# Development of a Simple Ceramic Membrane Bio-reactor
# for
# Wastewater Treatment

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# Development of a Simple Ceramic Membrane Bioreactor for Wastewater Treatment

A Thesis report submitted to the department of Civil Engineering of Khulna University of Engineering & Technology (KUET). Khulna, Bangladesh in partial fulfillment of the requirements for the degree of

**"Master of Science in Civil Engineering"**


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## Declaration

This is to certify that the Thesis Work entitled "Development of a Simple Ceramic Membrane Bio-reactor for Wastewater Treatment" has been carried out by Jewel Kumar Golder, in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work has not been submitted anywhere for any award of degree or diploma.

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October 30, 2011

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# Approval

This is to certify that the Thesis Work submitted by Jewel Kumar Golder entitled as "Development of a Simple Ceramic Membrane Bioreactor for Wastewater Treatment" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering under Khulna University of Engineering & Technology, Khulna, Bangladesh in October 30, 2011.

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## Abstract

In this study a low cost and simple type ceramic membrane was innovated for concurrent wastewater treatment and reuse. As the MBR processes are still costly in terms of price of membrane, maintenance cost and energy consumption. Therefore, a low cost and simple MBR will be ideal in the case of its application in developing countries. In this study, a simple Ceramic Membrane Bio-reactor was introduced to reduce the membrane cost, maintenance cost and operation costs for its application.

This technology can be used in treatment of septic tank effluent as well as other purpose for recycling of wastewater. Especially in urban areas where the soak well effluent cannot infiltrate into the ground as the infiltration rate is limited for a particular soil at particular place. This technology can also be very effective for recycling of wastewater. As most of the septic tank effluent in residential area is directly disposed into the storm water drain, this technology can be used for reducing pollution of that effluents. Therefore, an attempt was taken to study the performance of CMBR for its potential application in recycling and treatment of wastewater. Because the general increase of the fresh water demand, water shortages and environment protection, this technology can be useful to treat and recycling of wastewater as a sustainable solution of these problems. It is now also established that wastewater recycling is feasible and can contribute to sustainable water management. Besides groundwater recharge by infiltration, other applications of non-potable purposes, for example irrigation of parks, schools yards, cemeteries and golf courses, vehicle washing, fire protection, boiler feed water, air conditioning and concrete production and preservation of wetlands, recycled water can be used. Locally available and cheap materials (clay soil and rice bran) were used as ingredients to decline the membrane cost in this study. The ceramic membrane was submerged inside reactor to formulate as ceramic membrane bioreactor

(CMBR). Gravitational-filtration system was induced for collecting the effluent to reduce the operational cost, and the applicability of this low cost CMBR technology was checked in laboratory scale.

The average Turbidity Removal efficiency of all Reactors was 95.34%. The result shows that about 88.45% Color removal was achieved by the system. Turbidity and Color removal efficiency was excellent that's why the filtered water is more acceptable by the people as the aesthetic appearance of the water is good. The average SS removal efficiency was 95.25% by all Reactors which demonstrates that the removal of SS was very efficient by CMBR. About 81.55% COD removal was achieved by Ceramic Membrane Bio-reactor. From the results, it can be concluded that the CMBR has great potential in removing biodegrading organic pollutants from wastewater. The run time of CMBR was very good. The run time of CMBR was 242 days. The quality of effluent water was excellent as the effluent water was clear colored and odor- free. It was found that high removal efficiency of organic content was obtained that could be made it suitable for wastewater reuse. As the Ceramic Membrane was made by locally available materials the technology was inexpensive. Therefore, the technology is suitable and can be adapted in developing countries for wastewater treatment and reuse.

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# *Chapter 1*

# *Introduction*

## 1.1 BACKGROUND

Water is an essential resource for life. It has become more essential in various fields in today's development-oriented world. With ever-increasing urbanization, diversification of lifestyles, climate changes, industrialization and with the rise in population growth water demand is increasing in many regions around the world. Consequently, various problems relating to the increased amount of wastewater are becoming great environmental issue in recent days.

Water scarcity or water shortage is becoming a burning global issue in recent days with the significant increase of water demand. According to United Nations, 2-7 billion people will face water shortages by the year of 2050. Even now about 80 countries, comprising 20-40% of the world population are experiencing water stress as well as water shortage and during the last four decades the number of developing countries facing water scarcity, has increased (Hasan and Nakajima 2010). This situation is aggravated further by the pollution of fresh water resources due to the discharge of untreated wastewater from industrial enterprises and municipal wastewater. On behalf of concerning water and wastewater related issues, the decade 2005-2015 has been declared as "The International Decade of Action: Water for Life". Finding/re-creating adequate water supply as well as fully utilization of wastewater becomes important issues in sustainable environmental development.

The concurrent wastewater treatment and reuse secures the sufficient availability of fresh water and if wastewater can be reused, both the demand for water and the amount of wastewater can be reduced. Apart from the natural scarcity of fresh water resources, the developing countries in particular, the quality of the available freshwater also are deteriorating due to pollution which is intensifying the shortage. The reasons of this are for rapid economic development and shortage of stringent environmental protection regulations, many domestic and industrial wastewaters have been discharged into natural water bodies without sufficient treatment (Hasan and Nakajima 2010). There is very few wastewater treatment and reuse facilities in developing countries due to high costs of treatment processes, lack of awareness, shorten of effective environmental pollution control laws or law enforcement. However among the treatment options decentralized on-site systems are found more sustainable and cost effective. Although the treatment technology encompasses a vast number of options, along with them membrane technologies are regarded as key element of advanced wastewater reclamation and reuse schemes and are included in a number of prominent schemes worldwide as the membrane technologies have the potentiality of generating effluent with excellent reusable quality. Therefore an attempt has been undertaken in this research to evaluate the applicability of Ceramic Membrane Bio-Reactor with real wastewater treatment.



## 1.2 OBJECTIVES

The major goal of this study is to carry out initiative for the improvement of the further treatment of wastewater in developing countries by using an innovative, low cost and simple technology. For achieving the goal following successive objectives were fixed:

- To apply Ceramic Membrane in a Bioreactor (CMBR) for wastewater treatment.
- To determine the quality of effluent from CMBR.
- To observe the efficiency in flux of the developed CMBR.
- To monitor the overall operation and maintenance performances of the CMBR.

## 1.3 STRUCTURE OF THE STUDY

The study is enclosed with five different chapters with linkage between them. Fig: 1 represents the whole structure of this study with brief description.

**Chapter 1: INTRODUCTION**

*Statements of Problems with background, consecutive objectives of the study to resolve the problems and the structure of the study are described in this chapter*

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**Chapter 2: LITERAURE REVIEW: Domestic Wastewater in Developing Countries and Membrane Bioreactor (MBR)**

*Details about domestic wastewater and also greywater scenarios which include treatment and reuse situation, Overall review about membrane bioreactor (MBR) technology with merits and demerits for wastewater treatment and reuse are stated.*

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**Chapter 3: MATERIALS AND METHODS**

*A simple and low-cost ceramic membrane was innovated for wastewater treatment and reuse. Details Procedure of the ceramic membrane manufacturing and its characteristics are described. A details description of the CMBR technology for wastewater treatment and reuse were discussed in this chapter.*

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**Chapter 4: RESULTS AND DISCUSSION**

*The performance of the ceramic membrane bioreactor (CMBR) and the laboratory test results are discussed in this chapter.*

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**Chapter 5: CONCLUSIONS AND RECOMMENDATIONS**

*Concluding remarks with some recommendations are stated herein.*

Figure: 1-1 Structure of the study

# *Chapter 2*

# *Literature Review*

## 2.1 INTRODUCTION

The demand for water is increasing with the increasing industrialization, urbanization and the diversification of lifestyles. In addition to this, there have been problems relating to the increased amount of wastewater also, since aside from a minor quantity, most consumed water is transformed into wastewater. The aim of this chapter is to obtain an idea about the whole scenarios of wastewater especially in developing countries. In addition with the wastewater situation, wastewater treatment technologies, reuse conditions are also discussed. Because the general increase of the fresh water demand, water shortages and environment protection, MBR technology can be useful to treat and recycling of wastewater as a sustainable solution of these problem (Hasan and Nakajima 2010).

## 2.2 DOMESTIC WASTEWATER SITUATION, TREATMENT AND REUSE IN DEVELOPING COUNTRIES

### 2.2.1 *Definition and Types of Wastewater*

Wastewater is water that has been used and must be treated before it is released into another water body, so that it does not cause further pollution of water sources (SDWF Report 2007) or any water that is no longer wanted, as no further benefits can be derived out of it, is termed as wastewater (Hasan and Nakajima 2010).Wastewater comes from a variety of sources. Everything that we flush down our toilet or rinse down the drain is wastewater. Rainwater and runoff, along with various pollutants, go down street gutters and eventually end up at a wastewater treatment facility. Wastewater can also come from agricultural and industrial sources (SDWF Report 2007). Many of our daily chores such as bathing, doing laundry, flushing toilets, preparing meals, washing dishes and other activities generate wastewater

(DEQ Report 2010). Wastewater comprises the liquid waste or used water discharged from a municipality (including any human waste), industry or agriculture that contains a wide range of potential contaminants, dissolved or suspended matter and has suffered a loss of quality as a result. Rainfall that travels down a drain is also included in wastewater concept. The composition of wastewater is about 99% of water and only 1% of solid wastes (Hasan and Nakajima 2010).Wastewater can be treated in a certified plant and reused for human consumption.

There is a wide range of wastewaters and an equally wide range of technologies and techniques for mitigating the impacts of wastewaters on the receiving environment. Fig: 2-1 shows the different types of wastewater.

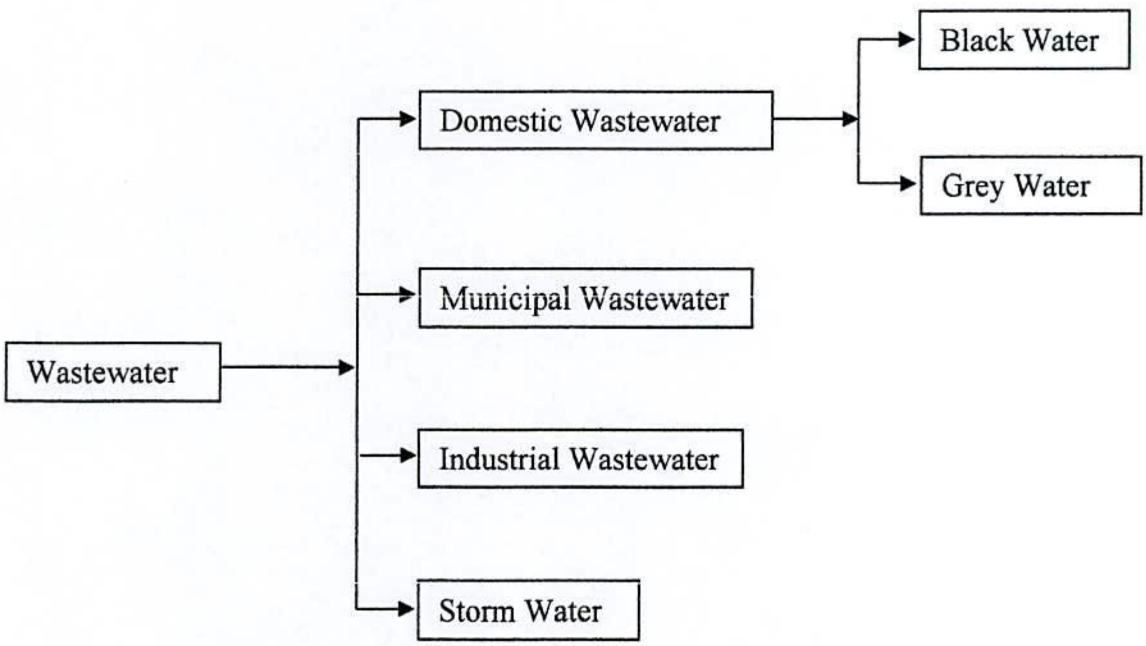



Fig: 2-1 Types of Wastewater

***Domestic wastewater*** is the liquid waste which originates in the sanitary conveniences, e.g., water closets (WC), urinals, bath, sink etc and in kitchens of dwellings by human activities. It contains organic substances and nutrient compounds, that can promote the growth of aquatic plant and lead to water pollution. The compositions of domestic wastewater vary with time and rate of water used depending on life quality, living habits, climate, community size and density of development (Hasan and Nakajima 2010).

***Blackwater*** consists of excreta (faces and urine), toilet paper, flushing water and some cleaning chemicals (Thanh et al. 2006). Blackwater is a relatively recent term used to describe wastewater containing fecal matter and urine. Blackwater usually comes from toilets. It is also known as brown water, foul water, or sewage. It is distinct from greywater or sullage, the residues of washing processes. Blackwater contains pathogens which need to decompose before they can be released safely into the environment.

***Greywater*** is wastewater that comes from the bath, shower, bathroom wash basins, clothes washing machine, laundry trough, dishwasher and kitchen sink. However, greywater from the kitchen sink is generally not recycled due to the contaminants it contains (Water Corporation Report 2008). It can be recycled on-site for uses such as landscape irrigation, and constructed wetlands. Greywater excludes discharge from WCs and urinals.

***Industrial wastewater*** includes the liquid discharge from spent water in different industrial processes such as manufacturing and food processing.

***Storm water*** is the surface runoff obtained during and immediately after the rainfall. Storm water is not as foul as other wastewater and hence can be carried through open drains or channels to dispose of in natural rivers or streams without any treatment (Hasan and Nakajima 2010).

***Municipal wastewater*** is the liquid waste comprises domestic and/or industrial discharge as well as storm water, groundwater infiltration and inflow. Municipal wastewater, which is 99% liquid, consists of suspended and dissolved solids, both organic and inorganic, and includes large numbers of microorganisms (Alberta Environment Report 2000).

### *2.2.2 The reasons of Concern about Wastewater*

Domestic wastewater (i.e. sewage) must be properly treated because it contains excessive nutrients, harmful bacteria/viruses and household chemicals that may contaminate the land and waters of our state and threaten public health (DEQ Report 2010). Although typical wastewater is over 99% water, the remaining 1% may contain substances that are potentially harmful to aquatic life and human. Many products using in everyday life (in kitchen, in bathroom) and from industries introduce toxic contaminants to the wastewater. Also, more "natural" substances such as bacteria and nutrients enter wastewater from human wastes.

Untreated or improper treated wastewater generally contains high levels of organic material, numerous pathogenic microorganisms, as well as nutrients and toxic compounds which pose risks both to the health of human and aquatic life. Excess nutrients pose a special threat by stimulating algal blooms that deplete dissolved oxygen after they die and decay. Various studies provide some examples of pollutants that can be found in wastewater and the potentially harmful effects these substances can have on ecosystems and human health:

- Decaying organic matter and debris can use up the dissolved oxygen in a lake so fish and other aquatic biota cannot survive;
- Excessive nutrients, such as phosphorus and nitrogen (including ammonia), can cause eutrophication or over-fertilization of receiving waters, which can be toxic to aquatic

organisms, promote excessive plant growth, reduce available oxygen, harm spawning grounds, alter habitat and lead to a decline in certain species;

- Chlorine compounds and inorganic chloramines can be toxic to aquatic invertebrates, algae and fish;
- Bacteria, viruses and disease-causing pathogens can pollute beaches and contaminate shellfish populations, leading to restrictions on human recreation, drinking water consumption and shellfish consumption;
- Metals, such as mercury, lead, cadmium, chromium and arsenic can have acute and chronic toxic effects on species.
- Many refractory compounds in high concentration such as phenol, thiocyanate, sulfide, cyanide, ammonia and so on. Furthermore, various compounds such as fluorene, pyrene, acenaphthene, phenanthrene and flouranthrene, can also be found in wastewaters. Particularly, phenolic compounds can easily migrate within different aqueous environments and contaminate groundwater because of their high solubility in water (Lim et al. 2002).

Other substances such as some pharmaceutical and personal care products, primarily entering the environment in wastewater effluents, may also pose threats to human health, aquatic life and wildlife. It thus entails environmental and health hazards and, consequently, must immediately be conveyed away from its generation sources and treated appropriately before final disposal (Hasan and Nakajima 2010).

### *2.2.3 Overall Situation of Wastewater in Developing Countries*

Because of the rapid population growth, economic development, urbanization, and shortage of stringent environmental protection regulations, many domestic and industrial wastewaters have been discharged into natural water bodies without sufficient treatment, which led to serious pollution situation of the surface water supplies in developing countries. Domestic and storm water in both cities and villages are discharged into open drains which finally ends up in the rivers without treatment. Wastewater form kitchen and other parts of homes are directed to nearby open drains (where drains are available) or onto the bear ground. Due to unaffordable cost of construction, most of the drains in the towns and cities are open as a result they are misused, sometimes serving as defecating sites for homes without adequate toilet facility. Industrial wastewater in developing countries is usually generated from food processing, textile, leathers, chemical & pharmaceuticals and mining industries. Few of them have full wastewater treatment plant and most of these industries empty their wastewater into nearby drains without or only by primary treatment (Hasan and Nakajima 2010).

Fig: 2-2 illustrates about some examples of the wastewater treatment scenarios. In Fig: 2-2 (a), from houses, only black water or black water and Greywater both are allowed to go to septic tank as on-site treatment and then after septic tank, permeant are set off to soakage-pit for groundwater infiltration. In the case of Fig: 2-2 (b) there is no soakage-pit. After septic tank, permeant are directly dispose to surface drain for ultimate dispose to nearby river or surface water courses. Or after septic tank, permeant are disposed into an open ditch for groundwater infiltration. In Fig: 2-2 (c), from houses black water from toilet are allowed to septic tank for treatment but greywater without any treatment are directly disposed to surface drain which finally goes to nearby river or other surface water courses, or openly disposed into a ditch to infiltrate the groundwater. All the above cases point up that, groundwater or surface water sources become polluted by any means in the end, which is alarming and need to notice. These phenomena are also intensifying the fresh water scarcity problems. Therefore it is necessary to introduce a low-cost, sustainable and effective technology with least maintenance which can be easily applicable in developing countries.

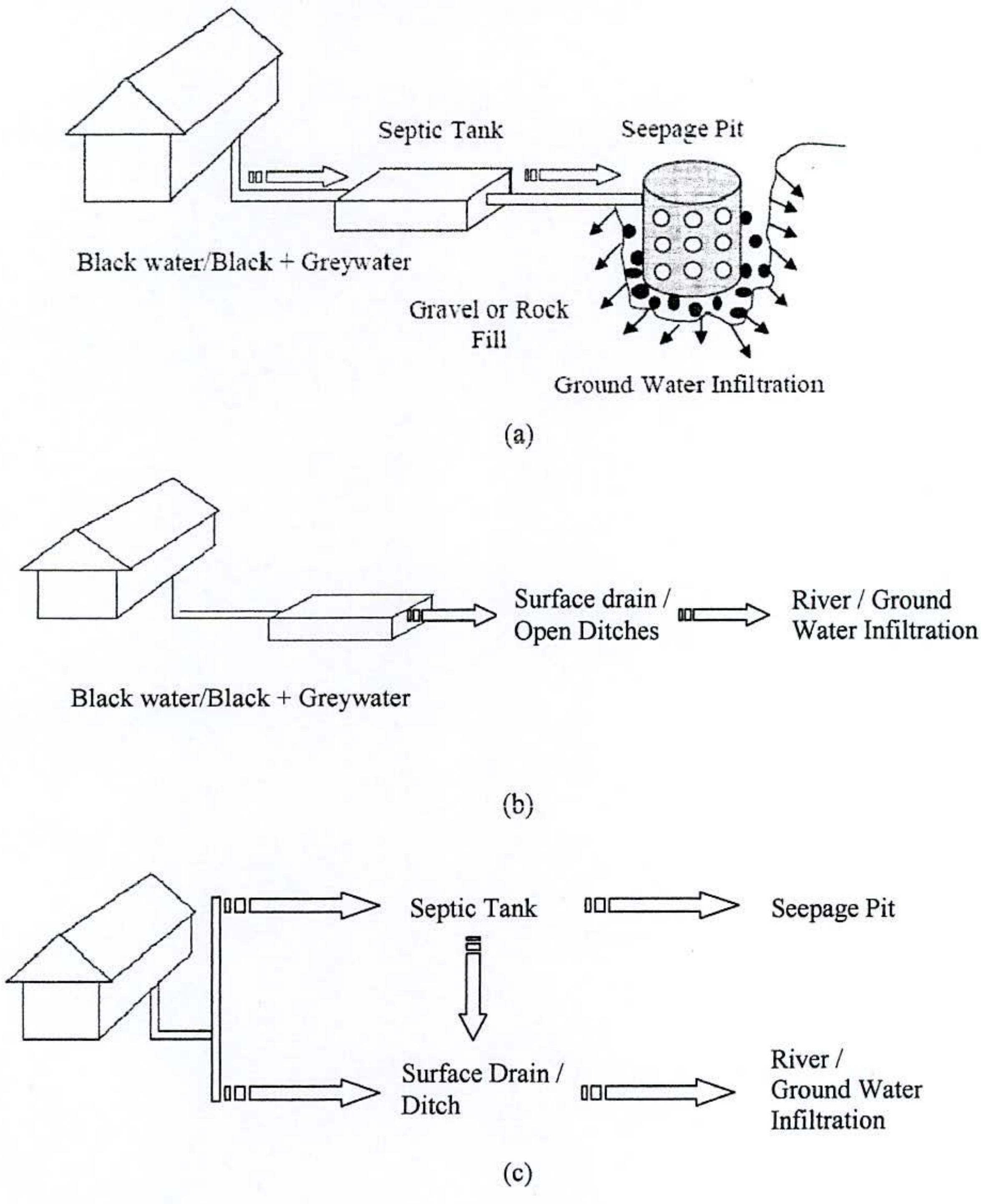



Fig: 2-2 (a-c) Examples of wastewater situation in developing countries

### *2.2.4 Wastewater Treatment Options in Developing Countries*

Wastewater treatment approaches vary from the conventional centralized system to the entirely decentralized and cluster systems.

#### *2.2.4.1 On Site (Decentralized) System*

The system in which wastewater is managed: collected, treated and disposed/reused at or near the point of generation is known as Decentralized wastewater treatment. Thus, it is also referred to as on-site management. According to the United States Environmental Protection Agency's (USEPA) study findings, decentralized wastewater management systems are appropriate for low-density communities and varying site conditions and are more cost-effective than centralized systems. They may include the use of conventional septic systems, advanced designs of on-site systems and cluster or other land-based systems. Yet, the effectiveness of the decentralized approach depends on the establishment of a management program that assures the regular inspection and maintenance of the system. Collection, treatment and disposal are three basic components of any wastewater management system of which collection is the least important for treatment and disposal of wastewater. Nonetheless, collection costs more than 60 percent of the total budget for wastewater management in a centralized system, particularly in small communities with low population densities. Decentralized systems keep the collection component of the wastewater management system as minimal as possible and focus mainly on necessary treatment and disposal of wastewater. While sustainable development includes a wide range of criteria including environmental, technical and socio-cultural factors; economics is the most important criterion in decision making in most developing countries. Decentralized wastewater management is being progressively considered because it is less resource intensive and more ecologically sustainable form of sanitation.

The decentralized systems can be applied on different scales. It can be applied to (1) individual households; (2) a cluster of homes; (3) a neighborhood; (4) public facilities; (5) commercial area; (6) industrial parks; and (7) small portions of large communities. There are decentralized systems that combine new technology and advanced treatment methods to treat effluent to a high standard, making wastewater acceptable for reuse in gardens, for firefighting purposes and homes as well. The available systems can be grouped into different categories. These are the tanks systems, the pond system and filter system. The tank systems are made up of Septic, Imhoff and Baffled tanks. The pond system talks about the duckweed, facultative pond and waste stabilization ponds (Hasan and Nakajima 2010).

The simple septic tank system is the most commonly known primary treatment method for onsite wastewater treatment because of its considerable advantages. Septic tanks remove most Settleable solids and function as an anaerobic bioreactor that promotes partial digestion of organic matter. Their main cause of failure is the unsuitability of the soil and the site characteristics. The conventional onsite wastewater treatment systems are not effective in removing nitrate and phosphorus compounds and reducing pathogenic organisms. As such, these systems can be used prior to further treatment and disposal. The simple septic tank system could be modified to provide advanced primary treatment of wastewater. The result of the modification would be a septic tank with an effluent filter vault or a septic tank with attached growth. The filter is the additional component for the former septic tank. This filter prevents some solids from entering the effluent and consequently clogging the treatment system as a whole. As for the latter, it is mainly an aerobic system used where the standard anaerobic septic tanks are not a good option. They are primarily used in places where the soil is poor, the groundwater is high, the land available is small or the site is sensitive (May et al. 2008).

The Imhoff tank is another primary treatment method that can accommodate higher flow rates than the septic tank, but it is less common (May et al. 2008).The presence of baffle wall prevents up flow of foul sludge particles from mixing with the effluent and as a result, the effluent remains fresh and odorless. This system is inexpensive and simple to operate and maintain. Yet, sludge may cause an odor problem if kept untreated for a long time (May et al. 2008). Baffled tanks system is an improvement of the septic tank. It consists of a settling tank followed by series of up flow chambers. The process of treatment is anaerobic degradation of suspended and dissolved solids. It has a high treatment efficiency compared to septic tank. Treatment with the filter system is similar to the baffled with filter media in some of the tanks. In addition, anaerobic condition is kept throughout the system (Hasan and Nakajima 2010).

*2.2.4.2 Off'site (Centralized) system*

Conventional or centralized wastewater treatment systems involve advanced collection and treatment processes that collect, treat and discharge large quantities of wastewater. Thus, constructing a centralized treatment system for small rural communities or peri-urban areas in low income countries will result in burden of debts for the populace (May et al. 2008). Centralized wastewater treatment system consists of: (1) centralized collection system (sewers) that collects wastewater from many wastewater producers: households, commercial areas, industrial plants and institutions, and transports it to (2) centralized wastewater treatment plant in an off-site location outside the settlement and (3) disposal/reuse of the treated effluent, usually far from the point of origin. Thus, it is also referred to as off-site management. This strategy was developed in the middle of the nineteenth century and it is connected to the development of urbanization and urban life style, as big concentrations of people resulted in more wastewater generated locally.

Within the framework of the centralized strategy, few treatment technologies can be applied. Ranging from simple screening and settling operations to sophisticated biological and chemical operations - many technologies exist. Basically, two main approaches for wastewater treatment can be identified: intensive and extensive.

Intensive treatment is the most common approach in the industrialized countries with Activated Sludge as the conventional technology. This conventional treatment is based on intensive biological treatment to remove pollutants, in relatively short time and confined space. Additional advanced treatment can be added such as disinfection unit (chlorination, ozonation, UV) and removal of nutrients (N and P), depends on the disposal/reuse requirements. These intensive technologies require smaller space area than the extensive technologies and thus have financial benefits especially in densely populated urban areas where land value is high. In addition, they can reach very high treatment efficiencies. However, they are energy intensive, require highly skilled manpower (for design, construction, operation and maintenance), and require large amount of capital for both construction and operation (Hasan and Nakajima 2010).

Extensive treatment (also referred to as natural treatment or ecological engineering) includes methods such as lagoons, stabilization ponds, and constructed wetlands. These are non-mechanical biological treatment systems in which natural processes of dissolution occur. The design of these "natural" systems is based on the stimulation of self-purification of water bodies or on the stimulation of natural biological processes. These systems are simple in operation and maintenance and have relatively low construction and operation costs. Their biggest disadvantage is that they have substantially greater land area requirements and thus they are only feasible when land is available and land prices are sufficiently low. In arid and semi-arid areas, however, where the effluent can be reused for irrigation, storage capacity is needed anyway in order to regulate between wastewater "production" which occurs throughout the year and effluent demand for irrigation which occur only through the dry summer months. Thus, ponds and lagoons can serve this need as well. These processes are well established and can fit to low-income rural communities. Most of them provide adequate treatment in terms of removal of organic matter, but some fail in removal of nutrients. Centralized systems are out of sight and hence, require less public participation and awareness. However, to collect and treat the wastewater, centralized wastewater treatment requires pumps and piping materials and energy, therefore increasing the cost of the system (May et al. 2008).

*2.2.4.3 Cluster System*

Cluster System can be either centralized or decentralized, serve more than a single household reaching up to 100 houses or more (May et al. 2008). Contrarily to the onsite systems, piping systems are needed for the cluster systems, yet they are comparatively shorter than those used for the conventional centralized systems. Cluster systems are more appropriate for the highly densely populated areas, having poor soil conditions and unfavorable topographic. Usually cluster systems are considered as a centralized system comparing to the onsite systems. However, a central wastewater system is more centralized than a cluster system.

*2.2.4.4 Issues of concern in developing countries*

Often, the high cost of wastewater treatment and management is a major impediment towards implementing such projects. Governments in developing countries have more pressing needs than wastewater management such as dealing with war and conflicts, health care and food supply. Wastewater management is frequently low on the list of priorities. Many developing countries suffer from political interference in environmental decisions such as site selection and other aspects related to construction and operation. Even the most advanced technology should be supported by the appropriate institutions and enforced legislation to ensure maximum efficiency. The financial support of international organizations and developed countries is essential, yet it is imperative that local conditions are considered to make full use of any aid. Otherwise, there is no point of funding such projects. The adoption of inappropriate technology and failure to take into consideration the local conditions of the targeted community result in project failure that is often blamed on the lack of technical know-how and financial resources. Sometimes millions are spent on construction and a few dollars on gathering reliable design data. Replication of successful projects is beneficial but the system should be adjusted to the local conditions, especially climatic conditions. More often than not, the low-cost technology is chosen without any other consideration. Rural areas in developing countries cannot meet current and future sanitation requirements with just one funded project. A comprehensive and long-term strategy that requires extensive planning and implementation phases is vital for sustainable wastewater management.

Given the huge differences between developed and developing countries in political structures, national priorities, socio-economic conditions, cultural traits, and financial resources, adoption of developed country's strategies for wastewater management is neither appropriate nor viable for developing countries. Considering the limitations of external and domestic financial resources in developing countries, it will be necessary to develop new innovative financial schemes. Besides, public awareness relating to the extent of adverse health impacts as a result of improper sanitation is minimal in these countries. Therefore, environmental education as well as public awareness and participation primarily of resource users should be given high priority to achieve sustainability. Providing local people with access to resources, education and information necessary to influence environmental issues that affect them is a necessity (May et al. 2008).

### 2.2.5 *Wastewater Reclamation and Water Reuse in Developing Countries*

It is important to understand the terminology used in the area of water reclamation and reuse. Wastewater reclamation means the treatment or processing of wastewater to make it reusable whilst water reuse is the use of treated wastewater for beneficial purposes such as agricultural irrigation and industrial cooling. Reclaimed water is a treated effluent suitable for an intended water reuse application. In addition, direct water reuse requires the existence of pipes or other conveyance facilities for delivering reclaimed water. Indirect reuse is discharge of an effluent to receiving water for assimilation and withdrawals downstream. In contrast to direct water reuse, water recycling normally involves only one use or user and the effluent from the user is captured and redirected back into that use scheme. In this context, water recycling is predominantly practiced in industry. Ultimately, as the treated water quality approaches that of unpolluted natural water, the practical benefits of water reclamation and reuse are evident. As more advance technologies are applied for water reclamation, such as carbon adsorption, advance oxidation, and reverse osmosis, the quality of reclaimed water can exceed conventional drinking water quality by most parameter, and it is termed repurified water.

To solve the worlds worsening water crisis, the need and benefit of water reclamation and reuse from sewage are assessed. Water reclamation and reuse are being considered as an unavoidable stage not only for alleviating the contradiction of growing water demand in connection with limiting water resources, but also for protecting existing water sources being polluted. Water reclamation and reuse provides a unique and viable opportunity to augment our water supplies. As a multi disciplined and important element of water resources development and management, water reuse can help to close the loop between water supply and wastewater disposal. Water reuse accomplishes two fundamental functions; (1) the treated effluent is used as a water resource of beneficial purposes, and (2) the effluent is kept out of streams, lakes and beaches; thus reducing pollution of surface water and groundwater. The foundation of water reuse is built upon the principle; (1) providing reliable treatment of wastewater to meet strict water quality requirements for the intended reuse application, (2) protecting public health and (3) gaining public acceptance. Whether water reuse is appropriate for specific locale depends upon careful economic considerations, potential uses for the reclaimed water, and the relative stringency of waste discharge requirement

The dominant water applications for water use include agricultural irrigation, landscape irrigation, ground water recharge, industrial reuse, environmental and recreational uses, non-profitable urban uses, and indirect and direct potable reuse. The relative amount of water used in each category varies locally and regionally due to differences in specific water use requirements and geopolitical constraints (Guo and Ngo 2008).

Due to lack of management, treatment facilities and flexibility of environmental regulations most of the municipal wastewater generated in developing countries is discharged into aquatic systems without treatment, making the receiving body unfit for its desired use in the years to come. Inadequate treatment facilities for sewage have deteriorated the water quality of aquatic resources. The situation is much worse because most of the cases wastewater is directly discharged into the nearby surface water. So, there is an urgent need to plan strategies and with equal importance for the development of wastewater treatment facilities and reuse. The future of urban water supplies for potable uses will grossly depend on efficient wastewater treatment systems and reuse, as the treated wastewater of upstream urban centers will be the source of water for downstream cities. To fight growing water stress, reclamation and reuse of treated wastewater for various day-to-day uses except for drinking purpose is necessary. Reuse of wastewater in developing countries may bridge the gap between supply and demand of water in the future (Hasan and Nakajima 2010).

## 2.3 DETAILS ABOUT GREYWATER

### *2.3.1 What is Greywater?*

Greywater includes all household wastewater except toilet waste. It can be a valuable water resource, and an increasing number of householders are recycling greywater for a variety of purposes. However, care must be taken with this practice as it can carry health and environmental risks (Environmental Health Unit Report 2003).

Different researcher have different opinion about the definition of Grey water some researcher want to include Kitchen waste as Grey water and others wants to exclude kitchen waste as Grey water. According to Jefferson Grey water arises from domestic washing operations. Include waste from hand basins, kitchen sinks and washing machines, but specifically exclude black water from toilets, bidets and urinals. On the other hand according to Christova Boal Greywater is defined as all wastewater from non-toilet plumbing fixtures around the home. The use of kitchen greywater is not recommended as a greywater source. NSW Heatlh report suggest that Greywater is wastewater which is not grossly contaminated by faeces or urine, i.e. the wastewater arising from plumbing fixtures not designed to receive human excrement or discharges and includes bath, shower, hand basin, laundry and kitchen discharges (Morel 2005).

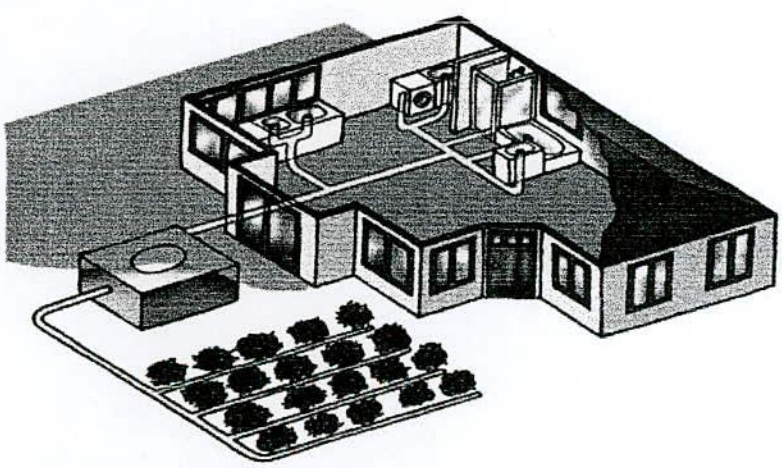


Fig: 2-3 Source of greywater from household (Water Corporation Report 2008)

Wastewater from kitchen sinks and dish washing is sometimes excluded from greywater sources because of the potential to introduce microbial contaminants and/ or oils and greases that would negatively impact the receiving environment. But in most sources kitchen wastewater is also contained in greywater.

Wastewater from the non-toilet plumbing fixtures around the households, or any office buildings, or etc is known as Greywater. So, it corresponds to wastewater from baths, showers, hand basins, washing machines, dishwashers and kitchen sinks, but excludes streams from toilets and is generally viewed as significantly less polluted than blackwater. Some authors exclude kitchen wastewater from the other greywater streams. Fig: 2-4 illustrates the domestic wastewater fraction and major greywater sources. Many previous investigations indicated that kitchen greywater was highly polluting, putrescible and contains many undesirable compounds (e.g., cooking oils). Since this water accounts for only about 5% of the average household consumption, its use as a greywater source is almost negligible and sometimes not recommended. The combined greywater from bathroom, showers and hand basins sources for the average family accounts for about 26% of total household consumption. Greywater from showers and hand basins normally contains soaps, shampoos, body-fats, hair, soils, and occasionally lint fabric fibers, skin, urine and faeces. The latter is more prevalent where the family comprises either very young children or the incontinent elderly. In addition, greywater may contain household cleaning products and wastes. Typically the average household uses about 15% of its water consumption in washing machines. Clothes washing detergents and bleaches, plus on occasion oils, paints and solvents, should be added to the list of constituents found in greywater from washing machines. Greywater constitutes the largest proportion of the total wastewater flow from households in terms of volume. Typically, 50-80% of the household wastewater is greywater. The published literatures indicated that the typical volume of greywater varies from 90-120 l/p/d depending on lifestyles, living standards, population structures (age, gender), customs and habits, water installations and the degree of water abundance. However the volume of greywater in low income countries with water shortage and simple forms of water supply can be as low as 20-30 Ipcd (Hasan and Nakajima 2010).

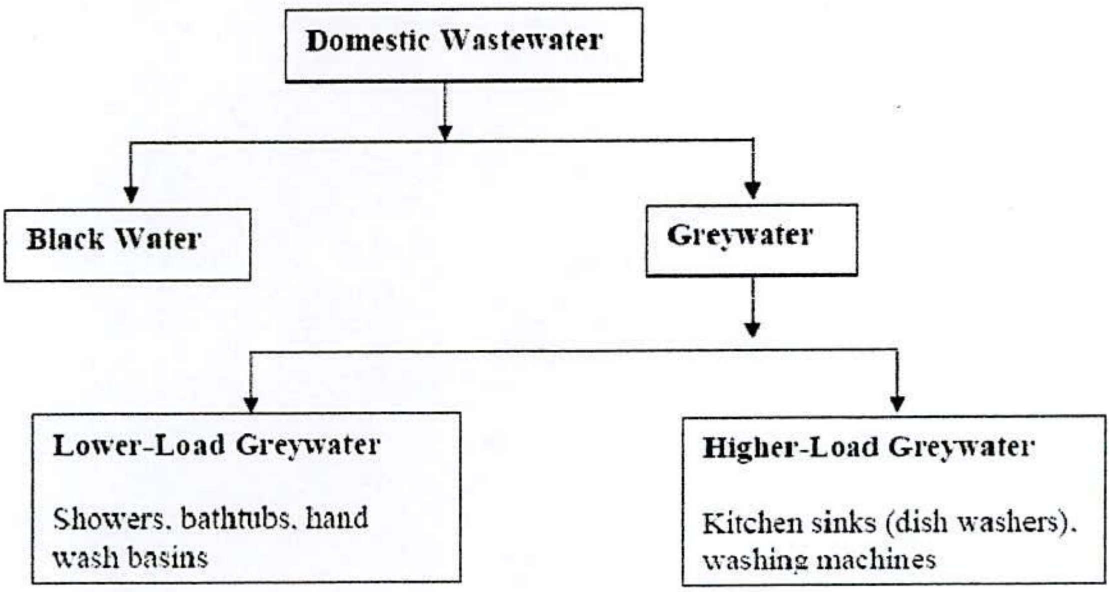



Figure: 2-4 Differentiation of household wastewater with major greywater sources

### *2.3.2 Greywater Composition and Characteristics*

Greywater exhibits significant variations in composition; within a specific sample group, within an individual showering or bathing operation and also between reported schemes. Greywater is a reflection of the household activities and so its characteristics are strongly dependent on living standards, social and cultural habits, number of household members and the use of household chemicals. Generally greywater is divided in four greywater categories based on its origin: bathroom, laundry, kitchen and mixed origin (Morel 2005).

### 2.3.3 Parameters affecting the characteristics of greywater

The composition of greywater depends on several factors, including sources and installations from where the water is drawn:

- Quality and type of the water supply (groundwater well or piped water)
- Type of distribution net for drinking water
- Type of distribution net for greywater (because of leaching from piping, chemical and
- Biological processes in the biofilm on the piping walls)
- Activities in the household (lifestyle, custom and use of chemical products)
- Installation from which greywater is drawn (kitchen sink, bathroom, hand basin or laundry wash)
- Type of source: household or industrial uses like commercial laundries
- Geographical location
- Demographics and level of occupancy
- Quantity of water used in relation to the discharged amount of substances

### 2.3.4 Water sources

Greywater can be divided into several groups, according to the source of the greywater. In this semester work the structure shown in Table 2-1 is used. Table: 2-1 gives a first overview of the general characteristics of the three main greywater source types.

Table: 2-1 Summary of untreated greywater characteristics from each source

| Water source | Characteristics |
|---|---|
| Laundry | *Microbiological:* variable thermotolerant coliform loads<br>*Chemical:* sodium, phosphate, boron, surfactants, ammonia and nitrogen from soap powders and soiled clothes<br>*Physical:* high in suspended solids, lint and turbidity<br>*Biological:* high in biochemical oxygen demand (BOD) |
| Bathroom | *Microbiological:* lower levels of thermo tolerant coliforms<br>*Chemical:* soap, shampoo, hair dyes, toothpaste and cleaning chemicals<br>*Physical:* high in suspended solids, hair, and turbidity<br>*Biological:* lower levels of concentrations of biochemical oxygen demand |
| Kitchen | *Microbiological:* variable thermo tolerant coliform loads<br>*Chemical:* detergents, cleaning agents<br>*Physical:* food particles, oils, fats, grease, turbidity<br>*Biological:* high in biochemical oxygen demand |

Source: (Morel 2005).

Normal use of products such as soap, shampoo, toothpaste, shaving cream, food scraps, cooking oils, dishwashing detergents, laundry detergents, hair and lint appears to do no harm to garden soils and plants if greywater is used for garden irrigation.

The most significant pollutants of greywater are powdered laundry detergents. These contain high salt concentration and in many cases still contain phosphorus, and are often very alkaline. Long term garden reuse of laundry water containing high salt and phosphorus concentrations can lead to salt accumulations in the soil and stunting of plants with low phosphorus tolerance. Regions with regular rainfall may not suffer salt build-ups due to leaching of salts from soil after rain. There are several alternatives to using powdered laundry detergents. These include liquid detergents (which are generally much lower in salt content, e.g. Ark), pure soap flakes (e.g. Lux soap flakes) or ceramic disks (e.g. Tri-Clean laundry disks). High strength cleaners should be avoided in the home, as they are often toxic to both people and the environment. If caustic cleaners are washed down the drain, they are likely to kill beneficial treatment bacteria in soils if greywater is reused for onsite garden irrigation.

### 2.3.5 Chemical parameters

General features of greywater are that it contains lower concentrations of organic matter, of some nutrients (e.g. nitrogen, potassium) and microorganisms than blackwater. But the concentrations of phosphorus, heavy metals and xenobiotic organic pollutants are around the same levels. The main sources for these pollutants are chemical products such as laundry detergents, soap, shampoo, toothpaste and solvents.

#### 2.3.5.1 General Hydrochemical parameters

The content of biological oxygen demand (BOD) and chemical oxygen demand (COD) indicates the risk of oxygen depletion due to the degradation of organic matter during transport and storing and the risk of sulphide production, causing bad smell. Most of the COD derives from household chemicals like dishwashing and laundry detergent, so that COD in greywater is expected to be at the same levels as the COD in household wastewater.

Table: 2-2 Measured values of general hydrochemical parameters and standard wastewater parameters in greywater

| Chemical properties | Laundry | Bathroom | Kitchen |
|---|---|---|---|
| pH | 9.3- 10 | 5- 8.1 | 6.3- 7.4 |
| EC [μS/cm] | 190- 1400 | 82- 20'000 | |
| Alkalinity [mg/l] | 83-200 as $CaCO_3$ | 24- 136 as $CaCO_3$ | 20.0- 340.0 |
| Hardness [mg/l] | - | 18- 52 as $CaCO_3$ | - |
| $BOD_5$ (mg/L) | 48-380 | 76- 200 | |
| COD [mg/l] | 375 | 280 up to 8000 | 26- 1600 |
| TOC [mg/l] | 100-280 | 15- 225 | - |
| DO [mg/l] | - | 0.4- 4.6 | 2.2- 5.8 |
| Sulfate [mg/l] | - | 12- 40 | - |
| Chloride (as Cl) [mg/l] | 9.0-88 | 3.1- 18 | - |
| Oil and grease [mg/l] | 8.0-35 | 37- 78 | - |

Source: (Morel 2005).

2.3.5.2 Nutrients in greywater

Washing detergents are the primary source of phosphates found in greywater in countries that have not yet banned phosphorus-containing detergents. According to Gunther, greywater has a typical N/P ratio of 2, thus far below the N/P ratio of around 10 which would be optimal for nutrient uptake by plants. This is very important if greywater is reused for irrigation. Nitrogen then represents the limiting substance, leading to a sub-optimal phosphorus uptake unless the plants can get nitrogen from other sources.

Table: 2-3 Measured values of nutrients in greywater

| Nutrients [mg/l | Laundry | Bathroom | Kitchen sink |
|---|---|---|---|
| Ammonia (NH3-N) | < 0.1- 3.47 | <0.1- 25 | 0.2- 23.0 |
| Nitrate and nitrite as N | 0.10- 0.31 | <0.05- 0.20 | - |
| Nitrate (NO3-N) | 0.4- 0.6 | 0- 4.9 | - |
| Phosphorus as PO4 | 4.0- 15 | 4- 35 | 0.4- 4.7 |
| Nitrogen as total | 1.0- 40 | 4.6- 20 | 15.4- 42.8 |
| Tot- N | 6- 21 | 0.6- 7.3 | 13- 60 |
| Tot- P | 0.062- 57 | 0.11- 2.2 | 3.1- 10 |

Source: (Morel 2005).

2.3.5.3 Ground elements in greywater

Grey water contains various Ground elements such as Calcium (Ca), Magnesium (Mg), Silicon (Si) etc. Table: 2-4 shows the values of ground elements in grey water.

Table: 2-4 Measured values of ground elements in greywater

| Nutrients [mg/l] | Laundry | Bathroom | Kitchen sink |
|---|---|---|---|
| Aluminium (Al) | <0.1- 21 | <1.0A- 1.7 | 0.67- 1.8 |
| Barium (Ba) | 0.019 | 0.032 | 0.018- 0.028 |
| Boron (B) | <0.1- 0.5 | <0.1 | - |
| Calcium (Ca) | 3.9- 14 | 3.5- 21 | 13- 30 |
| Magnesium (Mg) | 1.1- 3.1 | 1.4- 6.6 | 3.3- 7.3 |
| Potassium (K) | 1.1- 17 | 1.5- 6.6 | 19- 59 |
| Selenium (Se) | <0.001 | <0.001 | - |
| Silicon (Si) | 3.8- 49 | 3.2- 4.1 | - |
| Sodium (Na) | 44- 480 | 7.4- 21 | 29- 180 |
| Sulphur (S) | 9.5- 40 | 0.14- 3.3 | 0.12 |

Source: (Morel 2005).

Laundry wastewater was found to contain elevated sodium levels compared to other types of greywater. The sodium in the laundry wastewater may be caused by the use of sodium as counterion to several anionic surfactants used in powder laundry detergent and the use of sodium chloride in ion-exchangers. Products containing boron should be avoided as it is toxic to plants even in small amounts (Morel 2005).

2.3.5.4 Heavy metals in greywater

Plastic and metal piping both release compounds, such as Xenobiotic organic compounds and heavy metals to the water supply and greywater. The contents in greywater are dependent from three sources: 1) Chemical products, resulting from water use 2) The type of pipes used for transportation 3) The quality of the water supply when it leaves the water works.

Table: 2-5 Measured values of heavy metals in greywater

| **Heavy metals [μg/l]** | **Laundry** | **Bathroom** | **Kitchen sink** |
|---|---|---|---|
| Arsenic (As) | 0.001- <0.038 | 0.001- <0.038 | <0.038 |
| Cadmium (Cd) | <0.01- <0.038 | <0.01 | <0.007 |
| Chromium (Cr) | <0.025 | 0.036 | <0.025-0.072 |
| Cobalt (Co) | <0.012 | <0.012 | <0.012 |
| Copper (Cu) | <0.05-0.27 | 0.06-0.12 | 0.068-0.26 |
| Iron (Fe) | 0.29-1.0 | 0.34-1.4 | 0.6-1.2 |
| Lead (Pb) | <0.063 | <0.063 | <0.062-0.14 |
| Manganese (Mg) | 0.029 | 0.0003 | <0.0003-0.00047 |
| Mercury (Hg) | 0.0029 | <0.0003 | <0.0003-0.00047 |
| Nickel (Ni) | <0.025 | <0.025 | <0.025 |
| Silver (Ag) | <0.002 | <0.002 | <0.002-0.013 |
| Zinc (Zn) | 0.09-0.44 | 0.01-6.3 | 0.0007-1.8 |

Source: (Morel 2005).

### 2.3.6 Physical parameters

**Temperature:** Greywater temperatures are often higher than the temperature of the water supply due to hot tap water used for personal hygiene and laundry. High temperature favours microbial growth and leads to precipitation of e.g. calcite in supersaturated waters.

**Colour:** Color is another important concern in the treatment of any types of wastewater.

**Turbidity:** Turbidity is one of the basic concerns in the treatment of any types of wastewater. Turbidity occurs in most wastewater due to the presence of suspended clay, silt, finely divided organic and inorganic matters, plankton (algae) and micro-organisms.

**Content of suspended solids:** The measurements of suspended solids give information about the content of particles and colloids that could cause clogging of soil pores and installations. Generally highest values are found in greywater generated in kitchen sinks and washing machines (Morel 2005).

Table: 2-6 Physical properties of greywater

| Physical properties [mg/l] | Laundry | Bathroom | Kitchen sink |
|---|---|---|---|
| Color (Pt/Co units) | 50-70 | 60-100 | |
| Suspended solids | 79-280 | 48-120 | 134-1300 |
| TDS | | 126-175 | |
| Turbidity [NTU] | 14-296 | 20-370 | |
| Temperature [ °C] | 28-32 | 18-38 | |

Source: (Morel 2005).

### 2.3.7 Microbiological parameters

Generally there is very little known about the presence of microorganisms in greywater. Four types of pathogens may be present: viruses, bacteria, protozoa and intestinal parasites (helminths). It can, however, be expected, when evaluating microbiological parameters, that microbial populations of faecal origin in greywater cause the major health risk.

Pathogenic viruses, bacteria, protozoa and helminths (Helminth: Worm that is parasitic on the intestines of vertebrates especially roundworms and tapeworms and flukes) escape from the bodies of infected persons in their excreta and may be passed onto others via exposure of wastewater. These microorganisms may be introduced into greywater by hand-washing after using the toilet or changing nappies, baths, washing babies and small children, and from uncooked food products in the kitchen.

The available evidence indicates that almost all excreted pathogens can survive in soil and ponds for a sufficient length of time to pose potential risks to farm and pond workers. Pathogen survival on crop surfaces is much shorter than that in soil, as the pathogens are less well protected from the harsh effects of sunlight and desiccation. In some cases, however, survival times can be long enough to pose potential risks to crop handlers and consumers, especially when they exceed the length of crop (mainly vegetable) growing cycles (Morel 2005). If the greywater is reused for irrigation, parasitic protozoa and helminths will not be a problem in relation to groundwater contamination due to their large size, which results in their removal by filtration as the water percolates under gravity. Bacteria and virus contamination of groundwater may, on the other hand, be a serious problem.

Table: 2-7 Measured values of microbiological parameters in greywater

| Microbiological parameters | Laundry | Bathroom | Kitchen sink |
|---|---|---|---|
| Campylobacter spp. | n.d | n.d | |
| Candida albicans | | n.d | |
| Colifager PFU/ml | 102 x 103 | 388 x 103 | <3 |
| Cryptosporidia | n.d | n.d | |
| Eschericia coli* | $8.3 \times 10^6$ | $3.2 \times 10^7$ | $1.3 \times 10^5 - 2.5 \times 10^8$ |
| Faecal coliforms* | $9\text{-}\ 1.6 \times 10^4$ | $1\text{-}\ 8 \times 10^6$ | |
| Faecal streptococci* | $23\text{-}\ 1.3 \times 10^6$ | $1\text{-}\ 5.4 \times 10^6$ | $5.15 \times 10^3 - 5.5 \times 10^8$ |
| Faecal streptococci* | n.d | n.d | |
| Heterotrophic bacteria* | | Up to $1.8 \times 10^6$ | |
| Pseudomonas aeruginosa | | n.d | |
| Salmonella spp. | n.d | n.d | |
| Staphylococcus aureus** | | $1\text{-}\ 5 \times 10^5$ | |
| Thermotolerant coli* | $8.4 \times 10^6$ | Up to $8.9 \times 10^6$ | $0.2 \times 10^6 - 3.75 \times 10^8$ |
| Total coliform* | $56\text{-}\ 8.9 \times 10^5$ | $70\text{-}\ 2.8 \times 10^7$ | |
| Total bacterial population (cfu/100ml) | | $300\text{-}\ 6.4 \times 10^8$ | |

*** = per 100ml; ** = per ml** Source: (Morel 2005).

Organisms that are relatively resistant to disinfection will prevail longer within the system. The spores can be used as indicators of cumulative faecal contamination. Many species of helminths can infect humans but they cannot multiply within the host, with the exception of *Strongyloides*. *Legionella* poses a specific threat since it can be spread by aerosols and can be inhaled during surface irrigation or toilet flushing. Due to the fact that it is resistant to water treatment processes, it can become a serious problem. Urine is generally sterile and harmless but some infections may cause pathogens to be passed into the urine. The three principal infections are urinary schistosomiasis (*Schistosoma haematobium*), typhoid (*Salmonella typhi*) and leptospirosis *(Leptospira)* (Morel 2005).

### *2.3.8 Reuse of Greywater*

Water is an essential resource for life. In today's development-oriented world it has become more essential in various fields (Kim and Cho 1993). With ever-increasing urbanization and diversification of lifestyles and with the rise in population growth water demand is increasing in many regions around the world. This makes water a valuable resource in the coming years. In recent years not only the threats of improper greywater management have been recognized; there is an increasing international recognition that greywater reuse, if properly done, has a great potential as alternative water source for purposes such as irrigation, toilet flushing and others (Morel 2005). Today many large urban areas, even in regions that were traditionally considered as water ample (Japan, Europe), suffer from water scarcity. Consequently, interest in wastewater recycling has been raised, and continuous to be, practiced all over the world for the increase of water demand, water shortage due to low rainfall, economic and environmental issues, and supporting public health protection. Since the increases in water demand also generates increased water production, wastewater, if recycled, is a significant source that could potentially aid problems caused by lack of fresh water (Hasan and Nakajima 2010). Many different reuse options exist for treated greywater: 1) Residential reuse (flushing toilets, hand washing, cleaning, gardening etc.) 2) Irrigation of agricultural areas 3) Industry (washdown, cooling water, makeup water etc.) 3) Discharge into nearby streams, lakes or other water body. The level of treatment necessary depends on how the greywater is to be reused. Greywater reused for toilet flushing or for surface irrigation will need to be well filtered and disinfected, and in some instances, dyed to prevent confusion with potable water. Greywater used for subsurface irrigation may require only coarse filtration because the risk of human and vector contact is reduced. If one plans to install a greywater treatment system, one does best contacting local authorities to learn more about current legislation (Morel 2005).

The most common application for wastewater recycling is agricultural irrigation. However, other options such as industrial, recreational, environmental and urban reuse have been practiced. Potential sources identified for urban reuse are blackwater, greywater , and rainwater. However, at small scale the heavily polluted sources such as washing machines, dishwashers and kitchen sinks tend to be excluded whereas at larger scale all sources are used to maximize water savings. In some cases, mixed rain and greywater also have been used. The main advantage of recycling greywater is that it is a large source with a low organic content. To illustrate, greywater represents upto 70% of total consumed water but contains only 30% of the organic fraction and 9-20% of the nutrients. Moreover, in individual households, it has been established that greywater could support the amount of water needed for toilet flushing and outdoor uses such as car washing and garden watering. For example, in the UK, on average, toilet flushing and outdoor water use represent 41% of total domestic water usage; Greywater from showers, baths, hand basins, laundry and dishwashers correspond to 44% (Table 2-8). Another study revealed that 30% of the total household water consumption could be saved by reusing greywater for flushing toilets (Hasan and Nakajima 2010).

The most commonly described application for grey water reuse is toilet/urinal flushing which can reduce water demand within dwelling by up to 30%. However, grey water has been considered for many other applications including irrigation of lawns at cemeteries, golf courses and college campuses, vehicle washing, fire protection, boiler feed water, concrete production and preservation of wetlands (Jefferson et al. 2004).

Table: 2-8 Domestic water usage

| Use | Fraction of total water demand % |
|---|---|
| Toilet flushing | 35 |
| Wash basin | 8 |
| Shower and Bath | 20 |
| Laundry | 12 |
| Dishwasher | 4 |
| Kitchen sink | 15 |
| Outside use | 6 |

*Source: Environment Agency, UK.*

Reuse of greywater from bathrooms has been successfully used in Germany where it has been shown that it is technically feasible and health requirements can be met. Substantial volumes of water (15-55 Ipcd) can be reused and a dual system is possible. A review of the current water demands in large buildings revealed that not only greywater from bathrooms but also greywater from other sources (washing machine etc.) is needed to provide sufficient recycled water for non-potable uses. In a larger scale, other greywater applications have been considered, for example irrigation of parks, schools yards, cemeteries and golf courses, vehicle washing, fire protection, boiler feed water, air conditioning and concrete production and preservation of wetlands. Groundwater recharge by infiltration is another alternative way of handling greywater and thereby makes a shortcut in the urban hydrological cycle.

### *2.3.9 Treatment Technologies for Greywater Recycling*

2.3.9.1 General considerations

Depending above all on the economic aspects and required effluent quality (see below), greywater undergoes different degrees of treatment before being reused or disposed. There are usually three degrees of treatment defined.

Primary Treatment: The first step in wastewater treatment is used to remove most materials that float or will settle. Primary treatment removes about 30 percent of the carbonaceous biochemical oxygen demand from domestic sewage.

Secondary Treatment: During the second stage, bacteria consume the organic parts of the waste. Bringing together waste, bacteria, and oxygen accomplish it. This treatment removes floating and settleable solids and about 90 percent of the oxygen-demanding substances and suspended solids. Disinfection is the final stage of secondary treatment.

Tertiary Treatment: The last step consists of an advanced cleaning of wastewater that goes beyond the secondary or biological stage. It is removing nutrients such as phosphorus, nitrogen, and most BOD and suspended solids. Each treatment stage can be accomplished by a certain system. The systems of the different treatment stages can be combined sequentially to obtain the required quality for reuse and disposal (Morel 2005).

Table: 2-9 Classification of systems depending on treatment stage

| Primary treatment | Secondary treatment | Tertiary treatment |
|---|---|---|
| Sedimentation ponds<br>Septic tank<br>Imhoff tank | Aerobic ponds<br>Baffled septic tank<br>Anaerobic / fixed bed filters<br>Trickling filters | Maturation ponds |

2.3.9.2 Primary treatment systems

a) Sedimentation ponds:

Sedimentation/stabilization ponds shown in Figure: 2-5 can be used as first faecal sludge (FS) treatment step when land availability is not a problem. They can receive fresh FS. The raw FS is loaded onto the pond; solids settle and accumulate at the bottom of the pond while the clarified liquid flows out of the pond. Ponds are usually designed with a high retention time. Therefore, not only sedimentation but also anaerobic degradation contributes to the improvement of the effluent quality. It is assumed that large sedimentation ponds are more appropriate for the treatment of fresh public toilet sludge or a FS mixture containing a high amount of public toilet sludge. The reason is that the higher retention time would allow for partial stabilization of the fresh FS and thus reduce the negative impact of intense bubbling on particles settling. Sedimentation ponds have longer sediment removal intervals than septic tanks. Sludge is removed once, twice or more often per year. At least two parallel ponds are required to assure continuous operation. The sediment is removed after removal of the liquid column and a period of drying. Both liquid and sediments require further treatment. Sludge sediments to the bottom of the pond while the clarified liquid flows out of the pond. The main disadvantages is high land requirement and the main advantages are 1) Simple operation 2) Cheap construction 3) Good sedimentation properties and 4) Good stabilization capacities

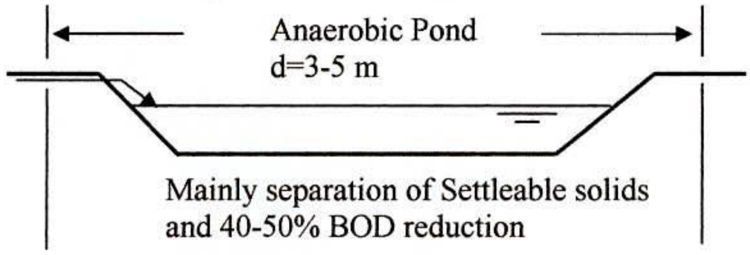



Figure: 2-5 Schematic of a sedimentation pond.

b) Septic tank:

Septic tanks (Figure: 2-6) are the most common small scale and decentralized treatment plants worldwide. They consist of an underground sedimentation tank having 2 to 3 compartments, in which settled sludge is stabilized by anaerobic digestion. Dissolved and suspended matter leave the tank untreated. They are used for wastewater containing Settleable solids, especially domestic wastewater. The settled sludge must be pumped out periodically. In septic tanks, COD is removed to 25 – 50 %.

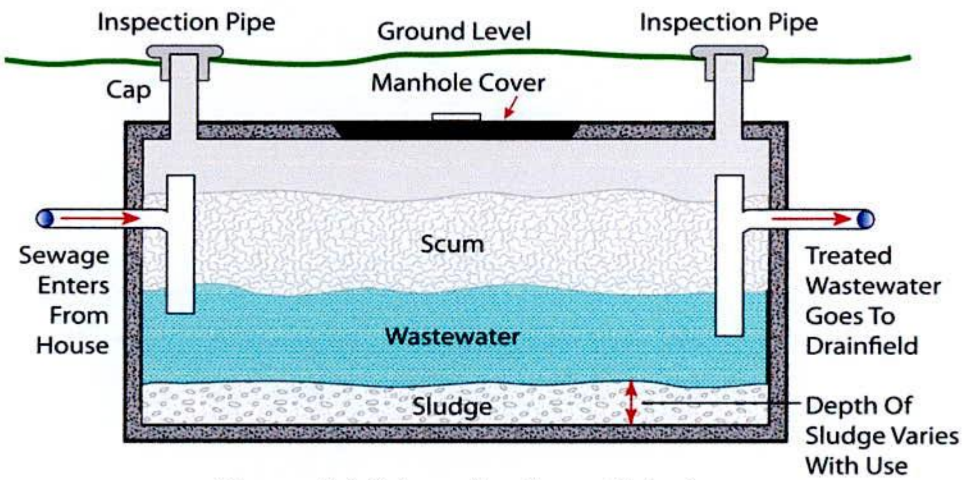



Figure: 2-6 Schematic of a septic tank.

Settleable solids in the wastewater sediment at the bottom of the tank. The sludge is anaerobically digested. Dissolved and suspended matters leave the tank. The main disadvantages are 1) Low treatment efficiency 2) Foul-smelling emissions created by anaerobic digestion. The main advantages of this system are 1) Simple operation 2) Little space requirements (underground) 3) Cost-efficiency regarding treatment

c) Imhoff tanks:

Imhoff tanks (Figure: 2-7) are used for domestic wastewater with flows above 3 m3/d. They separate the fresh influent from sludge and consist of a settling chamber being above a digestion chamber. The volume of the settling compartment should be able to contain 50 l/capita and the digestion chamber 120 l/capita. Baffle walls prevent up – flowing foul sludge particles from getting mixed with the effluent. This way, the effluent remains fresh and odorless. COD is removed to 25 – 50 %.

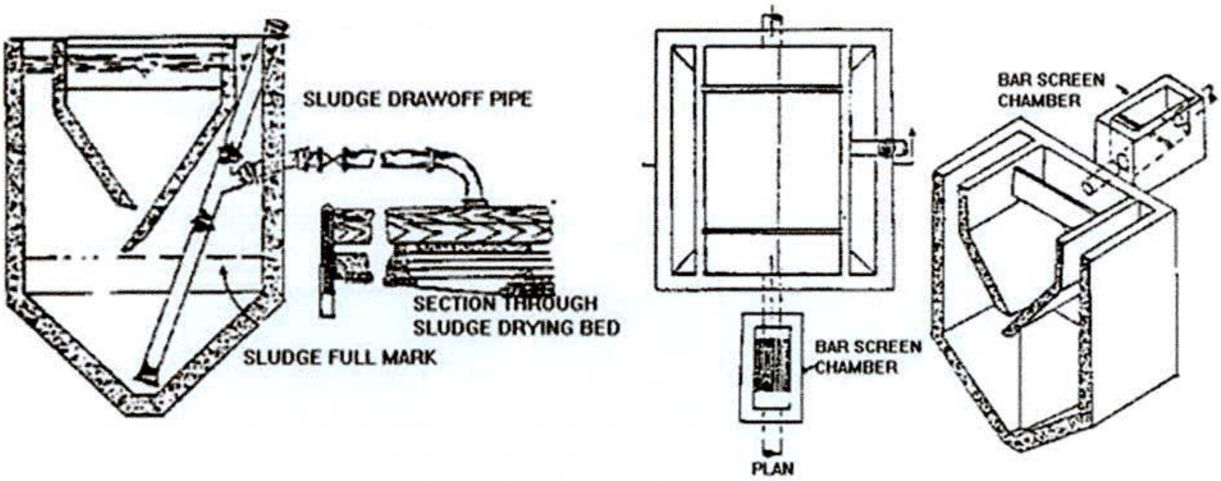



Figure: 2-7 Schematic of an Imhoff tank.

The digestion chamber is in the lower part of the tank and the settling chamber in the upper part. The baffle walls are installed diagonally. The main disadvantages of this system are 1) More complicated than septic tanks 2) Low treatment efficiency and 3) Regular de-sludging. The main advantages of this system are 1) Little space requirements (underground) 2) Odourless effluent 3) Clear separation of the two processes sedimentation and fermentation 4) Durable system.

b) Anaerobic / fixed bed filters:

Anaerobic filters (Fig: 2-9) can be used for pre-settled domestic and industrial wastewater of narrow COD/BOD ratio. Therefore, they can only be used in combination with primary treatment (for example a septic tank). Anaerobic filters can also treat non – Settleable and dissolved solids by bringing them in close contact with active bacteria mass on a filter media. The filter surface should be of 90 to 300 m2 per m3 of treated water and be rough. The tank should contain a volume of 0.5 – 1 m3/capita. The COD removal is about 70 – 90 %. Wastewater flows through a cleaning chamber before passing through a filter media.

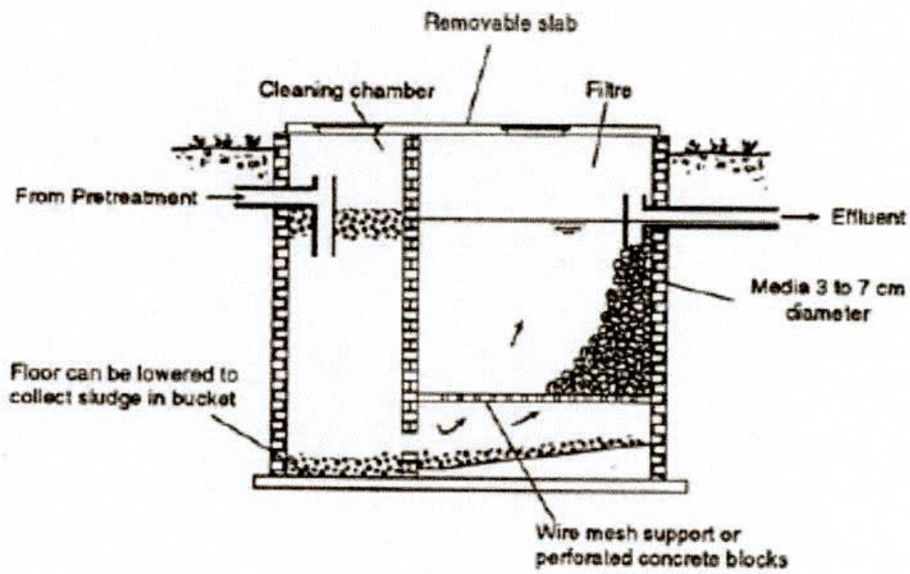



Figure: 2-9 Schematic of an anaerobic tank.

The main disadvantages of this system are 1) High construction costs (filter media) 2) Blockage of filter possible 3) Effluent can smell. The main advantages of this system are 1) Simple and durable system if well constructed and properly pre –treated wastewater enters it. 2) High treatment efficiency 3) Little space requirements (Morel 2005).

c) Trickling filter:

A trickling filter (TF) is a wastewater treatment system that biodegrades organic matter and can also be used to achieve nitrification. The wastewater trickles through a circular bed of coarse stones or plastic material. A rotating distributor (a rotating pipe with several holes across it) evenly distributes the wastewater from above the bed. The microorganisms in the wastewater attach themselves to the bed (also known as the filter media), which is covered with bacteria. The bacteria break down the organic waste and remove pollutants from the wastewater.

When excess nutrients become a concern, it becomes necessary to adapt "conventional" sewage treatment systems to meet the increased oxygen demand placed on receiving waters by high ammonia nitrogen concentrations in wastewater effluents. TFs and other attached-growth processes proved to be well – suited for the removal of ammonia nitrogen by oxidizing it to nitrate nitrogen (nitrification).

The main disadvantages of this system are 1) Additional treatment may be needed to meet strict discharge standards 2) Regular operator attention needed 3) Relatively high incidence of clogging 4) Relatively low loadings required depending on the media 5) Limited flexibility and control in comparison with activated sludge processes 6) Potential for vector and odour problems. The main advantages of this system are 1) Simple, reliable process that is suitable in areas where large tracts of land are not available for a treatment system 2) Effective in treating high concentrations of organic material depending on the type of media used 3) High degree of performance reliability 4) Appropriate for small- to medium-sized communities and onsite systems 5) Ability to handle and recover from shock loads 6) Relatively low power requirements 7) Durability of process elements 8) Level of skill and technical expertise needed to manage and operate the system is moderate

#### 2.3.9.4 Secondary and tertiary treatment systems

a) Constructed wetlands:

This system (Figure: 2-10) is used for the treatment of pre – settled domestic or industrial wastewater with COD < 500 mg/l. Wastewater flows horizontally through a filter, which is permanently soaked with water. Plants grow on the filter media in order to assimilate nutrients. Bacteria in the media degrade solids and soluble BOD to inorganic nutrients (ammonia and phosphorous). The granular media filters out solids. The filter works partly aerobic, partly anoxic and anaerobic. The area needed is approximately 5 m2/capita. The maximum loading rate for wastewater is 30 l/m2d and for organic material is 8 g BOD/m2d. The slope of the impervious liner should be 0.5 – 1 %. Wastewater flows through the soil. Plants growing on the soil assimilate the nutrients of the wastewater and soil bacteria mineralise nutrients.

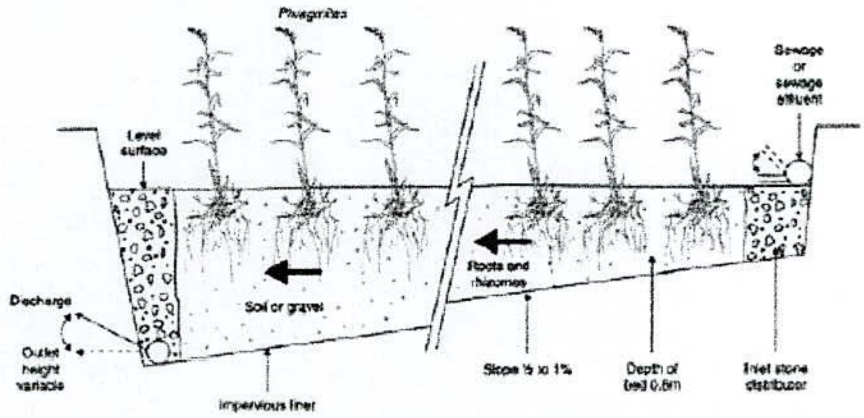



Figure: 2-10 Schematic of a constructed wetland system.

The main disadvantages of this system are 1) High space requirements 2) Costly (gravel) 3) Great care required during construction (pervious liner, etc.) 4) Intensive maintenance during the first 2 years The main advantages of this system are 1) High treatment efficiency, up to 95 % COD removal 2) No wastewater aboveground 3) No nuisance of odour 4) Good nutrient removal (Morel 2005).

b) Pond system:

This system (Figure: 2-11) consists of a series of artificial ponds comprising an anaerobic pond (see below), two parallel aerobic (facultative) ponds and two serially connected maturation ponds. The total area required amounts 6 to 8 m2/cap, including land for accession, etc. The net treatment area is 3 – 4 m2/capita. It is planned for a full treatment of wastewater (primary to tertiary treatment).

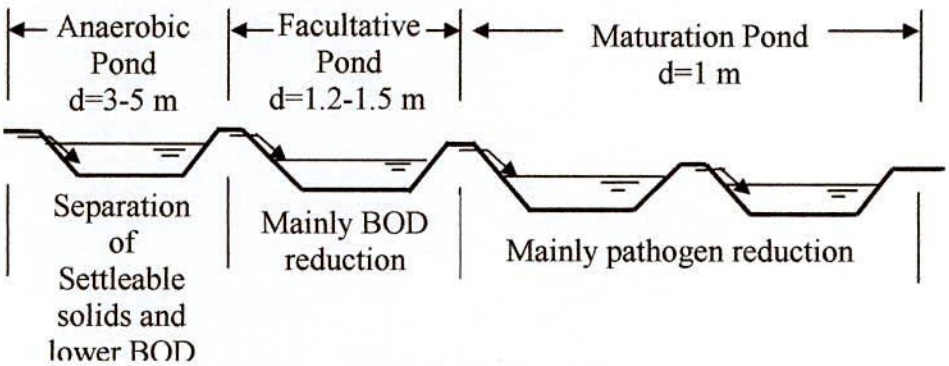


Figure: 2-11 Schematic of a series of ponds.

The main disadvantages of this system are 1) Large space requirements 2) Nuisance of mosquitoes and odour if undersized and 3) Algae can raise the effluent BOD. The main advantages of this system are 1) Simple construction 2) High pathogen removal rate 3) Little maintenance 4) High treatment efficiency and nitrogen removal

Anaerobic pond: Its function is the sedimentation and anaerobic digestion of sludge. It works like an open septic tank and can treat highly loaded wastewater (0.1 – 1 kg BOD/m3d) with BOD removal rates of 40 – 60 %. Its minimum depth should be 3 m to guarantee anaerobic conditions. The minimum dimensions of an anaerobic pond are 0.6 $m^3$/capita and 0.2 m2/capita. The retention time lasts 1 – 3 days.

Aerobic (facultative) pond: Its role is the aerobic degradation of suspended and dissolved matter. The BOD removal rates are 40 – 70 %. The maximum organic load shouldn't go beyond 20 g BOD/m2d. The oxygen supply occurs via water surface and photosynthesis. Its maximum depth should be 1.2 m to guarantee aerobic conditions. The minimum dimensions of an aerobic pond are 1.5 $m^2$/capita for domestic wastewater. The retention time lasts 10 – 20 days.

Maturation ponds: Their role is to mediate the final sedimentation of suspended stabilized solids, bacteria mass and pathogens. Their depth amounts 1 m and the area amounts 1.5 $m^2$/capita. The hydraulic retention time lasts approximately 10 days. There are normally 2 – 3 ponds constructed in series.

2.3.9.5 Descriptions of systems found in literature

This section presents an overview on different treatment systems found in literature. Six systems combining the treatment options described above will be characterised. These systems were implemented in both developed and developing countries. Different aspects like costs, space requirements, treatment efficiency, strengths and weaknesses will be discussed for these systems

a) Wetpark:

The name *wetpark* was given by the author Günther to this purification system because of its park-like composition and its wetland type structure (see Figure: 2-12). Wetparks are plants that encourage the subsurface flow of water and enhance interactions of the vegetation and microorganisms occurring in a riparian ecotone. They consist of four different elements, which are a) a section filled with lime-gravel, b) shore zones, c) ponds and d) a sand filter. Before entering the pond system, water is distributed over a bed filled with lime-gravel by means of inlet pipes. Lime-gravel increases the surface for organic material reduction by aerobic bacteria. After water has passed through the gravel bed, it is let in the root-zone of the planted vegetation of the shore. Finally, it is stored in a pond. Purification in the shorepond system is repeated three times consecutively. After the last pond, water is let into a sand filter and is collected in a well. In order to prevent water from percolating in deeper soil layers, a waterproof layer is placed under the whole purification plant.

The vegetation chosen is that prevailing in the normal wetland communities in the region. In Switzerland for example, anyone would choose *Phragmites australis* and *Typha latifolia*. The plants are continuously harvested and composted, in order to remove nutrients from the system. Some fishes and crayfishes are introduced into the ponds to control insect larvae and digest leaf litter and other organic matter.

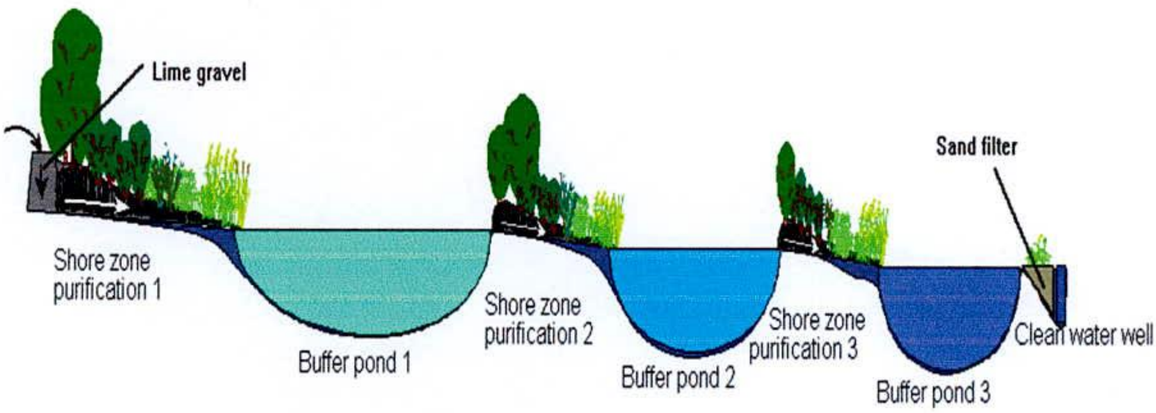



Figure: 2-12 Outline of the triplicate shore – pond system

b) Constructed wetlands:

Here the example of a system constructed for the household level is given. Nevertheless, the authors Shrestha et al have described systems for other levels that are constructed and dimensioned differently. Greywater is collected in a two-chambered settling tank for pretreatment. The pretreated water is led into a tank which feeds a vertical flow bed (6 $m^2$).

The flow bed is filled with coarse sand and planted with common reed (*Phragmites karka*) and *Canna sp.* The treated water is collected in an underground tank. The system doesn't need any electrical devices. Water is flushed hydro-mechanically into the bed 3 to 4 times a day. The collected water can be reused for flushing, gardening and cleaning (Morel 2005).

c) Ecomax:

There are six functional elements for the Ecomax septic system (shown in Figure: 2-13): 1) Two sequential septic tanks 2) Two Ecomax cells, used in rotation, each comprising a storage and leaching vessel 3) Amended soil treatment medium 4) A perimeter sub-surface drain to collect treated water for reuse 5) Sand veneer to provide substrate for grass growth and as means of blending the cells to their landscape setting and 6) Grass cover.

Wastewater is led into septic tanks, where sedimentation, floatation and aerobic digestion occur. After 2-3 days residence, the pre-treated effluent flows out of the tank and into the infiltration structure located in the Ecomax cells. Effluent inside the infiltration structure flows radially into the soil and towards the perimeter bund where it exits the system. The septic tanks are linked to two Ecomax cells. The effluent of the cells flows radially into the soil and towards the perimeter bund.

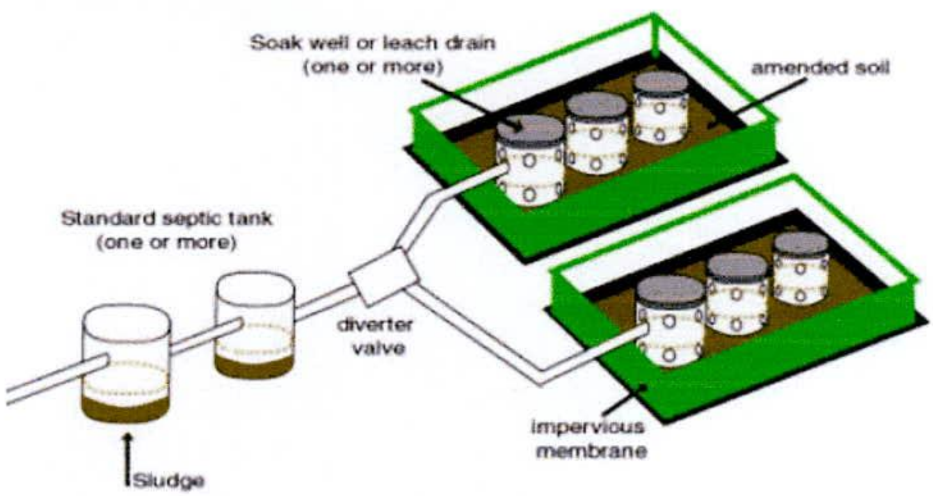



Figure: 2-13 Ecomax septic system.

d) Gaia-Movement system:

The Gaia-Movement system consists of a drum filled with sand and a duckweed pond or a reed bed. Wastewater is piped to the sand-filled drum. At the end of the pipe, a mosquito net catches possible waste. Then the water is let through the drum filled with sand. At the bottom of the drum a net stops sand coming into the outlet. After being filtered in the sand, greywater is piped into the duckweed pond or the reed bed, where it is treated. At the end of the whole process, the treated water is collected in a container and can be used for gardening. There are many tasks the owner of this system has to do to maintain it. The mosquito net, which catches waste, has to be emptied. Some of the duckweeds have to be removed every day. The reed should be cut once or twice a year. When the sand filter fills up with waste, the sand should be changed (Morel 2005).

e) Rota-Loo greywater system:

There are two different options of systems as shown in Figure: 2-14 and Figure: 2- 15.

Niimi absorption trench: Greywater from the building is piped into a holding tank. The holding tank is used as a surge tank and to catch any material that may have been washed down the sink. Material falls to the bottom and fats float on the top. The clearer water from the middle of the tank flows into a distribution box. The distribution box is used to determine which trench is being used and which one(s) are being rested. Every trench should be swapped over every six months. The holding tank should be desludged at least once every three years. The principle of the Niimi absorption trench is to keep the wastewater in an aerobic state near the surface of the soil where microorganisms and other soil fauna digest nutrients and pollutants. The holding tank and the distribution box are also illustrated (on the left side of Figure: 2-14).

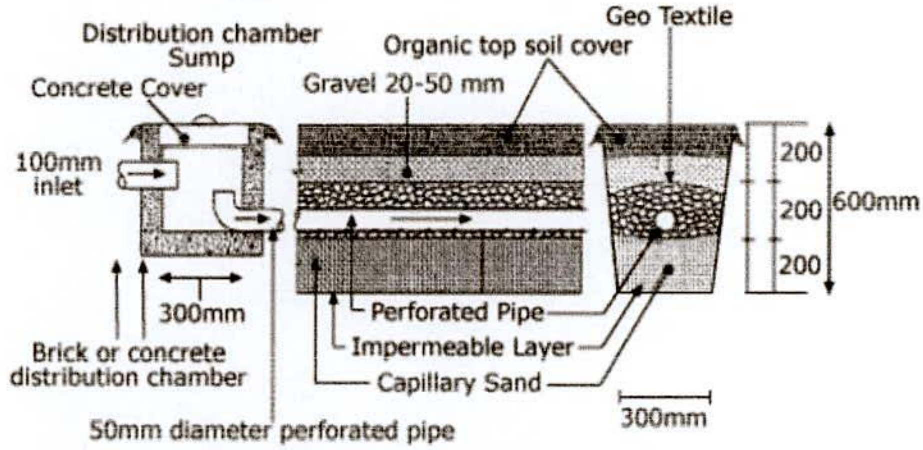



Figure: 2-14 Schematic of a Niimi absorption trench.

Reed bed filter system coupled with Niimi absorption trench: In this option, a supplementary element is added between the holding tank and the distribution box. The element in question is a reed bed with a slight slope. The reed bed uses the principles of evaporation and transpiration to process the greywater. The reed bed is installed between the holding tank and the distribution box (Morel 2005).

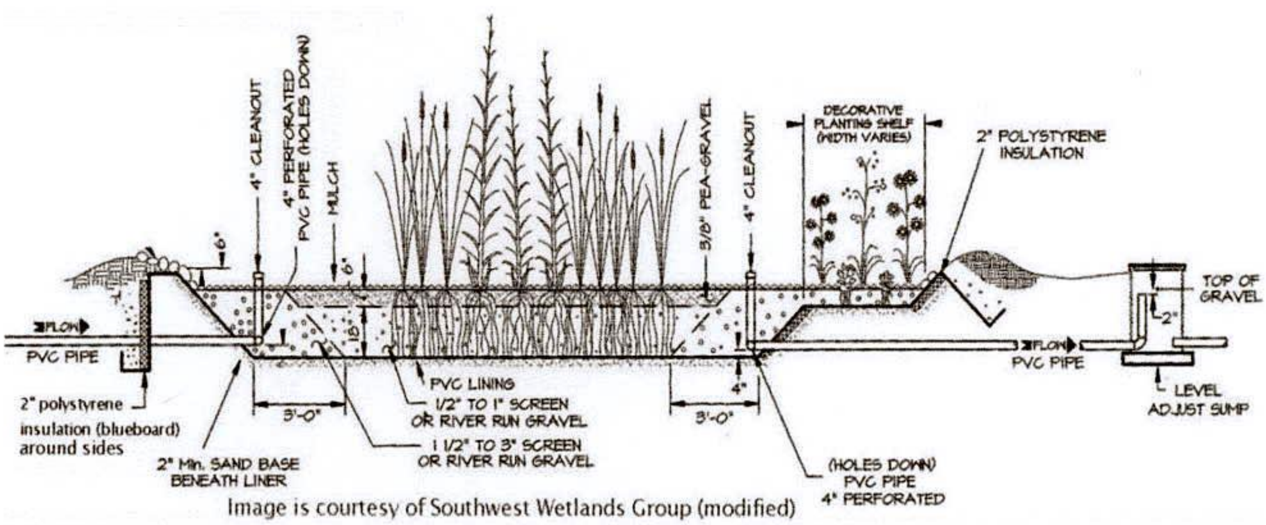



Figure: 2-15 Schematic of a Reed bed filter.

### *2.3.10 Greywater scenario in Bangladesh*

In Bangladesh, the greywater situation in terms of treatment and recycling is the most horrible. Most of the people think that greywater is not so much polluted like blackwater and so not only rural parts but also in urban area there is no treatment options for greywater. And greywater recycling is still unbelievable. Generally different scenarios are prevailed in urban and rural areas of Bangladesh about greywater (Hasan and Nakajima 2010). Fig: 2-16 represents the schematic scenario of greywater in urban area. In urban areas, greywater from different sources are discharged through different outlets of a house but at last are collectively discharged to the municipal surface drain. Fig: 2-17 represents greywater discharge outlets of a house in urban area. Red circled marked is for the outlet of water from kitchen and hand-basin, green circle marked is for shower water and both of these two outlets are opened to surface drain. However, yellow one is for blackwater from toilets to septic tank for the treatment.

On the other hand, this is different in rural areas. In rural areas, all types of greywater are allowed to discharge collectively through one outlet from a house and then discharge to surface drain or nearby ditch (Fig: 2-18 shows the scenario schematically). Both cases are existed in semi-urban areas. In addition, each and every where all discharge of greywater are allowed without any kind of treatment. So, usually, blackwater is treated by septic tank and greywater is directly discharged into environment without any kind of treatments in both urban and rural areas of Bangladesh (Hasan and Nakajima 2010).

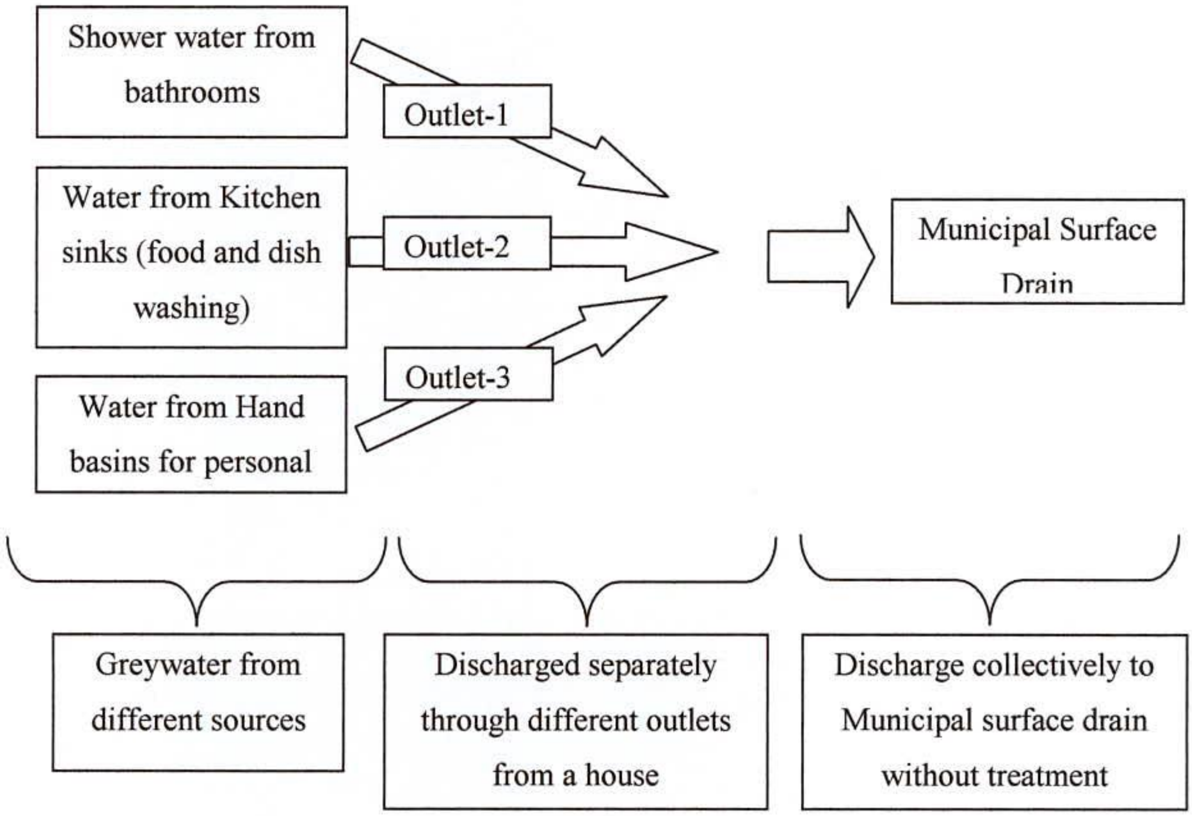



Fig: 2-16 Greywater Scenario for urban areas: Schematic view

Fig: 2-17 Greywater Scenario for urban areas: a house with 3 outlets, red-color from kitchen, green-color from bathrooms and yellow-color from toilets

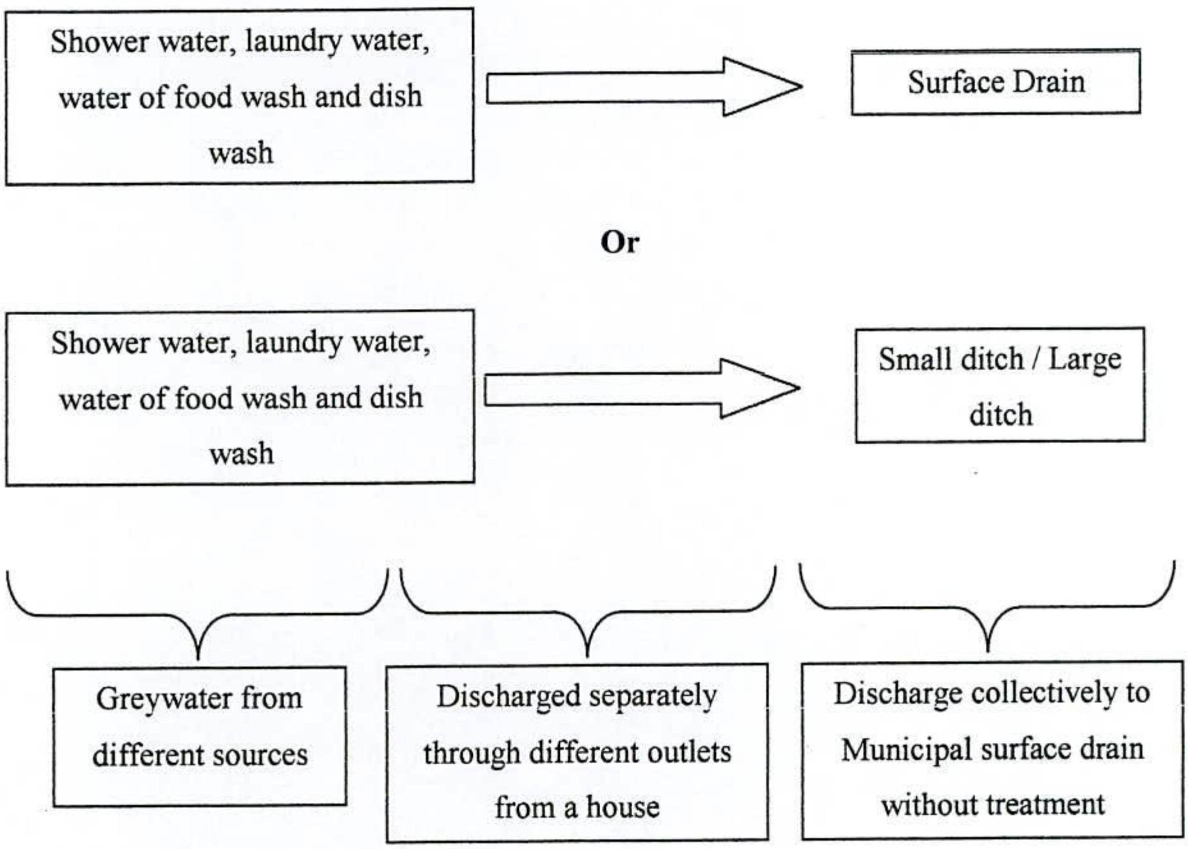



Fig: 2-18 Greywater Scenario for rural areas: Schematic presentation

Fig: 2-19 symbolizes of greywater scenario in rural areas. In rural areas, tube-well is the main source of water and all kids of domestic activities like bathing, washing of cloths, foods and dishes are done at tube-well spot. And all the water is allowed to go to a ditch for groundwater infiltration without any treatment (Hasan and Nakajima 2010). Or sometimes it is discharged to a nearby surface drain which phenomenon is revealed in Fig: 2-20.

Fig: 2-21 shows the photos of ditches. Fig: 2-21 (a) shows a ditch with larger area in which water is available throughout the year however Fig: 2-21 (b) shows a greywater collected ditch of small area (Red X marked) inside a house periphery, which becomes dry in summer season. Except discharge into ditches greywater is usually permitted to flow through surface drain of locality. Photo of Fig: 2-22 is the evidence of such surface drain in locality with greywater flows.

Fig: 2-19 Greywater Scenario for rural areas: actual photograph

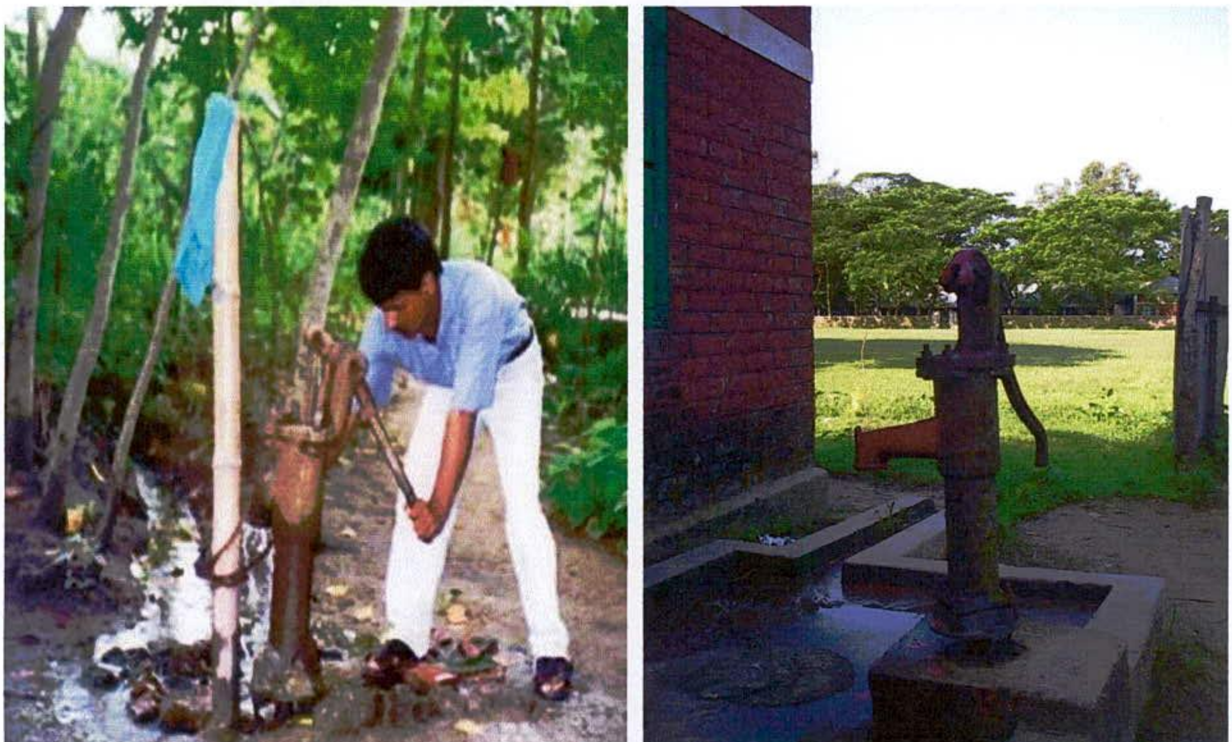


Fig: 2-20 Greywater is discharged to surface drain from tube-well spot

(a) (b)

Fig: 2-21 Greywater discharged outlets (circled marked) to ditch (a) ditch with large area (b) small ditch (red x -marked)

Fig: 2-22 Surface drains through locality with greywater flow

## 2.4 OVERVIEW OF MEMBRANE BIOREACTOR TECHNOLOGY

### *2.4.1 Explanation of the Technology*

Membrane bioreactor (MBR) technology is characterized as a combination of biological wastewater treatment (WWT) and membrane separation, by which biomass can retained in the system without conventional gravity sedimentation (Itokawa 2009). The Membrane Bioreactor is a simple, but very effective combination of the activated sludge treatment process and the membrane filtration process (Operator Notebook Report 2001). In other words Membrane bioreactor (MBR) is a wastewater treatment process in which the membrane separation technology integrated with activated sludge system. This function represents the combination of two basic processes- biological degradation and membrane filtration- in one process where suspended solids (SS) and micro-organisms are responsible for dissociating organic matter biologically followed by membrane separation. The suspended solids are completely separated from the treated water by the membrane unit, and all bio-mass are kept in the bioreactor. The advantages of the system are the high quality of its effluent (Cornelia et al. 2006). Membrane bioreactors (MBR) with submerged membrane modules have set the standard for the next generation of biological wastewater treatment plants as they offer two main advantages; a significantly improved effluent quality and a substantially smaller footprint (Gottberg et al. 2008). Based on the characteristics of wastewater from both industrial disposal and domestic wastewater treatment, the most efficient and effective way to treat it is by applying membrane process in a bioreactor. With new advances in membrane design and technology, the MBR processes appear to have a promising future in wastewater treatment sectors. The MBR process is an emerging advanced wastewater treatment technology that has been successfully applied at an ever increasing number of locations around the world (Chapman et al. 2003).

### *2.4.2 Hydraulics of MBR*

During MBR wastewater treatment, solid-liquid separation is achieved by Membrane unit. The basic principle is that the feed water passes over the membrane surface and the product is called permeate, whereas the rejected constituents form concentrate or retentate (Fig: 2-23). A membrane is simply a two-dimensional material used to separate components of fluids usually on the basis of their relative size or electrical charge. The capability of a membrane to allow transport of only specific compounds is called semi-permeability. This is a physical process, where separated components remain chemically unchanged. Components that pass through membrane pores are called permeate, while rejected ones form concentrate or retentate. Mass balance of the solute in the process can be presented by the equation:

$$Q_f C_f = Q_p C_p + Q_c C_c \text{..........} (1)$$

Where $Q_f$- feed flow rate; $C_f$- solute concentration in feed flow; $Q_p$ - permeate flow rate; $C_p$ - solute concentration in permeate; $Q_c$ - solute concentration in concentrate; $C_c$ -- solute concentration in concentrate. Membrane rejection of solutes can be calculated according to the following equation:

$$R = (C_f - C_p)/C_f \text{..................} (2)$$

Where $C_f$ is concentration of solute in feed flow and Cp represents its concentration in permeate. The fraction of feed flow converted to permeate is called yield, recovery or water recovery (S). Water recovery of the membrane process is given with the equation:

$$Y = Q_p/Q_f \text{.......................}(3)$$

Where $Q_p$ is the permeate flow and $Q_f$ is the feed flow.

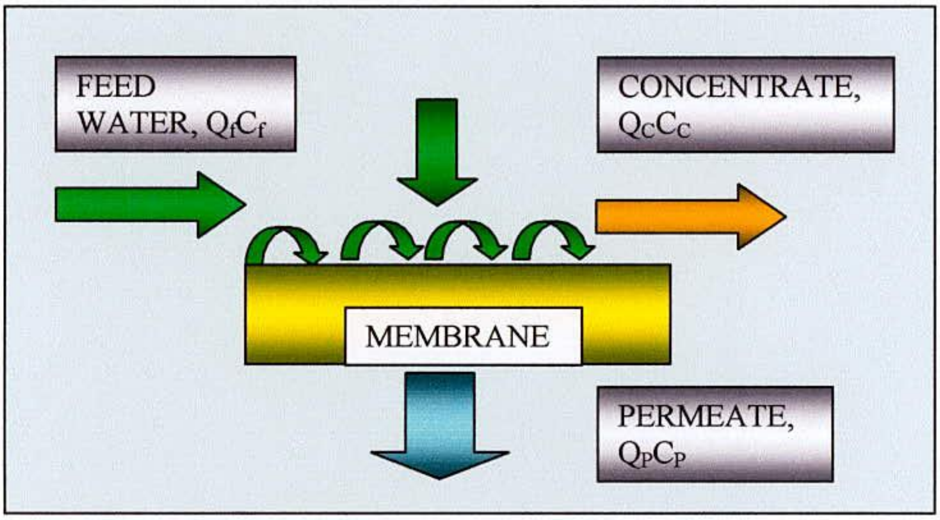



Fig: 2-23 Basic principle of membrane filtration

Recovery is normally close to 100% for dead-end filtration, while it varies significantly for cross-flow filtration depending on the nature and design of membrane process. Permeate flux (usually denoted as *J*) is the volume of water passed through a unit area of membrane per unit of time and it is often normalized to a standard temperature. The common unit for *J* is usually $L/m^2/day$, and most of the available data for MBR is given in that manner rather than in SI units. MBR membranes generally operate at fluxes between 10 and 100 $Lm^{-2}h^{-1}$. The flux is related to its driving force which is transmembrane pressure (TMP or $\Delta P$) while the membrane performance can be estimated from the membrane permeability *(K)*, which is calculated as permeate flux per unit of TMP and is usually given as $L/m^2/h/bar$ (Hasan and Nakajima 2010).

### *2.4.3 MBR History and Basic Operating Parameters*

Membrane bioreactor (MBR) is an improvement of the 100-year old CASP (Conventional Activated Sludge Processes), where the traditional secondary clarifier is replaced by a membrane unit for the separation of treated water from the mixed solution in the bioreactor (Xing et al. 2000). Since the 1980's, Membrane Bioreactors (MBR) have been successfully used to treat municipal, commercial and industrial wastewaters for discharge and reuse applications. Today, with thousands of installations operating worldwide, MBR technology is shaping the way we view wastewater treatment and water conservation in the US and around the world (Enviroquip, Inc Report 2011). The use of MBR technology in the area of wastewater treatment dates back to the early 1960s when processes like ultrafiltration (UF), microfiltration (MF) and reverse osmosis (RO) were applied as tertiary treatment or polishing steps. The original process was introduced by Dorr-Olivier Inc. and combined the use of an activated sludge bioreactor with a cross-flow membrane filtration loop. The flat sheet membranes used in this process were polymeric and featured pore sizes ranging from 0.003 to 0.01 um. Although the idea of replacing the settling tank of the conventional activated sludge process was attractive, it was difficult to justify the use of such a process because of the high cost of membranes, low economic value of the product (tertiary effluent) and the potential rapid loss of performance due to membrane fouling. As a result, the focus was on the attainment of high fluxes, and it was therefore necessary to pump the mixed liquor suspended solids (MLSS) at high cross-flow velocity at significant energy penalty (of the order 10 kWh/m3 product) to reduce fouling. Due to the poor economics of the first generation MBRs, they only found applications in niche areas with special needs like isolated trailer parks or ski resorts for example.

In Japan, full-scale commercial MBRs started to be installed in early 1980s, as an external cross-flow system (Itokawa 2009). The breakthrough for the MBR came in 1989 with the idea of Professor Yamamoto and co-workers to submerge the membranes in the bioreactor. Until then, MBRs were designed with the separation device located external to the reactor (sidestream MBR) and relied on high transmembrane pressure (TMP) to maintain filtration. With the membrane directly immersed into the bioreactor, submerged MBR systems are usually preferred to side-stream configuration, especially for domestic wastewater treatment. The submerged configuration relies on coarse bubble aeration to produce mixing and limit fouling. The energy demand of the submerged system can be up to 2 orders of magnitude lower than that of the side-stream systems and submerged systems operate at a lower flux, demanding more membrane area. In submerged configurations, aeration is considered as one of the major parameter on process performances both hydraulic and biological. Aeration maintains solids in suspension, scours the membrane surface and provides oxygen to the biomass, leading to a better biodegradability and cell synthesis (Hasan and Nakajima 2010). In an MBR system, the membranes are submerged in an aerated biological reactor. The membranes have porosities ranging from 0.035 microns to 0.4 microns (depending on the manufacturer), which is considered between micro and ultra filtration (Fitzgerald 2008).

The other key steps in the recent MBR development were the acceptance of modest fluxes (25% or less of those in the first generation), and the idea to use two-phase bubbly flow to control fouling. The lower operating cost obtained with the submerged configuration along with the steady decrease in the membrane cost encouraged an exponential increase in MBR plant installations from the mid 90s. Since then, further improvements in the MBR design and operation have been introduced and incorporated into larger plants. While early MBRs were operated at solid retention times (SRT) as high as 100 days with mixed liquor suspended solids up to 30 g/L, the recent trend is to apply lower solid retention times (around 10-20 days), resulting in more manageable mixed liquor suspended solids (MLSS) levels (10-15 g/L). In these new operating conditions, the oxygen transfer and the pumping cost in the MBR have tended to decrease and overall maintenance has been simplified. There is now a range of MBR systems commercially available, most of which use submerged membranes although some external modules are available; these external systems also use two-phase flow for fouling control (Hasan and Nakajima 2010).

### *2.4.4 Types of Membrane and Configurations of MBR Technology*

Membranes have evolved with new materials and applications. Membranes can be manufactured by a wide variety of materials which include inorganic membranes (sintered metals and ceramics) and organic membranes (polymers).

The *inorganic membranes* have better chemical, mechanical and thermal stabilities, but have disadvantages of being very fragile and more expensive than the organic membranes.

The *organic membranes* are widely used in water and wastewater applications because they are more flexible and can be put into a compact module with very high surface area. The organic membranes can be made from cellulose, and all synthetic polymers which have relatively good chemical, mechanical and thermal stability tendencies, and also provide the membranes with better antifouling properties through the use of hydrophilic polymers. The membranes primarily used in wastewater treatment are as follows:

*Plate and Frame* - The plate and frame membranes consist of two flat sheets of membrane material, usually an organic polymer, stretched across a thin frame. The space between the membrane sheets is placed under vacuum in order to provide the driving force for filtration.

Several plates are arranged in a cassette to allow for increased surface area and convenient modular design. The membrane cassette is immersed in the mixed liquor and the separation flow is from outside-in. For example, Kubota membranes have air induced liquid cross-flow along the plates. This creates turbulence and hinders cake formation and subsequent fouling. The organic polymer, polyethylene for example, has the required flexibility to move slightly in the cross-flow to allow three-dimensional dynamic forces to reduce cake formation. The cross-flow of air also acts to dissolve oxygen to and mix the contents of the reactor.

*Hollow fibre* - Hollow fibre membranes consist of long strands, or fibres, of hollow extruded membrane. They are most often of organic polymer construction and are applied much the same as plate and frame membranes. The fibres are mounted to a supporting structure that serves as a manifold for permeate transport as well as an air delivery system. Similar to the plate and frame modules, air induced liquid crossflow prevents excessive cake formation and increases the lifespan of the membrane. The fibres are most often employed in the outside-in arrangement. A vacuum is applied to the permeate manifold and this draws water from the reactor-side to the inside of the fibre and out of the system. As with the plate and frame membrane, hollow fibre membranes are also constructed in a cassette format to allow for the convenience of modular design (Hasan and Nakajima 2010).

*Tubular* - As the name implies, tubular membranes are hollow tubes with the membrane placed on the surface of the tube. Below the membrane surface is a supporting structure with high porosity. In most cases, tubular membranes are made of inorganic material such as ceramic and have a metal oxide membrane surface to provide a small nominal pore size. Tubular membranes have a different separation driving force than the previous two. Rather than vacuum pressure, the material to be separated flows along the membrane at high velocity under pressure. The velocity provides a transverse force to drive the water through the membrane while leaving the larger diameter particles behind. A tubular membrane could be used in the outside-in arrangement with the feed water flowing along the centre of the tube and the permeate passing to the outside walls, or the inside-out arrangement where the influent travels along the centre of the tube and travels axially outward.

There are two major configurations of MBR systems. In an MBR, solid/liquid membrane filtration occurs either 1) within the bioreactor which is known as *submerged MBR* (Fig: 2-24 (a)) or 2) externally through recirculation subject to a pressure drop across the membrane generated by either hydraulic head or a fitted pump. The latter type is termed as *side-stream MBR* (Fig: 2-24 (b)). *Submerged system* was developed by Yamamoto et al. in 1989 in which membrane is directly submerged into a bioreactor. This has been one of the major improvements of MBRs because of its lower power cost and hence has the potential to be applied to small wastewater treatment plants. In this case there is no re-circulation loop as the separation occurs within the bioreactor itself. This system reduces the operation costs. The pressure across the membrane in this system can be applied either by suction through the membrane or by pressurizing the bioreactor. In the case of *side'-stream system,* the membrane is independent of the bioreactor. Feed wastewater enters the bioreactor where it contacts with biomass. The mixture of feed wastewater and biomass is then pumped around a re-circulation loop containing a membrane unit where permeate is discharged and the retentate is returned to the bioreactor. Excess sludge is pumped out to maintain a constant sludge age. Backwash and chemical washing are used for cleaning the membrane.

Submerged types MBRs have been again classified into two categories in terms of membrane separation principles: a *suction-filtration type* and a *gravitational-filtration type.* In the former type, permeate is suctioned by a suction pump from the effluent side. In the latter type, permeate is pushed from the bulk-solution side by a pressure head of mixed liquor over membrane modules. The latter type, therefore, does not necessitate a suction pump for membrane separation thereby simplifying the structure.

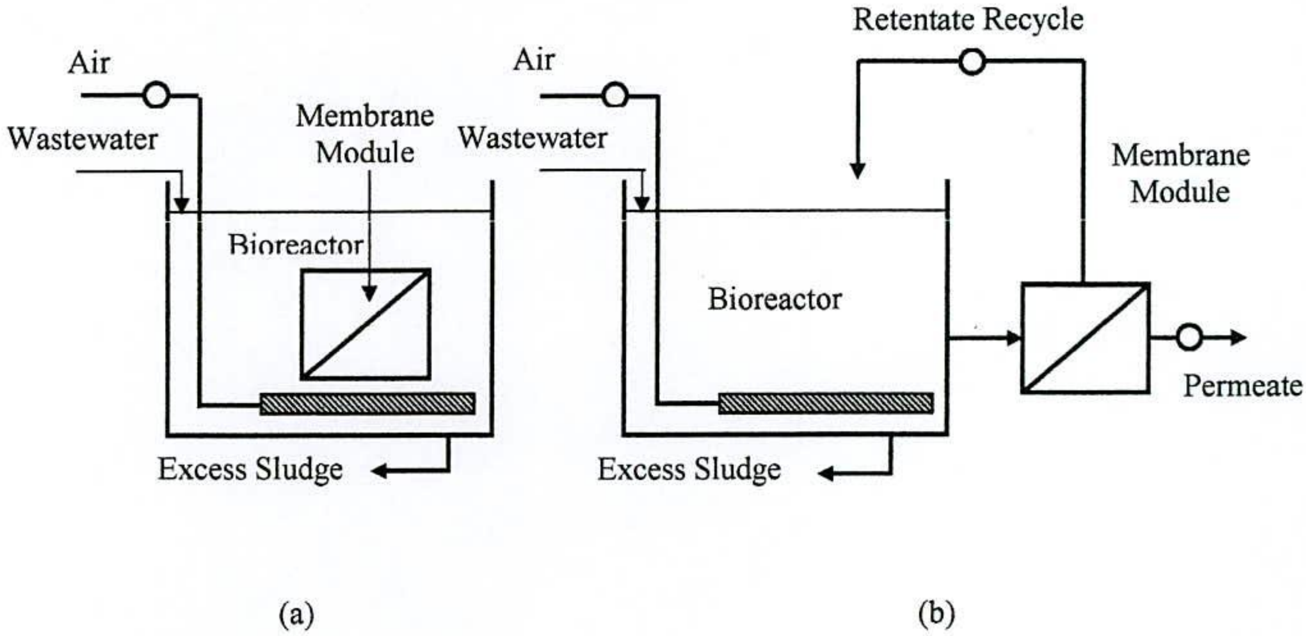



Fig: 2-24 (a) submerged MBR: filtration unit integrated into the bioreactor. (b) Side-stream MBR with a separate filtration unit with retentate recycled back to bioreactor

### *2.4.5 Selection of Ingredients Ratio and Ceramic Membrane Characterization*

From previous study it was found that for selecting the proportion of soil and rice bran, several tests were conducted including filterability, flexural strength. Ceramic bars (4x4x16 cm) (Fig: 3-2a) with different ratios (10%, 15%, 20% and 25% of rice bran by weight) were made and tested for strength and filterability. The burning procedure of the bars was same as above stated in laboratory. After burning, the ceramic bars were cut by 4x4x2 cm size and then performed the tests for selecting the appropriate proportion of the ingredients. A both side opened 1 L plastic measuring cylinder was used for the filterability test. A 4x4x2 cm size membrane bar was attached with a rubber cap and fixed at the bottom of the cylinder. The cylinder was then filled by de-ionized water and measured the volume of filtered water and water head with time. The flux of CMBR was then calculated. Flexural strength of the ceramic bars was examined by one point loading system. Load was applied at the center of the 4x4x16 cm ceramic bar and gradually increased until it failure. The flexural strength was calculated from applied load. The particle size distribution of soil was measured by the laser diffraction method. The apparent porosity of Ceramic Membrane was tested according to study of Yang. Pore size was measured from the particle size distribution of turbid water (mixture of water and clay soil) before and after filtration through Ceramic Membrane. After passing the turbid water through ceramic membrane, the filtrate was again filtered through 1 μm (Advantec 2C) filter paper and 5μm filter paper (Advantec 5C). The pore size was than estimated by comparing the particle size distribution curves (Hasan and Nakajima 2010). The particle size distribution showed that the selected soil for Ceramic Membrane contain approximate 40% sand, 50% silt and 10% clay. The filtration flux of membrane made with 10%, 15%, 20% and 25% rice bran at 28.5 cm of water head were 0.11±0.02, 0.16±0.01, 0.53±0.08 and 1.92±0.39 ml/cm$^2$/min respectively. On the other hand, the flexural strengths were 0.75±0.19, 0.48±0.15, 0.27±0.14 and 0.08±0.01 N/mm$^2$ respectively. These results indicate that burnt Ceramic Membrane with higher percentage of rice bran (25%) was weak in strength and was broken easily, while lower percentages (10% and 15%) presented a relatively low flow rate. On the basis of all these results, it seems that 80% soil and 20% rice bran was appropriate and was selected for manufacture of ceramic membrane. The porosity and pore size of the membrane (80% soil and 20% rice bran) was 60% and 1-5 μm, respectively. This pore size was created by the transformation of solid state of rice bran into ash when the membrane was burnt at 900°C. No significant difference was found with respect to the filterability, strength and other characteristics of the membrane modules between the two manufacturing conditions of laboratory and field level.

### *2.4.6 Advantages of MBR Technology*

MBR systems offer a wide range of benefits, such as:

- The effluent is of very high quality, very low in COD, very low in turbidity and suspended solids. The technology produces some of the most predictable water quality known. It is fairly easy to operate as long as the operation has been properly trained, pays strict attention to the proper operation, corrective maintenance, and preventative maintenance tasks (Operator Notebook Report 2001).
- The "simple filtering action" of the membranes creates a physical disinfection barrier, which significantly reduces the disinfection requirements.
- MBR systems provide this high effluent quality in a greatly simplified process. This requires only headworks, biological processes, membrane filtration and disinfection to meet the most stringent water quality standards. In comparison, conventional process requires additional primary treatment, secondary clarifiers, Enhanced Nutrient Removal and media filtration, prior to obtaining the same effluent characteristics. More importantly, the effluent quality is highly consistent with the membrane barrier and a more stable biomass (AMTA Report 2007).
- The treatment process also allows for a smaller "footprint" as there are neither secondary clarifiers nor tertiary filters which would be required to achieve similar water quality results. It also eliminates the need for a tertiary backwash surge tank, a backwash water storage tank, and for the treatment of the backwash water (Operator Notebook Report 2001).
- Combining space efficient membrane systems and operations at increased mixed liquor concentrations (commonly 8,000- 18,000 mg/l), MBR systems are highly space efficient (AMTA Report 2007).

- Can be designed with long sludge age, hence sludge production is low. Generally speaking it produces less waste activated sludge than a simple conventional system (Operator Notebook Report 2001). Sludge Yield of 20-40% less than conventional system (Fitzgerald 2008).
- MBR systems are simpler, with fewer process components and maintenance requirements and it is easier to operate because Gravity Filtration is used (Enviroquip, Inc Report 2011). Common maintenance is still required on mechanical components, but operators can now avoid difficulties in operation tied to sludge settling and clarifier (AMTA Report 2007).
- If re-use is a major water quality goal, the MBR process will be a major consideration. This process produces a consistent, high water quality discharge. When followed by a disinfection process, it allows for a wide range of water re-use applications including landscape irrigation, non-root edible crops, highway median strip and golf course irrigation, and cooling water re-charge. When Reverse Osmosis (RO) water quality is required, the MBR process is an excellent candidate for preparing the water for RO treatment (Operator Notebook Report 2001).
- The possibility of retaining all bacteria and viruses results in a sterile effluent, eliminating extensive disinfection and the corresponding hazards related to disinfection by products. Since suspended solids are not lost in the clarification step, total separation and control of solids retention time (SRT) and hydraulic retention time (HRT) are possible. Thus, optimum control of the microbial population and flexibility in operation are possible (Hasan and Nakajima 2010).
- Higher strength wastewater can be treated and lower biomass yields are realized. This also results in more compact system than conventional processes significantly reducing plant footprint. By increasing SRT, complete nitrification even under

extreme cold weather operating conditions, relatively easier cleaning procedure, and no phase change occurs are others advantages of this technology.

### *2.4.7 Demerits of MBR Technology*

Although MBR systems offer a wide range of benefits it has some Demerits, such as

- The disadvantages associated with the MBR are mainly cost related. High capital costs due to expensive membrane units and high energy costs due to the need for a pressure gradient have characterized the system (Cicek 2003).
- The wide spread application of the MBR process is constrained by membrane fouling. Fouling is troublesome, and its prevention is costly. Several papers and research endeavors have concluded that up to two-thirds of the chemical and energy costs in an MBR facility are directly attributable to reducing membrane fouling (Operator Notebook Report 2001). Membrane fouling can be simply defined as the decrease of flux over time. This phenomenon is commonly considered as a weakness point in MBR applications. Membrane clogging in the MBR process might be i) external fouling which results from biofilm growth, or adsorption or deposition of foulants on the top surface of the membrane and ii) internal fouling that takes place at the pore entrances or within the internal pore structure of the membrane. Adsorption is used here to mean an interaction between foulants and membranes. In recent reviews covering membrane applications to bioreactors and it has been shown that, membrane fouling is the most serious problem affecting system performance. Fouling leads to a significant increase in hydraulic resistance, manifested as permeate flux decline, making more frequent membrane cleaning and replacement necessary which then increase operating costs (Hasan and Nakajima 2010).

- There may be cleaning solutions that require special handling, treatment, and disposal activities depending on the manufacturer. These cleaning solutions may be classified as hazardous waste depending on local and state regulations (Operator Notebook Report 2001).
- Additionally, when operated at high SRTs, inorganic compounds accumulating in the bioreactor can reach concentration levels that can be harmful to the microbial population or membrane structure (Hasan and Nakajima 2010).

# *Chapter 3*

# *Materials and Methods*

## 3.1 MANUFACTURE OF CERAMIC MEMBRANE AND ITS CHARACTERIZATION

Due to diminishing water supplies and increasing population, wastewater reclamation is becoming necessary throughout the world to conserve natural water resources used for drinking water supply. The problem of fresh water scarcity is also prevailed in many parts of the world; especially developing countries are suffered much more. Therefore, wastewater treatment and reuse technology can be the effective solution for the crises. However, for the sustainability of any technology to adapt in the developing countries, simplicity and low-cost are the focal points.

Among all the technologies, membrane technology is found effective and hence gets the incomparable popularity in recent years for wastewater treatment and reuse. But high cost in terms of membrane cost is still the main barrier for the wide spread of this technology, especially in developing countries. If by any means, membrane cost can be eliminated by choosing cheap membrane materials then it will be a novel innovation.

The manufacturing process of an innovative, simple and low-cost Ceramic Membrane Bio-Reactor has been described in this chapter. For making the Ceramic Membrane Bio-Reactor cheap, easily and locally available materials (rice bran and clay soil) were chosen for wastewater treatment. About 80% clay soil and 20% rice bran was used for manufacture of ceramic membrane.

### *3.1.1 Ingredients of Ceramic Membrane*

Locally available clay soil and rice bran were used as ingredients of the ceramic membrane. Soil samples and rice bran were collected from the local brickfield and rice-mill respectively of Khulna city.

### *3.1.2 Size and Shape of the Ceramic Membrane*

The Ceramic Membrane module is hollow cylindrical in shape with one side closed. The dimension was as 10 cm of height, 10 cm of outer diameter and 6 cm inner diameter with 8 cm height (Table: 3-1 and Fig: 3-2).

**Table: 3-1** Specifications of the Ceramic Membrane Module

| Parameter | Description |
|---|---|
| Membrane material | Local Clay and Rice bran |
| Shape | Cylindrical (one side closed) |
| Outer Diameter, cm | 10 |
| Inner Diameter, cm | 6 |
| Height, cm | 10 |
| Surface area, $cm^2$ | 443 |

### *3.1.3 Making Procedure of Ceramic Membrane*

The flow chart of the making procedure of Ceramic Membrane is shown in Fig: 3-1. Locally collected clay soil samples were dried and grind by hammer. The dried and grind clay soil was sieved by 0.5 mm mesh. The rice burn was also dried and sieved by 1 mm mesh. Mixing ratio of the ingredients were 80% of clay soil and 20 % of rice bran on weight basis. This mixing proportion of the materials was selected by quantifying pore volume, pore size, compressive strength and filtration efficiency of several ceramic bars prepared with different ratios of the ingredients. Details about the selection of ingredients proportion were described in the next section.

To make the dough manually, dried ingredients were mixed homogeneously and then sufficient amount of water was used. Water of 400-500 ml was used with the dry homogeneous-mixed ingredients of 800 gm for making one membrane module. In the end, a hollow cylindrical shape was manually made with the dough as 10 cm height with 10 cm outer diameter and 6 cm inner diameter with one side opened (Fig: 3-2).

To make preferred shape, a wooden dice and PVC pipe of 10cm ht with 10cm outer diameter cut vertically in symmetrical were used. The membrane was then kept for 24 hrs for natural dry at room temperature, then oven dried at 105°C for 24 hrs and finally burnt in a muffle furnace in the laboratory. The temperature in muffle furnace was increased from room temperature to 900°C and kept this temperature for 2 hrs.

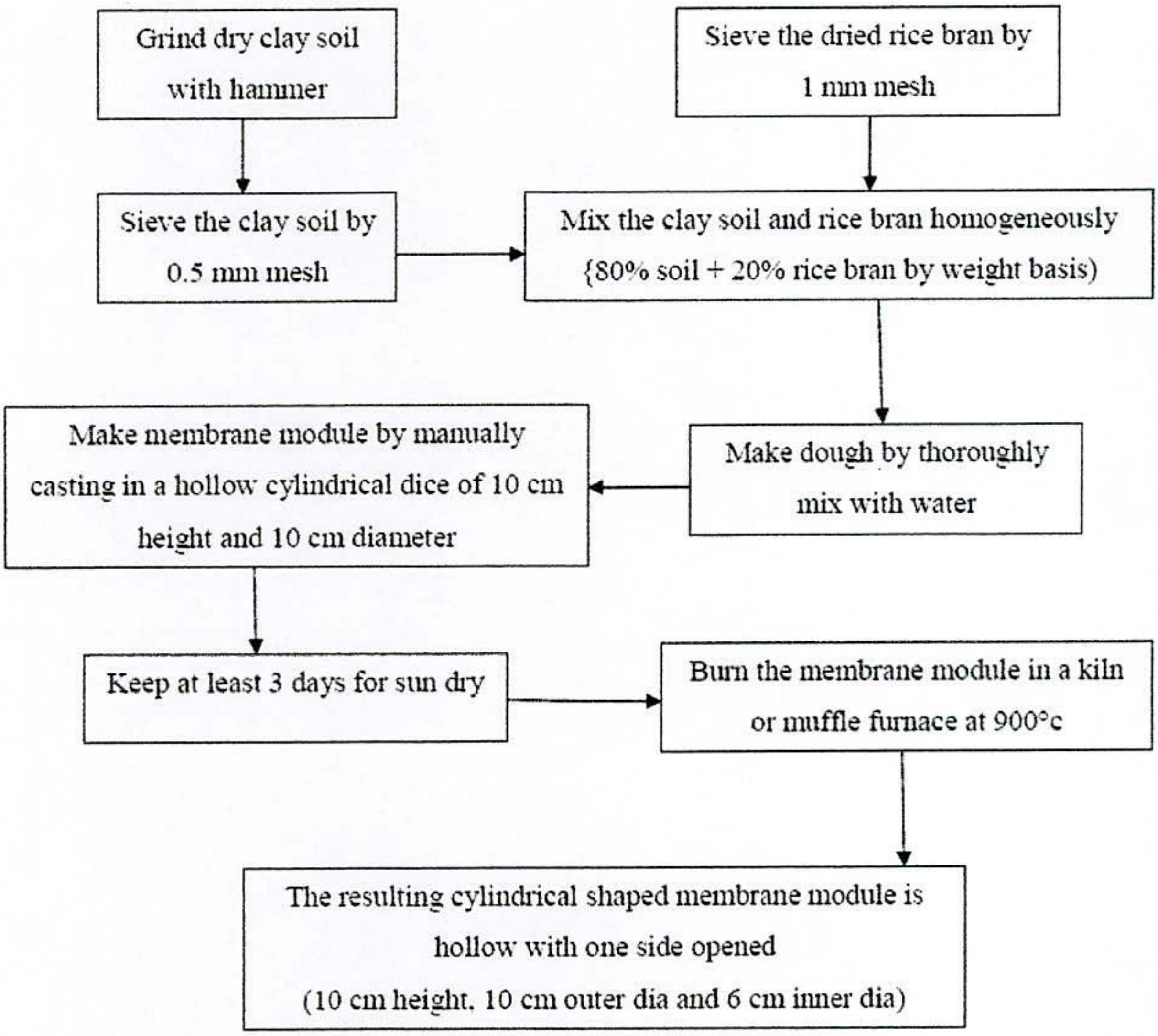
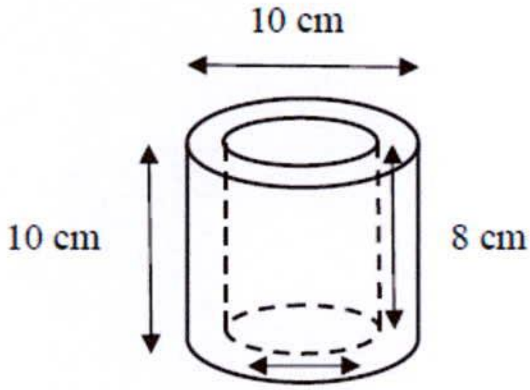



**Fig: 3-1** Flow chart of the making procedure of Ceramic Membrane Module

In order to reduce the manufacturing cost and to keep in mind the theme of "local made", tap water was used instead of de-ionized water, the membrane modules were dried at sunlight for 3-4 days rather than oven dry and finally burnt at field level in local kiln (Fig: 3-3). A small scale house-hold local kiln usually used as pottery burner was chosen for the purpose. And the burning procedure of the membrane modules was kept similar as that of the local pottery. To check and record the temperature from the beginning to the end of burning a thermometer was set. The temperature of the kiln was steadily increased from 34°C to 135°C at first 6.5 hrs. Then within next 15 min the temperature was suddenly raised up to 800°C and for next 2 hrs it was kept constant within the range of 800°C to 900°C. After that Temperature was decreased gradually as the firing was terminated. After the termination of firing the membrane modules were kept into the kiln for overnight and take out from the kiln in next morning.




(a)

(b)

Fig: 3-2 Schematic representation of developed of Ceramic Membrane module, a) Dimension of Ceramic Membrane b) Ceramic Membrane after burn

Fig: 3-3 Burn of Ceramic Membrane Modules at field level

## 3.2 EXPERIMENTAL SETUP OF CERAMIC MEMBRANE BIO-REACTOR

The newly innovated low-cost Ceramic Membrane Reactor is used for the treatment of wastewater with high COD concentration. The Ceramic Membrane was submerged inside a Reactor to formulate as Ceramic Membrane Bioreactor (CMBR). The aim of this chapter is to introduce this CMBR technology in wastewater treatment and reuse sectors. The possibility and the effectiveness of this technology was checked by monitoring the following parameters: a) Organic matter removal; b) Color removal c) SS removal; d) Turbidity removal; e) Fe removal; f) Permeate flux; g) Membrane clogging; h) maintenance and others.

### *3.2.1 Wastewater Used as Feed*

The wastewater used in this study was actual wastewater rather than synthetic Wastewater. The wastewater was collected from a drain near Dr. M. A Rashid Hall in KUET. The raw wastewater used as feed composed of effluent water from septic tank and bathing water from the residential Hall. During collection it has also been found that rain water also mixed with the raw wastewater. The concentration of various ingredients of raw wastewater was different. The intermittent flow of influent was applied in this study.

The objective was to measure influent and effluent characteristics of the raw wastewater. For this purpose various water quality parameter was determined to measure the performance of Ceramic Membrane Bio-Reactor.

### *3.2.2 Experimental Set Up*

For this research study 3 nos of lab-scale Ceramic Membrane Bio-Reactors (CMBRs) were set up as named R-1, R-2, and R-3. All the three Reactors were as cylindrical column shaped with 14 cm inner diameter and made by PVC pipe. The inner diameter of all the Reactors was same as 14 cm and heights was same as about 140 cm. Details specifications of all Reactors are shown in the Table 3-2. In each reactor, Membrane Module was directly submerged inside the Reactor. The Membrane was placed on a PVC plate and was made water tight by using Silica glue to prevent infiltration of water, tilting and floating. The PVC plate with Membrane was then placed at the end of PVC pipe. The Bio-Reactors were filled with raw wastewater. The wastewater was fed into each Reactor from the feed tank by peristaltic pump. The CMBRs were aerated from the beneath of membrane module through a diffuser, so that rising air bubbles can provide the membrane surface with more shear stress, which is effective for removing attached sludge out of membrane, and to mix the mixed liquor in the Reactor and also to maintain an aerobic environment for the normal growth of activated sludge.

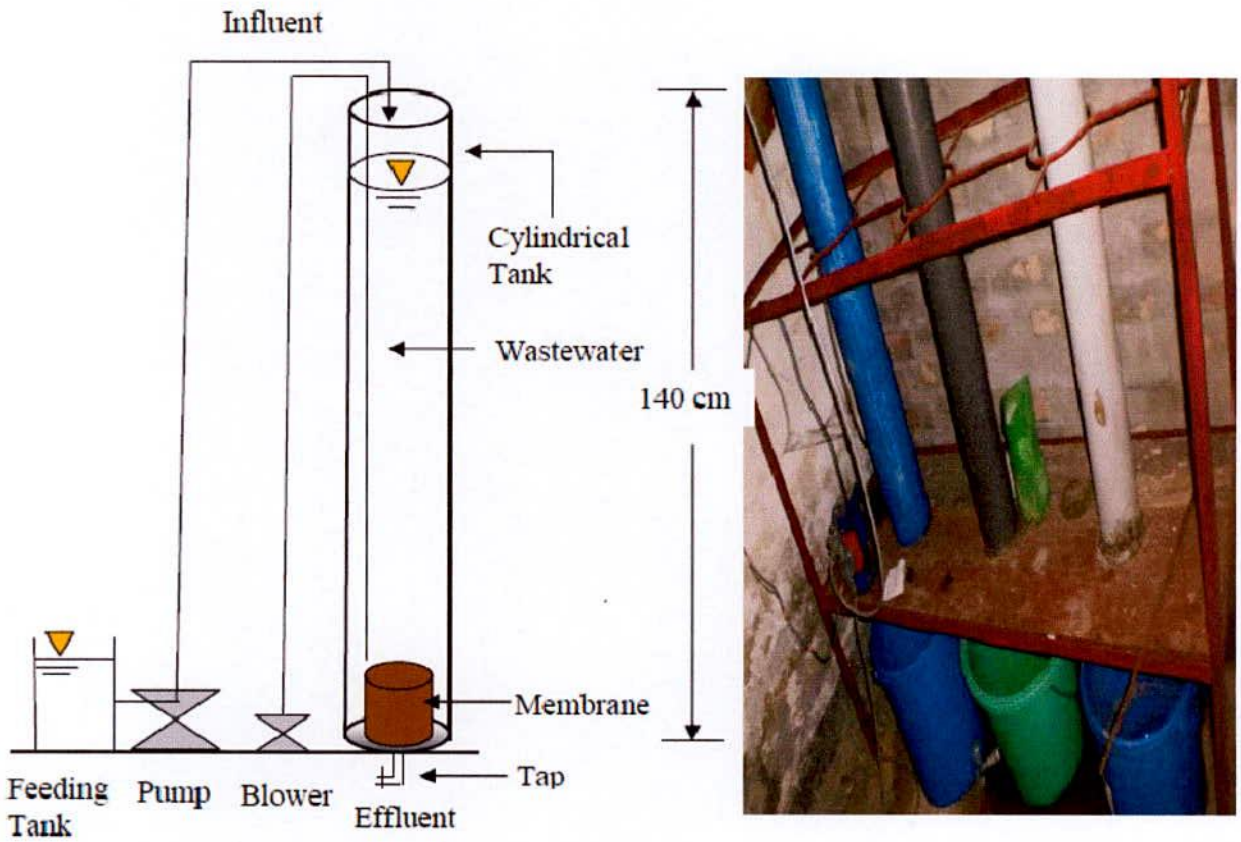
Table: 3-2 Specifications of all Reactors

| Reactors | R-1 | R-2 | R-3 |
|---|---|---|---|
| Working height of wastewater (cm) | 66 | 66 | 66 |
| Amount of wastewater used as feed (Liter/day) | 5.4 | 5.4 | 5.4 |
| Aeration period per day (hr) | 4-5 | 4-5 | 4-5 |

Intermittent aeration system was set up as 4 hr aeration per day by using the blower. The three Reactors R-1, R-2 and R-3 were under aerobic condition. Permeate from the Reactors was collected during the aeration period through outlet by gravitational pressure. The water was sampled every three days per week. The parameters analyzed were the level of Turbidity, Color, TS, TDS, SS, Fe and COD in the Bio-Reactor and permeate. Figure: 3-4 shows the schematic view of the system, displays photographs of the membrane media position in the Reactor and the CMBR under continuous operation in the laboratory. The CMBR systems were monitored by measurement of permeate flux, pH and DO. Sludge retention time (SRT) was infinitive as there was no sludge wastage except for sampling during the operation.

### *3.2.3 Analytical Methods*

During the operation, basic influent and effluent parameters-Turbidity, Color, Total Solids (TS), Total Dissolve Solids (TDS), Suspended Solids (SS), Chemical Oxygen Demand (COD), Iron (Fe) as well as the activated sludge parameters-pH and dissolved oxygen (DO) were analyzed according to the standard methods, as elaborated in Table: 3-3.




(a) (b)

**Fig: 3-4** a) Schematic representation of the system b) CMBR under operation in laboratory

pH was determined using a glass electrode pH meter (HACH- Sens*Ion*2 meter). DO was measured by DO meter (HACH HQ 40d, USA). TDS/TS/SS was measured by (Whatman 15.0 cm 1) filter paper. COD was measured by Closed Reflux Method. The COD data was also obtained from HACH Spectrometer (DR/2500) Test. All analytical analyses were carried out with appropriate reagents and blanks.

Table: 3-3 Standard methods of water quality analyses

| Parameter | Analytical methods |
|---|---|
| pH | pH meter (HACH SensIon2, USA) |
| DO | DO meter (HACH HQ 40d, USA) |
| COD | Closed Reflux method & HACH Spectrometer (DR/2500) |
| Turbidity | Turbidity meter (HACH 2100p Turbidity meter, USA) |
| Color | HACH Spectrometer (DR/2500) |
| TS/TDS/SS | Filter Paper Method (Whatman 15.0 cm 1) |
| Fe | HACH Spectrometer (DR/2500) |

## 3.3 MEMBRANE MAINTENANCE

The Run time of Reactor-1, Reactor-2 and Reactor-3 were 215 days. Within this time period Reactor-1 and Reactor-2 were clogged after 129 days from 29-12-10 to 04-05-11. Reactor-3 was clogged after 65 days and after cleaning it was clogged again at 129 days. A cake layer formation was found on all Ceramic Membrane surfaces because of the deposition of the floe sludge. It was also noticed that large amount of sludge was accumulated with the stand and blocked the bottom surface. This might be reduced the filterability of the bottom (Fig: 3-5). The membrane was then cleaned physically by removing the accumulated sludge with the help of water, knife and soft spongy brush. The result emphasized that membrane pores were not clogged; only cake layer was formed upon the membrane surface which was easily removable by physical cleaning. There was no need of chemical washing or change of the membrane.

**Fig: 3-5** Formation of cake layer on some portion of the membrane surface

Since a bulky amount of sludge was accumulated around the filter and was thought that the filterability of inner and outer surface was reduced, so the membrane position was changed. The filter was set again in the reactors for further continuation to check the flux variations.

Employing the principle of gravitational filtration, the ceramic membrane filtration was able to be continued for 129 days without membrane washing, Filtration rate was recovered and was still stable after the membrane washing on the 129 day. Physical cleaning was suitable and adequate for removing the cake layer to reclaim the ceramic membrane. Since the pore of the membrane was not clogged, only the sludge accumulation on membrane surface was occurred. Fig: 3-6 shows the cleaning procedure of Ceramic Membrane after clogging. After cleaning, the membrane was placed again as previous in the Reactor and the flux performance was observed (Fig: 3-7). It was found that the flux was increased remarkably to at every Reactor. Physical cleaning was very effective to recover the flux, even higher level than before.

Fig: 3-7 Setup of CMBR after clogging

# *Chapter 4*

# *Results and Discussion*

### 4.1 Operating Parameters

**4.1.1 Dissolved oxygen (DO) in CMBR:** Dissolved oxygen is one of the most important parameters in aquatic systems. This gas is an absolute requirement for the metabolism of aerobic organisms and also influences inorganic chemical reactions. Adequate dissolved oxygen is needed and necessary for good water quality. If dissolved oxygen levels in water drop below 5.0 mg/L, aquatic life is put under stress. Oxygen levels that remain below 1-2 mg/L for a few hours can result in large fish kills.

From laboratory test it was found that the average DO in influent wastewater was 3.47 mg/l. The average effluent DO by Reactor-1, Ractor-2 and Reactor-3 were 5.42 mg/l, 5.42 mg/l and 5.47 mg/l, respectively. During the accumulation of effluent water into the bucket it has been found that the effluent water was exposed to air and the value of DO increase because of aeration. The standard value of DO is 4.5 to 8 for discharging the wastewater into land water, public sewer and on irrigated land. The average effluent DO by all Reactors was 5.44 mg/l which is within the standard value.

**4.1.2 pH in CMBR:** pH is a term used universally to express the intensity of the acid or alkalinity condition of a solution. In most raw water sources, pH lies within the range 6.5-8.5. In water supply, pH is very important as the organism involved in treatment processes operate within a certain pH range.

The pH value in influent was within the range of 6.68 to 8.80 and the average pH value in influent was 7.97. The average pH value in Reactor-1, Reactor-2 and Reactor-3 were 7.99, 7.92 and 7.91 respectively. The pH of all Reactors was stable within the range of 7-8 as shown in Figure: 4-1.

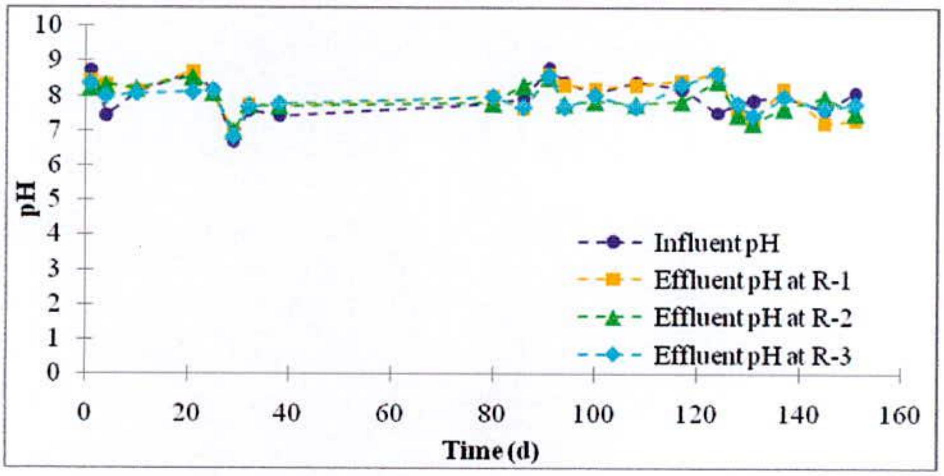



Figure: 4-1 Range of pH in CMBR

## 4.2 Turbidity Removal

**4.2.1 Influent and Effluent Characteristics:** Turbidity is one of the basic concerns in the treatment of any types of wastewater. Turbidity occurs in most wastewater due to the presence of suspended clay, silt, finely divided organic and inorganic matters, plankton (algae) and micro-organisms. From laboratory test it was found that average Turbidity in influent was 602.85 NTU with minimum and maximum value of 139 NTU and 3930 NTU respectively as shown in Table: 4-1. After treatment the effluent showed very low Turbidity as the average Turbidity of Reactor-1 was 11.57 NTU with minimum and maximum value of 2.05 NTU and 62 NTU respectively. The average effluent Turbidity of Reactor-2 was 15.45 NTU with minimum and maximum value of 1.66 NTU and 68.3 NTU respectively and the average Turbidity of effluent of Reactor-3 was 13.64 NTU with minimum and maximum value of 2.42 NTU and 50.2 NTU, respectively. Figure 4-2 and Figure 4-3 show influent and effluent characteristics of all Reactors. As can be seen, the Turbidity of influent water varies throughout the time period. As actual water was used rather than synthetic water, the influent Turbidity varies depending on quantity of water uses, consumption pattern, time, weathering etc. Some time effluent turbidity increased radically when influent turbidity is very high.

Table: 4-1 Influent and Effluent Turbidity of Wastewater.

| | Influent | Effluent | | |
|---|---|---|---|---|
| | | Reactor-1 | Reactor-2 | Reactor-3 |
| Average (NTU) | 602.85 | 11.57 | 15.45 | 13.64 |
| Minimum(NTU) | 19.1 | 2.05 | 1.66 | 2.42 |
| Maximum (NTU) | 2130 | 62 | 68.3 | 50.2 |

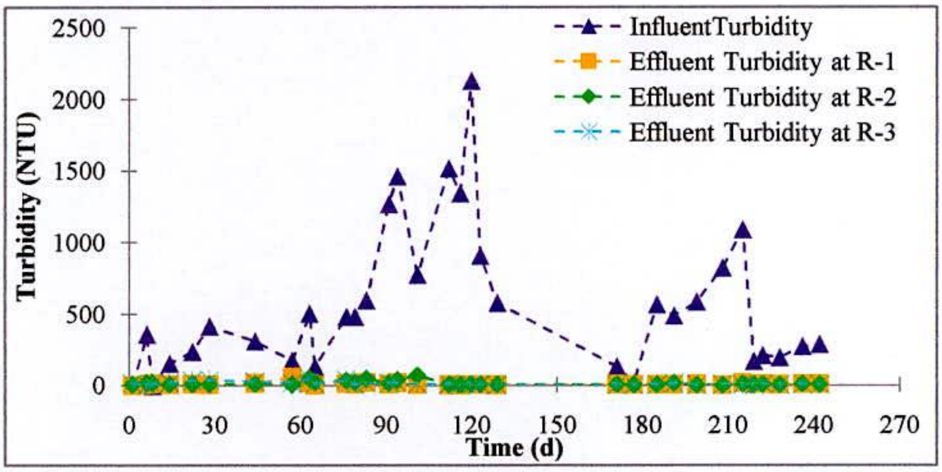



Figure: 4-2 Turbidity in Influent and Effluent

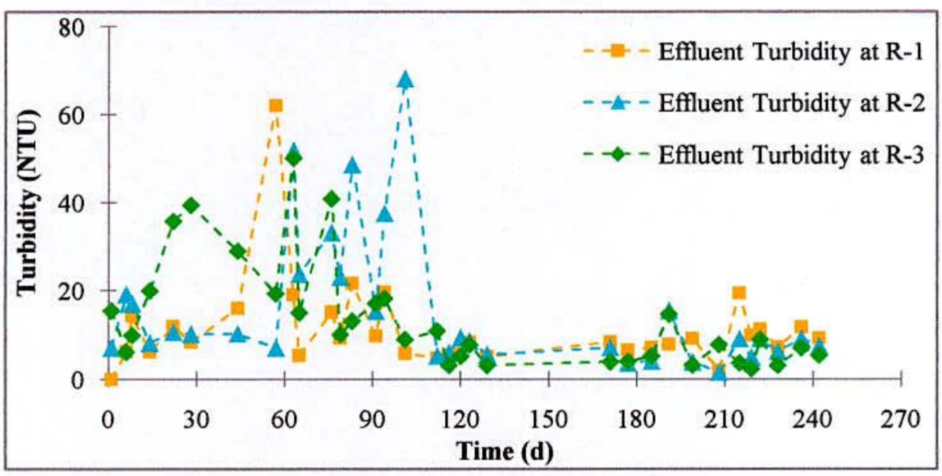



Figure: 4-3 Effluent Turbidity of CMBR

**4.2.2 Removal Efficiency:** Significant Turbidity removal was achieved by CMBR. Turbidity removal efficiency of Reactor-1, Reactor-2 and Reactor-3 were 95.31%, 95.49% and 95.21% respectively. The minimum and maximum Turbidity removal efficiency of Reactor-1 are 64.57% and 99.75% respectively. Turbidity removal efficiency of Reactor-2 varies from 80.63% to 99.80%. Turbidity removal efficiency of Reactor-3 varies from 78.38% to 99.76%. Figure: 4-4 shows Turbidity Removal Efficiency of all three Reactors.

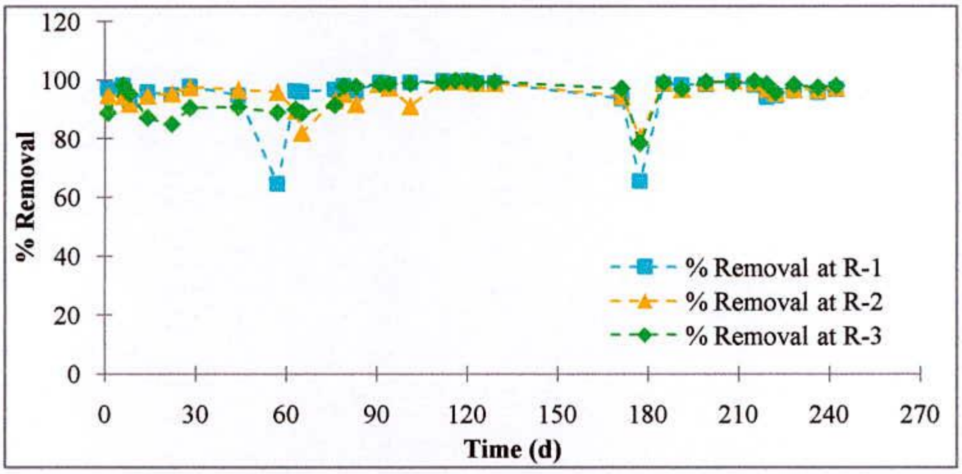



Figure: 5-4 Turbidity Removal Efficiency by CMBR

The average Turbidity Removal efficiency of all Reactors was 95.34%. It is worth to state that an excellent performance for Turbidity removal was observed for all Runs.

**4.3 Color Removal:**

**4.3.1 Influent and Effluent Characteristics:** From laboratory test it was found that the average Color in influent was 2294 Pt-Co with minimum and maximum value of 148 Pt-Co and 8130 Pt-Co respectively. Color reduced significantly by CMBR as average effluent Color of Reactor-1, Reactor-2 and Reactor-3 among 32 samples were 138.79 Pt-Co, 184.47 Pt-Co and 142.91 Pt-Co respectively. Color in influent and effluent is shown in Table: 4-2.

Table: 4-2 Influent and Effluent Characteristics of Color

| | Influent | Effluent | | |
|---|---|---|---|---|
| | | Reactor-1 | Reactor-2 | Reactor-3 |
| Average (Pt-Co) | 2293.74 | 138.79 | 184.47 | 142.91 |
| Minimum | 148 | 20 | 55 | 48 |
| Maximum | 8130 | 580 | 900 | 393 |

The variation of color in influent and effluent is shown in Figure: 4-5 and in Figure: 4-6. It was found that Color reduced significantly by all Reactors.

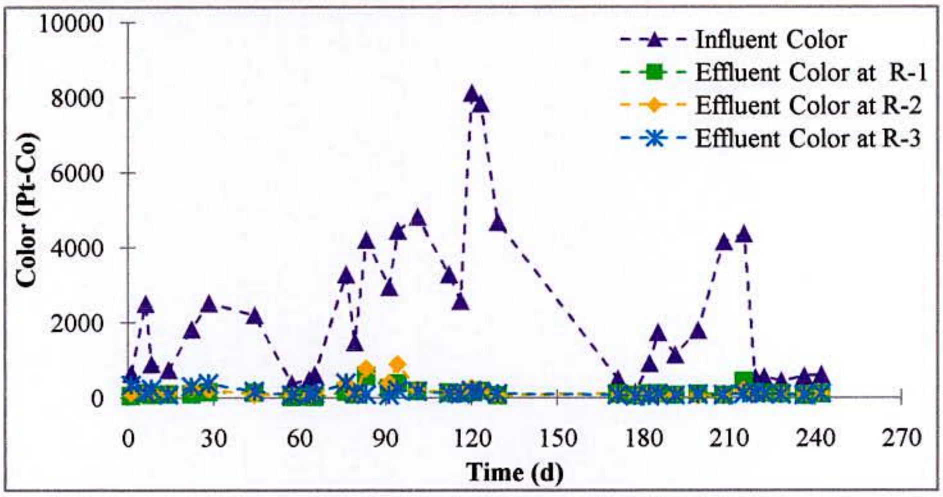



Figure: 4-5 Color in Influent and Effluent

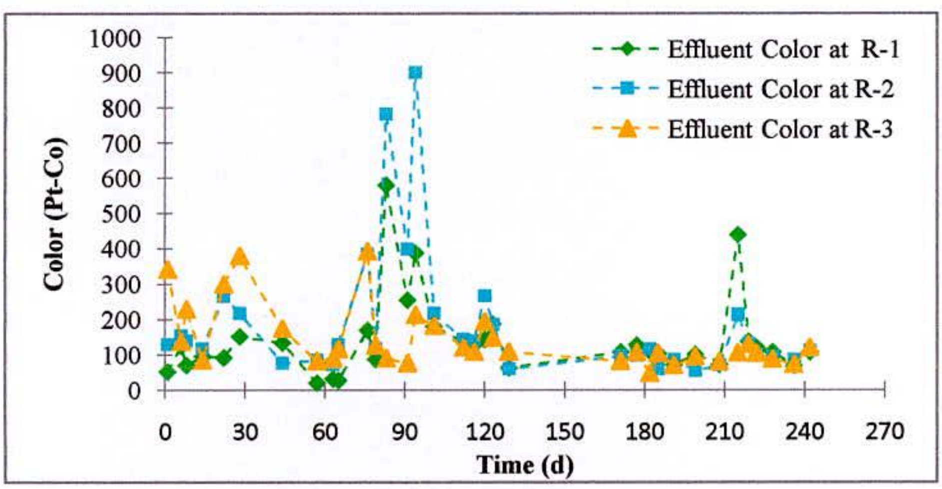



Figure: 4-6 Effluent Color by CMBR

**4.3.2 Removal Efficiency:** Significant Color removal efficiency was achieved by CMBR. Removal efficiency of Reactor-1, Reactor-2 and Reactor-3 were 90.10%, 87.48% and 87.78% respectively. The color removal efficiency of Reactor-1 was within the range of 54.73% to 98.65%. The color removal efficiency of Reactor-2 was within the range of 60.81% to 98.70% and color removal efficiency of Reactor-3 varied within 47.39% to 98.11%. The result emphasized that about 88.45% Color removal was achieved by the system. Figure 4-7 shows the Color removal efficiency of all Reactors.

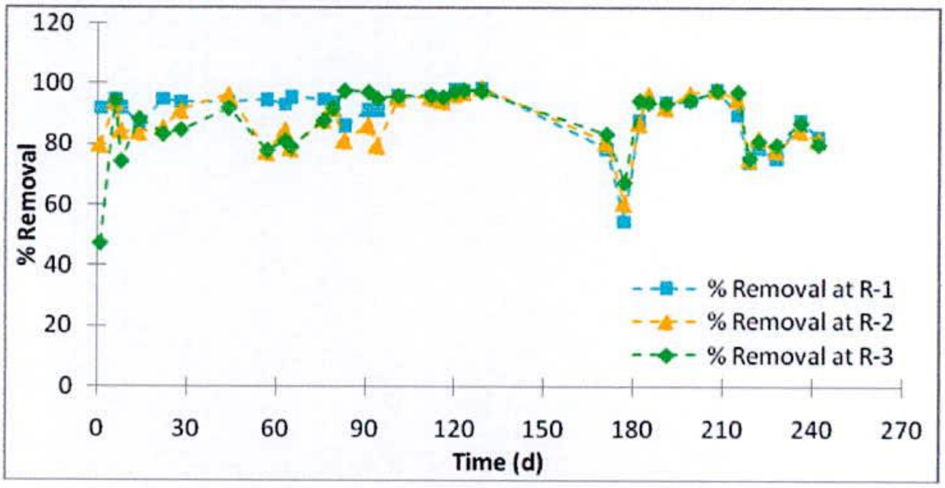



Figure: 4-7 Color Removal Efficiency by CMBR

As it is observed that effluent Color increased radically when the Color of influent is very high. As influent Color was very low at 177 days, the removal efficiency was low although the effluent color was below the average effluent color of 155.39 Pt-Co as shown in Figure 4-5 and 4-7.

### 4.4 COD Removal:

**4.4.1 Influent and Effluent Characteristics:** Disposal of wastewater containing high COD to receiving water bodies might cause oxygen depletion that will have harmful effects to living resources like fishes, or eventually make the environment anaerobic. Therefore, its removal is given more focus in any wastewater treatment facility.

Through the study it was found that the average COD of influent wastewater was 572.91 mg/l with minimum and maximum value of 92 mg/l and 1568 mg/l respectively. After treatment by CMBR the effluent showed very low COD as the average value of COD in effluent of Reactor-1, Reactor-2 and Reactor-3 were 68.40 mg/l, 84.91 mg/l and 78.36 mg/l respectively during the operation period. Table: 4-3 and Fig: 4-8 shows the concentration of COD in influent and effluent of all Reactors.

Table: 4-3 COD in Influent and Effluent

| | Influent | Effluent | | |
|---|---|---|---|---|
| | | Reactor-1 | Reactor-2 | Reactor-3 |
| Average (mg/l) | 572.91 | 68.40 | 84.91 | 78.36 |
| Minimum (mg/l) | 92 | 20.70 | 16 | 16 |
| Maximum (mg/l) | 1568 | 131.20 | 184 | 217 |

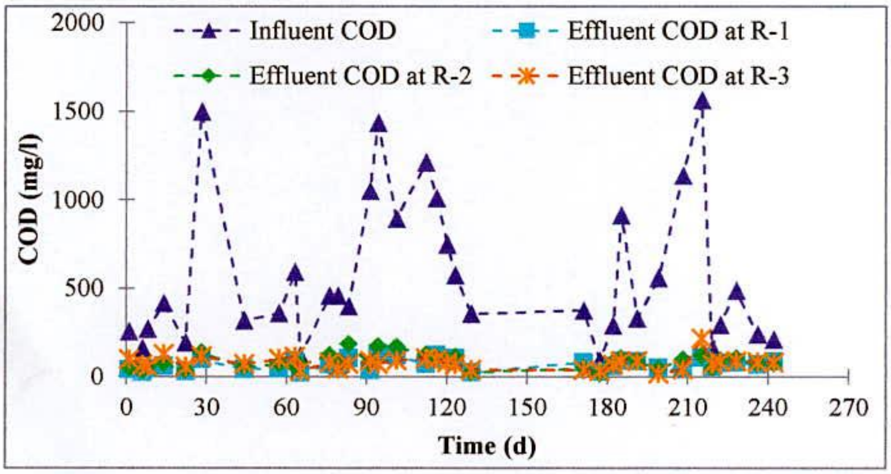



Figure: 4-8 COD concentration in Influent and Effluent

The standard value of COD is 200 mg/l for discharging the wastewater into land water. The standard value of COD for discharging the wastewater into public sewer and on irrigated land is 400 mg/l. The average effluent COD value by all Reactors was 77.22 mg/l which is well below the standard value.

**4.4.2 Removal Efficiency:** It has been that the COD removal efficiency of Reactor-1, Reactor-2 and Reactor-3 were 83.95%, 80.47% and 80.24% respectively. Figure 4-9 shows the COD removal efficiency of all runs. The COD removal efficiency of Reactor-1 was within the range of 59.52% to 96.68%. The COD removal efficiency of Reactor-2 was within the range of 46.67% to 93.26% and COD removal efficiency of Reactor-3 varied within 55.62% to 99.14%. It has also been found that about 81.55% of COD removal was achieved by the three Reactors. It is worth to state that an excellent performance for COD removal was observed by CMBR.

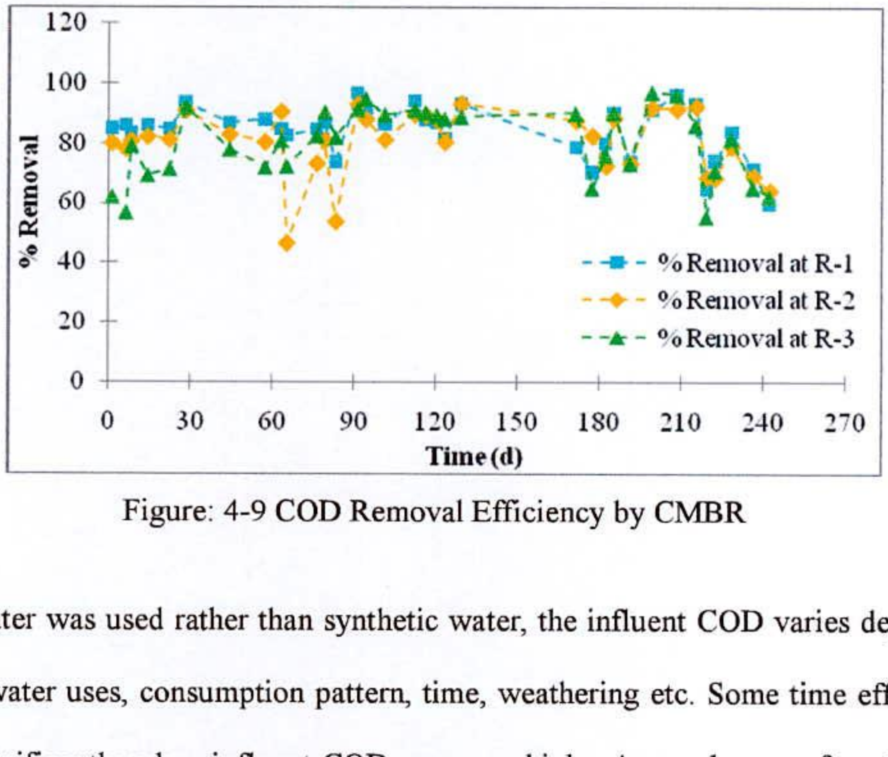



Figure: 4-9 COD Removal Efficiency by CMBR

As actual water was used rather than synthetic water, the influent COD varies depending on quantity of water uses, consumption pattern, time, weathering etc. Some time effluent COD increased significantly when influent COD was very high. As can be seen from Figure 4-8, the value of COD in influent water at 65$^{th}$ day was very low, about 120 mg/l. As CMBR can remove COD by a certain limit, the removal efficiency depends on influent COD. As initial COD was very low at 65$^{th}$ day its removal efficiency was low although the effluent COD of Reactor-, Reactor-2 and Reactor-3 were 20.7 mg/l, 64 mg/l and 33 mg/l respectively which were below the average effluent COD of 77.22 mg/l. The results presented above indicate that CMBR has great potential in removing biodegrading organic pollutants from wastewater.

### 4.5 TS, TDS, SS Removal:

**4.5.1 Influent and Effluent Characteristics:** TS, TDS, SS is one of the important concern in the treatment of wastewater. Its disposal causes clogging of sewerage system and also its disposal to water bodies have harmful effects to living resources.

It has been found that the average TS in influent were 3329 mg/l with minimum and maximum value of 1790 mg/l and 5189 mg/l, respectively. The Average TS in effluent of Reactor-1, Reactor-2 and Reactor-3 were 2040 mg/l, 2094 mg/l and 2123 mg/l, respectively. The concentration of TS, TDS, and SS in influent and effluent wastewater is shown in Table 4-4, Table 4-5 and in Table 4-6, respectively.

Table: 4-4 Total Solid in Influent and Effluent

| | Influent | Effluent | | |
|---|---|---|---|---|
| | | Reactor-1 | Reactor-2 | Reactor-3 |
| Average (mg/l) | 3329 | 2040 | 2094 | 2123 |
| Minimum (mg/l) | 1790 | 898 | 1005 | 948 |
| Maximum (mg/l) | 5189 | 3036 | 3151 | 3080 |

Table: 4-5 Total Dissolve Solid in Influent and Effluent

| | Influent | Effluent | | |
|---|---|---|---|---|
| | | Reactor-1 | Reactor-2 | Reactor-3 |
| Average (mg/l) | 2318 | 2017 | 2062 | 2095 |
| Minimum (mg/l) | 994 | 879 | 978 | 917 |
| Maximum (mg/l) | 3152 | 3020 | 3140 | 3040 |

The standard value of TS and TDS for discharging the wastewater into land water, public sewer and on irrigated land is 2100 mg/l. The average TS and TDS in effluent of all Reactors were 2085 mg/l and 2058 mg/l, respectively which are below the standard value.

Table: 4-6 Suspended Solid in Influent and Effluent

| | Influent | Effluent | | |
|---|---|---|---|---|
| | | Reactor-1 | Reactor-2 | Reactor-3 |
| Average (mg/l) | 1011 | 22.95 | 32.79 | 28.03 |
| Minimum (mg/l) | 28 | 1 | 2 | 1 |
| Maximum (mg/l) | 3080 | 49 | 83 | 84 |

Data also reveal that the TDS removal was not satisfactory due to the presence of chloride in influent wastewater. The average value of SS in influent was 1011.34 mg/l with minimum and maximum value of 28 mg/l and 3080 mg/l respectively. After treatment remarkable SS removal was achieved by CMBR as the average effluent SS of Reactor-1, Reactor-2 and Reactor-3 were 22.95 mg/l, 32.79 mg/l and 28.03 mg/l respectively. The variation of SS in influent and effluent is shown in Figure: 4-10 and in Figure: 4-11.

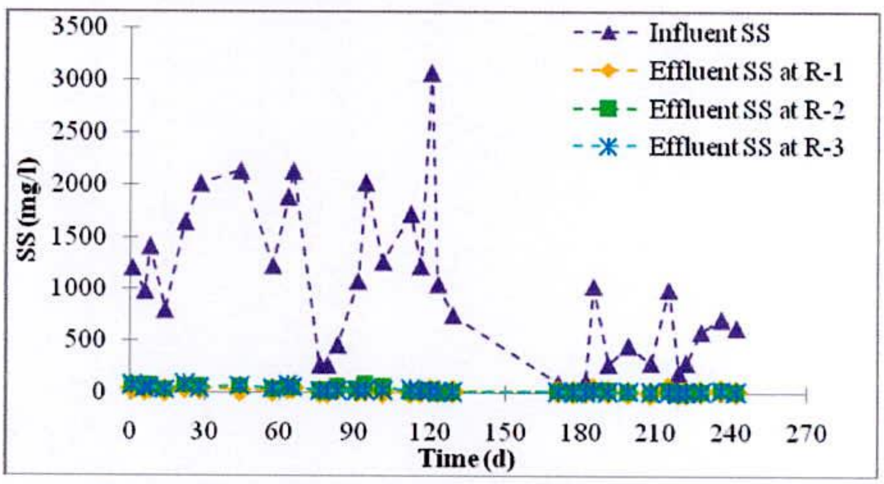



Figure: 4-10 Concentration of SS in Influent and Effluent

The standard value of SS for discharging the wastewater into land water is 150 mg/l. The standard value of SS for discharging the wastewater into public sewer is 500 mg/l and on irrigated land is 200 mg/l. The average effluent SS by all Reactors is 27.92 mg/l which is well below the standard value. So the effluent water can be applied for reuse purposes in terms of TS, TDS and SS concentration.

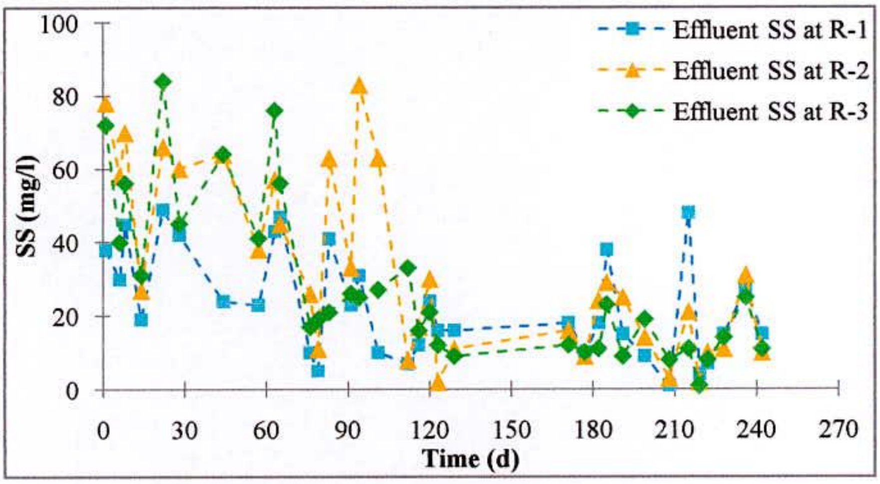



Figure: 4-11 Concentration of SS in Effluent

**4.5.2 Removal Efficiency:** TS removal efficiency of Reactor-1, Reactor-2 and Reactor-3 were 37.16%, 35.25% and 35.09% respectively and TDS removal efficiency were 12.81%, 9.77% and 9.73% respectively. The data also reveals that the SS removal efficiency of Reactor-1, Reactor-2 and Reactor-3 were 95.61%, 94.59% and 95.56% respectively. The average SS removal efficiency was 95.25% by all Reactors. The SS removal efficiency of Reactor-1 was within the range of 64.23% to 99.65%. The SS removal efficiency of Reactor-2 was within the range of 67.86% to 99.81% and SS removal efficiency of Reactor-3 varied within 64.29% to 99.48%. Figure: 4-12 and Figure: 4-13 shows TS and SS removal efficiency of all Reactors.

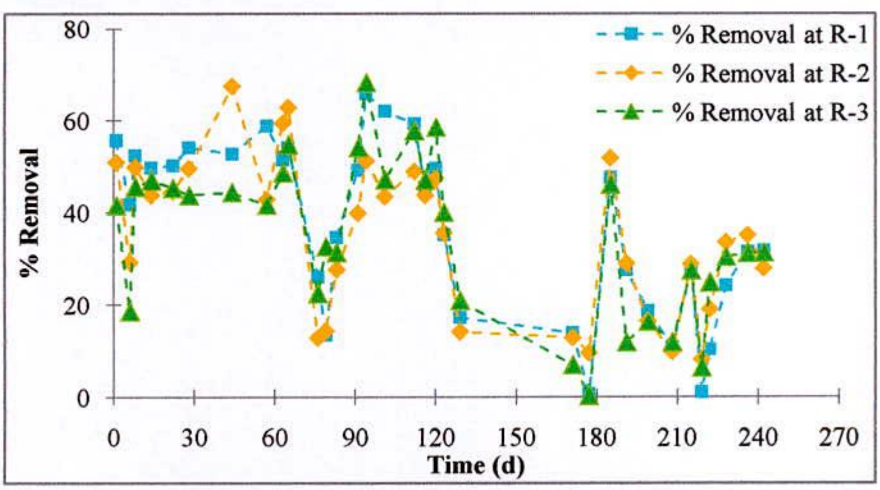



Figure: 4-12 TS removal efficiency by CMBR

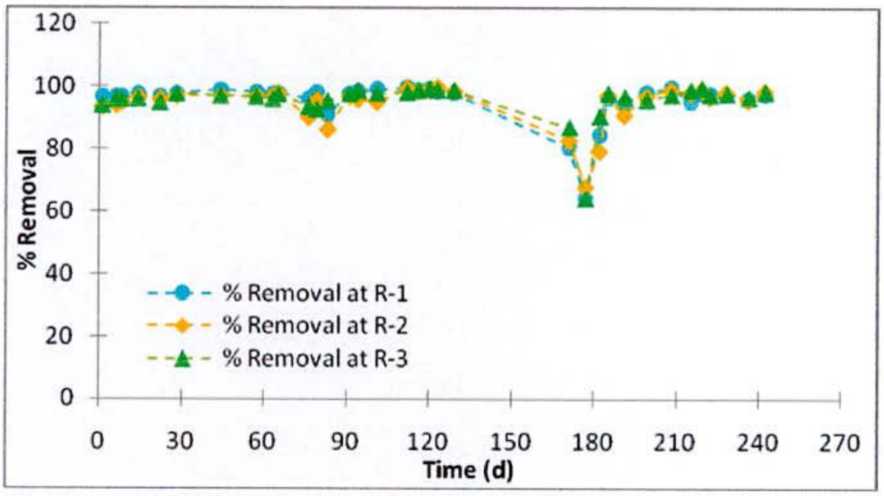



Figure: 4-13 SS removal efficiency by CMBR

As actual water was used rather than synthetic water, the influent SS varies depending on quantity of water uses, consumption pattern, time, weathering etc. Some time effluent SS increased significantly when influent SS was very high. It has been found that the value of SS in influent water at 177$^{th}$ day was very low, about 28 mg/l (as shown in Figure: 4-10). As CMBR can remove SS by a certain limit, the removal efficiency depends on influent SS. As influent SS was very low at 177$^{th}$ day its removal efficiency was also low although the effluent SS of Reactor-1, Reactor-2 and Reactor-3 were 10.0 mg/l, 9.0 mg/l and 10.0 mg/l respectively which were below the average effluent SS of 27.92 mg/l.



### 4.6 Fe Removal:

**4.6.1 Influent and Effluent Characteristics:** In this study, it was found that significant Fe removal was achieved by CMBR. The average concentration of Iron in influent wastewater was 0.2 mg/l which was very low because the wastewater used as influent in CMBR was surface water. As the concentration of Iron in Influent water was very low, the data collection was carried out up to 129 days. The average concentration of Iron (Fe) in effluent water was

0.02 mg/l with minimum and maximum value of 0.0 mg/l and 0.06 mg/l respectively. The concentration of Fe in influent and effluent water is shown in Figure: 4-14.

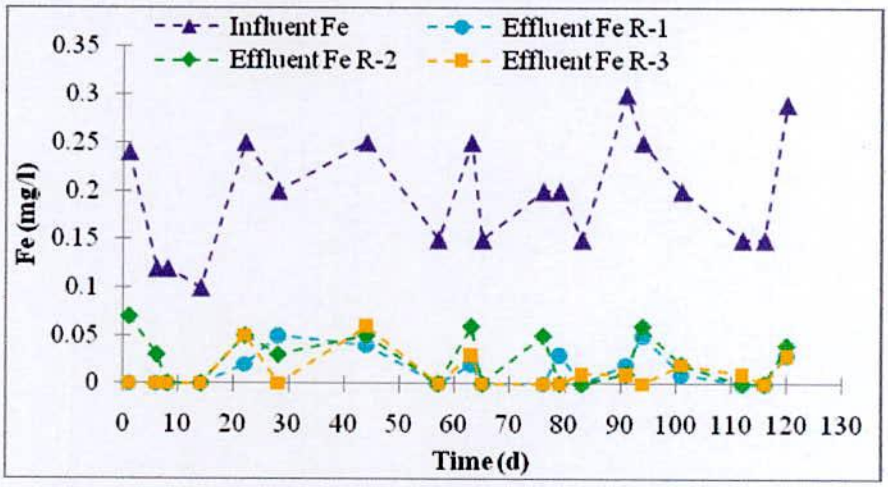



Figure: 4-14 Concentration of Fe in Influent and Effluent

**4.6.2 Removal Efficiency:** Iron removed significantly by CMBR. The Iron removal efficiency of Reactor-1, Reactor-2 and Reactor-3 were 93.99%, 88.98% and 95.1% respectively and the average removal efficiency of all Reactors was 92.69%. Figure 4-15 shows the Fe removal efficiency of all Reactors.

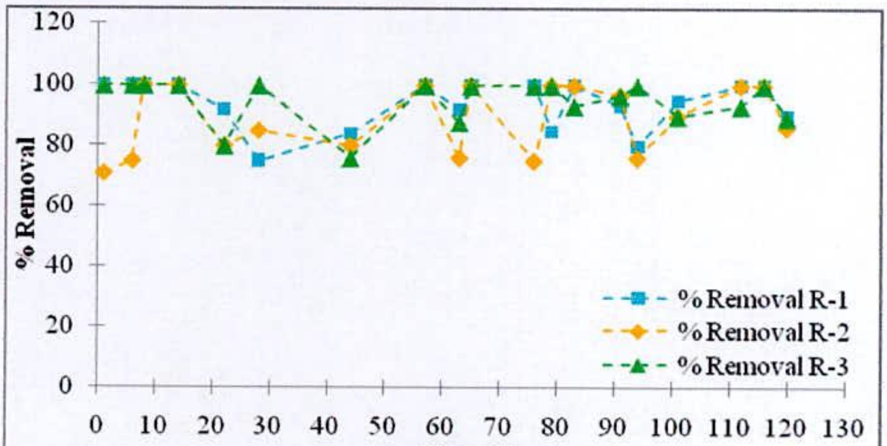



Figure: 4-15 Fe removal efficiency by CMBR

As CMBR can remove Iron by a certain limit, the removal efficiency depends on the concentration of influent Iron. When influent Fe was very low, its removal efficiency was also very low. The data show that the Iron removal efficiency was very good by CMBR.

## 4.7 Flux Performance

### 4.7.1 Variation of Flux:

The fluxes of different Reactors were determined by simple gravitational filtration method. Initial fluxes at R-1, R-2 and R-3 Reactor were found 100 ml/min 90 ml/min and 39 ml/min respectively. The Run time of Reactor-1 Reactor-2 and Reactor-3 were 242 days from 29-12-10 to 24-08-11. Within this time period Reactor-1 and Reactor-2 were clogged after 129 days. But Reactor-3 was clogged after 65 days and after cleaning it was clogged again at 129 days. Figure: 4-16 demonstrates the flux details of all Reactors.

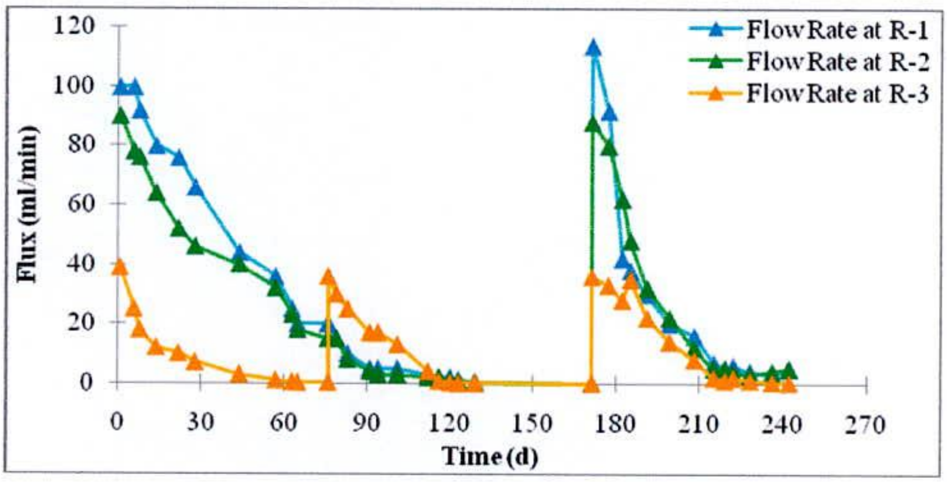



Figure: 4-16 Variation of Flux

As can be seen, Flux decreased gradually throughout the time period. The Flux of Reactor-1, Reactor-2 and Reactor-3 before clogging were 0.5 ml/min, 0.25 ml/min and 0.1ml/min respectively. It is noticeable that the membrane was not totally clogged rather its flow rate was very low. As blockage of the pores of the membranes by solid particles was removed by cleaning, sharp rise of the Flow rate occurred after 65 days and 171 days as shown in Figure: 4-16. A sharp decrease of the flux can occur due to non uniform air distribution into the membrane tank caused the total blockage of the gap between the membranes by solid particles (TS,TDS,SS), leading to reduction of the membrane flow capacity.

## 4.8 Other Findings

**4.8.1 Comparison between Chemical Method and Spectrometer Test:** For ease in research, most of the COD in this research obtained by Chemical Method (Closed Reflux Method) were compared with Spectrometer Test. It was found that the data obtained from Chemical Method was similar to the data obtained from HACH Spectrometer Test. Table: 4-7 and Fig: 4-17 demonstrates COD values obtained by Chemical Method and Spectrometer Test.

Table: 4-7 COD value by Chemical Method and Spectrometer Test

| Date | COD value by Chemical Method mg/l | COD value by Spectrometer Test mg/l |
|---|---|---|
| 13-03-11 | 472 | 458 |
| 13-03-11 | 112 | 122 |
| 16-03-11 | 54.4 | 60 |
| 20-03-11 | 376 | 399 |
| 23-03-11 | 98 | 104 |
| 23-03-11 | 196 | 184 |
| 28-03-11 | 872 | 1053 |
| 28-03-11 | 48 | 35 |
| 28-03-11 | 112 | 73 |
| 17-04-11 | 1160 | 1218 |
| 17-04-11 | 80 | 71 |
| 17-04-11 | 126 | 126 |
| 25-04-11 | 1000 | 750 |
| 25-04-11 | 104 | 90 |
| 28-04-11 | 88 | 105 |
| 28-04-11 | 120 | 112 |
| 25-07-11 | 41.6 | 48 |
| 01-08-11 | 88 | 71 |

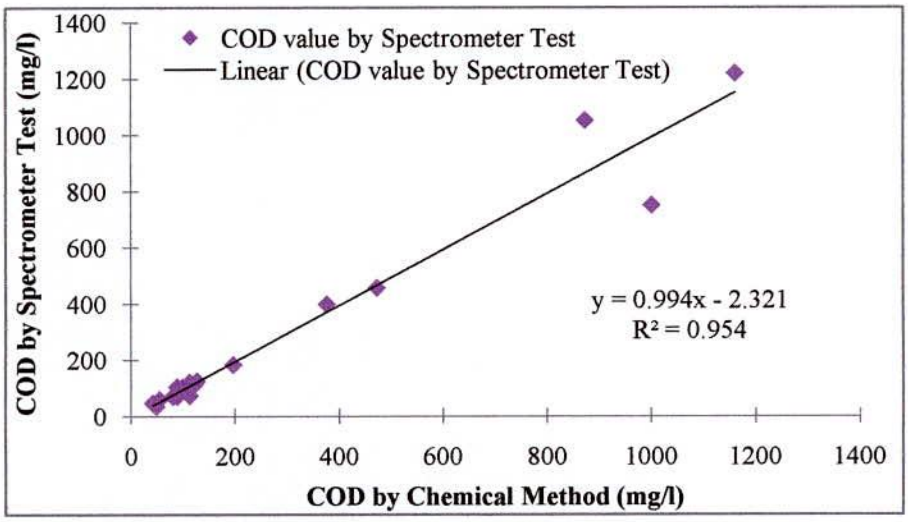



Figure: 4-17 Comparison between Chemical Method and Spectrometer Test

From laboratory Test it was found that the data obtained by Chemical method was very similar to the data obtained from Spectrometer Test. From Figure: 5-17 it can be seen that the value of Regression Coefficient $R^2$=0.95 which reveals that excellent accuracy was achieved by Chemical method.

**4.8.2 Chloride Test:** It has been found that TDS removal efficiency by CMBR was poor, for this reason Chloride Test was performed. Through laboratory test significant amount of Chloride was found in influent and effluent wastewater which means that there was salinity in wastewater. As Salinity or Chloride removal efficiency by filtration process is poor, TDS removal efficiency was not satisfactory. For example from Chloride test, it was found that influent chloride was 1050 mg/l where as effluent chloride was 790 mg/l which means that about 1711.5 mg/l NaCl was present in influent water and about 1287.7 mg/l NaCl was present in effluent water. The TDS in influent and effluent were 2930 mg/l and 2432 mg/l respectively which means other kinds of salt like $CaCl_2$ or KCl was also present in wastewater. For this reason TDS removal efficiency was not satisfactory.

### 4.8.3 BOD & COD Removal by Using Synthetic water and Actual Wastewater:

Organic matter in terms of COD and BOD is very important concern in the treatment of any types of wastewater. From previous study it has been found that COD concentration of synthetic wastewater used during the operation period was 4500 mg/l but COD concentration in the effluent dominated at 10 mg/l from first week of the operation. That means, about 99% of COD was removed (Hasan and Nakajima 2010). In this study actual wastewater was used as feed and it has been found that about 81.55% of COD removal was achieved by the CMBR. It is worth to state that an excellent performance for COD removal was observed for all Runs. The standard value of COD is 200 mg/l for discharging the wastewater into land water. The standard value of COD for discharging the wastewater into public sewer and on irrigated land is 400 mg/l. By using Actual wastewater, it has been found that the average effluent COD value by all Reactors was 77.22 mg/l which is well below the standard value.

From previous study it has been found that BOD concentration of synthetic wastewater used during the operation period was 5000 mg/l but effluent BOD was lower than 5 mg/l which meant, about 99.9% of BOD was removed (Hasan and Nakajima 2010). In this study actual wastewater was used as feed and it has been found that among six samples, the average BOD concentration of raw wastewater used during the operation period was 5.33 mg/l but average effluent BOD was about 0.96 mg/l which means that about 82% of BOD removal was achieved by CMBR.

Overall, it can be concluded that the CMBR has great potential in removing biodegrading organic pollutants from wastewater.

### 4.8.4 Nitrogen Removal:

Wastewater may contain high levels of the nutrients nitrogen. Excessive release to the environment can lead to a buildup of nutrient, called Eutrophication, which can in turn encourage the overgrowth of weeds, algae, and cyano-bacteria (blue-green algae). This may cause an algal bloom, a rapid growth in the population of algae. The algae numbers are sustainable and eventually most of them die. The decomposition of the algae by bacteria uses up so much of oxygen in the water that most or all of the water-animals die, which creates more organic matter for the bacteria to decompose. In addition to causing de-oxygenation, some algal species produce toxins that contaminate the water bodies. The removal of nitrogen is effected through the biological oxidation of nitrogen from ammonia (nitrification) to nitrate, followed by denitrification, the reduction of nitrate to nitrogen gas. Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. The oxidation of ammonia ($NH_3$) to nitrite ($NO_2^-$) is most often facilitated by *Nitrosomonas spp* and nitrite ($NO_2^-$) oxidation to nitrate ($NO_3^-$) by *Nitrobacter spp* or *Nitrospira spp.* Denitrification requires anoxic conditions to encourage the appropriate biological communities to form and it is facilitated by a wide diversity of bacteria. In denitrification process, wastewater acts as an electron donor for the reduction of nitrate ($NO_3^-$) to dinitrogen gas ($N_2$).

From previous study it has been found that T-N was reduced to less than 5 mg/l from initial concentration of 50 mg/l that shows more than 90% removal efficiency was obtained by CMBR (Hasan and Nakajima 2010).

### 4.8.5 Phosphorus Removal:

Phosphorus can be removed biologically in a process called Enhanced Biological Phosphorus Removal (EBPR). EBPR appears at the end of aeration and the beginning of anaerobic period in the absence of nitrate. Under these conditions a group of heterotrophic bacteria, called polyphosphate-accumulating organisms (PAO) will accumulate large quantities of polyphosphate and thereby phosphorous is removed (Hasan and Nakajima 2010).

From previous study it has been found that phosphorus concentration in synthetic wastewater was 5 mg/l but after 7 days of the operation period the concentration was decreased up to 1 mg/l for the effluent. About 80%, Phosphorous removal was achieved by CMBR (Hasan and Nakajima 2010). Therefore, it is worth to state that phosphorous removal was strongly affected by the EBPR process and was removed by CMBR technology.

### 4.8.6 Important Findings:

The total amount of wastewater used for all Reactors is about 550.8 liters (183.6 Liters for each Reactor). After 129 days of operation about 113 liters of wastewater was used for each Reactor. After 242 days of operation about 70.2 liters of water was used for each Reactor.

Table 4-8: Overall condition of Reactor-3 before Clogging

| Days | No of Sample | Water Used ( Liters) | Total Solids in Influent (Kg) |
|---|---|---|---|
| At 65 days | 10 | 54 | 0.21 |
| At 129 days | 11 | 60 | 0.20 |
| At 242 days | 13 | 70 | 0.21 |

From the above Table it has been found that the amount of Total solids was about 200 gm when the Reactor-3 was clogged. So clogging depends on the amount of Total Solids used as feed.

By considering similar situation of Reactor-1 and Reactor-2 before and after Clogging, it has been found that Reactor-1 and Reactor-2 was clogged and cleaned at 129 days. After 242 days when all Reactors were cleaned again then the Flow rate of R-1 and R-2 were 5 ml/min and 5 ml/min respectively. Table 4-9: shows the situation of Reactor-1 and Reactor-2 at similar flow rate before and after clogging.

Table 4-9: Overall condition of Reactor-1 and Reactor-3 at similar flow rate (about 5 ml/min)

| No of days | Total Sample | Flow rate at R-1 (ml/min) | Flow Rate at R-2 (ml/min) | Water Used (L) | TS in Influent (Kg) |
|---|---|---|---|---|---|
| Before Clogging at 91 days | 14 | 5 | 4 | 75.6 | 0.25 |
| After clogging at 242 days | 13 | 5 | 5 | 70.2 | 0.2 |

From the study it has been found that the flow rate of Reactor-1 and Reactor-2 at 91 days was about 5 ml/min (before clogging at 129 days) and the flow rate of Reactor-1 and Reactor-2 at 242 days was also about 5 ml/min (after clogging at 129 days). At 91 days the Total Solids in Influent used as feed was 250 gm and at 242 days the Total Solids in Influent used as feed was 200 gm. So the amount of Total Solids was very similar when the flow rate was about 5 ml/min for both Reactors before and after clogging. The total amount of water used as feed before and after clogging were 75 liter and 70.2 liter respectively (when the flow rate was about 5 ml/min). So Flow rate and Clogging of CMBR depend on the amount of Total Solids used as feed.

# *Chapter 5*

# *Conclusions and Recommendations*

## 5.1 CONCLUSIONS

A low cost and simple type ceramic membrane was innovated for concurrent wastewater treatment and reuse especially for wastewater treatment in this study. This simple type CMBR process was investigated from the laboratory experiments and it can be concluded that:

- ✓ Activated sludge can be easily separated through this Technology.
- ✓ Through this process sufficient amount of flux was obtained for the case of wastewater treatment.
- ✓ Turbidity removed significantly by Ceramic Membrane Bio-Reactor. The average Turbidity Removal efficiency of all Reactors was 95.34%. It is worth to state that an excellent performance for Turbidity removal was observed for all Runs.
- ✓ The result shows that about 88.45% of Color removal was achieved by the system. Turbidity and Color removal efficiency was excellent that's why the filtered water is more acceptable by the people as the aesthetic appearance of the water is good.
- ✓ Removal efficiency of organic matters in terms of COD was very much satisfactory in the case of wastewater treatment. About 81.55% of COD removal was achieved by Ceramic Membrane Bio-reactor. From the results, it can be concluded that the anoxic-aerobic CMBR has great potential in removing biodegrading organic pollutants from wastewater. This indicates that the Ceramic Membrane is able to retain the organic content from wastewater.
- ✓ The average SS removal efficiency was 95.25% by all Reactors which demonstrates that the removal of SS was very efficient by CMBR.
- ✓ The Total Solid removal was not satisfactory by CMBR as the average Total Solid Removal efficiency was 35.83%.

- ✓ Iron removed significantly by CMBR. The average Iron removal efficiency of all Reactors was 92.69%. The WHO guideline suggests that the concentration of Iron should be less than 0.3 mg/l in drinking water. The average concentration of Iron in effluent water was found 0.02 mg/l by CMBR which is well below even drinking water standard. So the Ceramic Membrane Bio-Reactor is very efficient to remove Iron from wastewater.
- ✓ Physical cleaning of the membrane was much simple and it was easy to remove the cake layer to reclaim the membrane.
- ✓ The run time of CMBR was very good. The longer and maximum run time of CMBR was 129 days.
- ✓ The quality of effluent water was excellent as the effluent water was clear colored and odor- free. It was found that high removal efficiency of organic content was obtained that could be made it suitable for wastewater reuse.
- ✓ As the Ceramic Membrane was made by locally available materials the technology was inexpensive. Therefore the technology is suitable and can be adapted in developing countries for wastewater treatment and reuse. The total cost for setup of Ceramic Membrane Bio-reactor in the laboratory was about 16500 Taka only.

## 5.2 RECOMMENDATIONS

On the basis of the performance study of the developed treatment unit, the following recommendations can be made for future work:

1. To study the performance of the developed CMBR in mass scale by designing a new treatment unit for use in the field level.
2. To study the performance of the developed CMBR by using various actual wastewater (Rice mill wastewater, Shrimp mill wastewater, Industrial wastewater etc).
3. To study the performance of the developed CMBR by observing various water quality parameter (Nitrogen, Phosphorus, TC, FC etc.).
4. Double filtration process can be adopted to observe the efficiency of CMBR.

With the above circumstances and in terms of various results found in this research the following tentative design of the CMBR technology can be proposed:

This tentative design is only for wastewater treatment and reuse. This can be applied as a decentralized system for one household of five members. Considering with the water quantity of 0.5 $m^3$/d, if assumed flux is 0.1 m/d then required membrane area needs to be 5.0 $m^2$. Therefore, if same ceramic membrane filter is used, then 114 numbers of membrane filter will be required. According to the required membrane area and keeping the tank height constant as 1.5 m, The tentative design of the tank is 1.5m x 1.5m x 1.5m with the membrane filters of 121 (11x 11) numbers. Figure: 5-1 and 5-2 shows the tentative design of the recommended Ceramic Membrane Bio-Reactor for wastewater treatment (Hasan and Nakajima 2010).

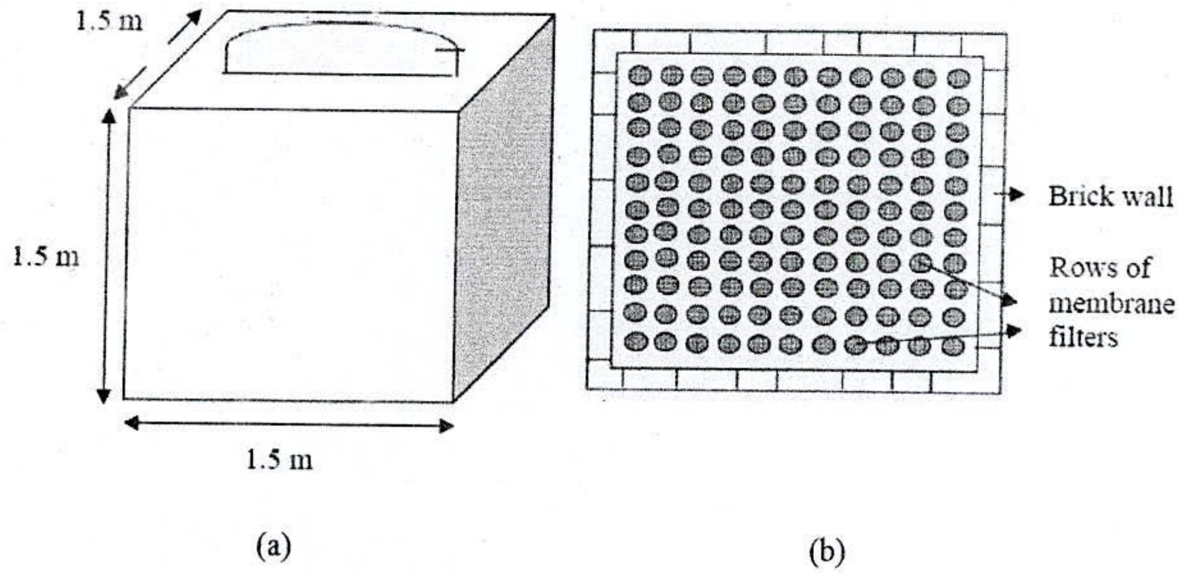



Figure 5-1: (a) Sketch of tank with dimensions (b) Cross-section of top view

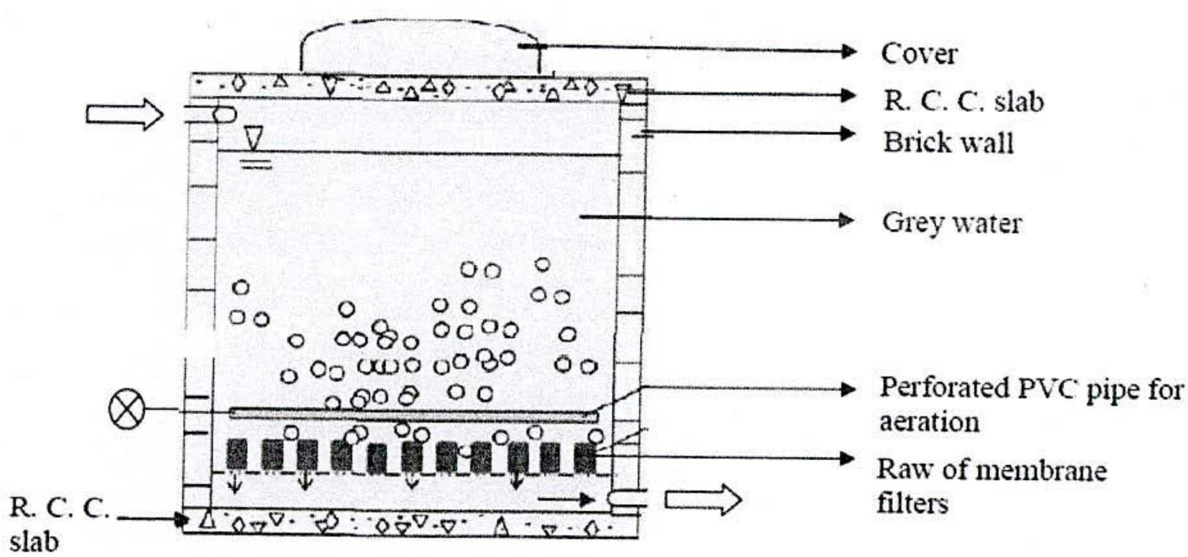



Figure 5-2: Details cross-section of side view of the tank (Hasan and Nakajima 2010).

## References:


Alberta Environment Report (2000) Guideline for Municipal Wastewater Irrigation. Alberta Environment, Municipal Program Development Branch, Edmonton, Alberta, Canada, pp.1-23.

AMTA Report (2007) A report of American Membrane Technology Association (AMTA), Florida, USA, pp. 1-3.

Chapman, S., Leslie, G. and Law, I. (2003) Membrane Bioreactors (MBR) for Municipal Wastewater Treatment–An Australian Perspective. A report of CH2M HILL Australia Pty Ltd, Australia, pp. 1-11.

Cicek, N. (2003) A review of membrane bioreactors and their potential application in the treatment of agricultural wastewater. A Thesis Report submitted at Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba, Canada, Vol. 45, pp. 37-45.

Cornelia, M., Rene, G., Bouchaib, E. H. and Matthias, K. (2006) Membrane bioreactor technology for the treatment of greywater from a sports and leisure club. *Water and Urban Wastewater Management in the Mediterranean Area*, Rabat, Morocco, pp. 1-2.

DEQ Report (2010) Oklahoma Department of Environmental Quality Environmental Complaints and Local Services Domestic Wastewater Management, Oklahoma City, pp. 1-6.

Environmental Health Unit, Report (2003) Greywater recycling: appropriate uses. Victoria, Australia, pp.1-2.

Enviroquip, Inc Report (2011) The Best Available Systems For Wastewater Treatment And Reuse. Austin, Texas, pp. 1-4.

Fitzgerald, K. S. (2008) Membrane Bioreactors. A report of TSG Technologies, Inc, Gainesville, pp. 1-2.

Guo, W. and Ngo, H. H. (2008) Specific Options in Biological Wastewater Treatment for Reclamation and Reuse. *Water and Water Treatment Technologies*, Sydney, Australia, pp. 2-5.

Gottberg, A. V., Antrim, B. and Kullmann, C. (2008) Retrofitting Existing MBR Systems with Next Generation MBR Technology. A report of Koch Membrane Systems, Inc, Wilmington, USA, pp. 1-6.

Hasan, M. M. and Nakajima, J. (2010) Development of Low Cost Ceramic Membrane Bioreactor for Decentralized Waste water Treatment and Reuse. A thesis for the Degree of Master of Engineering, Ritsumeikhan University, Japan, pp. 1-105.

Itokawa, H. (2009) State of The Art of MBR Technology and Its Perspective in Japan. Research and Technology Development Division, Japan Sewage Works Agency (JS), Toda City, Japan, pp. 1-12.

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R. and Judd, S. (2004) Grey water characterization and its impact on the selection and operation of technologies for urban reuse. *Water Science and Technology*, Vol. 50, No. 2, pp. 157-163.

Kim, S. and Cho, S. D. (1993) Application of Membrane in Municipal Wastewater Treatment and Reuse. *Korean Ind. & Eng. Chemistry*, Vol. 4, No. 4, pp. 1-2.

Lim, B R., Hu, H. Y. and Fujie, K. (2002) Biological Degradation and Chemical Oxidation Characteristics of Coke-Oven wastewater. A report of Future Technology Research Division, Korea Institute of Science and Technology, Cheongryang, Korea, pp. 1-2.

May, A. M., Nasr, J. A. and Tarhini, A. (2008) Decentralized approaches to wastewater treatment and management: Applicability in developing countries. *Environmental Management*, Beirut, Lebanon, pp. 1-8.

Morel, A. (2005) Greywater treatment on household level in developing countries. Thesis report at the Department of Environmental Sciences at the Swiss Federal Institute of Technology (ETH) and Swiss Federal Institute for Environmental Science and Technology (EAWAG), Zurich, Switzerland, pp.15-56.

Operator Notebook Report (2001) Membrane Bioreactor (MBR) in Wastewater Treatment. New York, USA, pp. 1-8.

SDWF Report (2007) Safe Drinking Water Foundation Report 2007, pp. 1-5.

Thanh, V. T. M., Busser, S., Nga, P. T., Morel, A. and Anh, N. V. (2006) Characteristics and Quantities of Domestic Wastewater in Urban and Peri-urban Households in Hanoi. *Proceedings of GMSARN International Conference on Sustainable Development*, Hanoi, pp. 1-2.

Water Corporation Report (2008) Plantation Grown Timber with Environmentally Safe vegetable. pp.1.

Xing, C. H., Tardieu, E., Qian, Y. and Wen, X. H. (2000) Ultrafiltration membrane bioreactor for urban wastewater reclamation. *Membrane Science*, Tsinghua University, China, Vol. 177, pp. 73-82.

# Appendix

## Test Results of Different Parameters

Table A-1: Data of Dissolve Oxygen (DO) of CMBR

| Date | No of days | Influent DO | Effluent DO at R-1 | Effluent DO at R-2 | Effluent DO at R-3 |
|---|---|---|---|---|---|
| 29-12-10 | 1 | 5.48 | 6.12 | 6.7 | 9.18 |
| 4-1-11 | 6 | 6.85 | 7.1 | 7.15 | 8.24 |
| 06-01-11 | 8 | 1.46 | 4.1 | 3.6 | 8.03 |
| 12/1/2011 | 14 | 1.71 | 7.87 | 6.9 | 7.47 |
| 20-01-11 | 22 | 0.84 | 4.3 | 5.1 | 8.93 |
| 26-01-11 | 28 | 1.82 | 5.1 | 6.1 | 3.6 |
| 9/2/2011 | 44 | 5.82 | 6.1 | 9.17 | 6.13 |
| 22-02-11 | 57 | 7.37 | 7.9 | 9.03 | 7.8 |
| 28-02-11 | 63 | 8.2 | 8.9 | 9.1 | 8.7 |
| 2/3/2011 | 65 | 8.04 | 8.89 | 8.83 | 9.1 |
| 13-03-11 | 76 | 3.59 | 5.2 | 8.05 | 6.1 |
| 16-03-11 | 79 | 3.8 | 6.34 | 5.2 | 4.13 |
| 20-03-11 | 83 | 0.38 | 0.34 | 0.7 | 0.9 |
| 28-03-11 | 91 | 2.19 | 5.2 | 5.52 | 4.9 |
| 31-03-11 | 94 | 4.73 | 4.11 | 1.05 | 4.9 |
| 6/4/2011 | 101 | 4.91 | 5.08 | 5.74 | 6.12 |
| 17-04-11 | 112 | 6.74 | 6.78 | 6.33 | 6.3 |
| 21-04-11 | 116 | 5.72 | 4.3 | 4.3 | 4.13 |
| 25-04-11 | 120 | 0.29 | 4.15 | 3.42 | 4.3 |
| 28-04-11 | 123 | 0.99 | 4.15 | 5.68 | 3.99 |
| 4/5/2011 | 129 | 0.46 | 2.65 | 2.43 | 2.65 |
| 15-06-11 | 171 | 1.28 | 5.34 | 4.19 | 2.23 |
| 21-06-11 | 177 | 3.93 | 4.37 | 5.97 | 2.03 |
| 26-06-11 | 182 | 0.45 | 2.3 | 4 | 4.08 |
| 29-06-11 | 185 | 2.8 | 6.1 | 5.3 | 5.71 |
| 4/7/2011 | 191 | 6.86 | 6.9 | 7.46 | 5.74 |
| 12/7/2011 | 199 | 0.42 | 4.03 | 2.64 | 1.51 |
| 21-07-11 | 208 | 0.85 | 6.89 | 2.12 | 5.32 |
| 28-07-11 | 215 | 0.37 | 0.68 | 1.1 | 2.19 |
| 1/8/2011 | 219 | 3.85 | 7.72 | 4.85 | 7.27 |
| 4/8/2011 | 222 | 5.32 | 6.93 | 7.02 | 6.31 |
| 10/8/2011 | 228 | 2.13 | 6.2 | 5.88 | 5.67 |
| 18-08-11 | 236 | 4.33 | 6.19 | 5.88 | 5.92 |
| 24-08-11 | 242 | 4.11 | 5.89 | 6.15 | 6.32 |

Table A-3: Turbidity Data of CMBR

| No of days | Influent Turbidity | Effluent Turbidity at R-1 | Effluent Turbidity at R-2 | Effluent Turbidity at R-3 |
|---|---|---|---|---|
| 1 | 139 | 4.17 | 7.1 | 15.5 |
| 6 | 358 | 6.23 | 19.2 | 6.23 |
| 8 | 211 | 14.32 | 17 | 9.99 |
| 14 | 155 | 6.2 | 8.2 | 20 |
| 22 | 239 | 11.95 | 10.7 | 35.89 |
| 28 | 416 | 8.32 | 10.2 | 39.5 |
| 44 | 313 | 16 | 10.3 | 29 |
| 57 | 175 | 62 | 7.09 | 19.3 |
| 63 | 503 | 19 | 52 | 50.2 |
| 65 | 133.3 | 5.37 | 23.8 | 15 |
| 76 | 482 | 15.1 | 33.3 | 41 |
| 79 | 482 | 9.23 | 23.1 | 10.2 |
| 83 | 597 | 21.7 | 48.8 | 13.1 |
| 91 | 1268 | 9.81 | 15.4 | 17.19 |
| 94 | 1462 | 19.6 | 37.7 | 18.24 |
| 101 | 776 | 5.87 | 68.3 | 9 |
| 112 | 1518 | 4.8 | 5.39 | 11 |
| 116 | 1344 | 5.1 | 6.12 | 3.28 |
| 120 | 2130 | 5.75 | 9.4 | 5.32 |
| 123 | 910 | 8.38 | 8.66 | 7.89 |
| 129 | 580 | 5.15 | 5.63 | 3.2 |
| 171 | 134 | 8.5 | 7.2 | 3.95 |
| 177 | 19.1 | 6.58 | 3.7 | 4.13 |
| 185 | 569 | 7.19 | 4.13 | 5.3 |
| 191 | 488 | 7.89 | 15.5 | 14.7 |
| 199 | 585 | 9.12 | 3.89 | 3.23 |
| 208 | 822 | 2.05 | 1.66 | 7.84 |
| 215 | 1090 | 19.4 | 9.14 | 3.76 |
| 219 | 169 | 9.85 | 4.97 | 2.42 |
| 222 | 210 | 11.3 | 9.21 | 9 |
| 228 | 198 | 7.21 | 6.31 | 3.22 |
| 236 | 275 | 11.8 | 9.2 | 7.1 |
| 242 | 288 | 9.31 | 7.52 | 5.5 |

Table A-4: Data of Color of CMBR

| No of days | Influent Color | Effluent Color at R-1 | Effluent Color at R-2 | Effluent Color at R-3 |
|---|---|---|---|---|
| 1 | 650 | 52 | 130 | 342 |
| 6 | 2500 | 125 | 155 | 137 |
| 8 | 901 | 70 | 140 | 230 |
| 14 | 737 | 96 | 117 | 85 |
| 22 | 1820 | 91 | 265 | 300 |
| 28 | 2518 | 152 | 218 | 380 |
| 44 | 2200 | 133 | 77 | 175 |
| 57 | 380 | 20 | 85 | 83 |
| 63 | 480 | 32 | 73 | 90 |
| 65 | 613 | 27 | 130 | 117 |
| 76 | 3280 | 169 | 385 | 393 |
| 79 | 1480 | 87 | 117 | 127 |
| 83 | 4210 | 580 | 782 | 91 |
| 91 | 2950 | 254 | 399 | 77 |
| 94 | 4450 | 387 | 900 | 213 |
| 101 | 4820 | 180 | 218 | 183 |
| 112 | 3290 | 137 | 145 | 121 |
| 116 | 2570 | 127 | 140 | 109 |
| 120 | 8130 | 143 | 267 | 195 |
| 123 | 7850 | 187 | 187 | 148 |
| 129 | 4680 | 63 | 61 | 109 |
| 171 | 506 | 108 | 97 | 83 |
| 177 | 148 | 67 | 58 | 48 |
| 182 | 908 | 109 | 116 | 48 |
| 185 | 1740 | 103 | 59 | 105 |
| 191 | 1145 | 71 | 86 | 71 |
| 199 | 1790 | 100 | 55 | 95 |
| 208 | 4150 | 71 | 71 | 81 |
| 215 | 4370 | 439 | 214 | 106 |
| 219 | 534 | 137 | 131 | 130 |
| 222 | 560 | 119 | 100 | 105 |
| 228 | 440 | 107 | 96 | 88 |
| 236 | 577 | 69 | 87 | 73 |
| 242 | 610 | 107 | 111 | 121 |

Table A-5: Data of Total Solids (TS)

| No of days | Influent TS | Effluent TS at R-1 | Effluent TS at R-2 | Effluent TS at R-3 |
|---|---|---|---|---|
| 1 | 2840 | 1256 | 1393 | 1660 |
| 6 | 3780 | 2200 | 2675 | 3080 |
| 8 | 3406 | 1621 | 1705 | 1853 |
| 14 | 1790 | 898 | 1005 | 948 |
| 22 | 3780 | 1879 | 2093 | 2064 |
| 28 | 4736 | 2172 | 2387 | 2661 |
| 44 | 5189 | 2450 | 1690 | 2883 |
| 57 | 3019 | 1241 | 1723 | 1760 |
| 63 | 5042 | 2443 | 2044 | 2588 |
| 65 | 4840 | 2222 | 1799 | 2187 |
| 76 | 2250 | 1664 | 1961 | 1745 |
| 79 | 2250 | 1948 | 1928 | 1515 |
| 83 | 3289 | 2147 | 2378 | 2258 |
| 91 | 2943 | 1495 | 1767 | 1347 |
| 94 | 3524 | 1204 | 1718 | 1116 |
| 101 | 4295 | 1629 | 2423 | 2269 |
| 112 | 3921 | 1596 | 2001 | 1654 |
| 116 | 3109 | 1704 | 1747 | 1646 |
| 120 | 5120 | 2574 | 2690 | 2121 |
| 123 | 3250 | 2106 | 2092 | 1948 |
| 129 | 3670 | 3036 | 3151 | 2900 |
| 171 | 2892 | 2488 | 2519 | 2692 |
| 177 | 2798 | 2780 | 2529 | 2786 |
| 182 | 2156 | 2148 | 2154 | 2271 |
| 185 | 3226 | 1688 | 1550 | 1735 |
| 191 | 2735 | 1982 | 1942 | 2409 |
| 199 | 2915 | 2369 | 2434 | 2439 |
| 208 | 3118 | 2781 | 2813 | 2748 |
| 215 | 3630 | 2608 | 2581 | 2631 |
| 219 | 2703 | 2674 | 2482 | 2531 |
| 222 | 3100 | 2777 | 2510 | 2328 |
| 228 | 2910 | 2205 | 1931 | 2024 |
| 236 | 2426 | 1660 | 1573 | 1666 |
| 242 | 2548 | 1737 | 1835 | 1748 |

Table A-6: Data of Total Dissolve Solids (TDS)

| No of days | Influent TDS | Effluent TDS at R-1 | Effluent TDS at R-2 | Effluent TDS at R-3 |
|---|---|---|---|---|
| 1 | 1630 | 1210 | 1315 | 1588 |
| 6 | 2800 | 2170 | 2617 | 3040 |
| 8 | 1986 | 1576 | 1635 | 1797 |
| 14 | 994 | 879 | 978 | 917 |
| 22 | 2130 | 1830 | 2027 | 1980 |
| 28 | 2719 | 2130 | 2318 | 2616 |
| 44 | 3051 | 2425 | 1626 | 2819 |
| 57 | 1785 | 1218 | 1685 | 1719 |
| 63 | 3152 | 2400 | 1987 | 2512 |
| 65 | 2704 | 2175 | 1754 | 2131 |
| 76 | 1986 | 1654 | 1935 | 1728 |
| 79 | 1986 | 1943 | 1917 | 1496 |
| 83 | 2831 | 2106 | 2315 | 2237 |
| 91 | 1863 | 1472 | 1734 | 1321 |
| 94 | 1496 | 1173 | 1635 | 1091 |
| 101 | 3020 | 1619 | 2360 | 2242 |
| 112 | 2190 | 1589 | 1993 | 1621 |
| 116 | 1877 | 1692 | 1730 | 1630 |
| 120 | 2040 | 2550 | 2660 | 2100 |
| 123 | 2200 | 2090 | 2090 | 1936 |
| 129 | 2920 | 3020 | 3140 | 2891 |
| 171 | 2800 | 2470 | 2519 | 2680 |
| 177 | 2770 | 2770 | 2520 | 2770 |
| 182 | 2040 | 2130 | 2154 | 2271 |
| 185 | 2194 | 1650 | 1521 | 1712 |
| 191 | 2460 | 1967 | 1917 | 2400 |
| 199 | 2460 | 2360 | 2420 | 2420 |
| 208 | 2830 | 2780 | 2810 | 2740 |
| 215 | 2630 | 2560 | 2560 | 2620 |
| 219 | 2510 | 2670 | 2480 | 2530 |
| 222 | 2810 | 2770 | 2500 | 2320 |
| 228 | 2320 | 2190 | 1920 | 2010 |
| 236 | 1713 | 1633 | 1542 | 1641 |
| 242 | 1918 | 1722 | 1825 | 1737 |

Table A-7: Data of Suspended Solids (SS)

| No of days | Influent SS | Effluent SS at R-1 | Effluent SS at R-2 | Effluent SS at R-3 |
|---|---|---|---|---|
| 1 | 1210 | 38 | 78 | 72 |
| 6 | 980 | 30 | 58 | 40 |
| 8 | 1420 | 45 | 70 | 56 |
| 14 | 796 | 19 | 27 | 31 |
| 22 | 1650 | 49 | 66 | 84 |
| 28 | 2017 | 42 | 60 | 45 |
| 44 | 2138 | 24 | 64 | 64 |
| 57 | 1234 | 23 | 38 | 41 |
| 63 | 1890 | 43 | 57 | 76 |
| 65 | 2136 | 47 | 45 | 56 |
| 76 | 264 | 10 | 26 | 17 |
| 79 | 264 | 5 | 11 | 19 |
| 83 | 458 | 41 | 63 | 21 |
| 91 | 1080 | 23 | 33 | 26 |
| 94 | 2028 | 31 | 83 | 25 |
| 101 | 1275 | 10 | 63 | 27 |
| 112 | 1731 | 7 | 8 | 33 |
| 116 | 1232 | 12 | 17 | 16 |
| 120 | 3080 | 24 | 30 | 21 |
| 123 | 1050 | 16 | 2 | 12 |
| 129 | 750 | 16 | 11 | 9 |
| 171 | 92 | 18 | 16 | 12 |
| 177 | 28 | 10 | 9 | 10 |
| 182 | 116 | 18 | 24 | 11 |
| 185 | 1032 | 38 | 29 | 23 |
| 191 | 275 | 15 | 25 | 9 |
| 199 | 455 | 9 | 14 | 19 |
| 208 | 288.7 | 1 | 3 | 8 |
| 215 | 1000 | 48 | 21 | 11 |
| 219 | 193 | 4 | 2 | 1 |
| 222 | 290 | 7 | 10 | 8 |
| 228 | 590 | 15 | 11 | 14 |
| 236 | 713 | 27 | 31 | 25 |
| 242 | 630 | 15 | 10 | 11 |

Table A-8: Data of Iron (Fe)

| No of days | Influent Fe | Effluent Fe at R-1 | Effluent Fe at R-2 | Effluent Fe at R-3 |
|---|---|---|---|---|
| 1 | 0.24 | 0 | 0.07 | 0 |
| 6 | 0.12 | 0 | 0.03 | 0 |
| 8 | 0.12 | 0 | 0 | 0 |
| 14 | 0.1 | 0 | 0 | 0 |
| 22 | 0.25 | 0.02 | 0.05 | 0.05 |
| 28 | 0.2 | 0.05 | 0.03 | 0 |
| 44 | 0.25 | 0.04 | 0.05 | 0.06 |
| 57 | 0.15 | 0 | 0 | 0 |
| 63 | 0.25 | 0.02 | 0.06 | 0.03 |
| 65 | 0.15 | 0 | 0 | 0 |
| 76 | 0.2 | 0 | 0.05 | 0 |
| 79 | 0.2 | 0.03 | 0 | 0 |
| 83 | 0.15 | 0 | 0 | 0.01 |
| 91 | 0.3 | 0.02 | 0.01 | 0.01 |
| 94 | 0.25 | 0.05 | 0.06 | 0 |
| 101 | 0.2 | 0.01 | 0.02 | 0.02 |
| 112 | 0.15 | 0 | 0 | 0.01 |
| 116 | 0.15 | 0 | 0 | 0 |
| 120 | 0.29 | 0.03 | 0.04 | 0.03 |

Table A-9: Data of Flow Rates of CMBR

| Date | No of days | Flow Rate at R-1 | Flow Rate at R-2 | Flow Rate at R-3 |
|---|---|---|---|---|
| 29-12-10 | 1 | 100 | 90 | 39 |
| 4-1-11 | 6 | 100 | 78 | 25 |
| 06-01-11 | 8 | 92 | 76 | 18 |
| 12/1/2011 | 14 | 80 | 64 | 12 |
| 20-01-11 | 22 | 76 | 52 | 10 |
| 26-01-11 | 28 | 66 | 46 | 7 |
| 9/2/2011 | 44 | 44 | 40 | 3 |
| 22-02-11 | 57 | 36 | 32 | 1 |
| 28-02-11 | 63 | 25 | 23 | 0.5 |
| 2/3/2011 | 65 | 20 | 18 | 0.25 |
| 13-03-11 | 76 | 20 | 15 | 36 |
| 16-03-11 | 79 | 15 | 15 | 30 |
| 20-03-11 | 83 | 10 | 8 | 25 |
| 28-03-11 | 91 | 5 | 4 | 17 |
| 31-03-11 | 94 | 5 | 3 | 17 |
| 6/4/2011 | 101 | 5 | 3 | 13 |
| 17-04-11 | 112 | 3 | 2 | 4 |
| 21-04-11 | 116 | 2 | 2 | 0.8 |
| 25-04-11 | 120 | 2 | 1 | 0.3 |
| 28-04-11 | 123 | 1 | 1 | 0.1 |
| 4/5/2011 | 129 | 0.5 | 0.25 | 0.1 |
| 15-06-11 | 171 | 0.01 | 0.01 | 0.01 |
| 15-06-11 | 171 | 114 | 88 | 36 |
| 21-06-11 | 177 | 92 | 80 | 33 |
| 26-06-11 | 182 | 42 | 62 | 28 |
| 29-06-11 | 185 | 38 | 48 | 35 |
| 4/7/2011 | 191 | 30 | 32 | 22 |
| 12/7/2011 | 199 | 20 | 22 | 14 |
| 21-07-11 | 208 | 16 | 12 | 8 |
| 28-07-11 | 215 | 7 | 5 | 2 |
| 1/8/2011 | 219 | 5 | 5 | 1 |
| 4/8/2011 | 222 | 6 | 4 | 2 |
| 10/8/2011 | 228 | 4 | 3 | 1 |
| 18-08-11 | 236 | 3 | 4 | 0.5 |
| 24-08-11 | 242 | 5 | 5 | 0.25 |