1 mg/l.

3.13.3.25 Nickel

Nickel was not detected in the samples collected in the year 2000. Wastewater sample of the year 2004 shows presence of the nickel in the influent, effluent and in biodisk-chamber of B3 RBC as 0.14 mg/l, 0.04 mg/l and 0.2 mg/l respectively. In B1 RB C it was not detected in the influent and effluent but in the biodisk-chamber it was measured as 0.16 mg/l. Effluent collection pond shows the presence of nickel with concentration of 0.03 mg/l.

3.13.3.26 Cobalt

Cobalt was also not measured in the samples collected in the year 2000. Wastewater sample of the year 2004 shows presence of the cobalt in the influent, effluent and in biodisk-chamber of B3 RBC as 0.01 mg/l, 0.0 mg/l and 0.01 mg/l respectively. In B1 RBC it was not detected in the influent and effluent shows concentration of 0.02 mg/l. In the biodisk-chamber of B1 RBC it was measured as 0.04 mg/l. Effluent collection pond shows the presence of cobalt as 0.01 mg/l.

3.13.4 Tertiary Treatment of Wastewater at Site

Wastewater was collected on 23rd January 2000, when maximum people were present in the Maitri station. Physico-chemical and trace metal analysis of the influent and effluent of B3 and B1 RBC are presented in the Table 3.13 and 3.14. Effluents collected from both the RBC's were further used to understand the potential of tertiary treatment. Data of the Analysis of tertiary treatment is presented in Table 3.17 to 3.20.

3.13.4.1 pH

The effluent of B3 RBC with pH 6.9 was further treated with alum which has increased pH to 7.0. Again passing it through activated carbon under gravity, it increased further to 7.8. It indicates that activated carbon imparting further alkalinity to the sample to increase the pH of the sample because of absorbance of CO₂. This is well within good range of the effluent to discharge or reuse. While kitchen effluent -B1 RBC, with 5.1 pH, acidic in nature amalgamated with alum dose, pH reduced to 5.0 as alum tends to decrease the pH, but, increased to 7.5 after passing through activated carbon. So it

indicated that activated carbon increases the pH due to adsorption of matter.

3.13.4.2 Dissolved Oxygen and Temperature

DO of the effluent of B3 RBC and B1 RBC, i.e. 4.3 mg/l at 6°C could not be measured after mixing with alum dose and further passing through activated carbon. The temperature of the alum dose amalgam and effluent from the activated carbon measured 11 °C, which was the room temperature, during time of experiment.

3.13.4.3 Suspended Solids

The effluent of B3 RBC with 26 mg/l of suspended solids increased the suspended solids in the solution to 78 mg/l after adding alum dose. It indicated that the either floc is not properly developed to conglomerate the colloidal and suspended particles or supernatant liquid is mixed with floc showing higher suspended particle concentration. Even though, alum dose contributing to increase the particle, activated carbon trapped around 38.5% of the suspended particles, thus overall removal achieved was 6.2%. B1 RBC effluent with 20 mg/l suspended solids (removal 79.4%) reduced to 13 mg/l (38.5% reduction) and after passing through activated carbon it further reduced to 8 mg/l, so overall reduction of 91.8% in the suspended solids, was achieved.

3.13.4.4 Nitrates

Nitrate concentration in the effluent of B3 RBC measured 2.45 mg/l (23% removal). After adding alum dose it reduced to 0.44 mg/l which was further it reduced to 0.14 mg/l by activated carbon (68.2% trapped). Overall removal of nitrate recorded was 95.5%. It was not detected in the effluent of B1 RBC and effluent of activated carbon.

3.13.4.5 Phosphate

Phosphate in the supernatant liquid from alum dose marginally increased from 1.5 mg/l to 1.6 mg/l in B3 RBC effluent. After passing through the activated carbon it was further increased marginally to 1.8 mg/l. In B1 RBC, phosphate recorded increased concentration of 2.8 mg/l from the influent i.e. 1.8 mg/l. After alum dosing it reduced to 1.2 mg/l and further through activated carbon it recorded 0.3 mg/l (75% removal).

Overall efficiency for phosphate achieved was 83.3%.

3.13.4.6 Ammonia

The effluent of B3 RBC measured ammonia 47.5 mg/l (61.2% removal) which was reduced by alum dosing to 42 mg/l and further it was reduced to 22 mg/l (47.6% removal) after passing through activated carbon. Total reduction occurred around 61.1% by RBC and tertiary treatment. Similarly, the effluent of B1RBC which measured ammonia in low amount i.e. 4.3 mg/l (10.4% reduction) reduces to 3.8 mg/l and 3.7 mg/l after alum dosing and in contact with activated carbon (2.6% removal) respectively. For ammonia overall efficacy implying tertiary treatment achieved was 22.9%.

3.13.4.7 Chemical Oxygen Demand

COD in the effluent of B3 RBC recorded was 306.0 mg/l (41.4% removal), 180.0 mg/l in the alum treated effluent and 126.0 mg/l in the activated carbon effluent. Implying tertiary treatment COD was reduced by 30%, whereas overall it reduced by 94.3%. Considering influent COD 522 mg/l. COD in the effluent of B1 RBC recorded 828.0 mg/l (68.9% removal), 576.0 mg/l in the alum treated effluent and 450.0 mg/l in the activated carbon effluent. Implying tertiary treatment COD reduction achieved by 21.9%, whereas overall it was reduced by 83.1%.

3.13.4.8 Biochemical Oxygen Demand

The strength of wastewater in terms of BOD of the effluent of B3 RBC measured 184.6 mg/l, whereas in the influent it was recorded 349.4 mg/l so reduction, was by 47.2%, which is not appreciable for functioning of RBC. While it is treated with alum dose BOD was reduced to 54.0 mg/l and further it reduced to 42.0 mg/l when tertiary treatment was conducted in 2000. It indicates that tertiary treatment helped in reducing the BOD by 22.2% and overall reduction achieved was 93.6%. Designed load of B3 RBC for the influent was 300 mg/l whereas in the influent it was recorded around 17% more than the desired value. The BOD of the effluent of B1 RBC measured 454.0 mg/l, whereas in the influent it was recorded 1636.4 mg/l i.e. 54.5% more than the designed value for influent i.e. 300 mg/l). Reduction occurred was 72.3%, which is not appreciable for

functioning of RBC. While it was treated with alum dose, BOD reduced to 414.0 mg/l and further it minimized to 247.0 mg/l when tertiary treatment is conducted. It indicates tertiary treatment helped in reducing the BOD by 40.3% and overall reduction achieved was 84.9%. It indicated that if the influent load of the BOD could regularize to meet design load, the tertiary treatment is effective to achieve the final effluent discharge to desired level of 20-30 mg/l of BOD. BOD may be contributing by dissolved organic carbon (*Imai et al., 2002*). Coagulation and subsequent absorption sequences has particularly no influence on the dissolved organic carbon (DOC) removal and it is independent on the sequence (*Haberkamp et al., 2007*).

3.13.4.9 Oil and Grease

Oil and grease in the influent of B3 RBC mixed due to hand washing after machine repairing, oil handling and cloth washing of logistics personnel, which gets the oil and grease stain from the vehicle repairing and washed in the laundry. In the effluent of B3 RBC it recorded 4.2 mg/l (27.6%), whereas after treatment trough alum and passing through activated carbon it was not detected in either of the effluents. Oil and grease in the influent of B1 RBC receive from washing of the utensils contains film of edible oil and butter. In the effluent of B1 RBC it recorded 2.8 mg/l (86.4% removal), whereas after treatment trough alum and passing through activated carbon it was not detected in either of the effluents. The reason may be oil and grease forming the layer on the surface of the RBC tank and, which do not get mix with water but trapped over the surface and not flowing outward. Formation of the film act as barrier for oxygen transfer that is how in the effluent of RBC the oxygen content subdued

3.13.4.10 Hydrocarbons

Hydrocarbons in the influent of B1 RBC was detected due to water used for hand washing, machine repairing, and cloth washing which gets the hydrocarbon deposit over skin and cloths while Aviation Turbine Fuel (ATF) and Petrol handling/ refilling was carried out by the logistics personnel. In the effluent of B1 RBC it is recorded $0.27\mu\text{g/l}$ (22.9% reduction), whereas after treatment trough alum and passing through activated carbon it was not detected in either of the effluents. Hydrocarbons in the influent of B1

RBC detected more than the B3 RBC. It may be due to water used for hand washing, machine repairing, handling lubricant and petrol by the logistics personnel in the wash basin of the kitchen rather than using other wash basin as habit to come straight for the meals from the control room and garage. In the effluent of B3 RBC it recorded $0.47\mu\text{g/l}$ (11.3% reduction), whereas after treatment trough alum and passing through activated carbon it was not detected in either of the effluent.

3.13.4.11 Copper

In the influent and effluent of B3 RBC before alum treatment it was recorded as 0.231 mg/l (45.5% removal) and 0.126 mg/l respectively. However after alum treatment and activated carbon absorption, copper was not detected in the effluent of RBC. The effluent of B1 RBC shows presence of copper as 0.012 mg/l (99.6% removal), whereas after alum treatment and effluent through activated carbon presence of copper was not recorded. Trace metals removal enhanced by adding alum with higher alkalinity in the water and wastewater (*Jagtap et al., 2003*).

3.13.4.12 Iron

Iron content in the effluent of B3 RBC recorded higher than the influent (3.79 mg/l) i.e 4.71 mg/l . Decanted effluent after alum treatment shows lower content of the iron i.e. 1.13 mg/l (11.5% removal), whereas when passed through the activated carbon it measured 1.0 mg/l . Overall removal was achieved was 73.6%. In the effluent of B3 RBC, iron concentration measured was 2.97 mg/l (35.9% removal), which was lower than the influent concentration i.e. 4.63 mg/l . Decanted effluent after alum treatment shows further lower content of the iron i.e. 2.16 mg/l , whereas when passed through activated carbon it measured 1.0 mg/l (20.8% removal). However, overall efficiency to remove iron reached to 63.1%.

3.13.4.13 Manganese

Manganese in the effluent of B3 RBC recorded 0.006 mg/l (76% removal), while it boosted by alum dose, presence of manganese was not recorded in the effluent of alum treatment and activated carbon absorption. In the B1 RBC effluent it measured 0.074 mg/l .

mg/l (34.5% removal) which further reduced to 0.025 mg/l after alum dosing and after passing through activated carbon it was not detected in the effluent.

3.13.4.14 Zinc

Zinc measured in the influent of B3 RBC was 0.49 mg/l and in the effluent it reduced to 0.241 mg/l (50.8% removal). Decanted effluent shows presence of zinc from the alum dosing jar concentration 0.079 mg/l, however it was not detected after coursing the alum treated effluent from activated carbon. In the B1 RBC the presence of zinc recorded was 30.6 mg/l, in the effluent it drastically reduced to 0.691 mg/l (99.6% reduction). After alum treatment it recorded 0.187 mg/l, which is completely absorbed by the activated carbon granules and not detected in the effluent of activated carbon treatment.

3.13.4.15 Cadmium, Chromium and Lead

Cadmium and Chromium was not detected in the influent and effluent of the B3 and B1 RBC.

3.14 Prediction of Water Quality at Priyadarshini Lake

In order to understand the impact of nutrient load discharge from the Maitri Station, a water quality prediction model (WASP7) is simulated. The simulation is carried out considering the seasonal variability of point load concentration, dissolved oxygen, biological oxygen demand, phosphorus and nitrogen level. The Model WASP7 will be comparing the effect of the variation of the pollutant load on the biochemical cycle and the ecological quality of the Priyadarshini Lake. The main objectives of the study are:

- ➔ To assess the water quality of Priyadarshini Lake considering accidental seepage of wastewater from pond into Lake during summer period, implying Water Quality and Analysis Software (WASP 7)
- ➔ To assess the probability of eutrophication in the Lake

3.14.1 Strength of the Model

- ↳ The WASP is a freeware program
- ↳ A user-friendly Windows-based interface
- ↳ A pre processor to assist modelers in the processing of data into a format that can be used in WASP
- ↳ High-speed WASP eutrophication and organic chemical model processors
- ↳ A graphical postprocessor for the viewing of WASP results and comparison to the observed field data
- ↳ This software is the most universal in comparison with other similar software
- ↳ WASP was approved by many foreign research institutes repeatedly
- ↳ The most important thing is that WASP is equipped with the detailed technical and methodical accompanying documentation

3.14.2 Limitation

The WASP model does not handle mixing zones or near field effects. The model also does not handle sinkable/floatable materials. WASP also requires extensive site-specific linkage efforts to couple with multi-dimensional hydrodynamic models. The model requires extensive amount of data for calibration and verification

3.14.3 Epilimnion and Hypolimnion Condition in Lake

A vertical Thermal structure develops with a well-mixed upper layer, the epilimnion, above a region of rapid temperature decrease, thermocline; which is above a layer of cooler, dense water, the Hypolimnion. In Late spring, the Epilimnion is thin and not much warmer than the rest of lake. As summer progresses, the Epilimnion thickens and increases in temperature from the combination of surface heating and wind mixing. During the fall, surface cooling and wind mixing results in a decrease of the epilimnion temperature and continue increase in thickness. When the temperature of Epilimnion reaches 4°C , the point of maximum water density, the fall overturn occurs, mixing the layer over its full depth. In colder climates, a weak reverse stratification can develop

during the winter, with surface temperature below 4°C and again lighter than deeper waters.

3.14.4 Probable Seepage from Wastewater Pond

The treated wastewater generated from Maitri is collected in waste stabilization pond. There is minor seepage from the wastewater pond towards the lake because it is located at higher elevation than the lake and the bottom soil is permafrost so from the bank of the pond seepage starts and joins the lake. The quantity is very less according to the visual observations. During the summer period around 2.6 m^3 of wastewater is collected in the pond every day. Assuming that the maximum of 5% seepage occurs every day for two months, till freezing starts total quantity of wastewater which would join the lake water is 7.8 m^3 . This will get diluted, sedimentation starts as well as the suspended and colloidal particles further travel towards middle of the lake and then towards outlet of the lake. If it is assumed that due to bottom slope of lake towards middle and high wind velocity, which is in the range of 20 km/h–150 km/h a complete mixing occurs and a dilution ratio found to be in the range of 7820 times which is considerably high.

3.15 Scenario of Problems to Estimate Pollution Load in Lake

3.15.1 Introduction

The treated wastewater generated from Maitri is collected in waste stabilization pond. There is minor seepage sometimes observed from the wastewater pond towards lake because it is located at higher elevation than the lake and the bottom soil is permafrost so from the bank of pond seepage starts and joins the lake. Because of this pollutant discharge in the lake, the water quality of lake may change, even though it is very small quantity and for very short period during summer.

3.15.2 Modelling Preparation

The Model Simulation is implemented for the period of 2 months from 1st December to 31st January. The water quality parameters were considered from the analysis table of water quality for the year 2000-2001. It is assumed for the worst case scenario that around 260 litre of treated wastewater may join Priyadarshini Lake every day. We use WASP model for the following scenario according to the conditions.

3.15.3 Input to the Model

3.15.3.1 Segment Description:

Priyadarshini Lake is divided into five segments on the bases of their volume, depth and area for the model (Table 3.21 and 3.22). The segment has been assumed to behave as surface segment. The epilimnion and hypolimnion scenario is not considered.

Table - 3. 21: Priyadarshini Lake Segments Description

Segments	Volume (m ³)	Length (m)	Width (m)	Slope (m/m)	Bottom Roughness (manning coefficient)
1	83660	200	235	0.01	0.0250
2	31590	270	130	.01	0.0250
3	397320	430	330	.01	0.0250
4	28957.5	130	165	.01	0.0250
5	47840	230	130	.01	0.0250

Table - 3. 22: Initial Concentration of the Segments

Segments	Ammonia	Nitrate	DO	CBOD
1	140	10	10	8
2	3	5	12	5
3	5	3	14	4
4	4	3	14	4
5	4	4	12	8

All values are in mg/l

3.15.4 Air Temperature

Due to high wind velocity and dry atmosphere, temperature shows variation all the days (Table 3.23). Temperature of two months (December 1999 to January 2000) is collected from India Meteorological Department (IMD) at Maitri station, which were entered as input to model;

Table - 3. 23: Air Temperature

Dates	Air Temperature
1 December	-0.3
2 December	0.5
3 December	1
4 December	1.3
5 December	0.6
6 December	-1.1
7 December	-1.5
8 December	-0.3
9 December	-1.5
10 December	-0.5
11 December	-2.1
12 December	-5.2
13 December	-5.8
14 December	2.2
15 December	2.1
16 December	1.9
17 December	1.1
18 December	0.7
19 December	0.4
20 December	-2.7
21 December	1.8
22 December	-0.9
23 December	-2.2
24 January	-1.7
25 December	-1.5
26 December	-2.2
27 December	-0.4
28 December	-1.7
29 December	0
30 December	3
31 December	3.2
1 January	3.2
2 January	2.6

Dates	Air Temperature
3 January	2.5
4 January	2.7
5 January	-0.1
6 January	-0.7
7 January	-1.2
8 January	0.4
9 January	0.5
10 January	-0.2
11 January	-0.15
12 January	-2.7
13 January	-3.7
14 January	-2.6
15 January	-0.6
16 January	1
17 January	0.6
18 January	-1.7
19 January	0.9
20 January	1
21 January	0.7
22 January	0.1
23 January	0.8
24 January	0.7
25 January	-1.3
26 January	-3.1
27 January	-1.4
28 January	-1.9
29 January	-2.5
30 January	-1.9
31 January	-0.4

3.15.5 Point Load

As mentioned earlier the treated waste water generated from Maitri was collected in waste stabilization pond. There is minor seepage from the waste water pond toward the lake is observed for some days. The quality of treated wastewater of point load is mentioned in the Table 3.24 below:

Table - 3. 24 : Point Load Discharge

S.No	Parameters	WW5
1	Ammonia as N	1525
2	Total Phosphate	17.20
3	COD	452
4	BOD	260
5	Oil and grease	5.2
6	Hydrocarbons	0.28
7	NO ₂ -N	0.01
8	NH ₃ -Nitrogen	58
9	Phenol	0.05
10	Nickel	0.03
11	Cadmium	ND
12	Chromium	ND
13	Copper	0.03
14	Lead	0.06
15	Iron	0.39
16	Manganese	0.10
17	Zinc	0.04
18	Cobalt	0.01

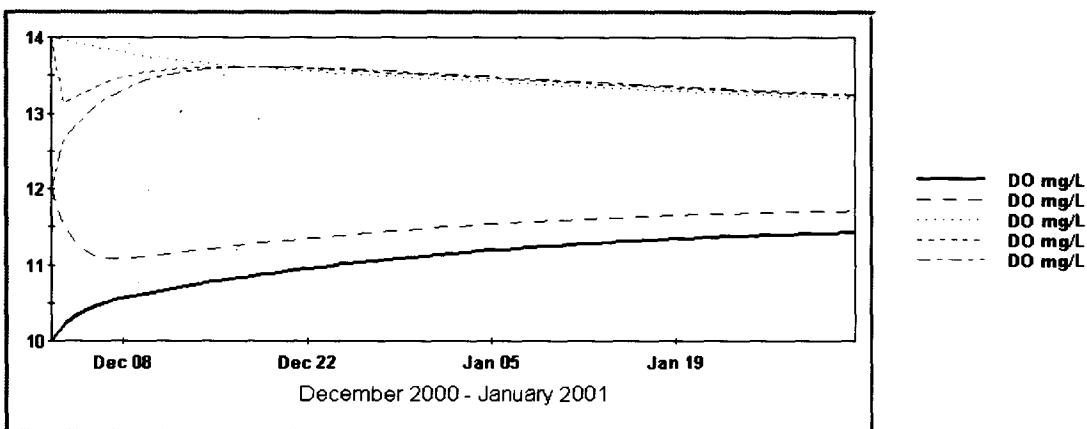
3.16 Results of Simulation from the Prediction Modeling

Model is simulated considering the point load discharge from the wastewater pond at the rate of 260 litres per day for continuous 60 days, which is hypothetical case for worst case scenario. Initial conditions of water qualities of the pond and Priyadarshini Lake are taken into account to predict the water quality after the point load mixing and to observe the scenario of eutrofication. Lake was divided into five segments for better representation of the lake's feature. The results of simulations are presented in showing by graphs. The variations of water quality parameters are described with the help of graphs. Various colors represent the concentration of particular parameter in segment 1 to 5, symbolically shown top to bottom in each graph.

3.16.1 Variation of Dissolve Oxygen

For Segment 1 in the beginning of December DO value started increasing from 10mg/l and reaches 11 mg/l at the end of January. For Segment 2 in the starting of December it was 12mg/l than it started decreasing till December 8 and then started slowly increasing till the end of January to value11.5 mg/l. For Segment 3, DO value at the starting of December was 14 and afterwards it started slowly decreasing to 13.5 at the end of January. For Segment 4, DO value at the starting of the month of December was 14 mg/l suddenly decreased to 13mg/l and then started decreasing slowly till the end of January. For Segment 5,DO value at the starting of December was 12mg/l then started increasing and reaches up to 13.5 at the mid of December. Then it again started decreasing slowly till the end of January (Figure 3.12).

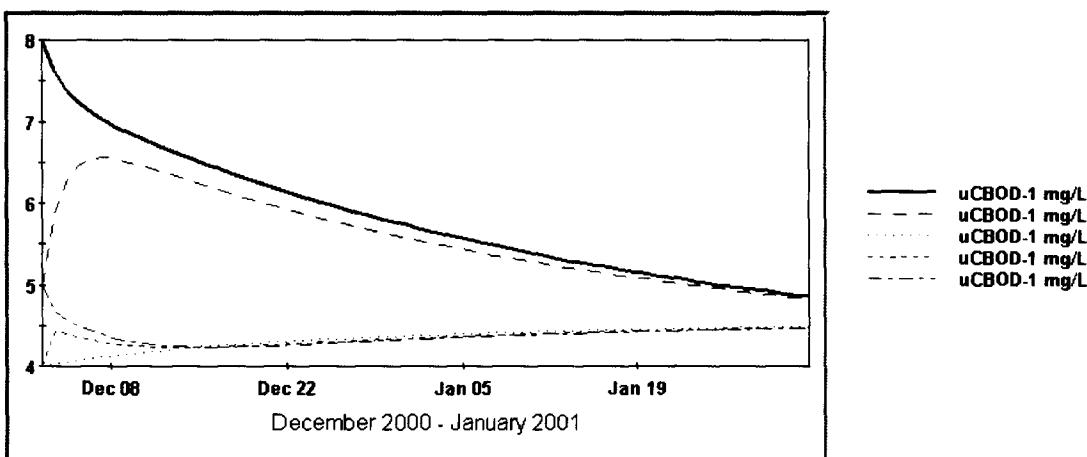
Figure - 3. 12: Variation of Dissolve Oxygen



3.16.2 Variation of Ultimate Biological Oxygen Demand

For Segment 1, uBOD value was 8 mg/l in the beginning of the December and started decreasing very fast till the end of January and reaches to 5mg/l. For Segment 2, uBOD value was 5 mg/l at starting of the December. It went up to 6.5 mg/l in the mid of the December and it suddenly started decreasing till end of January up to 5mg/l. For Segment 3, the uBOD value increases slowly from the starting of December till January end. For Segment 4, the uBOD value slowly increases for first few days and then starts decreasing for small value in the mid of December and it again start increased till the end of January. For Segment 5, the starting value of uBOD was 5 mg/l for the first day of December and then started decreasing till the end of January (Figure 3.13)

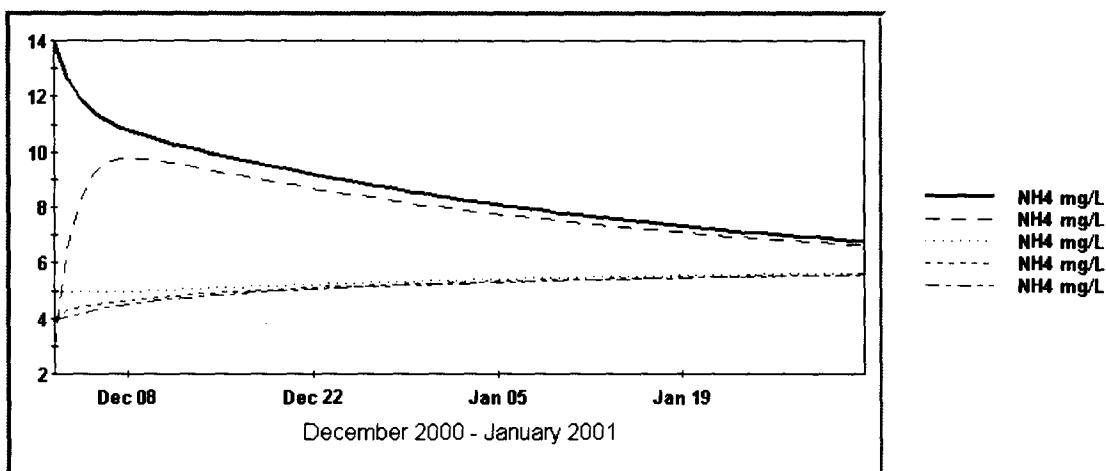
Figure - 3. 13: Variation of Ultimate Biological Oxygen Demand



3.16.3 Variation of Ammonia

For Segment 1, Ammonia (NH_4) value in the beginning of December is 14 mg/l and it starts decreasing very sharply till the end of January. For Segment 2, the NH_4 value is 2mg/l on the starting day of December and it increases 10mg/l in the mid of December and then starts decreasing till the end of January. For segment 3, the NH_4 value remains constant from starting of December till the end of January. For Segment 4, the value of NH_4 increases very slowly from 4mg/l in the beginning of December to 5mg/l at the end of January. For Segment 5 the value of NH_4 is 4 in the beginning of December and increases very slowly till the end of January up to 5 mg/l (Figure 3.14).

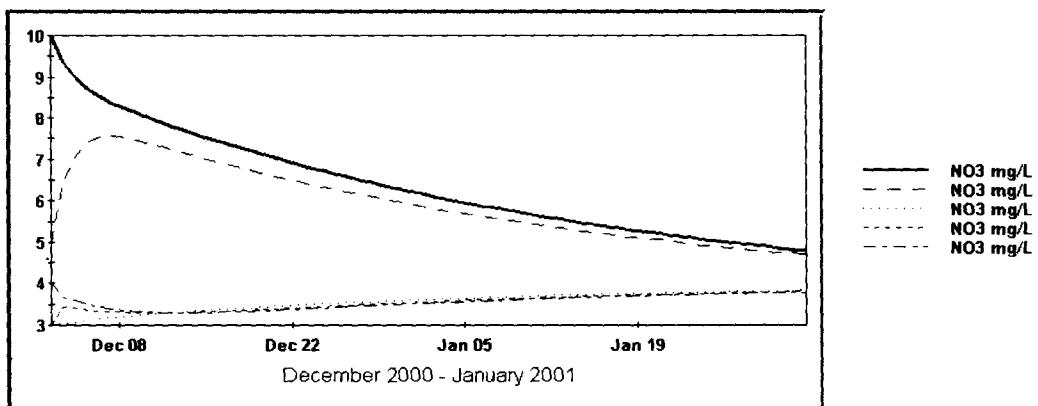
Figure - 3. 14: Variation of Ammonia



3.16.4 Variation of Nitrate

For Segment 1, the value of Nitrate (NO_3) is maximum in the beginning of December and started decreasing sharply till the end of January. For Segment 2, the value of Nitrate increases suddenly in the beginning and then decreasing till the end of January. For Segment 3, the value of Nitrate is very low in the beginning and started increasing till the end of January. For Segment 4 and 5, the value of Nitrate is decreasing till the mid of December and then increases very slowly till the end of January (Figure 3.15)

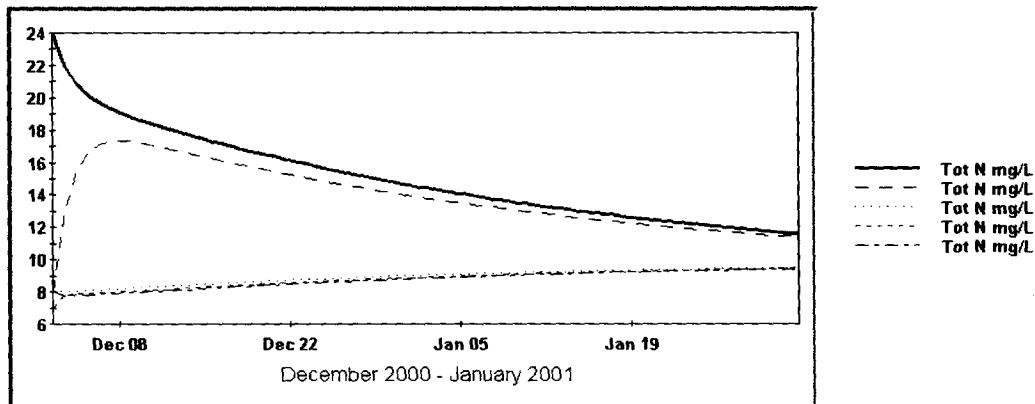
Figure - 3. 15: Variation of Nitrate



3.16.5 Variation of Total Nitrogen

For Segment 1, the value of Total Nitrogen is maximum in the beginning of the December and then started decreasing sharply till the end of January. For Segment 2, the value of Total Nitrogen is 8 mg/l in the beginning of December and it suddenly shoots up to 17mg/l for the starting few days and then it start decreasing till the end of January. For Segment 3, 4 and 5 the value of Total Nitrogen is increasing very slowly from December till the end of January (Figure 3.16) .

Figure - 3. 16: Variation of Nitrogen

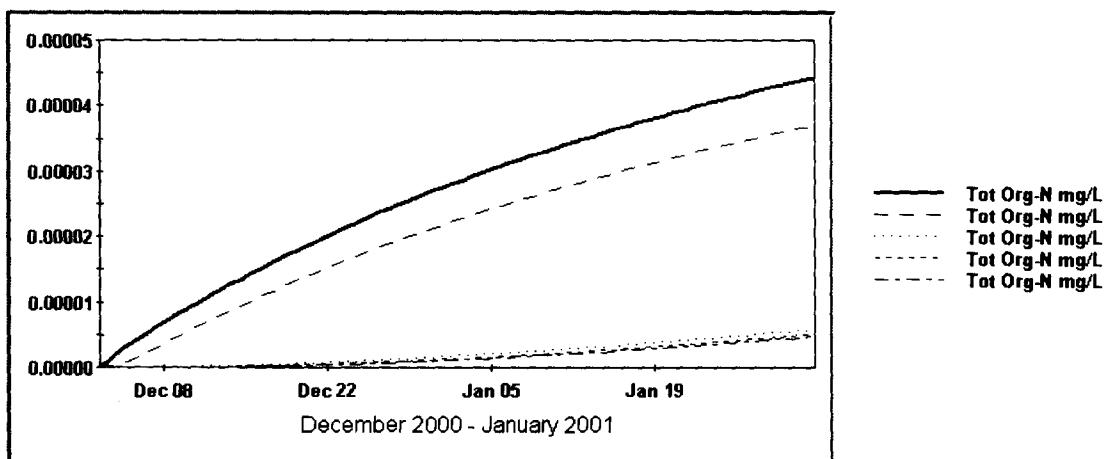


3.16.6 Variation of Total Organic Nitrogen

For segment 1, the value of total organic Nitrogen in the beginning of December started increasing from 0 to 0.00005 mg/l till the end of January. For segment 2 the value of

total organic Nitrogen increases from 0 to 0.000035 mg/l at the starting of December to till the end of January. For segment 3,4 and 5 the value of total organic nitrogen is zero till the end of December and started increasing very slowly from starting to till end of January (Figure 3.17).

Figure - 3. 17: Variation of Total Organic Nitrogen



3.17 Discussion

3.17.1 Lake Water Sample

Priyadarshini Lake which is a drinking water source for Maitri station spread over around 800x600 m. The maximum depth of the lake is estimated as 7.2 m. This lake receives water input from the connecting glacial lakes as well as receives wastewater seepage form the wastewater effluent collection pond. The surface water sample locations in the lake varied over the span of the time from 1994 to the 2004, owing to severe weather condition and logistics constrains. However at few locations like near pump house, northern side bank and near confluence point the glacial lake water (situated at south-east side) nearly match. The pH of the lake indicates that the water is slightly acidic to nearly neutral in nature, except in the year 2004. The value recorded is lower because of low temperature which tends to absorb more carbon-dioxide. Conductivity of the water indicates presence of minerals in low concentration in water. During 1994, 1995 and 2000 samples were collected during feeding of the glacial melt water and the value of

conductivity was in the range of 10-22 $\mu\text{s}/\text{cm}$ whereas in the year 2004 lower value was recorded because by that time intermixing of glacier melt water was stopped, except near confluence point of glacial melt water. The correlation (Bhandari and Nayal, 2008) between various physico-chemical parameter and heavy metals is presented in Table 3.25.

Table - 3. 25: Correlation between Various Parameters in Various Span of Sample Collated from Priyadarshini Lake and Glacial Lake

A. THE YEAR 1994

a. Priyadarshini Lake (Physico-Chemical Parameters)

	Turbidity	Conductivity	TOC	TDS	SS	Cl	SO ₄	NO ₃	DO
Turbidity	1								
Conductivity	-0.01	1							
TOC	0.60	-0.54	1						
TDS	0.89	-0.05	0.28	1					
SS	0.03	0.98	-0.61	0.07	1				
Cl	0.03	0.80	-0.05	-0.28	0.67	1			
SO ₄	-0.41	0.69	-0.97	-0.11	0.77	0.17	1		
NO ₃	-0.23	0.01	-0.72	0.25	0.18	-0.59	0.68	1	
DO	-0.10	0.95	-0.75	0.02	0.98	0.56	0.88	0.33	1

b. Trace Metal

	Cd	Cu	Cr	Pb	Fe	Mn	Zn
Cd	1						
Cu	0.31	1					
Cr	0.18	-1.00	1				
Pb	0.62	1.00	-0.66	1			
Fe	0.64	0.84	-0.92	0.91	1		
Mn	0.45	1.00	-0.80	0.98	0.97	1	
Zn	0.92	0.34	0.33	0.49	0.78	0.31	1

B. THE YEAR 1995

a. Priyadarshini Lake (Physico-Chemical Parameters)

	Turbidity	Conductivity	Cl	SO ₄	PO ₄	NO ₃	DO	BOD	COD	Total Hardness	Alkalinity
Turbidity	1.00										
Conductivity	0.14	1.00									
Cl\I	0.01	-0.71	1.00								
SO ₄	-0.46	-0.41	0.59	1.00							
PO ₄	0.50	-0.39	0.34	-0.30	1.00						
NO ₃	-0.29	-0.20	-0.36	-0.11	0.03	1.00					
DO	-0.31	0.21	0.32	0.19	-0.10	-0.66	1.00				
BOD	-0.30	0.24	0.18	0.51	-0.65	-0.16	0.41	1.00			
COD	0.55	0.72	-0.44	-0.28	-0.20	-0.68	0.08	0.08	1.00		
Total Hardness	0.18	0.65	-0.22	-0.37	0.25	-0.10	0.48	0.12	0.29	1.00	
Alkalinity	-0.16	0.12	0.29	0.40	0.16	0.04	0.30	0.13	-0.17	0.48	1.00

b. Glacial Lake situated West of Maitri Station (Physico-Chemical Parameters)

	Turbidity	Conductivity	Cl	SO ₄	PO ₄	DO	COD	Total Hardness	Alkalinity
Turbidity	1.00								
Conductivity	-0.26	1.00							
Cl	-0.07	-0.94	1.00						
SO ₄	-1.00	0.33	0.00	1.00					
PO ₄	-0.07	-0.94	1.00	0.00	1.00				
DO	0.12	-0.99	0.98	-0.19	0.98	1.00			
COD	-0.09	0.99	-0.99	0.16	-0.99	-1.00	1.00		
Total Hardness	0.56	0.65	-0.87	-0.50	-0.87	-0.76	0.78	1.00	
Alkalinity	1.00	-0.33	0.00	-1.00	0.00	0.19	-0.16	0.50	1.00

c. Glacial Lake situated South-East of Maitri Station- (Physico-Chemical Parameters)

	Turbidity	Conductivity	Cl	PO ₄	DO	COD	Total Hardness	Alkalinity
Turbidity	1.00							
Conductivity	-1.00	1.00						
Cl	0.72	-0.76	1.00					
PO ₄	-0.62	0.57	0.10	1.00				
DO	1.00	-0.06	0.70	0.78	1.00			
COD	0.46	-0.41	-0.29	-0.98	-0.88	1.00		
Total Hardness	-0.28	0.33	-0.87	-0.59	-0.96	0.73	1.00	
Alkalinity	0.72	-0.76	1.00	0.10	0.70	-0.29	-0.87	1.00

C. THE YEAR 2000

a. Priyadarshini Lake (Physico chemical Parameters)

	Turbidity	Conductivity	Cl	SO ₄	PO ₄	NO ₃	DO	BOD	COD	Na	K	Total Hardness	Alkalinity
Turbidity	1.00												
Conductivity	-0.26	1.00											
Cl	-0.30	-0.04	1.00										
SO ₄	0.10	0.67	0.19	1.00									
PO ₄	-0.36	0.00	0.47	-0.26	1.00								
NO ₃	-0.23	0.04	-0.27	-0.26	0.23	1.00							
DO	-0.21	-0.05	0.43	0.02	-0.04	-0.81	1.00						
BOD	0.34	-0.19	-0.33	-0.39	-0.16	0.35	-0.54	1.00					
COD	0.00	0.09	-0.37	0.02	0.26	0.43	-0.68	0.41	1.00				
Na	0.06	-0.16	0.43	-0.04	0.35	-0.06	0.12	-0.06	0.14	1.00			
K	-0.45	0.38	-0.25	-0.10	0.30	0.56	-0.16	-0.35	-0.03	-0.03	1.00		
Total Hardness	-0.43	0.34	-0.19	0.39	-0.18	0.38	-0.15	-0.53	0.06	-0.13	0.63	1.00	
Alkalinity	-0.49	-0.07	0.24	0.18	0.07	0.43	-0.26	-0.22	0.11	-0.28	0.09	0.59	1.00

b. Trace Metal

	Fe	Mn	Zn
Fe	1		
Mn	0.08	1	
Zn	0.62	0.15	1

D. THE YEAR 2004

a. Priyadarshini Lake (Physico chemical Parameters)

	Turbidity	Conductivity	Cl	TDS	SO ₄	PO ₄	DO	BOD	Na	K	Total Hardness	Alkalinity	Acidity
Turbidity	1												
Conductivity	0.43	1											
Cl	-0.20	0.03	1										
TDS	-0.18	0.02	1.00	1									
SO ₄	-0.52	-0.05	0.77	0.72	1								
PO ₄	-0.40	-0.39	0.44	-0.39	-0.54	1							
DO	-0.42	-0.98	-0.24	-0.23	-0.08	0.39	1						
BOD	-0.07	0.07	0.55	0.44	0.83	0.46	-0.16	1					
Na	-0.29	0.43	0.07	0.10	-0.11	0.46	-0.42	-0.48	1				
K	0.61	0.30	0.38	0.40	-0.11	-0.29	-0.42	-0.01	-0.20	1			
Total Hardness	0.18	-0.59	0.24	0.30	-0.23	0.29	0.47	0.38	-0.25	0.49	1		
Alkalinity	-0.58	0.18	0.16	0.12	0.43	0.07	-0.18	0.16	0.16	-0.01	-0.42	1	
Acidity	0.01	-0.41	-0.13	-0.16	0.11	-0.21	0.42	0.32	-0.86	0.21	0.15	0.30	1

From the Table 3.25 it can be stated that there is a very good correlation between turbidity-TDS ($r=0.89$) and moderate with turbidity-TOC ($r=0.6$) during the year 1994 whereas during 1995 and 2000 turbidity did not show correlation with any of the parameters, but during 2004 it showed good correlation with potassium ($r=-0.61$). Turbidity is mainly caused by suspended particles and colloidal particles both inorganic and organic in nature which is supported by positive correlation with TDS and TOC. Further, it is supported by positive correlation between TDS and SO_4 ($r=0.72$) during 2004. On the contrary in the glacial lakes (1995) turbidity showing negative relationship with SO_4 ($r=-1.0$) and positive correlation with alkalinity ($r=1.0$) which is seen in one glacial lake, situated west of Maitri. During the winter, when top layer of the lake freezes the bottom of the lake transforms into anaerobic condition in which SO_4 ions are reduced to H_2S after reacting with organic matter. Presence of more organic matter is responsible for turbidity.

Other glacial lake situated at south-east of Maitri showed positive correlation with alkalinity ($r=1.0$), DO ($r=1.0$), chloride ($r=0.72$) and negative with conductivity ($r=-1.0$) and phosphate ($r=-0.62$). The lake water is more alkaline possibly because of dissolved salts of weak acids and strong bases. Presence of algae was also observed in the lake water which must be contributing to alkalinity as it uses carbon dioxide for photosynthesis purpose. Positive correlation with chloride indicates the dissolution of salts from rocks in the glacial water, and positive correlation with DO indicates that total solids present are mainly suspended solids and dissolved solids.. A negative correlation with phosphate indicates presence of plankton which utilizes phosphorus for their growth.

Conductivity showed good correlation with SS ($r=0.98$) in 1994, however 1995 results does not show significant correlation. The pH of the water sample favors charged hydrogen or hydroxyl ion concentration. Uncharged soluble organic matter must have been carried in the form of suspended solids, which is supported by good correlation with suspended solids. In the year 1994, conductivity showed significant correlation with DO ($r=0.95$), because conductivity is mainly contributed by dissolved solids which affect the oxygen absorbance. During 1995 in the west side of glacial lake it showed negative

correlation with DO ($r=-0.99$) and in 2004 it showed significant negative correlation with DO (-0.98) in Priyadarshini Lake. This may be due to conductivity which is mainly contributed by dissolved solids and that affects the oxygen absorbance.. During 1994, conductivity showed good correlation with Cl ($r=0.80$) and SO₄ ($r=0.69$) in Priyadarshini lake whereas during 1995 it showed good correlation with COD ($r= 0.72$) and total hardness ($r=0.65$) but with chloride it showed negative correlation ($r=-0.71$). In the year 1995 in glacial lakes, conductivity was negatively correlated with chloride ($r=-0.94$), and phosphate ($r=-0.94$), and positively correlated with COD ($r=0.99$) and moderately with total hardness ($r=0.65$). In the west-side lake and south-east side lake conductivity is negatively correlated with chloride ($r=-0.76$) and alkalinity ($r=-0.76$). In the year 2000, conductivity showed a moderate correlation with SO₄ ($r=0.67$). COD is the method to determine the presence of total inorganic and organic particles which included suspended solids and therefore shows good correlation with conductivity. Among the anions SO₄ and Cl seems to be major constituents of water and show good correlation with conductivity during the year 1994 but, in 1995 it showed negative correlation because of mixing of salts from the rocks.

In the year 2004 there was no correlation found between conductivity and other elements. It is well known that ionic conductance is temperature dependent. During sample collection temperature measured was very low and does not favor with particular anions and cations. In the glacial lake it showed negative correlation possibly because of mixing of treated effluent discharge which increases COD and conductivity but reduces the DO concentration.. In the western side glacial lake because of effluent discharge, salts concentration increased and therefore showed significant positive correlation with conductivity. Whereas in other glacial lakes it must be due to rock salts derived from rocks. Though the lake water is defined as soft water, good correlation obtained between conductivity and hardness due to the presence of metallic ions in the water should be considered.

In the year 1994 total organic carbon showed negative correlation with SO₄ (-0.94), DO ($r=-0.98$), NO₃ ($r=-0.72$) and SS (-0.61). A variety of organic compounds may be present in water like detergents, hydrocarbon, fats, proteins etc. The oxidation of organic compound needs oxygen and therefore it shows negative correlation with DO. Wherever

inorganic matter is present near the seepage channel confluence point organic substance is low. Suspended solids were measured only in the years 1994 and 2004. In the year 1994, it showed good correlation with DO ($r=0.98$) SO_4 ($r=0.77$) and Cl ($r=0.67$). In the year 2004 suspended solids was measured at all the places and the value was less than one, so correlation was not determined. A good correlation of suspended solids with DO indicates the presence of dissolved solids in less quantity as part of total solids which includes suspended as well as dissolved solids (dissolved solid is responsible for decreasing trend of DO absorbance). Moderate positive correlation with sulfate indicates contribution of sulfate governing the suspended particle. Though nitrate is present in small quantity in lake water due to mixing in seepage channel, it brings suspended particles too. Sulfate showed good correlation with DO ($r=0.88$) and NO_3 ($r=0.68$) in the year 1994 in rest of the year it did not show correlation with any element/parameters.

Phosphate showed positive correlation with DO ($r=0.98$) in west-side lake and ($r=0.78$) in south-east glacial lake. However showed negative correlation with BOD ($r=-0.65$) in Priyadarshini with COD ($r=-0.99$) in west-side glacial lake and ($r=-0.98$) in south-east side glacial lake. Whereas with total hardness it showed significant correlation ($r=-0.87$) in west side glacial lake. Algae and cyanobacteria need phosphorus as nutrients for their growth. Positive correlation with DO indicates wherever phosphate concentration is high plankton are less. Negative correlation with BOD and COD indicates the mixing of wastewater produced from the bathroom and urinal into lake, is being contributed by inorganic phosphate which must have contributed by breakdown of proteins and elimination of the librated phosphates in the urine. Total hardness is imparted by multivalent cations, negative correlation of phosphate with total hardness in west side of lake shows that the treated effluent rich in detergent compound but less in urine discharge. Total hardness showed positive correlation with COD ($r=0.78$, $r=0.73$) in west side and south east glacial lake respectively and negative correlation with DO ($r=-0.76$, $r=-0.96$) in west side and south-east glacial lake and positive correlation with potassium ($r=0.63$) in 2000, supports the statement. A significant positive correlation of sulfate with BOD in 2004 ($r=-0.83$) indicates presence of organic matter in lake water which react with and produce hydrogen sulfite. Sodium showed negative correlation

with acidity ($r=-0.86$).

In the Priyadarshini lake in 1995 negative correlation between nitrate and COD ($r=-0.68$) and DO ($r=-0.66$) and with DO ($r=-0.81$) in the year 2000 was found. A negative correlation with DO indicates the presence of wastewater pollution. A moderate negative correlation between COD and DO was obtained in the year 2000 ($r=-0.68$). Chloride showed significant positive correlation with phosphate ($r=1$) in west side glacial lake in 1995 and with DO ($r=0.98$, $r=0.70$) in west side and south-east side lake. In 2004 it showed positive correlation with SO_4 ($r=0.77$) because chloride content increases with increase in minerals. It showed significant negative correlation with COD ($r=-0.98$) and total hardness ($r=-0.87$) in both west-side and south-east side lake in 1995. Negative correlation with hardness is caused by cations.

In the year 1994 there is a significant correlation found between copper and lead ($r=1.0$), copper and manganese ($r=1.0$), copper and iron ($r=0.84$) lead and manganese ($r=0.98$), lead and iron ($r=0.91$), iron and manganese ($r=0.97$) iron and zinc ($r=0.78$, $r=0.62$ in 2000), cadmium and zinc ($r=0.92$) and moderate correlation between cadmium and iron ($r=0.64$) and cadmium and lead ($r=0.62$). However negative correlation was noticed between chromium and iron ($r=-0.92$) chromium and manganese ($r=-0.80$) chromium and lead ($r=0.66$). In the year 1994 in Priyadarshini lake floating cans, steel drums were noticed. A vehicle garage and repair work shop was present near the lake from which battery waste which mainly contains lead, zinc, cadmium and copper might have contributed to lake water and floating steel drum must have contributed iron to the lake water. Presence of chromium in lake water can be explained as due to mixing of welding material waste during earlier stage of Maitri. However the concentration of heavy metal (trace metal) was not observed in the years 2000 and 2004. Most of the waste material either sank or removed from lake by this time so imparted less effect on surface water.

3.17.2 Lake Water Quality Prediction

From the results of the prediction implying WASP7 model applied to Priyadarshini lake, it can be seen that the concentration of BOD, ammonia, nitrate, nitrogen are seen decreasing with time except organic nitrogen which increases insignificantly. It can be

therefore concluded that, even though the seepage continues to mix with lake in the same rate for almost 45 days in a the year, the pollution level in the lake is not going to increase owing to glacial lake feeding and high wind velocity which mixes the lake water and increase the dilution ratio.

Chapter 4

Experimental Setup

4.1 Approach for Development of RBC models

RBCs are one of the standard methods of secondary biological wastewater treatment in which degradation and bi-oxidation are achieved predominantly by a biofilm which is attached to the rotating discs (*Pan and Hartmann, 1992; Arundel, 1995; Banerjee, 1997a; Casey, 1997; White et al., 2000*). Laboratory scale model (*Laopaiboon et al., 2002*) can be used to predict the effect of treatment on the operation of full scale RBCs. The experimental setup is zeroes into understand the role of microorganism in the biological treatment of wastewater using the model simulation replicating the kinetics of the in-use biological treatment plant. It is quite evident that with proper analysis and environmental control almost all the wastewater can be treated biologically. The objectives of the biological treatment through design model are to coagulate and remove the non-settleable colloidal solids and to stabilize the organic matter. The major objective is to reduce the organic content and nutrient such as nitrogen and phosphorus (*Ouyang et al., 1999*). All these can be achieved by understanding the role of microorganism and principally by bacteria, which convert colloidal and dissolved organic matters into various gases and into cell tissue which can be removed by the gravity settling.

4.1.1 Assumption in Designing the Laboratory Scale Model

The aim of this approach is to study and understand a simple, low cost single-stage RBC system, consisting of single stage anoxic and aerobic reactors, for the treatment of settled high-strength kitchen as well as laundry/urinal wastewater using two different model as well as combination thereof, and to evaluate its performance under various hydraulic and organic loading conditions and tertiary treatment.

- ↳ For this purpose it is assumed that the temperature inside the biological chamber of the RBC at Maitri, Antarctica shall be maintained in between 20 °C to 30 °C for efficient development of the microbes to consume the substrate (*Tawfik et al., 2002, 2004*,

2005). Mainly because at lower temperature the mesophillic bacteria cannot grow and work efficiently and psychrophilic bacteria were not inoculated in the RBC. This is quite evident that the efficiency of treating the waste in RBC drastically reduces in the low temperature at Maitri, which concluded that RBC contains mesophillic bacteria which can grow and work more efficiently in the higher range of the temperature.

- ◆ RBC is not directly exposed to the sunlight, so the development of algae is avoided.
- ◆ The wastewater contains only gray water and not the black water which is the requirement for the treatment of the wastewater through the RBC at Maitri station.

4.2 Design and Experimental Setup of Single Stage Laboratory Scale RBC Unit

Rotating biological contactors (RBC) have been employed in recent years for the treatment of various types of substrates, including municipal wastewater (Grady, 1983; Akunna and Jeffries, 2000; Griffin and Findlay, 2000; Nowak, 2000), and studies have been conducted to ascertain the effect on RBC performance with respect to factors such as disc rotation speed (Friedman et al., 1979), recirculation (Klees and Silverstein, 1992), temperature (Pano and Middlebrooks, 1983), presence of organic particulate matter (Figueredo and Silverstein, 1992), hydraulic conditions (Kugaprasatham et al., 1991), use of supplemental air (Surampalli and Baumann, 1992) and scale-up (Wilson et al., 1980).

Single-stage laboratory-scale RBC (Pynaert et al., 2002a, 2002b, 2003) units were constructed as replication the Maitri's B1 and B3 RBC. The units being served by a common motor and drive each with different drive shaft. Each unit consisted of an influent chamber, a disc chamber and an in-built settling tank. These compartments were separated by acrylic walls. The flow to the influent chamber was maintained through the pipe and pinchcock regulator, which obtained the wastewater from a storage tank. In each unit, the treated liquor from the disc chamber was passed to the settling tank, where the biomass (Low and Chase, 1999) was removed, before being discharged via an overflow tube. Settled biomass was removed from each settling tank via careful scouring. The treated effluent from each model was retained in a container for further analysis. Motor was fitted with the gear system through which the RPM could be

maintained from 2-10 in each model. The configuration of the single-stage laboratory-scale RBC unit is shown in Table 4.1 and 4.2 and Figure 4.1.

Table - 4. 1: Configuration of the Single Stage Laboratory Scale RBC (B1)

Features	Description	
	At Maitri (Designed)	Lab Scale Model
Design Load (litre/day)	1200	6
Operating Volume (litre/day)	700	6
No of Disc (No)	56	36
Surface area of disk (m^2)	56.0	0.28
Thickness of disk (mm)	4.0	1.5
Diameter/dimention of Disk (mm)	500x500	70
Diameter of shaft (mm)	100	6
Rotational speed (RPM)	5	5
Primary settling chamber volume (litre)	1170	8
Biozone volume (litre)	310	3
Final settling chamber volume (litre)	370	1.8
Surface area of FST (m^2)	0.52	0.0026
Spacing of disk (mm)	15	10
Disk Submergence (%)	45%	40%
Material (Wall/ Disk)	Glass Fibre Reinforced/ Polypropelene	Acrilic/Glass Fibre
Residence time in the disk stage (Hours)	6.2 designed and 10.6 working average	12

Table - 4. 2 : Configuration of the Single Stage Laboratory Scale RBC (B3)

Component and Arrangements	Value	
	At Maitri (Designed)	Laboratory Scale Model
Design Load (litre/day)	5000	25
Operating Volume (litre/day)	1950	25
No of Disc (No)	100	66
Surface area of disk (m^2)	200.0	1.0
Thickness of disk (mm)	4.0	1.5
Diameter/dimention of Disk (mm)	1000x1000	100
Diameter of shaft (mm)	150	6
Rotational speed (RPM)	5	7
Primary settling chamber volume (m^3)	5250	27
Biozone volume (m^3)	1100	10.5
Final settling chamber volume (m^3)	1300	6.5
Surface area of FST (m^2)	1.09	0.035
Spacing of disk (mm)	15	10
Disk Submergence (%)	45%	40%
Material (Wall/ Disk)	Glass Fibre Reinforced/ Polypropelene	Acrilic/Glass Fibre
Residence time in the disk stage (Hours)	4.8 designed and 13.5 working average	10.0

The RBC system consisted of an aerobic reactor made of fiberglass (Figure 4.1). Fully immersed biodisks, were connected via a stainless steel shaft to a motor and rotated at 2-10 rpm (different for B1 and B3 model), parallel to the direction of wastewater flow. Influent waste was fed to the unit through inlet ports in the wall and its effluent was directed by gravity to the other section and to final effluent collection point. These units had 36 disks of 7 cm in diameter, 0.0038 m^2 of B1 and 66 disks of 10 cm in diameter, 0.00785 m^2 of B3 with disk interval of 10 cm in both model, placed to enhance mixing. The total biomass support surface was 0.28 and 1.0 m^2 respectively for B1 and B3, and

the disks were 35% submerged (based on disk surface) and rotated at 2-10 rpm in the direction of flow. The high rotational speed, selected to prevent the significant solids accumulation, resulted in elevated dissolved oxygen (DO) concentrations. Two manual flow regulators, activated by a timer for appropriate periods, were used to feed settled municipal wastewater, and treated effluent was collected by gravity. Polypropylene carboys were used as holding vessels and the influent vessel was stirred at specified interval.

Figure - 4. 1 : Laboratory Scale Model (B1 and B3)

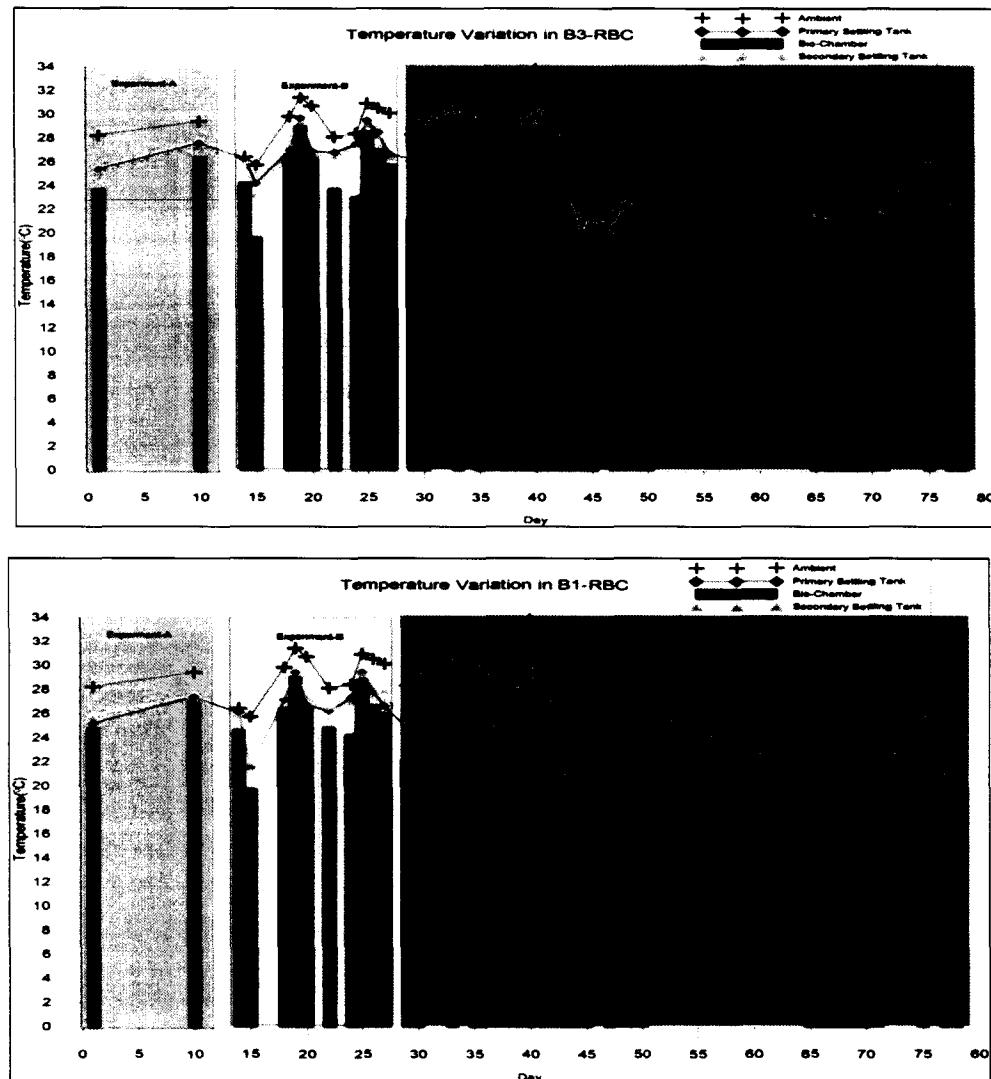


4.2.1 Operating Condition

The study was conducted for a period of 4 months (February 2005–May 2005). The operating temperature varied from 22 °C to 30 °C. The RBC system was loaded with 6 l/day for B1 and 25 l/day for B3 model. The temperature variation during the experiment inside the section and ambient temperature is shown in the Figure 4.2. From 16 March to 23 March, system was kept for stabilization and similarly while the

experiment changed, the system was kept for stabilization for 14 days and thereafter analysis was started.

Figure - 4. 2: Temperature Variation during Operation of RBC



4.2.1.1 Oxygen Content

The RBC system was evaluated for oxygen content by measuring the DO concentration and temperature at frequent intervals with a DO probe (Thermo Orian). DO was measured at influent and effluent of both the RBC. Simultaneous pH is also measured of the influent and effluent.

4.2.2 Simulation of Wastewater Generation

4.2.2.1 Kitchen Waste

At Maitri the B1 RBC receive wastewater from the kitchen only. Inside the kitchen normal food which contains from low calorie, carbohydrates and proteins to high calorie, carbohydrates and proteinaceous food is prepared which contains vegetarian food like, rice, pulses, packed vegetables, green vegetables and non-vegetarian food like meat, chicken, fish etc and hot drinks like tea, coffee and other milk contained hot drinks. Washing of the food item and utensils with soap solution add organic and inorganic matters to the production of the wastewater. To resemble the same in strength and characteristics of wastewater with the wastewater produce at Maitri, the canteen of the NCAOR campus was selected as the source. The food preparation and the ingredient used to prepare the food were found almost the same as of Maitri kitchen. Regular, 24 hourly, composite wastewater samples were collected from the sink of the NCAOR canteen kitchen. The BOD of which varied from 150 mg/l to 1200 mg/l and COD varied from 600 mg/l to 1600 mg/l which represent a typical wastewater variation of Maitri station. The RBC system was fed pre-settled (in a bucket for 2 hour) wastewater (*Hiras et al., 2004*). Primary sedimentation resulted in average COD, BOD and TSS removal.

4.2.2.2 Laundry/Bathroom/Urinal Wastewater

The B3-RBC at Maitri receives and treats the waste obtained from the laundry, bathroom and urinal. During the summer around 3-5 person use the laundry, whereas 25-35 people use bathroom and urinal every day. However the laundry use during the winter almost remains same whereas bathroom use reduces. In a year average washing powder supply (Ariel) is noted to be around 250-275 kg. Considering average wastewater produced from Laundry and bathroom around 1950 litre in a day, to prepare waste for model laundry-RBC 10 g washing powder was mixed in 25 litre of water. Similarly the soap both dry and liquid consumption being low per capita considered 10 ml per 25 litres. It is also accounted that around 40 people use the urinal in day which produces around 40 litres of wastewater contribute to 1950 litres of total waste. Considering the highest use, in 25 litre wastewater the amount of urinal waste is taken as around 50 ml, which was collected from the NCAOR, laboratory toilet block. To

produce the similar fluctuating strength and characteristics of waste which resembles to the laundry, bathroom and urinal waste 5-15 g of Ariel washing powder, 10-15 ml of soap solution and 25-50 ml of urine is mixed in water to prepare a total wastewater of 25 litres. This wastewater was generated everyday for the analysis purpose. The BOD varied from 130 mg/l to 980 mg/l and COD varied from 700 mg/l to 2250 mg/l which represents a typical wastewater variation of Maitri station received at B3 RBC.

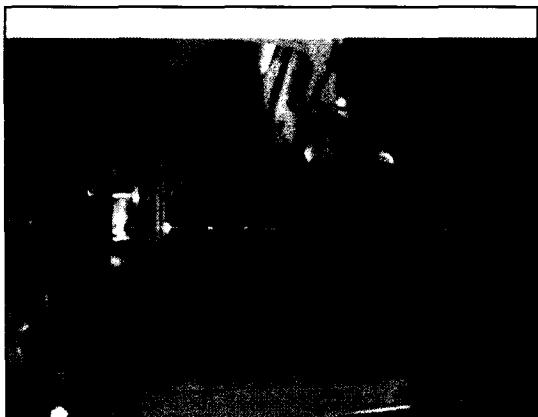
4.2.3 Microbe Generation on Biodisc, Various Combinations of Experiments

The bacteria/microorganism needs source of energy, carbon and inorganic elements (nutrients) such as nitrogen, phosphorus, calcium and magnesium and minor nutrients of importance include zinc, manganese, molybdenum, selenium, cobalt, copper, nickel and vanadium.. Apart from these organic nutrients (known as growth factors) are also required for the growth of the cell synthesis (*Stainer et. al, 1986*).

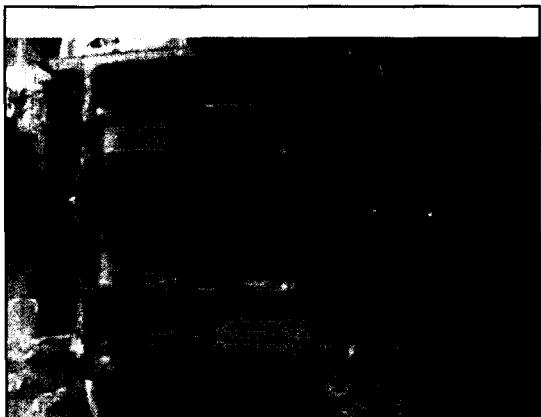
An inoculum of settled sewage (100 ml) from campus sewage septic tank was added into the disc stage of the RBC units filled with the water. The units were operated as a batch system for 24 h before the flow of the developed wastewater was introduced to the units at a rate of 25 litre/day and 6 litre/day in B3 and B1 model respectively. After 15 days the surface of the discs was covered by a thin homogeneous biofilm about 1 mm thick, termed as a young biofilm. The young biofilm continued to grow and after one month formed an irregular biofilm over the disc which varied in thickness between 2 and 3 mm and the reactors were thereafter operated in series in the continuous flow test mode. This resembled the biofilm observed on operational RBCs at Maitri and was referred to as a mature biofilm (Figure 4.3). Microbial heterogeneity of wastewater biofilm developed in laundry (B1) and kitchen (B3) RBC are shown in Figure 4.4.

Figure - 4. 3 : Pattern of Microbial Growth in RBC

(a) B1 RBC without bacterial growth



(b) B3 RBC without bacterial growth



(c) B1 RBC- initial bacterial growth



(d) B3 RBC - initial bacterial growth



(e) B1 RBC - Dense bacterial growth



(f) B3 RBC - Dense bacterial growth

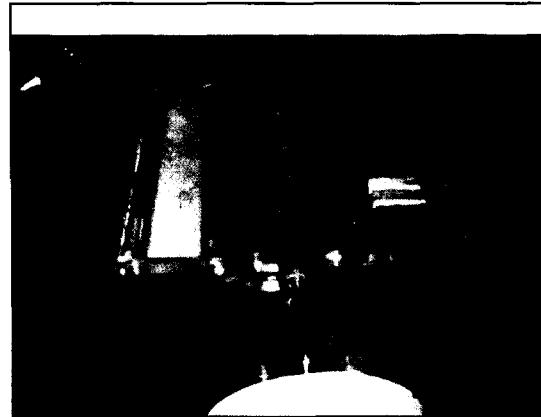
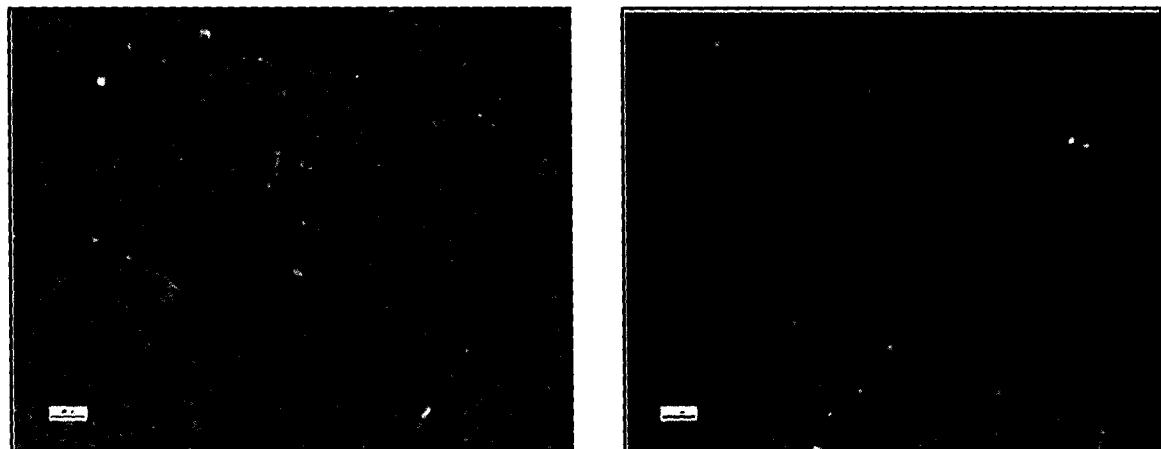


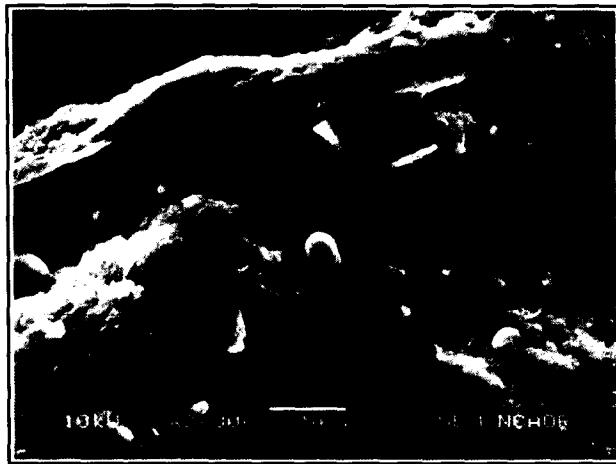
Figure - 4. 4 : Microbial Heterogeneity of Biofilm of Laundry and Kitchen RBC



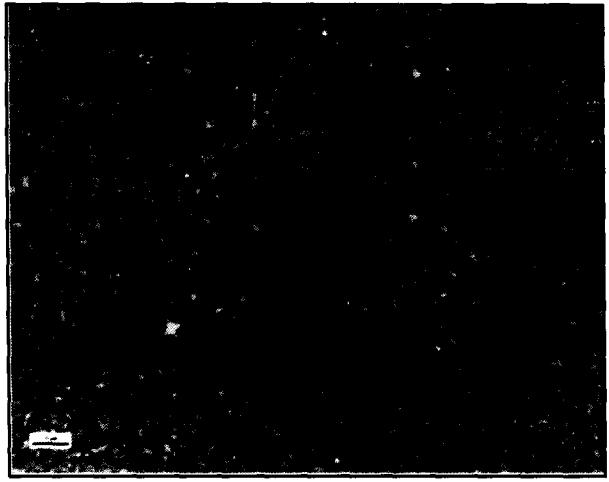
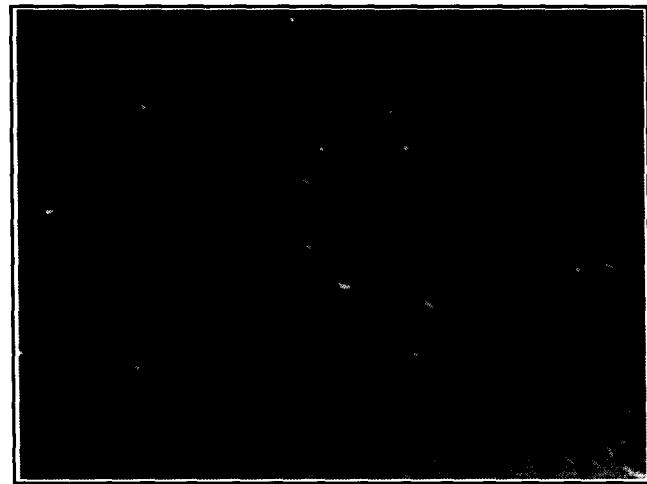
a: SEM images showing scattered, rod shaped, spherical cocci and stalked rod shaped bacteria embedded in slime layer of laundry RBC biofilm



b: Polarizing microscope images showing bacteria and fungal spore embedded in slime layer of laundry RBC biofilm



c: SEM image showing scattered, rod shaped, spherical cocci and stalked rod bacteria embedded in slime layer of kitchen RBC biofilm



d: Compound and Polarizing microscope images showing bacteria embedded in slime layer of kitchen RBC biofilm

Experiment Scenario

- ◆ Both the units (B1 and B3) were operated independently containing the kitchen and urinal/laundry waste for 15 days and samples from inlet and outlet were analysed. The RPM of B1 and B3 units were maintained at 5.5 and 7 respectively.
- ◆ In this span of 10 days experiment was conducted in which the treated kitchen effluent of B1 RBC was mixed at inlet of B3 unit along with B1 influent, so system acted as partial two stage RBC. Final combined effluent from B3 RBC and influents of both RBC were analyzed for the physico-chemicals parameters. The RPM of B1 and B3 units were maintained at 5.5 and 7 respectively.
- ◆ After stabilizing for 5 days the common effluent of partial two stage RBC was treated with alum and activated carbon and physico chemical analyses was carried out for fifty days under varying effluent load conditions, except in between two weeks during that period sample could not be analysed, however feeding of influent was continued.
- ◆ Again two weeks time was given for bacterial stabilization/growth and decay and then analysis was continued for another two weeks. In this span of experiment the RPM of B1 and B3 were maintained at 5.5 and 7 respectively

4.3 Tertiary Treatment

In order to improve the treatment efficacy of the RBC, tertiary treatment i.e alum dose and activated carbon in the series were also experimented at the exit point of effluent. The results suggest that it is advantageous to add at least a portion (*Omoike and Vanloon, 1999*) of the alum at the exit of the RBC. This enhances phosphorus removal by co-precipitation under conditions where the concentration of organic matter is relatively low.

4.3.1 Alum Dosing

The phosphorus concentration in the wastewater may vary and it may be present in different form of phosphorus which is little complex and difficult to remove from the domestic wastewater. In the wastewater treatment process, addition of chemical coagulants can occur at various points, including: immediately upstream of the primary clarifier, in the aeration chamber during aeration, immediately after the aeration chamber but prior to final clarification and at more than one point simultaneously

(Bowker and Stensel, 1990). Depending on the particular plant, each of these locations has advantages and disadvantages. Because the complexing components of wastewater, including some organic compounds, compete with hydrogen carbonate and phosphate species for the aluminum ions, the possible effect of organic matter on phosphorus removal is one of the important factors that has been considered in determining the point of addition of the coagulant in this study. The purpose of adding coagulant in the wastewater treatment is to have better understanding to measure possible interactions and effects of the various wastewater components and the removal of the BOD, COD, phosphorus and trace metal in the system. Controlled precipitation was carried out under specified conditions and direct measurements of other parameters were carried out as suggested by (Al-Rehali and Misabahuddin, 2000).

An attempt has been made at the laboratory to observe the effect of tertiary treatment on the effluents of RBC. In this regard the effluent is primarily treated through the Aluminium potassium sulfate ($\text{AIK}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$) i.e. potash alum dose by flocculation (USEPA, 2000) One gram of alum is mixed well in a litre of distilled water and 10,20,40,80 and 150 ml of aqueous solution is mixed and flocculated well in a litre of series of waste obtained from inlet of B1 and B3 RBC (Figure 4.4).

An optimum dose of alum (Omoike and Vanloon, 1999) solution which gave the maximum settlement of the suspended particles is selected and is mixed with the effluent at regular interval and then passed through the activated carbon column. For this purpose alum dose of 80 mg/l is selected for flocculation and settling the particles.

There after collected supernatant liquid is passed vertically up through the vertical column of 15 cm diameter and 16.5 cm height consists of activated carbon of total weight of 700 grams of 2.0-5.0 mm size (Figure 4.5).

4.3.2 Activated Carbon (Charcoal)

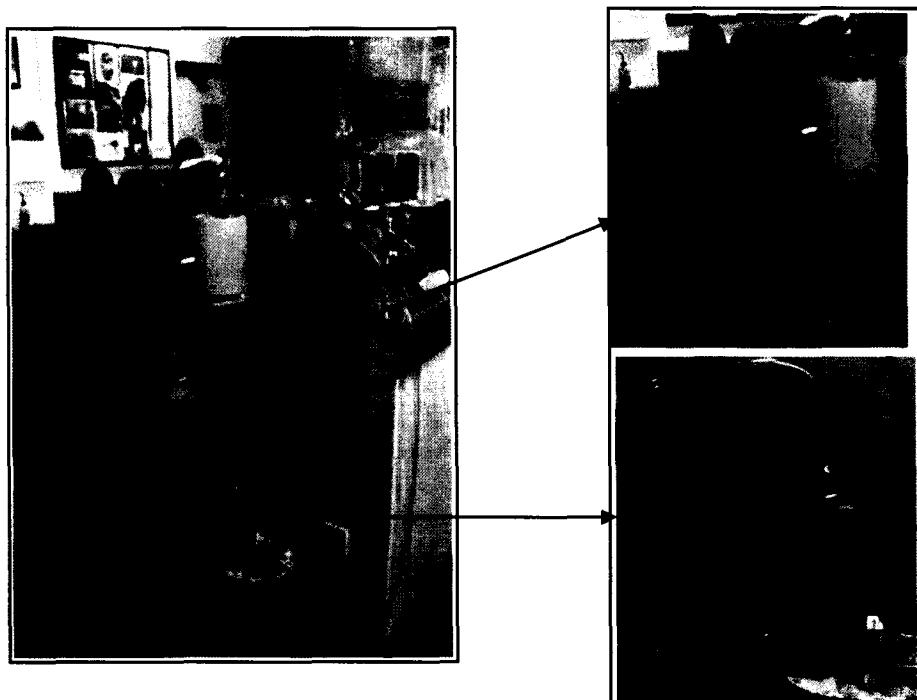
Activated carbons are successfully applied for the purification or supplementary purification of potable and wastewater. It's highly developed porous structure and large specific surface area indicate that they exhibit a considerable adsorption capacity towards various pollutants, both organic and inorganic (Razvigorova et al., 1998). Granulated activated carbon has been proposed by the Environmental Protection

Agency to eliminate or reduce potentially carcinogenic organic substances in public supplies. Activated carbons are successfully applied for the purification or supplementary purification of potable and wastewater.

Figure - 4. 5 : Flocculation with Alum Dose



Figure - 4. 6 : Alum Treated Effluent and Activated Carbon Treatment



4.4 Analysis Results

In this study the effects of the disk rotational speed, mixing of nutrient and combined treatment on a mature, one-month-old, biofilm in RBCs have been investigated. The effect of various treatment combinations on the treatment efficiency of the RBCs was determined by measuring the reduction in chemical oxygen demand (COD), biochemical oxygen demand (BOD), trace metal, phosphorus, nitrate and other parameters of the domestic wastewater applied. The results of experiments are shown in Figure 4.6 to 4.14.

Figure - 4. 7 : Variation of pH, Temperature, Conductivity and Dissolved Oxygen, during Lab Experiment

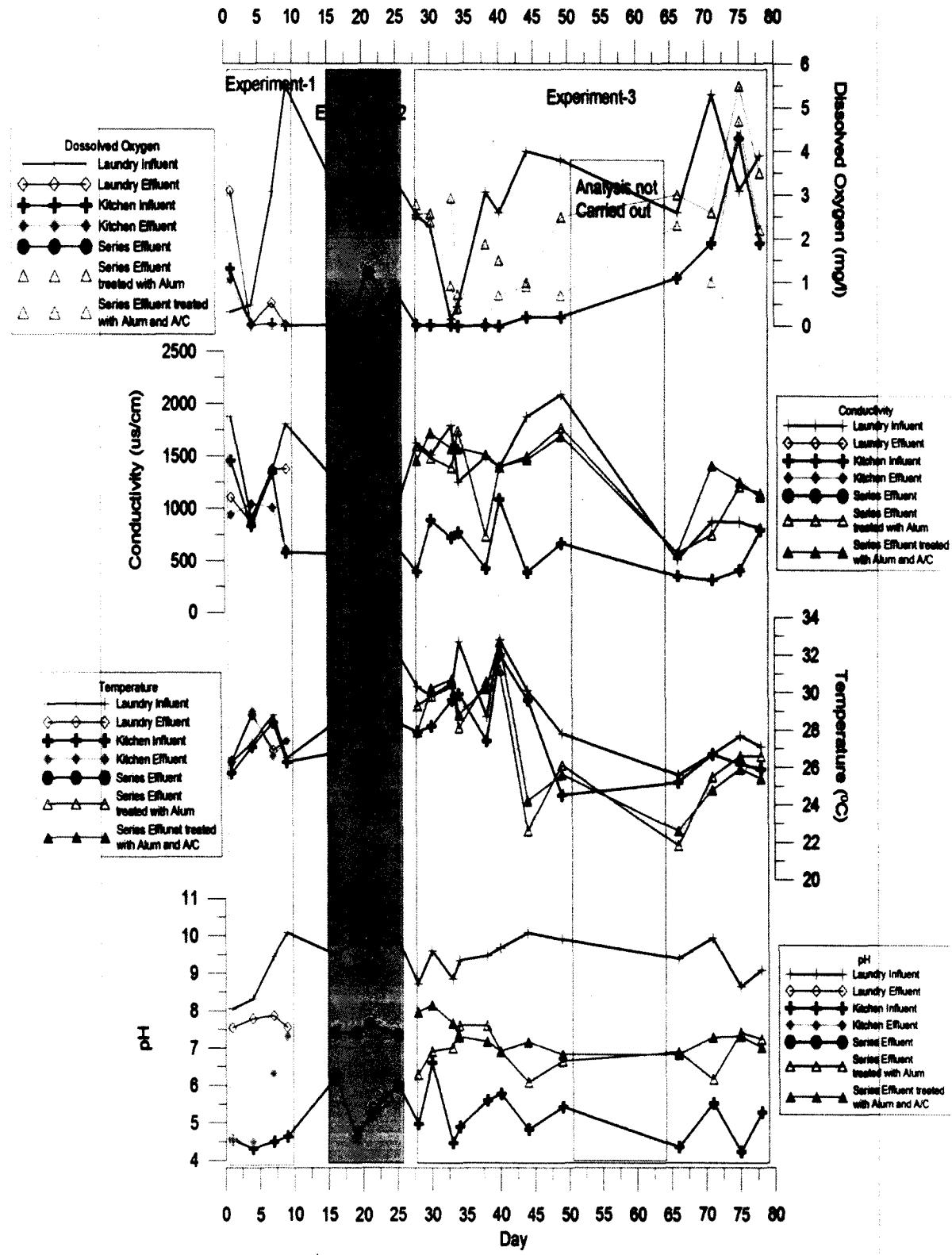


Figure - 4. 8 : Variation of Total Solids, Dissolved Solids and Suspended Solids during Lab Experiment

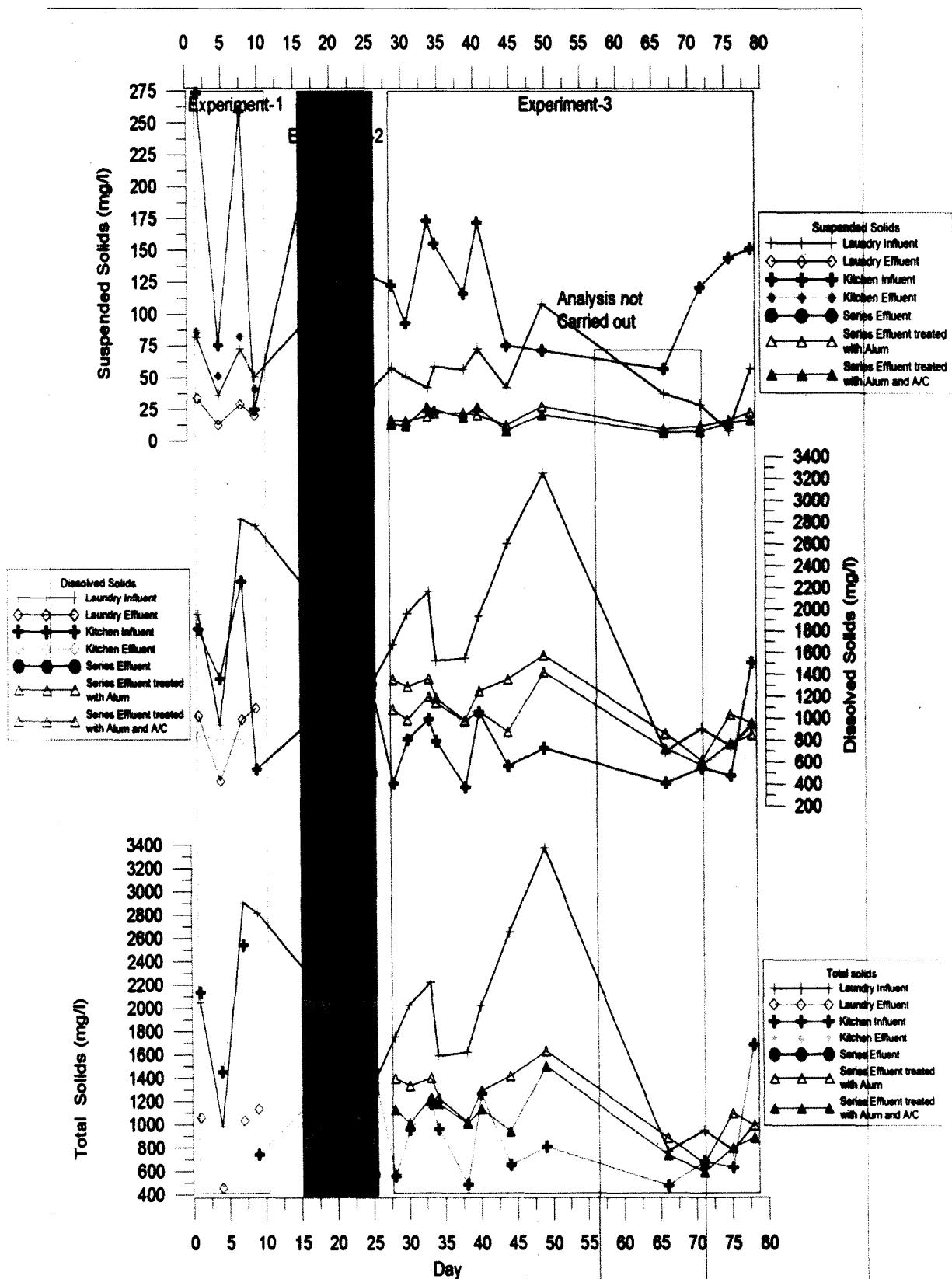


Figure - 4. 9 : Variation of Volatile Suspended Solids and Volatile Dissolved Solids during Lab Experiment

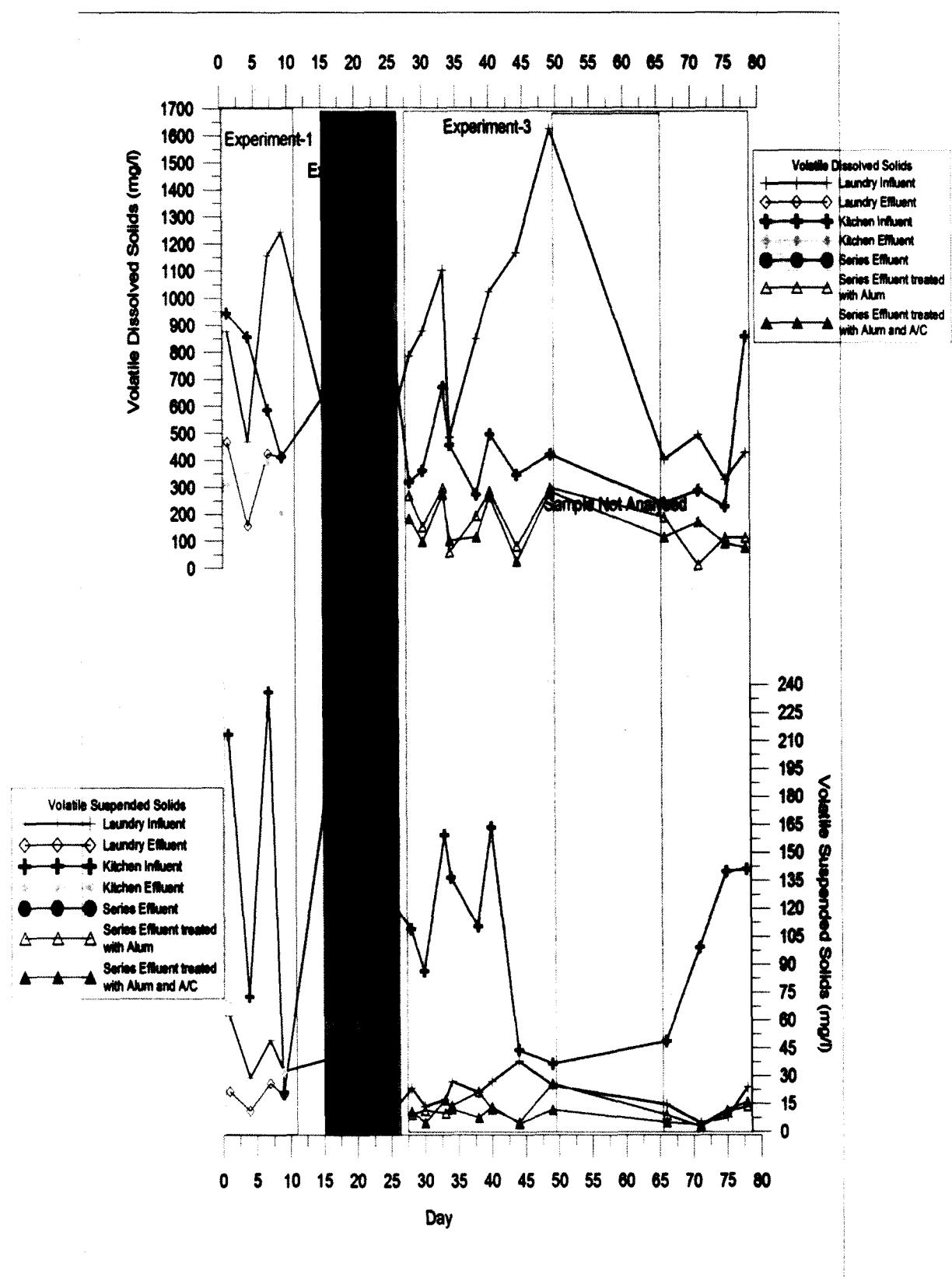


Figure - 4. 10 : Variation of Ammonia, Nitrate and Total Phosphate during Lab Experiment

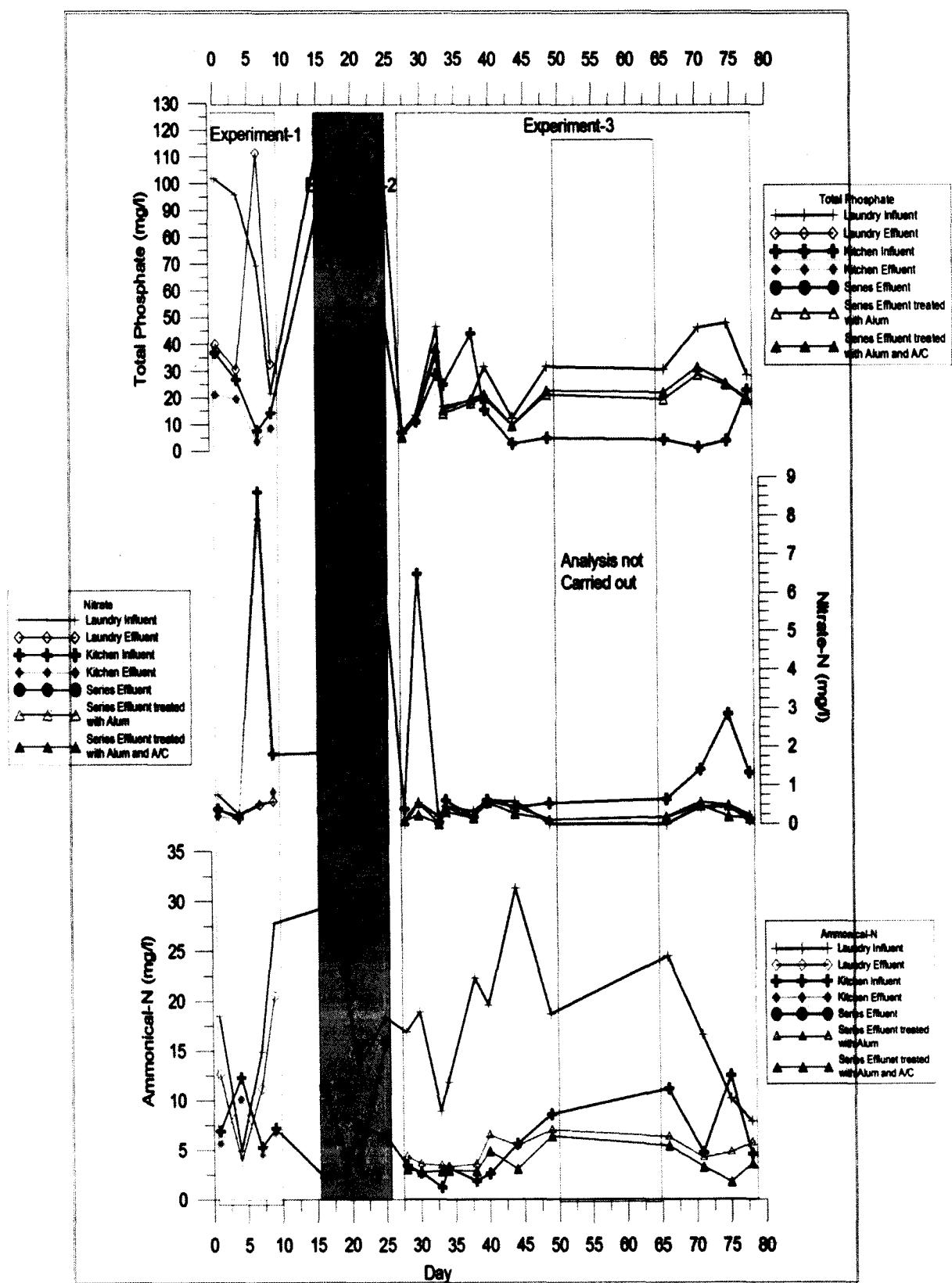


Figure - 4. 11 : Variation of Biochemical Oxygen Demand, Chemical Oxygen Demand and Turbidity during Lab Experiment

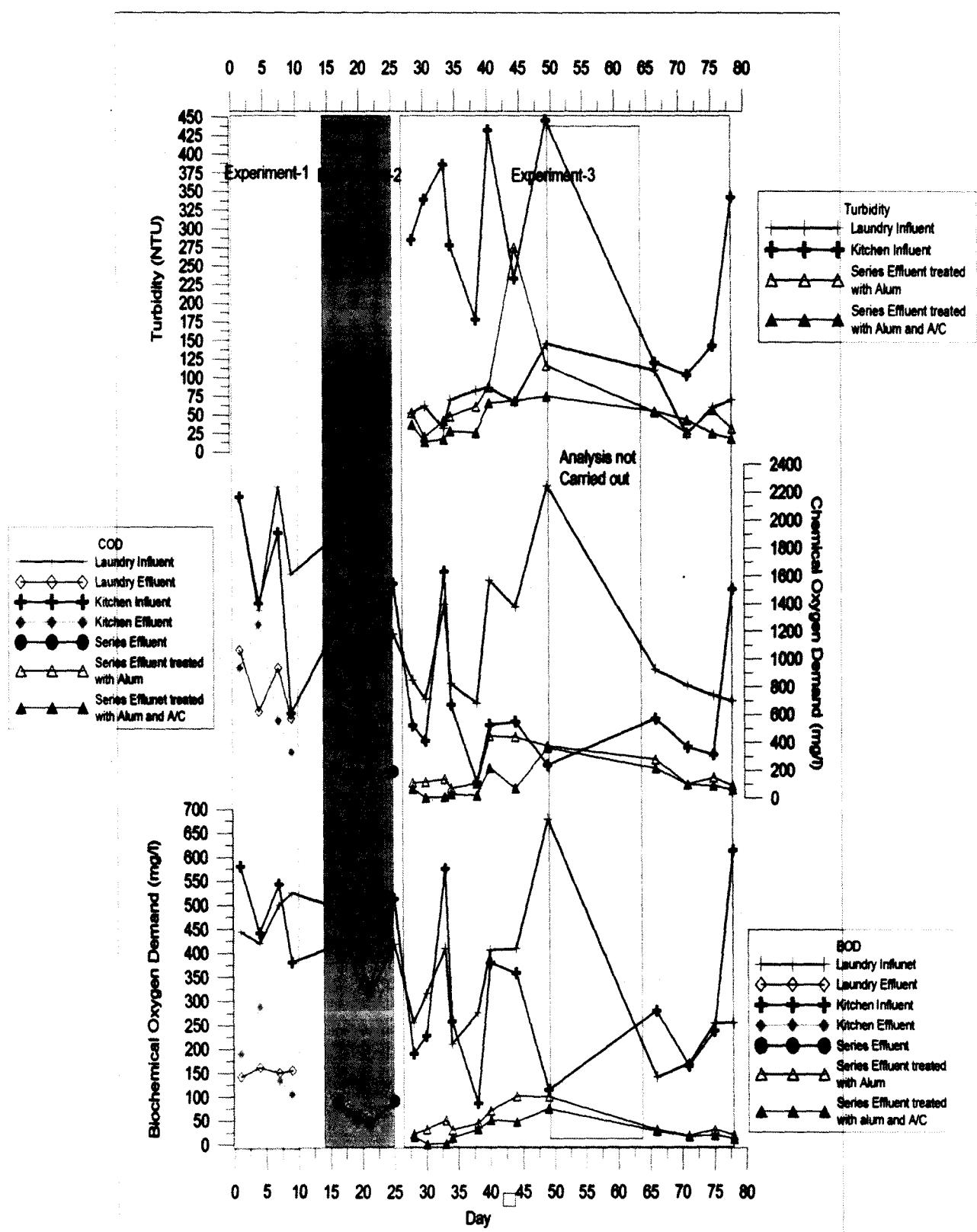


Figure - 4. 12 : Variation of Sodium, Potassium and Calcium during Lab Experiment

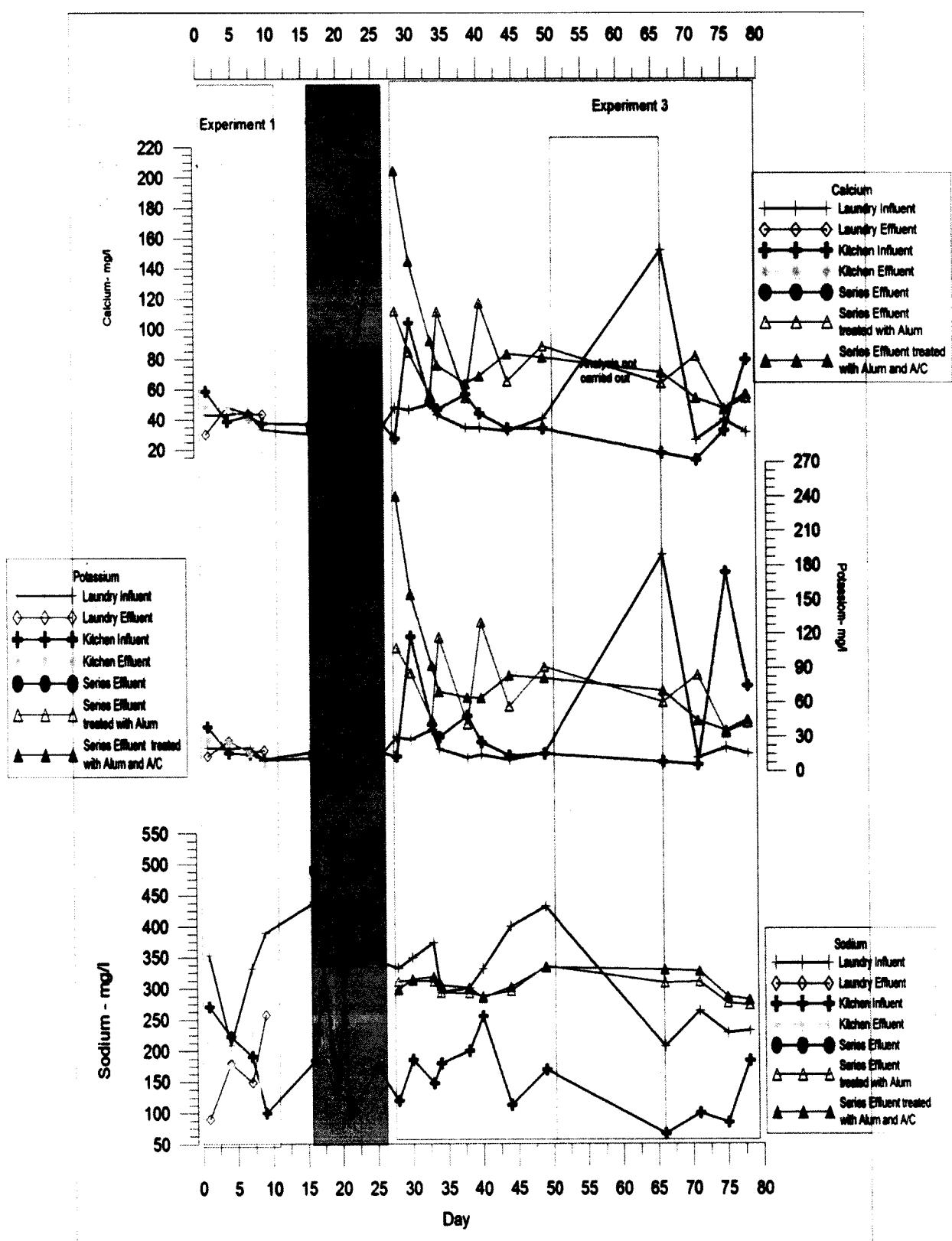


Figure - 4. 13 : Variation of Chromium, Manganese and Iron during Lab Experiment

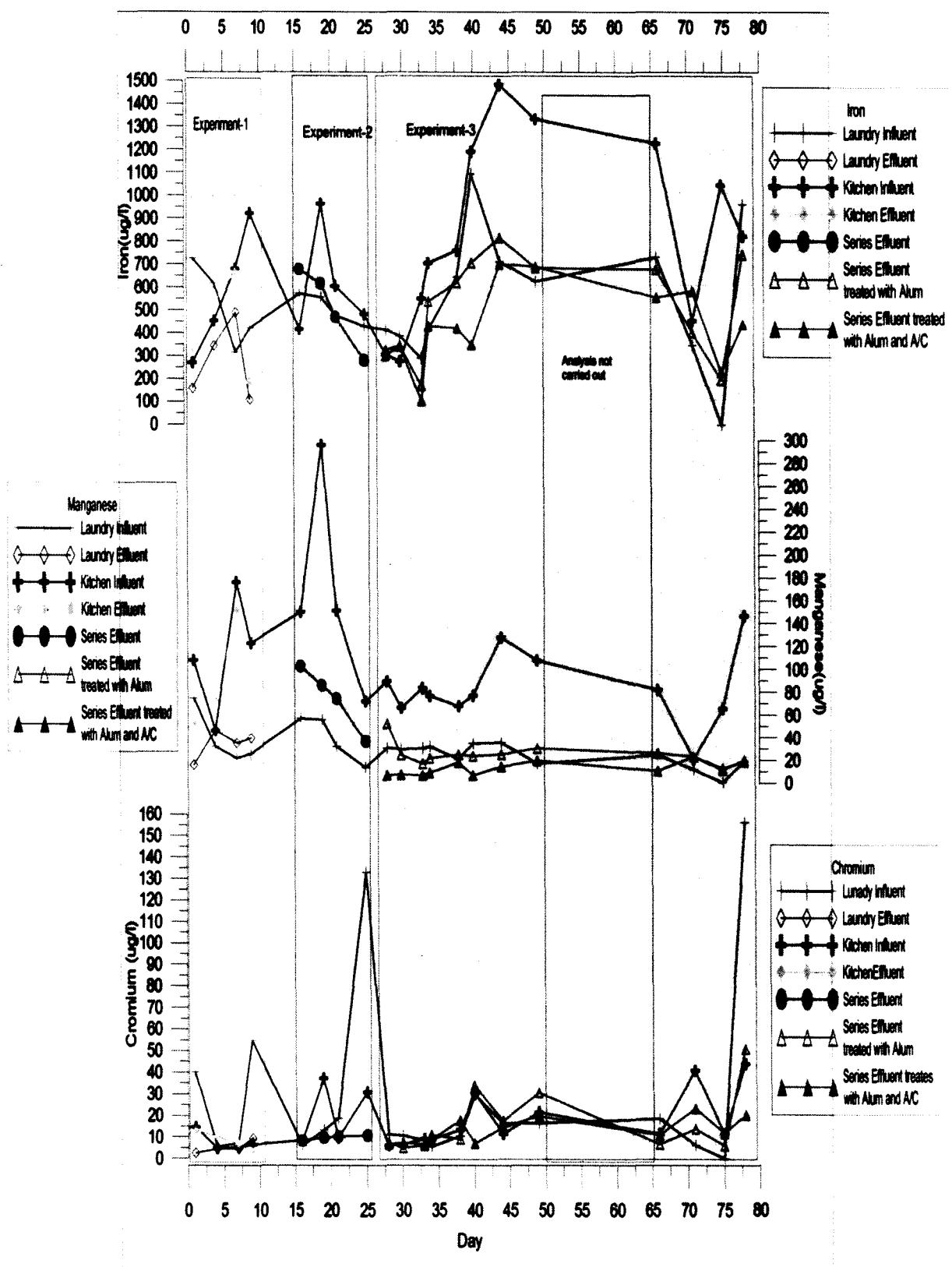


Figure - 4. 14 : Variation Zinc and Nickel during Lab Experiment

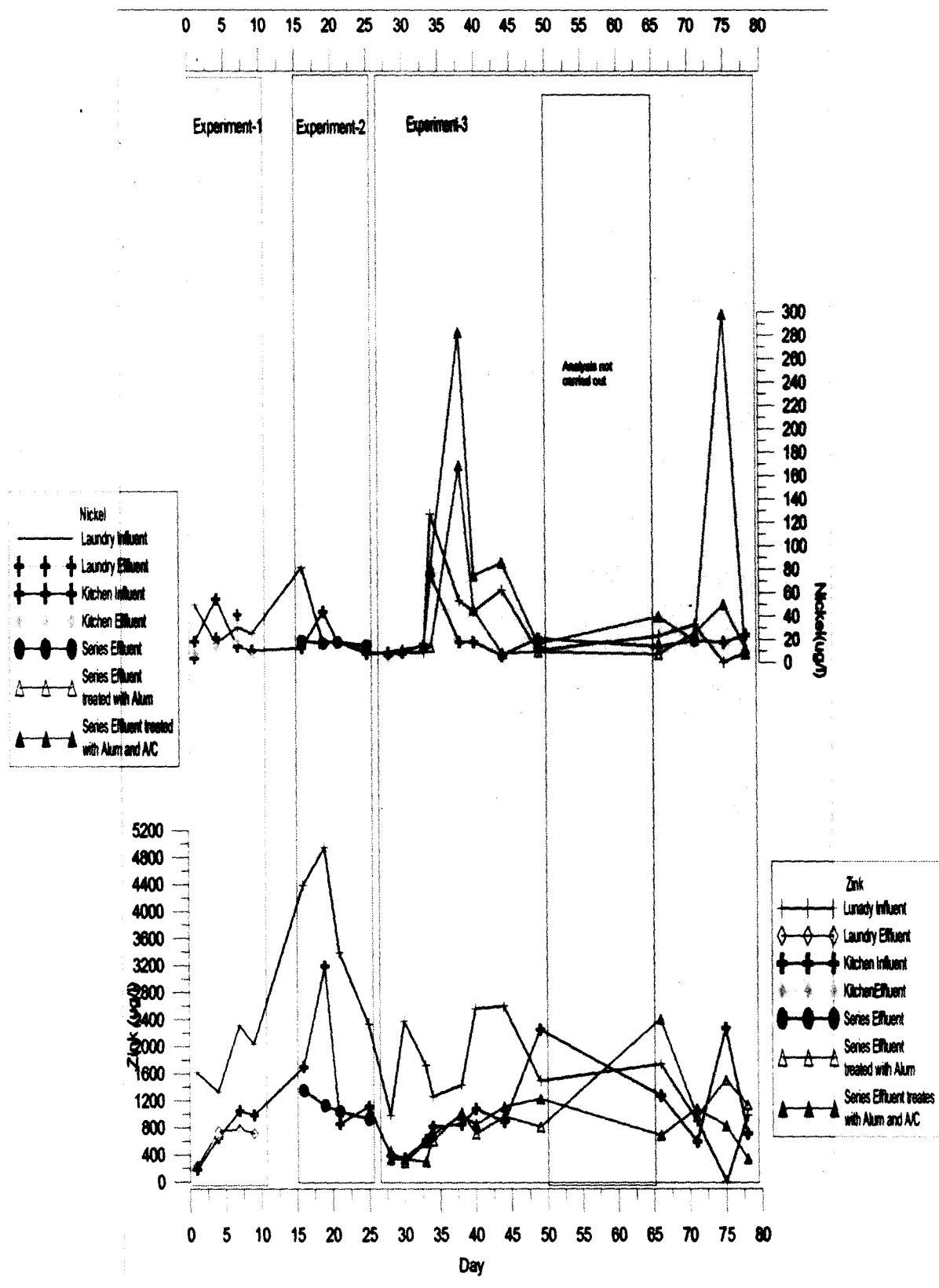
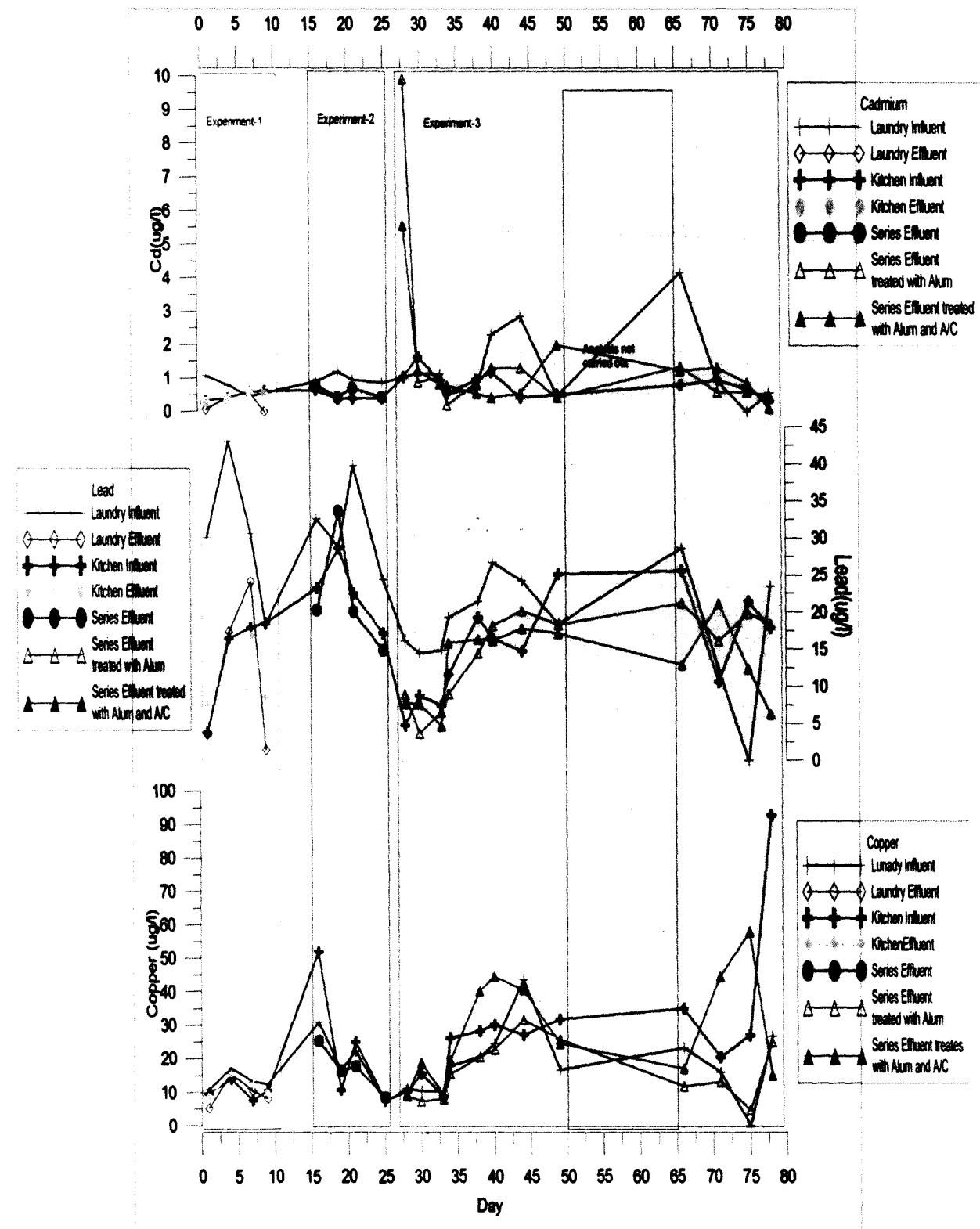


Figure - 4. 15 : Variation of Copper, Lead and Cadmium during Lab Experiment



4.5 Results

Three combinations of the experiment were conducted during lab study. In first experiment laundry and kitchen RBC were run separately, so analysis of influents and effluents were carried out separately and results presented accordingly. The efficacy of both RBCs carried out estimating the percentage reduction from influent of particular parameter to effluent. In the second experiment laundry and kitchen RBC were converted into partial two stage system. In this combination separate wastes were fed to both RBC, but the effluent of kitchen RBC was further diverted at PST of laundry RBC. So laundry effluent provided the quality of combined treated effluent. The analysis of influents of both the RBC's and combined effluent was carried out accordingly. For calculation purpose to understand the efficacy of the system during second experiment, a combined influent load of both RBC according to respective flow and concentration of particular parameter was estimated and compared with combined effluent. In the third experiment, system was run as partial two stage treatment and further combined effluent from laundry RBC was treated with alum and thereafter activated carbon. So analysis of both influents and effluents after alum treatment and activated carbon treatment are presented in the results. For efficacy estimation the combined influent load on partial two stage system is calculated and compared with effluents for particular parameters.

4.5.1 Temperature Variation inside RBC Cell

Temperature plays an important role in the production and multiplication of bacteria. During the experiment the ambient temperature recorded was $28 \pm 3^{\circ}\text{C}$. From the Figure 4.2 it can be seen that the temperature in the primary settling tank (PST), secondary settling tank (SST) and bio-chamber were observed lower than the ambient. Temperature of SST was always found lower than the PST (21 to 31°C) in both the RBCs. The temperature in the bio chamber falls much lower than the PST and SST, in both the RBCs. Inside bio-chamber the temperature varied viz. $23.4 \pm 3.5^{\circ}\text{C}$ in B3 RBC whereas in the B1 RBC it varied viz. $23.5 \pm 3.6^{\circ}\text{C}$. Lower temperature inside the chamber was recorded lower because of the microbial activity which is endothermic reaction, absorbs the heat for reaction and reproduction. It is observed that the

experiment conducted in the temperature range helps to grow thermophilic bacteria. The correlation coefficient between ambient temperature and bio-chamber of B3-RBC is found to be 0.905 whereas in between ambient temperature and bio-chamber of B1-RBC it is 0.894 during experiment-A. While during experiment-C the correlation coefficient between ambient temperature and bio-chamber of B1-RBC is 0.849, and between ambient temperature and bio-chamber of B3-RBC is 0.768. In the third experiment the effluent of kitchen is mixed with the influent of B1-RBC which affected the growth of microbes which is reflected in lower value than the previous experiment. It indicates that nutrient or food affects the microbial growth and treatment of the wastewater.

4.5.2 pH

For bacterial growth the most predominant range of pH is 6.5 to 8.5, where bacteria dominates over fungi otherwise in lower pH, fungi competes with bacteria. Influent of the Laundry showed pH 9.4 ± 0.6 , throughout the experiment, whereas kitchen influent showed pH 5.1 ± 0.7 . This resembles the pH of the influent of the RBC at Maitri. During the first experiment the pH of influent of laundry RBC recorded 8.9 ± 0.9 and effluent recorded 7.7 ± 0.15 and of kitchen influent recorded 4.5 ± 0.13 whereas effluent shown pH 5.7 ± 1.4 . This indicates that after treatment, effluent of Laundry RBC changing from base to neutral and of kitchen also improves. In the second experiment the effluent of the kitchen RBC is mixed with the influent of Laundry RBC. In this experiment influent of laundry RBC recorded 9.7 ± 0.2 pH, whereas kitchen influent recorded 5.5 ± 0.7 , and the combined treated effluent shows pH 7.5 ± 0.13 . This gives a very good indication that at the bio-chamber waste is bearing optimum pH on which bacteria can grow and thrive on. In the third experiment while the combined effluent is further treated with alum dose and activated carbon the pH has changed. Influent of laundry RBC and kitchen varied from 9.4 ± 0.5 and 5.2 ± 0.7 pH respectively. After adding alum dose the combined effluent imparted pH 6.8 ± 0.5 which increased further to 7.3 ± 0.4 after treating through activated carbon.

4.5.3 Conductivity and Turbidity

In the first test which is normal run of RBC's, conductivity in the influent of laundry RBC recorded $1489 \pm 452 \mu\text{s}/\text{cm}$. Conductivity of the laundry effluent shows reduction which is measured as $1178 \pm 244 \mu\text{s}/\text{cm}$. Kitchen influent recorded conductivity of $1051 \pm 415 \mu\text{s}/\text{cm}$ which after treatment reduced to $901 \pm 197 \mu\text{s}/\text{cm}$ in the effluent. This result indicated that the dissolved solids and colloidal particles which mainly impart conductivity are being utilized by microbes and the reduction in the conductivity is $17 \pm 19\%$ for laundry RBC and $7 \pm 28\%$ for kitchen RBC. During the second experiment conductivity for laundry influent recorded was $1334 \pm 279 \mu\text{s}/\text{cm}$ and kitchen influent reads shows $486 \pm 144 \mu\text{s}/\text{cm}$. While the kitchen effluent is mixed at PST with laundry RBC and the combined effluent produces conductivity of $968 \pm 49 \mu\text{s}/\text{cm}$. It can be stated that second experiment shows reduction in conductivity of $46 \pm 3\%$. It indicates that in the second experiment the microbial cells chemically reacts with the substrate and consume dissolved organic and inorganic substances.

In the third experiment while system was operated as partial two stage RBC and the combined effluent treated with alum dose and activated carbon the influent of laundry shows conductivity $1341 \pm 486 \mu\text{s}/\text{cm}$ and conductivity of kitchen waste shows conductivity $601 \pm 251 \mu\text{s}/\text{cm}$. Further after treatment with alum dose it reduced to $1272 \pm 402 \mu\text{s}/\text{cm}$ ($33 \pm 15\%$ reduction) and after passing through activated carbon it increased rather than reduction to $1393 \pm 311 \mu\text{s}/\text{cm}$ (increase $-16 \pm 38\%$). Alum is mixed which acts as coagulant and binds the suspended and colloidal matter and settles down, while activated carbon adsorb the organic matter and trace metals and tend to increase the conductivity by dissolution of particles in the liquid.

Turbidity could not be recorded for the first and second experiment. In the third experiment turbidity recorded in laundry influent $72 \pm 33 \text{ NTU}$ while in the kitchen influent it is recorded higher i.e $274 \pm 119 \text{ NTU}$ because of type of food waste generated from the kitchen. The combined effluent mixing together both the effluent resulted in $111 \pm 40 \text{ NTU}$. After treatment with the alum, turbidity reduced to $54 \pm 28 \text{ NTU}$ ($50 \pm 17\%$ NTU reduction) and further passing through activated carbon it reduced to $38 \pm 23 \text{ NTU}$ ($40 \pm 21\%$ NTU reduction). Alum proves to be an effective measure to reduce the turbidity. Overall reduction in turbidity measured was $67 \pm 17\% \text{ NTU}$.

employing tertiary treatment.

4.5.4 Temperature and Dissolved Oxygen (DO)

During the first experiment considering normal run of RBC's average DO in the influent of laundry RBC recorded was 3.1 ± 0.5 mg/l, while average temperature remained $27.2 \pm 1.1^{\circ}\text{C}$ average. DO of the laundry effluent shows reduction in the DO level i.e. 0.41 ± 0.51 mg/l (temperature varied $27.3 \pm 1.0^{\circ}\text{C}$). In the influent and effluent of kitchen RBC the DO varies from 0.34 ± 0.64 mg/l to 0.27 ± 0.51 mg/l, while temperature in influent and effluent varies from $26.6 \pm 1.2^{\circ}\text{C}$ to $27.3 \pm 1.2^{\circ}\text{C}$ respectively. Lower DO level in the effluent may be due to initial DO concentration in the influents at particular higher temperature and secondly due to the utilization of the available oxygen by microbes in the bio chamber.

In the second experiment DO of the laundry and kitchen influent varied from 2.98 ± 0.43 to 0.23 ± 0.38 mg/l respectively with temperature variation of $30 \pm 1.6^{\circ}\text{C}$ and $28.2 \pm 0.9^{\circ}\text{C}$. While the kitchen effluent is mixed at PST of laundry RBC and the combined effluent produces DO of 0.5 ± 0.53 mg/l and temperature remains in the range of $28.3 \pm 1.7^{\circ}\text{C}$. In the bio-chamber of laundry RBC due to mixing of kitchen effluent which contains trace metal and bacteria, temperature decreases. Further temperature decrease is due to utilization of the heat for multiplication of microbes and passing of cold water tube to maintain the temperature nearly $25\text{-}27^{\circ}\text{C}$. Combined effluent has given DO level in between the laundry and kitchen influent levels which can be due to the dilution effect.

Third experiment continued in progression of the second experiment to treat the effluent with alum dose and activated carbon, the influent of laundry and kitchen waste shows DO in the range of 2.81 ± 1.4 mg/l and 0.8 ± 1.3 mg/l respectively (temperature $29.1 \pm 2.3^{\circ}\text{C}$ and $27.2 \pm 2.2^{\circ}\text{C}$, respectively). Further while combined effluent is treated with alum dose, DO is 2.32 ± 1.36 mg/l (temperature $27.4 \pm 3.0^{\circ}\text{C}$) and after passing through activated carbon it reduces to 1.78 ± 1.3 mg/l (temperature $27.4 \pm 3.1^{\circ}\text{C}$). The influent of the kitchen has shown DO level nearly zero. Alum settles down the organic and inorganic compound which remains in the effluent and thus reduces the BOD and increases the DO level, while activated carbon slightly tend to reduce the DO level

because of closed chamber which is devoid of direct oxygen from the ambient. Apart from the constituents of the liquid, temperature and salinity also play an important role in defining the DO level.

4.5.5 Total Solids, Suspended Solids and Dissolved Solids

Total solids (TS) contain total suspended solids (TSS) and dissolved solids (TDS). Total dissolved solid is a measurement of inorganic salts, organic matter and other dissolved materials in water (USEPA). In the first experiment considering normal run of RBC's TS, TDS and TSS in the laundry influent varied from 2189 ± 891 mg/l, 2118 ± 882 mg/l and 60 ± 21 mg/l respectively and in the effluent it is recorded 922 ± 311 mg/l, 879 ± 307 mg/l and 24 ± 9 mg/l which indicates reduction in TS, TDS and TSS in the range of $56 \pm 7\%$, $57 \pm 7\%$ and $61 \pm 3\%$ respectively. The TS, TDS and TSS in the kitchen influent varied from 1719 ± 790 mg/l, 1490 ± 738 mg/l and 158 ± 16 mg/l respectively, whereas in the effluent it was recorded 790 ± 216 mg/l, 711 ± 207 mg/l and 65 ± 22 mg/l which also indicates reduction in TS, TDS and TSS in the range of $49 \pm 14\%$, $46 \pm 19\%$ and $26 \pm 63\%$ respectively. In one of the samples, SS was recorded on higher side in effluent as compared to influent. It may be due to the presence of some floating particles of higher diameter and size in the influent which must have settled down. It is noticed that the concentration of total solids and total dissolved solids in the kitchen RBC is lower than the laundry RBC and total solids concentration is largely governed by the dissolved solids, whereas suspended solids concentration found more in kitchen influent rather than in the influent of laundry RBC.

In the second experiment while the effluent of kitchen (Influent contains TS- 1039 ± 365 mg/l, TDS- 864 ± 355 mg/l and TSS- 151 ± 37 mg/l, and flow with 6 litre/day) is mixed with influent of laundry (TS- 1872 ± 384 mg/l, TDS- 1747 ± 367 mg/l and TSS- 108 ± 62 mg/l) with flow of 25 litre/day, it acts as a partial two stage RBC. The combined TS, TDS and TSS calculated were 1711 ± 290 mg/l, 1576 ± 280 mg/l and 116 ± 48 mg/l respectively. Final combined effluent shows the reduction in the values of TS, TSS and TDS to 616 ± 66 mg/l, 537 ± 59 mg/l and 42 ± 7 mg/l respectively i.e reduction in range of $64 \pm 4\%$, $66 \pm 4\%$ and $63 \pm 13\%$ respectively. Results of the second experiment show the removal of TS, TDS and TSS in the final effluent is higher than the first experiment when treated as two stages RBC. At the time when kitchen treated effluent, mixed with influent

of the laundry RBC the bacterial growth increased many folds, due to provision of necessary nutrients available in kitchen effluent needed for bacterial growth which utilizes the dissolved organic matter as food.

Third experiment continued in progression of the second experiment to treat the effluent with alum dose and activated carbon. While the effluent of kitchen which contains TS- 863 ± 365 mg/l, TDS- 719 ± 337 mg/l and TSS- 121 ± 40 mg/l in influent, and flow with 6 litre/day is mixed with influent of laundry TS- 1713 ± 797 mg/l, TDS- 1660 ± 781 mg/l and TSS- 52 ± 24 mg/l with flow of 25 litre/day, it acts as partial two stage RBC. The combined TS, TDS and TSS calculated were 1563 ± 651 mg/l, 1478 ± 638 mg/l and 65 ± 20 mg/l respectively. After treating with alum the combined effluent (31 litre a day) shows reduction in TS, TDS and TSS occurred in range of 1198 ± 272 mg/l, 1150 ± 268 mg/l and 18 ± 5 mg/l respectively i.e reduction, $15\pm26\%$, $13\pm28\%$ and $71\pm6\%$. Higher concentration of dissolved solids is noticed in the alum treated effluent. Mixing of alum has the tendency to increase the dissolved solids as it contains coagulated flocks of particle. But the removal of suspended solids recorded is very high. Further treatment with activated carbon TS, TDS and TSS reduced to 1015 ± 246 mg/l, 972 ± 231 mg/l and 17 ± 7 mg/l respectively i.e they reduced by TS $15\pm9\%$, TDS $15\pm10\%$ and SS $11\pm25\%$.

During the treatment with activated carbon some particles of carbon mixed with effluent, in few samples, show higher suspended particles. Overall reduction was noted after implying tertiary treatment in TS, TDS and TSS up to $29\pm19\%$, $27\pm22\%$ and $74\pm9\%$ respectively. Results indicate that the tertiary treatment (activated carbon) implying RBC as partial two stage unit helps to remove the solids. However, treating separately two types of waste shows better response in solid removal. It can be concluded through the third experiment that detention time if reduced from the designed, it remarkably affect the removal of solids. And due to dense population of microbes some portion might have sloughed disk off and added in the combined effluent. Another possible reason is decrease in the designed detention time of the influent on the RBC as flow increased by 24%, which gives less time for the particle settling.

4.5.6 Volatile Suspended Solid (VSS) and Volatile Dissolved Solid (VDS)

In the first experiment considering normal run of RBC's VSS and VDS in the laundry influent varied from 43 ± 15 mg/l to 937 ± 349 mg/l respectively and in the effluent it was recorded as 19 ± 6 mg/l and 365 ± 141 mg/l which shows reduction in VSS and VDS in the range of $53 \pm 12\%$ and $61 \pm 9\%$ respectively. The VSS and VDS in the kitchen influent varied from 136 ± 105 mg/l to 700 ± 244 mg/l respectively, whereas in the effluent it was recorded as 53 ± 16 mg/l and 315 ± 82 mg/l which shows reduction in VSS and VDS in the range of $30 \pm 58\%$, and $52 \pm 15\%$ respectively. It is noticed that the volatile suspended solids concentration in the kitchen RBC is higher than the laundry RBC and volatile dissolved solids are higher in the laundry influent.

In the second experiment while the effluent of kitchen which contains VSS- 144 ± 37 mg/l and VDS- 540 ± 361 mg/l in influent, and flow with 6 litre/day is mixed with influent of laundry (VSS- 48 ± 43 mg/l and VDS- 632 ± 154 mg/l) with flow of 25 litre/day, it acts as partial two stage RBC in which at the first stage only kitchen effluent is treated and in the second stage mixed effluent is treated. The combined VSS and VDS recorded as 66 ± 33 mg/l and 615 ± 82 mg/l respectively. Final combined effluent treated in partial two stage RBC, shows the reduction in the VSS and VDS in the range of $42 \pm 20\%$, and $84 \pm 5\%$ respectively. Result of the second experiment shows the removal of VSS and VDS in the final effluent is higher than the first experiment while treated separately.

Third experiment continued in progression of the second experiment to treat the effluent with alum dose and activated carbon. The influent of kitchen which contains VSS- 106 ± 45 mg/l and VDS- 414 ± 188 mg/l, and flow with 6 litre/day is mixed with influent of laundry (VSS- 20 ± 9 mg/l and VDS- 799 ± 396 mg/l) with flow of 25 litre/day, connected with two stage RBC. The combined VSS and VDS calculated was 37 ± 10 mg/l and 724 ± 320 mg/l respectively. After treating with alum the combined effluent (31 litre a day) the reduction occurred in the range of 12 ± 6 mg/l and 173 ± 100 mg/l respectively for VSS and VDS (reduction VSS $65 \pm 23\%$ and VDS $72 \pm 13\%$). Further, treatment with activated carbon, VSS and VDS reduced to 10 ± 5 mg/l and 151 ± 85 mg/l respectively (reduction, $7 \pm 42\%$ for VSS and $18 \pm 35\%$ for VDS), however in few samples the VDS values were noticed at higher side which may be due to mixing of coagulant and carbon particles. Overall reduction noted after implying tertiary treatment for VSS and

VDS was $73\pm10\%$ and $78\pm10\%$ respectively. Results indicate that blended treated effluent when passed through activated carbon shows increase in the volatile dissolved solids noticeably. Reason attributed is mixing of bacterial cell during endogenous phase which convert cell tissue in the inert and non biodegradable form. Another reason may be due to the abrasion effect of the higher solids on activated carbon particle when added to the effluent and contributing to VSS. It can be concluded that treating effluent in two stages and thereafter applying tertiary treatment helps in effective removal of VSS while VDS can be removed effectively without implying tertiary treatment.

4.5.7 Ammonia Nitrate and Total Phosphate

During the first experiment considering normal run of RBC's ammonia, nitrate and total phosphate in the laundry influent varied from 16.5 ± 9 mg/l, 0.52 ± 0.22 mg/l and 72 ± 36 mg/l respectively and in the effluent it was recorded as 12 ± 7 mg/l, 0.40 ± 0.16 mg/l and 54 ± 39 mg/l, respectively, which shows reduction in ammonia, nitrate and phosphate in the range of $26\pm5\%$, $7\pm24\%$ and $4\pm69\%$. It shows that ammonia is reduced but nitrate and phosphate was recorded higher in the effluent of laundry RBC. The ammonia, nitrate and phosphate in the kitchen influent varied from 8 ± 3 mg/l, 2.7 ± 4 mg/l and 21 ± 13 mg/l respectively, whereas in the effluent it was recorded as 7 ± 2 mg/l, 2.2 ± 3.8 mg/l and 13 ± 9 mg/l which shows reduction in ammonia, nitrate and phosphate in the range of $14\pm6\%$, $30\pm24\%$ and $14\pm11\%$ respectively. Kitchen RBC has better efficiency rather than laundry RBC in removal of ammonia, nitrate and phosphate.

In the second experiment the effluent of kitchen which contains ammonia 8 ± 3 mg/l, nitrate 2.7 ± 4 mg/l and phosphate 53 ± 17 mg/l in influent, and flow with 6 litre/day is mixed with influent of laundry (ammonia 21 ± 7 mg/l, nitrate 1.45 ± 1.43 mg/l and phosphate 116 ± 6 mg/l) with flow of 25 litre/day. The combined ammonia, nitrate and phosphate concentration recorded was 18 ± 5 mg/l, 1.97 ± 1.4 mg/l and 104 ± 7 mg/l respectively. Final combined effluent contains 9 ± 6 mg/l ammonia, 0.75 ± 0.35 mg/l nitrate and 118 ± 5 mg/l phosphate after treatment in partial two stage RBC. It shows reduction in the in ammonia and nitrate by $50\pm34\%$ and $48\pm47\%$ but increase in phosphate by $-14\pm11\%$.

Third experiment continued in progression of the second experiment to treat the effluent with alum dose and activated carbon. The effluent of kitchen which contains ammonia- 5 ± 4 mg/l, nitrate- 1.28 ± 1.8 mg/l and phosphate- 14 ± 13 mg/l in influent, and flow with 6 litre/day is mixed with influent of laundry (ammonia- 17 ± 7 mg/l, nitrate- 0.3 ± 0.2 mg/l and phosphate- 28 ± 14 mg/l) with flow of 25 litre/day, connected with two stage RBC. The combined ammonia, nitrate and phosphate calculated were 15 ± 6 mg/l, 0.49 ± 0.45 mg/l and 25 ± 11 mg/l respectively. After treating combined effluent with alum, effluent concentration recorded was ammonia- 5 ± 1 mg/l, nitrate- 0.31 ± 0.21 mg/l and phosphate- 20 ± 9 mg/l. Removal of ammonia, nitrate and phosphate concentration noticed in the range of $64\pm16\%$, $23\pm40\%$ and $17\pm8\%$ respectively. Alum dosing proves to be an effective medium to bring down ammonia and phosphate, but for nitrate removal it is not consistent. Alum treated effluent was further treated with activated carbon in which ammonia, nitrate and phosphate recorded 3 ± 1 mg/l, 0.21 ± 0.16 mg/l and 19 ± 8 mg/l respectively (reduction $25\pm15\%$, $23\pm22\%$ and $6\pm3\%$ for ammonia, nitrate and phosphate respectively). It is noticed that the overall reduction in the concentration of ammonia, nitrate and phosphate after implying tertiary treatment was $73\pm11\%$, $38\pm41\%$ and $23\pm8\%$ respectively.

4.5.8 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

In the Antarctic station because of the limited use of water the BOD and COD is always recorded on the higher side as compared to tropical countries. The experiment was conducted in the three stages to understand the removal efficiency. In the first experiment in which both the RBC were used to treat the waste separately, the concentration of BOD was recorded in laundry and kitchen RBC as 473 ± 49 mg/l, 487 ± 92 mg/l, while COD recorded was 1839 ± 429 mg/l and 1521 ± 645 mg/l respectively. In the effluent BOD recorded 153 ± 8 mg/l and 180 ± 80 mg/l in laundry and kitchen RBC, whereas COD recorded in the effluent was 789 ± 239 mg/l and 767 ± 407 mg/l. Treating the waste separately, the removal efficiency occurred in laundry RBC $62\pm6\%$ for BOD and $57\pm6\%$ for COD. Kitchen RBC shows the response almost in the same range i.e. $62\pm18\%$ for BOD and $46\pm26\%$ for COD, during the first experiment. However COD reduction found little lower in comparison to laundry RBC

In the second experiment the effluent of kitchen was mixed with the influent of the laundry at the PST to understand the effect of nutrient on the combined treatment and removal efficiency. Laundry influent contains BOD 396 ± 79 mg/l and COD 1408 ± 386 mg/l. The kitchen influent shows concentration of BOD 417 ± 79 mg/l and COD 1186 ± 474 mg/l. The combined concentration while mixing together recorded BOD 400 ± 73 mg/l and COD 1365 ± 361 mg/l. After treatment the influents from partial two stage RBC the concentration in the effluent recorded was 71 ± 23 mg/l and 193 ± 92 mg/l for BOD and COD respectively. This shows the reduction in BOD and COD by $83 \pm 3\%$ and $85 \pm 3\%$.

The third experiment was conducted to understand the effect of tertiary treatment like alum dose and activated carbon on the treated effluent treatment. In this experiment the laundry influent contains BOD 316 ± 146 mg/l and COD 1070 ± 482 mg/l. The kitchen influent shows concentration of BOD 291 ± 166 mg/l and COD 618 ± 470 mg/l. The combined BOD and COD recorded while mixing together the influents as BOD 311 ± 122 mg/l and COD 982 ± 397 mg/l. After treatment the influents from partial two stage RBC and further with alum the concentration in the effluent recorded 47 ± 29 mg/l and 202 ± 142 mg/l for BOD and COD respectively. This shows the reduction in BOD and COD by $85 \pm 5\%$ and $80 \pm 9\%$. In this experiment the concentration of the BOD and COD recorded was slightly lower than the second experiment but removal of the BOD is slightly higher after addition of alum and COD is slightly reduced compared to second experiment. After passing through the activated carbon the BOD and COD recorded was 27 ± 22 mg/l and COD 104 ± 108 mg/l it indicates that BOD and COD further reduced by $40 \pm 28\%$ and $50 \pm 33\%$ respectively. The overall removal efficacy of the RBC after converting two stage and employing tertiary treatment shows $91 \pm 5\%$ and $90 \pm 8\%$ for BOD and COD respectively.

4.5.9 Sodium, Potassium and Calcium

Sodium and potassium are the essential elements of soap. Sodium, potassium and calcium are hardly removed by the biological or coagulation treatment. In the first experiment in which both the RBCs used to treat the waste separately the concentration of Na, K and Ca was recorded in influent of laundry RBC as 321 ± 78 mg/l, 18 ± 5 mg/l and 41 ± 5 mg/l respectively while same varies in laundry effluent as 169 ± 69 mg/l, 19 ± 6

mg/l and 41 ± 8 mg/l respectively the reduction occurred in the range of $44 \pm 26\%$, $-17 \pm 56\%$ and $-2 \pm 25\%$ respectively. Na, K and Ca in the influent of kitchen RBC was recorded as 196 ± 72 mg/l, 20 ± 13 mg/l and 44 ± 10 mg/l respectively while same varies in effluent as 159 ± 70 mg/l, 19 ± 10 mg/l and 38 ± 14 mg/l respectively, the reduction occurred in the range of $19 \pm 20\%$, $3 \pm 47\%$ and $13 \pm 31\%$ for Na, K and Ca respectively. Concentration of sodium was recorded higher in the laundry effluent because of higher consumption of detergent and soap. In kitchen the liquid detergent and powder detergent is also being used for cleaning of utensils so slightly higher range of sodium and potassium are noticed.

In the second experiment, the effluent of kitchen is mixed with the influent of the laundry at the PST to understand the effect of nutrient on the combined treatment and removal efficacy. Laundry influent contains Na, K and Ca 392 ± 74 mg/l, 14 ± 7 mg/l and 34 ± 8 mg/l respectively. The kitchen influent shows concentration of Na, K and Ca 248 ± 198 mg/l, 13 ± 4 mg/l and 33 ± 8 mg/l respectively. The combined Na, K and Ca recorded while mixing together as Na 341 ± 147 mg/l, K 34 ± 35 mg/l and Ca 71 ± 62 mg/l. After the treatment from partial two stage RBC the concentration in the effluent recorded was Na 364 ± 90 mg/l, K 14 ± 35 mg/l and Ca 34 ± 5 mg/l. This shows the increase in concentration in the effluent which occurred in the range of $-1.5 \pm 48\%$, $-182 \pm 342\%$ and $-119 \pm 214\%$ for Na, K and Ca respectively.

Third experiment was conducted to understand the effect of tertiary treatment with alum dose and activated carbon on the treated effluent. In this experiment, laundry influent contains Na, K and Ca as 312 ± 71 mg/l, 34 ± 50 mg/l and 48 ± 33 mg/l respectively. The kitchen influent shows concentration of Na, K and Ca, 150 ± 55 mg/l, 47 ± 51 mg/l and 45 ± 26 mg/l respectively. The combined Na, K and Ca recorded while mixing together as Na 281 ± 61 mg/l, K 36 ± 39 mg/l and Ca 48 ± 26 mg/l. After the treatment the influents from partial two stage RBC and further with alum the concentration in the effluent recorded are Na 301 ± 18 mg/l, K 74 ± 32 mg/l and Ca 78 ± 25 mg/l. This shows that there is increase in concentration in the effluent which occurred in the range of $-12 \pm 25\%$, $-265 \pm 269\%$ and $-91 \pm 88\%$ for Na, K and Ca respectively. After passing through the activated carbon Na, K and Ca in the effluent recorded concentration as 308 ± 18 mg/l, 87 ± 57 mg/l and 87 ± 45 mg/l This shows increase in concentration in the

effluent which occurred in the range of $-2.2 \pm 3\%$, $-24 \pm 59\%$ and $-14 \pm 41\%$ for Na, K and Ca respectively. The overall removal efficacy of the RBC after converting two stages and employing tertiary treatment shows in the concentration for Na, K and Ca as $-15 \pm 29\%$, $-275 \pm 255\%$, and $-101 \pm 99\%$.

4.5.10 Chromium (Cr), Manganese (Mn) and Iron (Fe)

In the first experiment in which both the RBC used to treat the waste separately the concentration of Cr, Mn and Fe recorded in influent of laundry RBC was $27 \pm 24 \mu\text{g/l}$, $38 \pm 24 \mu\text{g/l}$ and $520 \pm 186 \mu\text{g/l}$ respectively, while same varies in laundry effluent as $5 \pm 3 \mu\text{g/l}$, $34 \pm 13 \mu\text{g/l}$ and $276 \pm 175 \mu\text{g/l}$ respectively indicating the reduction in the range of $58 \pm 35\%$, $-20 \pm 66\%$ and $35 \pm 62\%$ respectively. In the influent of kitchen RBC Cr, Mn and Fe was recorded as $8 \pm 5 \mu\text{g/l}$, $113 \pm 59 \mu\text{g/l}$ and $581 \pm 282 \mu\text{g/l}$ respectively while same varies in effluent as $8 \pm 4 \mu\text{g/l}$, $74 \pm 55 \mu\text{g/l}$ and $428 \pm 213 \mu\text{g/l}$ respectively, the reduction occurred in the range of $-21 \pm 73\%$, $22 \pm 61\%$ and $11 \pm 47\%$ for Cr, Mn and Fe respectively. Cr removal is better in laundry RBC rather than in the kitchen, on the contrary Mn has better removal in kitchen while in laundry effluent it is being added. However, Fe is being absorbed by microbes in both RBC but relatively better in laundry RBC.

In the second experiment the treated effluent of kitchen RBC is mixed with the influent of the laundry at the PST to understand the effect of nutrient on the combined treatment and removal efficacy. Laundry influent contains Cr, Mn and Fe as $43 \pm 60 \mu\text{g/l}$, $39 \pm 21 \mu\text{g/l}$ and $509 \pm 67 \mu\text{g/l}$ respectively. The kitchen influent shows concentration of Cr, Mn and Fe as $21 \pm 15 \mu\text{g/l}$, $167 \pm 93 \mu\text{g/l}$ and $616 \pm 243 \mu\text{g/l}$ respectively. The combined Cr, Mn and Fe recorded while mixing together was $38 \pm 50 \mu\text{g/l}$, $64 \pm 32 \mu\text{g/l}$ and $530 \pm 81 \mu\text{g/l}$. After treatment the influents from partial two stage RBC the concentration in the effluent recorded are Cr $10 \pm 1 \mu\text{g/l}$, $75 \pm 30 \mu\text{g/l}$ and $512 \pm 176 \mu\text{g/l}$. The removal for Cr and Fe occurred with $36 \pm 50\%$ and $5 \pm 25\%$, however Mn is added in the effluent with $-25 \pm 28\%$.

Third experiment was conducted to understand the effect of tertiary treatment with alum dose and activated carbon on the treated effluent. In this experiment, the laundry influent containing Cr, Mn and Fe as $24 \pm 42 \mu\text{g/l}$, $24 \pm 10 \mu\text{g/l}$ and $552 \pm 303 \mu\text{g/l}$

respectively and the kitchen influent shows concentration of Cr, Mn and Fe as 18 ± 13 $\mu\text{g/l}$, 84 ± 32 $\mu\text{g/l}$ and 845 ± 408 $\mu\text{g/l}$ respectively were combined. Cr, Mn and Fe recorded in the combined while mixing together as 23 ± 36 $\mu\text{g/l}$, 36 ± 12 $\mu\text{g/l}$ and 609 ± 289 $\mu\text{g/l}$ respectively. After treatment the influents from partial two stage RBC and further with alum the concentration in the effluent recorded was 16 ± 14 $\mu\text{g/l}$, 25 ± 10 $\mu\text{g/l}$ and 519 ± 222 $\mu\text{g/l}$. This shows increase in concentration of Cr by $-9\pm70\%$ but reduction in Mn and Fe by $22\pm37\%$ and $12\pm18\%$ respectively. After passing through the activated carbon Cr, Mn and Fe recorded in the effluent are 13 ± 6 $\mu\text{g/l}$, 19 ± 6 $\mu\text{g/l}$ and 429 ± 181 $\mu\text{g/l}$, which shows increase in concentration of Cr by $-13\pm59\%$ but reduction in Mn and Fe by $20\pm21\%$ and $13\pm27\%$ respectively. The overall removal efficacy of the RBC after converting two stages and employing tertiary treatment shows increment in the concentration in Cr by $-29\pm138\%$ and reduction in Mn and Fe by $34\pm47\%$, and $21\pm36\%$ respectively.

4.5.11 Nickle (Ni) and Copper (Cu)

In the first experiment in which both the RBC used to treat the waste separately the concentration of Ni and Cu is recorded in influent of laundry RBC as 30 ± 14 $\mu\text{g/l}$ and 13 ± 3 $\mu\text{g/l}$ respectively, while same varies in laundry effluent as 19 ± 17 $\mu\text{g/l}$ and 10 ± 4 $\mu\text{g/l}$ respectively. There is reduction in Ni and Cu occurred in the range of $22\pm64\%$ and $29\pm18\%$ respectively. In the influent of kitchen RBC Ni and Cu was recorded as 24 ± 20 $\mu\text{g/l}$ and 10 ± 3 $\mu\text{g/l}$ respectively while same varies in effluent as 11 ± 6 $\mu\text{g/l}$ and 11 ± 3 $\mu\text{g/l}$ respectively which indicates the reduction for Ni in the range of $34\pm49\%$ but increase in the concentration Cu by $-14\pm32\%$ respectively. Cu removal is better in laundry RBC rather than kitchen RBC on the contrary Ni has better removal in kitchen while in laundry effluent it was recorded slightly less.

In the second experiment the effluent of kitchen is mixed with the influent of the laundry at the PST to understand the effect of nutrient on the combined treatment and removal efficacy. Laundry influent contains Ni and Cu as 31 ± 34 $\mu\text{g/l}$ and 19 ± 10 $\mu\text{g/l}$ respectively. The kitchen influent shows concentration of Ni and Cu as 20 ± 16 $\mu\text{g/l}$ and 24 ± 20 $\mu\text{g/l}$ respectively. Ni and Cu recorded in the combined while mixing together as 75 ± 30 $\mu\text{g/l}$ and 512 ± 176 $\mu\text{g/l}$. After treatment the influents from partial two stage RBC the concentration in the effluent recorded are 29 ± 26 $\mu\text{g/l}$ and 20 ± 12 $\mu\text{g/l}$. The

reduction in Ni and Cu occurred, $11\pm53\%$ and $6\pm22\%$. Treating separately two wastes has better response for Ni removal whereas combined treatment in two stages RBC has positive response for Cu removal.

Third experiment was conducted to understand the effect of tertiary treatment with alum dose and activated carbon on the treated effluent. In this experiment, the laundry influent contains Ni and Cu as $32\pm36 \mu\text{g/l}$ and $18\pm11 \mu\text{g/l}$ respectively. The kitchen influent shows concentration of Ni and Cu as $20\pm18 \mu\text{g/l}$ and $29\pm21 \mu\text{g/l}$ respectively. Ni and Cu in the combined while mixing together, was $30\pm32 \mu\text{g/l}$ and $20\pm11 \mu\text{g/l}$ respectively. After treatment the influents from partial two stage RBC and further with alum the concentration in the effluent recorded Ni and Cu $31\pm46 \mu\text{g/l}$ and $16\pm9 \mu\text{g/l}$ respectively. This shows increase in concentration Ni in range of $-118\pm394\%$ but reduction in Cu by $19\pm20\%$. After passing through the activated carbon Ni and Cu recorded in the effluent are $78\pm103 \mu\text{g/l}$ and $28\pm16 \mu\text{g/l}$ respectively, which shows increase in Ni and Cu by $215\pm317\%$ and $149\pm319\%$ respectively. The overall removal efficacy of the RBC after converting two stages and employing tertiary treatment shows increment in the concentration Ni and Cu by $-71\pm151\%$ and $109\pm291\%$ respectively.

4.5.12 Zinc (Zn), Cadmium (Cd) and Lead (Pb)

In the first experiment in which both the RBCs used to treat the waste separately the concentration of Zn, Cd and Pb was recorded in influent of laundry RBC as $1824\pm436 \mu\text{g/l}$, $0.72\pm0.27 \mu\text{g/l}$ and $30\pm10 \mu\text{g/l}$ respectively, while same varies in laundry effluent as $621\pm259 \mu\text{g/l}$, $0.27\pm0.28 \mu\text{g/l}$ and $12\pm11 \mu\text{g/l}$ respectively. Reduction recorded for Zn, Cd and Pb in the range of $65\pm17\%$ $53\pm51\%$ and $65\pm33\%$ respectively. In the influent of kitchen RBC Zn, Ni and Pb was recorded as $718\pm398 \mu\text{g/l}$, $0.49\pm0.14 \mu\text{g/l}$ and $14\pm7 \mu\text{g/l}$ respectively, while same varies in effluent as $569\pm179 \mu\text{g/l}$, $0.44\pm0.12 \mu\text{g/l}$ and $11\pm4 \mu\text{g/l}$ respectively. The reduction occurred for Zn and Cd in the range of $21\pm26\%$ and $9\pm6\%$ but increase in the concentration of Pb by $-5\pm65\%$. Removal of Zn, Cd and Pb is better in laundry RBC rather than kitchen RBC.

In the second experiment the treated effluent of kitchen RBC was mixed with the influent of the laundry at the PST. Laundry influent contains Zn, Cd and Pb as $3765\pm1152 \mu\text{g/l}$, $0.98\pm0.15 \mu\text{g/l}$ and $31\pm6 \mu\text{g/l}$ respectively. The kitchen influent shows concentration of

Zn, Cd and Pb as $1713 \pm 1043 \mu\text{g/l}$, $0.45 \pm 0.12 \mu\text{g/l}$ and $23 \pm 0.47 \mu\text{g/l}$ respectively. Zn, Cd and Pb recorded in the combined while mixing together was $3367 \pm 1099 \mu\text{g/l}$, $0.87 \pm 0.11 \mu\text{g/l}$ and $25 \pm 5 \mu\text{g/l}$. After treatment the influents from partial two stage RBC the concentration in the effluent recorded was $1111 \pm 178 \mu\text{g/l}$, $0.59 \pm 0.18 \mu\text{g/l}$ and $22 \pm 8 \mu\text{g/l}$ for Zn, Cd, and Pb respectively. The reduction in Zn, Cd and Pb is noted as $65 \pm 8\%$, $31 \pm 23\%$ and $10 \pm 37\%$ respectively. Treating separately two wastes has better response for Zn, Cd and Pb removal in laundry whereas in kitchen RBC it shows better response only for Zn and Cd and combined treatment in two stage RBC has positive response for Zn, Cd and Pb removal but slightly lower than laundry RBC if waste is treated separately.

In the third experiment the laundry influent contains Zn, Cd and Pb as $1506 \pm 762 \mu\text{g/l}$, $1.3 \pm 1.1 \mu\text{g/l}$ and $18 \pm 8 \mu\text{g/l}$ respectively. The kitchen influent shows concentration of Zn, Cd and Pb as $1006 \pm 641 \mu\text{g/l}$, $0.82 \pm 0.36 \mu\text{g/l}$ and $15 \pm 67 \mu\text{g/l}$ respectively. Zn, Cd and Pb recorded in the combined while mixing together was $1409 \pm 585 \mu\text{g/l}$, $1.2 \pm 0.77 \mu\text{g/l}$ and $15 \pm 6 \mu\text{g/l}$ respectively. After treatment the influents from partial two stage RBC and further with alum the concentration in the effluent recorded was $955 \pm 564 \mu\text{g/l}$, $1.3 \pm 1.8 \mu\text{g/l}$ and $14 \pm 6 \mu\text{g/l}$ for Zn, Cd and Pb respectively. This shows increase in concentration of Cd and Pb in range of $-50 \pm 197\%$ and $-7 \pm 20\%$ but reduction in Zn by $10 \pm 89\%$. After passing through the activated carbon Zn, Ni and Pb recorded in the effluent are $732 \pm 338 \mu\text{g/l}$, $1.21 \pm 1.4 \mu\text{g/l}$ and $13 \pm 5 \mu\text{g/l}$, which shows the decrease in concentration of Zn by $11 \pm 40\%$, but increase in Cd and Pb by $-51 \pm 144\%$ and $-1.5 \pm 50\%$ respectively. The overall removal efficacy of the RBC after converting two stages and employing tertiary treatment shows reduction in the concentration in Zn by $36 \pm 49\%$, whereas increase is recorded of Cd and Pb by $-88 \pm 222\%$, and $-761 \pm 2691\%$ respectively.

Correlation coefficient during three experiments, among various physico-chemical parameters are presented from Table 4.3 to Table 4.12.

Table - 4. 3 : Correlation among Various Parameters during First Experiments (Laundry RBC Influent and Effluent)

	pH	Temp	Cond.	DO	TS	DS	SS	VSS	VDS	BOD	COD	NH ₃	NO ₃	PO ₄	Na	K	Ca
pH	0.00																
Temp	-0.04	0.09															
Conductivity	0.83	0.24	0.59														
DO	-0.62	-0.41	0.57	-0.54													
	0.52	-0.13	0.90	0.58	0.90												
DS	0.52	-0.14	0.90	0.58	0.90	0.89											
SS	-0.14	0.01	0.69	-0.11	0.53	0.51	1.00										
VSS	0.38	0.37	0.58	0.36	0.87	0.86	0.83	0.67									
VDS	0.31	-0.11	0.89	0.36	0.82	0.81	0.85	0.73	0.81								
BOD	0.27	0.16	-0.72	0.22	-0.40	-0.37	-0.97	-0.98	-0.35	-0.05							
COD	-0.47	0.15	0.37	-0.47	0.20	0.17	0.93	0.98	0.10	-0.19	0.90						
NH ₃	0.71	-0.37	0.85	0.80	0.79	0.80	0.28	0.10	0.87	0.84	0.22	1.00					
NO ₃	0.87	0.06	0.66	0.89	0.96	0.97	0.32	0.09	0.99	0.98	0.37	0.88	0.54				
PO ₄	0.28	0.89	-0.10	0.16	0.56	0.55	0.49	0.36	0.44	0.37	0.70	-0.08	0.10	-0.01			
Na	0.78	-0.09	-0.07	0.79	0.21	0.24	-0.70	-0.84	0.31	0.57	-0.65	0.38	-0.37	-0.85	0.14		
K	-0.10	0.13	-0.86	-0.16	0.21	-0.68	-0.93	-0.85	-0.67	-0.42	-0.87	-0.64	-0.97	0.08	-0.83	0.02	
Ca	0.41	0.49	-0.76	0.31	-0.19	-0.17	-0.83	-0.88	-0.18	0.10	-0.65	-0.38	-0.89	-0.32	-0.53	-0.17	-0.13

Table - 4. 4 : Correlation among Various Parameters during First Experiments (Kitchen RBC Influent and Effluent)

	pH	Temp	Cond.	DO	TS	DS	SS	VSS	VDS	BOD	COD	NH ₃	NO ₃	PO ₄	Na	K	Ca
pH	0.68																
Temp	-0.69	0.08															
Conductivity	-0.82	0.46	0.62														
DO	0.25	-0.67	0.65	1.00													
TS	-0.64	0.20	0.79	0.46	0.81												
DS	-0.65	0.27	0.79	0.41	0.83	0.87											
SS	0.00	0.16	1.00	0.63	0.94	0.91	1.00										
VSS	-0.21	0.06	0.98	0.70	0.91	0.89	0.95	0.92									
VDS	-0.66	0.70	0.63	-0.04	0.83	0.89	0.61	0.69	0.45								
BOD	-0.89	-0.05	0.03	0.09	0.06	0.15	-0.08	-0.08	0.78	0.07							
COD	-0.83	-0.11	0.21	0.28	0.20	0.27	0.10	0.09	0.89	0.25	0.44						
NH ₃	-0.65	-0.15	-0.62	-0.33	-0.56	-0.48	-0.70	-0.69	0.27	-0.58	-0.41	0.98					
NO ₃	0.02	0.86	0.41	-0.35	0.64	0.64	0.49	0.59	-0.38	0.36	0.31	-0.61	0.99				
PO ₄	-0.38	-0.67	0.11	0.61	-0.09	-0.07	0.00	-0.09	0.85	0.17	0.27	0.63	-0.86	0.97			
Na	-0.61	0.64	0.75	0.09	0.91	0.95	0.73	0.79	0.48	0.73	0.82	-0.06	0.52	-0.02	0.66		
K	-0.64	-0.15	0.59	0.59	0.91	0.56	0.50	0.47	0.99	0.63	0.76	0.41	-0.35	0.77	0.97	0.72	
Ca	-0.73	0.10	0.66	0.45	0.66	0.71	0.58	0.58	0.92	0.69	0.82	0.35	-0.13	0.59	0.95	0.60	0.52

Table - 4. 5 : Correlation among Various Parameters during Second Experiments (Laundry RBC Influent and Combined Effluent)

	pH	Temp	Cond.	DO	TS	DS	SS	VSS	VDS	BOD	COD	NH ₃	NO ₃	PO ₄	Na	K	Ca
pH	-0.32																
Temp	0.97	0.64															
Conductivity	-0.32	-0.71	0.96														
DO	0.10	0.20	0.35	-0.96													
TS	-0.95	-0.74	-0.04	0.17	0.80												
DS	-0.85	-0.78	0.01	0.36	0.81	0.88											
SS	-0.76	-0.82	0.68	-0.61	0.86	0.77	0.80										
VSS	-0.66	-0.81	0.78	-0.63	0.84	0.74	0.81	0.68									
VDS	-0.69	0.29	-0.66	-0.26	-0.14	-0.18	0.23	0.46	-0.60								
BOD	-0.03	0.15	-0.73	0.92	-0.16	0.00	-0.88	-0.78	-0.87	0.90							
COD	-0.69	-0.45	-0.40	0.59	0.48	0.59	-0.40	-0.34	-0.70	0.95	0.75						
NH ₃	0.16	0.44	-0.88	0.82	-0.44	-0.30	-0.87	-0.72	-0.92	0.73	0.14	0.26					
NO ₃	0.31	0.12	0.61	-0.85	-0.12	-0.27	0.75	0.67	0.83	-0.98	-0.63	-0.71	0.29				
PO ₄	-0.26	-0.80	0.95	-0.22	0.73	0.70	0.39	0.15	0.79	-0.18	0.51	0.42	0.88	-0.90			
Na	-0.68	-0.06	-0.65	0.09	0.19	0.21	-0.01	0.19	-0.77	0.56	0.14	0.16	-0.82	0.73	-0.43		
K	0.65	0.91	-0.83	0.43	0.19	-0.84	-0.64	-0.48	-0.63	0.11	-0.49	-0.38	-0.54	0.60	-0.99	-0.34	
Ca	0.68	0.90	-0.80	0.48	-0.91	-0.83	-0.69	-0.54	-0.61	0.13	-0.45	-0.33	-0.48	0.54	-0.82	-0.40	-0.53

Table - 4. 6 : Correlation among Various Parameters during Second Experiments (Kitchen RBC Influent and Combined Effluent)

	pH	Temp	Cond.	DO	TS	DS	SS	VSS	VDS	BOD	COD	NH ₃	NO ₃	PO ₄	Na	K	Ca
pH	-0.21																
Temp	-0.11	0.00															
Conductivity	-0.90	0.51	0.47														
DO	-0.31	0.99	0.21	-0.60													
TS	0.18	-0.49	0.80	0.98	0.55												
DS	0.10	-0.64	0.66	0.99	0.38	0.34											
SS	-0.54	0.36	0.87	0.40	0.92	0.95	0.83										
VSS	-0.65	0.42	0.79	0.30	0.88	0.92	0.75	0.78									
VDS	0.39	0.10	0.45	0.24	0.40	0.30	0.54	0.54	-0.43								
BOD	0.70	-0.93	-0.25	0.50	-0.56	-0.64	-0.26	-0.38	-0.05	-0.22							
COD	0.48	-0.82	0.44	0.95	0.10	0.02	0.41	0.28	0.46	0.47	0.37						
NH ₃	0.83	-0.77	-0.40	0.27	-0.65	-0.73	-0.37	-0.47	-0.36	-0.38	-0.53	-0.25					
NO ₃	-0.62	0.96	-0.01	-0.73	0.33	0.40	0.00	0.14	-0.19	-0.05	0.06	0.15	0.65				
PO ₄	-0.93	0.15	0.30	0.14	0.37	0.46	0.21	0.23	0.83	0.33	0.52	0.68	-0.26	0.51			
Na	0.77	-0.34	0.58	0.67	0.37	0.27	0.63	0.56	-0.04	0.58	0.39	-0.86	0.22	0.10	0.12		
K	0.72	-0.23	-0.71	-0.39	0.37	-0.80	-0.65	-0.66	-0.85	-0.73	-0.86	-0.26	-0.02	-0.47	-0.93	-0.54	
Ca	0.68	-0.26	-0.76	-0.39	-0.80	-0.85	-0.70	-0.71	-0.82	-0.77	-0.89	-0.18	-0.09	-0.42	-0.92	-0.54	-0.51

Table - 4. 7 : Correlation among Various Parameters during Third Experiments (Laundry RBC Influent and Combined Alum Treated Effluent)

	pH	Temp	Cond.	DO	TS	DS	SS	VSS	VDS	BOD	COD	Turb.	NH ₃	NO ₃	PO ₄	Na	K	Ca
pH	-0.43																	
Temp	-0.33	0.60																
Conductivity	-0.03	0.66	0.69															
DO	-0.40	-0.66	-0.53	0.44														
TS	0.01	0.54	0.86	-0.38	0.87													
DS	0.00	0.55	0.85	-0.39	0.86	0.86												
SS	-0.06	0.30	0.46	-0.21	0.47	0.46	0.73											
VSS	0.03	0.01	0.37	-0.10	0.43	0.41	0.72	0.22										
VDS	-0.22	0.21	0.50	-0.36	0.50	0.49	0.55	0.20	0.61									
BOD	0.57	0.24	0.71	0.12	0.84	0.84	0.52	0.63	0.85	0.84								
COD	0.55	0.14	0.35	0.23	0.55	0.55	0.38	0.52	0.60	0.60	0.76							
Turbidity	0.50	0.17	0.49	0.26	0.55	0.56	0.14	0.70	0.51	0.46	0.49	0.26						
NH ₃	0.33	-0.29	-0.06	0.45	0.21	0.20	0.42	0.27	0.28	0.42	0.60	0.71	0.31					
NO ₃	0.40	0.22	-0.27	0.29	-0.21	-0.21	-0.32	-0.16	-0.27	-0.23	-0.22	-0.20	0.16	0.86				
PO ₄	-0.10	-0.30	-0.20	-0.08	-0.17	-0.16	-0.23	-0.54	-0.04	0.06	0.19	0.29	-0.45	-0.07	0.93			
Na	0.34	-0.12	0.50	-0.02	0.57	0.56	0.46	-0.08	0.60	0.45	0.53	0.15	0.27	-0.38	-0.07	0.58		
K	0.28	0.60	0.22	-0.16	0.57	0.28	0.51	0.25	0.21	0.13	0.28	0.11	0.10	0.17	-0.34	0.29	-0.13	
Ca	0.20	0.64	0.26	-0.19	0.29	0.28	0.50	0.29	0.20	0.12	0.24	0.11	0.08	0.13	-0.41	0.30	-0.17	-0.13

Table - 4. 8 : Correlation among Various Parameters during Third Experiments (Kitchen RBC Influent and Combined Alum Treated Effluent)

	pH	Temp	Cond	DO	TS	DS	SS	VSS	VDS	BOD	COD	Turb	NH ₃	NO ₃	PO ₄	Na	K	Ca
pH	-0.08																	
Temp	0.44	0.50																
Conductivity	0.12	0.36	0.48															
DO	-0.17	-0.66	-0.30	0.85														
TS	0.08	0.28	0.39	-0.52	0.11													
DS	0.08	0.29	0.40	-0.53	0.12	0.13												
SS	0.24	0.00	0.54	-0.26	0.45	0.46	0.34											
VSS	0.24	-0.30	0.29	-0.24	0.08	0.11	-0.08	-0.09										
VDS	0.04	0.09	0.33	-0.44	0.09	0.08	0.06	0.07	0.17									
BOD	0.04	0.19	0.15	-0.38	-0.04	0.00	-0.31	-0.43	0.00	-0.04								
COD	-0.02	0.20	0.14	-0.23	-0.05	-0.01	-0.35	-0.41	-0.10	0.02	-0.22							
Turbidity	-0.17	0.21	-0.20	-0.21	-0.22	-0.18	-0.40	-0.50	-0.15	0.00	-0.18	0.06						
NH ₃	-0.07	-0.30	0.10	0.11	0.12	0.17	-0.36	-0.39	0.07	0.08	-0.11	0.25	0.53					
NO ₃	0.38	0.36	0.20	0.27	0.04	0.02	0.09	0.10	-0.27	-0.15	-0.38	-0.04	0.04	0.52				
PO ₄	-0.26	-0.13	0.02	0.32	0.21	0.20	0.35	0.33	0.23	0.28	0.35	0.24	0.08	-0.17	0.15			
Na	0.20	-0.25	-0.11	-0.49	-0.34	-0.31	-0.53	-0.59	-0.24	-0.41	-0.22	0.40	-0.02	-0.01	-0.29	-0.14		
K	0.40	0.45	0.44	-0.50	-0.34	0.05	0.11	0.05	-0.07	-0.26	-0.26	0.40	-0.31	-0.02	-0.20	0.41	-0.43	
Ca	0.37	0.46	0.41	-0.52	0.06	0.03	0.14	0.08	-0.06	-0.26	-0.24	0.40	-0.35	-0.06	-0.17	0.40	-0.43	
																	-0.11	

Table - 4. 9 : Correlation among Various Parameters during Third Experiments (Alum Treated Effluent and Activated Carbon Treated Effluent)

	pH	Temp	Cond	DO	TS	DS	SS	VSS	VDS	BOD	COD	Turb.	NH ₃	NO ₃	PO ₄	Na	K	Ca
pH	-0.12																	
Temp	0.37	0.95																
Conductivity	-0.06	0.58	0.66															
DO	0.10	-0.04	-0.01	0.67														
TS	0.12	0.45	0.77	-0.45	0.87													
DS	0.15	0.47	0.75	-0.45	0.86	0.87												
SS	0.51	0.71	0.46	-0.42	0.45	0.46	0.77											
VSS	0.43	0.47	0.39	-0.01	0.33	0.34	0.66	0.33										
VDS	-0.11	0.45	0.24	-0.21	0.36	0.36	0.42	0.31	0.74									
BOD	-0.25	-0.26	0.19	-0.10	0.37	0.36	0.33	0.46	0.32	0.81								
COD	-0.25	-0.34	0.06	0.16	0.20	0.20	0.21	0.38	0.40	0.51	0.68							
Turbidity	-0.55	-0.46	0.12	-0.19	0.26	0.26	-0.04	0.07	0.21	0.73	0.89	0.67						
NH ₃	-0.22	-0.28	0.02	-0.11	0.20	0.21	0.25	0.41	0.46	0.46	0.62	0.15	0.81					
NO ₃	-0.17	0.01	-0.12	-0.16	-0.35	-0.36	-0.22	-0.35	-0.40	0.03	0.28	-0.33	0.14	0.84				
PO ₄	0.19	0.08	-0.34	0.13	-0.29	-0.30	0.08	-0.02	0.08	-0.05	-0.10	-0.05	-0.03	-0.12	1.00			
Na	-0.35	-0.35	-0.14	-0.19	0.00	0.00	-0.19	0.05	0.07	0.15	0.07	-0.06	0.03	-0.24	0.32	0.86		
K	-0.38	0.29	0.42	-0.14	0.00	0.48	-0.10	-0.09	0.40	-0.12	-0.14	-0.07	-0.23	-0.27	-0.58	0.43	0.37	
Ca	-0.37	0.30	0.44	-0.14	0.48	0.48	-0.09	-0.10	0.37	-0.13	-0.16	-0.07	-0.25	-0.24	-0.58	0.42	0.38	0.46

Table - 4. 10 : Correlation among Various Trace Elements during First, Experiments

a. Laundry RBC Influent and Effluent

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
Cr	0.51							
Mn	-0.39	-0.85						
Fe	-0.93	-0.48	-0.46					
Ni	-0.79	-0.69	-0.71	-0.40				
Cu	-0.76	-0.60	-0.15	-0.87	0.99			
Zn	-0.44	-0.99	-0.76	-0.89	0.64	0.33		
Cd	-0.96	-0.50	-0.40	-0.41	0.61	0.14	-0.42	
Pb	-0.95	-0.51	-0.44	-0.39	0.57	0.19	-0.45	0.61

b. Kitchen RBC Influent and Effluent

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
Cr	0.62							
Mn	-0.37	0.51						
Fe	-0.44	0.18	-0.23					
Ni	-0.49	0.30	-0.11	0.25				
Cu	-0.75	-0.46	-0.04	0.83	0.60			
Zn	-0.76	0.13	0.11	0.40	0.03	0.55		
Cd	-0.70	0.70	0.85	-0.45	-0.45	0.96	0.96	
Pb	-0.71	0.32	0.16	0.22	-0.17	0.59	0.37	0.58

Table - 4. 11 : Correlation among Various Trace Elements during Second, Experiments

a. Laundry RBC Influent and combined Effluent

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
Cr	0.71							
Mn	-0.94	0.95						
Fe	-0.91	0.99	0.99					
Ni	-0.93	0.74	0.73	0.69				
Cu	-0.86	0.82	0.83	0.87	0.99			
Zn	-0.75	0.88	0.91	0.92	0.89	0.74		
Cd	-0.59	0.37	0.40	0.78	0.91	0.20	-0.41	
Pb	-0.60	0.71	0.66	-0.09	0.12	0.85	0.98	0.01

b. Kitchen RBC Influent and Effluent

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
Cr	0.48							
Mn	-0.44	0.59						
Fe	-0.28	0.67	0.27					
Ni	-0.73	0.35	-0.03	0.15				
Cu	-0.68	0.30	-0.15	0.07	0.91			
Zn	-0.47	0.34	-0.12	0.12	0.86	0.35		
Cd	-0.97	-0.20	-0.56	-0.41	0.94	-0.40	0.77	
Pb	0.46	1.00	0.91	0.98	-0.18	0.92	-0.23	0.96

Table - 4. 12 : Correlation among Various Trace Elements during Third Experiments

a. Laundry RBC Influent and combined Alum treated Effluent

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
Cr	0.82							
Mn	-0.16	0.34						
Fe	0.43	0.30	0.86					
Ni	-0.14	-0.23	0.04	0.15				
Cu	0.41	0.27	0.75	0.33	0.85			
Zn	0.11	-0.42	0.12	-0.13	0.15	-0.24		
Cd	-0.12	0.31	-0.06	-0.25	-0.12	-0.07	0.10	
Pb	0.26	-0.40	0.41	-0.06	0.44	-0.13	0.34	0.24

b. Kitchen RBC Influent and combined Alum treated Effluent

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
Cr	0.77							
Mn	-0.25	0.08						
Fe	0.37	0.55	0.67					
Ni	-0.03	-0.29	-0.02	-0.05				
Cu	0.41	0.61	0.64	0.02	0.49			
Zn	0.09	0.04	0.52	-0.13	0.34	0.45		
Cd	-0.31	0.07	-0.34	-0.34	-0.32	-0.33	0.24	
Pb	0.45	0.26	0.82	-0.18	0.49	0.61	-0.58	0.79

c. Alum treated Effluent and Activated Carbon Treated effluent

	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb
Cr	0.44							
Mn	-0.25	0.66						
Fe	0.31	0.16	0.75					
Ni	-0.28	-0.35	-0.11	0.77				
Cu	-0.01	-0.40	0.07	0.46	0.15			
Zn	0.10	-0.11	0.45	0.29	0.53	0.23		
Cd	-0.29	0.91	-0.33	-0.24	-0.33	-0.26	0.90	
Pb	0.03	-0.06	0.44	0.26	0.44	0.17	-0.32	0.51

4.6 DISCUSSION

Biological wastewater treatment involves the transformation of dissolved and suspended organic contaminants to biomass and evolved gases like CO₂, CH₄, N₂ and SO₂ (*Low and Chase, 1999*). Thermophilic wastewater treatment system demonstrated removal of significant BOD and COD (*LaPara and Alleman, 1999; LaPara et al., 2000*) and laboratory scale study carried out by many scientists showed that the system successfully achieved 80% COD removal. It is recognized that per capita BOD loads in Antarctica tend to be high. (*Lori et al., 1996*) cite a figure of 100-120 g BOD per person, contrasting this figure of 60 g BOD per person is often quoted in textbooks (*Connor, 2008*). It is also possible that the higher per capita BOD in most research stations might be caused by a more concentrated waste stream and little dilution from wash water since water use is restricted. Flow rate in most of the stations varies from 100-165 litres per capita per day. Both the RBC at Maitri tends to run on the full design capacity assuming future load in the station for worst case scenario and variation in the day to day load of BOD and COD.

4.6.1 First Experiment (Separate Treatment)

In the first experiment gray water from laundry and kitchen sink was treated separately for ten days and intermittent analysis of the influent and effluent was carried out. The removal of the BOD and COD recorded was around 62% BOD and 57% COD for laundry waste and 62% BOD and 46% COD for the kitchen waste. The average BOD load in both RBC was kept higher than the designed load by 57% in laundry and 62% in kitchen RBC. This load is corresponding to similar load being generated at present at Maitri station and accordingly the COD load also increases. Average BOD/COD ratio in the influent was found to be 0.26 which decreases in the effluent to 0.23 in the laundry waste, while in the kitchen it is recorded 0.37 in the influent which decreases to 0.25 in the effluent. The ratio of BOD/COD for the wastewater is 0.4 to 0.8 for of the black water which contains human excreta. The ratio recorded here is less as organic matter which mainly attributes to BOD is less in gray water as compared to black water. The organic loading to laundry RBC recorded average 11.8 g BOD/m²/day and 45.9 g COD/m²/day, whereas in kitchen RBC it is recorded 10.4 g BOD/m²/day and 32.6 g COD/m²/day. The organic loading in this experiment noticed still in the range of values

generally accepted for secondary treatment with nitrification, 7.0-15 g BOD₅/m²/day (*Metcalf and Eddy, 1995*). Disk rotational speed effect is also observed on BOD and COD removal. During first five days the rpm of laundry RBC kept 1.6 and of kitchen RBC 5.5. Further the rpm of laundry RBC increased to 7 which eventually increased the COD removal by 5% and BOD by 8% average.

Demand parameters (BOD and COD) show significant correlation with; BOD-NH₃ ($r=0.84$ laundry), BOD-NO₃ ($r=0.98$ laundry), COD-COD ($r=0.9$ laundry), COD-Na ($r=0.82$ kitchen), COD-Ca ($r=0.82$ kitchen) and a good correlation between COD-PO₄ ($r=0.7$ laundry), COD-K ($r=-0.87$ laundry, $r=0.76$ kitchen). This indicates that COD is dominated by these inorganic elements. Therefore if concentration in the influent increases, concentration in the effluent also increases owing to limitation of microorganism to absorb and convert these elements. The kitchen influent did not show any correlation with effluent parameters. If organic load increases the removal efficiency also increases in the laundry RBC as shown by significant negative correlation between, conductivity-BOD ($r=-0.72$ laundry). A significant positive correlation among influent and effluent of RBC; SS-COD ($r=0.93$ laundry), VDS-COD ($r=0.89$ kitchen). VDS-BOD ($r=0.78$ kitchen) shows that if the concentration of SS increases it does not settle beyond an optimum range due to colloidal impact and in therefore in the effluent the concentration increases and SS are dominated by inorganic matter and therefore COD recorded is high. However a negative correlation between SS-BOD ($r=-0.97$ laundry), indicates settling of SS settles or being absorbed by microorganism if they are organic in nature.

During the experiment, average temperature in the bio chamber recorded is 25°C for laundry RBC and 25.8°C for kitchen RBC, which was around three degrees less than the ambient temperature. This indicates the use of organic matter and energy in the form of heat in the synthesis of the microorganism grown in the bio-disk. Costly and Wallis (2000) experimented on the lab scale wastewater treatment from RBC and found that poor biofilm development prompted before insertion of a heating element which maintained medium temperature at 26°C. However biofilm development prior to addition of the heating element was limited. Significant correlation was found between laundry influent and effluent and kitchen influent and effluent between the parameters;

pH-conductivity ($r=0.83$ laundry, $r=-0.82$ kitchen). A positive correlation in the laundry shows increase in concentration of detergent tends to increase pH hence the conductivity in the effluent. Whereas negative correlation in the kitchen RBC, which is acidic in nature indicates, if pH increases it can support growth of microorganism and removal of total solids which in turn decreases the conductivity. On the contrary if pH decreases the organic removal capacity of microorganism decreases which increases BOD and COD in effluent which can be supported by negative correlation obtained between pH-BOD ($r=-0.89$ kitchen), pH-COD ($r=-0.83$ kitchen).

Nitrification (*Vabboliene et al., 2007*) depends on pH and alkalinity. In the laundry influent pH was almost higher than 7.5, so conversion of ammonia to nitrate was facilitated hence showing significant correlation between pH- NO_3 ($r=0.87$ laundry) and a good correlation ($\leq 0.80 \geq 0.70$) between pH- NH_3 ($r=0.71$ laundry). Other nutrients which are needed for the growth of microorganism are Na, K and Ca apart from nitrogen, phosphorus and trace metals. The effect of pH can be seen in the removal of Na and Ca. A significant correlation between pH-Na ($r=0.78$ laundry), pH-Ca ($r=-0.73$ kitchen), indicates that at higher pH in the laundry influent Na absorption is low whereas, in the kitchen waste which is acidic in nature if pH is increases Ca absorption increases and therefore Ca presence decreases in the effluent.

Temperature plays an important role in the nitrification process and rate, which is higher at higher temperature. This can be seen from positive correlation of influent and effluent of kitchen RBC; temperature- NO_3 ($r= 0.86$ kitchen). The above statement also supports a significant correlation among; NH_3-NH_3 ($r=0.98$ kitchen), NH_3-NO_3 ($r=0.88$ laundry), NO_3-NO_3 ($r=0.99$ kitchen). Dissolved oxygen supports the nitrification process which is noticed to be higher in laundry influent rather kitchen influent indicated by significant correlation DO- NH_3 ($r=0.8$ laundry), DO- NO_3 ($r=0.89$ laundry), DO-DO ($r=1$ kitchen). A negative correlation between temperature and VDS ($r=0.7$ kitchen) indicates that at higher temperature microorganism absorbs the organic part of the VDS, and left behind inorganic part. It is seen that there was competition among the organic and inorganic absorption to the microorganism. Further, when DO is high, organic consumption is accelerated and reduction in inorganic consumption is noted. This statement is substantiated by significant correlation between DO-Na ($r=0.79$ laundry). It is also

noticed that overall ammonia was dropped at a higher organic loading which can be attributed to the domination of heterotrophic (*Chuang and Ouyang, 2000*) bacteria at a high organic loading rate which exerted a negative effect on the rate of nitrification (*Tawfic et al., 2002*).

Conductivity is mainly attributed to the presence of ions in the water and weak salts. This is supported by a significant correlation in the influent and effluent; conductivity-TS ($r=0.9$ laundry), conductivity-DS ($r=0.9$ laundry), conductivity-SS ($r=1$ kitchen), conductivity-VTS ($r=0.88$ laundry), conductivity-VSS ($r=0.98$ kitchen), conductivity-VDS ($r=0.89$ laundry), conductivity- NH_3 ($r=0.85$ laundry). A negative correlation between conductivity-Ca ($r=-0.76$ laundry) indicates that calcium though one of the elements responsible for conductivity, it is hardly being removed. Other elements are being removed in higher percentage and therefore conductivity is governed by other elements in the influent.

Total solids mainly contains dissolved solids i.e. average 96% in laundry influent and 85% in kitchen influent and are found to be removed on an average 56.5% from laundry and 49.5% from the kitchen effluent. In the laundry influent the ratio of VDS/DS recorded is 0.45 and VSS/SS recorded is 0.72, whereas in effluent ratio of VDS/DS is reduced to 0.41 but VSS/SS increased to 0.84. In the kitchen influent VDS/DS ratio recorded is 0.54, and VSS/SS is 0.87 and in the effluent same is reduced to 0.45 and 0.82 respectively. Volatile dissolved solids were removed on an average 61% and 52% from the laundry and kitchen influent whereas volatile suspended solids was removed from laundry influent by 53.5% and from the kitchen on an average 30%. This ratio substantiates that large portion of suspended solids is contributed by organic matter. In the effluent, the volatile solids from dissolved as well as suspended solids were removed marginally. This can be seen from significant correlation obtained between TS-TS ($r=0.9$ laundry, $r=0.81$ kitchen), TS-DS ($r=0.9$ laundry, $r=0.83$ kitchen), TS-SS ($r=0.94$ kitchen), TS-VSS ($r=0.87$ laundry, $r=0.91$ kitchen), TS-VDS ($r=0.82$ laundry, $r=0.83$ kitchen), TS- NO_3 ($r=0.89$ laundry), TS-Na ($r=0.91$ kitchen) TS-K ($r=0.91$ kitchen). Total Dissolved Solids (TDS) is a measure of inorganic salts, organic matter and other dissolved material in water (*USEPA, 1986*). TDS do not differentiate among ions whereas it integrates all anions and cations in the sample (*Phyllis et al., 2007*).

Significant correlation obtained validates the statement; DS-DS ($r=0.89$ laundry, $r=0.97$ kitchen), DS-SS ($r=0.91$ kitchen) DS-VTS ($r=0.81$ laundry, $r=0.93$ kitchen), DS-VSS ($r=0.86$ laundry, 0.89 kitchen), DS-VDS ($r=0.81$ laundry, $r=0.89$ kitchen), DS-NH₃ ($r=0.8$ laundry), DS-NO₃ ($r=0.97$ laundry), DS-Na ($r=0.91$ kitchen), DS-K ($r=0.91$ kitchen), SS-VSS ($r=0.83$ laundry, $r=0.95$ kitchen), SS-VDS ($r=0.85$ laundry), SS-Ca ($r=-0.83$ laundry), VDS-NH₃ ($r=0.87$ laundry), VDS-NO₃ ($r=0.99$ laundry), VDS-PO₄ ($r=0.85$ kitchen), VDS-Ca ($r=0.92$ kitchen) and indicates the removal of solids depend upon the influent concentration. Another possible reason is that laundry waste contains the detergent and the soap and urine quantity so phosphate, ammonia and sodium recorded average 3.5, 2 and 1.6 times higher than the kitchen waste. Kitchen waste on the contrary has higher nitrate concentration than the laundry, which is mainly due to the early nitrification in the influent itself which is attributed by ingredient of the waste. The pH of the kitchen waste is recorded acidic and the DO concentration obtained is also less in the kitchen influent which is responsible for bacterial growth and function and therefore removal efficiency is slightly lower in kitchen RBC than the laundry RBC.

A good correlation exist between TS-NH₃ ($r=0.79$ laundry), TS-Na ($r=0.79$ laundry, $r=0.71$ kitchen), SS-VTS ($r=0.7$ kitchen), VSS-Na ($r=0.79$ kitchen). A negative correlation between SS-K ($r=-0.93$ laundry) shows suspended particles have the ability to coagulate the dissolved potassium ion which facilitates settling of K and therefore higher the suspended particles in the influent, lower the potassium concentration in the effluent.

Alkalinity plays an important role in nitrification process. Higher alkalinity increases the process of nitrification. Alkalinity is caused by the presence of hydroxides, carbonates and bicarbonates and of elements such as calcium, magnesium, sodium, potassium, phosphate or ammonia. If these elements are present the nitrification rate increases. On the contrary de-nitrification process occurred in anoxic condition and microorganism requires carbon which is present in organic matter. Nutrients showing significant and good negative correlation between NO₃-PO₄ ($r=-0.86$ kitchen) NO₃-K ($r=-0.97$ laundry), NO₃-Ca ($r=-0.89$ laundry), Na-K ($r=-0.83$ laundry) indicates process of de-nitrification which increases the alkalinity. Significant and good positive correlation; PO₄-PO₄ ($r=0.97$ kitchen), PO₄-Na ($r=-0.85$ laundry), Na-K ($r=0.97$ kitchen), Na-Ca ($r=0.95$

kitchen) PO₄-K ($r=0.77$ kitchen) and K-K ($r=0.72$ kitchen) indicates the removal of these all elements is limited to microorganism's absorption/conversion.

Unlike the organic compounds metals are totally non-degradable and hence tend to accumulate in the environment (Baird and Cann, 1995). Although metals cannot be broken down into other products they may, as a result of biological action undergo changes in valency and /or undergo conversion into organometallic compounds (a 1992). The metal binding capacity for the heavy metals recorded is the decreasing order Pb>Zn>Cr>Cd>Fe>Cu>Ni (65.5%, 65%, 58%, 53%, 35%, 29%, 22%) whereas the Mn and Co are added into the effluent. A sizeable increase in the removal of metals was noted after pH is increased to 10. On the contrary, in the kitchen RBC the removal of metals occurred in decreasing order Ni>Mn>Fe>Cd (34%, 22%, 11%, 9%), whereas negative removal occurred for Pb, Zn, Cu and Cr. The removal of Mn during startup was high while as experiment progressed higher concentration was noticed in the effluent. It also gives idea that cells may exhibit resistant mechanism to enable them to withstand high concentration of such metals and hence exhibits either low sorption or desorption capacities. Among the trace metal parameters of influent and effluent a significant and good negative correlation was noted among; Cr-Fe ($r=-0.93$ laundry), Cr-Cd ($r=-0.96$ laundry), Mn-Mn ($r=-0.85$ laundry), Mn-Zn ($r=-0.99$ laundry), Ni-Cu ($r=-0.87$ laundry), Ni-Zn ($r=-0.89$ laundry), Cr-Ni ($r=-0.79$ laundry), Cr-Cu ($r=-0.75$ kitchen), Cr-Zn ($r=-0.76$ kitchen), Cr -Pb ($r=-0.71$ kitchen), and they provide the information that there is competition exists among these metals for the bio-sorption (Taseli et al., 2008). A positive significant and good correlation among Fe-Cd ($r=0.85$ kitchen), Zn-Cd ($r=0.96$ kitchen) Ni-Zn ($r=0.83$ kitchen), Cu-Cu ($r=0.99$ laundry), Cr-Cd ($r=0.7$ laundry), Mn-Cd ($r=0.7$ kitchen) indicates that these metals do not offer competition among themselves for bio-sorption.

4.6.2 Second Experiment (Partial Two Stage Waste Treatment)

In the second experiment gray water from kitchen after treatment is mixed with influent of the laundry RBC. For five days the system is run almost with same BOD and COD strength for stabilization and thereafter for ten days. Intermittent analysis of the influent of the laundry and kitchen and final effluent from laundry is carried out. This experiment was conducted taking into consideration (a) It will act as two stage two stage system,

however the organic and hydraulic load will increase on the laundry RBC (b) that microorganism of laundry will get more carbon since treated effluent will always has BOD from kitchen treated effluent for re-production and so effect of the treatment can be assessed (c) that there will be effect on organic, nutrient, solids, trace metal removal and nitrification-de-nitrification. During the experiment rpm of laundry RBC maintained to 7 and kitchen RBC maintained to 5.5.

In this experiment the BOD is reduced by 17% COD by 24% as compared to laundry influent value of first treatment and in the kitchen influent BOD is reduced by 15% and COD by 22% as compared to first experiment value. However it is kept still higher (32%) than designed for laundry RBC and around 39% for kitchen RBC in terms of BOD. Startup inoculums has a significant influence on the initial reactor performance (Okabe et al., 1996) which is shown in the removal capacity of RBC's first few days. The average removal of the BOD and COD recorded was around 83% and 85% respectively. The removal rate shows much higher than the first experiment. This means if system is connected as two stage and initial strength is lowered system can function well to remove BOD and COD. This load corresponds to similar average load being generated at present at Maitri station and accordingly the COD load also increases. Average BOD/COD ratio in the influent found to be 0.28 for laundry and 0.35 in the kitchen influent which is recorded 0.36 in the combined effluent. The organic loading on kitchen RBC recorded as 8.93 g BOD/m²/day and 25.4 g COD/m²/day, whereas in the due to only laundry influent it is recorded 9.9 g BOD/m²/day and 35.2 g COD/m²/day. Since system was working as partial two stage reactor there is additional organic as well as hydraulic loading imparted due to treated effluent form kitchen RBC on laundry RBC.

Demand parameters (BOD and COD) shows significant correlation with influents of laundry and kitchen with combined effluent from laundry; BOD-BOD ($r=0.90$ laundry), BOD-COD ($r=0.95$ laundry), BOD-NH₃ ($r=0.73$ laundry), COD-COD ($r=0.75$ laundry). This indicates that BOD and COD are dominated by inorganic matters and therefore if concentration in the influent increases, concentration in the effluent also increases owing to limitation of microorganism to absorb and convert these matters. However negative correlation between BOD-NO₃ ($r=-0.98$ laundry) indicates that if organic load is reduced and tends to increase concentration of salts, alkalinity benefits for ammonia conversion

into nitrate through nitrification. On the contrary kitchen influent shows significant negative correlation with combined effluent; BOD-K ($r=-0.73$ kitchen), BOD-Ca ($r=-0.77$ kitchen), COD-K ($r=-0.86$ kitchen), COD-Ca ($r=-0.89$ kitchen). This showed higher organic content in the kitchen effluent which supports microorganism to absorb these elements. If organic load is increased the removal efficiency also increases in the laundry RBC as shown by significant negative correlation between, conductivity-BOD ($r=-0.73$ laundry). A significant negative correlation among influents and combined effluent of RBC viz.; SS-BOD ($r=-0.88$ laundry), VSS-BOD (-0.78 laundry), VDS-BOD ($r=-0.87$ laundry), VDS-COD ($r=-0.70$ laundry), showed mixing of kitchen waste into laundry positively increasing the removal of solids from laundry RBC. However a positive correlation between VDS-BOD ($r=0.78$ kitchen) concludes the optimum efficacy of microorganism to absorb the organic load.

During the experiment, average temperature in the bio chamber recorded was average 25.3°C for laundry RBC and 25.6°C for kitchen RBC, which is around four degrees less than the ambient temperature. Higher temperature and a good range of pH towards base has a positive effect on the BOD and COD removal which is supported by significant correlation between pH-BOD ($r=0.70$ kitchen), but at higher temperature the DO was also reduced which is a requirement of the microorganism to treat the waste aerobically. This is substantiated by significant correlation between temperature-BOD ($r=-0.93$ kitchen), temperature-COD ($r=-0.82$ kitchen), DO-BOD ($r=0.92$ laundry), DO-COD ($r=0.95$ kitchen). A significant correlation between pH-temperature ($r=0.97$ laundry) supports the statement of positive effect of pH on the combined treatment which tends to create better environment to the growth of microorganism by using heat and carbon as source thus lowering the effluent temperature.

A significant negative correlation between pH-conductivity ($r=-0.90$ kitchen), indicates that if pH increases which supports microorganism growth, removal of total solids increases and conductivity decreases and if pH decreases, the organic removal capacity of microorganism decreases. Nitrification depends on the pH and alkalinity. The pH in combined effluent recorded average 7.5, whereas average pH of kitchen influent recorded 5.5 and of laundry 9.6. A significant correlation between pH- NH_3 ($r=0.83$ kitchen) indicates lower pH of kitchen affecting removal of NH_3 though overall removal

of ammonical-nitrogen recorded average 50%.

A significant correlation exist between SS-NH₃ ($r=-0.83$ laundry), SS-NO₃ ($r=0.75$ laundry), conductivity-NH₃ ($r=-0.88$ laundry) which indicates that though SS was less and DS was higher in laundry influent nitrification rate was significant and SS of kitchen and DS of kitchen was not contributing in noticeable way. But the correlation between DO-NH₃ ($r=0.82$ laundry) suggests, even though DO was higher in laundry influent it is being consumed by kitchen effluent organic matter. However, nitrate presence in the laundry influent affecting phosphate removal but supporting sodium absorption as it showed significant positive correlation between NO₃-PO₄ ($r=0.88$ laundry) and negative correlation between NO₃-Na ($r=-0.82$ laundry).

Nutrients showing significant and good negative correlation between Na-K ($r=-0.99$ laundry, $r=-0.93$ kitchen), Na-Ca ($r=-0.82$ laundry $r=-0.92$ kitchen) PO₄-PO₄ ($r=-0.90$ laundry) indicates that they are being utilize by cell even though in less quantity and a competition was developed for consumption among them. However the overall removal of sodium, potassium and calcium was noticed negative in the combined effluent.

The effect of the pH can be seen in the removal of the Na and Ca. A significant correlation between pH-PO₄ ($r=-0.93$ kitchen), pH-Na ($r=0.77$ kitchen), pH-K ($r=0.72$ kitchen) concludes that lower pH of kitchen affecting the phosphate removal by microorganism which is adding pre accumulated phosphate into the effluent. Even dilution effect on the pH tends to release the sodium and potassium in the effluent by laundry RBC which is shown in the result as negative removal. However no good correlation was observed between pH of influents and Ca of combined effluent.

Temperature plays an important role in the nitrification rate (*Du et al., 2003*) which increases at higher temperature. This can be seen from positive correlation of kitchen influent and combined effluent of kitchen RBC i.e. temperature-NH₃ ($r=-0.77$ kitchen), temperature-NO₃ ($r=0.96$ kitchen) supported by; NH₃-NO₃ ($r=-0.71$ laundry). A significant effect of pH and temperature is attributed to removal of solids as pH-TS ($r=-0.95$ laundry), pH-DS ($r=-0.85$ laundry), pH-SS ($r=-0.76$ laundry), temperature-TS ($r=-0.74$ laundry), temperature-DS ($r=-0.85$ laundry), temperature-SS ($r=-0.82$ laundry), temperature-VSS ($r=-0.81$ laundry), temperature-PO₄ ($r=-0.80$ laundry). However

positive correlation between temperature-K ($r=0.91$ laundry), temperature-Ca ($r=0.90$ laundry) suggests the negative effect on removal of these elements. Dissolved oxygen support the nitrification which is consumed during conversion of ammonia to nitrate which is supported by significant correlation between DO-DO ($r=-0.96$ laundry), DO-DO-NO₃ ($r=-0.85$ laundry $r=-0.73$ kitchen), whereas correlation; temperature-DO ($r=0.99$ kitchen) shows even though DO of the influent of the kitchen is less, mixing with influent of laundry which contains higher DO has less effect on the combined DO of effluent being the flow of kitchen 76% less, than laundry flow. A positive correlation between DO-TS ($r=0.98$ kitchen), DO-DS ($r=0.99$ kitchen) shows that less DO concentration in kitchen tends to less removal of the solids in the combined effluent.

Conductivity is mainly attributed to the presence of ions in the water and weak salts. This is supported by a significant correlation in the influent and effluent viz. conductivity-conductivity ($r=0.96$ laundry), conductivity-VSS ($r=0.78$ laundry, $r=0.79$ kitchen), conductivity-PO₄ ($r=0.94$ laundry), conductivity-TS ($r=0.80$ kitchen) and conductivity-SS ($r=0.87$ kitchen). This positive correlation indicated that in this experiment, even though these solids and ions are being removed, the removal is directly proportional to the influent concentration. However, a negative correlation between conductivity-K ($r=-0.83$ laundry, $r=-0.71$ kitchen), conductivity-Ca ($r=-0.80$ laundry, $r=-0.76$ kitchen), proves the addition of these elements through microbes in the effluent while conductivity is low in the influent.

Total solids mainly containing dissolved solids average 93% in laundry influent and 85% in kitchen influent found to be removed average 64% were measured in combined effluent. VDS/DS and VSS/SS is recorded around 0.45 average and 0.38 average in laundry influent whereas in kitchen influent it is recorded 0.56 average and 0.95 average. In the combined effluent the VDS/DS and VSS/SS were reduced to 0.18 and 0.89 respectively. Volatile dissolved solids and volatile suspended solids were removed on average 84% and 42% respectively were recorded in the combined effluent. This experiment was found to be better than treating waste separately in terms of total solids removal. A significant positive correlation among influents and combined effluent between DS-DS ($r=0.88$ laundry), DS-SS ($r=0.77$ laundry $r=0.95$ kitchen), DS-VSS ($r=0.74$ laundry $r=0.92$ kitchen), DS-K ($r=0.80$ kitchen), SS-SS ($r=0.80$ laundry,

$r=0.83$ kitchen), SS-VSS ($r=0.81$ laundry $r=0.75$ kitchen), VSS-VSS ($r=0.78$ kitchen), , TS-DS ($r=0.81$ laundry), TS-SS ($r=0.86$ laundry $r=0.92$ kitchen), TS-VSS ($r=0.84$ laundry $r=0.88$ kitchen), VDS- NO_3 ($r=0.83$), VDS- PO_4 ($r=0.79$ laundry $r=0.83$ kitchen) indicates the capacity of removal up to a certain level through biological treatment otherwise it increases in same ratio as it is in the influent and vice versa. However, a significant negative correlation between DS-K ($r=-0.84$ laundry), DS-Ca ($r=-0.83$ laundry $r=-0.85$ kitchen), VDS-Na ($r=-0.77$ laundry), VDS-K ($r=-0.85$ kitchen), VDS-Ca ($r=-0.82$ kitchen) TS-TS ($r=-0.80$ laundry), TS-Ca ($r=-0.80$ kitchen) and VSS-Ca ($r=-0.91$ kitchen) concludes that total solids which are dominated by dissolved solids in both the RBCs and mainly with Na, K in the laundry are not removed in proportion they exists in the influent and they are being released from the microbes in the effluent. The above statement is also supported by a significant correlation between VSS- NH_3 ($r=-0.72$ laundry), VDS- NH_3 ($r=-0.92$ laundry). A negative correlation indicates that at higher temperature microorganisms absorb the organic part of the VDS and VSS which contains organic and inorganic matter and left the inorganic part less consumed.

The metal binding capacity for the heavy metals were recorded in the decreasing order $\text{Zn} > \text{Cr} > \text{Cd} > \text{Ni} > \text{Pb} > \text{Cu} > \text{Fe}$ (65%, 36%, 31%, 11%, 6%, 5% average) whereas Mn is added into the effluent. The average pH of the laundry measured 9.7 and of kitchen influent 5.5 and the combined average pH of the effluent measured was 7.4. When compared with the first experiment removals of trace metals are lower than laundry RBC and higher than the kitchen RBC when they are run individually. So the effect of pH is addressed well on the trace metal removal. The removal of Mn during startup was high while experiment progressed higher concentration was noticed in the effluent.

Among the trace metals in influents and combined effluent a significant and good negative correlation was found among between Cr-Cr ($r=0.71$ laundry), Cr-Mn ($r=-0.94$ laundry), Cr-Fe ($r=-0.91$ laundry), Cr-Ni ($r=-0.93$ laundry $r=-0.73$ kitchen), Cr-Cu ($r=-0.86$ laundry), Cr-Zn ($r=-0.75$ laundry) Cr-Cd ($r=-0.97$ kitchen), indicates that Cr offer competition among other metals for biosorption but if concentration of Cr increases from the optimum level, release from biocell occurs in the effluent. Significant correlation between Mn-Mn ($r=0.95$ laundry), Mn-Fe ($r=0.99$ laundry), Mn-Co ($r=0.90$ laundry),

Mn-Ni ($r=0.74$ laundry), Mn-Cu ($r=0.82$ laundry), Mn-Zn ($r=0.88$ laundry), Mn-Pb ($r=0.71$ laundry $r=1.0$ kitchen), Fe-Fe ($r=0.99$ laundry), Fe-Ni ($r=0.73$ laundry), Fe-Cu ($r=0.83$ laundry), Fe-Zn ($r=0.91$ laundry), Fe-Pb ($r=0.91$ kitchen), Ni-Cu ($r=0.87$ laundry), Ni-Zn ($r=0.92$ laundry), Ni-Cd ($r=0.78$ laundry), and Ni-Pb ($r=0.98$ kitchen) are observed.

Competing ions affect the capacity of bacterial biomass to remove cations (*Collins and Stotzky, 1989*) and may explain the lack of cadmium removal in the current investigation. Copper or zinc affects the binding of cadmium to biomass. It is also studied that binding capacity of the copper is known to increase rapidly with increase in pH in the range of 3-5 with maximum adsorption at pH 5 (*Harris and Ramelow, 1990*). However, at higher pH of 5.5 formation of copper hydroxide initiates (*Wong et al., 1993*), this can be supported by significant correlation of metals between Cu-Cu ($r=0.99$ laundry $r=0.91$ kitchen), Cu-Zn ($r=0.89$ laundry $r=0.86$ kitchen), Cu-Cd ($r=0.91$ laundry $r=0.94$ kitchen), Zn-Zn ($r=0.74$ laundry), Zn-Pb ($r=0.85$ laundry $r=0.92$ kitchen), Cd-Cd ($r=0.76$ kitchen) Cd-Pb ($r=0.98$ laundry), Pb-Pb ($r=0.96$ kitchen), which suggests that Mn, Fe, Ni, Cd (*Trevors et al., 1986*) mainly have dominance in the laundry influent and Pb, Zn and Cu in the kitchen influent and indicates that these metals do not offer competition among themselves for biosorption. Cells are able to withstand the presence of such metals by means of various resistance mechanisms, which may either prevent initial uptake of the ion or provide a means of expelling any absorbed ion from the cell.

So it can be concluded that, an increase in hydraulic loading, resulting from two stage system had limited negative impact on metal removal but improved organic, nitrogen and solids removal efficiency.

4.6.3 Third experiment (Partial Two Stage Waste Treatment Extended with Tertiary Treatment)

Third experiment conducted in continuation to second experiment and extended with alum dose treated combined effluent with activated charcoal treatment. Total duration for the experiment last for fifty days however after twenty days analysis could not be carried out for next fourteen days, though the system was continued to feed with almost

same strength of waste in both the RBC. Thereafter analysis continued for next twelve days. This experiment was conducted taking into consideration the effect of tertiary treatment on organic, nutrient, solids, trace metal removal and nitrification-denitrification by providing organic load nearly to design load. During the experiment rpm of laundry RBC maintained to 7 and kitchen RBC maintained to 5.5.

In this experiment on an average BOD was reduced by 10%, COD by 24% as compared to laundry influent value of second treatment and in the kitchen influent BOD was reduced by 30% and COD by 48% as compared to second experiment value. However, it is kept still higher around 10% than designed for laundry RBC and around 3% lower for kitchen RBC in terms of BOD. But, the variation in the load still noticed higher $\pm 46\%$ for BOD and $\pm 45\%$ for COD in laundry influent, whereas variation for BOD in the kitchen influent noticed was $\pm 57\%$ and for COD it was $\pm 76\%$. The average removal recorded was around 85% for BOD and 80% for COD after two stage treatment and alum dosing. Further after activated charcoal treatment the BOD and COD reduced on average by 40% and 50% respectively. The overall efficacy on an average recorded in terms of BOD removal was 91% and in terms of COD it is 90%. The removal rate shows higher compared to the second experiment. It is noticed that if the BOD and COD load is near or less than design load the overall efficacy of the system reaches to 99.3% for BOD and 99.5% for COD during initial and end period, on the contrary while BOD and COD load is higher than the design the efficacy is reduced. Average BOD/COD ratio in the influent is found to be 0.31 for laundry and 0.52 in the kitchen influent which was reduced after alum dosing to 0.24 but increased to 0.36 after passing through activated charcoal. The reason behind this is the alum dose which helps in suppressing the solids containing inorganic and organic but activated charcoal tends to reduce inorganic substance more than organic.

The organic loading to kitchen RBC recorded on an average 6.23 g BOD/m²/day and 13.2 g COD/m²/day whereas same in the laundry RBC was recorded 7.9 g BOD/m²/day and 26.75 g COD/m²/day. Apart from loading of laundry influent additional loading from effluent of kitchen RBC was also contributed on laundry RBC reactor. Demand parameters BOD and COD showed significant correlation with influents of laundry and kitchen with alum dosed effluent viz. COD-COD ($r=0.76$ laundry), TS-BOD ($r=0.84$

laundry), DS-BOD ($r=0.84$ laundry), VDS-BOD ($r=0.85$ laundry). This indicates that the effect of solids on the BOD and COD removal after alum dose which is inversely proportional to the total solids added in the laundry influent which is supported by significant correlation among; conductivity-TS ($r=0.86$ laundry), conductivity-DS ($r=0.85$ laundry), TS-TS ($r=0.87$ laundry), TS-DS ($r=0.86$ laundry), DS-DS ($r=0.86$ laundry), SS-SS ($r=0.73$ laundry), SS-VSS ($r=0.72$ laundry), VSS-turbidity ($r=0.70$ laundry), turbidity- NH_3 ($r=0.71$ laundry).

Activated charcoal has highly developed porous structure and large specific surface area and exhibits considerable adsorption capacity towards various pollutants (Razvigorova, 1998). But have ability to react with some of the compounds in the water leading to formation of other compounds. After passing waste water through activated carbon the analyses showed a significant correlation between alum and activated carbon treated effluent i.e COD-turbidity ($r=0.89$), BOD-BOD ($r=0.81$), indicates the inorganic and organic substances mainly adsorbed by activated carbon with an optimum capacity, hence turbidity reduces which is supported by significant correlation between TS-TS ($r=0.85$), TS-DS ($r=0.86$), DS-DS ($r=0.87$), SS-SS ($r=0.77$), VDS-VDS ($r=0.74$).

During the experiment average temperature in the bio chamber recorded was 23.5°C for laundry RBC and 24.16°C for kitchen RBC, which is around five degree less than the ambient temperature. Lower temperature was maintained putting a small pipe through which cold water was passed intermittently. Higher temperature and a good range of pH towards base has a positive effect on the BOD and COD removal which was supported by significant correlation between DO-DO ($r=0.85$ kitchen), Nitrification depends on the pH and alkalinity. The pH in alum treated effluent recorded was average 6.8, whereas average pH of kitchen influent recorded was 5.1 and of laundry 9.3. A significant correlation between pH- NH_3 ($r=0.83$ kitchen) indicates lower pH of kitchen affecting removal of NH_3 though overall removal of ammonical-nitrogen was recorded as average 73%, nitrate 38% and phosphate 23%. A significant correlation exist between NO_3-NO_3 ($r=0.86$ laundry), PO_4-PO_4 ($r=0.93$ laundry) which indicates that the laundry influent nitrification rate is significant and kitchen is not contributing in noticeable way. However nitrate presence after alum dose treatment and sodium depends on the initial concentration as it has shown significant correlation between NO_3-NO_3 ($r=0.84$) Na-Na

($r=0.86$).

The metal binding capacity as well as settling capacity while alum was added to the combined effluent for the trace heavy metal recorded in the decreasing order (*Uzun and Guzel, 2000*) Mn>Cu>Fe>Zn (22%, 19%, 12%, 10%) whereas the Ni, Cd, Cr and Pb are found more in the effluent. The possible reason may be that medium range metals (atomic weight 50-65) coagulate more rapidly than heavy range metals (>100 atomic weight). However, Cr is exceptional for this statement. Further treating with activated charcoal the removal range exists as Zn>Mn>Fe (36%, 20%, 13%). This shows that metals which cannot be removed by biosorption, activated carbon proves effective in removal of these metals. However Pb, Cd, Ni, Cu and Cr are added to the effluent treated by activated charcoal.

Among the trace metals in influents and combined effluent treated with alum, a significant and good correlation was found between Cr-Cr ($r=0.82$ laundry $r=0.77$ kitchen), Mn-Mn ($r=0.91$ Alum), Fe-Fe ($r=0.86$ laundry), Fe-Cu ($r=0.75$ laundry), and Fe-Pb ($r=0.82$ kitchen) indicates that removal from alum dosing is inversely proportional to the concentration before alum treatment. A significant and good correlation between the alum treated effluent and activated carbon treated effluent Fe-Fe ($r=0.75$ alum), Ni-Ni ($r=0.77$ alum), Cu-Cu ($r=0.85$ laundry), Cd-Cd ($r=0.90$ alum), Pb-Pb ($r=0.79$ kitchen) also indicates that the capacity of activated carbon reaches to an optimum point and then removal decreases. Results tend to assume that on the surface of activated charcoal some compounds formed due to reduction/reaction as a part of interaction of particular elements with the carbon. These elements may accumulate on the porous surface and react together in the long run and use of activated carbon to treat the waste. Thus it necessitates regenerating or changing the activated carbon after design period.

This experiment successfully concludes that coagulation removes predominantly macromolecular substances from the secondary effluent (*Haberkamp et al., 2007*). A combination of coagulation and adsorption applying technically appropriate dosages can largely enhance the removal of pollutants.

Chapter 5

Design and Application of Advance Treatment Process

5.1 Plant Design in Antarctica: Factual Conditions

5.1.1 Extreme Conditions

As mentioned earlier, climatic conditions in Antarctica are severe with annual temperature range from -40°C to $+5^{\circ}\text{C}$ and with wind gusts of up to 200 km/h (*Heaton and Paterson, 2003*) especially at bases situated away from coastal area. Inland, temperatures are much lower. At the Amundsen-Scott South Pole station, one of only two permanently occupied inland bases, temperatures range from -83°C to -14°C , with a mean of -5°C , while the wind blows constantly, with an average speed of 20 km/h (*Flynn et al., 1994*). At Maitri station, temperature vary from -35°C to $+7^{\circ}\text{C}$. Blizzards are not infrequent and can develop very quickly; snowfalls, but drifts of windblown snow accumulate around prominent objects such as buildings. Freezing of pipes connecting plant components is a serious problem (*Lori et al., 1992*). It also means that treated effluent discharge is usually best done intermittently so as to minimize the chance of outfall pipes freezing up. This in turn implies that plants need to include a buffer tank in which treated effluent can be stored until the next discharge (*Connor, 2008*).

5.1.2 Load Fluctuation

Plants must also be able to handle widely varying hydraulic and BOD loads, since number of people wintering at research stations is a small fraction of those present during the peak summer resupply period. Most people present on the bases have similar work schedules, so diurnal load fluctuations are pronounced and have to be allowed. Another aspect is that numbers on stations tend to alter stepwise, for example when the resupply vessel arrives. This means that plants need to be adjusted rapidly to the load

changes. This problem is most acute at seasonally occupied stations.

5.1.3 Modular Design

The climate, together with the prolonged period of darkness during winter and the fact that stations maintain only a skeleton staff during the winter months, means that there exists a total of perhaps eight weeks in summer when conditions are good for outdoor construction work (*Heaton and Paterson, 2003*). Much of this time will be needed for transport of plant components to the selected site, installation, and connection of pipes and utilities. Modular, prefabricated plants that can be easily disassembled for shipping and readily reassembled on site are therefore virtually a necessity. Such plants can also be commissioned and modified prior to shipping, alleviating demands on the limited staff available on-site at research stations. For convenience of transport and handling, and to protect plant components during the rough weather characteristics of the southern ocean, most countries are opting to build their plants inside the containers.

The Scott base plant fits inside two ISO-20 shipping containers (*New Zealand, 2002*), while, the Neumayer and Jubany plants were built into containers 2.0 m long, 1.8 m wide and 1.8 m high, made of stainless steel to minimize problems with corrosion (*Ahammer et al., 2000*). Compactness is necessary if plants are to fit into containers. It also has other advantages, reducing the plant's footprint and its visual impact (*Heaton and Paterson, 2003*) as well as minimising heating costs. Rate of microbial waste decomposition processes are temperature dependent and till date plants have all been designed to run at 12°C (*New Zealand, 2002*) or above.

Plants need also to have low energy consumption. Energy is expensive in Antarctica, being derived from hydrocarbon fuels shipped in at high cost and stored in heated storage tanks. Aside from saving money, installing a low power demand plant means a reduced output of emissions from the base's power station (*Connor, 2008*).

5.2 Problem of Wastewater Discharge at Maitri Station

Waste water was always a matter of concern in Antarctica in terms of its proper treatment and discharge. The Maitri station is situated in the lower elevation than the surrounding glacier and ice sheet. According to the Madrid Protocol the treated effluent can be discharged either by making hole in the ice pit or into the sea. On the contrary

both the option are impractical to opt for final effluent discharge.

5.2.1 At India Bay

Maitri is situated in a valley area surrounded by the glacier at south side, ice bound hillocks at rest of the sides. It is around 80 km from the ice shelf and open sea boundary. It generates around 875 m^3 of wastewater each year. Assuming 20% of wastewater loss through evaporation due to less humid and high wind prevailing in the region, transporting the effluent (around $700\text{-}800 \text{ m}^3$) to the coast is possible by loading effluent in as many as 40-50 heated tanks of 20 kl capacity. But at one time only 10 piston bully can be operated, so five round from Maitri to sea coast is not a solution in that particular environment. The present effluent discharge, may be violating the Madrid Protocol obligations.

5.2.2 Ice Pit

Ice pit is available around one to two km away from waste generation source at higher level. Laying trace heated pipe for one to two km and attaching pump to lift the liquid at desired elevation will require installation of additional generator sets, which will consume more fuel and emit the foul gases and particulate matters thus pollute the environment.

5.3 Option for Final Discharge of Wastewater

5.3.1 Improving the Effluent Quality and Discharge on Land

A practical solution for wastewater management system considering the conditions of location of Maitri station, environment and Madrid protocol is to redesign the treatment system with ancillary units, tertiary treatment units and fine quality discharge at land concept. Such a design will minimise, reuse and recycle waste generated by its activities as far as practicable and will ensure that waste is disposed of with minimal environmental impacts. This design shall include alternative technologies, materials and disposal options, and identify areas to ensure meeting Madrid Protocol.

5.4 Ancillary Unit Design Requirement for RBC's

Disposal of Antarctic wastes has both, environmental and financial costs. By minimizing the strength of waste produced these costs can be reduced. Reduction of constituents which affect the biological and tertiary treatment system needs to be added before and

after the RBCs for production of potable water quality effluent. Following units are required to be designed and added:

- ↳ Equalization Tank
- ↳ Oil and Grease Trap
- ↳ Sludge Dewatering
- ↳ Tertiary Treatment Unit
- ↳ Reverse Osmosis
- ↳ UV Disinfection

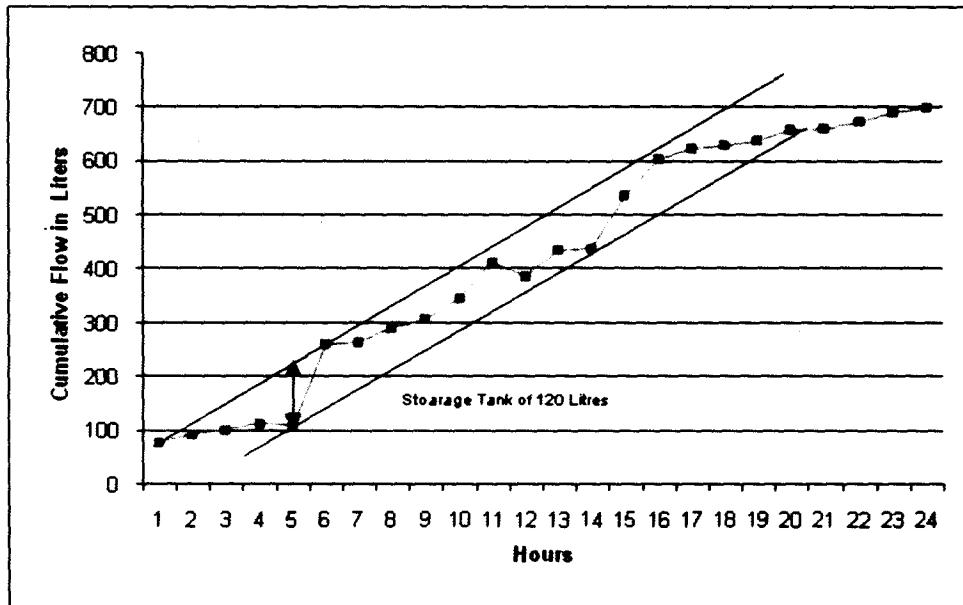
5.4.1 Equalization Tank

Flow equalization is the damping of flow rate variation so that a constant or nearly constant flow rate can be achieved. The benefits from application of flow equalization are; (a). biological treatment is enhanced, because shock loadings are eliminated or minimized as inhibiting substances can be diluted and pH can be stabilized. (b) the effluent quality and thickening performance of secondary sedimentation tanks following biological treatment is improved through constant solid loading. (c) effluent-filtration surface area is reduced. Flow equalization not only improves the performance of treatment system but is also an attractive option for upgrading the performance of overloaded treatment plants.

5.4.1.1 Mass curve for B1 RBC

The cumulative mass flow drawn for 24 hours while the occupancy of the station was highest, against the time, shows that total volume of equalization tank required is 120 litres. Considering additional volume for contingency and sludge requirement a tank of 200 litres is proposed for B1 RBC (Figure 5.1).

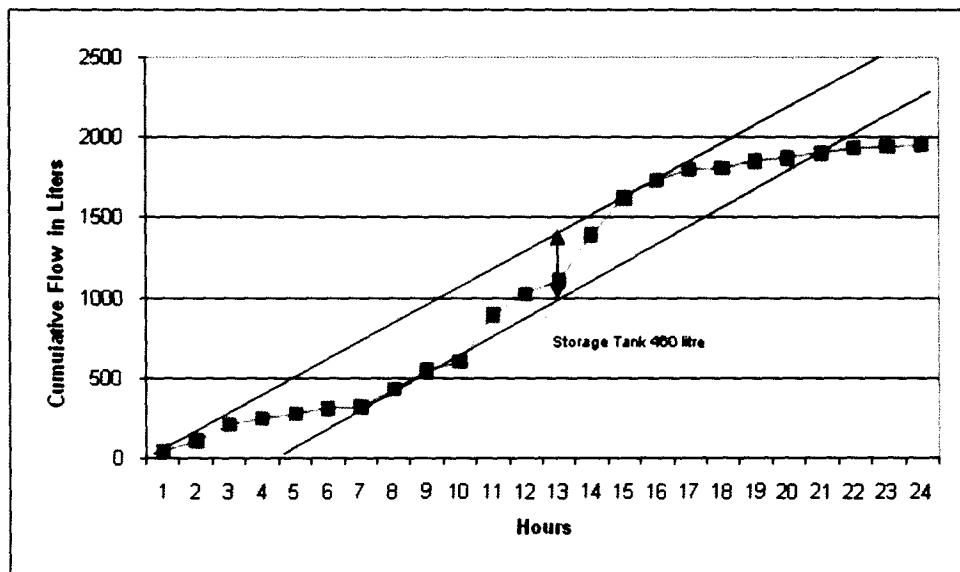
Figure - 5. 1 : Mass Curve for B1 RBC



5.4.1.2 Mass Curve for B3 RBC

Hourly mass curve drawn for 24 hours for B3 RBC shows that there is a requirement of a tank holding total volume of equalization tank of around 460 litres. It is proposed to have 600 litres (Figure 5.2), keeping additional storage for contingency and sludge.

Figure - 5. 2 : Mass Curve for B1 RBC



5.4.2 Fats, Oil and Grease Trap

Fats and oil are the major components of food stuff. The term grease is commonly used for fats, oils, waxes and other related constituents found in wastewater. Fats and oils are compounds of alcohol or glycerol with fatty acids. The glycerides of fatty acids that are liquid at ordinary temperature are called oils, and those that are solids are called fats. Fats and oils are contributed to domestic wastewater through butter, margarine, meats, seeds, nuts, certain fruits and vegetables. Fats are among the more stable organic compounds and are not easily decomposed by bacteria. It is necessary to remove oil and grease before they enter biological wastewater unit.

Normally oil and grease trap are designed on the basis of detention time and surface area:

Detention time: 3-30 minutes may be selected

$$\text{Surface Area can be calculated with formulae as : } \frac{(6.22 \times 10 - 3 \times Q)}{V_r}$$

Wherein

Q is Rate of flow in m^3/day , and

V_r = Minimum rising velocity of the oily material to be removed in
 m/minute ($0.25 \text{ m}/\text{minute}$ in most cases)

VOLUME OF TANK

$$V = Q \times t$$

Wherein,

V = Volume of tank (m^3)

Q = Flow (m^3)/minute

t = detention time (minutes)

For B1 RBC (flow 700 litres/ day)

$$V = \frac{0.7 \times 30}{24 \times 60}$$
$$= 14.6 \text{ litres} \sim 15 \text{ litres}$$

For B3 RBC (flow 1950 litres/ day)

$$V = \frac{1.95 \times 30}{24 \times 60}$$
$$= 40.6 \text{ litres} \sim 41 \text{ litres}$$

SURFACE AREA OF THE TANK

Assuming 250 m² for flow of 1 m³/s (rather using equation mentioned earlier)

For B1 RBC

$$\text{Surface Area (A)} = 172 \text{ cm}^2 \sim 200 \text{ cm}^2$$
$$= 10 \times 20 \text{ cm (a x b)}$$

For B3 RBC

$$\text{Surface Area (A)} = 485 \text{ cm}^2 \sim 500 \text{ cm}^2$$
$$= 20 \times 25 \text{ cm (a x b)}$$

DEPTH OF TANK

For B1 RBC

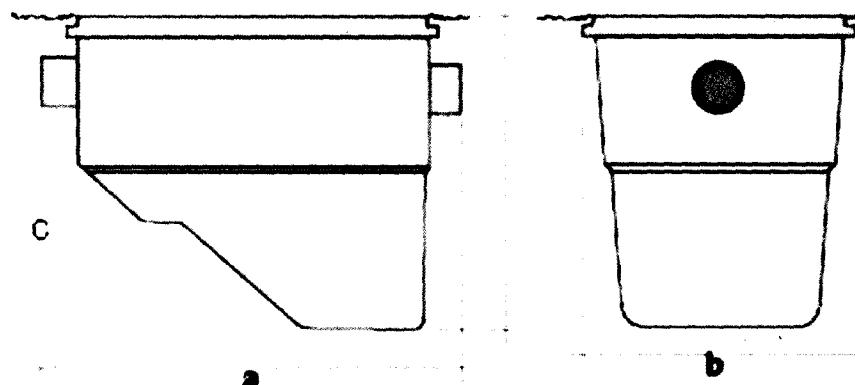
Depth (D) = V/A = 75 cm and 15 cm free board ~ 90 cm (c)

For B3 RBC

Depth (D) = V/A = 82 cm ~ 85 and 15 cm free board = 100 cm (c)

Figure 5.3 is showing the elevations of oil and grease trap.

Figure - 5. 3 : Elevations of Oil and Grease Trap



5.4.3 Sludge Dewatering

Sludge is produced in the RBC's primary and secondary settling tank. Additional sludge will also be produced from the equalization tank, oil and grease trap, chemical coagulation and reverse osmosis process. Sludge dewatering is a physical unit operation used to reduce the moisture content of sludge. There are various methods available for sludge dewatering which have their own advantages and disadvantages of energy, quality, water requirement, skilled operator, noise, maintenance, automation., area requirement, and site protocol and they are classified as ;

- ↳ Vacuum Filter
- ↳ Solid bowl centrifuge
- ↳ Imperforate basket centrifuge
- ↳ Belt filter press

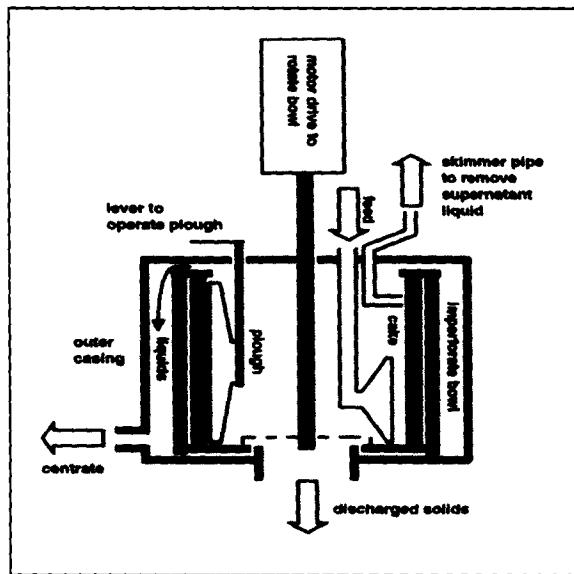
- ◆ Recessed plate filter press
- ◆ Sludge drying beds
- ◆ Sludge lagoons

Considering designed sludge volume of 800 litres and cleaning in 180 days, total sludge production from B1 RBC would be 1600 litres in a year, whereas B3 RBC will produce 1530 litres in 90 days cleaning period which equals to 6120 litres in a year. Another volume of centrate which is expected to be produced from RO, may be around 40% of total waste water (900 m^3) is around 360 m^3 . So, total centrate/sludge production would be around 368 m^3 . Monitoring various environmental conditions following sludge dewatering system has to be adopted.

5.4.3.1 Imperforate Basket centrifuge

The tubular and chamber bowl designs are used wherever the dirt content of the liquid is low, so that the stoppages for cleaning are infrequent. If the solid content of the suspension is higher which is true at Maitri as using RO produces higher solid content, then the imperforate basket centrifuge (Figure 5.4) has to be used to separate the solids, and produce a reasonably clean liquid. This consists of a simple drum-shaped basket or bowl, usually rotating around a vertical axis. The solids accumulate in the basket and are compressed by a centrifugal force, but they are not dewatered. When the rotation of the bowl is stopped, the residual liquid will drain out including some from the interstices of the solid, and the layer of solids can be removed manually, by scraping or shoveling, or by lifting out a lining bag. Unloading can be achieved semi-automatically, without stopping the machine, first by use of a skimmer pipe to remove the residual liquid, and then by lowering a knife blade into the solid and cutting it out of the bowl. As the solids have not been dewatered at all, they may be fluid enough to flow out through the same skimmer pipe. Based on the total volume of sludge per day required to be dewatered it can be designed commercially.

Figure - 5. 4 : Imperforate Basket Centrifuge

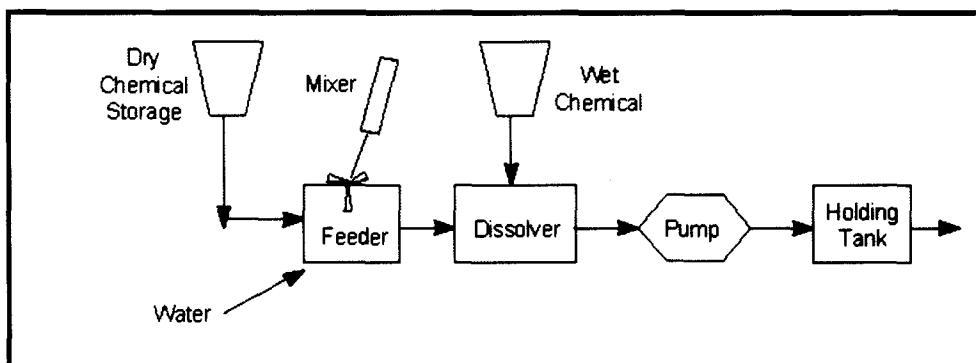


5.4.4 Tertiary Treatment Unit

5.4.4.1 Coagulation by Alum Dosing

It is possible by chemical precipitation to obtain a clear effluent, substantially free from matter in suspension, or in colloidal state. There are various chemicals available for chemical precipitation i.e Alum- $\text{Al}_2(\text{SO}_4)_3 \cdot 18 \text{ H}_2\text{O}$, Ferric Chloride- FeCl_3 , Ferric sulfate- $\text{Fe}_2(\text{SO}_4)_3 \cdot 3\text{H}_2\text{O}$, Ferrous Sulfate- $\text{FeSO}_4 \cdot 7 \text{ H}_2\text{O}$, Lime- $\text{Ca}(\text{OH})_2$. Laboratory experiment have been conducted adopting Aluminum Potassium Sulfate- $\text{AlK}(\text{SO}_4)_2 \cdot 18\text{H}_2\text{O}$ to observe the effect of alum in reducing the BOD, COD and suspended and dissolved particles. For any given wastewater the optimal treatment strategy should be determined by jar testing (USEPA, 2000). Jar test conducted for lab scale experiment and at Maitri, concluded use of 80 mg/l of alum for kitchen waste effluent and 40 mg/l of alum for bathroom/laundry RBC. Chemical precipitation is normally carried out through a chemical feed system, most often a automated system. An automatic feed system may consist of storage tanks, metering pumps, overflow containment basins, mixers, and aging tanks, injections quills, shot feeders, piping, fittings and valves (Figure 5.5). Chemical precipitation unit is required to be installed before the effluent enters to activated carbon unit and RO.

Figure - 5. 5 : Flow Diagram of a Chemical Feed System



B1 RBC which has effluent flow of 29.2 litres/hr will require around 28 grams of alum dose to be mixed in a litre of water maintaining discharge in 24 hours, to mix with the effluent. B3 RBC will require 78 gms of alum dose in a day to mix in two litre of water, maintaining discharge and mixing with effluent in a day.

5.4.4.2 Activated Carbon Treatment

Carbon adsorption is primarily used for removal of refractory organic compounds, as well as residual amounts of inorganic compounds such as nitrogen, sulfides and heavy metals (*Metcalf and Eddy, 1995*). Under the normal conditions, after treatment with carbon, the effluent BOD ranges from 2 to 7 mg/l and effluent COD ranges from 10 to 20 mg/l. Generally fixed bed column is used for contacting wastewater with Granular Activated Carbon (GAC). The sizing of carbon contactor is based on four factors: contact time, hydraulic loading rate, carbon depth and number of contactors. Rapid Small Scale Column Test (RSSCT) is useful to predict the performance of pilot scale or full scale carbon column. For the single column design as in the case of Maitri, breakthrough curve is useful to arrive at the bed life. In the field, the breakthrough adsorption capacity (x/m)_b of a GAC in a full scale column is some percentage of the theoretical adsorption capacity found from the isotherm. The time to breakthrough can be calculated using following relationship:

$$t_b = \frac{(x/m)_b m_{GAC}}{Q (C_0 - C_b/2)}$$

$$(x/m)_b = X_b/M_c$$

Wherein

$(x/m)_b$ = field breakthrough adsorption capacity (g/g)

X_b = mass of organic material adsorbed in the GAC column at breakthrough, g

M_c = mass of the carbon in the column, g

m_{GAC} = mass of the carbon in column, g

Q = flowrate m³/day

C_o = influent organic concentration, g/m³

C_b = breakthrough organic concentration, g/m³

t_b = time to breakthrough, day

The theoretical adsorption capacity of the carbon for a particular contaminant can be determined by developing its adsorption isotherm. The adsorption characteristics of activated carbon used in wastewater treatment can be described by Freundlich isotherm (*Metcalf and Eddy, 2009*). The amount of material adsorbed is determined as a function of the concentration at constant temperature and the resulting function is called as adsorption isotherm.

$$\frac{x}{m} = K_f C_e^{1/n}$$

Wherein,

x/m = mass of adsorbate adsorbed per unit mass of adsorbent, mg adsorbate/g activated carbon

- K_f = Freundlich capacity factor (mg absorbate/g activated carbon)
 $(L \text{ water}/\text{mg adsorbate})^{1/n}$
- C_e = equilibrium concentrate of adsorbate in solution after adsorption, mg/l
- $1/n$ = Freundlich intensity parameter

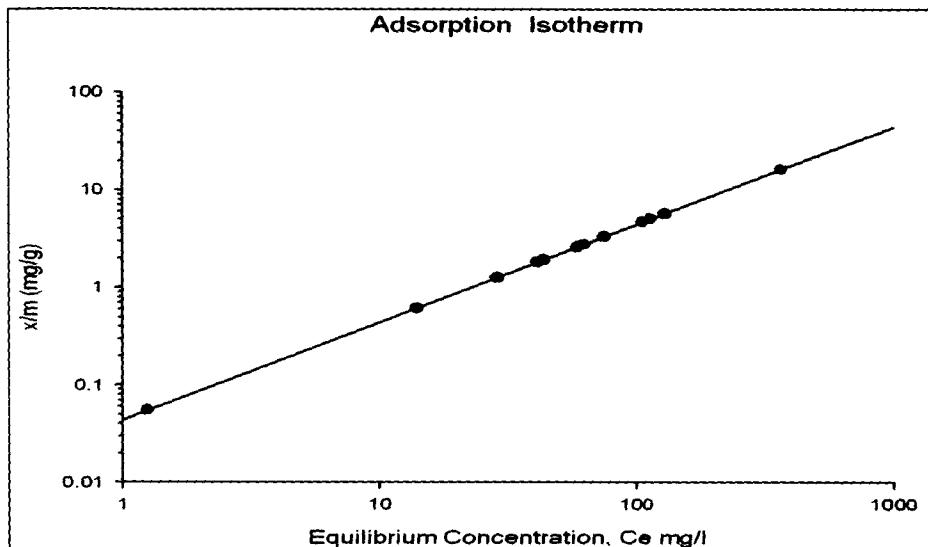
In the laboratory experiment the mass of adsorbent, m is 700 gms which is kept constant throughout the experiment. Table 5.1 shows the adsorbent and adsorbate value.

Table - 5. 1 : Adsorbent and Adsorbate Value (for COD)

C_0 (mg/l)	C_e (mg/l)	C_0-C_e (mg/l)	x/m (mg/g)
112.0	68.2	43.8	1.9
115.7	1.6	114.1	5.1
139.5	9.5	130.0	5.8
70.7	29.5	41.3	1.8
108.2	2.0	106.2	4.7
293.2	218.1	75.1	3.3
439.5	72.0	367.5	16.3
376.5	362.5	14.0	0.6
279.5	217.0	62.5	2.8
102.0	100.7	1.3	0.1
149.5	90.7	58.8	2.6
92.0	63.2	28.8	1.3

Using above equation and the table, parameters adsorption isotherm is plotted in log-log graph and shown below in the Figure 5.6

Figure - 5. 6: Adsorption Isotherm



From the figure it is estimated that line intercepts (c) at x/m value 0.048, value of C_e is 1, and K_f is 1.106, whereas slope ($1/n$) is 0.455.

5.4.5 Operational Performance of GAC Contactor (Laboratory Experiment)

A. EMPTY BED CONTACT TIME (EBCT)

$$EBCT = \frac{V_b}{Q} = \frac{A_b D}{v_f A_b} = \frac{D}{v_f}$$

Wherein,

$EBCT$ = empty bed contact time, h

V_b = volume of GAC in contactor, m^3

Q = volumetric flow rate, m^3/h

A_b = cross sectional area of GAC filter bed m^3

D = length of GAC in contactor, m

v_f = linear approach velocity, m/h

In the experiment $Q = (25 + 6) = 31$ litre, Density of GAC = 240.1 g/l and diameter of column 0.15 m

Here $A = A_b$)

$$V_f = \frac{Q}{A} = \frac{31 \times 4}{1000 \times 24 \times 3.14 \times 0.15 \times 0.15}$$

$$EBCT = \frac{0.15}{0.073}$$

$$= 2.05 \text{ h}$$

B. CARBON USAGE RATE (CUR) IN g GAC/LITRE

$$= \frac{m_{GAC}}{Qt}$$

$$= \frac{C_o - C_e}{q_e}$$

$$= \frac{C_o - C_e}{K_f C_o^{1/n}}$$

$$= \frac{43.8}{1.106 (112)} 0.455 \\ = 4.63$$

C. MASS OF CARBON REQUIRED FOR GIVE EBCT

$$= EBCT \times Q \times \rho_{GAC}$$

ρ_{GAC} = activated carbon density

(Weight of carbon used in column-700 g, diameter of column, 0.15 m and height, 0.165 m)

$$= 700 \times 4 / (3.14 \times 0.15 \times 0.15 \times 0.165 \times 1000)$$

$$= 240.1 \text{ g/l}$$

$$= 2.05 \times (31/24) \times 240.1$$

$$= 635.7 \text{ g} \text{ (actual used 700 g)}$$

D. VOLUME OF WATER TREATED FOR GIVEN EBCT AND MASS OF GAC

= mass of GAC for given EBCT/ GAC usage rate

$$= 700/4.63$$

$$= 151.1 \text{ litre}$$

E. BED LIFE OF GAC USED IN EXPERIMENT

= Volume of water treated for EBCT/ Q

$$= 151.1 / 31$$

$$= 4.87 \sim 5 \text{ day}$$

Bed life of the activate carbon considering laboratory experiments is shown in Table 5.2.

Table - 5. 2 : Bed Life for different COD loading

CO (mg/l)	Ce (mg/l)	Co-Ce (mg/l)	Bed Life (day)
112.0	68.2	43.8	4.4
115.7	1.6	114.1	1.7
139.5	9.5	130.0	1.6
70.7	29.5	41.3	3.8
108.2	2.0	106.2	1.8
293.2	218.1	75.1	4.0
439.5	72.0	367.5	1.0
376.5	362.5	14.0	24.1
279.5	217.0	62.5	4.7
149.5	90.7	58.8	3.8
92.0	63.2	28.8	6.2

5.4.6 Design of Field scale GAC Column

For the designing of the field scale Granular Activated Carbon Column (GAC), already designed parameters available are tabulated for the comparison and calculation purpose in the Table 5.3.

Table - 5. 3 : Lab Scale column (LSC) and Full Scale Column (FSC)

Parameter	Unit	RSSC	FSC
Particle Diameter	mm	0.2	0.5
Carbon Density	g/l	240	450
EBCT	h (hour)	2.05	-
Loading Rate (vf)	m/h	0.073	-
Flow Rate	litre/day	31	5000
Column Diameter	mm	150	-
Column Length	mm	165	-
Weight of GAC	gram	700	-

A. EBCT FOR FSC

Assuming the time of operation of the field column as 100 days which has to treat total flow of 5000 litre per day.

$$Q_{FC} = 5000 \text{ litre /day}, t_{FC} = 100 \text{ d} \quad (\text{FC} - \text{Full scale and LC} - \text{Lab Scale})$$

So the Volume of water that will pass through the column

$$V_{FC} = Q_{FC} \times t_{FC}$$

$$= 5000 \times 100$$

$$= 500 \text{ m}^3$$

$$\begin{aligned} \text{EBCT} &= \text{EBCT}_{LC} \frac{t_{FC}}{t_{LC}} \\ &= (100/4.4) * 2.05 \end{aligned}$$

$$= 46.5 \text{ h} = 1.9 \text{ day}$$

B. LENGTH OF THE COLUMN

$$L_{FC} = \frac{Q_{LC} \times EBCT_{FC}}{A_{FC}}$$

(Assuming diameter of column = 0.8 m, $A_{FC} = (\pi/4) \times 0.8^2 = 0.5 \text{ m}^2$)

$$= 5 \times 1.93/0.5$$

$$= 19.3 \text{ m}$$

C. MASS OF ABSORBENT REQUIRED FOR FSC

$$M_{FC} = \frac{Q_{LC} \times EBCT_{FC} \times d_{FC}^2 \times \rho_{FC}}{d_{SC}^2}$$

$$= (5 \times 2.05 \times 0.8^2 \times 240)/(0.15^2 \times 24)$$

$$= 2915 \text{ kg}$$

Comments: total length of 0.8 m diameter column is 19.3 m which has to fill with total 2915 kg of GAC. But considering 1.5 m length each column of 0.8 m diameter total 24 columns has to be opted to accommodate activated carbon of density 240 kg/m³.

5.4.7 Membrane Filtration

The wastewater reclamation and reuse involves membrane filtration (*Madaeni, 1999, Rosenberger et al., 2006*) based advance treatment (*Ramirez et al., 2003*). This treatment produces high quality effluent with very low conductivity without any microbiological problems. Membrane process includes microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), dialysis and electrolysis (ED). The requirement at Maitri based on the influent characteristics and desired high quality effluent it would be desired to include microfiltration followed by nanofiltration or reverse osmosis process which will treat the effluent from secondary treatment unit. Microfiltration has typical operating range of 0.08-2.0 μm, nanofiltration is of 0.001-0.01 μm and reverse osmosis of 0.0001-0.001 μm. RO process is suitable to remove very small molecules, color, hardness, sulfates, nitrate, sodium and other ions (*Metcalf and Eddy, 2009*). Decentralized treatment of domestic wastewater offers the possibility of water and nutrient reuse (*Ellen et al., 2005*). Recently, the introduction of Ultra Low Pressure Reverse Osmosis (ULPRO) membrane has widened the horizon of RO in

purification of surface water as well as desalination of brackish water (Ozaki and Li, 2002). Study shows that ULPROM with multi-layer thin film, composites of aromatic polyamide which has high rejection of organic compounds under very low pressure. Table 5.4 shows the typical performance of membrane filtration unit.

Table - 5. 4 : Typical Performance of MF used as Pretreatment for RO

Constituents	MF influent (mg/l)	MF effluent (mg/l)	Average reduction (%)	Reduction reported in literature (%)
TOC	10-31	9-16	57	45-65
BOD	11-32	<2-9.9	86	75-90
COD	24-150	16-53	76	70-85
TSS	8-46	<0.5	97	95-98
TDS	498-622	498-622	0	0-2
NH ₃ -N	21-42	20-35	7	5-15
NO ₃ -N	<1-5	<1-5	0	0-2
PO ₄	6-8	6-8	0	0-2
SO ₄	90-120	90-120	0	0-1
Cl	93-115	93-115	0	0-1

(Whitley and Burchett, 1999)

Nanofiltration also known as “loose” RO, can reject particles as small as 0.001 μm . Both inorganic and organic constituents, bacteria and viruses are removed and disinfection requirement is minimized. In wastewater treatment RO is used for the removal of dissolved constituents from wastewater remaining after advance treatment like microfiltration. Table 5.5 shows the typical performance of RO system.

Table - 5. 5 : Typical Performance of RO used

Constituents	RO influent (mg/l)	RO effluent (mg/l)	Average reduction (%)	Reduction reported in literature (%)
TOC	9-16	<0.5	>94	85-95
BOD	<2-9.9	<2	>40	30-60
COD	16-53	<2	>91	85-95
TSS	<0.5	~ 0	>99	95-100
TDS	498-622	9-19	0	90-98
NH3-N	20-35	1-3	96	90-98
NO3-N	<1-5	0.08-3.2	96	65-85
PO4	6-8	0.1-1	~99	95-99
SO4	90-120	<0.5-0.7	99	95-99
Cl	93-115	0.9-0.5	99	90-98
Turbidity	0.03-0.08 NTU	0.03 NTU	97	40-80

(Whitley and Burchett, 1999)

5.4.8 UV Disinfection

The germicidal properties of radiation emitted from Ultraviolet (UV) light sources as a wastewater disinfectant has evolved during 1990. With proper dosage UV radiation has proved to be an effective bactericide and virucide for wastewater, while not contributing to the formation of toxic byproducts (Metcalf and Eddy, 2009). System can be adopted as open channel or closed channel disinfection. The effectiveness of the UV disinfection process depends on the characteristics of the microorganism. An UV disinfection system can be installed at Maitri station to avoid any bacterial contamination through discharge of treated wastewater.

5.5 Outcome

Wastewater treatment and management in Antarctica is on one side requirement of Madrid Protocol and on other side need of the hour. Final wastewater effluent discharge after maceration/biological treatment especially for the stations situated inland needs different approach. The stations, situated near the coastal areas have the option to treat

the waste to an optimum stringent standard and discharge into sea. However, the energy consumption and cost involved affect the policy and environmental concern. At Maitri station after conducting experiment and taking into consideration various aspects, it is found necessary to design the ancillary units such as; equalization tank, oil and grease trap, sludge dewatering unit, tertiary treatment unit of activated carbon. The final effluent after passing through the activated carbon further needs to be polished using Reverse Osmosis and disinfected with UV disinfection unit. An attempt has been made in the present study to design equalization tanks, oil and grease trap and tertiary treatment unit for Maitri station. Considering the lab scale experiments it can be concluded that present RBC system at Maitri can be upgraded with installation of these units to get fine quality effluent water.

Summary and Conclusions

The establishment of research stations made it necessary to provide for sewage disposal. For the environmental protection of Antarctica, Madrid Protocol came into force in the year 1998 with minimum standards for sewage treatment and disposal. The provisions in this protocol are not particularly onerous and some countries have opted for ambitious treatment systems, however many countries in Antarctica are not opting to consider treatment beyond minimum standards prescribed by the Madrid Protocol. Harsh climatic condition, weather and remoteness severely affect the technology implementation for waste management in Antarctica, which is a challenging task in terms of energy savings and cost. Many countries are using the widely known biological treatment system like Rotating Biological Contactor (RBC) as secondary treatment system, but the detailed performance analysis either not carried out or not available.

Maitri station of India situated in the Schirmacher oasis around 80 km from the sea coast is surrounded by glacier. Unlike the coastal stations where black water is produced which consists fecal coliform bacteria due to presence of human excreta, at Maitri station grey water is produced from two different sources like laundry which contains wastewater from bath and wash basin, and kitchen sink. These wastes are being treated in two separate RBCs of 5 kl (B3-RBC) and 1.2 kl (B1-RBC), since the start of station in the year 1989-90. The problem associated with the treatment system are (a) that their efficacy is less than 50% for BOD and COD removal and also nitrification rate is poor, as they are kept in separate compartments outside of Maitri station, they are forced to work in very low temperature, generally below 15°C and sometimes even below 5°C, (b) seepage through the treated wastewater collection pond joins Priyadarshini Lake having an area of 0.29 km² which is a prominent water source for Maitri station, (c) treated effluent from wastewater collection pond is discharged around 320 m away near a glacial lake, and this effluent seeps into to glacial lake, further, during the summer due to glacier melting and excess water from lake, ultimately joins Priyadarshini Lake.

The problems therefore could be viewed as need of an integrated assessment of wastewater treatment system and water bodies which have the potential of getting

polluted. During summer period around 60-70 persons stay at Maitri and in the adjoining summer huts, and during winter round 25 people live in Maitri station. Water requirement in the Maitri station fluctuates between 1.70 m³/day in winter and 5.70 m³/day during summer. Out of total quantity of water intake 80% (3100 litres average) is used at Maitri and 20% (700 litres average) is diverted to summer camp. Usages of water at Maitri produce average 63% wastewater from laundry, bathroom and wash basin whereas 23% wastewater is produced from kitchen sink, rest 14% is accounted on water loss. Effluent is collected in the pond after biological treatment through secondary unit situated nearby outfall of RBCs. No other primary or tertiary unit is installed to support the treatment system.

The outlet and inlet pipes are bound with trace heating elements to keep the pipes warm in freezing atmosphere. During austral summer ambient temperature hardly reached +5°C to +8°C for few hours in a day which is sufficient to melt the frozen ice formed over liquid, for nearly 30 to 40 days in a year. During this period top ice cover of Priyadarshini Lake melts as well as Dakshin Gangotri glacier situated just behind Maitri station melts. The combined effect of melting is mixing pathway for water and wastewater by; (a) interconnected glacial lakes situated at east and west of Maitri at higher elevation than Priyadarshini Lake feeds Priyadarshini Lake from both the ends. When melting is high, water overflows from northern periphery of Priyadarshini Lake which is around 7.2 m deep and joins a small pond. (b) Effluent of wastewater collection pond which remains frozen throughout the year except for few days in austral summer seeps through the outer periphery and joins Priyadarshini Lake, situated at lower elevation. However the flow is small but cannot be ignored as Priyadarshini Lake is drinking water source for Maitri station. (c) A portion of melted effluent from pond is discharged away and after traveling joins the nearby glacial lake situated 320 m west of Maitri station and further during feed from glacial melt water, it overflows and joins another glacial lake and abuts on Priyadarshini Lake.

With this background it is felt necessary to assess the water quality of the lakes as they are part of integrated system and being affected by the wastewater discharge. To assess the effect of contamination, past results of water quality parameters of Priyadarshini Lake, glacial lake and Control Lake were taken into account which were collected and

analyzed by the previous expedition members during the years 1994 and 1995 and compared with the present study results carried out during the years 2000 and 2004. Results indicated that Priyadarshini Lake is slightly acidic in nature. This can be explained as in low temperature carbon dioxide dissolves in the water and shift the pH from neutral to acidic. Further, conductivity and dissolved solids present in low quantity supports the presence of very less salts. The effect of dissolution of salts from the rock debris was noticed in the glacial lakes which feed to Priyadarshini Lake. Dissolved oxygen is found to be very near to the theoretical values as prescribed in the text book for such low temperature and salinity except at the locations of seepage discharge conjunction point and where summer camp effluent has the probability to abut on lake. At these points BOD noticed is also slightly higher.

Past record of 1994 showed the effect of trace metal contamination in Priyadarshini Lake especially of Pb, Cd and Zn and reason was existence of vehicle repairing garage from where the battery waste, oil etc. sometimes seep and reached the lake. However, analysis carried out in later years did not show the effect of trace metals especially not observed after removal of garage from that particular place. Effect of pollen and spores deposition which might have traveled from long distances can be recorded with increase in algae and moss around the lake which in turn increase in alkalinity of the lakes. Higher concentration of moss and algae was noticed near the confluence point of wastewater seepage, final discharge and at the confluence point of glacial lake and Priyadarshini Lake due to extraction of nutrients from effluent. Analysis of recent years show increased hardness which is due to the effect of open discharge from summer camp bathrooms.

Water quality prediction model WASP7 is used to predict the water quality of Priyadarshini Lake taking into consideration mixing of wastewater seepage from collection pond in the same rate for nearly 45 days. To compute volume of the lake, GPS recorded periphery coordinates were used to calculate the area and depth was recorded by manually with the help of string at various locations inside the lake. Implying SURFER software and Simpsons rule, volume of the lake was calculated. Inflow to the Priyadarshini Lake was measured by change in the water level of the lake with respect to glacier melts during austral summer. Effect of the seepage into lake was

computed using pattern of demand parameters and nitrogen and the lake was divided into five segments. However, external dilution effect is not taken into account opting worst case scenario. Minor increase in ammonia, nitrate and total nitrogen was noticed in the segment especially where seepage mixed and DO concentration was found slightly lower than before mixing scenario. However in rest of the segment no adverse effect was noticed.

RBCs were analyzed during all four years by taking influent and effluent samples from both the B1 and B3 system on a particular day. Two sets of samples were collected during the years 1994 and 1995 by other expedition members and another two sets were collected during the present study period. Efficacy of B1 RBC before the present study period was found to be less than 50% in terms of BOD and COD and increased to around 70% in terms of BOD and COD after increasing temperature of bio-chamber to nearly 20°C. But in later years negative value of COD was noticed due to higher sludge deposition in the secondary settling tank. Similarly, efficacy of B3 RBC noticed in all the three years was less than 35% in terms of BOD and 40% in terms of COD. On the contrary in the later years the negative efficiency was noted. No mechanism installed for prior removal of organic load before entering to RBC as these RBC were working with higher than design load. An attempt was made to assess the effect of alum and activated carbon to remove organic, nitrogen and trace metal loading from the unturned RBC. A small experiment conducted at Maitri on one day composite effluent from RBC implying alum dose and thereafter passing effluent through activated carbon. Results were encouraging with BOD and COD removal by 20% and 30% and ammonia by 47%. It was noticed that RBCs were functioning to treat much higher load than designed. All the Antarctic stations have higher concentrations of organic as well as inorganic load as compared to tropical countries owing to less water consumption.

In order to understand the functions of RBC in a similar way as treatment is in progress in Maitri by treating waste separately, three sets of experiments were conducted on the laboratory scale model of RBC reducing the ratio by 1:200. First experiment was conducted by keeping similar higher organic load than designed on the RBC with full designed hydraulic load and assuming future scenario of increased number of occupants and assuming that RBC has to be installed with temperature maintained nearly 25-30°C

in a containerized module. Kitchen influent was made available through institute's canteen representing almost similar nature of wastewater. For laundry and urinal, wastewater collected from urinal mixed into water along with soap and detergent. Calculations were made according to daily consumption at Maitri station. Three weeks time was given to grow the microbes on the bio-disk filling chambers with water and seeds. First experiment was conducted for ten days collecting alternate days influent and effluent composite samples. Results showed the efficacy for BOD, COD and TDS removal with around 62% for BOD and 57% for COD and 57% TDS from laundry influent and 62% BOD and 46% COD and 46% TDS from the kitchen influent. The results clearly indicate the effect of higher temperature in improving efficacy which is certainly much better than present removal capacity at Maitri station though still less than desired. Reasons for low efficacy is attributed to very high organic load than designed and lack of carbon and other nutrient needed to grow microbes in laundry RBC and lower rpm in kitchen RBC. Recognizing this fact, second experiment was conducted converting the system into partial two stage RBC by diverting treated kitchen RBCs effluent with laundry influent and lowering organic load slightly in both RBC. In this experiment, efficacy further improved to 83% for BOD and 85% for COD and 66% for TDS. This experiment clearly showed the effect of carbon and other nutrients required to RBC and working of microbes in removal of organic load. This experiment was continued for nearly ten days.

In the third experiment, to enumerate the application of tertiary treatment which includes alum dose and activated carbon treatment and entrusted on the combined effluent of partial two stage system, the experiment for nearly fifty days was continued. Results of the third experiment proved the effect of tertiary treatment by showing improvement in average efficacy of 91% BOD and 90% COD which in some instances reached to 99.3% for BOD and 99.5% for COD, while load was kept near to design load. On an average, overall removal recorded was 73% for ammonical-nitrogen, 38% for nitrate and 23% for phosphate. Results also showed that metals which could not be removed by biosorption can be effectively removed by activated carbon in the order, Zn>Mn>Fe>Co, however Pb, Cd, Ni, Cu and Cr are added to the effluent treated by activated carbon.

At present, the RBCs are working on higher organic load and therefore to remove the

prior load and to bring it to nearly design load, ancillary units are needed to install such as equalization tank, oil and grease trap, which are designed according to station demand and can be easily installed. Sludge dewatering would be more beneficial in order to reduce the back adding of BOD and COD in the effluent and to reduce the waste quantity for back loaded items for India from Antarctica. Alum dose can be given to the combined treated effluent after converting system into two stage partial treatment units in similar fashion and dose, as experimented at lab scale and there after activated carbon treatment can be implied. Activated carbon module needed for Maitri would consists of around 2915 kg of GAC filled in 13 columns of 1.5 m length and 0.8 m diameter to work efficiently throughout the year without regeneration. However, it can either be regenerated or replaced at the end of the year. To make sewage treatment higher than minimum standards prescribed by Madrid Protocol, the activated carbon treated effluent can be treated with Reverse Osmosis system combined with UV disinfection by installing and operating them at Maitri station. To achieve best practical approach for the final discharge of RO treated effluent, it can be directly sprinkled with fine spray over open land. Regular discharge has to be made rather than storing in wastewater pond, in order to completely stop the seepage towards Priyadarshini Lake.

Further Work Proposed

- ◆ Experiment can be conducted on running the RBC at higher rpm such as 10, 15 and 25 to assess the effect of rpm on organic loading and trace metal removal.
- ◆ The effect of prior and post alum dosing and using various coagulant in removal of organic and trace metal can be assessed
- ◆ The effect of various types of membrane to treat the tertiary treated effluent can be assessed
- ◆ Experiment can be conducted to evaluate the role of various consortiums of microbes as well as psychrophilic bacteria to treat particular type of waste

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Appendix-1

ANNEX III TO THE PROTOCOL ON ENVIRONMENTAL PROTECTION TO THE ANTARCTIC TREATY WASTE DISPOSAL AND WASTE MANAGEMENT

ARTICLE 1 GENERAL OBLIGATIONS

1. This Annex shall apply to activities undertaken in the Antarctic Treaty Area pursuant to scientific research programmes, tourism and all other governmental and non-governmental activities in the Antarctic Treaty Area for which advance notice is required under Article VII (5) of the Antarctic Treaty, including associated logistic support activities.
2. The amount of wastes produced or disposed of in the Antarctic Treaty Area shall be reduced as far as practicable so as to minimise impact on the Antarctic environment and to minimise interference with the natural values of Antarctica, with scientific research and with other uses of Antarctica which are consistent with the Antarctic Treaty.
3. Waste storage, disposal and removal from the Antarctic Treaty Area, as well as recycling and source reduction, shall be essential considerations in the planning and conduct of activities in the Antarctic Treaty Area.
4. Wastes removed from the Antarctic Treaty Area shall, to the maximum extent practicable, be returned to the country from which the activities generating the waste were organized or to any other country in which arrangements have been made for the disposal of such wastes in accordance with relevant international agreements.
5. Past and present waste disposal sites on land and abandoned work sites of Antarctic activities shall be cleaned up by the generator of such wastes and the user of such sites. This obligation shall not be interpreted as requiring:
 - (a) the removal of any structure designated as a historic site or monument; or
 - (b) the removal of any structure or waste material in circumstances where the removal by any practical option would result in greater adverse environmental impact than leaving the structure or waste material in its existing location.

ARTICLE 2 WASTE DISPOSAL BY REMOVAL FROM THE ANTARCTIC TREATY AREA

1. The following wastes, if generated after entry into force of this Annex, shall be removed from the Antarctic Treaty Area by the generator of such wastes:
 - (a) radio-active materials;
 - (b) electrical batteries;
 - (c) fuel, both liquid and solid;
 - (d) wastes containing harmful levels of heavy metals or acutely toxic or harmful persistent compounds;
 - (e) poly-vinyl chloride (PVC), polyurethane foam, polystyrene foam, rubber and lubricating oils, treated timbers and other products which contain additives that could produce harmful emissions if incinerated;
 - (f) all other plastic wastes, except low density polyethylene containers (such as bags for storing wastes), provided that such containers shall be incinerated in accordance with Article 3 (1);
 - (g) fuel drums; and
 - (h) other solid, non-combustible wastes;provided that the obligation to remove drums and solid non-combustible wastes contained in subparagraphs (g) and (h) above shall not apply in circumstances where the removal of such wastes by any practical option would result in greater adverse environmental impact than leaving them in their existing locations.
2. Liquid wastes which are not covered by paragraph 1 above and sewage and domestic liquid wastes, shall, to the maximum extent practicable, be removed from the Antarctic Treaty Area by the generator of such wastes.
3. The following wastes shall be removed from the Antarctic Treaty Area by the generator of such wastes, unless incinerated, autoclaved or otherwise treated to be made sterile:

- (a) residues of carcasses of imported animals;
- (b) laboratory culture of micro-organisms and plant pathogens; and
- (c) introduced avian products.

ARTICLE 3

WASTE DISPOSAL BY INCINERATION

1. Subject to paragraph 2 below, combustible wastes, other than those referred to in Article 2 (1), which are not removed from the Antarctic Treaty Area shall be burnt in incinerators which to the maximum extent practicable reduce harmful emissions. Any emission standards and equipment guidelines which may be recommended by, inter alia, the Committee and the Scientific Committee on Antarctic Research shall be taken into account. The solid residue of such incineration shall be removed from the Antarctic Treaty Area.
2. All open burning of wastes shall be phased out as soon as practicable, but no later than the end of the 1998/1999 season. Pending the completion of such phase-out, when it is necessary to dispose of wastes by open burning, allowance shall be made for the wind direction and speed and the type of wastes to be burnt to limit particulate deposition and to avoid such deposition over areas of special biological, scientific, historic, aesthetic or wilderness significance including, in particular, areas accorded protection under the Antarctic Treaty.

ARTICLE 4

OTHER WASTE DISPOSAL ON LAND

1. Wastes not removed or disposed of in accordance with Articles 2 and 3 shall not be disposed of onto ice-free areas or into fresh water systems.
2. Sewage, domestic liquid wastes and other liquid wastes not removed from the Antarctic Treaty Area in accordance with Article 2, shall, to the maximum extent practicable, not be disposed of onto sea ice, ice shelves or the grounded ice-sheet, provided that such wastes which are generated by stations located inland on ice shelves or on the grounded ice-sheet may be disposed of in deep ice pits where such disposal is the only practicable option. Such pits shall not be located on known ice-flow lines which terminate at ice-free areas or in areas of high ablation.
3. Wastes generated at field camps shall, to the maximum extent practicable, be removed by the generator of such wastes to supporting stations or ships for disposal in accordance with this Annex.

ARTICLE 5

DISPOSAL OF WASTE IN THE SEA

1. Sewage and domestic liquid wastes may be discharged directly into the sea, taking into account the assimilative capacity of the receiving marine environment and provided that:
 - (a) such discharge is located, wherever practicable, where conditions exist for initial dilution and rapid dispersal; and
 - (b) large quantities of such wastes (generated in a station where the average weekly occupancy over the austral summer is approximately 30 individuals or more) shall be treated at least by maceration.
2. The by-product of sewage treatment by the Rotary Biological Contacter process or similar processes may be disposed of into the sea provided that such disposal does not adversely affect the local environment, and provided also that any such disposal at sea shall be in accordance with Annex IV to the Protocol.

ARTICLE 6

STORAGE OF WASTE

All wastes to be removed from the Antarctic Treaty Area, or otherwise disposed of, shall be stored in such a way as to prevent their dispersal into the environment.

ARTICLE 7

PROHIBITED PRODUCTS

No polychlorinated biphenyls (PCBs), non-sterile soil, polystyrene beads, chips or similar forms of packaging, or pesticides (other than those required for scientific, medical or hygiene purposes) shall be introduced onto land or ice shelves or into water in the Antarctic Treaty Area.

ARTICLE 8

WASTE MANAGEMENT PLANNING

1. Each Party which itself conducts activities in the Antarctic Treaty Area shall, in respect of those activities,

establish a waste disposal classification system as a basis for recording wastes and to facilitate studies aimed at evaluating the environmental impacts of scientific activity and associated logistic support. To that end, wastes produced shall be classified as:

- (a) sewage and domestic liquid wastes (Group 1);
 - (b) other liquid wastes and chemicals, including fuels and lubricants (Group 2);
 - (c) solids to be combusted (Group 3);
 - (d) other solid wastes (Group 4); and
 - (e) radioactive material (Group 5).
2. In order to reduce further the impact of waste on the Antarctic environment, each such Party shall prepare and annually review and update its waste management plans (including waste reduction, storage and disposal), specifying for each fixed site, for field camps generally, and for each ship (other than small boats that are part of the operations of fixed sites or of ships and taking into account existing management plans for ships):
- (a) programmes for cleaning up existing waste disposal sites and abandoned work sites;
 - (b) current and planned waste management arrangements, including final disposal;
 - (c) current and planned arrangements for analysing the environmental effects of waste and waste management; and
 - (d) other efforts to minimise any environmental effects of wastes and waste management.
3. Each such Party shall, as far as is practicable, also prepare an inventory of locations of past activities (such as traverses, fuel depots, field bases, crashed aircraft) before the information is lost, so that such locations can be taken into account in planning future scientific programmes (such as snow chemistry, pollutants in lichens or ice core drilling).

ARTICLE 9 CIRCULATION AND REVIEW OF WASTE MANAGEMENT PLANS

1. The waste management plans prepared in accordance with Article 8, reports on their implementation, and the inventories referred to in Article 8 (3), shall be included in the annual exchanges of information in accordance with Articles III and VII of the Antarctic Treaty and related Recommendations under Article IX of the Antarctic Treaty.
2. Each Party shall send copies of its waste management plans, and reports on their implementation and review, to the Committee.
3. The Committee may review waste management plans and reports thereon and may offer comments, including suggestions for minimising impacts and modifications and improvement to the plans, for the consideration of the Parties.
4. The Parties may exchange information and provide advice on, inter alia, available low waste technologies, reconversion of existing installations, special requirements for effluents, and appropriate disposal and discharge methods.

ARTICLE 10 MANAGEMENT PRACTICES

Each Party shall:

- (a) designate a waste management official to develop and monitor waste management plans; in the field, this responsibility shall be delegated to an appropriate person at each site;
- (b) ensure that members of its expeditions receive training designed to limit the impact of its operations on the Antarctic environment and to inform them of requirements of this Annex; and
- (c) discourage the use of poly-vinyl chloride (PVC) products and ensure that its expeditions to the Antarctic Treaty Area are advised of any PVC products they may introduce into that area in order that these products may be removed subsequently in accordance with this Annex.

ARTICLE 11 REVIEW

This Annex shall be subject to regular review in order to ensure that it is updated to reflect improvement in waste disposal technology and procedures and to ensure thereby maximum protection of the Antarctic environment.

ARTICLE 12 CASES OF EMERGENCY

1. This Annex shall not apply in cases of emergency relating to the safety of human life or of ships, aircraft or equipment and facilities of high value or the protection of the environment.
2. Notice of activities undertaken in cases of emergency shall be circulated immediately to all Parties and to the Committee.

ARTICLE 13

AMENDMENT OR MODIFICATION

1. This Annex may be amended or modified by a measure adopted in accordance with Article IX (1) of the Antarctic Treaty. Unless the measure specifies otherwise, the amendment or modification shall be deemed to have been approved, and shall become effective, one year after the close of the Antarctic Treaty Consultative Meeting at which it was adopted, unless one or more of the Antarctic Treaty Consultative Parties notifies the Depositary, within that time period, that it wishes an extension of that period or that it is unable to approve the amendment.
2. Any amendment or modification of this Annex which becomes effective in accordance with paragraph 1 above shall thereafter become effective as to any other Party when notice of approval by it has been received by the Depositary.

**ANNEX IV TO THE PROTOCOL ON ENVIRONMENTAL PROTECTION TO THE
ANTARCTIC TREATY
PREVENTION OF MARINE POLLUTION**

**ARTICLE 1
DEFINITIONS**

For the purposes of this Annex:

- (a) "discharge" means any release howsoever caused from a ship and includes any escape, disposal, spilling, leaking, pumping, emitting or emptying;
- (b) "garbage" means all kinds of victual, domestic and operational waste excluding fresh fish and parts thereof, generated during the normal operation of the ship, except those substances which are covered by Articles 3 and 4;
- (c) "MARPOL 73/78" means the International Convention for the Prevention of Pollution from Ships, 1973, as amended by the Protocol of 1978 relating thereto and by any other amendment in force thereafter;
- (d) "noxious liquid substance" means any noxious liquid substance as defined in Annex II of MARPOL 73/78;
- (e) "oil" means petroleum in any form including crude oil, fuel oil, sludge, oil refuse and refined oil products (other than petrochemicals which are subject to the provisions of Article 4);
- (f) "oily mixture" means a mixture with any oil content; and
- (g) "ship" means a vessel of any type whatsoever operating in the marine environment and includes hydrofoil boats, air-cushion vehicles, submersibles, floating craft and fixed or floating platforms.

**ARTICLE 2
APPLICATION**

This Annex applies, with respect to each Party, to ships entitled to fly its flag and to any other ship engaged in or supporting its Antarctic operations, while operating in the Antarctic Treaty Area.

**ARTICLE 3
DISCHARGE OF OIL**

1. Any discharge into the sea of oil or oily mixture shall be prohibited, except in cases permitted under Annex I of MARPOL 73/78. While operating in the Antarctic Treaty Area, ships shall retain on board all sludge, dirty ballast, tank washing waters and other oily residues and mixtures which may not be discharged into the sea. Ships shall discharge these residues only outside the Antarctic Treaty Area, at reception facilities or as otherwise permitted under Annex I of MARPOL 73/78.
2. This Article shall not apply to:
 - (a) the discharge into the sea of oil or oily mixture resulting from damage to a ship or its equipment:
 - (i) provided that all reasonable precautions have been taken after the occurrence of the damage or discovery of the discharge for the purpose of preventing or minimising the discharge; and
 - (ii) except if the owner or the Master acted either with intent to cause damage, or recklessly and with the knowledge that damage would probably result; or
 - (b) the discharge into the sea of substances containing oil which are being used for the purpose of combating specific pollution incidents in order to minimise the damage from pollution.

**ARTICLE 4
DISCHARGE OF NOXIOUS LIQUID SUBSTANCES**

The discharge into the sea of any noxious liquid substance, and any other chemical or other substances, in quantities or concentrations that are harmful to the marine environment, shall be prohibited.

**ARTICLE 5
DISPOSAL OF GARBAGE**

1. The disposal into the sea of all plastics, including but not limited to synthetic ropes, synthetic fishing nets, and plastic garbage bags, shall be prohibited.
2. The disposal into the sea of all other garbage, including paper products, rags, glass, metal, bottles, crockery, incineration ash, dunnage, lining and packing materials, shall be prohibited.
3. The disposal into the sea of food wastes may be permitted when they have been passed through a comminuter or grinder, provided that such disposal shall, except in cases permitted under Annex V of MARPOL 73/78, be made as far as practicable from land and ice shelves but in any case not less than 12 nautical miles from the nearest land or ice shelf. Such comminuted or ground food wastes shall be capable of passing through a screen with openings no greater than 25 millimeters.
4. When a substance or material covered by this article is mixed with other such substance or material for discharge or disposal, having different disposal or discharge requirements, the most stringent disposal or discharge requirements shall apply.
5. The provisions of paragraphs 1 and 2 above shall not apply to:
 - (a) the escape of garbage resulting from damage to a ship or its equipment provided all reasonable precautions have been taken, before and after the occurrence of the damage, for the purpose of preventing or minimising the escape; or
 - (b) the accidental loss of synthetic fishing nets, provided all reasonable precautions have been taken to prevent such loss.
6. The Parties shall, where appropriate, require the use of garbage record books.

ARTICLE 6

DISCHARGE OF SEWAGE

1. Except where it would unduly impair Antarctic operations:
 - (a) each Party shall eliminate all discharge into the sea of untreated sewage ("sewage" being defined in Annex IV of MARPOL 73/78) within 12 nautical miles of land or ice shelves;
 - (b) beyond such distance, sewage stored in a holding tank shall not be discharged instantaneously but at a moderate rate and, where practicable, while the ship is *en route* at a speed of no less than 4 knots.

This paragraph does not apply to ships certified to carry not more than 10 persons.

2. The Parties shall, where appropriate, require the use of sewage record books.

ARTICLE 7

CASES OF EMERGENCY

1. Articles 3, 4, 5 and 6 of this Annex shall not apply in cases of emergency relating to the safety of a ship and those on board or saving life at sea.
2. Notice of activities undertaken in cases of emergency shall be circulated immediately to all Parties and to the Committee.

ARTICLE 8

EFFECT ON DEPENDENT AND ASSOCIATED ECOSYSTEMS

In implementing the provisions of this Annex, due consideration shall be given to the need to avoid detrimental effects on dependent and associated ecosystems, outside the Antarctic Treaty Area.

ARTICLE 9

SHIP RETENTION CAPACITY AND RECEPTION FACILITIES

1. Each Party shall undertake to ensure that all ships entitled to fly its flag and any other ship engaged in or supporting its Antarctic operations, before entering the Antarctic Treaty Area, are fitted with a tank or tanks of sufficient capacity on board for the retention of all sludge, dirty ballast, tank washing water and other oily residues and mixtures, and have sufficient capacity on board for the retention of garbage, while operating in the Antarctic Treaty Area and have concluded arrangements to discharge such oily residues and garbage at a reception facility after leaving that area. Ships shall also have sufficient capacity on board for the retention of noxious liquid substances.
2. Each Party at whose ports ships depart *en route* to or arrive from the Antarctic Treaty Area undertakes to ensure that as soon as practicable adequate facilities are provided for the reception of all sludge, dirty ballast, tank washing water, other oily residues and mixtures, and garbage from ships, without causing undue delay, and

according to the needs of the ships using them.

3. Parties operating ships which depart to or arrive from the Antarctic Treaty Area at ports of other Parties shall consult with those Parties with a view to ensuring that the establishment of port reception facilities does not place an inequitable burden on Parties adjacent to the Antarctic Treaty Area.

ARTICLE 10

DESIGN, CONSTRUCTION, MANNING AND EQUIPMENT OF SHIPS

In the design, construction, manning and equipment of ships engaged in or supporting Antarctic operations, each Party shall take into account the objectives of this Annex.

ARTICLE 11

SOVEREIGN IMMUNITY

1. This Annex shall not apply to any warship, naval auxiliary or other ship owned or operated by a State and used, for the time being, only on government non-commercial service. However, each Party shall ensure by the adoption of appropriate measures not impairing the operations or operational capabilities of such ships owned or operated by it, that such ships act in a manner consistent, so far as is reasonable and practicable, with this Annex.
2. In applying paragraph 1 above, each Party shall take into account the importance of protecting the Antarctic environment.
3. Each Party shall inform the other Parties of how it implements this provision.
4. The dispute settlement procedure set out in Articles 18 to 20 of the Protocol shall not apply to this Article.

ARTICLE 12

PREVENTIVE MEASURES AND EMERGENCY PREPAREDNESS AND RESPONSE

1. In order to respond more effectively to marine pollution emergencies or the threat thereof in the Antarctic Treaty Area, the Parties, in accordance with Article 15 of the Protocol, shall develop contingency plans for marine pollution response in the Antarctic Treaty Area, including contingency plans for ships (other than small boats that are part of the operations of fixed sites or of ships) operating in the Antarctic Treaty Area, particularly ships carrying oil as cargo, and for oil spills, originating from coastal installations, which enter into the marine environment. To this end they shall:
 - (a) co-operate in the formulation and implementation of such plans; and
 - (b) draw on the advice of the Committee, the International Maritime Organization and other international organizations.
2. The Parties shall also establish procedures for cooperative response to pollution emergencies and shall take appropriate response actions in accordance with such procedures.

ARTICLE 13

REVIEW

The Parties shall keep under continuous review the provisions of this Annex and other measures to prevent, reduce and respond to pollution of the Antarctic marine environment, including any amendments and new regulations adopted under MARPOL 73/78, with a view to achieving the objectives of this Annex.

ARTICLE 14

RELATIONSHIP WITH MARPOL 73/78

With respect to those Parties which are also Parties to MARPOL 73/78, nothing in this Annex shall derogate from the specific rights and obligations thereunder.

ARTICLE 15

AMENDMENT OR MODIFICATION

1. This Annex may be amended or modified by a measure adopted in accordance with Article IX (1) of the Antarctic Treaty. Unless the measure specifies otherwise, the amendment or modification shall be deemed to have been approved, and shall become effective, one year after the close of the Antarctic Treaty Consultative Meeting at which it was adopted, unless one or more of the Antarctic Treaty Consultative Parties notifies the Depositary, within that time period, that it wishes an extension of that period or that it is unable to approve the measure.
2. Any amendment or modification of this Annex which becomes effective in accordance with paragraph 1 above shall thereafter become effective as to any other Party when notice of approval by it has been received by the Depositary.

LIST OF PUBLICATION FROM RESEARCH WORK IN PEER REVIEWED JOURNALS

Tiwari A.K., Kulakarni S., Ramteke S., Nayak G.N. (2006) Environmental quality at Maitri station in Antarctica. Journal of Environmental Science and Engineering, Vol 48, No 3, 191-198.

Tiwari A.K., Nayak G.N. (2007) Water abundance and effect of glacier melting at Priyadarshini lake in Antarctica. Journals of Institutions of Engineers, Vol 88, 27-32. (Awarded Shrimati Shiromadevi award by Institutions of Engineers, Kolkata).

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Environment Quality at Maitri Station in Antarctica

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A comprehensive study of air, water and soil quality was undertaken during the austral summer of 1999-2000 at the Indian Polar Research Station "Maitri" in compliance with the statutory requirements of the article 3 of Protocol on Environmental Protection to the Antarctic Treaty. The main objective of the study was to assess the impacts of various scientific programs and their associated logistic support facilities on the fragile ecosystem of Antarctica. Identification of major sources of pollution and quantification of pollutants in different environmental components were carried out through an extensive environmental monitoring program spread over a period of 5-7 weeks. Preliminary studies reveal that the levels of pollution are not alarming but there is scope for concern looking into the critical aspects of Antarctic environment and the carrying capacity of the environment surrounding Maitri station.

Key words : *Antarctica, air, noise, water quality, RBC, reactive barriers*

Introduction

Antarctica is the largest and most pristine wilderness on Earth, covering an area of approximately 13.6 million square km¹. It is made inhospitable by extreme cold, presence of a massive permanent ice sheet and the floating ice shelves. Anthropogenic activities in Antarctica have the potential of producing both contemporaneous and long-term environmental impacts on the nearly pristine surroundings. "Maitri", India's indigenously designed polar research station in Antarctica is located in the Schirmacher Oasis at 70°45'53" S latitude and 11°44'03" E longitude. It is built on an ice-free rocky moraine at an elevation of 117m above mean sea level.

The station consists of four blocks that comprise of lodging, medical facilities, communication control system, computer room, gymnasium, cold storage, sports room, lounge, dining, kitchen, boiler-room, laundry room, bathrooms and toilets. Three containerized modules of generators are located outside on the southern side of the Maitri station. Priyadarshini Lake (also called Zub Lake) covers an area of 0.35 km² and forms the major source of water supply. It is situated about 225 m away from the station in the northern direction. The consumption of water is relatively more in austral summer compared to the rest of the year when it fluctuates between 1.70 (winter) and 5.7 (summer) m³/day. It is during the austral summer that most scientific activities are carried out in and around the station. In addition, emissions due to electricity generators and toilet incinerators, and volume of wastewater generated are significantly more during this period.

The Protocol on Environmental Protection² to the Antarctic Treaty³ which was adopted in 1991 by the Antarctic Treaty nations provides for the comprehensive protection of the Antarctic environment, and sets out tightly drawn rules governing human activities there. The protocol on environmental protection to the Antarctic Treaty, which has been agreed to by 28 Antarctic Treaty Consultative Parties (ATCPs), including India⁴ in 1991, requires environmental impact assessment (EIA) to be applied in the planning and operation of all activities undertaken in Antarctica. Adhering to this protocol, a comprehensive environmental assessment exercise covering air, water and soil was undertaken.

Materials and methods

Water quality assessment

Extensive monitoring of surface water bodies located in the proximity of Maitri station in particular and in the Schirmacher Oasis region in general was undertaken as part of the EIA studies during the austral summer of 1999-2000. The main surface water bodies identified in the region were Priyadarshini Lake, its feeding glacial waters and other lakes (referred as Control Lakes). Rotating Biological Contactors (RBC) installed at Maitri to treat the greywater generated in station, are made of Glass fiber Reinforced Polyester (GRP), which is extremely robust and easy to transport and install. The RBC units are located in separate rooms that are not exposed to sunlight to prevent the growth of algae, which could intervene with microbial attachment⁵ and sometimes

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overburden the discs with extra mass. The treated effluent is collected in pond. A seepage channel (observed for short period) arising from near the treated effluent collection pond and apparently joining Priyadarshini Lake was also considered for the study. The water from these different sources was assessed for its physical, inorganic, nutrient, and organic parameters. Additionally, the prevailing levels of some selected heavy metals were also quantified. The important factors that are likely to affect the water quality in the region, especially Priyadarshini Lake, are the closeness of summer camp to it and the emergence of afore-referred seepage channel at higher elevation. In the past, food packets, empty cans, empty fuel drums and other solid wastes sometimes got carried over into the lake due to high wind velocities prevailing in the region. However, in subsequent expeditions everything was removed during environmental cleaning operations and introduction of proper solid waste management practices. In the light of these factors, assessment of water quality was considered essential and of utmost priority.

Ten sampling locations, denoted as W1 to W10, were selected in different directions in the Priyadarshini Lake for proper assessment of its water quality. Six locations, denoted

as GL1a, GL1b, GL2, GL3, GL4a and GL4b, were identified in four glacial lakes located on western side of the station. Three additional locations, denoted as CL1a, CL1b and CL2, were comprised of two freshwater lakes, referred as Control Lakes. These samples from Control Lakes were used to obtain the background concentrations, since the lakes were situated some distance away from the station and assumed to be untouched by the prevailing activities. The sampling locations are depicted in Fig. 1. On each sampling occasion, surface water samples were collected using pre-cleaned apparatus and stored in sterilized polypropylene bottles. The sample preservation and their analysis for different water quality parameters were carried out as per the standard procedures set out in the Standard Methods (Standard Methods for the Examination of Water and Wastewater). Certain parameters, viz. pH, conductivity, temperature, turbidity and dissolved oxygen, were estimated immediately upon collection of the samples. Some samples were preserved, which were to be analyzed later for determining nutrient, organic and inorganic parameters as well as levels of heavy metals. All analyses were performed according to the Standard Methods for analysis of water and wastewater⁶. For the analysis of heavy metals, samples were preserved and analyzed by GBC, Atomic Spectrophotometer in laboratory.

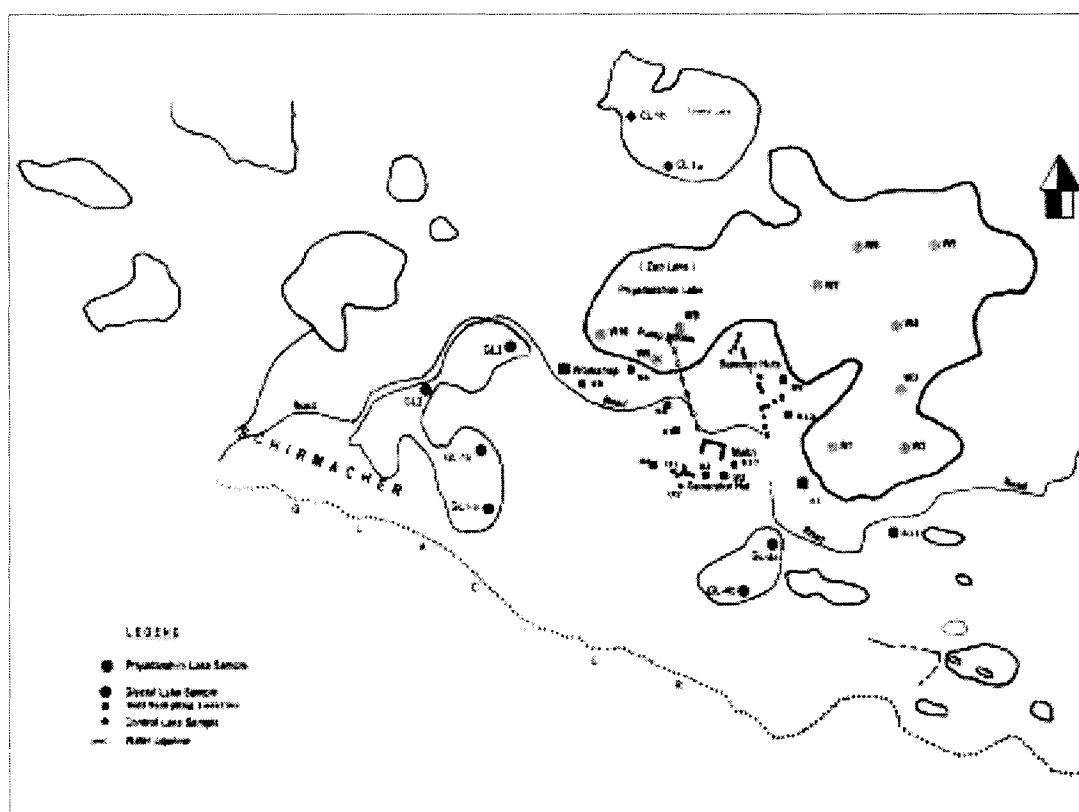


Fig. 1: Locations for water and soil quality monitoring

Air quality assessment

An extensive ambient air quality monitoring (AAQM) was carried out in the Schirmacher region surrounding Maitri station. Total seven locations were identified for this purpose. These were selected in such a way that six of them were located in the downwind direction of a known source(s) of air pollution, while one of the monitoring stations was located in the upwind direction of Maitri station in order to gather information on the background concentration prevailing in the ambient atmosphere. The existing sources of air pollution in the region were identified as generators, boiler, incinerator-based toilets and vehicular (piston pulley, cranes and dozers) movement. Besides exhaust gases, helicopters (during hovering, landing and take off from helipads) and vehicles also contributed towards suspended particulate matter (SPM). The main gaseous pollutants monitored were sulphur dioxide (SO_2) and oxides of nitrogen (NO_x), as the basic fuel was being used as JetA1 – ATF (Aviation turbine fuel). The other parameter of concern monitored was the particulate matter in the atmosphere in the form of SPM. These pollutants were monitored on a 24 hourly basis, continuously for a period of seven days at each location by means of high volume air sampler (HVAS). The particulate matter was determined gravimetrically, while the gaseous pollutants were estimated spectrophotometrically. Micrometeorological parameters such as ambient temperatures, wind-speed and wind-direction were continuously monitored during the entire period of the study.

Soil quality assessment

Soil and sediment play crucial role in ecosystem functioning. In order to carry out a critical assessment of soil, an extensive soil sampling programme was undertaken in and around Maitri station in the Schirmacher region. Total fourteen soil samples S1 to S12 and O1 and O2 representing various areas of activities including the seepage channel, workshop, oil-storage and generator were collected. Locations O1 and O2 represent soil samples collected from oil-spilled areas. The various sampling locations are presented in Fig.1. The parameters such as particle size, texture, water holding capacity, pH, nutrient load, cation exchange capacity (CEC), organic content, hydrocarbon, and oil & grease were analyzed. Due to extreme cold conditions and scarcity of nutrients, limited plant growth was observed, except for some species of bryophytes, algae and lichens, which are adapted to endure the extreme weather were found ubiquitously on the rocky plains, lakesides, hills and nunataks. These species as well as the scattered excreta of migratory birds such as Skuas and Snow Petrels are responsible for presence of organic matter in the Antarctic soil so far as the non-anthropogenic sources are concerned.

Considering the major activities of earlier and ongoing expeditions in the region including emissions from generators,

accidental minor oil-spillages, suspected treated wastewater seepage and solid waste dumping, the likelihood of deterioration of soil characteristics has been taken into account. Accordingly, during this expedition the pertinent locations were identified and soil samples were collected for detailed characterization. In the present study, soil sampling locations were classified into areas having activities and areas without any anthropogenic activity so that a proper assessment of soil quality could be carried out.

Eleven soil sampling locations associated with regular anthropogenic activities were identified around the station. Surface coring soil samples were collected using auger and stored in clean and labelled polythene bags covered with aluminum foil. Specific physicochemical parameters such as particle size distribution, texture, water holding capacity, pH, nutrient load, cation exchange capacity, exchangeable cations and percent organic content were determined as per the standard methods. Levels of hydrocarbon and oil & grease in the soils were also estimated to assess the impact of oil-spillages on the land environment.

Results and discussion

Water quality

The physicochemical characteristics of various water samples are shown in Table 1. The physical characteristics indicated that pH is on acidic side ranging between 5.8-6.5 for glacial lakes and 6.3-6.5 for samples from Priyadarshini Lake. The acidic nature of glacial lakes is indicative of precipitated water with low conductivity, turbidity and dissolved solids, whereas the slightly higher pH in Priyadarshini Lake indicates dissolution of minerals through inlet run-off waters causing increase in conductivity and dissolved solids. The electrical conductivity ranged between 10-28 $\mu\text{S}/\text{cm}$. Hardness varied in the range 5.0 – 10.1 mg/L. During sample collection, it is observed that temperature of surface water varied from -1.0°C to +3.5°C, where as turbidity of water samples found in between 0.4 to 1.5 NTU. Heavy metals were recorded in the ranges of 0.191 mg/L to 1.655 mg/L for Fe, 0.005 mg/L to 0.39 mg/L for Mn, from BDL (below detectable limit) to 0.348 mg/L for Pb, which were found below detectable limits in all the points. Iron concentrations at many places were recorded at little higher side because of attribution of glacial melt water which comes over the rocks and debris left over due to retreating of Dakshin Gangotri glacier and mixes with water.

The inorganic parameters in terms of sulphate and chloride were found to lie in the ranges of 0.6-1.8 mg/L and 1.8-3.4 mg/L respectively. The nutrient parameters such as nitrate and phosphate were recorded in the ranges of 0.09 to 1.2 mg/L and BDL to 1.8 mg/L respectively. Dissolved oxygen levels in various water samples were found to range between

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Table 1: Surface water quality - organic and nutrient characteristics

Particulars of Sample	Denoted as	Dissolved Oxygen	Nitrate	Total PO ₄	BOD ₅	COD
South-southeast (SSE) side of P. Lake 50m away from western bank	W1	14.0	0.3	BDL	3.1	8.0
Southeast side of P. Lake 75m away from eastern bank	W2	14.0	0.4	0.2	3.3	12.0
East-southeast side of P. Lake 50m away from west bank	W3	14.1	0.4	1.4	3.0	12.4
SSE of P. Lake 60m away from west bank	W4	14.1	0.3	0.7	3.2	14.0
Eastern side of P. Lake	W5	13.5	0.5	1.1	3.2	18.8
NE side of P. Lake	W6	13.5	0.4	0.3	3.0	16.8
Centre of P. Lake	W7	13.7	0.2	0.8	3.8	21.4
Near pump house in P. Lake	W8	14.0	0.1	0.4	3.9	12.4
SW side of P. Lake 3m from seepage channel	W9	12.8	1.2	0.8	4.2	19.6
West-southwest side of P. Lake 5m away from bank	W10	13.7	0.2	0.5	3.6	12.0
Control Lake 1 located north of Maitri station	CL1 (A)	13.4	0.1	0.3	1.4	16.0
Northern side of Control Lake 1	CL1 (B)	13.6	0.05	1.2	1.8	7.2
West side of Control Lake 2	CL2	10.2	0.14	BDL	1.1	12.4
Glacial Lake 1 located southwest of Maitri station	GL1 (A)	12.5	0.1	0.6	1.9	4.4
Glacial Lake 1, sampling point near joining Glacial Lake 2	GL1 (B)	11.8	0.05	1.8	2.2	5.6
Glacial Lake 2 located west of Maitri station	GL2	12.4	0.04	0.9	1.9	4.7
Glacial Lake 3 located northwest of Maitri station	GL3	13.4	0.2	0.2	1.9	15.2
Northeast (NE) side of Glacial Lake 4	GL4 (A)	13.4	0.09	0.4	2.1	10.8
Southeast side of Glacial Lake 4	GL4 (B)	13.8	0.18	0.2	2.7	12.8

Note : All values expressed in mg/L. BDL is below detectable limit; P stands for Priyadarshini; BOD₅ is biochemical oxygen demand measured as difference in dissolved oxygen over a 5-day period; COD is chemical oxygen demand.

10.2 to 14.1 mg/L at temperatures 0-1°C indicating a very high reaeration capacity of the surface water bodies and very little photosynthetic activity therein. The concentrations of chloride, nitrates, BOD₅ (biochemical oxygen demand) and COD (chemical oxygen demand) in the samples from Priyadarshini Lake were found well within the permissible limits⁷. However, their levels were on a relatively higher side compared to those of control lakes. This might be due to incoming seepage and decomposition of moss from surrounding areas. Nitrification⁸ inside the RBC is probably hampered due to low alkalinity in the wastewater. It is also observed that oil and grease which mix in the influent, making the film over the liquid and thus disrupting the oxygen transfer at sediments tank, however, in the biological chamber due to continuous movement of the disc oil and grease start emulsifying. Microbial growth is observed on the disc but of grey color, which is a clear indication of overloading on the treatment system. The biomass development in aerobic unit did not always cover the entire disk surface⁹. It was also observed that the values of dissolved solids, electrical conductivity and nutrients in the glacial lake lying on west were on the higher side as compared to the one

situated on the eastern side of Maitri station. This can be explained on the basis of geological setting of different water bodies. The water bodies lying on western side are located at a lower contour compared to those situated on eastern side. Moreover, the water body on west of the station lies at a distance of 210 m from the point of discharge of treated effluent from pond. Therefore, possibility of contamination of glacier water through seeped wastewater cannot be ruled out. But the kitchen, laundry and bathroom mainly produce grey water. Human excreta were burnt in the incinerators and ash was collected and removed from Antarctica Treaty area. Heavy metal levels in all the water samples were recorded well within the permissible limits of drinking water. The results indicate that except for the seepage channel, all the water samples possessed characteristics for drinking water quality as stipulated by the USEPA. To receive the higher effluent quality through RBC in cold climate, bioaugmentation of nitrifying bacteria for short solids retention time nitrification, is an attractive alternative for wastewater treatment plants in cold climate¹⁰ and mixing of centrate from kitchen RBC can be used as a source for bioaugmentation of other RBC.

Ambient air quality

Based on the micrometeorological data gathered during the study period, a windrose diagram was designed. The windrose diagram depicting prevailing wind pattern for January 2000 is shown in Fig. 2. It can be observed from the windrose that the prevalent wind directions were from ESE, E and SSE. Wind prevailed from ESE and E directions for 23.5% and 16.5% of the time respectively. For 13.5% of the time, the wind direction was recorded as SE and SSE. Calm period was recorded for 5% of time. The maximum wind velocity was found to be more than 10.8 m/s for 16% of the time. For 34.5 % of the time, it was found to lie between 5.1 and 8.2 m/s. The result of air quality monitoring for suspended particulate matter is presented in Tables 2. The 98 percentile values were computed for each of the gaseous pollutant. It was found that the 98 percentile values for suspended particulate matter varied in the range 6.0 to 69.7 $\mu\text{g}/\text{m}^3$. The higher level of the SPM was recorded due to arrest of airborne particles in the high wind uplifted from the crushed rocks that converted into soil. Organic particles were observed in minute quantities. The concentrations of SO_2 and NO_x were found to lie in the range BDL to 10.1 $\mu\text{g}/\text{m}^3$ (98 percentile value) and BDL to 21.1 $\mu\text{g}/\text{m}^3$ (98 percentile value) respectively as the high volume samplers were kept very close to the generator vent where plume was expected to touch the ground level. The concentrations of gaseous pollutants as well as the particulate matter for locations in the downwind direction of the generators were significantly higher compared to the one in upwind direction because of emissions from fuel utilization for energy

Table 2: Ambient air quality - cumulative percentile of suspended particulate matter

Location	Min	Avg.	Cumulative Percentiles			Max
			50	75	98	
Near Aditya generator	32.0	45.3	47.0	52.0	56.6	57.0
Near Bhaskara generator	52.0	61.3	62.0	66.0	69.7	70.0
Near Boiler exhaust	42.0	49.3	48.0	53.0	57.6	58.0
Near Workshop	5.0	7.0	7.0	8.0	8.9	9.0
Near helipad	9.0	10.3	10.0	11.0	11.9	12.0
Downwind of toilet modules of summer-camp*	15.0	18.3	18.0	20.0	21.8	22.0
Upwind direction of Maitri station	3.0	4.7	5.0	5.5	6.0	6.0

Note : All values expressed as 24 hourly averages in mg/m^3 ;

*Located approx. 100m from Maitri station

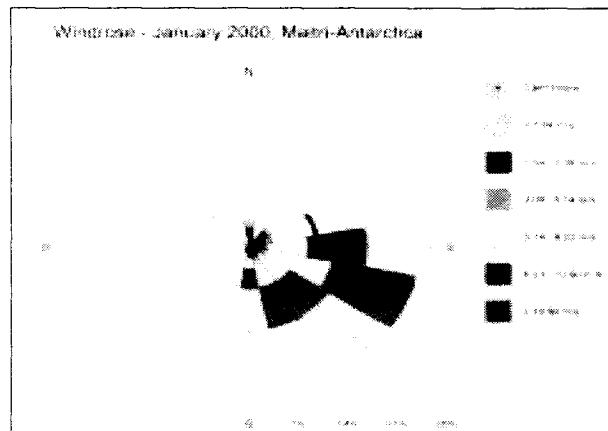


Fig. 2: Windrose indicating characteristics of prevailing wind pattern during study period

production day in and day out. The value of suspended particulate matter recorded near the incinerator toilets of summer camp was also slightly high owing to proximity to pollution source. The prevailing high wind velocities in the region are responsible for fast mixing of air pollutants with fresh air and their subsequent dilution. However, fast winds may carry fine air borne particulates to far off places.

Soil quality

In general, the soil in the region was of coarse type and poor in nutrient and organic contents. Organic contents were found to be more in the seepage channel. The physical nature of soils, as presented in Tables 3 and 4, is characterized by selecting specific parameters, viz. particle size distribution, water holding capacity and soil textural class. Knowledge of particle size distribution leads to important conclusions about the oxygen content and origin of soils. The particle size distribution of soils collected from impact zone in terms of percentage of sand, silt and clay is shown in Table 4. Percent compositions of different particles were found: clay 6 to 17%, silt 1 to 14%, coarse sand 31 to 58% and fine sand 28 to 40%. The results indicate that the area is dominated by sandy and loamy sand type of soil. The water holding capacity of the soil in the study area varied between 19.56 and 40.73%. The sediments collected were found to be rich in coarse particle size, moderate in crystalline particles and dominated by pebbles characteristic of a terminal moraine, a type of glacial deposit. The pH of soil is an important factor, which indicates whether it is alkaline or acidic in nature. It is controlled by high concentration of basic cations and excess organic matter. The

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Table 3 : Nutrient and organic content of soil

Sampling Location	Denoted as	pH	Organic Carbon	Organic Matter	Total Nitrogen (mg/100 g)
			(%)	(%)	
Confluence point of Glacial melt channel & P*. Lake, ESE of Maitri	S1	7.2	0.5	0.8	90.0
Behind Maitri station adjacent to generator	S2	7.8	0.4	0.7	34.0
Area between neighboring generators	S3	7.9	0.3	0.5	78.4
Near storage of empty oil drums	S4	7.6	0.1	0.13	56.0
Near workshop	S5	7.3	0.2	0.4	56.0
Downstream of seepage channel near P. Lake, NW of Maitri	S6	8.2	0.2	0.4	11.2
Downstream of wastewater collection pond	S7	7.8	0.2	0.3	44.8
From the channel where final treated effluent flows and joins glacial lake	S8	8.2	0.4	0.7	78.4
Near summer-camp	S9	6.8	0.2	0.4	34.0
15m away in southeast direction of Maitri	S10	7.4	0.2	0.4	22.4
East of Maitri on Hill	S11	7.6	0.3	0.5	22.4
Near summer-camp bathroom	S12	8.2	0.2	0.4	34.0
Area behind generators	O1	7.5	0.8	1.3	22.4
Near oil handling area adjacent to generators	O2	7.6	2.7	4.6	22.4

*P stands for Priyadarshini

Table 4: Physical characteristics of soil

Sampling Location	Denoted as	Particle size distribution (%)				Texture	Bulk density (g/cc)	Water holding capacity (%)	Porosity
		Coarse sand	Fine sand	Silt	Clay				
Confluence point of Glacial melt channel & P*. Lake, ESE of Maitri	S1	44	39	11	6	Loamy sand	1.4	27.1	38.87
Behind Maitri station adjacent to generator	S2	52	34	5	9	Sandy	1.29	28.56	37.76
Area between neighboring generators	S3	55	28	7	10	Loamy sand	1.43	27.60	40.22
Near storage of empty oil drums	S4	58	32	2	8	Loamy sand	1.58	23.28	37.59
Near workshop	S5	31	38	14	17	Sandy loam	1.56	22.59	36.24
Downstream of seepage channel near P. Lake, NW of Maitri	S6	49	35	7	9	Loamy sand	1.46	23.40	35.07
Downstream of wastewater collection pond	S7	56	35	1	8	Sandy	1.39	27.03	38.32
From the channel where final treated effluent flows and joins glacial lake	S8	52	38	3	7	Sandy	1.39	31.26	44.66
Near summer-camp	S9	50	38	4	8	Sandy	1.31	23.56	31.66
15m away in southeast direction of Maitri	S10	42	38	13	7	Loamy sand	1.5	23.64	36.38
East of Maitri on Hill	S11	50	33	4	13	Sandy loam	1.75	19.56	35.07
Near summer-camp bathroom	S12	43	38	10	9	Loamy sand	1.38	24.0	33.82
Area behind generators	O1	52	34	5	9	Sandy	1.51	26.90	41.28
Near oil handling area adjacent to generators	O2	50	40	2	8	Sandy	1.10	40.73	45.72

*P stands for Priyadarshini

physicochemical chemical properties are summarised in **Tables 3 and 4**. The pH of soil in the study area was found to be alkaline and in the range of 6.8-8.2. The nutrient load in terms of total nitrogen and percent organic matter ranged from 11.2 to 90 mg/100g and 0.13 to 4.6% respectively. Among the exchangeable cations, Ca^{++} , Mg^{++} , Na^+ and K^+ were found to lie in the range of 0.2 to 3.08 meq/100g, 0.88 to 1.76 meq/100g, 0.6 to 2.96 meq/100g and 0.23 to 1.1 meq/100g respectively. The cation exchange capacity (CEC) is an important property of soil that is generally used for characterizing its ability to supply cation nutrients to plants. It is the consequence of positive electric charges on clay and humus particles in soils and is balanced by adsorption of positively charged counter ions. CEC largely determines the storage capacity of soil for plant nutrient ions. The CEC of the soils in the region was found to be in the range of 4.5 to 8.4 meq/100g. The concentration of hydrocarbon was found to vary from 0.1 to 1.3 $\mu\text{g/g}$ while that of oil & grease was found to lie in the range of 8 to 4156 mg/100g of soil. The high values represent samples taken from oil-spilled soil located near oil handling area adjacent to one of the generators. A practical solution for hydrocarbon contaminated soils is bioremediation by indigenous microorganism¹¹ and low temperature (0-7 °C) can still allow oil bioremediation. The seepage through pond can also be controlled through application of Permeable Reactive Barriers (PRBs). It will contribute significantly to the transient management of contaminated surface and subsurface waters in Antarctica. PRB are viewed as an ideal remediation methodology for use in Antarctica since they are passive, simple to install require little to no maintenance and should be able to cope well with the changing flow regimes and weather condition that occur during summer months¹².

Conclusion

The environmental assessment exercise throws light on the status of water, air and soil quality of the Schirmacher region, where Indian Polar Research Station, Maitri is located in Antarctica. The year round maintenance combined with the increased scientific activity during austral summer every year at the Maitri station results into transport of materials to and from Antarctic continent. Anthropogenic activity of any kind is bound to disturb the fragile ecosystem. The temperature inside the RBC should maintain 12°-20°C throughout the year effectively for denitrification¹³. However, owing to good environmental practices adopted at Maitri station including

proper waste classification, regular cleaning up, and treatment of wastewater the pollution is kept at bay. Despite all care, there is always scope for accidental contamination as well as transport of some solid waste into lakes due to strong winds which can directly or indirectly affect the quality of water and soil in isolated pockets albeit to a very small extent.

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Water Abundance and Effect of Glacier Melting at Priyadarshini Lake in Antarctica

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Priyadarshini lake also called Zub lake covers an area of 0.29 km² and forms the major source of water supply to the Maitri. The consumption of water at Maitri is relatively more in austral summer compared to the rest of the year and it fluctuates between 1.70 m³/day in winter and 5.7 m³/day in summer. Although the inflow volumes to the lake can vary widely from one summer to another owing to temperature differences, changes of annual losses over both summer and winter take place. Melt water runoff from surrounding glaciers during the short austral summers is the only significant source of water that maintains the lake. Using the paddle boat, marked string with weight and GPS, depth and boundary line was recorded. The maximum recorded depth was 7.2 m. From 2nd January to 29th January, 2000 the water level recorded continuously has shown the increase in water level. The total area of the lake was estimated is around 2 76 944 m² after accumulation of feed water, which is 4.49% less than the GPS monitored area. Further volume calculated is 6 50 358 m³. The average water consumption at Maitri is around 900 m³/year. The inflow of water due to annual glacial melt is around 61132 m³. Therefore even in the winter period sufficient water is available to be consumed by Maitri. This water abundance through Priyadarshini Lake will sustain for many years even if there is no inflow of water. The water quality of the lake is unchanged by the intrusion of seepage water channel from the wastewater pond due to less quantity and high dilution ratio and due to replenishment of water from glacial melt.

Keywords: Lake; Volume; GPS; Glacier melt; Water quality

INTRODUCTION

Antarctica is the largest and most pristine wilderness on earth, covering an area of approximately³ 13.6 million km². It is inhospitable due to extreme cold, presence of a massive permanent ice sheet and the floating ice shelves. Less than 2.0% of the continent here is ice free. Scientific research is the major human activity being carried out in Antarctica. 'Maitri', India's indigenously designed polar research station in Antarctica is located on the Schirmacher Oasis at 70°45'53" S latitude and 11°44'03" E longitude. It is built on an ice-free rocky moraine at an elevation of 117m above mean sea level. Maitri is an all year round base which is situated on Schirmacher Oasis which is on the Nunatak, Vassfjellet close to the ice shelf. The Nunatak is located on Dronning Maud Land. Maitri is surrounded by a number of small lakes. A glacier to the south of the station covers parts of the nunatak and ends about 400 m from the main building.

The Maitri station consists of four blocks that comprise of lodging, medical facilities, communication control system, computer room, gymnasium, cold storage, sports room, lounge, dining, kitchen, boiler-room, laundry room,

bathrooms and toilets. Three containerized modules of generators are located outside on the southern side of the Maitri station.

SITE DESCRIPTION

Priyadarshini Lake covers an area of 0.29 km² and forms the major source of water supply to the Maitri station. The lake is situated about 225 m away north of the Indian permanent research station 'Maitri'. The consumption of

Table 1 Monthly water consumption pattern at Maitri

Month	Maximum Water Supply in a Day, m ³ /day	Minimum Water Supply in a Day, m ³ /day	Total Water Supply in a month, m ³ /day	Average Water Supply, m ³ /day	Summer Consumption, m ³ /day
January	9.0	2.5	121.8	3.92	24.8
February	7.0	5.0	164.5	5.67	23.8
March	4.0	1.5	66.3	2.21	4.0
April	4.5	2.5	50.4	1.68	0.0
May	4.2	3.1	56.6	1.82	0.0
June	4.0	3.0	53.1	1.77	0.0
July	7.5	3.0	58.9	1.90	0.0
August	5.0	3.2	63.5	2.04	0.0
September	5.0	3.0	67.7	2.25	0.0
October	5.0	3.5	52.3	1.69	0.0
November	5.0	3.0	57.2	1.90	0.0
December	5.5	1.8	62.3	2.09	0.0

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Figure 1 Location of Maitri and Priyadarshini lake
water at Maitri is relatively more in austral summer compared to the rest of the year. The volume of the water fluctuates between $1.70 \text{ m}^3/\text{day}$ in winter and $5.7 \text{ m}^3/\text{day}$ in summer (Table 1). It is during the austral summer that most of the scientific activities are carried out. The number of consumers are more during the summer as total strength reaches to around 75 in a day. However during winter it remains around 25. Lake is surrounded by small hill along east and north direction, the south and western side is fairly sloppy terrain.

Although inflow volumes to the lake can vary widely from one summer to another owing to temperature differences, annual losses over both summer and winter may also change. Melt water runoff from surrounding glaciers during the short austral summers is the only significant source of water that maintains the lake, during winter sublimation from the ice cover is the dominant loss from the lake.

MATERIALS AND METHODS

Area Measurement

In the year 1987 the area of the Priyadarshini lake was estimated⁴ as 0.297 km^2 . In the year 2000, global positioning system (GPS) of make Corvallis Microtechnology Inc. version 2.4 has used as a mapping tool without differential correction⁵. The accuracy of this instrument was quoted as $10 \text{ m} - 30 \text{ m}$. In the last week of the January when the ambient temperature was around -4°C to -2°C and there was no inflow of water, instrument (GPS) was calibrated with necessary inputs and it was set to record the position at every five seconds. Holding the GPS in handheld positions of the points were recorded while moving on foot just nearby the edge of the water around the lake, keeping the instrument vertically above the water except at few locations where easy approach was not possible. After getting all the coordinates it was converted into graphical data and with the application of GPS and SURFER total area was computed.

Depth Measurement and Volume of Lake

Before feeding of glacial melt water the depth of water at various places were recorded using a marked string with around 2 kg weight, which was attached at bottom to keep

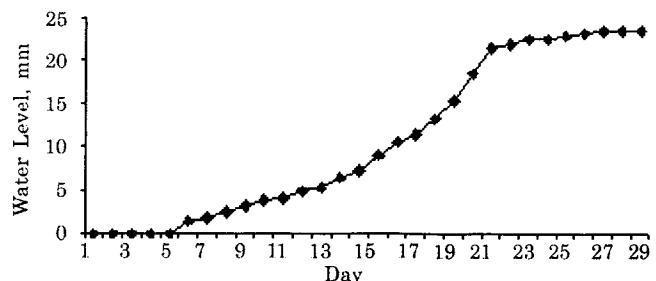


Figure 2 Daily water increment in Priyadarshini lake

the string vertically over the point. Using the paddle boat and GPS, depth was measured and coordinates were recorded at the respective points at 55 locations within the lake. Care was taken to lower the string gradually into water and so as to avoid penetration into algal mats present at bottom of the lake. As soon as the string was slack, the depth was recorded. Maximum depth recorded was 7.2 m at Priyadarshini lake.

Additional Feed Water Measurement

The volume of water of Priyadarshini lake never remains the same because of the Schirmacher glacier, which is around 1200 m away from the lake and melts when ambient temperature reach as to $+1^\circ\text{C}$ to $+5^\circ\text{C}$ for couple of days. This melted water joins glacial lakes formed adjacent to glacier and from these lakes ultimately it joins Priyadarshini lake. After reaching a certain level, the water outflows from Priyadarshini lake to adjacent lake. To measure the inflow into the lake two iron rods at the bank of the lake were fixed at two feet distances. A cotton string was tightened in between the iron rods and leveled with the help of spirit level, keeping in view that it just touched to the water surface level when there was no inflow in to the lake as ambient temperature recorded was -2°C . After a few days when the temperature started raising, the glacier started melting and the melt water started feeding into Priyadarshini lake through connecting glacial lake. Daily at evening, level of the lake water was measured over the string using a scale. From 2nd January to 29th January 2000 (Figure 2) the water level recorded continuously showed the increase in water level upto 18th January and after that it remains constant for three days. It was noted that the excess water started diverting to a connecting lake situated downward side of the Priyadarshini lake and after three days temperature went down and glacier melting stopped which was the barrier feeding of water into the lake. Maximum air temperature recorded on 9th and 20th January, was $+4.4^\circ\text{C}$.

Sample Collection and Preservation

Samples from various locations of the lake were collected twice in the year 2000 and 2004 using grab sampler from the same locations. The temperature was measured at each of the sampling point. Collected samples brought to the laboratory at Maitri and processed to measure the basic physicochemical parameters, such as, pH, BOD, COD, conductivity, TSS, Cl, $\text{NH}_3\text{-N}$, DO, total alkalinity and

turbidity. The rest of the samples collected were preserved with HNO_3 for heavy metal analysis and with H_2SO_4 for organic, oil and grease analysis. The samples were sealed properly and brought to India for further analysis in the laboratory. Samples were filtered with $0.45 \mu\text{m}$ Whatman filter papers. All the analyses were performed using standard methods¹. The analysis of heavy metals were carried out on GBC, atomic spectrophotometer in the laboratory.

RESULTS AND DISCUSSIONS

Total demand of water estimated based on the average consumption of water as approximately 353 m^3 during the summer and 522 m^3 during the winter. During the summer in the month of January lake water melts and water is available for intake. From the month of February onwards the water starts freezing. So the water from the bottom of lake is drawn using the submersible pump and with the help of heating coils. However it is necessary to estimate the quantity of water available at the lake for avoiding the risk associated during a very harsh climate in the winter season. Total area of the lake estimated through GPS (Figure 2) is around 289972 m^2 . However the contour map drawn using the SURFER 7 of the same coordinates shows that the total area is 276944 m^2 , which is 4.49% less than the GPS monitored area. The range of the accuracy of the GPS used is between 10 m to 30 m without

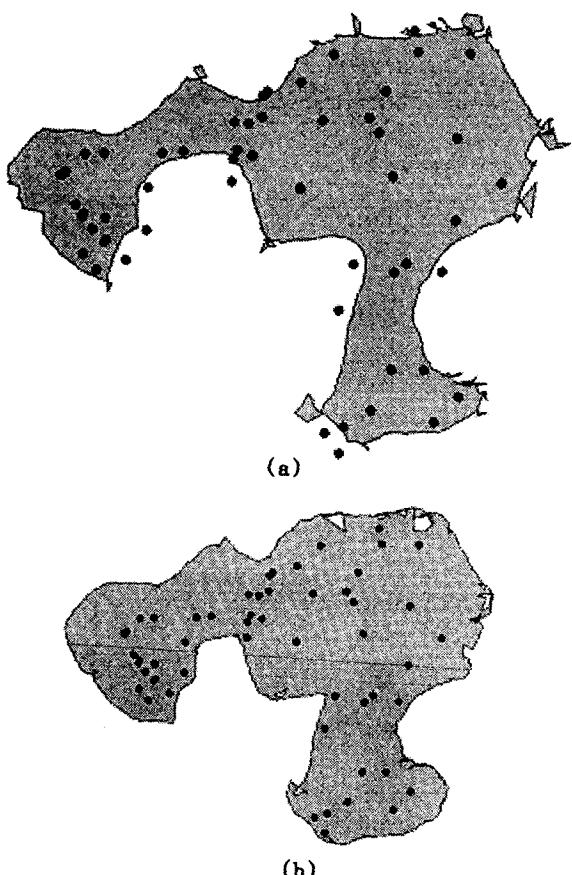


Figure 3 Area of lake (a) 20 m inward correction and (b) 20 m outward correction

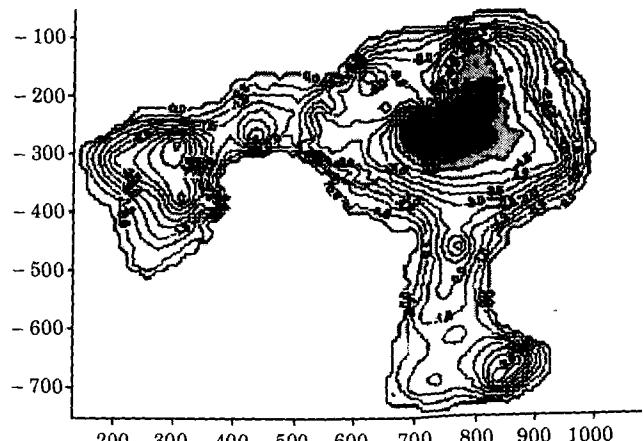


Figure 4 Depth contour of Priyadarshini lake

differential correction⁵. The deviation from accurate position may be in any direction. For this purpose this is assumed that the deviation is on an average of 20 m and may be either in or off side. Considering both these options it is estimated that 20 m off gives (Figure 3) the total area of approximately 360802 m^2 (24.4% more) and considering 20 m inside points from the present recorded points (Figure 4) gives the area around 223070 m^2 (23.0% less).

Volume of the Lake

Considering the same coordinates, contour mapping and GPS data gives average depth which ranges from 2.34 m to 2.24 m. Based on this the volume of water estimated is 650358 m^3 . Considering the area of lake of 20 m offside the, volume would be 808197 m^3 and 20 m inside the volume would be 499695 m^3 . For more realistic approach to facilitate the calculation of volume within the envelope, the area of lake is considered as 276944 m^2 and volume calculated is 650358 m^3 . The recorded rise in the water level was 230 mm, therefore the volume before the water inflow into the lake was estimated to be 589226 m^3 . This shows that due to the glacial melt, the total inflow of the water into Priyadarshini lake is around 61132 m^3 . The average consumption of water at Maitri is about $900 \text{ m}^3/\text{year}$. Except the Maitri there is no other user who draws the water from the lake and no seepage was observed.

Further in this area due to high wind velocity and dry atmosphere the relative humidity is recorded varying from 5% – 35%. Therefore the water evaporation rate is quite high which is $217.5 \text{ l/m}^2/\text{year}$. During the winter period when the upper 3 m of the lake water is freezed the water available below at the lake is estimated as 124429 m^3 . This reveals that this lake possesses an inverse thermal stratification with a minimum temperature of -2°C to 0°C at the surface and a positive temperature at the bottom.

Effect on Water Quality

The treated wastewater generated from Maitri is collected in waste stabilization pond. There is minor seepage from the wastewater pond towards lake because it is located at higher elevation than the lake and the bottom soil is

Table 2 Physical demand, nutrient and heavy metal analysis of Priyadarshini lake water in time frame

Sampling Location / Parameter	Year	Near SW Side of Pump House	SW Side of Seepage Channel	WSW Lake	Middle of Lake	SSE at Point of Lake	Glacial Lake at SE Side of Lake	Glacial Lake at SW Side of Lake
pH	2000	6.4	6.3	6.3	6.4	6.4	6.0	6.1
	2004	5.6	5.0	5.2	5.37	5.37		
Conductivity, $\mu\text{s}/\text{cm}$	2000	19	22	19	26	28	10	15
	2004	12.2	16.6	23.6	8.0	6.5		
Turbidity, NTU	2000	1.2	1.0	1.7	1.0	1.0	1.4	1.5
	2004	<1	<1	<1	<1	<1		
Alkalinity	2000	4.0	4.8	4.6	4.3	4.2	5.3	3.5
	2004	8.0	4.0	4.0	5.0	6.0		
Total Hardness as CaCO_3	2000	6.5	8.4	7.4	7.5	8.3	10.1	6.2
	2004	12.0	8.0	7.0	7.0	13.0		
Calcium Hardness	2000	4.5	6.2	5.6	5.5	6.3	7.6	4.8
	2004	6.0	5.0	5.0	5.0	12.0		
Chloride	2000	2.8	2.4	2.8	2.6	2.9	2.8	2.9
	2004	2.1	2.2	3.1	6.4	5.2		
Sulphate	2000	1.2	1.2	1.6	1.7	1.8	1.5	1.1
	2004	2.0	3.0	1.0	2.0	1.0		
Sodium	2000	1.6	1.5	1.5	1.5	1.5	1.4	1.2
	2004	3.0	3.0	3.0	3.0	3.0		
Potassium	2000	0.4	0.8	0.4	0.5	0.8	0.4	0.3
	2004	1.0	1.0	1.0	0.0	1.0		
Nitrates, ($\text{NO}_3^- - \text{N}$)	2000	0.1	1.2	0.2	0.2	0.3	0.09	0.05
	2004	0.5	0.4	BDL	BDL	BDL		
Total Phosphate	2000	0.4	0.8	0.5	0.8	BDL	0.4	1.8
	2004	2.3	2.0	2.5	4.2	6.3		
Dissolved Oxygen	2000	14.0	12.8	13.7	13.7	14.0	13.4	11.8
	2004	14.4	14.2	14.0	14.8	14.8		
Biochemical Oxygen Demand	2000	3.9	4.2	3.6	3.8	3.1	2.1	2.2
	2004	0.5	4.0	BDL	3.0	BDL		
Chemical Oxygen Demand	2000	12.4	19.6	12.0	21.4	8.0	10.8	5.6
	2004	>5	>5	>5	>5	>5		
Oil and Grease	2000	BDL	BDL	BDL	BDL	BDL	Not measured	Not measured
	2004	BDL	BDL	BDL	BDL	BDL	Not measured	Not measured
Hydrocarbon, $\mu\text{g/l}$	2000	0.17	0.10	0.10	0.13	0.11	Not measured	Not measured
	2004	BDL	BDL	BDL	BDL	BDL	Not measured	Not measured
Cadmium	2000	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	2004	BDL	BDL	BDL	BDL	BDL		
Chromium	2000	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	2004	0.01	0.01	0.01	0.01	0.01		
Copper	2000	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	2004	BDL	0.01	BDL	0.03	BDL		
Iron	2000	0.568	0.129	0.995	0.615	0.574	0.601	1.655
	2004	0.07	0.14	0.17	0.06	0.09		
Manganese	2000	0.011	0.02	0.03	0.071	0.017	0.04	0.175
	2004	BDL	0.01	0.01	0.01	BDL		
Lead	2000	BDL	BDL	BDL	BDL	BDL	BDL	BDL
	2004	BDL	0.01	BDL	0.01	0.01		
Zinc	2000	0.001	BDL	47.9	0.132	0.072	0.119	0.15
	2004	0.02	0.01	BDL	BDL	BDL	Not measured	Not measured

Note : BDL: Below detection limit; All values are in mg/l.

Table 3 Surface Water Quality – Priyadarshini lake – diversity of zooplankton

Sampling Location	Year	Total Count/m ³	Organism in Groups, %					Shannon Diversity Index	Weaver Index
			Protozoa	Rotifera	Copepoda	Nematoda	Insecta		
Near Pump House	2000	360	–	50	–	50	–	1.00	–
	2004	ND	–	–	–	–	–	–	–
SW side of lake near seepage channel	2000	180	–	–	100	–	–	0.00	–
	2004	ND	–	–	–	–	–	–	–
WSW side of lake	2000	180	–	100	–	–	–	0.00	–
	2004	ND	–	–	–	–	–	–	–
Middle of lake	2000	180	100	–	–	–	–	0.00	–
	2004	ND	–	–	–	–	–	–	–
SSE side at confluence point of lake at south – east direction	2000	540	67	33	–	–	–	0.914	–
	2004	ND	–	–	–	–	–	–	–

permafrost so from the bank of pond seepage starts and joins lake. The quantity is very less according to the visual observations. During the summer period around 2.6 m³ of wastewater is collected in the pond every day⁶. Assuming that the maximum of 5% seepage every day for two months, till freezing starts total quantity of wastewater which would join the lake water is 7.8 m³, get diluted, sedimentation starts as well as the suspended and colloidal particles further travel towards middle of the lake and then towards outlet of the lake. If it is assumed that due to bottom slope of lake towards middle and high wind velocity, which in range of 20 km/h–150 km/h a complete mixing occurs and a dilution ratio found to be range of 7820 times which is quite higher side.

The samples collected in the year 2000 were before the glacier melting, and in the year 2004 the samples from the same location were collected after glacial melting. During the year 2004, the value of pH is low because the ambient temperature was –2°C, (in year 2000 ambient temperature was 4°C during sampling) which would result

the mixing of CO₂ into the lake water and reducing the pH. It is dilution effect that the turbidity is reduced to <1 at all the sampling locations in the year 2004. Dissolved oxygen at all the places including the confluence seepage channel is improved as compared to 2000 where at this point it was recorded as 12.8 mg/l (Table 2). Similarly the pollution indicator NO₃–N, bio-chemical oxygen demand, chemical oxygen demand and hydrocarbon have significantly reduced at all the sampling locations in the year 2004. Among the heavy metals iron, manganese, lead and zinc concentration found to be low except near confluence point where iron concentration found little higher and possible cause is old iron drinking pipeline which would be rusted and contributing to iron concentration. At middle of lake and at confluence point the copper concentration has been found out little higher in the year 2004 than the year 2000. Cadmium and chromium are found below the detection limit in both the samples. There is replenishment of water around 61000 m³, depending upon the ambient temperature of particular year. In the biological sample zooplankton found to be less

Table 4 Surface water quality – Priyadarshini lake – diversity of phytoplankton

Sampling Location	Year	Total Count/m ³	Organism in Groups, %				Shannon Diversity Index	Weaver Index
			Chlorophyceae	Bacillariophyceae	Cyanophyceae	Euglenophyceae		
Near Pump House	2000	–	–	–	–	–	–	–
	2004	136	66	22	12	–	–	3.412
SW side of lake near seepage channel	2000	440	100	–	–	–	–	0.000
	2004	123	58	20	–	22	–	3.612
WSW side of lake	2000	–	–	–	–	–	–	–
	2004	131	60	29	11	–	–	3.891
Middle of Lake	2000	440	–	–	100	–	–	0.000
	2004	129	48	32	–	20	–	3.408
SSE side at confluence point of lake at south – east direction	2000	880	–	100	–	–	–	0.000
	2004	135	67	33	–	–	–	3.671

and diversity as shown from Shannon weaver index, but in the year 2004, it is totally washed off. Among the phytoplankton the diversity index was poor in the year 2000 while in year 2004, it showed a reasonable diversity according to Shannon weaver index. The possible cause is due to the growth of algae, moos and lichen at the channel of glacier melt water which joins lake.

CONCLUSION

Priyadarshini lake situated near Maitri is the source of water for Maitri. The average water consumption by Maitri is around 900 m³/year. Inflow of water to the lake due to glacial melt, which is around 61132 m³/year. Even during the winter, sufficient water is also available to consume by Maitri. The water abundance available through Priyadarshini lake will sustain for many more years to come even if there is no inflow of water and even the water evaporation rate is high. The water quality of the lake has not been changed by the intrusion of small quantity of wastewater through seepage water channel from possibly due to maintained high dilution ratio and also due to replenish of water from the glacial melt. However in the interest of maintaining quality of water in the Priyadarshini lake, it is essential to take steps to control the seepage of wastewater to the lake by carpeting the pond liner and permeable reactive seepage barrier².

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Environmental Awareness in Indian Antarctic Scientific Programme

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Antarctica is well known for its valuable reserves and various ongoing important scientific activities. At one side where the Antarctic environment governs the southern hemisphere's weather pattern and in other side it is considered as datum for environmental pollution comparison. Environmental awareness is very essential in conducting any scientific programme, logistics arrangements or regular activities to shift the material, energy generation etc. Maitri can accommodate around 25 people during winter and around 45 additional scientists in summer huts built in front of the Maitri. It is built to keep the environment impact minimum. There is always chance of generation of the pollution, which definitely needs to cater the awareness to control and manage at source level rather than at sink point.

Keywords : Antarctica; Maitri; Environmental impact

INTRODUCTION

Antarctica is the place which is known as place of superlative degrees, the coldest, windiest and driest continent. Antarctica is the last vast wilderness on the planet. It is an important part of the Earth's system. By acting as a global heat sink, it helps to control the climate and weather. The stability of the Antarctic ice sheets is of concern to those living in low-lying areas; they contain enough water to raise global sea level almost 70 m. Antarctica holds 70% of the Earth's freshwater, and 91% of Earth's ice. Antarctica influences the global ocean. Cold, dense and oxygen-rich waters originate in Antarctica and replenish the ocean's supply of bottom water, helping to drive ocean circulation. The sea surrounding Antarctica supports marine life from tiny ice-dwelling algae to the great whales. Through investigations of Antarctica better understanding of how this vast, ice-covered continent responds to environmental change can be developed. This knowledge can predict the response of all of Earth's systems to future environmental change.

Activities in Antarctica are governed by the Antarctic Treaty of 1961, which applies to the area south of 60 degree South latitude, including all ice shelves. The concept of setting aside areas for special protection was introduced in 1964 when the Antarctic Treaty Consultative Parties (ATCP's) adopted the agreed measures for the conservation of Antarctic Flora and Fauna.

SCIENTIFIC ACTIVITIES IN ANTARCTIC ENVIRONMENT

Scientists found Antarctica valuable and important place to conduct research in various disciplines. The importance of Antarctica reflects in following points:

- ♦ Antarctica plays an important role in understanding

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the earth's magnetic field and the interaction with charged particles from the sun. It is perhaps the only place in the southern hemisphere from where simultaneous activities in the ionosphere and the earth's magnetic field can be observed. Presence of strong natural Electro Magnetic signals forms an ideal environment for conducting studies on radio-wave propagation and radio-noise both in the ionosphere and the lower atmosphere¹.

- ♦ In the Mesozoic era, the super-continent of Gondwanaland had a common landmass of five continents, namely, Africa, Antarctica, Australia, India and South America. Later, the continents drifted apart with the oceans in between. Thus, Antarctica holds the master key to the earth's history.
- ♦ Geologists believe that some of the richest deposits of several minerals, oil, gas, and gas hydrates, polymetallic nodules, etc could be found in the Antarctic landmass and in the surrounding sea-bed. Thus, Antarctica is a continent of great scientific value.
- ♦ The north and south poles maintain the heat budget of the world. The heat transported through the atmosphere and the oceans to the poles is dissipated in space in the form of long-wave radiation. The cold air going from Antarctica, when meets the warm air in the atmosphere of the lower latitude, changes into moisture-bearing clouds. Thus, Antarctica regulates the global climate, particularly of the southern hemisphere.
- ♦ The Indian, Atlantic and the Pacific Oceans meet around Antarctica forming a distinct body of water which girdles the earth and is uninterrupted by any landmass. The mixing process between cold and warm water in this body of water demarcates the area of Antarctic convergence which has its own physical, chemical and biological characteristics.
- ♦ Antarctica provides a unique, unpolluted and stable environment for carrying out scientific observations. It is far away from all sources of environmental contamination and thus remains an unpolluted datum point from which global changes due to pollution could be monitored.

♦ Unlike the Pacific and the Atlantic Oceans, which communicate to both North Pole (Arctic) and South Pole (Antarctic), the Indian Ocean has its northern boundaries closed with landmass. It, therefore, communicates only to the Antarctic ocean and south pole from which it derives much of its fertility and energy.

♦ Many important oceanographic features of the Indian Ocean are governed by the Antarctic Ocean. Hence, to understand the processes occurring in the Indian Ocean, it is necessary to have the knowledge of at least that part of the Antarctic Ocean which joins the Indian Ocean.

♦ The glaciers of Antarctica comprise about 90 per cent of the earth's ice. Thus, the continent holds about 75 per cent of the freshwater reserve the earth in a solid state.

♦ Antarctic Ocean supports biological communities of few species which has large populations and short food chain process. It is among the richest biological provinces on the earth. The important organism regulating the simple food chain in the Antarctic waters is 'krill' (like shrimp).

ANTARCTIC GOVERNANCE

Antarctica is governed by Antarctic Treaty System (ATS). Antarctica Treaty was formed in the year 1959 by 13 nations and decided to use Antarctica land only for scientific experiments and peaceful purpose. Due to frontier science programme and India's commitment to the principle of Antarctica Treaty, India achieved the following milestones:

- ♦ India admitted to the Antarctic Treaty on August 19, 1983 and soon after obtained a consultative status on September 12, 1983
- ♦ India was admitted as a member of Scientific Committee on Antarctic Research (SCAR) on October 1, 1984.
- ♦ India became the member of Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) in 1986.
- ♦ India ratified the environment protocol to the Antarctic Treaty in 1997, thus upholding its commitment to preserve the pristine continent
- ♦ India also became the chairman of CCAMLR in 1998 for a period of two years

A PLACE TO LIVE, EXPERIMENT AND SCOPE OF ENVIRONMENTAL DEGRADATION

First wintering expedition conducted the various scientific experiments from permanent station, Dakshin Gangotri that was built in the year 1983. After that in the year 1988-89 India built its second indigenous station Maitri at Schirmacher Oasis, which is well equipped and facilitated to accommodate the scientists, round the year and allow them to conduct their scientific experiments.



Figure 1 Second Indian permanent research station, Maitri
Maitri can accommodate around 25 people during winter and around 45 additional scientists in summer huts built in front of the Maitri. It is built to keep the environment impact minimum. There is always chance of generation of pollution, which definitely needs to cater the awareness to control and manage at source level rather than at sink point.

Tourism

Antarctica is often thought of as a pristine land untouched by human disturbances. Unfortunately this is no longer the case. For little more than a hundred years, people have been travelling to Antarctica and visited most of the parts in short time and some footprints left therein. More recently attitudes have changed as the people begin to realize that there are few unvisited places left on the earth and that of enormous value to humanity. The clean air, water and ice of Antarctica are now of global importance to science for understanding how the Earth's environment is changing naturally and nature of human activity. Tourist operators are beginning to tap the huge demand to visit the last great wilderness on Earth. Paradoxically both the science and tourism have the potential to damage the qualities that can draw them to Antarctica.

Transportation

Modern polar and marine research requires intensive technical and logistic support and personal efforts and a close cooperation within the institute at national and international level. National Centre for Antarctic and Ocean Research (NCAOR) an autonomous society of Ministry of Earth Sciences (MOES), Government of India, provides operational support to all approved programs in accordance with the principles and policies formulated by the MOES/NCAOR. NCAOR provides various resources including Ship and Helicopters, powerful communications technologies, living and working facilities and other logistic support to the scientists to carry out the research work in Antarctica.

ENVIRONMENTAL IMPACT AND MONITORING

Human Activities and Natural Process

Because of human interference, either due to conducting any scientific activity or tourism, the area of interest has potential to be affected by human activities either regularly, infrequently or indirectly, even though it was never carried out in the area. Biological or abiotic components or processes of the area should be checked whether it is vulnerable to any existing or likely future human activities in the area. The impact is directly, indirectly or cumulative impact over the temporal and spatial scale should also be assessed. If there is any disturbance occurs how much time does it take to return to pre-disturbance or equilibrium levels should also be assessed.

It is important to study whether the natural process like atmosphere, climate, marine, biological and glacial likely to modify the area or its original values. It is required to study the short and long term variations or seasonal changes in the population of biota present in the area. Any human impact if there exists so it should also be seen whether the resultant is smaller or larger than the impact due to natural process. There are chances that the area may be protected by its own natural capabilities from the outside disturbance and if it is so, up to what extent it can be protected.

Non-antarctic Threats

It is very important to study whether the designated area is going to be affected by the threats which are not originating in Antarctica but result of long range transport of contaminants, such as, long lived chemical pollutants and alien species.

Scientific Uncertainty

There may be uncertainty to know about the impacts on the area by the human or natural phenomenon. If it is not known, the possible impacts by various means should be assessed so that whether these uncertainties can have the significant threats to the area.

NEED OF WASTE MANAGEMENT AND ENVIRONMENTAL AWARENESS

The Antarctic environment is highly susceptible to the impacts of human activities, and has much less natural ability to recover from disturbance when undertaking activities in the field. The collection and coordination of relevant information facilitates, the science and support operations that assists in this process, accurately record the custodian, location (preferably by GPS) and usage details of all field activities, such as, sample sites, field camps, depots, oil spills, markers, equipment etc should be recorded in environmental management database .

All supplies and equipment taken into the field must be removed, except a permit provides otherwise. All wastes produced in the field, other than human wastes and grey water, must be returned to the station or ship providing support. Human wastes and grey water should also be returned to the station or ship providing support to the greatest extent possible and must not be disposed of in ice-free areas or ice/snow-covered areas with flow lines terminating in ice-free areas.

Expedition members should also be aware in avoiding the use or dispersal of foreign materials that are difficult to collect and remove. Strip down excess packaging before going off-station, is necessary to minimize the waste taken into the field. The collection or disturbance of any biological or geological specimen or man-made articles may only be undertaken with prior approval and if required, in accordance with a permit² (in case to work in Antarctica specially protected area).

Fueling, Vehicle Movement and Travel in the Area

Some biological communities and geological formations are especially fragile, even when concealed by snow, one should be alert and avoid such features when traveling to and between the field locations.

Vehicle and helicopter usage should be restricted to essential tasks to minimize atmospheric emissions, track formation, physical disturbance of the land surface or biological communities, wildlife disturbance and the potential for fuel spills. When vehicle use is essential, access should be restricted to the areas with permanent ice/snow and designated ice-free routes. Fuel spills are difficult to clean up and take many years to dissipate. Vehicles and other equipment should be fully fuelled on station before departure, to reduce the need for refueling in the field. Refueling or changing oil in windy conditions or in areas that might direct accidental spillage into the lakes, vegetation or other sensitive areas, should be avoided. One should always use fuel cans with nozzles/funnels and an absorbent spill pad/drip tray. When travelling on foot, one should use established tracks and designated crossing points wherever possible. Where such tracks do not exist, the most direct route can be taken to avoid vegetated areas and delicate geological formations, such as, sediments, streambeds and lake margins. These features have taken many thousands of years to form and may also be of major scientific importance.

One should extremely be cautious not to feed the wildlife. When around wildlife be quiet, move slowly, stay low to the ground and adhere to the minimum approach distances, unless authorized by a permit³.

Field Camps

Existing field huts and campsites should be used wherever possible. Otherwise, campsites should be located as far

away as practicable from lakeshores, streambeds, vegetated sites and wildlife, to avoid contamination and/or disturbances. Maximize the use of fixed helicopter pads so that a minimal area is disturbed, and to allow the landing site to be cleaned up when the camp is removed.

It can be ensured that the equipment and stores are properly secured at all times to prevent foraging by wildlife and dispersion by high winds or helicopter rotor wash. Use of water wisely to minimize the volume of liquid to be returned to the station. Solar or wind powered generators should be utilized wherever possible to minimize fuel usage.

Field Work

It is essential that all clothing and equipment is meticulously cleaned before being brought to Antarctica and before moving between sampling locations, to prevent contamination, cross-contamination and the introduction and spread of foreign organisms. One should not build cairns, and minimize the use and extent of stake networks or other objects to mark sites; such markers should be removed on completion of the related task. When permitted to the sample, adhere to the sample size specified in the permit and consider the samples from the least conspicuous location possible. One should always use a drop sheet when sampling the soils. Backfill soil pits can prevent the wind erosion and dispersal of deeper sediments.

Everybody should take great care when handling the chemicals and fuels and ensure that they have appropriate materials with them to catch and absorb spills⁴. Minimum use of liquid water and chemicals should in practice, otherwise it could contaminate the isotopic and chemical record within the lake or glacier ice.

The chemical and biological constituents of lakes can vary greatly with the depth. To prevent contamination, or toxic effects on the biota at the surface, avoid reintroducing large volumes of water obtained from lower in the water column. Excess water or sediment should be returned to the station for appropriate disposal or treatment also it

can ensure that the sampling equipment is securely tethered and leave nothing frozen into the ice that may cause later contamination⁵.

One should not wash, swim or dive in lakes unless authorized to do so; these activities contaminate the water body and physically disturb the water column, delicate microbial communities, and sediments

CONCLUSION

To protect the environmental values of the Antarctica, environmental awareness is essential to manage the pollution and control on it, which is integral part of the expedition. This provides essential features to reflect in the management plan and an edge on the human disturbance and encroachment on the area. Environmental assessment study leads to prepare the environmental code of conduct for the area. Environmental awareness among the expedition members and tourists shall be very much useful in general to protect the pristine environment. The Antarctic area is already under the strict surveillance of protocol on environmental protection to the Antarctica Treaty, which keeps an sharp eye on any natural changes which also resultant to create awareness among the visitors to Antarctica .

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Wastewater Fate at Maitri in Antarctica

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At 'Maitri' drinking water source is Priyadarshini Lake which is situated at 200 m away from the station. Water consumption leads to wastewater generation and to treat the waste water two rotating biological contactors (RBC), B1 and B3 of different capacity were installed. The maximum treatment capacity of B3 RBC is 5 kl/d and B1:RBC is having capacity of 1 kl/d. At the sampling point temperature, pH was measured and within 15 min of sampling it was brought to the laboratory at Maitri to analyse basic parameters, ie, BOD, COD, conductivity, TSS, Cl, NH₃-N, DO, total alkalinity and turbidity. The treatment efficacy of B1:RBC was observed only 66.7% in terms of BOD and 68.9% of COD. But, due to lower pH, the ammonia nitrogen of effluent was less than the influent because the ammonia producing bacteria were not working effectively at lower pH. Tertiary treatment at lab scale of B1 RBC shows that BOD and COD are further removed by 40.3% and 21.9%, respectively. The treatment efficacy of B3:RBC was observed only 29.8% in terms of BOD and 41.4% of COD. The BOD and COD were further removed by 22.2% and 30%, respectively in tertiary treatment of B3 RBC at lab scale experiment. The tertiary treatment was found to be very effective even when the treatment system was not tuned fully, however, if tuned and tertiary treatment system was applied further the efficacy improvisation would have been expected upto 95%-98%.

Keywords: Rotating biological contactor; Efficacy; Tertiary treatment; Biochemical oxygen demand; Chemical oxygen demand

INTRODUCTION

Antarctica is known for superlatives, windiest, coldest and driest continent on earth, India has set its second permanent station in Antarctica on the Dronning Maud land of Schirmacher Oasis¹, as designated in 'Maitri' at 70°45'57" S and 11°44'09" E. To carryout various scientific activities around 55 persons during the summer and around 25 persons during the winter, one can stay at Maitri station. Drinking water is sourced from Priyadarshini Lake, which is situated at 200 m away from the station. Water consumption leads to wastewater generation. To treat the waste water in two different places rotating biological contactors (RBC) are installed². The major objective of an RBC is the removal of soluble organic matter by conversion into insoluble microbial cells, which can be removed by sedimentation, thereby providing an effluent of high quality. The maximum capacity³ of B3:RBC is 5 kl/d and B1:RBC is 1 kl/d. These systems were installed during the IX-Indian Antarctic Scientific Expedition (IASE) in the year 1989-90. During the summer period, the lowest temperature recorded around -15° C and maximum +4°C during the winter lowest temperature as recorded around -38° C. The treatment systems were installed in enclosed room outside of Maitri.

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which is in operation throughout the year irrespective of seasonal variation became of summer and winter. The performance of RBC was evaluated in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and ammonical nitrogen (NH₃-N).

Water Consumption

Water collected from the lake is used by the resident of Maitri as well as the summer camp members. Water is collected in the tanks at Maitri from where it is discharged to summer camp tank for further use by resident of summer camp, however during winter period; water is consumed only by winter members because no one stays at summer camp. Summer camps utilize the water from the month of January to March (Figure1). Water flow was measured from the flow meter installed at submersible pump of the pumping house. The flow was also verified from two marked storage tanks of size 1mX1mX3m based on the initial and final volume difference at particular time of the day after and before pumping the water into the storage tank. Maximum water supply in a month is recorded as 164.5 m³ in the month of January and minimum 50.4 m³ in the month of April.

Wastewater Source

Wastewater generated from the kitchen by dishwashing, washbasins, washing of food grains, which is organic in nature and contains oil and grease too. All the waste generated inside the kitchen is carried through the combination of insulated iron and thick plastic pipe to B1:RBC. Another type of waste is generated from bathroom,

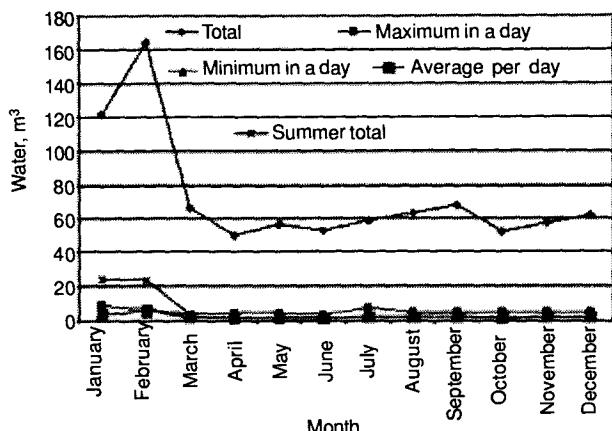


Figure 1 Monthly water supply pattern

washbasin and laundry which is alkaline in nature and carried to B3:RBC through combination of copper, iron and thick insulated plastic pipe.

MATERIAL AND METHODS

Rotating Biological Contactor (RBC)

Design Features

Klargester bio discs are manufactured in glass fibre reinforced polyester (GRP). These RBC are light in weight, easy to transport and easy to install. GRP is extremely robust, but susceptible to damage by sharp objects and from point loads. The RBC consists of banks of polypropylene media attached to a central shaft and is supported by two bearings, which are mounted on the rear bearing support bracket and the drive platform steelwork. The main operational features of the rotor unit are outlined below.

The RBC is divided into three stages by means of a fixed baffle attached to the biozone and rotating baffles fixed to the shaft. The media is split into stages designed to promote effective and efficient growth of bio-culture to effect treatment.

The RBC is rotated slowly through a reduction gearbox and peripheral drive gear and is arranged so that a proportion of its surface area is submerged in the effluent at any one time. As the RBC rotates, the surface of the media is subjected alternately to sewage and air, encouraging an aerobic, biologically active film of micro-organisms (biomass) to become established on each side of the media sheets. This biologically active film grows in size, is self regulating and oxidizes the pollutants in the sewage. The micro organisms use the untreated waste as a substrate (food) and as they do so, multiply in number, maintaining a specific biomass thickness to ensure optimum process efficiency. Material from the first stages of the RBC falls into the primary settlement tank (PST) through the pipe in the biozone casing, whereas material from the remaining stages of RBC is kept in suspension and carried forward into the final settlement tank (FST).

In order to ensure a balanced and constant flow a stable environment, dosing buckets fitted to the first stage of the RBC shaft lift and transfer the partially clarified liquor to the final stages of RBC at a constant rate, irrespective of changes to incoming flow rates and water level.

The final settlement tank (FST) comprises the secondary settlement or final zone, which is situated under the drive motor. It is formed by a full depth GRP baffle across the width of the unit and it is in this final zone that any biological culture, which falls from the later stages of RBC, is allowed to settle out. The treated effluent enters this zone from the biozone. By utilising the procedure, sludge storage volume of B1:RBC was kept as 300 l and desludging period was 180 days, whereas for B3:RBC sludge storage volume was kept as 1530 l and desludging period was 91 days. Design features of B1:RBC and B3:RBC are enumerated in Table 1.

Operation

Generally, the RBC units are located in separate rooms that are not exposed to sunlight to prevent the growth of algae, which could intervene with microbial attachment⁴ and at sometime overburden the discs with extra mass. The B1:RBC was designed for maximum hydraulic load for 1.2 m³/day and BOD load as 0.36 kg/day whereas B3:RBC was designed to take maximum hydraulic load as 5.0 m³/day and BOD load as 1.5 kg/day. The equipment was designed to achieve an effluent discharge standard of not more than 20 mg/l of BOD and 30 mg/l suspended solids and 20 mg/l of ammonia nitrogen assuming that ambient temperature within the plant is 5° C. The RBC comprises main components, namely, primary settling zone, biozone and secondary settling zone. The direction of disc rotation was selected to be opposite to the direction of wastewater flow in order to reduce on short circuiting. The ambient temperature under which sample collection and analysis performed ranged between -12° C to +3° C.

Water Balance at Maitri

In order to find out the water consumption, distribution loss

Table 1 Design features of B1 and B3 RBC

Design features	Description	
	B1:RBC	B3:RBC
Design load, l/day	1200	5000
Number of disc	56	100
Surface area of disk, m ²	56.0	200.0
Thickness of disk, mm	4.0	4.0
Dia/dimension of disk, mm	500x500	1000x1000
Dia of shaft, mm	100	150
Rotational speed, RPM	5	5
Spacing of disk, mm	15	15
Disk submergence, %	45%	45%
Power requirement	50 W	150 W

and waste water production during the month of January in a particular day when the population at the station was maximum, at all the inlet and outlet to the maximum extent possible volume of water was recorded on one hourly basis for 24 hours. From water balance diagram (Figure 2) it is depicted that 79.5% of water was used by Maitri station and rest 21.5% by summer camp inclusive of losses and waste generation. In B3:RBC influent quantity was 63% (1.95 kl) of water available to Maitri and 23 % (0.7kl) go to B1:RBC as influent. A sum of around 86.5% of water consumption was collected as wastewater pond.

Flow Measurement

As the flow meter was not available at the inlet and outlet points of the RBC's, a 'Fill and Measure' method was used to assess the volume at inlet as well as outlet points. Volume was measured at every hour for 24 h and then cumulative volume was calculated to produce a mass curve. Mass curve was developed to design the storage and feeding tanks for B1:RBC and B3:RBC to help in arresting the shock load, which would improve the efficacy of treatment system. Storage tank capacity for B1:RBC calculated around 90 l where as for B3:RBC it is 460 l.

Sample Collection and Preservation

The wastewater produced from various sources was directly fed in to RBC through two separate pipes. Wastewater generated from kitchen was directly fed through single pipe to B1:RBC, where as wastewater generated from washbasin, bathroom, laundry and urinals were collected in separate small pipes which ultimately joins the single pipe before feeding to B3:RBC. Composite samples (24 h) were collected before the inlets to RBC, from appropriate places at various course of time, and from outlets of RBCs, as well as from tap water which were stored in high density polypropylene bottles. At the sampling point temperature pH was measured and within 15 min of sampling it was brought to the laboratory at Maitri station and analysed for basic parameters, i.e., BOD, COD, conductivity, TSS, Cl, NH₃-N, DO, total alkalinity and turbidity. Rest sample

collected was preserved with HNO₃ for trace metals and H₂SO₄ for organic, oil and grease, sealed properly and brought to India for further analysis in the laboratory. Samples were prepared by filtering with 0.45 µm Whatman filter papers. All analyses were performed according to standard methods for analysis of water and wastewater⁵. Samples for trace metal analysis were preserved and analyzed by GBC, atomic spectrophotometer in the laboratory.

Tertiary Treatment Experiment

An attempt was made at the laboratory to observe the effect of tertiary treatment on the effluents of RBC. In this regard the effluent was primarily treated through the alum dose by flocculation and the obtained supernatant liquid was passed through the vertical column of 90 mm dia with 165 mm height consisting of activated charcoal (2-5 mm dia and 600-1000 m²/g sp. surface area) of total weight of 700 g. Influent before introduction of alum and effluent through activated carbon treatment was analyzed for temperature, pH BOD, COD, conductivity and DO at Maitri laboratory and later trace metals at the Institute's laboratory. One gram of alum was mixed well in distilled water and 10, 20, 40, 80 and 150 ml of aqueous solution was mixed and flocculated well in a liter of series of waste obtained from inlet of B1:RBC and B3:RBC. An optimum dose of alum solution which gave the maximum settlement of suspended particles was selected to pass through the activated carbon column. For this purpose, alum dose of 80 mg/l was selected for B1:RBC influent and 40 mg/l for B1:RBC influent. The influent waste from both the RBC's and effluent after optimum dosing of alum and effluent from the activated carbon column was further analyzed for physico chemical parameters

RESULTS AND DISCUSSIONS

Kitchen RBC (B1)

The wastewater treatment system is RBC which was installed at Maitri in the year 1999. These RBC's are designed and manufactured by Klargest Company, UK. Since the beginning, wastewater produced at Maitri is segregated and being treated in different RBCs. Kitchen waste contains high organic matter, which generates from washing of food grains, dishes condense milk, vegetable oil and others sources. The strength of the waste changes day to day, pertaining to the food habits during various occasions. Hydraulic loading on B1:RBC was noticed maximum during the summer which is 0.08 l/m² d. Three samples collected were on various course of time such as business-as-usual, normal day and the day when strength was high, and different varieties of food served. The average water consumption as shown in water balance diagram depicted 1.045 kl, out of which, wastewater converted, reaches to the kitchen RBC (B1) was approximately 0.7 kl per day during the summer period when the strength is more, however during the winter period it reduces. Three samples were collected and analyzed in different course of time, where first

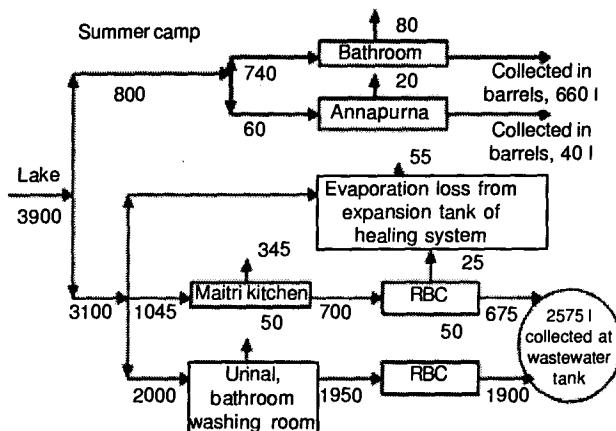


Figure 2 Water balance at Maitri station

sample was collected in the first week of January running as-usual-scenario. It shows that waste is of acidic nature and septic which of high strength of BOD and COD. The treatment efficacy was observed only 66.7% of BOD and 68.9% of COD. But due to lower pH the ammonia nitrogen of effluent is less than the influent because the ammonia producing bacteria were not working effectively at lower pH. Nitrification was probably hampered due to low alkalinity in the wastewater⁶. Oil and grease which were also mixing in the influent making the film over the liquid and thus disrupting the oxygen transfer at sediments tank. However, in the biological chamber due to continuous movement of the disc it was emulsifying. Microbe growth was observed on the disc of gray color which is clear indication of the overloading on the treatment system. The biomass development in aerobic unit did not always cover the entire disk surface⁷. Mostly suspended BOD and COD were removed in the sediment tanks and biological chamber reduces the BOD and COD load contributing due to dissolved matter. The trace heavy metals were removed very effectively as the copper, iron and zinc which are essential growth elements for bacteria were consumed by the bacteria but the temperature was as low as 8°C to 6°C which was not optimal temperature for microbes to work effectively for denitrification⁸ as compare to 12°C to 20°C. It was also noticed that the rpm of biodisc is 1.2, during the treatment process. Realizing lower temperature in the biozone, the temperature inside biodisc increased to 22°C and after few days the composite samples were collected and analyzed. Increase in temperature could only improve the ammonia nitrogen content in the effluent which shows the nitrogen decaying bacteria started growing and assimilating the organic content but still the efficiency for BOD removal was 48.3% and for COD it was around 24.7%. The third samples were taken on the day when the strength was high at the

station. The temperature was maintained at biodisc as 20°C to 22°C. It was observed that ammonia nitrogen in the effluent is further improved and the nitrate concentration is also recorded. This is the indicator that the treatment efficiency was improved and the BOD removal efficiency observed as 45.8% and COD as 49.2% even though when the load was more (Table 2). This RBC was designed as maximum BOD of 300 mg/l in the influent with the maximum flow of 1.32 m³/day. The overloading was also observed and quite evident from the grey color of the microbes as developed on the biodisc. This high BOD and COD were adding to the effluent from the secondary settling tank where from the sludge was not removed properly and the anaerobic condition generated and producing gases which kept suspended the sludge and finally to the effluent which ultimately added upto more BOD and COD value in the effluent. Oil and grease and hydrocarbon are also responsible to hamper the treatment efficiency of the system. Among the trace metals in the third sample, copper, manganese, zinc concentration found lower in the effluent except the iron content and the possible reason might be the introduction of inorganic iron from the iron pipe which is little old.

Tertiary Treatment B1:RBC

Four liters of treated effluent collected from B1 RBC to study the tertiary treatment and effect of series treatment. To assess the optimum dose of alum for maximum settlement of particles present in the wastewater, four jar of one litre capacity filled with treated wastewater and different dose of alum mixed in water and stirred for 5 min. The jar selected for further treatment, which shows the maximum settlement of coagulated particles. Supernatant liquid holding the volume of 900 ml passed through the column filled with activated carbon, with a constant rate of flow 50 ml/min.

Table 2 Physico-chemical characteristics of wastewater of B1 (Kitchen)

Parameters	Sample 1		Tertiary treatment (effluent)		Sample 2		Sample 3	
	Influent	Effluent	Alum	Activated carbon	Influent	Effluent	Influent	Effluent
pH	5.08	5.10	5.0	7.5	4.99	4.54	5.9	6.5
DO, mg/l	0.00	0.70	-	-	0.53	1.00	0.6	1.5
Temperature, °C	8.00	6.00	11.0	11.0	22.00	21.00	20.0	19.0
Total suspended solids, mg/l	97.00	20.00	13	8.0	-	-	-	-
Nitrates, mg/l	ND	ND	ND	ND	-	-	-	-
Phosphates, mg/l	1.80	2.80	1.2	0.3	-	-	-	-
Ammonia nitrogen, mg/l	4.80	4.30	3.8	3.7	2.85	3.54	4.7	71.5
Chemical oxygen demand, mg/l	2664.00	828.00	576.0	450.0	728.00	548.00	2387.0	1212.0
Biochemical oxygen demand, mg/l	1363.00	454.00	414.0	247.0	620.00	320.00	600.0	325.0
Oil and grease, mg/l	20.60	2.80	ND	ND	-	-	-	-
Hydrocarbons, g/l	0.53	0.47	ND	ND	-	-	-	-

The analysis results (Table 2) shows that even at low temperature and when the treated system was not functioning to desired level of treatment, suspended solids were reduced by 35%. BOD and COD removal was obtained as 8.8% and 30.4%, respectively. Among the trace metals, manganese iron and zinc were further reduced. The supernatant liquid after alum dosing was passed through the column of activated carbon, which increased the pH of liquid to 7.5 reduced the suspended solids by 38.5%. BOD and COD were further removed by 40.3% and 21.9%. Oil, grease and hydrocarbons were completely removed and the trace metal were also completely removed except iron.

Urinal Laundry Bathroom RBC (B3)

Another RBC (B3) was also installed in the year 1999 at Maitri which is designed and manufactured by Klärteger Company, UK. In this RBC, waste was discharged through a common connecting pipe from bathroom, urinal and laundry. Hydraulic loading on the RBC was maximum during the summer is $0.102 \text{ l/m}^2 \text{ d}$. Three samples were collected on various occasion such as business-as-usual, normal day and the day when strength was maximum inside the Maitri station as well as in summer huts. The average water consumption as shown in water balance diagram depicted as 2.0 kl and wastewater produce and reaches to RBC (B3) is approximately 1.95 kl per day during the summer period when the strength was more. Three samples were collected and analyzed in different course of time in conjunction with the samples collected of kitchen RBC. First sample was collected in the first week of January running as-usual scenario. It shows that waste pH is normal in nature, DO content is very less (Table 3) which was of moderate strength of BOD and COD. The treatment efficacy was observed only 29.8% of BOD and 41.4% of COD. But due to lower temperature inside the biozone the ammonia nitrogen

of effluent was less than the influent because the ammonia producing bacteria were not working effectively at lower temperature. Oil and grease which were also mixing in the influent from the washing of hands muddled with grease and oil and sometimes small containers of the boiler room, consisting oil and grease makes the film over the liquid and thus disrupting the oxygen transfer at sediments tank. However, in the biological chamber due to continuous movement of the disc, it was emulsifying. Saline layer of microbe growth was observed very less on the disc. The trace heavy metals were removed from the biozone as the copper, iron and zinc which are essential growth elements for bacteria were consumed by the bacteria, but the temperature is low as 8° C to 6° C , which is not optimal temperature to work microbes effectively as compared to 12° C to 20° C . RPM of the biodisc recorded was low as 1.4. The optimum temperature was not maintained in the biodisc so it was raised to 21° C and after few days the composite samples were collected and analyzed. Increase in temperature could only improve the ammonia nitrogen content in the effluent which shows the nitrogen decaying bacteria started growing and assimilating the organic content but still the efficiency for BOD removal was 16.7% and for COD it was 25.7%. The third samples were taken on the day when the strength was high at the station. The temperature was maintain at biodisc to 19° C to 21° C , and it was observed that ammonia nitrogen in the effluent is further improved and so the nitrate concentration was also recorded. This is the indicator that the treatment efficiency was improved and the BOD removal efficiency observed as 31.5% and COD as 44%. This RBC was designed of maximum BOD of 300 mg/l in the influent with the maximum flow of $5.0 \text{ m}^3/\text{day}$. BOD load is less than the design load and the pH of the effluent were recorded of reasonable quality. Laundry effluent which consist nitrogen and

Table 3 Physico-chemical characteristics of wastewater of B3 (urinal, bathroom and laundry)

Parameters	Sample 1		Tertiary treatment (effluent)		Sample 2		Sample 3	
	Influent	Effluent	Alum	Activated	Influent	Effluent	Influent	Effluent
	carbon							
pH	7.20	6.90	7.00	7.80	6.98	7.28	5.2	7.2
DO, mg/l	0.40	4.30	-	-	0.54	4.60	0.3	3.8
Temperature, $^\circ\text{C}$	8.00	6.00	11.00	11.00	21.00	21.00	19.0	19.5
Total suspended solids, mg/l	41.00	26.00	78.00	48.00	-	-	-	-
Nitrates, mg/l	3.18	2.45	0.44	0.14	-	-	-	-
Phosphates, mg/l	0.30	1.50	1.60	1.80	-	-	-	-
Ammonia, mg/l	122.50	47.50	42.00	22.00	9.80	21.80	71.0	165.0
Chemical oxygen demand, mg/l	522.00	306.00	180.00	126.00	280.00	208.00	400.0	224.0
Biochemical oxygen demand, mg/l	158.00	114.00	54.00	42.00	120.00	100.00	108.0	74.0
Oil and grease, mg/l	5.80	4.20	ND	ND	-	-	-	-
Hydrocarbons, g/l	0.35	0.27	ND	ND	-	-	-	-

phosphorus required for bacteria cell reproduction but the carbon, calcium, magnesium and other trace elements are not in the effluent to generate the bio cells. This resulting into undeveloped biodisc and thus the treatment efficiency was low. Oil, grease and hydrocarbon were also responsible to hamper the treatment efficiency of the system. Among the trace metals in the third sample copper, manganese, zinc concentration were found lower in effluent except the iron content (Table 3).

Tertiary Treatment B3:RBC

The first sample obtained from both the RBC were used for laboratory study of the tertiary treatment. Four liters of treated effluent collected from B1 RBC to study the tertiary treatment and effect of series treatment. To assess the optimum dose of alum for maximum settlement of particles present in the wastewater, four jar of one litre capacity filled with treated wastewater and different dose of alum mixed in water and stirred for 5 min. The jar selected for further treatment, which shown maximum settlement of coagulated particles. Supernatant liquid holding the volume of 900 ml passed through the column filled with activated carbon, with a constant rate of flow 50 ml/min. The optimum alum dose influent was selected and the analysis results (Table 3) shows that pH of the effluent was further improved to 7.0. Suspended solids were increased due to flocculation process of colloidal particles which kept them in suspension. Nitrates and ammonia were reduced and BOD and COD were reduced by 52.6% and 41.2%, respectively. Oil, grease and heavy metals were removed. Among the trace metals, manganese and zinc were removed and iron was reduced. The supernatant liquid after alum dosing was passed through the column of activated carbon, which increased the pH of liquid to 7.8 reduced the suspended solids by 38.5%. BOD and COD were further removed by 22.2% and 30%. Oil, grease and hydrocarbons were completely removed trace metal are also completely removed except the iron.

CONCLUSION

The BOD load from kitchen waste was very high, which contains high organic matters. Both the RBC's were designed to accept the BOD load of 300 mg/l, to work at optimum temperature of 12° C to 20° C designed rpm of RBC's were 5 where as during operation it was noticed around 1 rpm to 2 rpm. The lower rpm of RBC transfers less oxygen to the bacteria and diffuses less oxygen to the liquid inside the biozone. The RBC's were designed to bear the shock loading but operating in low temperature, fluctuation in the flow, affect the treatment process because ammonia removal rate significantly decrease by sudden cooling. Waste obtained from the different sources are being treated in two different RBC's this resulting in availing more food and trace elements in B1:RBC, which are essential in cell growth to bacteria and found deficiency in B3:RBC. As the maximum flow of B3:RBC was 5 m³/day whereas average

waste flow of Maitri was around, 3.1 m³/day. This indicates that entire waste load could be treated into single RBC (B3). This would not only neutralize the pH of waste but also provide essential growth elements to bacterial cell.

Bioaugmentation of nitrifying bacteria for short solids retention time nitrification is an attractive alternative for wastewater treatment plants in cold climate and mixing of centrate from kitchen RBC, which could be used as a source for bioaugmentation of B3:RBC. Improvements in the treatment efficacy could also be achieved if the RBC system can be step feed as compared to single feed mode.

Oil and grease trap should be fixed before the waste enters into RBC which would help in faster cell development rather than becoming toxic to bacteria. An equalization tank of around 460 l for B3:RBC and around 120 l for B1:RBC would be equally useful with alum dosing to regulate flow variation as well as settlement of suspended solids of kitchen waste thus reducing overall BOD load. Temperature of the biozone should also be maintained to around 20o C for proper cell growth of the bacteria.

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