Decentralized Treatment of Domestic Wastewater Using Membrane Based Septic Tank (MBST)

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By

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APPROVAL SHEET

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Abstract

Septic tanks are widely used in rural and urban areas treating domestic wastewater from individual and cluster of houses, however, due to their low treatment and biodegradation capacity, they are still considered as intermediate (primary) treatment option leading to several basic health and environmental risks. In this regard, a study has been made on a modified septic tank by submerging a membrane module having pore size 1-3 µm inside the wastewater between the settled sludge and floating scum termed as Membrane Based Septic Tank (MBST). Introduction of membrane filtration further enhanced the treating capacity with safe effluent disposal or reuse in agriculture and horticulture. During 100 days of continues operation and monitoring, spiral design membrane module with 1 m^2 effective area was used. This system was found to produce satisfactory results, where the average removal efficiencies of COD, BOD_5, TSS, phosphate, nitrate, nitrite, ammonium and total-coliform were 71, 76, 82, 47, 48, 40, 27 and 88%, respectively. However, during the filtration process, membrane fouling was found to be the major limitation for MBST system. Membrane fouling characterization was performed by developing trans-membrane pressure (TMP) profiles. The system was operated at flux rates of 6, 8 and 10 L/m^2-h (LMH) and fouling frequencies were found to be at 15, 8 and 5 days, respectively at terminal TMP of 60 KPa. Membrane was physically cleaned and examined for membrane resistance analysis after each operating cycle. Physical cleaning was found to be effective in removing cake layer resistance while pore blocking resistance progressively increased after each filtration cycle. The system has shown effective treatment efficiencies on a much lower capital and simple design compared to high cost membrane systems.

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List of Abbreviation

Abbreviation	Description
MBST	Membrane base septic tank
RT	Total resistance
RC	Cake resistance
RM	Intrinsic membrane resistance
RF	Resistance due to pore blocking
EPA	Environment Protection Agency
IESE	Institute of Environmental Sciences and Engineering
NEQS	National Environmental Quality Standards
WHO	World Health Organization
NTU	Naphthalometric turbidity unit
TMP	Trans-membrane pressure
P	Phosphorous
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
SS	Suspended Solids
MGD	Million Gallon Per Day

Chapter 1

INTRODUCTION

1.1. Background

Access to water and sanitation is a fundamental human right that is supported by international law and declarations. As a matter of fact, 21^{st} century is witnessing high population growth accompanied with industrialization and urbanization. These two phenomena have led to an unbalanced situation between water demand and natural recharge. Global availability of clean portable water is becoming a big threat to the habitat of human kind. Over 2.6 billion people around the globe are living without adequate sanitation facilities and nearly 900 million people doesn't have access to drinking water from improved water resources (UN-Water, 2010). Worldwide 2.4 million lives could be saved if adequate water and reliable sanitation is made available along with the practice of appropriate hygiene (Prüss-Üstün *et al.*, 2008). It is well understood that in this situation the cost for rectifying is high, so the only way is to provide at least some degree of treated water and economically sound and sustainable sanitation solutions (Tebbutt, 1998).

The fresh water consumption has increased many folds from start and the end of the 20^{th} century. At present, the world population is roughly about 6.8 Billion, around one third of the countries are considered to be in water emergency which is when to demand is more than 10% of supply. If this situation continued, globally two third of the population will be living in water scarce regions (Macedonio *et al.*, 2012).

The situation is alarming and getting worse in developing countries which suffer from lack of proper wastewater collection and sewer systems in the rural and peri-urban areas (Al-Shayah, and Mahmoud, 2008). It is very often that the quality of available water is deteriorated and compromised due to lack of collection and treatment. The indiscriminate discharge of domestic and industrial untreated effluents have worsened the quality of the available water resources.

Discharging untreated wastewater may lead to several basic health and environmental risks, therefore to reduce the impacts, affordable treatment technologies shall be established for such waters (Tchobanoglous *et al.,* 2003). In developing countries, the centralized treatment option is expensive and not feasible in large urban areas due to complexity of sewerage network, whereas many houses, cluster of houses, and small communities even lack sewer systems (Crites and Tchobanoglous, 1998). In this context, it is preferred to adopt on-site treatment options based upon the situation, locality and environment (Lens *et al.,* 2001, Luostarinen and Rintala, 2005).

Pakistan being victim of poor water and sanitation situation is losing 4% of its economy to bad sanitation and water supplies. The urban (36%) and rural (64%) population has 72% and 34% access to water and sanitation respectively. There is a dire need to provide on-site domestic wastewater treatment solutions that treats domestic wastewater up to the National Environmental Quality Standards (NEQS), Pakistan Environmental Protection Agency (PEPA) and is safe for disposal or use in landscaping, horticulture and irrigation.

The residential areas which lack proper wastewater treatment system depend only on on-site treatment of wastewater like septic tanks (Chaggu *et al.,* 2002). Septic tank system allows the on-site treatment for wastewater for houses, cluster of residences, or small commercial units (McCarty *et al.*, 2001).

The main treatment in septic tank is due to flotation and sedimentation with little biodegradation of organic matter, the effluent flows into the sewer systems or leachate fields in case of no sewer system available. It is well understood that septic tanks can only be used in areas which do not have centralized treatment facilities (Michael, 2004). Septic tanks are constructed with a soil absorption field. Due to its simplicity and economic viability in construction and maintenance, this system is gaining preference for on-site wastewater treatment systems. However, septic tank as a conventional on-site wastewater treatment system provides only primary treatment with very low biological degradation (Moore, 2010). The soil absorption field receives a significant load of organic matter, suspended solids, and nutrients. The effluent suspended solids and pathogens are not only harmful to environment but also clog up the native receiving soil's pores, making the system to fail (Jamal Khan *et al*., 2013).

Therefore various studies shows various modification in septic tanks to improve its treating capacity. One of the improved septic tank is modifying it with the use of membrane technology termed as membrane based septic tanks.

Therefore, in this study a 'membrane based septic tank (MBST)' was investigated to achieve high treatment efficiencies while maintaining low capital and maintenance costs. This study was in collaboration with Asian Institute of Technology (AIT), Thailand, Stellenbosch University, South Africa and Water-Aid UK in Pakistan, which aimed at developing and conducting research on a low cost and advance on-site treatment technology, such as MBST, in context of peri-urban and rural areas. Woven Fiber Microfiltration (WFMF) membrane modules in the form of spiral and flat sheet were used for this study which were provided by the partners AIT Thailand and Stellenbosch University, South Africa.

A septic tank with a membrane submerged inside, termed as Membrane Based Septic Tank (MBST), is a new and advance technology to treat and reclaim wastewater on-site and reuse at source.

In this study, the septic tank in IESE - NUST Building was modified with a membrane. The membrane module was placed inside the septic tank, fully submerged, where wastewater was reclaimed by applying suction pressure through a peristaltic pump. In order to meet one of the objectives, the membrane filtration performance and its ability to withstand fouling was analyzed by Trans-membrane Pressure (TMP) profiling with different operational flux rates. The treatment performance of the MBST was also investigated in terms of organic matter, coli-forms, suspended solids and nutrients removal.

1.2. Objective of Study:

The research had the following objectives:

- Design and install membrane modules in the Septic Tank at IESE Building, NUST campus, Sector H-12, Islamabad.
- Evaluate the fouling frequencies of membranes at different flux rates
- Investigate treatment performance and operational parameters of the membrane based septic tank in terms organic matter, solids, nutrients removal, etc.

1.3. Scope of Study:

The scope of the study include:

- Design and construct flat sheet and spiral membrane modules and analyze its performance in terms of physical, chemical and biological parameters
- Monitoring of TMP at different flux rates, resistance analysis, and modules maintenance in term of physical cleaning of membranes.

LITERATURE REVIEW

2.1. Water Stress and Scarcity in World

Water is the most important resource available to human kind for the sustainable development of human society as well as for the subsistence of earth's ecosystems (Vörösmarty *et al.*, 2010). As a matter of fact, the gap between the supply and demand is becoming more and more intense with time due to rapid pace of socio-economic development (Zeng *et al.*, 2013). At present, there are more than 50 countries around the globe experiencing water scarcity (FAO, 2005) and expectedly another 70 countries to be added by 2025.

Water stress and water scarcity conditions for an area are set by United Nations, which are defined as having annual water supplies bellow 1700m^3 and 1000m^3 per capita respectively (UNEP, 2005).

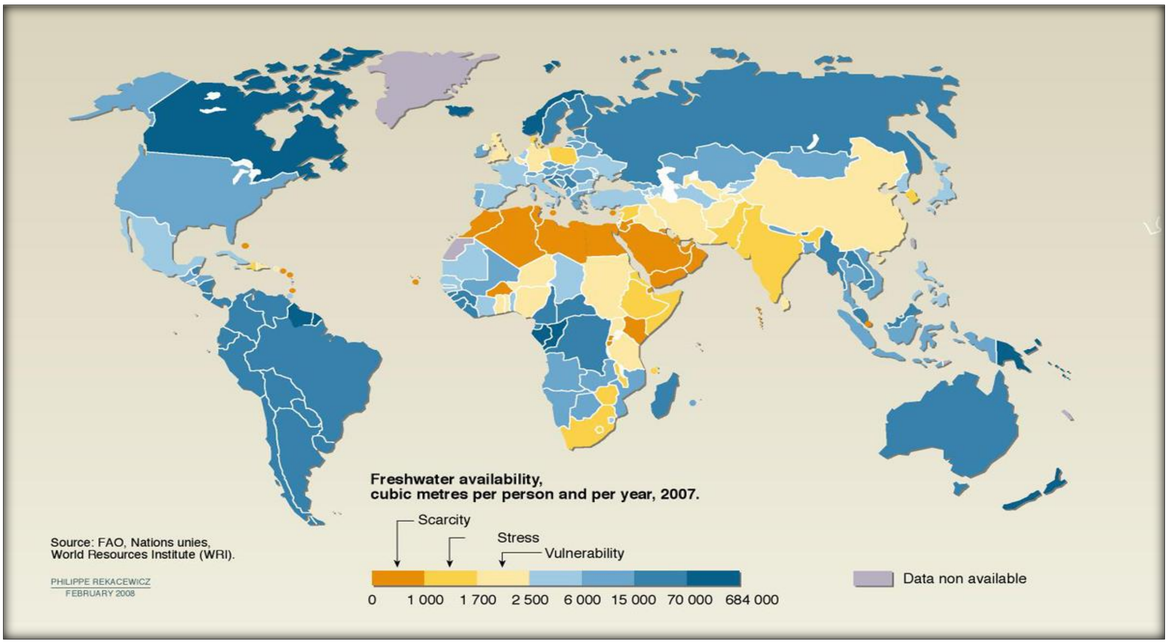


Figure 2.1: Global water stress and scarcity

2.2. Water and Sanitation in Developing Countries

Developing world in witnessing around 1.3 billion people without proper water supply and more than 2 billion are with inadequate sanitation. In other words, approximately 70% of the population in the developing countries lack facilities of water, sanitation, and personal hygiene (Tebbutt, 1998). Worldwide 2.4 million lives could be saved if adequate water and reliable sanitation is made available along with the practice of appropriate hygiene (Prüss-Üstün *et al.,* 2008). It is well understood that in this situation the cost for rectifying is high, so the only way is to provide at least some degree of treated water and economically sound and sustainable sanitation solutions (Tebbutt, 1998). In developing countries, rural schemes are not as feasible due to limited resources.

Developing countries suffer from lack of proper wastewater collection and treatment facilities, especially in rural areas. The centralized collection and treatment systems are apparently too costly and complex to solve their wastewater problems (Al-Shayah and Mahmoud, 2008). The mechanism of water shortages in developing countries is very complex due to simultaneous interrelated factors such as population growth, lack of infrastructure and limitations in natural water resource especially in urban areas (Bruggen *et al.,* 2010).

Therefore to create global attention towards this issue, international organizations have taken initiatives to improve water and sanitation schemes. UN has set targets and indicators in order to meet Millennium Development Goals (MDGs), which is reducing by half the number of people without adequate water supplies, and the same goal for sanitation is recently added at Johannesburg Earth Summit (World data bank, 2013). The decade 2005-2015 is declared as a decade of water by World Health Organization (WHO) (Montgomery *at al.,* 2007)

International community has reaffirmed the principle of progressive realization in Rio 20 and United Nations Conference on sustainable development with a declaration of commitment to progressive realization of access to safe drinking water and basic sanitation for all and has linked this to poverty eradication, women's empowerment and human health's protection (Luh *et al.*, 2013)

2.3. Scenario in Pakistan

2.3.1. Vulnerability

Pakistan, being a developing country, has faced numerous humanitarian crises, disasters, political unrest, and poverty. The facilities of public health have been badly threatened, especially after the disasters of earthquake of 2005 and floods of 2010 (Zulfiqar *et al.*, 2010, Warraich *et al.*, 2011).

Records show about 1.6 million deaths in all natural disasters in the past 65 years (Ahmad, 2010). Pakistan ranks at number 80 among 122 nations regarding drinking water quality. Drinking water sources, both surface and groundwater are contaminated with coliforms, toxic metals and pesticides throughout the country. Various drinking water quality parameters set by WHO are frequently violated (Azizullah *et al.*, 2011).

At Present, only 6 out of 10 persons have access safe drinking water. Government has set targets to address this issue, in which 93% by 2015 and 100% by 2025 will gain access to safe drinking water (NDWP, 2009). Surface and ground water sources are contaminated by various biological, inorganic and organic pollutants (Malik, 2009). Population of Pakistan is likely to reach 221 Million by 2025 which will exert excessive pressure on the available water resources to fulfill the demands

2.3.2. Water availability

Pakistan is now in the list of water deficit countries due to depleting ground and surface water resources. Water availability to is decreased from 1,299 m^3 per capita in year 1996-97 to 1,100 m^3 per capita in year 2006 and it is anticipated to be less than 700 m^3 per capita by 2025 (Pak-SCEA 2006).

2.3.3. Wastewater treatment - A review of Pakistan

Pakistan is a low income country, where only 8% of the wastewater generated is treated (Sato *et al.*, 2013). Wastewater is directly discharged into drain which is ultimately received by natural water bodies causing water pollution. There is no biological treatment system in Pakistan, except for Islamabad and Karachi, which too treat less than 8 % of wastewater generated. Therefore non-conventional water sources for irrigation is getting importance in Pakistan (Murtaza & Zia, 2012).

Literature shows that in Pakistan, 8 out of 388 cities have wastewater primary treatment facilities. There are 3 plants in Islamabad in which one is functional. Two plants in Karachi with only screening and sedimentation facility. The situation is same at Faisalabad. In rural areas, wastewater treatment concept is nonexistent.

2.4.Wastewater – A Potential Threat to Public Health and Environment.

Wastewater is used water generated from various activities in our daily lives around the communities from residential and non residential sources. Wastewater is harmful to public health and can pollute the environment unless properly treated. It is a matter of fact, that there never will be any more or less water on earth than there is at present, which means the wastewater generated is going to be reused and without proper treatment, the world's overall potable water supply greatly suffers. Apart from potential threat to public health and the environment, the wastewater has the potential of affecting the local economy, residential business development, and other aspects of our daily lives. Before mid-18th century, there were no proper treatment concepts for wastewater, therefor wastewater and other wastes were dumped or supplied to nearby water bodies, which later, resulted in epidemics of cholera, dysentery, typhoid and many other water borne diseases.

2.4.1. Domestic Wastewater

Domestic wastewater is composed of black and grey water, according to their generation at source. The black water is generated from toilets and grey water from baths, kitchens and washing places (Henze and Ledin, 2001). It is reported that majority of the pathogenic bacteria, nutrients and organic matter is present in black water (Terpstra, 1999) which magnifies the importance of black water treatment. Table 2.1 shows the characteristics of domestic wastewater, black water and grey water.

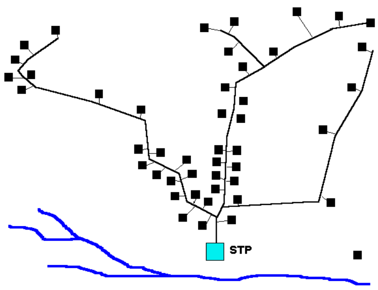
Table 2.1: Average characteristics of domestic, black and grey waste water from conventional toilets

Factor (mg/1)	Domestic Wastewater	Black Water	Grey Water
BOD	110–410	310–610	110–410
COD	200–750	910–1500	210–710
N	21–81	120–320	9–31
P	5–22	45–95	3–8

Source: (Henze and Ledin, 2001)

2.5.Wastewater Collection and Treatment Concepts

Wastewater treatment system approaches can be classified into two concepts. The first one is centralized, in which the whole area is connected and the collection system is central and wastewater through this network reaches a nearby treatment plant if available and gets treatment. The second approach is called cluster or decentralized approach. In which the collection is not centralized and if the treatment is to be made. It could only be possible to install on-site treatment solution for wastewater to get treatment. Typically centralized wastewater collection system is costly and require larger pipes and big infrastructure (USEPA. 2004). Whereas, the decentralized system treats wastewater from individual households or cluster of houses (Tchobanoglous *et al*, 2004).



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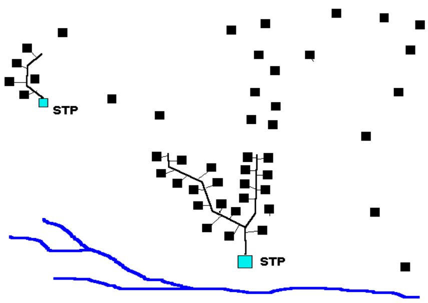

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Figure 2.2: Centralized and decentralized Concepts (Rocky Mountain Institute, 2004)

2.5.1. Centralized with advantages and disadvantages

As discussed earlier, centralized systems for collection and treatment involves larger volumes of wastewater (West, 2001), thus this network due to its concept, is very costly and can be applicable to larger cities with developed economies. The construction of centralized treatment is not recommended for low income countries or cities due to its cost (Parkinson, 2003).The centralized treatment and collection system has advantages and disadvantages, which are discussed in Table 2.2.

Table 2.2: Advantages and disadvantages of centralized systems

Description/Aspect	Advantages	Disadvantages
Technology	Known and Modern technology Very good performance and is installed in all developed countries.	Treatment ability in dry weather and heavy rains is poor Prone to leakages Less flexible Not suitable for low income countries
Economic	operational and maintenance cost is less	High capital cost (infrastructure)
Environmental	Protection of National water resources due to its concept protection of environment for septic conditions Increased infrastructure safety due to storm water and wastewater management Public Acceptance Control due to centralized approach	Areas with water shortages are not suitable for this kind of network, as it utilizes large amount of water High nutrients load due to combined collection system Leaking collection system network can cause risk of pollution

Source: (Adopted from Zaidi, 2005)

2.5.2. Decentralized with advantages and disadvantages

Decentralized systems are recommended and suitable for communities with low income since it is economical and flexible than centralized systems. Decentralized systems consists of conventional septic tanks, modified septic tanks with baffles, or any other on-site treatment system for houses or cluster of houses. This system require frequent checkup for operation and maintenance. The decentralized systems are getting popular with time due to their less resource demanding and sustainability (Tchobanoglous and Crites, 2003). The advantage and disadvantages of this system is discussed below in tabulated for in Table 2.3

Table 2.3: Advantages and disadvantages of decentralized systems

Description/Aspect	Advantages	Disadvantages
Technical	Short and simple collection system Appropriate and suitable for all type of localities. Flexible Onsite treatment Low capital cost for sever system Sustainable	Unfamiliar and new technology Prototype application have not proved to be having high treatment Underestimated O and M costs
Economic	Easy to install and run Low equipment costs Low water usage Low sludge production	Training costs for new installation and O & M Control over multiple facilities O & M know how required
Social / environmental	Treated water reuse for non-potable purposes Reclamation and reuse at source water Low environment risk	Poor public perception O&M failures

Source: (Adopted from Zaidi, 2005)

2.6.Challenges to wastewater management

Water is essential to sustaining our life. It is one of the basic human right to have clean water for drinking, other hygiene and non-potable purposes. Developed nations has somehow fulfilled the need to proper supply of water for essential human needs.

As a matter of fact, the stress on water's availability is increasing day by day. The amount of wastewater generated from houses and other commercial sources have been increasing since the evolution of industrial era and population burst. Although there is a lot of work done to address the shortage and availability of water but still we are way back in addressing the need to properly equip our cities in order to face the challenge of water shortages (Nelik, 2012). There are significant resources for natural water but still world is observing water stress conditions both in terms of quality and quantity.

Increased urbanization with higher living standards have multiplied the need for high quality water (Qadir *et al.*, 2008). It has become very hard to extend the development of collection networks for water and sewage systems due to uncontrolled urbanization and resettlement.

As a whole, the biggest challenge is the amount of water in terms of quality and quantity to be decreasing while on the other hand, the demand for water is growing. The developed world has somehow coped with the situation, but the underdeveloped countries where low income and high population growth are additional challenges, doesn't have enough resources to meet supply and demand requirements.

The increased cost of centralized treatment systems also suggest alternatives to this system because they are expensive and difficult to maintain (USEPA, 2002).

2.7.On-site treatment solutions

2.7.1. A septic tank

A septic tank consists of a tank and a soil absorption field that is constructed to allow treated effluent to penetrate into the soil. A septic tank in its simple format is primary treatment solution which is efficient in removing pollutants to reduce environmental risks to surrounding (Christopher *et al.*, 2005). The need of better performance and high standards for effluents have led to major changes in the design of septic tanks, since they are used widely in peri-urban and urban areas in developed countries. An anaerobic treatment system is suitable and safe for on-site systems (Zeeman and Lettinga, 1999) due to its easy installation and small foot prints

2.7.1.1. Limitations

Table 2.4 presents a lists indicators and their respective sources

Table2.4: Problems and their sources for septic tanks

Problems	Sources
Odor	Insufficient ventilation ,Blockage inside tank within chambers, Inadequate area for biodegradation
Backflow	Blockage of inlet drainage field area deficiency overfilling of tank
Solids flow out from tank	Insufficient biodegradation overfilling of tank
Groundwater pollution	Blockage of absorption zone Drainage field insufficient area overfilling of tank leakage within the walls of septic tank
Groundwater penetration to the tank	Inappropriate location Elevated water table

Source: (Butler, 1995)

2.7.2. Modified septic tanks

2.7.2.1.Sewage treatment unit (STU)

Sewage treatment unit (STU) is a low cost solution for sanitation in rural areas. The sole purpose of STU is on-site treatment of domestic sewage where conventional means are not possible or available. Due to high cost of conventional individual sewage treatment systems poor rural and peri-urban population can hardly afford it and hence avoid it. This leads to open defecation and other sewage disposal related issues. Solution can be a system which combines the positives of both municipal and single sewage treatment systems yet remain low cost and affordable for the poor.

STU consists of different sewage treatment units i.e. separation tank, sedimentation tank, gravel filter and effective microbial tank which are combined to form a compact system. The advantage of STU over septic tank is that it provides filtration along with microbial removal reducing the sewage retention time.

STU takes raw sewage in, allows the solids to settle and allow supernatant to flow through the gravel bed into the next chamber. Microorganisms in the anaerobic environment in the tank digest the sludge and scum. The surface scum is also prevented from leaving the tank. Sludge retention time and quantity is reduced by introducing additional Effective Microorganisms (EM) in the last chamber. Sewage water enters into a chamber from one side where solids are separated and black water then enters into a large portion of the tank through T- pipe. The water then passes into next portion of tank through a gravel filter. The EM solution added into it further accelerates the treatment process hence reduces the bad smell and bacteria count.

Many laboratory tests showed that the effluent discharging from STU is safe to dispose of in open channels, if it is managed according to the guidelines. However, during the actual field conditions, it has a limitation where sometimes people find it hard to pour the effective microbe solution in STU which leads to reduce the design life of the STU along with the risk of unsafe effluent disposal into the environment.

2.7.2.2. Anaerobic Baffled Reactor coupled with anaerobic peat filter (ABR-APF)

2.7.2.2.1. Anaerobic baffled reactor (ABR)

Anaerobic baffled reactor is a type of wastewater treatment technology in which water is forced to flow over, under or through the series of baffles from inlet to outlet by compartmentalizing conventional septic tank with the help of baffles which serve the purpose of both primary and secondary clarifier within the same tank by separating solid retention time (SRT) from HRT (McCarty and Bachmann, 1992). The anaerobic treatment in baffled reactors can mineralize the organic matter which is considered first step for the sustainable treatment and reclamation of domestic wastewater (Vanlier and Lettinga, 1999). Anaerobic reactors have high organic loading rates by keeping the biomass SRT in the reactor independent of influent HRT as compared to Continually Stirred Tank Reactors (CSTRs), thus resulting in lower reactor volume and ultimately allowing application of high volumetric loading rates e.g. 10-40 kg COD/m^3.d (Iza *et al.,* 1991). The compartments inside the tank acts as zones for growth of microbial population establishing a sludge blanket. Majority of solids are removed at the beginning of ABR due to increased contact with the biomass resulting in low sludge generation and high SRT. The technology is very robust due to their capacity to withhold major shocks producing high treatment efficiencies and is being recommended for on-site wastewater treatment due to its easy installation and low capital cost.

2.7.2.2.2. Anaerobic peat filter (APF)

The process of filtering through a porous media is based on principles of capturing of particles rather than solid's mass removal. Filter performance in wastewater is mainly evaluated by total suspended solids (TSS) and often turbidity removal (Adin & Asano, 1998). Peat being a filter media, acts as very good sorbent for removal of noxious products form septic tank effluent, which do not allow direct disposal to landscape around the residential communities.

The peat media is acidic in nature due to the presence of humic acid in it. It has also proved to be an effective adsorbent and filtration medium for treatment of wastewater compared to commercially available adsorbent Activated Carbon (AC). Peat can be efficiently used for removal of suspended solids, oils, organic matter, slime, odorous gases, few heavy metals and nutrients (Couillard, 1992). Peat supports microbial population thus making peat an ideal biological filter medium for wastewater systems.

2.7.3. Membrane Technology and Onsite Treatment Systems

Membrane is a semi-permeable material that works as a filter in treatment systems. It allows selectively particular size of matter through it, whereas retaining the other. Membrane is classified into four groups that are used in accordance to the size required to be filtered and retained. These four groups are microfiltration (MF), ultra filtration (UF), nano filtration (NF), and reverse osmosis (RO).

Membrane based systems have been improved significantly for water and wastewater treatment management. Developed countries are using membrane technology on a big scale, but the trend is emerging in the developing countries as well such as China. (Anon, 2006). However, keeping aside its importance and benefits in water and wastewater treatment, cost and flux are one of the major limitations. Although the technology has radically reduced its cost (Churchhouse, 2000), still more reduction in cost is required to achieve a target whereby low income countries can use it for its population and get benefits from it.

2.7.3.1. Woven fiber microfiltration (WFMF) membranes

Membrane gets fouled during the operation in membrane based systems. However strategies like scouring and back flushing can reduce the rate of fouling but will not prevent it eventually from being fouled. Therefore, the ability of membranes to be cleaned and filtration recovery is a critical aspect for this technology to be viable.

It is possible to use certain chemicals to clean membranes, however, if cleaning through chemical is avoided due to development in membranes fabrication, the impacts of this technology will be improved to great extent. Further, it will allow the technology to emerge on a large scale in developing countries with low income.

Woven fiber microfiltration membranes (WFMF) have been previously investigated, where the major advantage for its usage being no requirement of chemical cleaning. Drying and physical cleaning was found sufficient to remove the fouling layer (Jamal khan *et al.* 2013). WFMF membranes have narrowly distributed pore structure which can be physically cleaned easily.

2.7.3.2.Membrane based septic tank (MBST)

A septic tank with a membrane submerged inside for filtration of wastewater is termed as Membrane Based Septic Tank (MBST). It is a new and advance technology to treat and reclaim wastewater on-site and reuse at source accordingly.

The MBST has been under investigation around the world. It is expected to satisfy the objective to treat wastewater at source without any further treatment by satisfying effluent standards as per National Environmental Quality Standards NEQS (Pak-EPA). Moreover, non-potable domestic water demand could be met with this system and if the system showed desired performance in terms of treatment and operation, it can be further up-scaled for commercialization, at lower capital investment and replicated in houses, cluster of houses, and buildings.

Chapter 3

MATERIAL AND METHODS

3.1. Development of membrane based septic tank (MBST)

This study was carried out on a Full scale Membrane Based Septic (MBST) tank having 4m^3 volume. There were 3 membrane modules used in this study, termed as M1, M2 and M3. M1 and M2 were WFMF membranes while M3 was a flat sheet membrane module. These membranes were used as a filter in septic tank. The specifications are reported in detail bellow. The modules were fully submerged inside secondary chamber of the septic tank as shown in Figure 3.1. The main operations under this study were to investigate fouling frequency of membranes and treatment performance.

In the first operation, membrane modules were tested against permeate flow rates at 6, 8 and 10 LMH. Permeate was withdrawn by applying suction pressure using peristaltic pump. During this operation, TMP and flow rates were continuously recorded

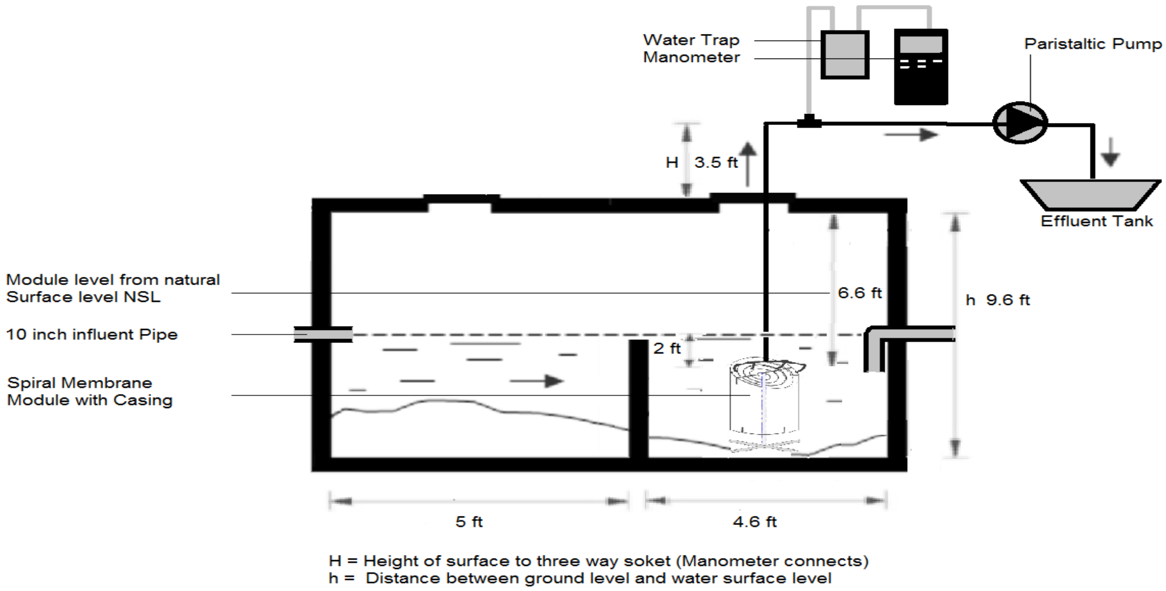


Figure 3.1: MBST schematic diagram with immersed membrane

3.2. Membranes design, specifications and material

The design and specifications of M1, M2 and M3 are illustrated below in tables and figures respectively.

3.2.1. Design

M1 membrane had one permeate outlet port with dimensions 140 cm in length to 35 cm wide as shown in Fig 3.2

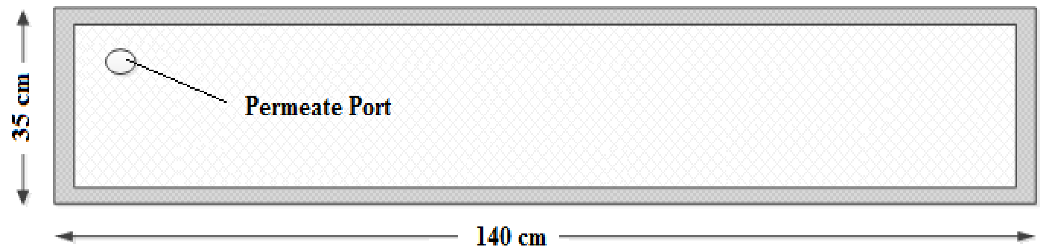


Figure 3.2: M1 design with one permeate outlet

M2 membrane had three permeate outlet port with dimensions 140 cm in length to 35 cm wide as shown in Fig 3.3

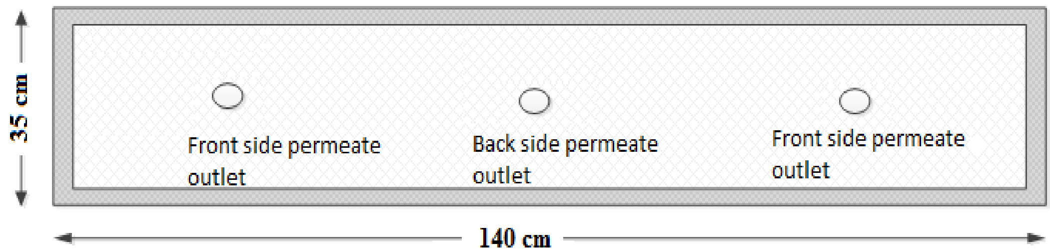


Figure 3.3: M2 design with three permeate outlets

M3 membrane was used in a flat sheet module with configuration as shown in Figure 3.4. The membrane was attached on both sides of the module frame. Four membrane frames were used which were equal in dimensions, making an effective filtration area of 1 m^2

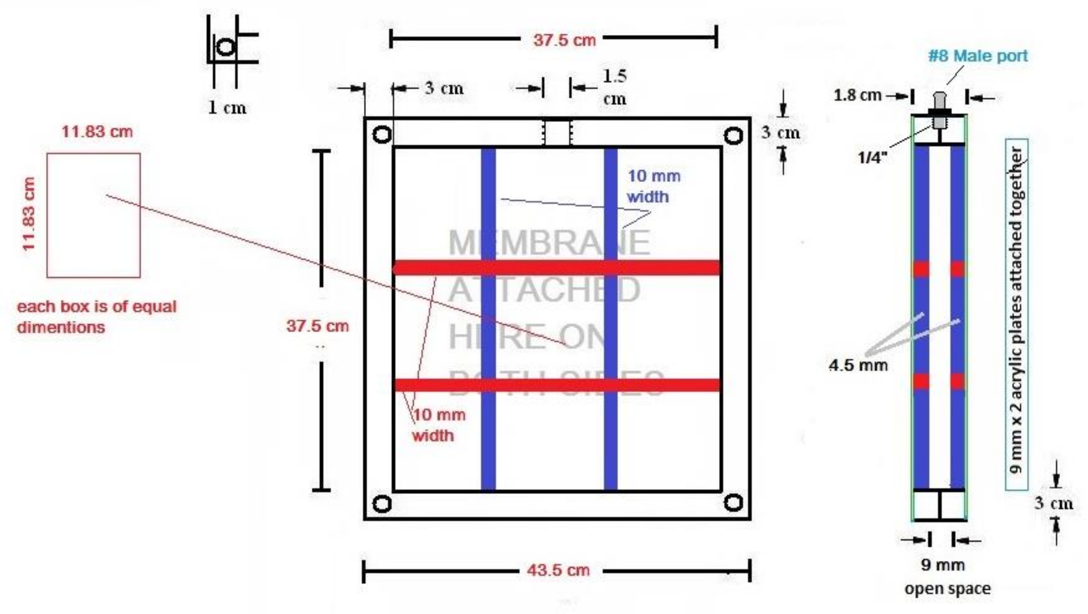


Figure 3.4: M3 design with three permeate outlets

3.2.2. Specifications

The specifications of membranes used in this study are presented in Table 3.1 and 3.2

Table 3.1. Woven fiber microfiltration (WFMF) membrane specifications

Membrane type	**Specifications**	
	M1(Spiral membrane)	**M2(Spiral membrane)**
Membrane type	Dead-end mode, outside-in, Spiral sheet	Dead-end mode, outside-in, Spiral sheet
Number of membrane modules	1 (Folded on either side)	1 (Folded on either side)
Filter	Membrane folds in the form of spiral and plastic separator mesh between two folds	Membrane folds in the form of spiral and plastic separator mesh between two folds
Outlet Ports	1 (right most corner)	3, (2 ports at one side and 1 port at center of another side)
Material	Polyester fabric (Carbon)	Polyester fabric (Carbon)
Pore size	1 – 3 µm	1 – 3 µm
Effective size L x W	140 cm x 35 cm (x 2 sides)	140 cm x 35 cm (x 2 sides)
Total membrane area	(2 x 140 x 35) /10000 = 1 m^2	(2 x 140 x 35) /10000 = 1 m^2

Table 3.2. Flat sheet (M3) membrane Specifications

Membrane type	**Specifications (Flat sheet)**
Membrane type	Dead-end mode, outside-in, Flat sheet
Number of membrane modules	4 (membrane sheets attached on either side of the module frame)
Filter	2 sheets (fixed)+1 spacer between the 2 flat sheets
Outlet Ports	One Port on top middle side of module
Material	Polyester
Pore size	1 – 55 µm
Effective size L x W	35 cm x 35 cm (x 2 sides) & (x 4 frames)
Total membrane area	(2 x 35 x 35 x 4) /10000 = I m^2

3.2.3. Material

The M2 membrane with 3 permeate outlet ports is the main focused membrane used as a spiral sheet in this study. The material is a carbon fabric microfiltration membrane. Following figures shows the membrane with pore size analysis.

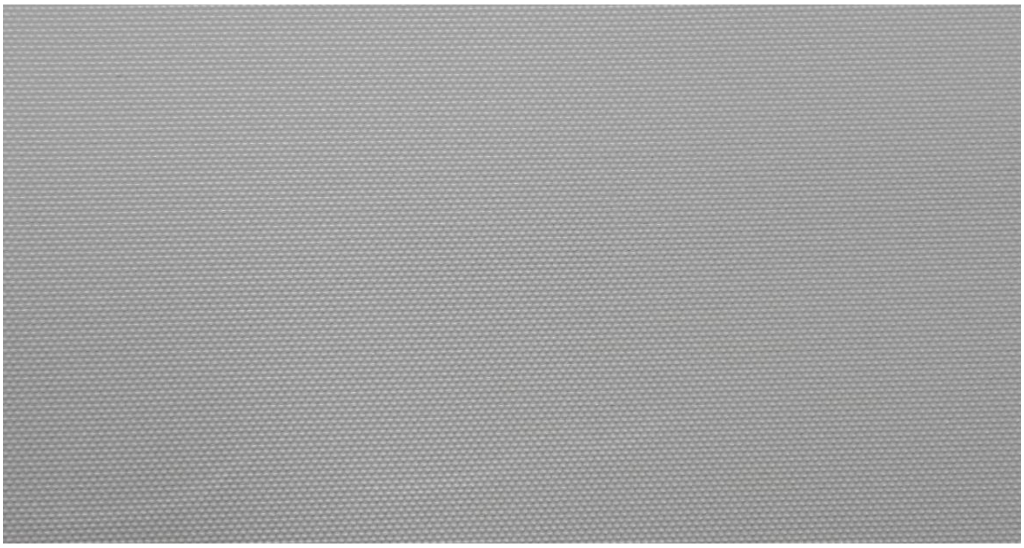
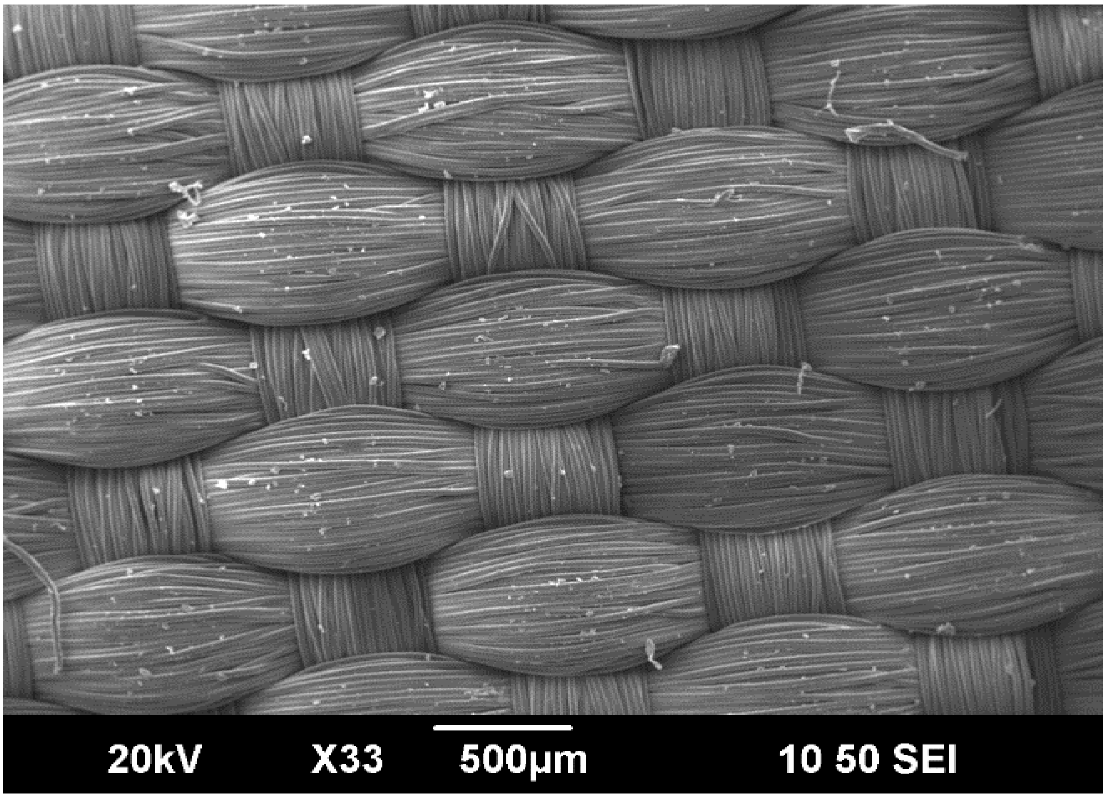


Figure 3.5 WFMF Spiral Sheet Membrane (Camera Image)



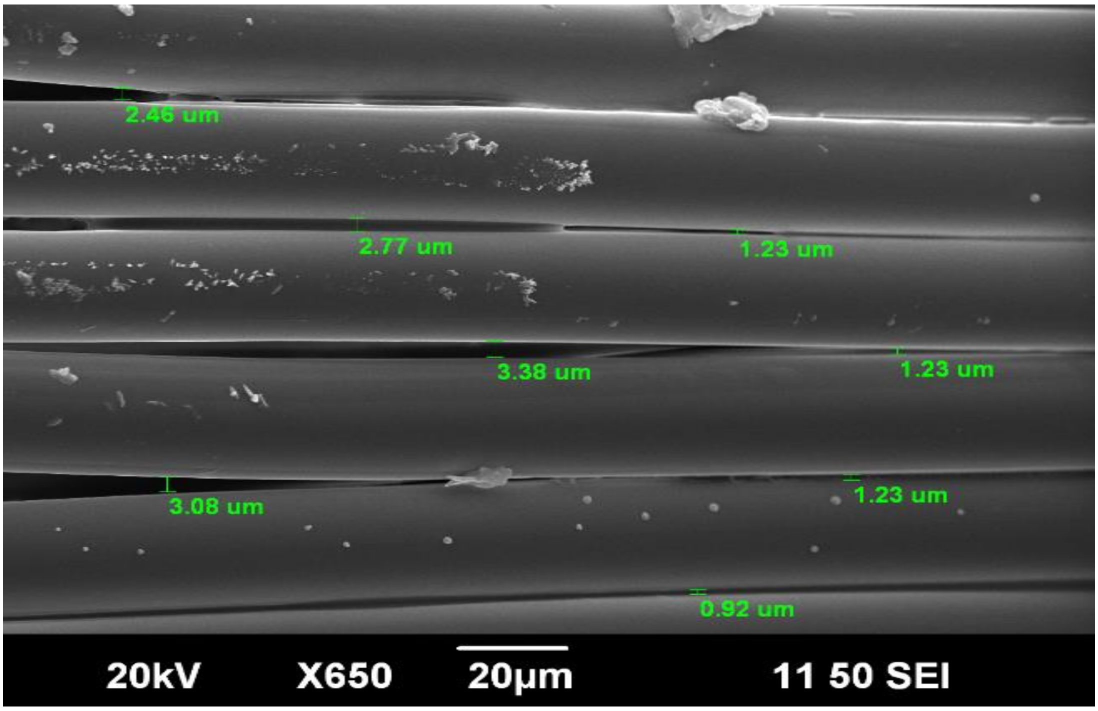
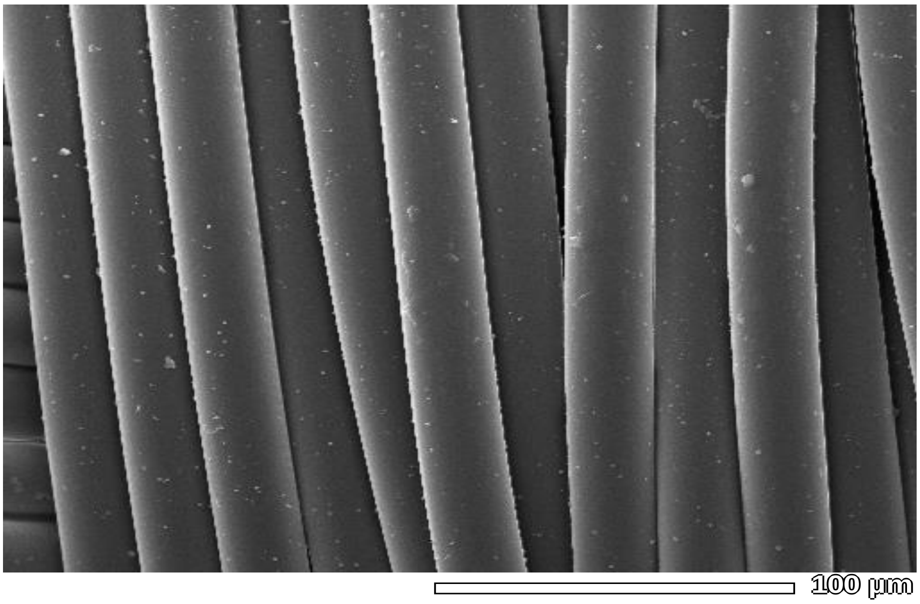
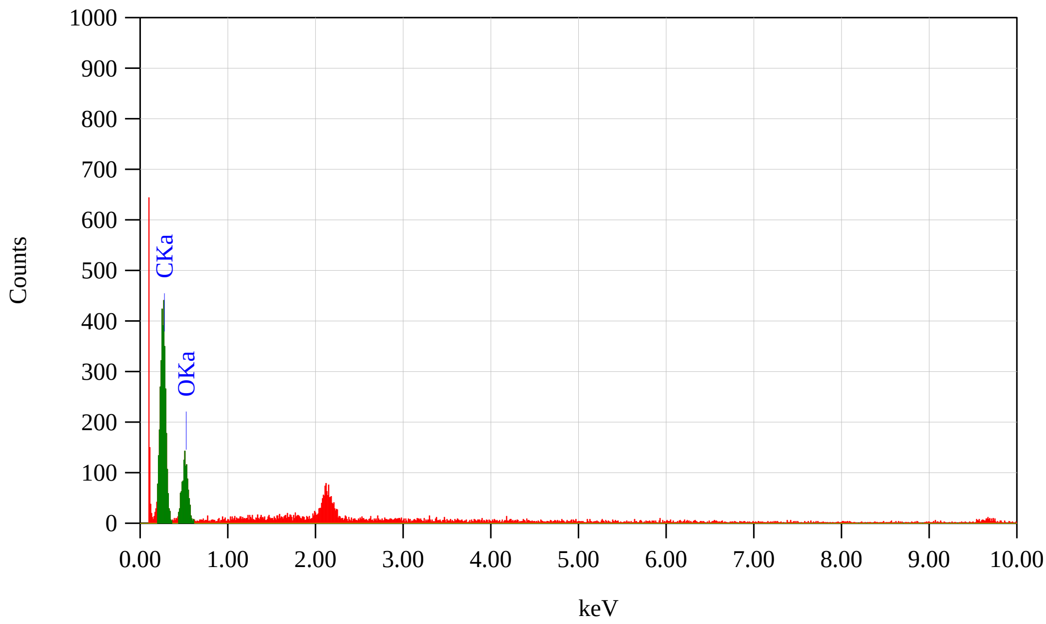


Figure 3.6 SEM of membrane 20 µm material and pore size analysis

The Scanning electron microscopic (SEM) analysis for M2 spiral sheet membrane is presented below.





ZAF Method Standard less Quantitative Analysis

Fitting Coefficient: 0.8167

Element	(keV)	Mass%	Error%	Atom%	Compound	Mass%	Cation	K
C K	0.277	52.77	0.37	59.82				57.4254
O K	0.525	47.23	2.60	40.18				42.5746
Total		100.00		100.00				

The M3 membrane (Flat sheet) in this study is a carbon compressed material with varying pore size. Figure 3.7 shows M3 membrane with pore size analysis.

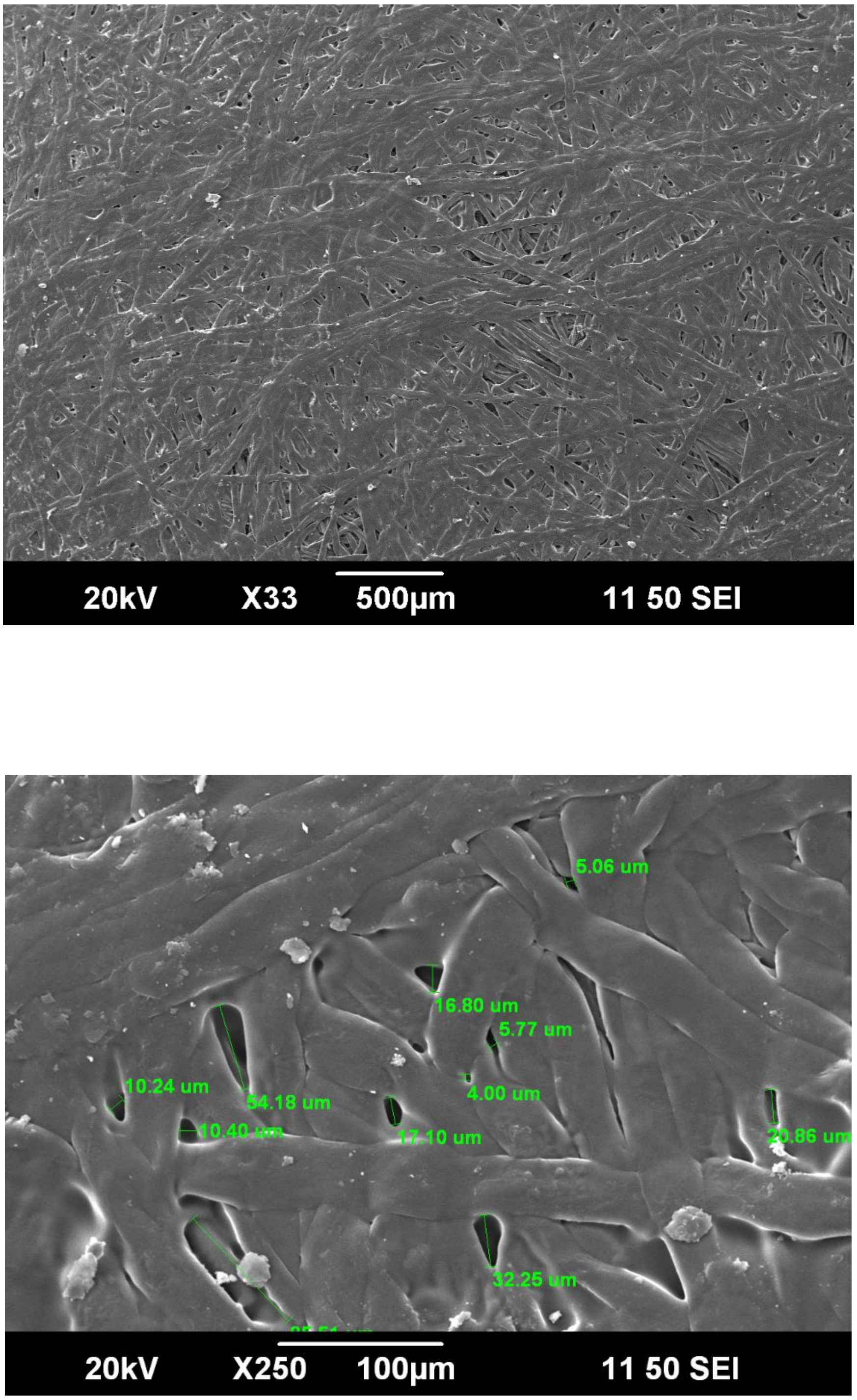
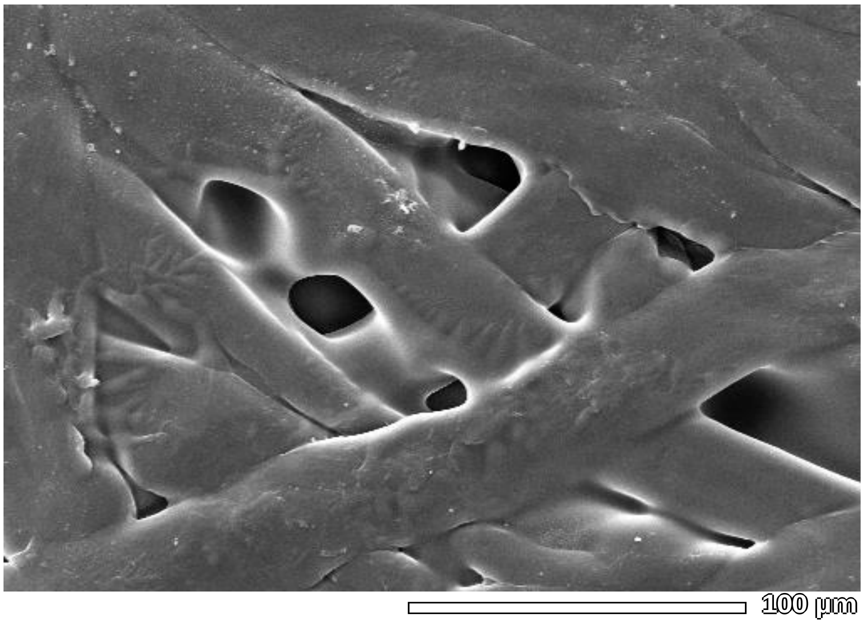
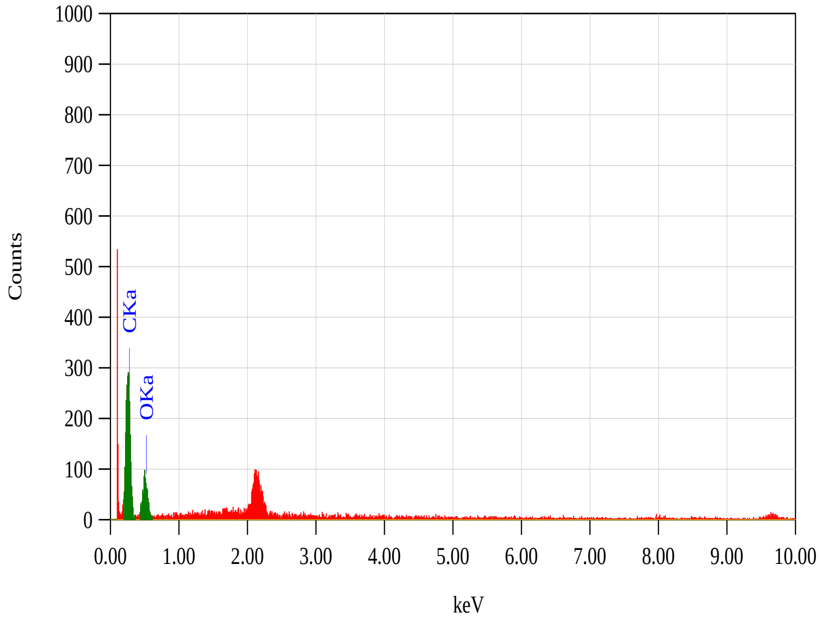


Figure 3.7 SEM of membrane 100 µm material and pore size analysis (Flat sheet)

The Scanning electron microscopic (SEM) analysis for M2 spiral sheet membrane is presented below.





ZAF Method Standard less Quantitative Analysis

Fitting Coefficient: 0.9008

Element	(keV)	Mass%	Error%	Atom%	Compound	Mass%	Cation	K
C K	0.277	52.76	0.56	59.81				57.4095
O K	0.525	47.24	3.94	40.19				42.5905
Total		100.00		100.00				

3.3. Sampling Methodology

Grab samples were collected from the influent and effluent points shown in Figure 3.8.

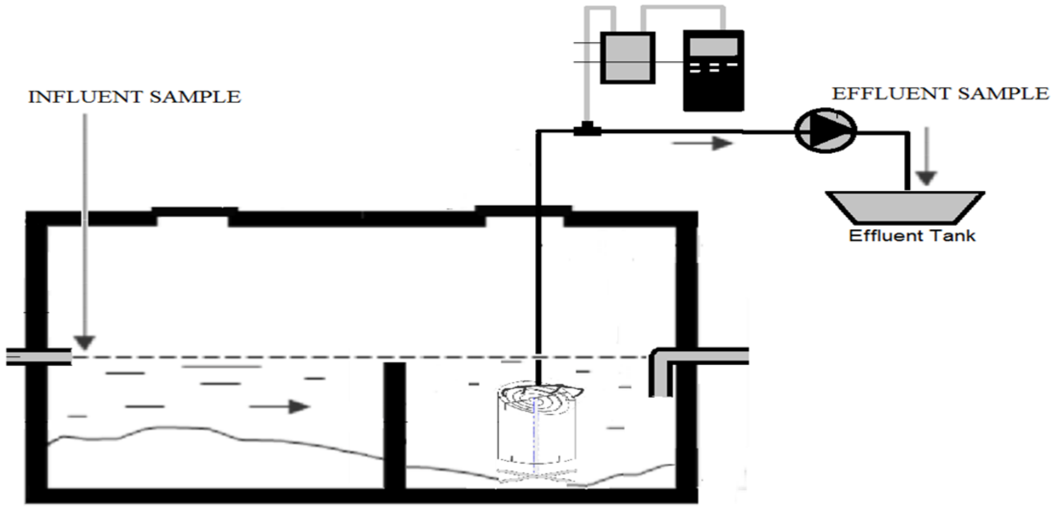


Figure 3.8: Sampling Points in Septic Tank

3.4. Analytical Parameters and Treatment Methods

MBST system was tested for its treatment performance, during which tests were performed on samples collected on alternate days of the week. The physico-chemical and biological parameters analyzed are presented in Table 3.3

Table 3.3: Parameters, Treatment methods and equipment

Parameters analyzed	**Technique**	**Equipment/Material**	**References**
TSS/VSS	Filtration-Evaporation	1.2 µm (GF/C, Whatman); 105°C oven drying, 550°C	APHA.,2005
COD	Closed reflux	COD reactor, digital Titrator (SCHOTT)	APHA.,2005
BOD	DO measurement.	Incubation bottles 300 mL, Water Bath	APHA.,2005
NH_4^+-N, NO_2^- -N, NO_3^--N, Po_4^{-3}.	HACH standard methods	Spectrophotometer, HECH reagents	APHA.,2005
Feacal coliform Analysis	MF filtration	Filtration assembly , media EMB agar	APHA.,2005

3.5. MBST Operation

3.5.1. Maintenance and cleaning of membrane

While maintaining the MBST operation, each filtration run for a membrane with a specific flow rate (i.e. 6, 8, 10 LMH) was considered complete each time when TMP reached its terminal point of 60 Kpa. The terminal pressure was calculated mathematically by formula given bellow

$$P_1 \quad = TMP + (H+h)\ \rho\ g$$

$$TMP \ = \ P_1 - (H+h)\ \rho\ g$$

TMP	= Trans Membrane Pressure (Calculated)
P_1	= Pressure gauge reading
ρ	= Density of water (1000 kgm^{-3})
g	= Gravity of acceleration (10 ms^{-2})
H	= Height of surface to three way socket (pressure gauge Connects)
H	= Distance between ground level and water surface

In order to minimize irreversible fouling the operation was stopped at this stage and membrane had to be taken out and disconnected from the system for physical cleaning, sun drying for 36 hrs. and resistance analysis.

Initially the intrinsic membrane resistance (R_m) for virgin membrane analysis was found using DI water, before submerging it into wastewater. At this stage, the intrinsic membrane resistance equals the total hydraulic resistance (R_t) i.e. R_m. = R_t, due to the fact that at this point, there is no cake layer and no pore clogging. Membrane was than submerged into wastewater inside septic tank after initial virgin membrane resistance analysis at laboratory and the operation was started.

At the end of each filtration run, membrane was disconnected from the system and cake layer was removed after sun drying for 36 hours before resistance analysis in laboratory.

During the resistance analysis, membrane was physically cleaned by spraying tap water and using brushes to remove cake layer and deposited solids. The membrane module was kept in dry and clean conditions for the next filtration run after each cleaning protocol and resistance analysis. Below figures shows a virgin membrane before operation and a clogged membrane after operation

Figure 3.9: Clean membrane and clogged membrane

3.6 Membrane Resistance Analysis

After completion of each filtration run and disinfection process, the membrane module was taken inside the laboratory. The laboratory scale setup was established at Wastewater laboratory, IESE is shown in Figure 3.10

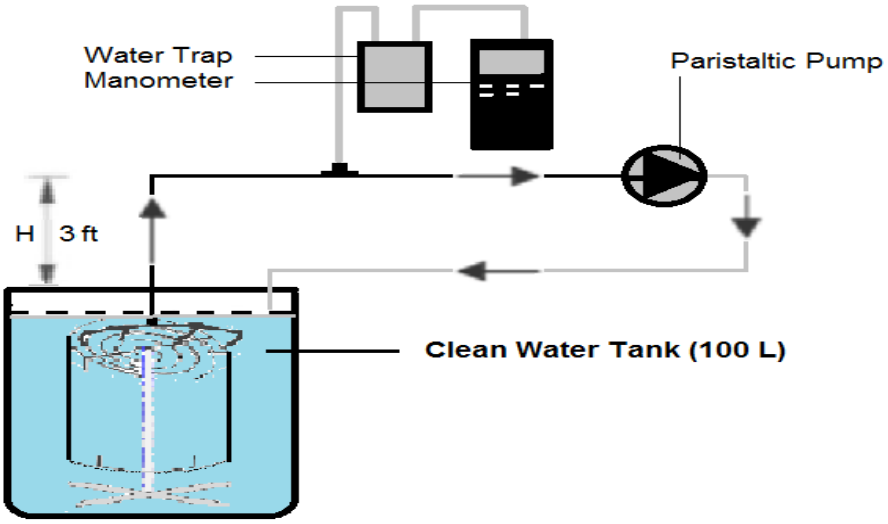


Figure 3.10: Laboratory scale setup for membrane resistance analysis

The resistance analysis were performed with cake layer deposition, before physical cleaning and without cake layer after physical cleaning. During the resistance analysis, the total hydraulic resistance (R_t), intrinsic membrane resistance (R_m.), cake layer resistance (R_c.) and pore blocking resistances (R_p.) were measured and recorded.

The resistance-in-series model was applied to estimate the filtration characteristics using following equations (Jamal khan, 2008):

$$R_t = R_m + R_c + R_p$$

Where;

J = Operational flux ($L/m^2.s$) or LMH.

ΔP = TMP (kPa),

μ = viscosity of permeate (Pa.s),

f_t = temperature correction to 20°C, $f_t = e^{-0.0239(T-20)}$

R_t = total hydraulic resistance (m^{-1}),

R_m = intrinsic membrane resistance (m^{-1}),

R_c = reversible cake resistance created by the cake layer (m^{-1}) and

R_p = irreversible fouling caused by adsorption of dissolved / colloidal onto the surface of membrane and also into the pores (m^{-1}).

The resistances R_t, $R_m + R_p$ and R_c, were found by filtering DI water with and without cake layer for a period of 20 min for each flow rate. Profiles were developed for resistances against different fluxes i.e. 4, 6, 8, 10, 12, 14, 16 and to 18 LMH.

Further, $R_p + R_p$ and R_c were found using equations,

$$R_t = R_p + R_m + R_c \text{ (With cake layer)}$$

$$R_t = R_p + R_m \text{ (without cake layer)}$$

The cake layer resistance was found using equation $R_c = R_t - (R_m + R_p)$

Chapter 4

RESULTS AND DISCUSSIONS

4.1. Membrane Fouling Frequency Analysis

During the filtration process, membrane fouling was found to be one of the major limitation for MBST system. Membrane fouling characterization was performed by developing trans-membrane pressure (TMP) profiles. TMP and flux data obtained from the MBST system were recorded, at an approximate interval of every 3rd hour during a day, from 9 AM onwards till 11 PM each day.

4.1.1. Fouling Frequencies of Spiral Membrane Module

The system was operated at flux rates of 6, 8 and 10 L/m^2-h (LMH) during the spiral membrane analysis. The average fouling frequencies were found to be 15, 8 and 5 days, respectively as shown in Figure 4.1. Average fouling cycles were obtained by running each flux cycle three times to achieve triplicate fouling frequencies. The cleaning procedures of membrane module and suitable flux operation showed 8 LMH to be optimum for spiral membrane module. The membrane was considered fouled and the corresponding cycle was completed each time when TMP reached to a terminal TMP of 60 KPa (Calculated). The filtration operation was stopped each time after reaching terminal TMP and membrane module along with its casing were taken out of the system for physical cleaning and resistance analysis.

As shown in Figure 4.1 during 6 LMH phase, the MBST system was operated for maximum 45 days, over which the TMP reached 60 KPa in 15 days. During the initial stages, the TMP rise was slow with respect to time compared to higher flux rates. A significant increase in the hydraulic resistance was observed at the end of each filtration cycle as TMP reached its terminal level of 60 kPa, while the permeate flux of the MBST system decreased to about 60% of its initial flux rate.

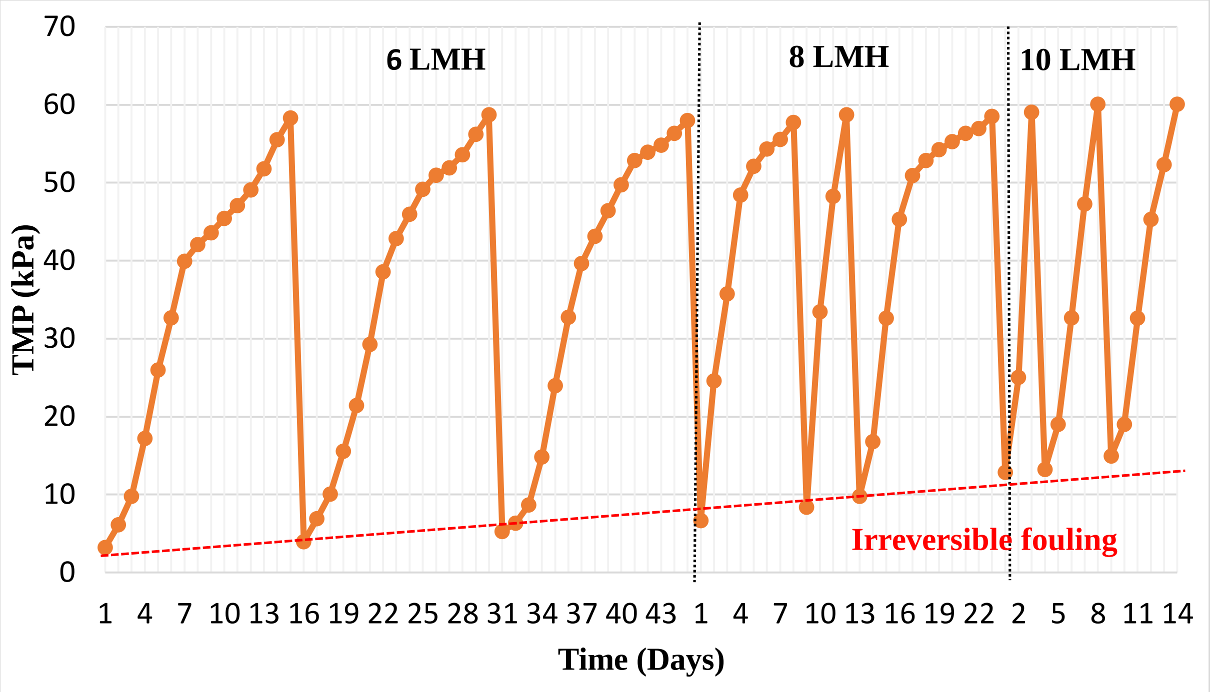


Figure 4.1: TMP profiles at different flux rates for spiral membrane module

As the operational cycle continued, it was found that fouling of the membrane increased as shown in Figure 4.1.

As the filtration of wastewater continued, membrane starts clogging which results in the rise of TMP. At 60 kPa membrane is considered fully clogged so the operation is stopped. After cleaning process, the operation is started again, It was observed that each successive filtration run started with a higher value than the preceding one showing irreversible fouling increase due the the fact that this permeability recovery could not be effectively achieved with physical cleaning protocol only. During the operation, the average startup TMP for first cycle was recorded to be 3.2 kPa, which than increased to as much as 14.9 kPa during the startup of ninth cycle, showing approximately 20% increase in total irreversible fouling trend, thus, matching the results to that of study conducted on membranes by Saadath Ali (Jamal khan et al., 2013). It was observed that modifying the outlet ports for 1 to 3 points did not have significant influence on the filtration cycle or TMP.

4.1.2. Fouling Frequencies of Flat Sheet Membrane Module

The system was operated at flux rates of 8 and 10 L/m^2-h (LMH) during the flat sheet membrane analysis. The average fouling frequencies were found to be 6 and 3 days respectively, as shown in Figure 4.2. In this case, the average fouling cycles were obtained by running each flux rate two times to achieve duplicate fouling frequencies. The cleaning procedures of membrane module and suitable flux operation showed 8 LMH to be optimum for flat sheet membrane module as well. The membrane was considered fouled and the corresponding cycle was completed each time when TMP reached to a terminal TMP of 60 KPa (Calculated). The filtration operation was carried out in the same pattern as in case of spiral sheet module.

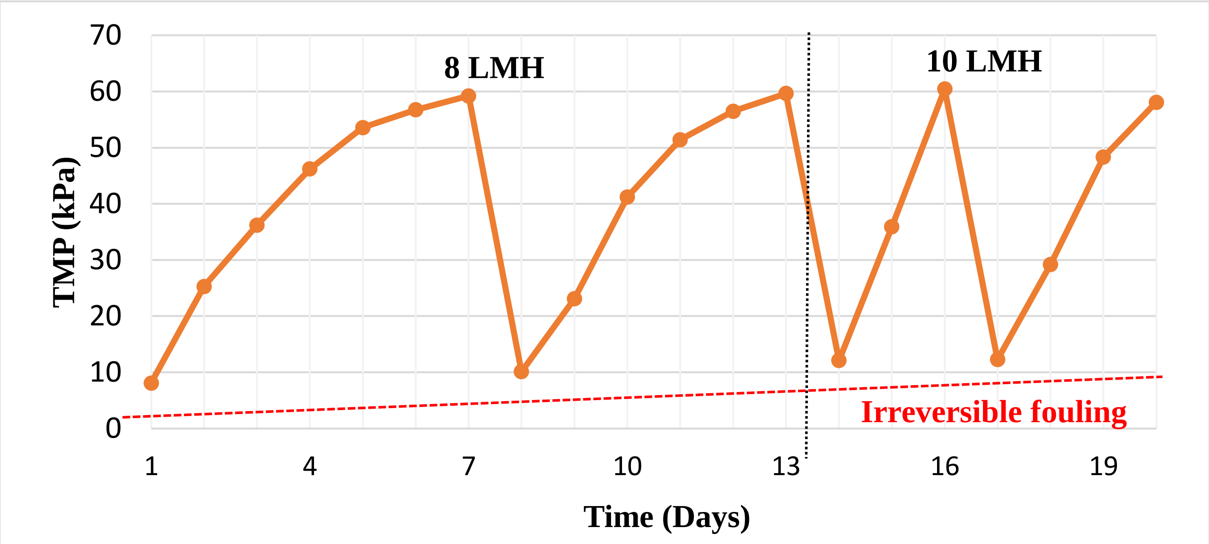


Figure 4.2: TMP profiles at different flux rates for flat sheet membrane module

Figure 4.2 shown that during 8 LMH phase, the MBST system was operated for maximum 14 days, over which the TMP reached 60 kPa in 7 days. During the initial stages, the TMP rise is slow with respect to time compared to higher flux rates.

The fouling cycle duration reduced by the change in membrane type. The SEM analysis of flat sheet module showed a high variation in the pore size of membrane. It was also found that the major effective area of membrane had no pores, the rest of remaining pores clogged quickly resulting in a decreased period of fouling. Moreover, the physical cleaning of woven membranes (spiral type) were found to be more effective as compared to non-woven membranes (flat sheet type)

Further, in this case of flat sheet membrane too, a significant increase in the hydraulic resistance was observed at the end of each filtration cycle, while the permeate flux of the MBST system observed a drop of 60 % compared to initial flux rate. As the operational cycle continued, it was found that irreversible fouling of the membrane increased as shown in Figure 4.2. After each successive filtration run, the TMP profile cycle started with a higher value than the preceding one.

During the operation, the average startup TMP for first cycle was recorded to be 8 kPa, which than increased to as much as 12 kPa during the startup of 4^{th} cycle, showing approximately 7% increase in total irreversible fouling trend.

4.2. Membrane Resistance Analysis

The resistance-in-series model was applied during both spiral and flat sheet membrane operational phases, to estimate the total hydraulic resistances offered during filtration process and to find out filtration recovery after application of cleaning protocols. The resistance analysis results are presented in Table 4.3 and 4.4 for spiral membrane module and flat sheet membrane module respectively, representing average resistance values after replicate experimental measurements.

4.2.1. Resistance analysis of spiral membrane module

The resistance analysis for spiral membrane are shown in Table 4.1. After every cycle for each operational fluxes i.e. 6, 8 10 LMH, measurements for R_m, R_c, R_t and R_m +

R_p were carried out. It was found that the values for R_m + R_p increased indicating physical

RESISTANCES		6 LMH	8 LMH	10 LMH
R_m ($x10^{12}m^{-1}$)		1.63	1.22	0.98
R_t ($x10^{12}m^{-1}$)	RUN1	3.26	2.24	2.28
	RUN2	3.40	2.34	2.36
	RUN3	3.68	2.75	2.28
	AVG	**3.45**	**2.45**	**2.31**
R_m+R_p ($x10^{12}m^{-1}$)	RUN1	0.40	0.71	0.89
	RUN2	0.54	1.12	0.89
	RUN3	0.68	1.02	0.81
	AVG	**0.54**	**0.95**	**0.87**
R_c ($x10^{12}m^{-1}$)	RUN1	2.85	1.53	1.38
[R_c=R_t-(R_m+R_p)]	RUN2	2.85	1.22	1.47
	RUN3	2.99	1.73	1.47
	AVG	**2.90**	**1.49**	**1.44**
R_c/R_t (%)		84.21	61.10	62.35
(R_m+R_p)/R_t (%)		15.78	38.89	37.64

cleaning protocol to be partially effective in permeability recovery. While on the other hand, values for R_c witnessed a slight increase after every consecutive run, indicating the physical cleaning to be very effective in removing cake layer resistance. It was also found that the values for R_c decreased as the operational flux rate increased from 6 to 10 LMH, which shows that the longer the filtration period, higher will be the cake layer thickness leading to a higher cake layer resistance (R_c) value. In this particular case, R_c values for 6 LMH is the highest as compared to other flux rates, where the average filtration period was recorded 15 days.

Further, as shown in Table 4.1, the ratios for R_c/R_t and (R_m + R_p)/R_t were found to be 84-62 % and 15-37 % respectively, showing that cake layer contribution to the total hydraulic resistance to be much greater than the pore blocking resistance and as earlier discussed, physical cleaning was found effective in removing the cake layer resistance (R_c) but relatively ineffective in reducing pre clogging resistance (R_p)

Table 4.1: Resistances at different fluxes for membrane module

4.2.2. Resistance analysis of flat sheet membrane module

The resistance analysis for flat sheet membrane are reported in Table 4.2. As discussed earlier, measurements for R_m, R_c, Rt and R_m + R_p. were carried out for each operational flux i.e. 8 and10 LMH.

It was found that the values for R_m + R_p increased indicating physical cleaning protocol to be partially effective in filtration recovery. While on the other hand, values for R_c. remained unchanged after every consecutive run, indicating the physical cleaning to be very effective in removing cake layer resistance.

Table 4.2: Resistances at different fluxes for flat membrane module

Resistance analysis at different fluxes (Flat sheet)			
		M3	
RESISTANCES		8 **LMH**	10 **LMH**
Rm(x10+E12m-1)		1.63	1.80
Rt(x10+E12m-1)	**RUN1**	**3.98**	**4.33**
	RUN2	4.39	4.82
	AVG	4.19	4.58
Rm+Rp(x10+E12m-1)	**RUN1**	**2.04**	**2.70**
	RUN2	2.55	2.86
	AVG	2.30	2.78
Rc**(**x10+E12m-1)	**RUN1**	**1.94**	**1.63**
	RUN2	1.84	1.96
	AVG	1.89	1.80
Rc/Rt(%)		45.12	39.29
Rm+Rp/Rt (%)		54.88	60.71

Further, as shown in Table 4.2, the ratios for R_c/R_t and $(R_m + R_p)/R_t$ were found to be 39-45 and 55-61 % respectively, showing less cake layer contribution to the total hydraulic resistance than the pore blocking resistance compared to WFMF spiral membrane.

4.3. Treatment performance of MBST

4.3.1. Treatment performance of WFMF (Spiral Sheet) MBST

MBST system with WFMF spiral module was analyzed for its treatment performance. The system was found to have produced satisfactory results where the average removal efficiencies of COD, BOD_5, TSS, and fecal-coliform were 71, 76, 82, and 88% respectively. The results further shows a removal of 47, 49, 40 and 27 % average removal in terms of phosphate, nitrate, nitrite and ammonium respectively. Table 4.3 presents the treatment performance results for each water quality parameter tested in this study compared with National environmental quality standards (NEQS) Pakistan environmental protection agency (Pak-EPA) standards for inland disposal.

Table 4.3. Treatment performance of MBST (Woven membrane, spiral type)

Parameters	Unit	Influent	Effluent	Removal %	NEQS
COD	mg/L	124 ± 49	32 ± 14	71	150
BOD	mg/L	88 ± 36	18 ± 9	75	80
TSS	mg/L	232 ± 113	36 ± 28	82	200
VSS	mg/L	175 ± 89	73 ± 40	55	
Ammonium	mg/L	37 ± 13	24 ± 9	27	40
Nitrite	mg/L	36 ± 18	18 ± 6	40	
Nitrate	mg/L	15 ± 12	6 ± 4	49	
Phosphate	mg/L	26 ± 12	12 ± 6	47	
pH		7.6 ± 0.5	7.9 ± 0.5		6.0 - 9.0
Total coliform	CFU/100ml			88	

The effluent concentrations for each parameter analyzed were found below the permissible national environment quality standards (NEQS).

Keeping in view the treatment performance with MBST system using a spiral membrane module, it can be considered as one of the potential option for onsite decentralized treatment solution with no other further treatment required. Further, the high removal efficiency for total coliform suggests that the treated effluent from MBST can be reused at source for horticulture and landscaping

4.3.2. Treatment performance of (Flat Sheet) MBST

MBST system with WFMF flat sheet module was analyzed for its treatment performance. The system was found to achieve results where the average removal efficiencies of COD, BOD_5 and TSS were 50, 57 and 58%, respectively. The results further shows a removal of 43, 42, 34 and 25% average removal in terms of phosphate, nitrate, nitrite and ammonium respectively. Table 4.4 presents the treatment performance results for each parameter tested in this study compared with NEQS – Pak EPA for disposal.

Table 4.4. Treatment performance of MBST (Flat Sheet)

Parameters	Unit	Influent	Effluent	Removal %	NEQS
COD	mg/L	139±26	70±15	50	150
BOD	mg/L	87±	38±	57	80
TSS	mg/L	285±34	121±27	58	200
VSS	mg/L	209±37	119±15	42	
Ammonium	mg/L	41±6	30.1±7	25	40
Nitrite	mg/L	38±4	25±2	34	
Nitrate	mg/L	15±2	9±0.35	42	
Phosphate	mg/L	31±15	19±10	43	
pH		8±0.15	7.7±0.26		6.0 – 9.0

The effluent concentrations for each parameter analyzed were found to be below the permissible national standards NEQS.

Keeping in view the results produced with MBST system using a flat sheet membrane module, it can be considered that treatment performance however, was low compared to the spiral sheet membrane module. The pore size analysis shows that this membrane used as a flat sheet has a range of pore size varying from 1 micron to as much as 60 micron, which allow bigger solids to pass through this membrane. The results shows the effects of this type of membrane with bigger size of pores, making it less reliable in terms of treatment performance. In this study, the real wastewater used was from university building and the untreated effluent was still under the permissible limits, therefore this system with flat sheet can be considered for onsite decentralized treatment solution but further research should be made using membrane with lower range of pore size (i.e. WFMF membrane) is recommended.

4.4. Comparative analysis of Spiral and Flat sheet membrane

4.4.1. Treatment comparison

The treatment performance of WFMF spiral membrane Spiral was found better compressed to carbon fiber Flat sheet membrane. The removal efficiencies for COD, BOD_5 and TSS were better in case of WFMF spiral membrane than flat sheet membrane. However, the removal trend for nutrients, were found to be almost same with a relatively higher removal in case of spiral membrane. The results are compared in a Figure 4.3.

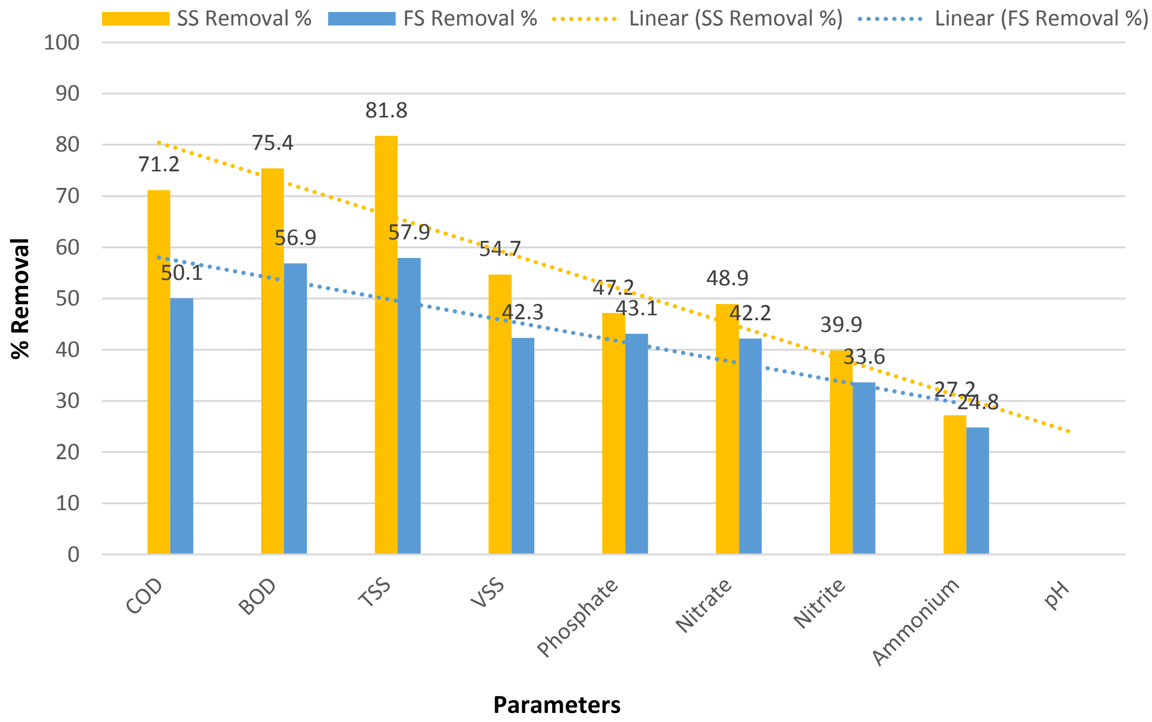


Figure 4.3: Treatment performance comparison for spiral and flat sheet of MBST

Spiral sheet has narrow pore distribution due to its woven fiber fabrication, while flat sheet membrane being non-woven has broad pore distribution, as earlier shown in the SEM pictures, this being reason for spiral membrane having higher rejection capability than the Non-woven flat sheet membrane

4.4.2. Filtration comparison

The overall operation for Spiral and Flat sheet membrane modules (excluding disinfection and resistance analysis time) were 82 and 20 days respectively. Table 4.5 presents the comparison of fouling periods in days against operational flux rates for spiral and flat sheet MBST setups.

Table 4.5: Filtration comparison of Spiral and Flat sheet membranes

Flux (LMH)	Fouling Period (Days)	
	Spiral	Flat
6	15	Not Tested
8	8	6
10	5	3

The Fouling frequencies for spiral membrane were found more, compared to the flat sheet membrane. The woven spiral membrane can be more effectively physically cleaned compared to the non-woven flat sheet due to their fabrication and pore structure distribution The total number days of continues operation excluding the membrane cleaning and analysis time for spiral membrane was 82 days while for flat sheet it was 20 days.

CONCLUSIONS AND RECOMMENDATIONS

This study was aimed at developing an on-site or decentralized wastewater treatment system for individual or cluster of houses in rural and peri-urban areas. The system was developed adopting an approach that combined old treatment technology i.e. septic tank with new advanced membrane technology. The system after successful treatment and operation has following important conclusions.

5.1. Conclusions

MBST system was found to produce satisfactory results, where the average removal efficiencies of COD, BOD_5, TSS, and total-coliform were 71, 76, 82, and 88% respectively. The treated wastewater had no further requirement for a tertiary treatment to satisfy national environmental quality standards (NEQS) for disposal. With removal of coliform to about 88%, MBST effluent can be considered as suitable for non-potable purposes such as horticulture and landscaping. However, during the filtration process, membrane fouling was found to be the major limitation for MBST system. Further, membrane fouling characterization was performed by trans-membrane pressure (TMP) profiles. The system was operated at flux rates of 6, 8 and 10 L/m^2-h (LMH) and average fouling periods were found to be 15, 8 and 5 days, respectively at terminal TMP of 60 kPa. Keeping in view the results of fouling frequencies, the cleaning procedures of membrane module and suitable flux operation, the flux rate of 8 LMH was considered optimum for spiral sheet membrane module.

After each successive filtration operation run, membrane was found to be irreversibly fouled resulting in TMP profile cycle starting with a higher value than the preceding one. Physical cleaning was found to be very effective in removing cake layer resistance while partially effective in restoring the intrinsic membrane permeability and filtration recovery. It was found that longer the filtration run for a specific fouling cycle, higher will be the contribution of cake layer resistance (R_c) to total hydraulic resistance (R_t).

Although there was no significant change observed with the increase in number of outlet permeate ports from one to three in the spiral membrane module, even then, this membrane module design proved to be better in performance, compared to membrane module with one outlet permeate port tested prior, showing an overall flexibility in operation.

The treatment capacity of WFMF spiral membrane Spiral was found to be better than the carbon fiber Flat sheet membrane. The removal efficiencies for COD, BOD_5 and TSS were better in case of WFMF spiral membrane than flat sheet membrane. However, the removal trend for nutrients, were found to be almost same with a relatively higher removal in case of spiral sheet.

The MBST system is preferred and recommended for onsite domestic wastewater treatment, due to the fact that it showed treatment efficiencies on much lower capital and simple design compared to high cost membrane systems.

5.2. Recommendations

Following recommendations are important for future study.

- MBST flux rate shall be further investigated with new WFMF membranes and is recommended to be up-scaled for actual field studies.
- Effluent of MBST is recommended to be analyzed for non-potable purposes such as landscaping and horticulture in actual field conditions.
- MBST shall be operated with renewable energy sources.

- Aeration near membrane module is recommended to be introduced to further decrease membrane fouling by scouring effect and improve membrane filtration recovery.

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APPENDIX A

PROJECT IN FIGURES

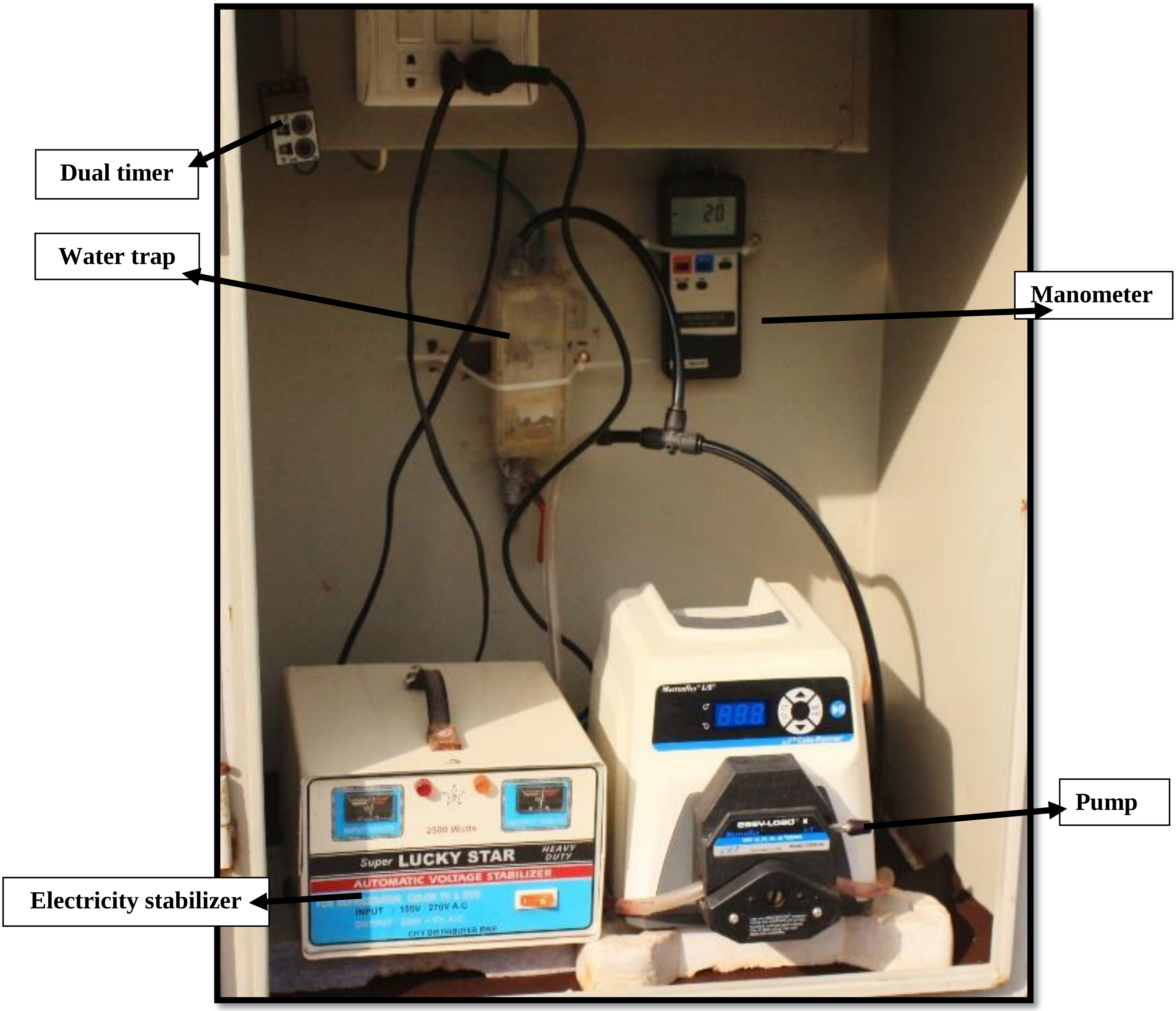

Figure A1: MBST control panal

Figure A2: MBST Setup at IESE building

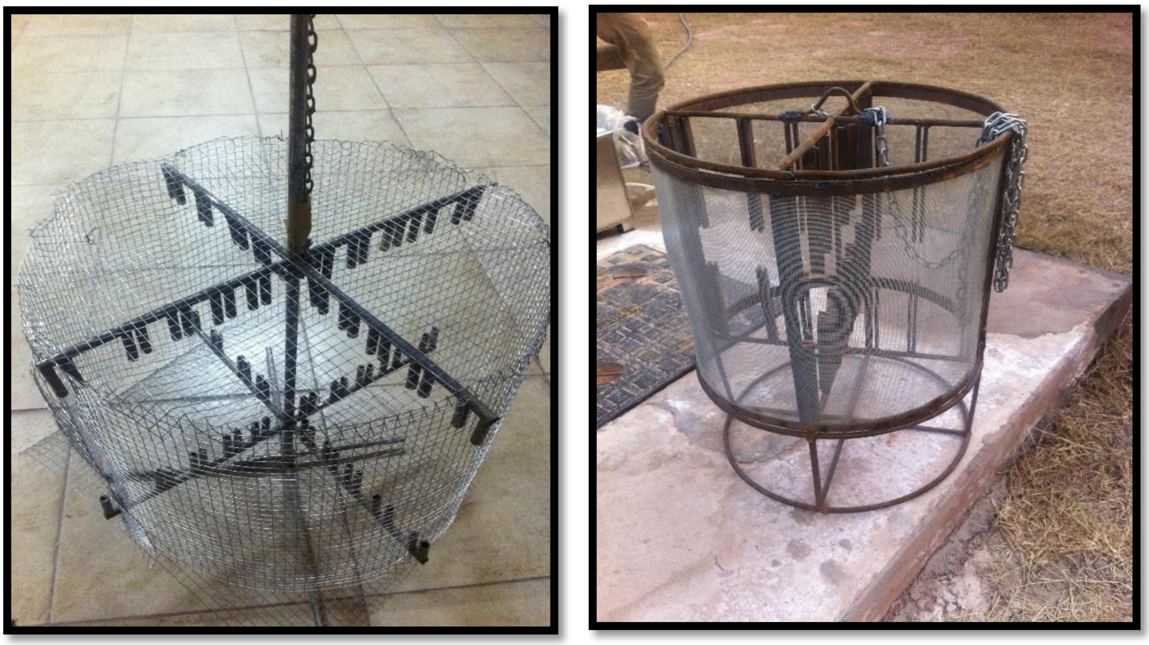

Figure A3: Old and improved Module Casing for MBST System

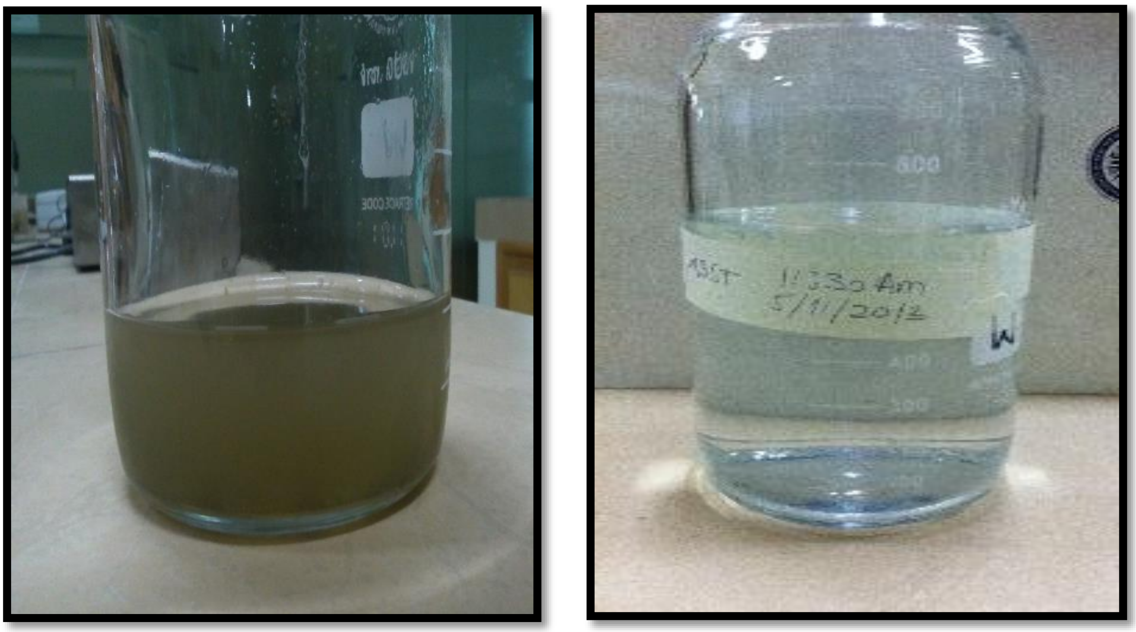

Figure A4: Influent and effluent of MBST System

Figure A5: Flat sheet membrane module and Casing

APPENDIX B

MBST PERFORMANCE PARAMETERS

Table B- 2: Influent and Effluent values for COD, BOD_5 and TSS for MBST system

Date	COD (mg/L)		BOD(mg/L)		TSS (mg/L)	
	IN	OUT	IN	OUT	IN	OUT
2-Jan	65	20			86	10
3-Jan	85	35			40	2
6-Jan	123	26	76.26	14.3	160	4
8-Jan	129	32			178	3
9-Jan	149	45			192	8
10-Jan	96	35	62.4	22.05	60	1.5
13-Jan	64	23			140	12
15-Jan	179	11	112.77	9.35	210	10
18-Feb	150	35			230	8
20-Feb	135	53			260	1
21-Feb	110	50	58.3	28	233	0
23-Feb	123	45			99	0
24-Feb	83.2	25	45.76	21.25	159	40
26-Feb	62.45	19			133	60
1-Mar	54	15			98	40
3-Mar	51	40	35.7	18	110	80
4-Mar	90	30			136	2
10-Mar	132	21			650	20
12-Mar	213	19	146.97	12.35	315	2
14-Mar	77	22			400	20
16-Mar	253	32			400	60
17-Mar	85	24			350	80
19-Mar	75	25	48.75	13.75	250	120
20-Mar	65	30			150	30
24-Mar	85	35	63.75	21.7	175	32
26-Mar	95	36			210	20
3-Apr	96	26	64.32	11.7	250	10
5-Apr	198	50			450	15
6-Apr	225	65			380	18
7-Apr	198	70			189	21
10-Apr	221	62	152.49	39.0	289	52
12-Apr	150	50			152	60
14-Apr	165	54			230	80
15-Apr	162	65	111.78	39	285	70
17-Apr	175	52			251	20
19-Apr	180	45			360	30
21-Apr	135	36			324	41
23-Apr	160	47	136	23.9	290	33
25-Apr	175	23			310	21
27-Apr	90	21	68.4	10.9	150	22
29-Apr	95	25			130	63
2-May	75	21			120	75

4-May	92	13			169	89
6-May	125	17	93.75	8.84	243	23
8-May	51	25			100	41
10-May	54	35			136	21
12-May	74	42			124	23
14-May	95	26	72.2	13.2	163	59
16-May	137	13			357	37
19-May	160	17			310	45
21-May	146	25			365	69
23-May	192	34	138.24	12.7	386	62
25-May	141	35			298	72
27-May	128	25			255	89
29-May	136	18			310	63
31-May	120	25.6	93.6	14.7	198	57
2-Jun	92.8	6.4			210	24
AVG	**124.07**	**32.4**	**87.85**	**18.6**	**232**	**36.3**
SND. DEV.	**49.89**	**14.7**	**36.96**	**9.16**	**113.08**	**28.9**

Table B- 2: Influent and effluent values for nitrate, nitrite & ammonium with removal percentage for MBST system

S.NO.	**Nitrate (mg/L)**			**Nitrite (mg/L)**			**Ammonium (mg/L)**		
	IN	**OUT**	**% R**	**IN**	**OUT**	**% R**	**IN**	**OUT**	**% R**
1	9.3	5.6	39.8	33	20	39.4			
2	6	2.8	53.3	21	18	14.3			
3	7.5	3.9	48.0	26	19	26.9			
4	9.7	5.2	46.4	37	23	37.8	49	44.7	8.77
5	11.5	5.9	48.7	39	28	28.2	59	12.9	78.1
6	12.3	6.5	47.2	41	30	26.8	25	20	20
7	OR	0.7		OR	21		36.2	26.5	26.8
7	7.8	4.8	38.5	22	15	31.8	29	23.1	20.3
8	8.5	4.2	50.6	25	18	28.0	23.5	21.5	8.51
9	9.9	5.5	44.4	29	18	37.9	36	26	27.7
10	45	18.9	58	87	9	89.6			
11	36	13.2	63.3	36	8	77.7			
AVG	**14.9**	**6.4**	**48.9**	**36.0**	**18.9**	**39.9**	**36.8**	**25.0**	**27.2**
SND. DEV.	**12.95**	**4.90**	**7.31**	**18.26**	**6.48**	**22.9**	**13.04**	**9.82**	**23.7**

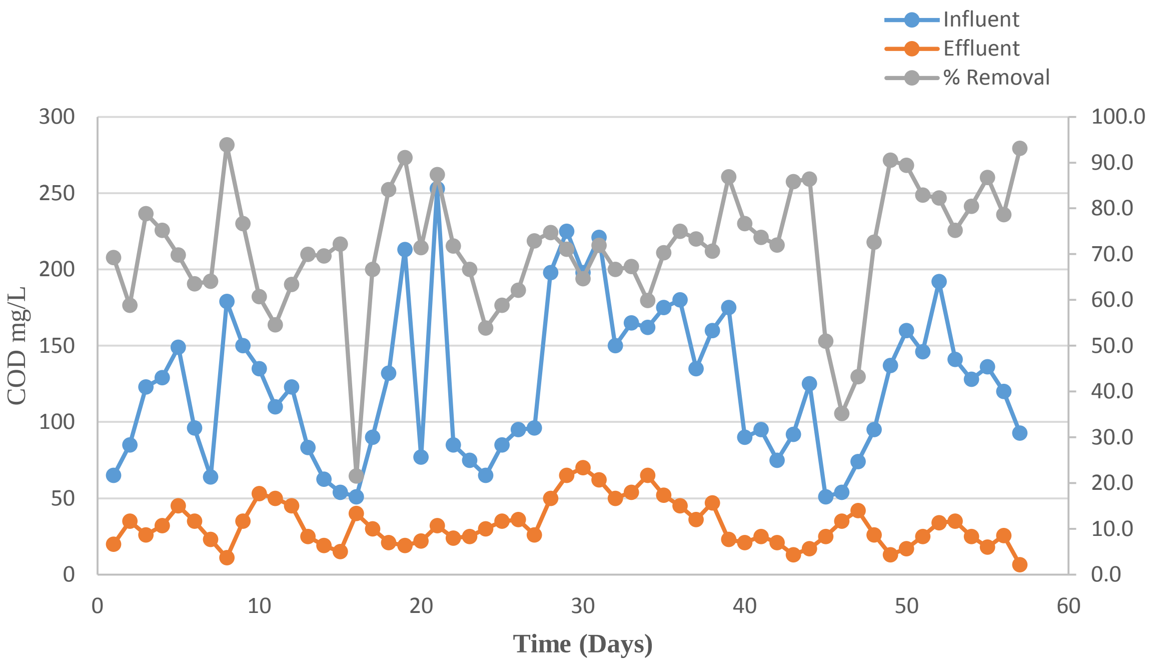

Figure B-1: COD Influent, Effluent and Removal Efficiency for MBST system

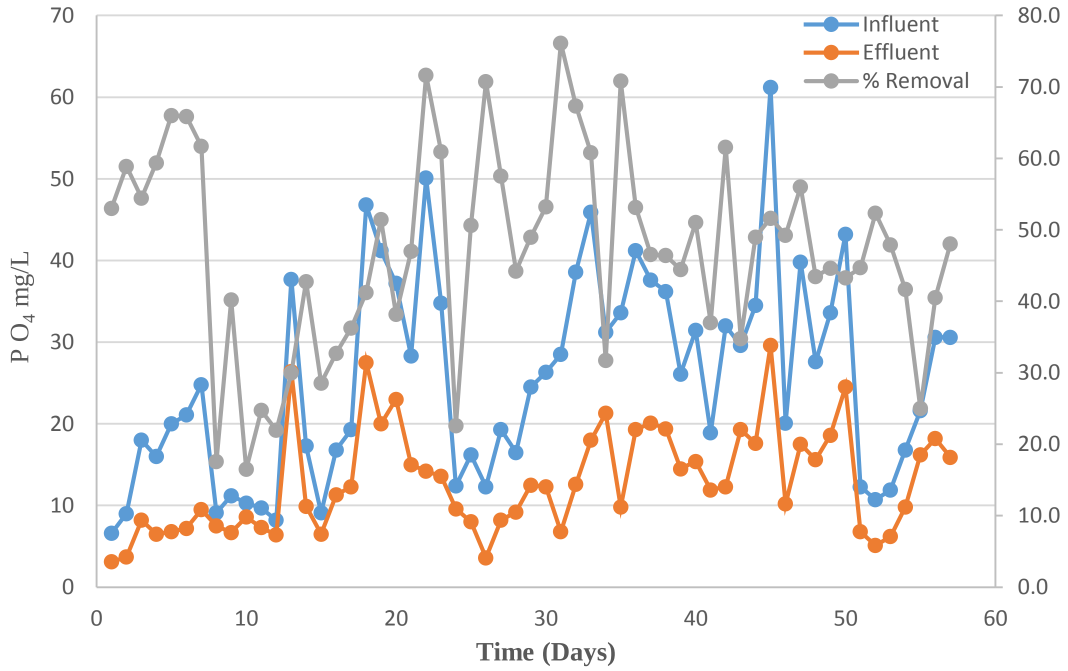

Figure B-2: PO_4 influent, Effluent and Removal Efficiency for MBST System

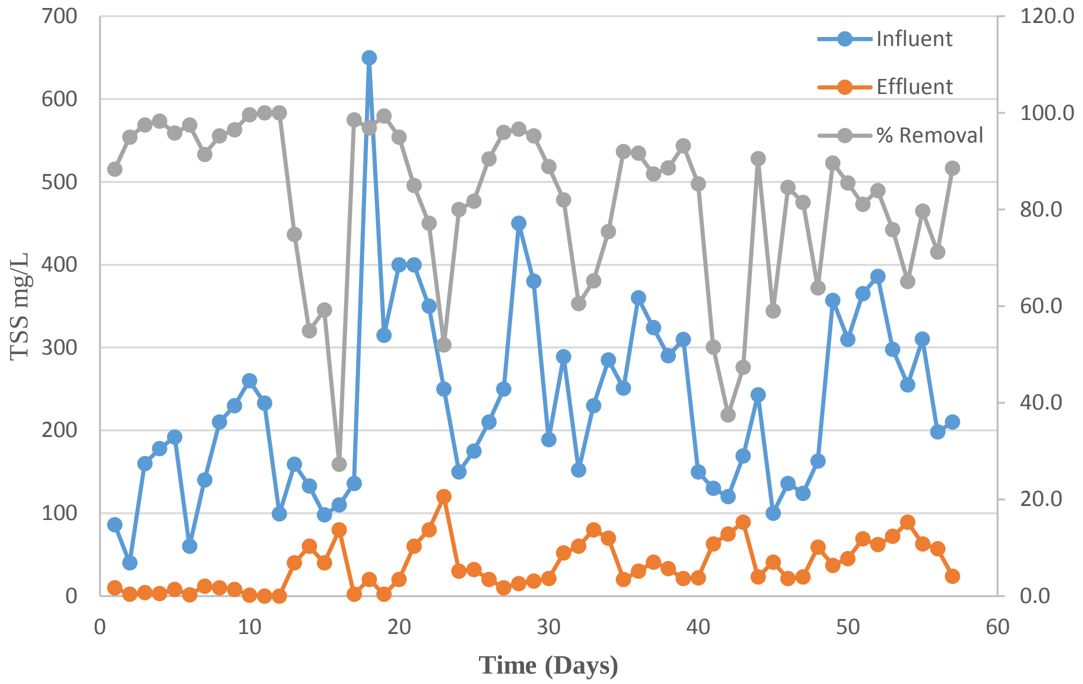

Figure B-3: TSS influent, Effluent and removal efficiency for MBST System

APPENDIX - C

PROTOCOLS

1. **TSS and VSS Determination**

Procedure:

Whattaman filter papers (pore size of 1.5µm) with filtration assembly were used for these two tests. 50 mL of sample was passed through pre weighted filter paper through vacuum created by filtration assembly. These filter papers were placed in preheated oven at 103°C for 2 hours to remove moisture. Later on filter papers were brought down to room temperature by placing in desiccator. Total suspended solids were determined by using the following formula;

$$TSS = (A - B) * 1000/Volume\ of\ sample(ml)$$

Where

A = initial weight of filter paper

B = weight of filter paper after oven drying

For calculation of TVSS pre weighted filter papers were placed in pre heated muffle furnace at 550°C for 15 minutes. To bring down the temperature of filter papers to room temperature it was placed in desiccator to avoid contact with air. TVSS were calculated by using formula;

$$TVSS = (A - B) * 1000/Volume\ of\ sample(ml)$$

A = weight of filter paper after oven drying

B = weight of filter paper after placing it in muffle furnace

2. **Estimation of Fecal Coliform**

Procedure:

MF technique was use for the determination of coliform. Sartorius membrane filters of pore size 0.45µm were passed by serial dilutions and placed on one day prepared EMB agar poured plates. Plates were incubated for 24 hours and colonies of fecal coliform were counted by using colony counter.

Phosphorous Determination

Procedure:

25 mL of clear distilled water was used as blank to zero the pre-programmed spectrophotometer, set at 480 program number and 430 nm wavelength before. 1mL Vanadate Molybdate reagent was added to 25 mL to determine the amount of phosphorous present in the sample. Results were obtained after 3 minute reaction time in the form of mg/L.

3. **Nitrate and Nitrite Determination**

Procedure:

10 mL of clear distilled water was also used in these tests to zero the pre-programmed spectrophotometer. It was set at 355 and 373 program numbers and 500 and 585 nm wavelength for nitrate and nitrite determination respectively. Special nitrate and nitrite pallets were added to the 25 mL sample and after 10 minutes reaction time results were obtained in the form of mg/L.

4. **Ammonium Determination**

Procedure:

Prepared vials of ammonium were used to determine ammonium by adding one pallet of ammonium salicylate and one pallet of ammonium cyanurate and 0.1 mL of sample .Blank was also run to calibrate the pre-programmed spectrophotometer set at 343 and wavelength of 655 nm. 20 minutes reaction time was given and results were obtained in the form of mg/L.

5. **COD Determination**

Procedure:

A COD vial was prepared by using 1.5 mL potassium dichromate, 3.5 mL sulfuric acid reagent and 2.5 mL sample. This vial was digested in COD digester for 2 hours and cooled to room temperature. 2 drops of orthophenanthroline ferrous complex (Ferroin) indicator was added to this cool mixture and titrated with ferrous ammonium sulfate (FAS) until red brown color is obtained. Following formula is used to calculate the COD;

$$COD\ \left(\frac{mg}{L}\right) = \{(A - B) * N * 8000\}/\ (Volume\ of\ sample\ mL)$$

Where

N = Normality of FAS

A = Volume of FAS used to titrate blank mL

B = Volume of FAS used to titrate sample mL

6. **BOD_5 Determination**

BOD test was performed by measuring initial and final temperatures and dissolve oxygen for influent and effluent using DO Meter. Following formula was used to calculate BOD

$$BOD\left(\frac{mg}{L}\right) = (D0 - D5) * 1000/f$$

Where

D0 = Initial DO

D5 = DO after 5 days incubation

f = dilution factor