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 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°05‘37"S Latitude, 12°00‘00" 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°45'53" S latitude and 11°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.
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 Blenkham, 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 obligated 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 (°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 background 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 wastewater. 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 (Metcalf and Eddy, 1995)**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Factor</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Process applicability</td>
<td>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.</td>
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<td>2.</td>
<td>Applicable flow range</td>
<td>The process should be matched to the expected range of flow rates. For example, stabilization ponds are not suitable for extremely large flow rates.</td>
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<td>3.</td>
<td>Applicable flow variation</td>
<td>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.</td>
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<tr>
<td>4.</td>
<td>Influent-wastewater characteristics</td>
<td>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.</td>
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<td>5.</td>
<td>Inhibiting and unaffected constituents</td>
<td>What constituents are present and may be inhibitory to the treatment processes? What constituents are not affected during treatment?</td>
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<tr>
<td>6.</td>
<td>Climatic constraints</td>
<td>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.</td>
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<tr>
<td>7.</td>
<td>Reaction kinetics and reactor selection</td>
<td>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.</td>
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<td>8.</td>
<td>Performance</td>
<td>Performance is usually measured in terms of effluent quality, which must be consistent with the effluent-discharge requirements.</td>
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<td>9.</td>
<td>Treatment residuals</td>
<td>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.</td>
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<tr>
<td>10.</td>
<td>Sludge-processing</td>
<td>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.</td>
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Cont. Table 1.1

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<tr>
<th>S.No.</th>
<th>Factor</th>
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<tr>
<td>11.</td>
<td>Environmental constraints</td>
<td>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.</td>
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<td>12.</td>
<td>Chemical requirements</td>
<td>What resources and what amounts must be committed for a along 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?</td>
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<td>13.</td>
<td>Energy requirements</td>
<td>The energy requirements, as well as probable future energy cost, must be known if cost-effective treatment systems are to be designed.</td>
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<td>14.</td>
<td>Other resource requirements</td>
<td>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?</td>
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<tr>
<td>15.</td>
<td>Personnel requirements</td>
<td>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?</td>
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<td>16.</td>
<td>Operating and maintenance requirements</td>
<td>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?</td>
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<tr>
<td>17.</td>
<td>Ancillary processes</td>
<td>What support processes are required? How do they affect the effluent quality, especially when they become inoperative?</td>
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<tr>
<td>18.</td>
<td>Reliability</td>
<td>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 so such occurrences affect the quality of the effluent?</td>
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<tr>
<td>19.</td>
<td>Complexity</td>
<td>How complex is the process to operate under routine or emergency conditions? What levels of training must the operators have to operate the process?</td>
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<tr>
<td>20.</td>
<td>Compatibility</td>
<td>Can the unit operation or process be used successfully with existing facilities? Can plant expansion be accomplished easily?</td>
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<tr>
<td>21.</td>
<td>Space availability</td>
<td>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?</td>
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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 $\text{CO}_2$, $\text{H}_2\text{O}$, $\text{NO}_3$ and $\text{SO}_4$. The flock (zoogleal 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 Tricking 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\textsubscript{3}, is liberated and oxidized by chemical and bacterial means, giving a gradual reduction of NH\textsubscript{3} and an increase of NO\textsubscript{2} and NO\textsubscript{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 conglomerate 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>
<thead>
<tr>
<th>Sr. No.</th>
<th>Station Name</th>
<th>Country</th>
<th>Location</th>
<th>No. of occupants</th>
<th>Water Requirement</th>
<th>Waste Treatment Method</th>
<th>Discharge Method and Effluent Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Latitude Longitude</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Aboa</td>
<td>Finland</td>
<td>73°03'S 013°25'W</td>
<td>n/a</td>
<td>20</td>
<td>Grey water is not treated</td>
<td>Discharged on ice covered area which ultimately drains into sea</td>
</tr>
<tr>
<td>2</td>
<td>Amundsen-Scott</td>
<td>USA</td>
<td>89°59.85'S 139°16.37'E</td>
<td>55-60</td>
<td>95 litres/person/day</td>
<td>Nil</td>
<td>Sewage is discharged in abandoned wells</td>
</tr>
<tr>
<td>3</td>
<td>Bellingshausen</td>
<td>Russia</td>
<td>62°11.78'S 058°57.65'W</td>
<td>25</td>
<td>38</td>
<td>Septic sewage treatment system</td>
<td>Discharged untreated sewage into nearby stream</td>
</tr>
<tr>
<td>4</td>
<td>Casey</td>
<td>Australia</td>
<td>66°17.00'S 110°31.18'E</td>
<td>20</td>
<td>70</td>
<td>Rotating Biological Contactor and UV filtration</td>
<td>Discharged into Marine Environment</td>
</tr>
<tr>
<td>5</td>
<td>Comandante Ferraz</td>
<td>Brazil</td>
<td>62°05.00'S 058°23.47'W</td>
<td>12</td>
<td>40</td>
<td>Three stage passive filtration system</td>
<td>Discharged inshore to Martel Inlet below the low tide line</td>
</tr>
<tr>
<td>6</td>
<td>Concordia (2)</td>
<td>France &amp; Italy</td>
<td>75°06.12'S 123°23.72'E</td>
<td>14</td>
<td>50</td>
<td>83 litres/person/day 1) UV filtration 2) Nano filtration 3) Reverse Osmosis 75% is recycled except for drinking</td>
<td>In well in Polar Ice Sheet</td>
</tr>
<tr>
<td>7</td>
<td>Davis</td>
<td>Australia</td>
<td>68°34.63'S 077°58.35'E</td>
<td>22</td>
<td>70</td>
<td>Rotating Biological Contactor</td>
<td>Discharged into Marine Environment</td>
</tr>
<tr>
<td>8</td>
<td>Dumont d'Urville</td>
<td>France</td>
<td>66°39.77'S 140°00.08'E</td>
<td>26</td>
<td>100</td>
<td>-</td>
<td>Sewage and domestic liquid waste is deposited into the sea, with toilet and food first being ground</td>
</tr>
<tr>
<td>Sr. No.</td>
<td>Station Name</td>
<td>Country</td>
<td>Location</td>
<td>No. of occupants</td>
<td>Water Requirement</td>
<td>Waste Treatment Method</td>
<td>Discharge Method and Effluent Quantity</td>
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</tr>
<tr>
<td>9</td>
<td>Enigma Lake</td>
<td>Italy</td>
<td>74°42.81'S 164°02.49'E</td>
<td>9</td>
<td>-</td>
<td>Biological sewage treatment plant and with chlorine disinfection</td>
<td>Discharged into marine environment</td>
</tr>
<tr>
<td>10</td>
<td>Great Wall</td>
<td>China</td>
<td>62°12.98'S 165°37.73'E</td>
<td>10</td>
<td>30</td>
<td>Processed through sewage treatment plant</td>
<td>Discharged treated/untreated into tidal basin</td>
</tr>
<tr>
<td>11</td>
<td>Halley</td>
<td>United Kingdom</td>
<td>75°34.90'S 026°32.47'E</td>
<td>11</td>
<td>65</td>
<td>Sewage macerated</td>
<td>Discharged to ice pit</td>
</tr>
<tr>
<td>12</td>
<td>Law - Racovita</td>
<td>Australia &amp; România</td>
<td>69°23'S 076°23'E</td>
<td>n/a</td>
<td>13</td>
<td>Grey water is collected in 200-L drums and returned to Australia</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Mawson</td>
<td>Australia</td>
<td>67°36.28'S 062°52.25'E</td>
<td>13</td>
<td>60</td>
<td>Rotating Biological Contactor</td>
<td>Discharged into Marine Environment</td>
</tr>
<tr>
<td>14</td>
<td>McMurdo</td>
<td>USA</td>
<td>77°50.88'S 166°40.10'E</td>
<td>250</td>
<td>1000</td>
<td>An anoxic zone, an aerobic zone, clarification and disinfection</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Neumayer</td>
<td>Germany</td>
<td>70°38.00'S 008°15.80'E</td>
<td>6</td>
<td>43</td>
<td>Grey and black water is cleaned with filter and UV radiation system</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>O'Higgins</td>
<td>Chile</td>
<td>63°19.25'S 057°54.02'E</td>
<td>17</td>
<td>50</td>
<td>State-of-the-art sewage treatment plant</td>
<td>Discharged into marine environment</td>
</tr>
<tr>
<td>17</td>
<td>Progress 2</td>
<td>Russia</td>
<td>69°23'S 076°23'E</td>
<td>20</td>
<td>77</td>
<td></td>
<td>Discharged to the ocean</td>
</tr>
<tr>
<td>18</td>
<td>Rothera</td>
<td>United Kingdom</td>
<td>67°34.17'S 068°07.20'E</td>
<td>22</td>
<td>110</td>
<td>Type pack 3 sewage treatment plant with UV filtration</td>
<td>Discharged into Bay</td>
</tr>
<tr>
<td>19</td>
<td>SANAE IV (3)</td>
<td>South Africa</td>
<td>71°40.42'S 002°49.73'E</td>
<td>10</td>
<td>80</td>
<td>Filtration through biological treatment and then UV filtration</td>
<td>Discharged into ice</td>
</tr>
<tr>
<td>Sr. No.</td>
<td>Station Name</td>
<td>Country</td>
<td>Location</td>
<td>No. of occupants</td>
<td>Water Requirement</td>
<td>Waste Treatment Method</td>
<td>Discharge Method and Effluent Quantity</td>
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<td>-----------------------------------------------------------------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>20</td>
<td>Scott Base</td>
<td>New Zealand</td>
<td>77°51.00'S 166°45.77'E</td>
<td>10</td>
<td>85</td>
<td>Aerated submerged media process system. Sludge generation is low at 0.65L/person/day (at 1.5% solids)</td>
<td>Discharged directly to sea</td>
</tr>
<tr>
<td>21</td>
<td>Signy</td>
<td>United Kingdom</td>
<td>60°43'S 045°36'W</td>
<td>n/a</td>
<td>10</td>
<td>Liquid wastes such as medicines and used oil, to be brought back to Japan</td>
<td>Discharged directly to sea</td>
</tr>
<tr>
<td>22</td>
<td>Syowa</td>
<td>Japan</td>
<td>69°00.37'S 039°35.40'E</td>
<td>40</td>
<td>110</td>
<td>Grey water is treated through three chamber filtration systems and then UV filtration. Incinerators are used to burn excreta</td>
<td>Discharged on open land</td>
</tr>
<tr>
<td>23</td>
<td>Troll (4)</td>
<td>Norway</td>
<td>72°00.12'S 002°32.03'E</td>
<td>nil</td>
<td>18</td>
<td>Grey water is not treated</td>
<td>Discharged on ice covered area which ultimately drains into sea</td>
</tr>
<tr>
<td>24</td>
<td>Wasa</td>
<td>Sweden</td>
<td>73°03'S 013°25'W</td>
<td>nil</td>
<td>9</td>
<td>Grey water is not treated</td>
<td>Discharged on ice covered area which ultimately drains into sea</td>
</tr>
<tr>
<td>25</td>
<td>Zhongshan</td>
<td>China</td>
<td>69°22.27'S 076°23.22'E</td>
<td>15</td>
<td>30</td>
<td>-</td>
<td>Disposed after treatment to the ocean</td>
</tr>
</tbody>
</table>

- 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.

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 Alleman 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 (Alleman 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) predenitrification 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 (BOD₅), 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°C to 10°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 m².h/m³) should be used for treatment of high strength (COD=5 kg/m³) 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).

(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 stakeholders. 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

<table>
<thead>
<tr>
<th>Model</th>
<th>References</th>
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<tr>
<td>Enhanced Stream Water Quality Model (QUAL 2E)</td>
<td>Brown and Barnwell, 1987</td>
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<tr>
<td>Three-Dimensional Hydrodynamic-Eutrophication Model (HEM-3D)</td>
<td>Park et al., 1995; Sisson et al., 1997</td>
</tr>
<tr>
<td>Tidal Prism water Quality Model (TPWQM)</td>
<td>Shen et al., 2002</td>
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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 biomonitors 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 (-1.8°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