Study on Fouling Behavior and Treatment Performance of Flat Sheet Woven Fiber Microfiltration (WFMF) Membrane

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By

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APPROVAL SHEET

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LIST OF ABBREVIATIONS

MBST	Membrane base septic tank
R_T	Total resistance
R_C	Cake resistance
R_M	Intrinsic membrane resistance
R_F	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	Nephelometric turbidity unit
TMP	Trans-membrane pressure
P	Phosphorous
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
SS	Suspended solids
MGD	Million gallon per day
TC	Transition countries
DC	Developing countries

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ABSTRACT

Woven-fiber microfiltration (WFMF) membrane was investigated as onsite treatment technology for water and wastewater treatment. In this regard, flat sheet woven-fiber microfiltration (WFMF) membrane was submerged in septic tank as membrane based septic tank (MBST) for wastewater treatment. Objective was to reduce fouling frequency and prolong filtration time by operating laboratory scaled MBST at three filtration-relaxation modes (FRM) of 30_{min}-10_{min}, 45_{min}-15_{min} and 60_{min}-20_{min} corresponding to 36, 24 and 18 cycles/day, operated at 8 LMH flux. The average fouling rate (dTMP/dt) was found to be 17, 10 and 15 kPa/day respectively. Results revealed that 45_{min}-15_{min} to be optimum FRM while the variation in removal efficiencies of COD, TSS and NH_4-N was 55-78, 60-85 and 30-40% respectively. Flat sheet WFMF membrane was also evaluated for water treatment having turbidity 25±5, TSS 200±50 and fecal coliform 120±20 using optimized FRM. The removal efficiencies for turbidity, TSS and fecal coliform were 78-89, 56-65 and 92-99% respectively. The treated water needed further disinfection to be within limits of WHO drinking water quality standard. Physical and chemical cleaning was applied separately on membrane and it was found that pore blockage resistance which caused irreversible fouling may only be controlled by chemical cleaning.

Chapter 1

INTRODUCTION

1.1 Background

Industrialization and urbanization imbalance the availability and demand of water, leading to water scarcity. Global scarcity of clean potable water is becoming a big threat to the existence of human kind. Globally, 0.9 billion people do not have access to safe drinking water in developing countries from which 38 million people belong to Pakistan (Riaz, 2009). Moreover, remaining resources of fresh water are also being contaminated by the release of untreated industrial and municipal wastewater. Since ground water also being withdrawn extensively, there is no option but to treat the wastewater and reuse it.

Wastewater is the main cause of environmental and health issues if not properly treated. More than 2.4 million people could be saved by proper sanitation and hygiene (Prüss-Üstün *et al.*, 2008). Proper treatment technologies must be used to treat domestic and industrial source of wastewater (Tchobanoglous *et al.*, 2003). More than 2.6 billion people don't have access to proper sanitation around the globe (UN-Water, 2010). Due to unavailability of adequate sanitation (collection and treatment), ground and surface water resources are also deteriorated and compromised.

Figure 1.1 shows the difference in effluent treatment efficiency of particular pollutants in developed and developing countries with respect to effluent discharge standard (Sperling & Chernicharo, 2002). In developed countries centralized treatment system are used for compliance of effluent with standards which consists of proper channels of pipe lines. Wastewater collects from towns and communities in the sewage system through gravity and transported to point where full scale treatment plant is installed to treat that water.

In the areas where there is no proper channel of pipelines for the collection, treatment and disposal of wastewater, the centralized treatment system can't be used. The alternative to the centralized treatment system is decentralized treatment system, also known as an on-site treatment system that treats the wastewater at the source of production.

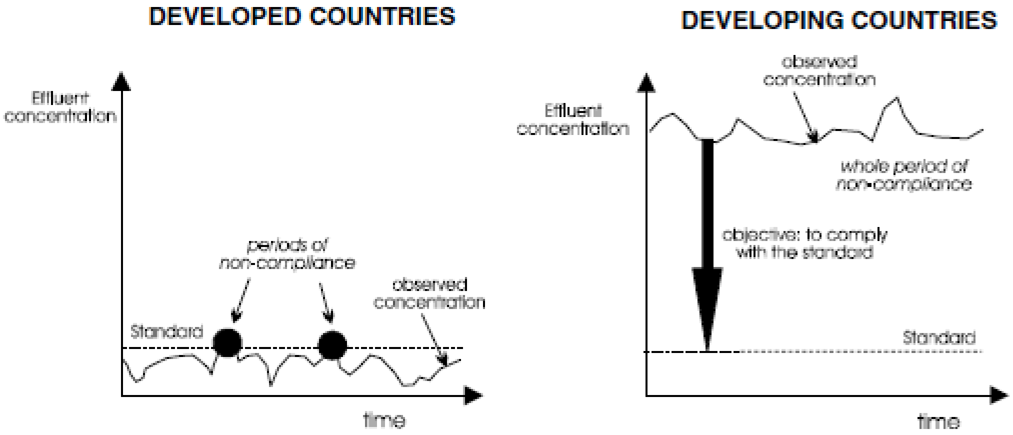

Figure 1.1 Difference in effluent treatment efficiency of particular pollutants in developed and developing countries with respect to effluent discharge standard (Sperling & Chernicharo, 2002).

Pakistan is a developing country and only 1% of wastewater is collected and treated through the centralized treatment system. Centralized system is considered mandatory for all communities in developed countries; however, it is complex and costly to build. Economical treatment technologies should be used to reduce the impact of wastewater on health and the environment. On-site treatment options are feasible for developing countries based upon the situation, locality and environment (Lens *et al.*, 2001; Luostarinen and Rintala, 2005).

Pakistan has been losing 4 % of its GDP annually because of improper sanitation and hygiene facilities. Proper treatment and management of wastewater may make it as a renewable resource as no-potable water for horticulture and sludge as fertilizer (Pettygrove and Asano, 2006).

The rural and urban population has 34 and 72% access to sanitation and water respectively. National Environmental Quality Standards (NEQS) of domestic wastewater may be achieved by using low cost on-site treatment technologies for safe disposal and non-potable purposes e.g. irrigation, horticulture and landscaping, but need further disinfection for laundry and car washing.

Small communities and residential area of developed and developing countries which don’t have a proper sanitation system rely on decentralized system for wastewater treatment i.e. septic tanks (Chaggu *et al.*, 2002). Different types of septic tank are used for different purposes e.g. Small communities, commercial units and household etc. (McCarty *et al.*, 2001).

Septic tank is used for primary treatment of wastewater because of its effective sedimentation and flotation. Organic matters are also degraded due to anaerobic conditions (Moore, 2010). Permeate may be used for non-potable purposes or directed toward sewer system.

Septic tank can be utilized as a part of locality not equipped with centralized treatment system (Michael, 2004). The soil absorption field is one of types of the septic tank and preferable because of financial viability and simplicity in most treatment to septic tank effluent. The soil absorption field receives a significant load of nutrients, suspended solids and organic matters. The effluent pathogens and suspended solids may clog the soil pores which cause the failure of the system (Khan *et al*., 2013).

Consequently, different studies have been carried out on different alteration in septic tanks to enhance its treating efficiency. Membrane based septic tank (MBST) is a modified and efficient type of septic tank in which membrane is used as filter media.

Hence, the study was carried out on membrane based septic tank (MBST) as low cost on-site treatment technology having high treatment efficiency. A flat sheet woven fiber microfiltration (WFMF) membrane was used to carry out this research.

Membrane module was submerged inside the septic tank for reclamation of wastewater known as MBST. It is an advance and low cost onsite technology for reclamation of wastewater and reuse at source.

A laboratory scale setup of MBST was installed in water and wastewater laboratory at Institute of Environmental Sciences and Engineering (IESE), NUST. Membrane module was fabricated with woven fiber microfiltration membrane (WFMF) and submerged in a membrane bioreactor tank.

The removal efficiencies of the MBST system were observed and concluded that MBST was able to efficiently remove Chemical Oxygen Demand (COD), Suspended Solids (SS), Ammonium-Nitrogen (NH_3-N) and Phosphate-Phosphorous (PO_4^{-3}-P) from domestic wastewater.

1.2 Objectives

The following objectives were achieved through this research work

1. Designing and installation of laboratory scale membrane based septic tank (MBST) in a wastewater laboratory at IESE, NUST, Islamabad.
2. Optimization of filtration/relaxation mode (FRM) and treatment performance of woven fiber microfiltration (WFMF) membrane for wastewater treatment.
3. Comparison of physical and chemical cleaning protocols for WFMF.
4. Evaluation of WFMF system for water treatment using optimized conditions.

1.3 Scope of study

The scope of the study includes:

1. Designed and operated the flat sheet membrane module with surface area of $0.05 m^2$ having the pore size of 1-3 µm.
2. Optimized MBST operation under filtration to relaxation mode;
    - 30 min filtration and 10 min relaxation
    - 45 min filtration and 15 min relaxation
    - 60 min filtration and 20 min relaxation
3. Monitored TMP, conducted resistance analysis test and maintenance of membrane in term of physical and chemical cleaning.

Chapter 2

LITERATURE REVIEW

Water is valuable and principle need in every aspect of life. Approx. 71% of the world is covered with water and out of it 96.5% is held by the sea, which is saline and can’t be used for drinking purposes. Approx. 0.9 billion people don’t have access to fresh drinking water which is expected to increase to more than 1.3 billion by 2025 (Hoffmann, 2009).

Every third person on earth is affected by water scarcity. According to WHO 60% people of earth will be affected by water scarcity under these conditions by 2025. Gap between demand and supply is also increasing due urbanization and industrialization (WHO, 2009). Currently, Pakistan is among the 50 countries around the world, which are experiencing water scarcity (FAO, 2005).

2.1 Overview: Wastewater treatment

Wastewater is produced by various sources. Everything that flushes from the toilet or wash down to drain is wastewater. Domestic wastewater consists of greywater and black water (Henze, 2001).

Primary and secondary treatment of wastewater is necessary before releasing it into a water body to meet National Environmental Quality Standards (NEQS). Dilution of wastewater is another technique to decrease the degree of contamination, but require large quantity of water.

Pakistan is a developing country, where 8% of the total wastewater is treated (Sato *et al.*, 2013). Wastewater is also polluting underground water because of releasing untreated wastewater to water bodies. Pakistan has only few centralized biological treatment plant in Islamabad and Karachi. These wastewater treatment plants are also not fully functioned because of economic issues.

Wastewater originated from sink, bath and kitchen etc. is called greywater and wastewater coming from toilets as urine and feces are called black water. Potentially harmful bacteria, organic matter and nutrients are present in domestic black water (Terpstra, 1999) making its management of great significance (Lettinga *et al*, 2001).

Strength of wastewater increases in term of COD and BOD as the concentration of organic matter increases. COD and BOD of wastewater also depend on consumption, i.e. BOD of wastewater 200–250 mg/L where, the daily consumption is 350-400 l/capita and 300-700 mg/L where the daily consumption 40-100L/capita respectively.

Wastewater is collected to a main sewer line through a channel of small sewer system from societies and end up at centralized wastewater treatment plant.

Table 2. 2 Average characteristics of black, gray and domestic wastewater

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

Source: (Henze and Ledin, 2001)

Wastewater is also generated from agricultural and industrial sources (SDWF, 2008). The centralized treatment systems are costly and required extensive infrastructure of sewer lines (USEPA, 2004).

2.2 Wastewater and its impact

Wastewater is produced from different sources in daily routine activities. Wastewater is potentially harmful to human health and environment if not properly treated. In villages, people dig pits in front of their houses to dump wastewater or drain it to nearby fresh water bodies, resulting in dysentery, epidemics of cholera, typhoid and other water borne diseases.

Due to shortage of water, people are forced to use wastewater for irrigation purposes (Hamilton *et al*., 2007). There are concerns about wastewater irrigation related to groundwater pollution and deterioration of the irrigated soil resulting from the accumulation of wastewater-born metals and organic pollutants (Munoz *et al.,* 2009). However, soil contamination is often assessed with respect to risks for human health from crop consumption, while ignoring the potential impacts on soil habitat quality for terrestrial organisms (Prosser and Sibley, 2015).

Environmental impacts of wastewater irrigation have been studied by monitoring individual wastewater-born pollutants in soil or water using laboratory or semi-field experiments (Ternes *et al.*, 2007; Munoz *et al.*, 2009; Grossberger *et al.*, 2014) or by measuring the removal efficiency of wastewater-born pollutants and pathogens via constructed wetlands, bank filtration or soil aquifer treatment (Verlicchi and Zambello, 2014). Soil passage of treated wastewater can enhance the biodegradation of pollutants compared to the discharge into streams, however, adsorptive pollutants may also be retained in the soil and accumulate (Munoz *et al.*, 2009). The centralized treatment systems typically collect and treat large quantity of wastewater, which require larger pipes, big infrastructure (USEPA, 2004). Alternatively, decentralized treatment systems treat wastewater of individual dwellings (Tchobanoglous *et al*, 2004). Although decentralized treatment systems can treat and recycle wastewater on or near the point of generation, on the other hand, centralized treatment systems recycle/dispose far-off from the source point (Hamilton, 2007).

2.2.1 Contamination of surface and ground water

The impact on groundwater quality of sewage and wastewater is well documented and a major concern globally (Banks *et al.,* 2002; Howard, 2007). The traditional method of collecting and discharging wastewater using septic tanks lead to wastewater leakage, which severely effect soil and groundwater properties (Arundel, 2000). The increase of un-useful plants, ground pollution and geotechnical problems of many underground constructions are mainly associated with wastewater seepage into the subgrade soil (Crawford and Burn 1998).

2.2.2 Soil degradation

Trace elements such as lead, mercury, cadmium, zinc, cobalt and chromium originating from various sources may finally reaches to soil. These metals are concentrated in the plant tissues and then transferred across the food chains into human beings.

2.3 Evaluation of treatment technologies

There are five matrices used for evaluation and selection of on-site wastewater treatment technologies.

2.3.1 Treatment/Production capacity

Any onsite wastewater treatment technology, where selected must fulfill the National Environmental Quality Standards (NEQS) and production capacity.

2.3.2 Contaminant removal/deactivation

Wastewater should be free of fecal coliforms, viruses, bacteria and protozoa. Treatment of water is necessary to remove and kill all these contaminants. Heavy metals are persistent contaminants and very difficult to remove some of heavy metals cadmium, chromium, arsenic, mercury, lead, these metals are very toxic to human health and cause different disease (Nriagu, 1990).

2.3.3 Process economics

The system used for domestic wastewater treatment must be economical because in developing country these are burden on government.

2.3.4 Operations and maintenance

Generally, the operation of on-site treatment system is not so simple and require a skilled person to operate the system. Local construction material should be used for regular maintenance to ensure the long life of the system.

2.3.5 Community–technology interaction

This can include a broad range of factors that impact the adoption of on-site technologies, including but not limited to: treatment performance, ease of use, historical experiences with water/wastewater, and social/cultural aspects.

2.4 Wastewater treatment in developing and developed countries

Globally, 2.6 billion people don’t have proper sanitation from which 2 billion people belong to developing countries. In other words, approximately 70% of population in developing countries lack the facilities of water, sanitation, and personal hygiene (Tebbutt, 1998). More than

2.4 million people could be saved by proper sanitation and hygiene (Prüss-Üstün *et al.*, 2008). In developing countries, rural schemes are not as feasible due to limited resources.

Developing countries don't have proper facilities for the collection and treatment of wastewater, particularly in semi urban and rural areas. The centralized systems are complex and costly to build and manage (Al-Shayah and Mahmoud, 2008).

International organizations are taking interest as a global issue to improve sanitation and hygiene schemes. World Health Organization (WHO) declared a 2005-2015 as decade of water (Montgomery *et al.*, 2007).

Most of the developing countries lies in the regions having warm climate. Even in Pakistan, high temperatures persist 8 to 9 months of a year. Therefore, anaerobic technologies are less expensive and highly effective in warm climate (Foresti 2001).

Pakistan is a developing country and on ranked 80th out of 122th regarding drinking water quality. Surface and groundwater are badly contaminated with toxic metals coliform and pesticide due to improper sanitation and management. More than 70% people are forced to live without proper sanitation because of disasters, poverty, humanitarian crises and political unrest. 1.6 million people have dead in last 65 years because of natural disasters (Ahmad, 2010). Scale of deaths and damages are increases when emergency based facilities are not provided on time (Ahmad, 2010). In natural disasters, i.e. 2005's earthquake and 2010's flood damaged the sanitation system and basic public health facilities (Zulfiqar *et al.*, 2010; Warraich *et al.*, 2011).

2.5 Centralized and decentralized treatment technologies

2.5.1 Centralized system

Centralized systems consist of a large network of sewer lines which collect and treat large volume of wastewater (West, 2001). Centralized treatment systems are costly and burden for small communities of low income countries (Parkinson, 2003).

Although treated water from centralized wastewater treatment may easily manage and meet the NEQs. Centralized systems can treat specific quantity of wastewater, however, as the population increases upgradation and for expansion of technologies are needed for sustainable approaches to save water resources (Petros *et al*, 2009).

Still, several treatment systems are not successful and unsustainable because they were just copied from other regions without considering the suitability of the equipment for the society, land, and the environment. Merits and demerits of centralized treatment systems are discussed in Table 2.2 in different aspects.

Table 2.2 Advantages and disadvantages of centralized treatment 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 treatment

Wastewater managed and treated on or near the point of generation is called decentralized or on-site treatment system. Generally, decentralized system is used for recycling or disposal of wastewater from remote communities, individual homes, institutions or industries, on or near the generation point (Tchobanoglous, 1995).

Decentralized systems are suitable for less dense communities and economical then centralized systems. The basic components of decentralized systems are conventional septic tank. Up till now, the efficiency of decentralized systems relies upon the standard checkup and maintenance. Collection, treatment and disposal are the basic mechanisms of any wastewater treatment system, but collection has the least important for treatment of wastewater. However, collection expenses contain more than 65 percent of the total funds for wastewater management in a centralized system, mainly in those areas with low population densities (Hoover, 2004).

On the other hand, decentralized system keeps the collection component as minimal as possible. Decentralized wastewater systems are getting popular because they are less resource demanding and more ecologically sustainable form of sanitation (Tchobanoglous and Crites, 2003). Other merits and demerits of decentralized wastewater systems are listed in Table 2.3.

Table 2.3 Advantages and disadvantages of decentralized treatment system.

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
	Treated water reuse for non-potable	Poor public perception

Social/ environmental	purposes Reclamation and reuse at source water Low environment risk	O&M failures

Source: (Adopted from Zaidi, 2005)

2.6 Water and wastewater treatment technologies

Special technologies, design for water and wastewater treatment with less time and high quantity and quality are membrane based and non-membrane based. These technologies may be changed according to the situation and place.

2.7 Non-membrane based treatment technologies

2.7.1 Physical based treatment

Physical treatment is performed by using different filters such as bio-sand filter, pressure filters and novel filters. In this process water and wastewater passes through the media i.e. peat, crush glass, sand and gravels to improve its quality.

2.7.1.1 Bio sand filter

A bio sand filter (BSF) can be used in small scale. An individual or community having a limited population can use this technology. This filter is very simple in design and may be made by filling the tank with gravel and sand in layers to remove the contaminants and pathogen from impure water.

When water or wastewater passes through this media after some time a biofilm developed on surface of media which degrade the organic matter and kill the pathogens (Mahmood *et al.*, 2011). Laboratory experiments show that it may remove greater than 95% turbidity with removal of microbes, viruses remove 1 log, bacteria remove 2 logs, and protozoa remove 3 logs (Palmateer *et al.,* 1999; Duke *et al.,* 2006; Stauber *et al.,* 2006; Elliott *et al.,* 2008; Murphy *et al.*, 2010).

BSF is a modular system and was used in Pakistan in 2005 during the disaster of the earthquake (Mahmood *et al.,* 2011). Regardless of the small removal of microbes by using BSF, significant decrease in pathogen was noted. Pathogens are the main cause of diarrhea and these pathogens are removed by 3 logs (99.9%) which decrease the probability of diarrhea up to 54% (Tiwari *et al.*, 2009)

Performance of BSF is improved by using media of sand being oxide coated that shows maximum removal of 1 log (90%) Escherichia coli and Coliforms. Iron oxide media are adhesive to microbes when these microbes come near to the media they attach to the media, which increase the removal efficiency (Ahammed and Davra. 2011)

The disadvantage of BSF that is requires relatively long time to develop biofilm on the surface which is responsible of treatment and regular maintenance because with the passage of time biofilm become thicker and thicker and head loss become increase.

2.7.1.2 Pressure filter

Pressure driven filters can treat/produce large quantity of water in less time. This filter consists of a tank from which the water distributes to the surface of the filter as shown in Figure 2.1. This water passes through the filter with pressure and pure water is produced relatively in small time (Clarke and Steele, 2009). Pressure filter is modular and compact.

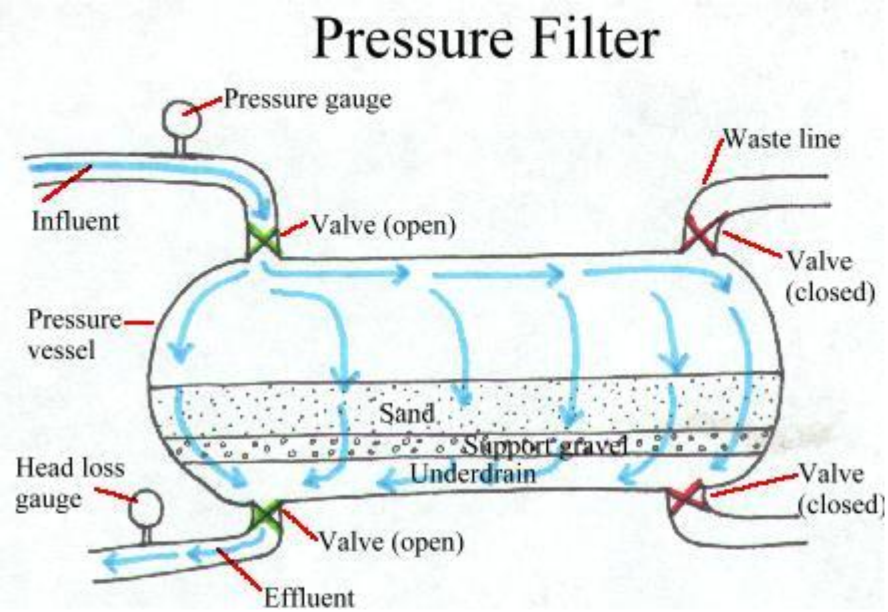

Figure 2.1 Process flow diagram of pressure filter (Dorea *et al.*, 2006).

Productivity of pressure filter is high, then bio sand filters. Pressure filter is available in two types modular and mobile. Mobile filters are classified according to their media, media with diatomaceous earth also known as pre-coat filter and the media with sand known as sand pressure filters (Dorea *et al.*, 2006).

2.7.1.3 Novel filters

It was a combination of different metrics to enhance treatment efficiency. Bacteria and virus removal efficiency varied by varying the quality of water if the water was more turbid than removal efficiency for bacteria was 2.6 to 3.3 log and if the water clear then removal efficiency was 3.9 to 4.7 logs. The nano-particles is recommended for the small community level because it may produce the drinking water of high quality with very less energy consumption.

2.7.2 Chemical based treatment

2.7.2.1 Clarification

Clarification is one of the methods of water purification by using chemicals such as alum or ferrous as coagulants. However, due to economical factor, wastewater cannot be treated with this method. These treatment systems are modulator and may operate in batch or continuous mode (Dorea, 2009). Coagulants are used to reduce the turbidity. Many types of coagulants are used to treat the water, such as alum, moringa oleifera, ferrous, Jatropha curcas and Guar gum (Ndabigengesere and Subba, 1998).

It may remove 2 logs of *fecal coliforms* (Dorea and Clarke, 2006). Clarifier performance shows that this system is rich and able to produce the drinking water with low turbidity for a long period of time.

2.7.2.2 Chlorination

Chlorination is one of the efficient methods for treatment and disinfection of water and wastewater. Halogen compounds like chlorine and iodine is easily available at local places and relatively cheap (Backer, 2008). Using a chlorination method large quantity of water may be treated.

This method is very cheap and people may use it at household and community level. Sodium hypochlorite is one of the chemicals used for chlorination. It was widely used during the Indonesian tsunami (Gupta *et al.,* 2007). Other chemical used for chlorination is sodium dichloro-isocyanurate. The lifetime of this chemical is also very high and found in bulk which is easier to transport than liquid.

When these chemicals are used for disinfection of drinking water having organic matter, produce disinfection by products known as trihalomethanes (THMs) which is toxic to human health. THM only effect when water use for long duration of time. Chlorine dose changes with turbidity, bacteria, viruses, temperature and organic matters.

2.7.2.3 Combined coagulant-disinfectant powder

Coagulants and disinfectants are mixed in this method to treat water. This method is used to get water of relatively of high quality. There are some coagulants and disinfectants which are used to treat water, such as bentonite, ferric sulfate, poly (acrylamide), sodium carbonate, chitosan (used as flocculating aids), calcium hypochlorite (used as disinfectant) and potassium permanganate (used as oxidizing agent).

The coagulants and disinfectants are mixed with 10 L of impure turbid water (Roller *et al.,* 2003). After sometime, clean water is obtained. This method is suitable for small community and household level (Lougheed, 2006).

2.7.2.4 Adsorption (Activated carbon)

Adsorption is commonly used ahead of disinfection stages because it is used to remove substances such as disinfectants by products, particulates and organics (Tobin *et al.,* 1981; Bell *et al*., 1984). This system is not much more efficient in the removal of microbes and pathogens (Snyder *et al*., 1995). Activated carbon is one of the adsorbents which is used widely to remove organics. Activated carbon is present in granulated from known as granular activated carbon (GAC) and powdered from known as powdered activated carbon (PAC).

Activated carbon may remove the microbial removal at initial stages, but reduces as development of biofilm on the surface of activated carbon (Wallis *et al*., 1974). This biofilm may be removed by varying operation conditions of treatment plant such as, low filter temperature, short residence time and high flow rate (Su *et al*., 2009). However, activated carbon’s performance decrease with the passage of time. Activate carbon is mainly used to remove intensive odor and objectionable taste (Backer, 2008) and needs regular maintenance because of clogging with particulates and biofilm.

2.7.3 Thermal or light based treatment

Treatment of water using solar is considered as an effective method. UV rays from sun are utilized to kill pathogen present in raw water. Plastic bottles are filled with water and placed directly in the sunlight for a whole day. The bottle should be transparent to obtain maximum penetration of UV rays through water. This method is only effective at the place where maximum sunlight is available otherwise 2 to 3 days are required for disinfection.

2.7.3.1 Boiling

Boiling is very old and effective technique for purification of drinking water commonly at household level. Boiling may kill pathogens and viruses which are responsible for waterborne diseases. Boiling may kill also some pathogens which are resistant to chlorination (Sobsey, 2002).

Thermotolerant Coliforms (TTC) (Clasen *et al*., 2008; Rosa *et al.*, 2010) and *fecal coliforms* (FC) (Clasen *et al.*, 2008) are very persistent and be killed by disinfection but boiling at high temperature. Studies in Indonesia (Gupta *et al.*, 2007), Peru (Oswald *et al.*, 2007), and Zambia (Psutka *et al*., 2011) showed that boiling, quality of water was not much improved mainly due to unsafe handling, protection and storage (Psutka *et al.*, 2011). Boiling may only remove some pathogens, but chemicals cannot be removed.

2.7.3.2 Thermal pasteurization

Pasteurization applied moderately to treat the water, but requires less temperature as compared to boiling. Temperature required in pasteurization is 75 ^{0}C. This method is suitable for individual and household level.

In this method waste heat from cooking or any other activity is used to treat the water. Removal efficiency of *E. coli* is 5 log (99.999%). However, this system has some disadvantages which cause to left the use of this technology for example in Bangladesh a study reported that 80 people left this system out of 100 because of its high cost, inconvenience and mechanical problems (Gupta *et al*., 2008).

2.7.3.4 Solar disinfection

Sun is the unlimited source of heat with free of cost and may be used to treat water. This method is very effective but also has some limitations (Reed, 2004). Raw water should be less turbid to effectively disinfect the water. PET containers are filled with water of low turbidity; well mix it and ensure that dissolved oxygen (DO) level is maximized and then place the water directly to the sunlight for 2 days if sunlight is not intensive otherwise 6 hours is enough (CDC, 2008). Some bottles release toxic leachate to water so PET should be used because it is free of toxic material (Sobsey, 2002; Schmid *et al*., 2008).

Solar disinfection kills bacteria and pathogens as UV rays passes through the water and increases temperature of water (Murinda and Kraemer, 2008). Solar disinfection may produce bacteria free water. Case study of Kenya shows that solar disinfection has positive effects to reduce diarrhea from 10 to 16 % (Conroy *et al*., 1996) from the age of 5 to 16 years (Conroy *et al.*, 1999).

The disadvantage of this system is that it may only apply in the region where intense solar radiation is available. If solar radiations are low, then increase the residence time. Coating of TiO_2 (Wei *et al.*, 1994) on the bottle of PET (Duffy *et al.*, 2004) will increase the effectiveness of treatment.

2.7.3.5 UV disinfection

Ultra Violet (UV) radiations having wavelength of 240 µm are used for the disinfection of water and wastewater. Point-of-use UV unit called UV 007 used for disinfection of water from 2.5 to 20 L (Berg, 2010). This system is compact and easy to operate and may be used at individual and household level. It may remove 2.3 logs of MS-2 coliphage depend on the transmittance.

Its performance is greatly affected by increase in turbidity because maximum pathogen will deactivate if maximum UV light transmit though water (Gadgil *et al.*, 1998). However, pre-filtration is required to reduce the turbidity for effective disinfection.

2.7.3.6 Solar distillation

Solar distillation is very simple and common technology used for disinfection of water (Aboabboud *et al.*, 1997). Radiation of the sun is used to treat the water (Bouchekima *et al.*, 1998). This method may be used at individual or at household level, having the demand of water less than 50 m^3 per day (Bouchekima *et al.*, 1998). This method is very cheap and its cost still forms 0.0024 to 0.02 US dollars per liter (Madani and Zaki, 1995) which is less than all other WTs at this scale (Hanson *et al.*, 2004).

2.8 Membrane based treatment technologies

The membrane is most efficient and emerging technology because of its high productivity with less time. There are different types of membrane classified on the bases of operational forces such as the osmotic hydraulic difference (hydraulic gradient), temperature and pressure driven membranes (Mulder, 2000; Fane *et al.*, 2011).

Reverse osmosis (RO), ultrafiltration (UF), nano-filtration (NF) and microfiltration (MF) are membrane based technologies in which pressure is used as driving force.

Osmotic difference is used as driven force in forward osmosis (FO) which is less energy consumption technology (Cath *et al.*, 2006). The main disadvantage is its energy requirements and fouling. But every membrane system has a different energy consumption level, cost and efficiency.

2.8.1 Pressure-driven membrane processes

2.8.1.1 Microfiltration (MF)

MF membranes are most widely used on a small scale. Microfiltration system are of different types, could be fiber or ceramic filter. Ceramic filter is locally made by firing the clay mixture with rice husk and saw dust which creates small pores just like activate carbon (Halem *et al.*, 2009). Pathogens and bacteria removing efficiency of MF membrane is good, but virus's removal efficiency is less.

Average removal *E. coli* with this system is 3 log, but it varies with changes in water quality. If the water is more turbid its removal efficiency decreases to 1.7 logs and if the water is less turbid than its removal efficiency increase to 4.9 logs.

2.8.1.2 Ultra-filtration (UF)

Ultra-filtration system has a maximum efficiency of removing bacteria and viruses as well as turbidity reduction from drinking water (Laıneet *et al.*, 2000). The efficiency of the system may be decreased with deposition of organic matter on the surface of the membrane and formation of biofilm due to long term operation without proper maintenance.

Mobile ultra-filtration system was designed by (He, 2009) that was operated with bicycle. This system was wonderful for the place where no electricity was available.

2.8.1.3 Nano-filtration (NF)

Nano-filtration membranes are very effective to remove multivalent ions and dissolved organics (Fane *et al.,* 2011). This system can't treat the saline water having monovalent ions (Greenlee *et al.,* (2009), Oh *et al*. (2000)). This is a pressure driven membrane, so it may only be used where electricity is available. It can be coupled with bicycle to provide the necessary pressure.

2.8.1.4 Reverse osmosis (RO)

RO membranes are very effective to remove monovalent ions and dissolved organics. RO system needs pretreatment system because if the low quality water passes through the membrane it can be fouled and rapid degradation of membrane can occur.

The disadvantage of RO system is its high energy cost usually power system is damaged after disasters so these are the limitation of the system. RO is practical only when there is no fresh water supply or the water quality is uncertain. Wind energy can be used to operate the system for desalination. A mobile RO demonstration plant for brackish water desalination has also been reported (Khalid *et al., 2016*).

2.8.2 Osmotically-driven membrane processes

2.8.2.1 Forward osmosis

Forward osmosis commonly known as (FO) is one of the efficient treatment technologies used for water and wastewater treatment. Organics, pathogens, bacteria, viruses and inorganic are removed by using FO without electricity (McGinnis and Elimelech, 2008).

Forward osmosis works on the base of hydraulic gradient in which water moves from high gradient to low gradient as shown in Figure 2.2. Water passes through a permeable membrane due to the movement from high water potential to a low water potential which is called hydraulic gradient.

When the contaminated water passes through the membrane it permits only water to pass through and remaining contaminants, i.e. organic and inorganic are retained on the surface of membranes known as rejects.

In the latter case, the process could be considered an osmotic dilution (OD), which is similar to direct osmotic concentration (DOC), with the exception that the final product in OD is the diluted draw-solution instead of the concentrated feed-solution.

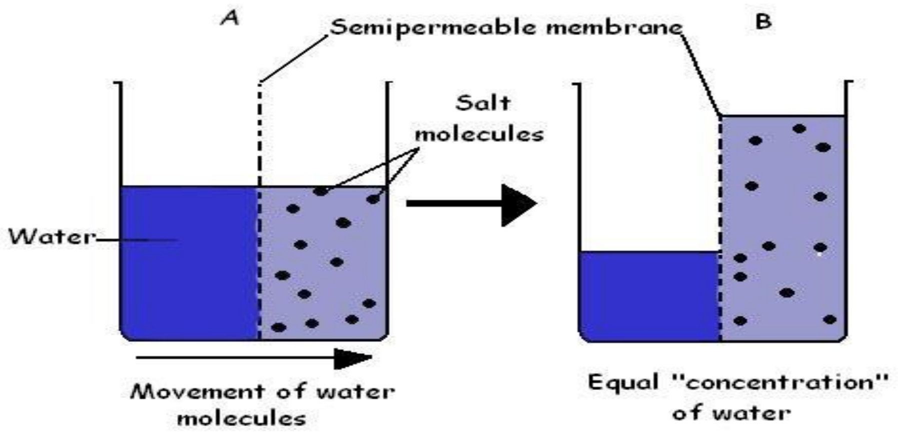

Figure 2.2 FO process diagram

2.8.3 Thermally-driven membrane processes

2.8.3.1 Membrane distillation

Membrane distillation (MD) is a hybrid separation process consisting of three steps: (i) evaporation of water on the feed side; (ii) migration of water vapor to the permeate side via membrane pores; and (iii) condensation of water vapor on the permeate side (Bouguecha *et al.*, 2005; Susanto, 2011). The driving force for MD is the vapor pressure difference due to a temperature gradient between the feed and permeate sides (Susanto, 2011). Therefore, it requires only a moderate working temperature that can be achieved using a solar thermal collector (Banat *et al.*, 2002; Blanco Ga´lvez *et al*., 2009).

2.9 Membrane bio reactor (MBR)

Membrane bio reactor (MBR) is an advance technology for wastewater treatment which combines both activated sludge process and separation by membrane filtration unit. Wastewater is supplied to the reactor where microorganisms use this as a substrate for growth, maintenance and metabolism. Biologically treated water is separated by membrane either MF or UF discussed above. Activated biomass is recycled back to aeration tank (Drews. 2010; Poostchi et al., 2012). The first full scale MBR was established in North America in 1970 and after that in japan in 1980.

MBR is gaining attention for treating domestic as well as industrial wastewater with advantages of better effluent quality for reuse as compared to conventional activated sludge process, small foot print, lower waste production, more flexibility and higher robustness (Cosenza et al., 2013; Masse et al., 2006)

2.9.1 MBR Configuration

In MBR, filtration unit is coupled with bio reactor with one of two basic configuration

1. Side stream MBR
2. Submerged MBR

2.9.1.1 Side stream MBR (SS-MBR)

In SS-MBR, bioreactor is coupled with membrane unit placed outside where MLSS is circulated through the unit. To control deposition of suspended matter on membrane surface, high cross velocity id required by circulation pump demanding high energy is consumed (Clech et al., 2005).

2.9.1.2 Submerged MBR (SMBR)

In SMBR, membrane is submerged in activated sludge. This configuration was found to be more effective then side stream MBR. In SMBR shear stress produced by aeration is high as compared to SS- MBR and can be easily controlled by varying aeration rate which ultimate results in high permeate rate and low membrane fouling “(Howell et al., 2004).

2.10 Aerobic and anaerobic MBRs

Aerobic and anaerobic type of degradation are depending upon the redox conditions depending upon electron acceptor. In aerobic type of MBRs, air is continuously or intermittently supplied, course bubbles help in membrane scouring to avoid rapid membrane fouling and proper environmental for microorganism growth. Operational cost of aerobic MBR increases due to the air supply as compare to anaerobic MBR, where air is not needed. Growth rate of aerobic microorganism is high while anaerobic microorganism is slow growing, therefor retention time increases in anaerobic MBR. Side stream configuration is mostly used for anaerobic type of MBR

2.11 Septic tank

Septic tank is an on-site treatment technology used to treat wastewater at point of generation for individual household or small communities. Anaerobic conditions inside the septic tank allows the degradation of a small portion of organic matter and settling of suspended solids for primary treatment of wastewater (Clearinghouse, 2000).

Concept of septic tank was given in 1860 and implemented in 1883 which was consisted of concrete tank having two portions of wastewater treatment. After that the septic tank use increased rapidly and now it is implemented in many parts of the world (Butler *et al*., 1995).

The soil absorption field system is a conventional septic system, it is inexpensive to build and require minimum maintenance. However, conventional septic tank can only provide primary treatment (settlement of solids) with little biological degradation. The soil absorption field receives a significant load of nutrients, suspended solids and organic matters. The effluent pathogens and suspended solids can clog the soil pores which cause the failure of the system (Khan *et al*., 2013).

2.11.1 Limitations of conventional septic tank

Table 2.4 Problems and their respective sources

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 of 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)

2.12 Modified septic tank

2.12.1 Sewage treatment unit (STU)

Sewage treatment unit (STU) is a simple and low cost sanitation solution for semi urban and rural areas. The main purpose of STU is on-site treatment of domestic sewage, where conventional means are not possible or available. Due to the 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. The 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 conventional septic tank is that it provides filtration along with microbial removal reducing the solid retention time (SRT).

STU takes raw sewage in, allows the solids to settle and allow supernatant to flow through the gravel bed in 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. 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 the next portion of the 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.

2.12.2 Anaerobic baffled reactor (ABR) coupled with anaerobic peat filter (APF)

2.12.2.1 Anaerobic baffled reactor (ABR)

The 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 clarifiers within the same tank by separating the solid retention time (SRT) from HRT (McCarty and Bachmann, 1992). The anaerobic treatment in baffled reactors can mineralize the organic matter which is considered a 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 continuously stir tank reactors (CSTRs). Thus resulting in lower reactor volume and ultimately allowing application of high volumetric loading rates e.g. 10-40 kg COD/m3. day (Iza *et al.,* 1991). The compartments inside the tank acts as zones for growth of microbial population establishing a sludge blanket. Majority of solids is removed at the beginning of ABR due to increased contact with the biomass resulting in the 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.

2.12.2.2 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 is a filter media, acts as very good sorbent for removal of noxious product form septic tank effluent, which do not allow direct disposal to landscape around the residential communities.

The peat media are 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.

2.12.3 Membrane base septic tank (MBST)

The membrane can be defined as a selective barrier which only permit a particular species to pass through whereas retaining the course of others.

Use of membrane based systems has considerably improved, for water/ wastewater management (Anon, 2006). Mainly in big-scale use of membrane technology is obviously set up in the developed countries, but a great enhancement is predicted in developing countries e.g. China (Anon, 2006).

Conventional wastewater treatment techniques take more space and are less efficient, therefore it is important to evaluate advanced wastewater treatment technologies which produce reusable water in comparatively less time and space. But there is need of extensive research in the field of advanced wastewater treatment to make them economically viable.

2.12.3.1 Woven fiber microfiltration (WFMF) membrane

In most real applications, a membrane will eventually become fouled. Operational strategies such as scouring, sub-critical flux operation and back flushing etc. reduce the rate of fouling, but will not prevent the eventual fouling of the membrane. The ability to clean and recover permeability after being fouled is a critical aspect of the technical viability of any membrane technology. It is usually possible to find a mixture of chemicals that will remove any given fouling layer. However, if chemical cleaning can be avoided the applicability, economics and environmental impact of the technology will improve greatly. It will also make the technology more sustainable in developing economies, where regular access to chemical cleaners may not be guaranteed.

In previous investigations into WFMF, a major advantage was that the system never required chemical cleaning. Mechanical agitation e.g. pulsing or drying was sufficient to remove the fouling layer.

Chapter 3

MATERIALS AND METHODS

This study was carried out based on laboratory scale membrane based septic tank (MBST). Different specifications and types of flat sheet membrane modules were designed and investigated under this study. Previous studies were carried out on the spiral and non-woven flat sheet modules. The membrane was used as filter media in the septic tank. Specification of membrane and membrane module are discussed below in Table 3.1. The main purpose of this study was to optimize the filtration to relaxation mode (FRM) to reduce fouling frequency and get maximum flux.

3.1 Designing and installation of laboratory scale MBST

In this study, an experimental setup of laboratory-scale membrane based septic tank (MBST) was designed and installed in the water and wastewater laboratory at IESE, NUST, Islamabad. The main purpose of this study was to reclaim wastewater by investigating operational parameters and treatment performance at different filtration to relaxation modes at constant flux. Flat sheet woven fiber microfiltration membrane (WFMF) used for modification of septic tank and providing secondary treatment to domestic wastewater as shown in Figure 3.1 was submerged in bio tank having 2.6 L of working volume and dimensions were 33 cm height, 20 cm length and 4 cm width.

The flat sheet WFMF membrane immersed in membrane tank was having pore size of 1-3µm with effective filtration area of 0.05 m^2 and dimensions were 21 cm height, 15 cm length and 1 cm width. Operational flux was maintained at 8 LMH resulting HRT of 4 hr.

Membrane module was placed 5 cm above from rector tank bottom and 5 cm below the water level and free board was 2 cm. Suction pressure was created by connecting one membrane port with peristaltic pump (Longer BT300-2J China), while second port was used occasionally to remove trapped air from the module and connected piping. Digital manometer (840099 Data-logging, 15 PSI, USA) was used for continuous recording of trans-membrane pressure (TMP) and controlling the filtration to relaxation cycle during operation.

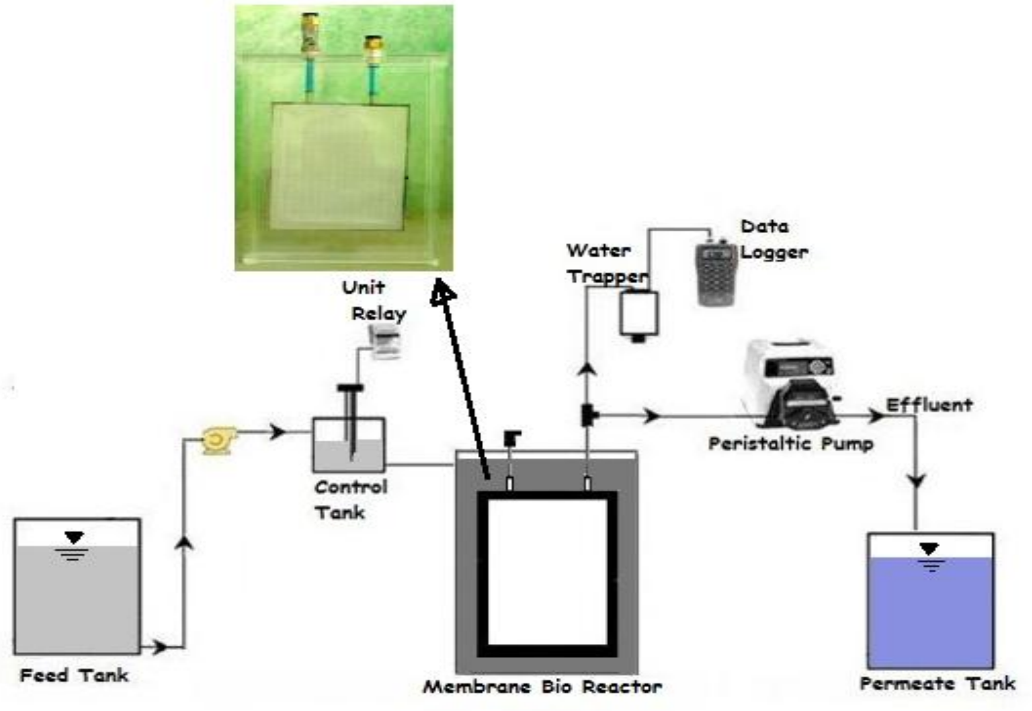

Figure 3.1 Schematic diagram of laboratory scale membrane based septic tank (MBST)

Wastewater level in membrane tank was maintained by using level control tank. Wastewater was automatically filled in bio tank by using solenoid valve relay unit level and sensors. The laboratory scale membrane module and bio-tank are shown in Figure 3.2.

Figure 3.2 Membrane bio-tank and module

3.1.1 Specifications of membrane module

The membrane was bind on both sides of the membrane module using binding material (40 Callibre PVC Cement, clear, Hydroseal Canada). Specification of woven fiber microfiltration (WFMF) membrane and its module are reported in Table 3.1.

Table 3. 1 Specifications of membrane module

Item	**Specification**
Membrane type	Dead-end mode, outside-in, flat sheet
Configuration	2 sheets (fixed) + 2 spacers
Material	Polyester fiber
Pore size	1-3 um
Outlet port	2
Effective size:	$0.05m^2$

Material of the module was PVC with sheet thickness of 1 cm, length 15 cm and width of 18 cm. Cut the pieces of PVC sheet having an edge at 45^o and joined them with PVC binding glue to make it rectangular frame. PVC sheet was cleaned using acetone to remove dust residue.

Figure 3. 3 PVC membrane module

Two outlet ports were fixed to the module. The purpose of first port was to create suction through peristaltic pump and second was used to escape the trap air from inside the module.

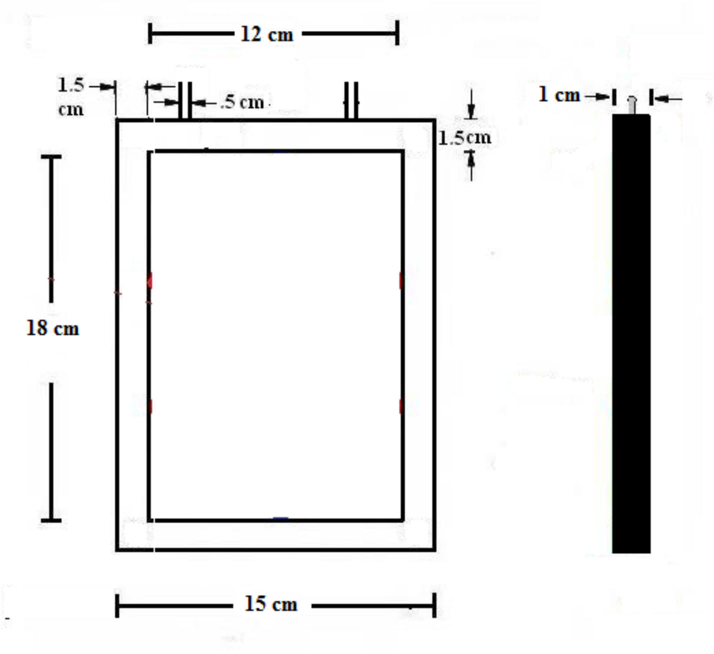

Figure 3. 4 Dimension of membrane module

Spacer was fixed inside the membrane module. Purpose of this spacer was to give direction to flow and maintain space between the membrane sheets during suction.

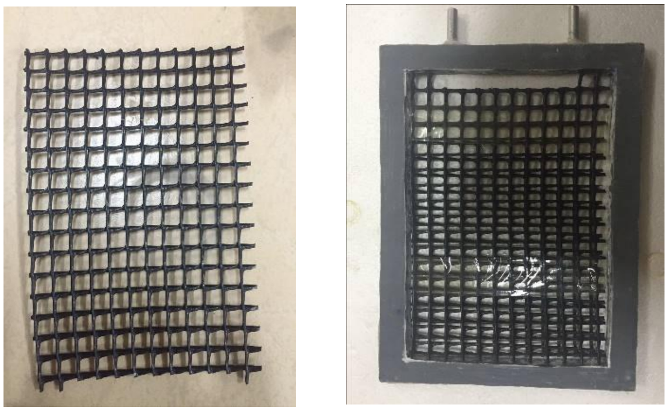

Figure 3.5 Spacer and fixation of spacer in module

Glue was applied separately on membrane sheet and PVC module to make sure that no part of membrane sheet and membrane module remain dry. The membrane sheet was placed on top of membrane module and pressed continuously for 5 minutes to fix it completely. Membrane module was air dried for 12 hours and then placed it in cold water for 24 hr. for maximum strength.

3.2 Membrane material

The material of woven fabric microfiltration membrane (WFMF) was polyester. Arrangements of fiber in WFMF via scanning electron microscopy (SEM) at resolution of 500 µm as shown in Figure 3.6. This SEM image depicts the uniform arrangement of fiber which allows the membrane to restrict the particles greater than 0.3 µm.

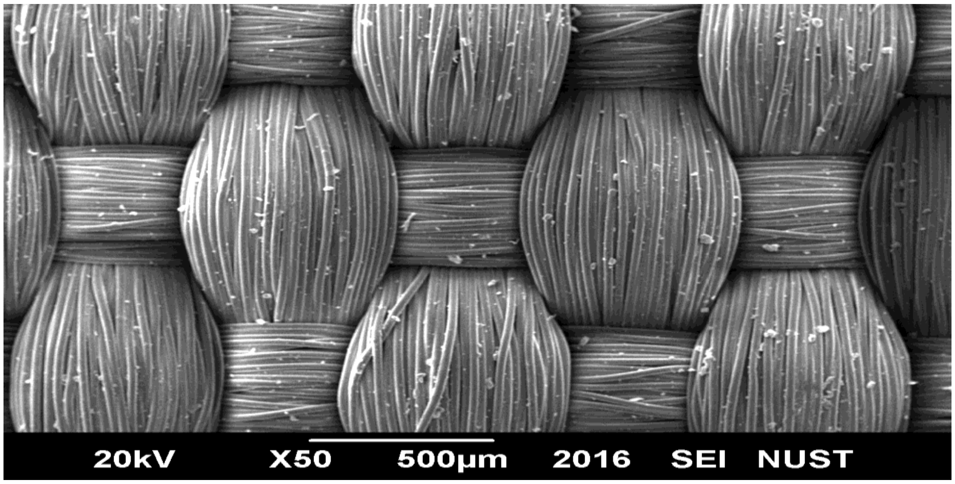

Figure 3.6 Arrangement of fiber in woven fiber microfiltration membrane via scanning electron microscopy (SEM) at 500 µm

The SEM view in Figure 3.7 of WFMF membrane at 10 µm shows average width of membrane fibers is 24µm and pore size is 0.3µm. The visual observation of membrane shows the small particles of dust during manual handling.

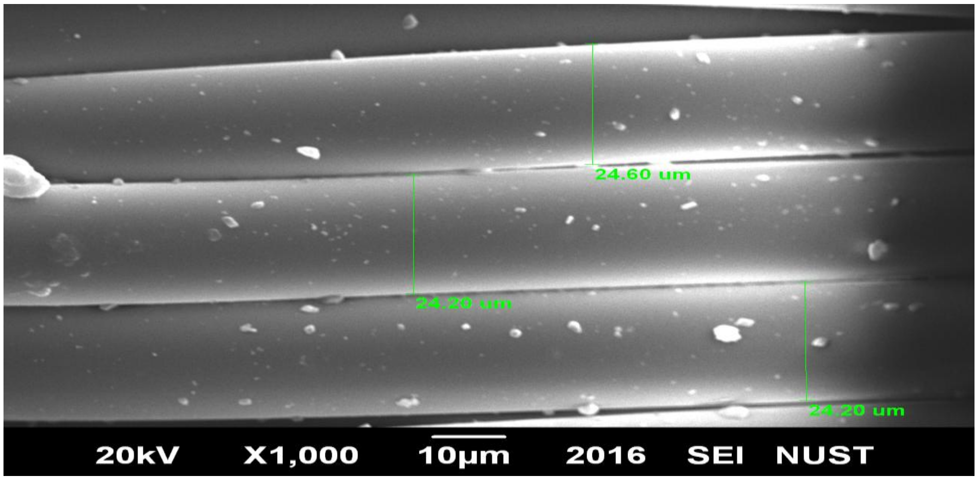

Figure 3.7 Scanning electron microscopy (SEM) of virgin membrane at 10 µm

In Figure 3.8 the SEM results shows that in polyester membrane major portion of material was comprises of carbon and potassium

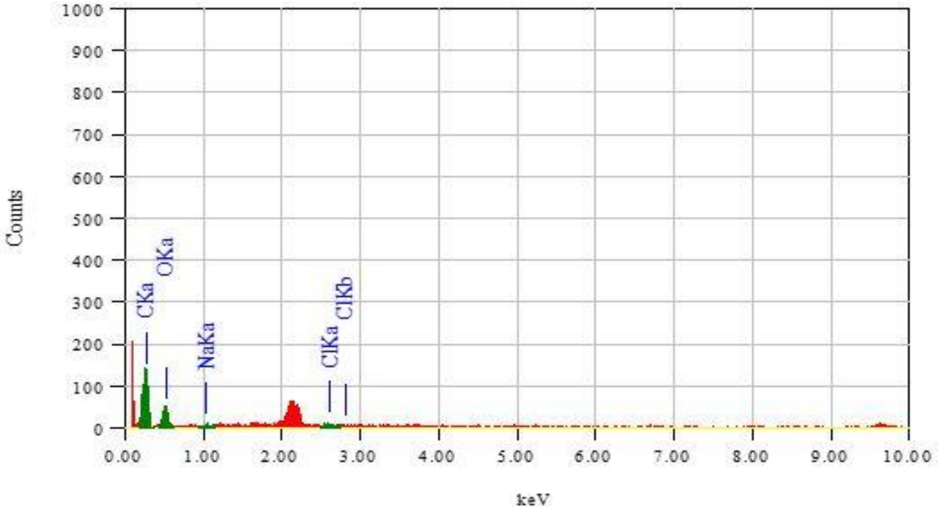

Figure 3.8 Chemical composition of virgin membrane

The pore of woven fiber microfiltration (WFMF) membrane was blocked as shown in Figure 3.9 resulted in reduced flux and rise in trans membrane pressure (TMP).

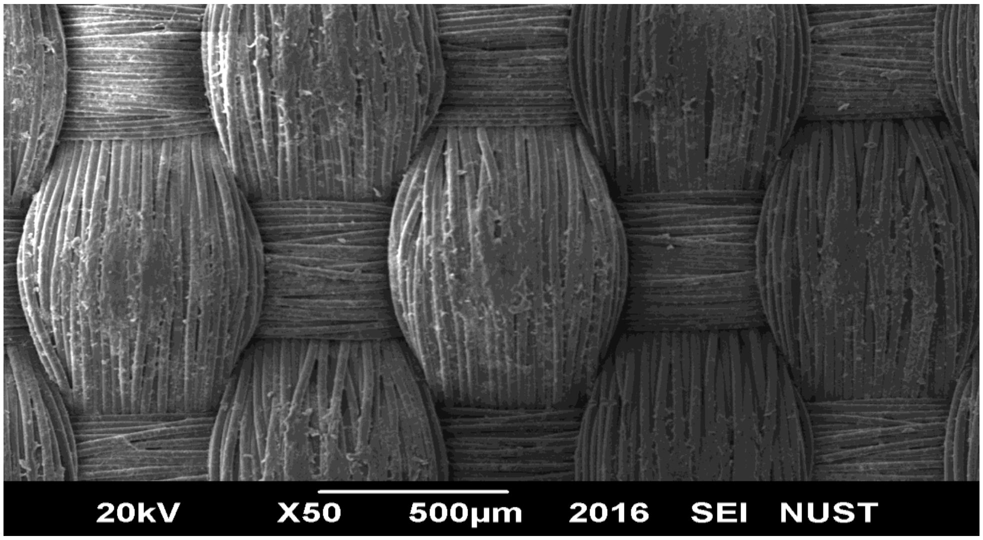

Figure 3.7 SEM of fouled membrane at 500 µm

The view of fouled membrane at 10 µm is shown in Figure 3.10. it was observed that fouling layer consolidated on surface of membrane and clogged the pores resultant in reduced the net flux and increased in Trans membrane pressure (TMP).

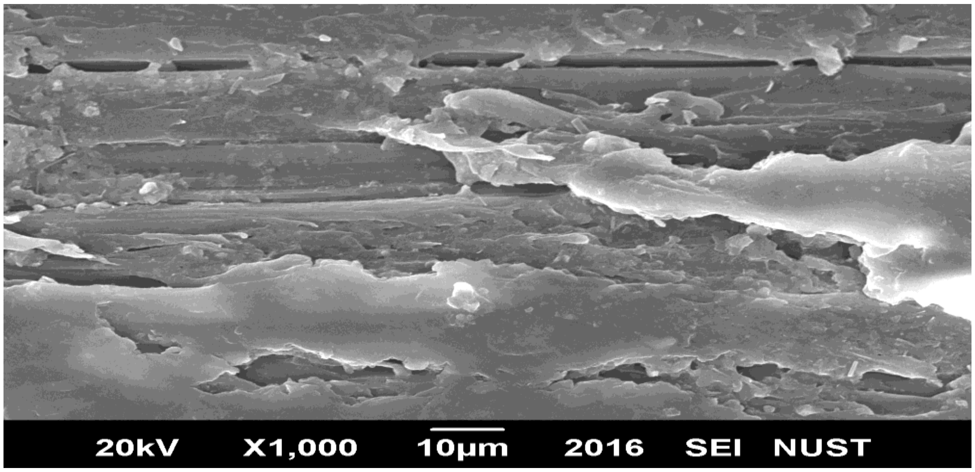

Figure 3.8 Scanning electron microscopy of fouled membrane at 10 µm

After detail analysis of fouled membrane, it was investigated that major composition of fouling layer was comprising of iron, calcium, aluminum magnesium and chlorine as shown in Figure 3.11.

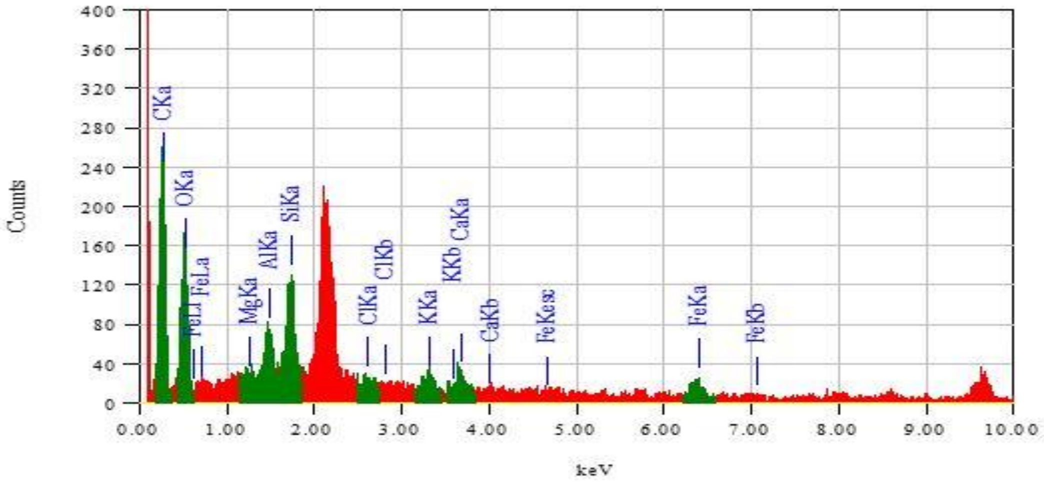

Figure 3.9 Chemical composition of fouled membrane

3.3 Analytical parameters

Influent sample from feed tank while effluent sample from permeate tank were analyzed for water quality parameters such as TSS, COD, fecal coliform, ammonium-nitrogen, phosphate-phosphorous and turbidity using following techniques and equipment reported in Table 3.2. The technique, material and equipment used for analysis was recommended by American Public Health Association (APHA) 2012.

Table 3.2 Water quality parameters, technique and equipment/material

Parameters analyse	**Techniques**	**Equipment/material**
Total suspended solids (TSS)	Filtration-Evaporation	1.2 µm (GF/C, Whatman); 105^{o}C oven
Turbidity	NTU	HACH Turbidimeter 2100N
Chemical oxygen demand (COD)	Closed Reflux	COD Tube; 150^{o}C oven
Ammonium-nitrogen (NH_4^+-N) Phosphate-phosphorous (PO_4^{-3}-P)	Hach Reagents	Spectrophotometer (DR 2010, Hach)
Faecal coliform (FC)	MF Filtration	Filtration Assembly, Media EMB Agar

(Source: APHA, 2012)

3.4 Wastewater characteristics

Medium strength synthetic domestic wastewater having C:N:P as 100:5:2 was used as influent for MBST. Recipe of synthetic wastewater to maintain 200 mg/L COD included, Glucose 205 mg/L, Ammonium Chloride 38.4 mg/L, Potassium Di-hydrogen Phosphate 17.5 mg/L, Calcium Chloride 2 mg/L, Magnesium Sulphate 2 mg/L, Ferric Chloride 0.6 mg/L and Manganese Chloride 0.4 mg/L. pH of 7-7.5 was maintained using sodium bicarbonate. Characteristics of real primary settled wastewater is reported in Table 3.3.

Table 3. 3 Characteristics of primary settled wastewater

Parameters (mg/L)	**Raw wastewater**
COD	160-190
pH	7.5-8.0
Ammonium-nitrogen	11-12.5
Phosphate-phosphorous	10-14

3.5 MBST operation

3.5.1 Maintenance of membrane

During the MBST operation, each membrane filtration run with an effective flux of 8 LMH was considered complete, when TMP reached to 50 kPa. The terminal pressure was calculated mathematically by the formula given below

$$P1 = TMP + (H+h)\ \rho\ g \qquad \text{(Equation 3.1)}$$

$$TMP = P1 - H\ \rho\ g \qquad \text{(Equation 3.2)}$$

TMP = Trans Membrane Pressure (Calculated)

P 1 = Pressure gauge reading

ρ = Density of water (1000 kg/m^3)

g = Acceleration due to gravity (10 m/s^2)

H = Height of outlet port of membrane in M tank to manometer connector

In order to minimize irreversible fouling the operation was stopped when TMP reached to 50 kPa, membrane had to be disconnected from the system for physical and chemical cleaning and for resistance analysis.

Initially the intrinsic membrane resistance (R_m) for virgin membrane was analyzed using DI water, before submerging it into wastewater. At this stage, the intrinsic membrane resistance equaled the total hydraulic resistance (R_t) i.e. $R_m = R_t$, due to the fact that at this point, there was no cake layer and no pore clogging. The membrane module was then submerged into bio reactor after initial virgin membrane resistance analysis and the operation was started. At the end of each filtration run, the membrane was disconnected from the system and submerged into sodium hypochlorite for chemical cleaning in the laboratory.

During the resistance analysis, membrane was physically cleaned by spraying tap water and using brushes to remove the cake layer and deposited solids. The membrane module was kept in dry and clean environment for the next filtration run after each cleaning protocol and resistance analysis. Figures 12 below shows a virgin membrane before operation and a clogged membrane after operation

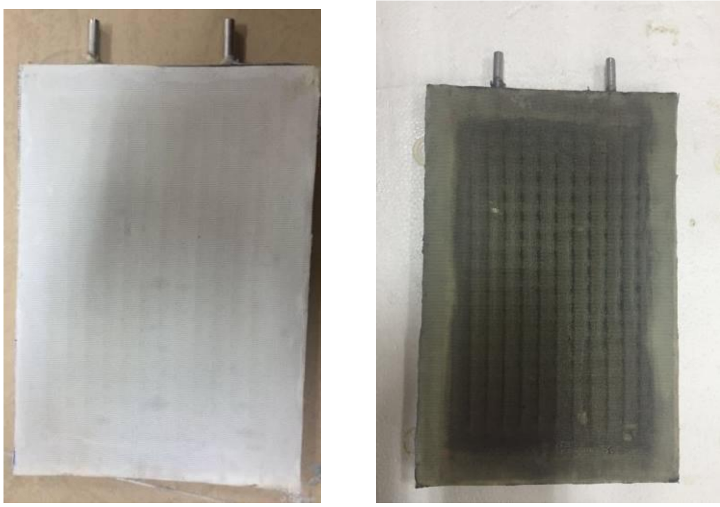

Figure 3.12 Virgin membrane before treatment and fouled membrane after treatment

3.5.2 Membrane resistance analysis

After completion of each filtration run and disinfection process, the resistance analysis was performed. During the resistance analysis, the total hydraulic resistance (R_t) was calculated using Equation 3.3.

$$R_t= \Delta P/\mu J \qquad \text{(Equation 3.3)}$$

The resistance-in-series model was applied to estimate the filtration characteristics using equations 3.4.

$$R_t = R_m + R_c + R_p \qquad \text{(Equation 3.4)}$$

Where;

J = operational flux (L/m2. s) or LMH,

ΔP = TMP (kPa),

μ = viscosity of permeate (Pa.s),

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}),

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 15 min for each flow rate. Profiles were developed for resistances against different fluxes i.e. 4, 6, 8, 10, 12, 14, 16 and 18 LMH.

Further, total resistance with cake and without cake were found using equations 3.5 and 3.6.

$$R_t = R_p + R_m + R_c \text{ (With cake layer)} \qquad \text{(Equation 3.5)}$$

$$R_t = R_p + R_m \text{ (without cake layer)} \qquad \text{(Equation 3.6)}$$

The cake layer resistance was found using equation 3.7

$$R_c = R_t - (R_m + R_p) \qquad \text{(Equation 3.7)}$$

3.6 Membrane cleaning protocol

Prior to start to filtration run, membrane was cleaned chemically and physically using following protocols.

3.6.1 Physical cleaning

Membrane were washed by spraying tap water and using a brush to remove the deposited solids. After physical cleaning membrane module was sun dried for 24 hr. before next filtration cycle.

3.6.2 Chemical cleaning

Membrane was cleaned chemically using NaOCl (0.03%w/v) to remove microbiological deposited layer from membrane surface. After chemical cleaning membrane module was sun dried for 24 hr. before next filtration cycle.

3.7 Filtration to relaxation mode (FRM)

Filtration to relaxation modes (FRM) in which filtration is the represent the interval to treat the wastewater and relaxation is the interval to stop the filtration to restore the membrane permeability. If relaxation exclude from the process than membrane might take short time to foul. In this study three different FRM were selected and operated the membrane under each FRM for three time.

Chapter 4

RESULTS AND DISCUSSION

4.1 Membrane fouling tendencies

Membrane fouling was evaluated through trans membrane pressure (TMP) profiling which was recorded with the help of data-logging manometer during membrane filtration. The main purpose of this study was to optimize filtration to relaxation mode by continuous monitoring of TMP under constant flux of 8 LMH and the filtration operation was stopped when the TMP reached 50 kPa. In previous studies terminal pressure of WFMF membrane was 80 kPa caused the deposition of consolidated irreversible fouling layer resulted in sudden TMP rise and flux drop. But in this study the operation was stopped at 50 Kpa to avoid irreversible fouling. Membrane resistance analysis was carried out to determine the total resistance (R_t), cake resistance (R_c), pore blocking resistance (R_p), and intrinsic membrane resistance (R_m).

This research was carried out in three phases.

- Optimization of filtration/relaxation mode (FRM) and treatment performance of woven fiber microfiltration (WFMF) membrane for wastewater treatment.
- Comparison of physical and chemical cleaning protocols for WFMF membrane.
- Evaluation of WFMF system for water treatment using optimized FRM mode.

4.2 Phase1

4.2.1 Optimization of filtration-relaxation mode (FRM)

Laboratory scaled MBST setup was operated at three FRM of 30_{min}-10_{min}, 45_{min}-15_{min} and 60_{min}-20_{min} crossponding to filtration cycles 36, 24 and 18/day respectively, at constant operational flux of 8 LMH throughout the study. The objective was to optimize an effective FRM by evaluating trans-membrane pressure TMP and fouling trend.

4.2.2 Membrane fouling

Khan et al. (2013) carried out a study on MBST having FRM of 8_{min}-2_{min} at different fluxes and terminal TMP was 80 kPa. However, it was observed that due to large working head (distance b/w membrane module and peristaltic pump), relaxation time was too short to restore membrane permeability and caused rapid membrane fouling. On other hand, due to extreme terminal TMP of 80 kPa the membrane surface was exposed to cake compression causing irreversible fouling layer and flux reduction 80%.

Therefore, in this study, the setup was operated at three different FRM in order to optimize filtration to relaxation time for reduction of rapid fouling while terminal TMP was reduced to 50 kPa to avoid irreversible fouling layer.

After continuous operation at three FRM for three successive cycles under each FRM, results revealed that the average fouling rates (dTMP/dt) at 30_{min}-10_{min}, 45_{min}-15_{min} and 60_{min}-20_{min} were 16.7, 10 and 15 kPa/day respectively. Results revealed that, TMP profile of the FRM mode 45_{min}-15_{min} showed less fouling frequency than others and found to be optimized FRM as shown in Figure 4.1. The graph shows membrane was fouled within 4 days in 1st cycle of FRM 30_{min}-10_{min} while in 2nd and 3rd cycle membrane was fouled within 2.5 and 2 days respectively. In FRM 45_{min}-15_{min} membrane fouling period was 6, 5 and 4 days for 1st, 2nd and 3rd run respectively. Similarly, in FRM 60_{min}-20_{min} membrane fouling period was 5, 4 and 2 days for 1st, 2nd and 3rd run respectively.

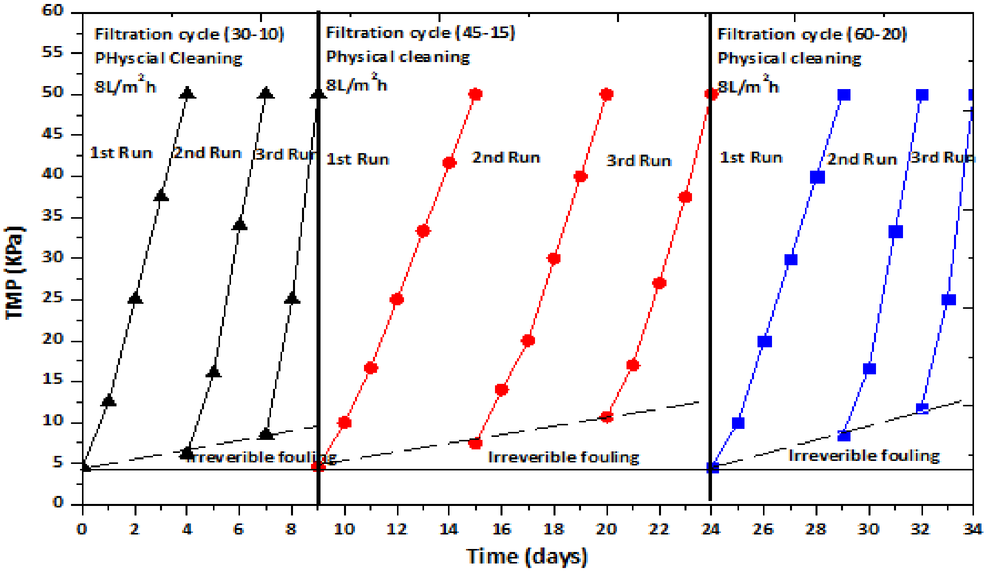

Figure 4.1 TMP profile at different filtration cycle

4.2.3 Treatment performance of MBST

MBST treatment performance was determined in terms of COD, TSS, NH_4-N and Phosphate-Phosphorous concentrations and removal efficiencies. MBST satisfied the post treatment requirement based on results. Further, cake deposit layer on membrane acted as secondary membrane and increase the treatment performance because of decreased in pore size; while, flux rate was reduced 60%. During operations under each filtration cycle, removal efficiencies were relatively similar as pH range 7.1-8.6, COD 65-78% and NH_4-N removal was observed 30-45%.

The graph in Figure 4.2 shows that influent variation of COD was from 150 to 185 mg/L and WFMF was capable of removing the COD less than 50 mg/L which is about 78%.

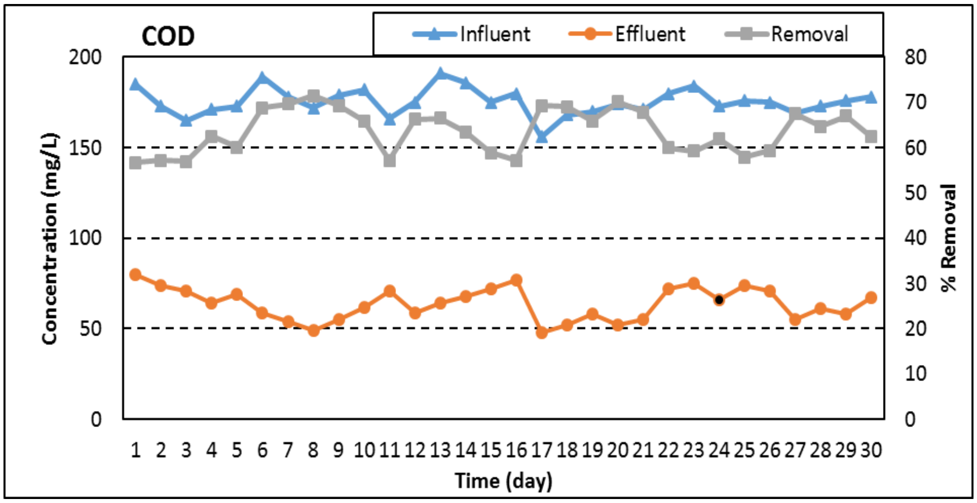

Figure 4.2 COD removal for wastewater in MBST

The graph in Figure 4.3 shows that the average concentration of ammonium-nitrogen (NH_4-N) in wastewater was 12 mg/L while, according to NEQS, the concentration of NH_4-N was already below the limit which is 40 mg/L. The removal efficiency of NH_4-N WFMF membrane

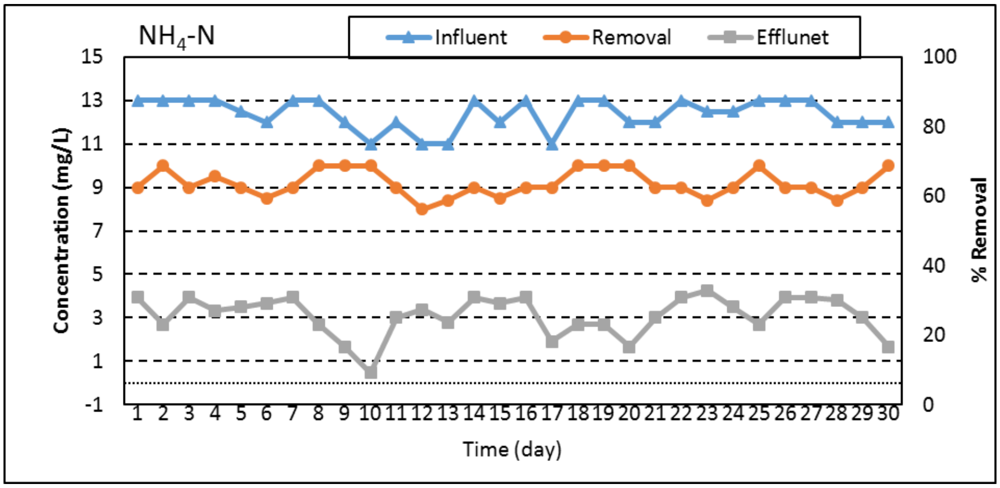

Figure 4.3 Ammonium-Nitrogen removal for wastewater in MBST

Organic matter and solids deposited on membrane caused the formation of biofilm/cake layer and acted as secondary membrane which improved removal efficiencies; however, this layer was also responsible for reduction in flux rate and membrane fouling. Removal efficiencies of three FRM are shown in Table 4.1.

Table 4.1 Removal efficiencies at different filtration to relaxation mode (FRM)

Parameters	**Influent (mg/l)**	**% Removal**			**Effluent (mg/l)**	**NEQS (mg/L)**
		(30-10)	**(45-15)**	**(60-20)**		
COD	170 ± 20	61±3%	65±2%	69±2%	60-45	150
PO_4^{+3}-P	13 ± 2	26±5	28±4	32±2	9-11	40
NH_4^{+1}-N	11 ± 2	20±4%	24±3%	26±4%	8-10	40
pH	7.6-8.1	7.8-8.0	7.8-8.0	7.8-8.0	7.5-8.0	6-9

4.3 Phase 2

4.3.1 Comparison of cleaning protocols

Physical cleaning protocols were followed in Phase 1 and found 7% increase in irreversible fouling after successive filtration cycles. Phase 2 was conducted to reduce irreversible fouling by cleaning the membrane with 0.03% NaOCl using concentration of 2000 mg/L for 6 hours. System was operated at optimized FRM 45_{min}-15_{min} and resistance analyses was conducted between successive cycles. It was observed that after chemical cleaning irreversible fouling was reduced from 7 to <1 %, while fouling rate also reduced from 10 to 8.8 kPa/day which prolonged filtration duration as shown in Figure 4.4.

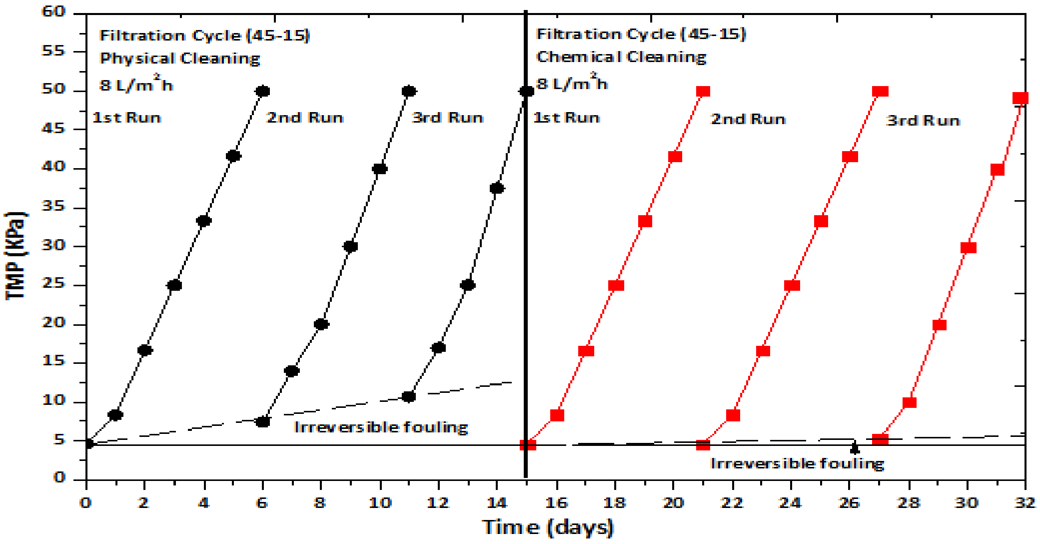

Figure 4.4 TMP profile with physical and chemical cleaning.

4.4 Phase 3

4.4.1 Onsite water treatment technology

Flat sheet WFMF membrane was evaluated as onsite water treatment technology. Surface raw water was collected from Rawal water treatment plant Islamabad. 1 mm mesh sieve was used to remove fine particles lager then 1 mm and then water was pumped into membrane reactor tank.

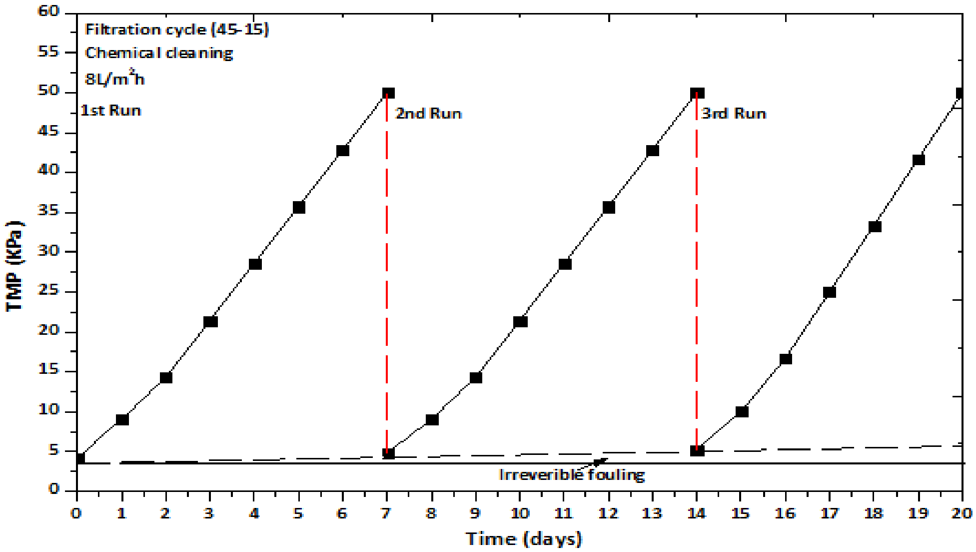

Figure 4.5 TMP profile of onsite water treatment technology

System was operated at optimized FRM, operational flux of 8 LMH and terminal pressure of 50 kPa. Chemical cleaning protocol was followed to avoid irreversible fouling. Three consecutive filtration cycles were performed to eliminate the fouling behavior of WFMF membrane as shown in Figure 4.5.

4.4.2 Treatment performance of WFMF as water treatment technology

Results reveled that woven fiber microfiltration (WFMF) can effectively treat low strength raw water having turbidity of less than 30 NTU. Treatment performance revealed that removal efficiency of turbidity and TSS were 78-89 and 56-65% respectively, within limits of WHO but *Escherichia Coliform (E. coli)* were 90-99% and needed further disinfection to be within limits of WHO as shown in Figure 4.6-4.8.

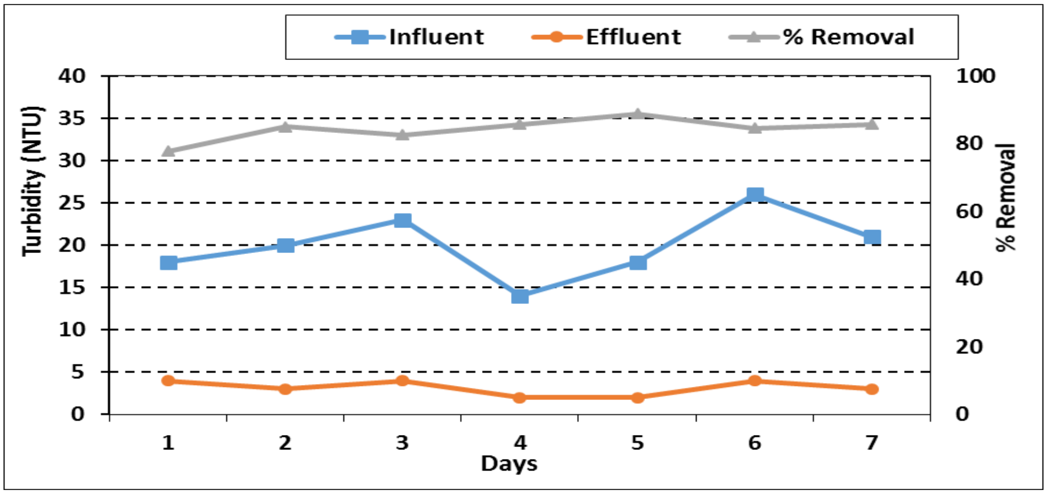

Figure 4.6 Turbidity removal of WFMF membrane

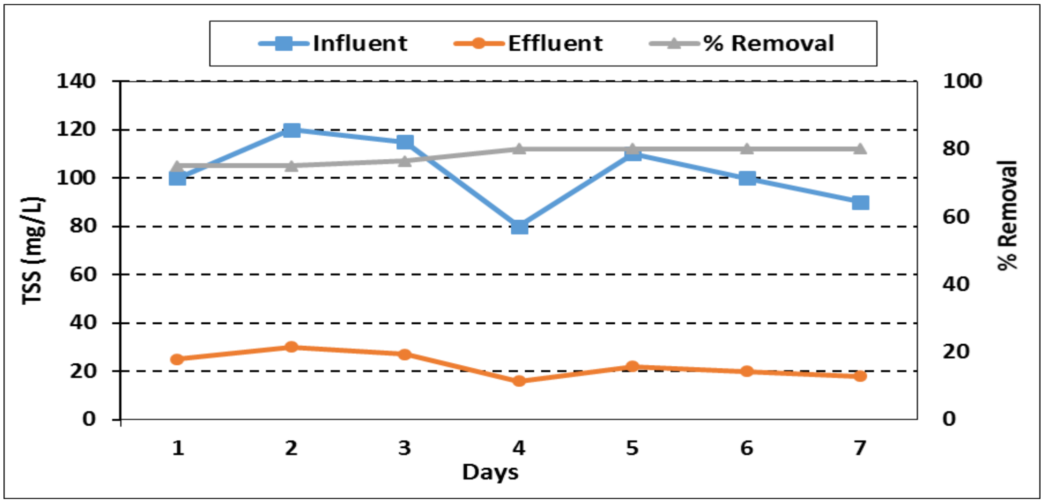

Figure 4.7 TSS removal of WFMF membrane

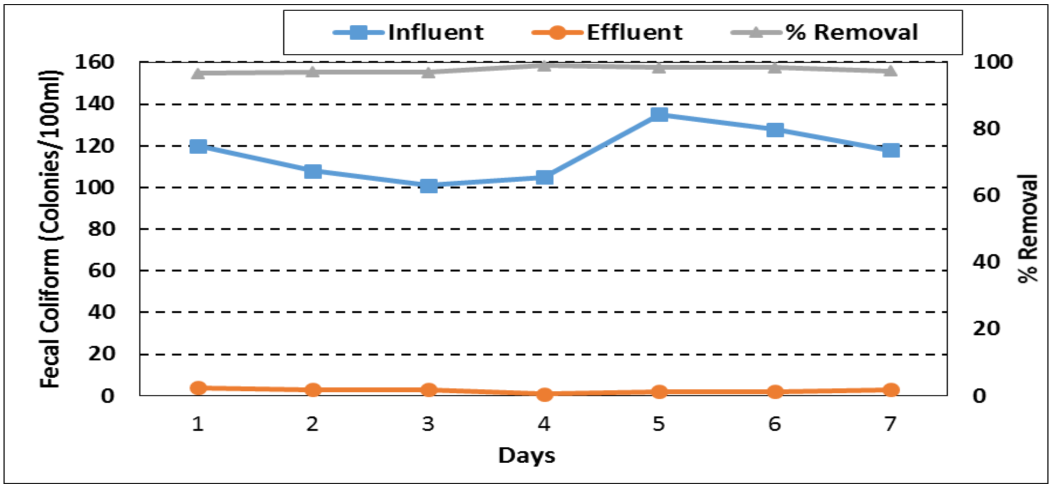

Figure 4.8 Fecal coliform removal of WFMF membrane

The Water quality parameters and removal efficiencies with respect to National Drinking Water Standards are shown in Table 4.2

Table 4.2 Water quality parameters and removal efficiencies with respect to National Drinking Water Standard (2010) and WHO guidelines (2011)

Parameters	**Unit**	**Influent**	**Effluent**	**% Removal**	**WHO guidelines**	**National Drinking Water Standards**
Turbidity	NTU	25±5	3 ± 2	84-92	<5	<5
TSS	mg/L	100 ± 20	20 ± 10	58-65	---	---
E. coli	CFU/100mL	120±15	3 ± 2	96-99	Must not be detected in 100 ml sample	Must not be detected in 100 ml sample

4.4.3 Chlorination

Chlorination is considered as economical method for disinfection. Different dosage of sodium hypo-chloride (NaOCl) was added in 1 litter of sample as 0.5, 1, 1.5, 2, 2.5 and 3 mg/L. Residual chlorine was checked after 1 hour in each sample and found 2 mg/L as an optimum dosage for disinfection having residual chlorine of 0.5 mg/L as shown in Figure 4.9.

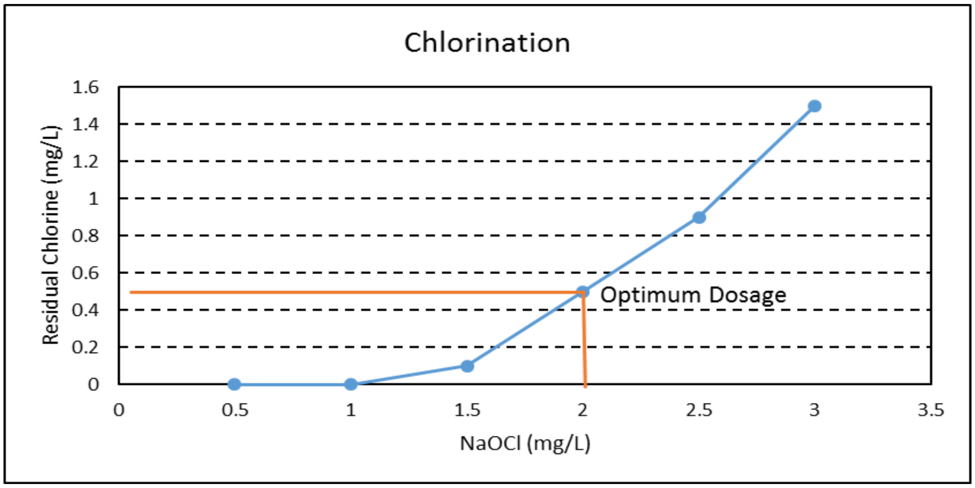

Figure 4.9 Optimum dosage of chlorination for effective disinfection of water

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

WFMF membrane found to be multipurpose, low cost and emergency treatment option. Conventional septic tank was upgraded by inserting flat sheet WFMF membrane which proved to be an appropriate onsite solution for wastewater treatment. Membrane fouling was overcome by increasing suction to relaxation time. Flux was maintained at 8 LMH and filtration-relaxation mode (FRM) varied as 30_{min}-10_{min}, 45_{min}-5_{min} and 60_{min}-20_{min}. It was concluded on the bases of results that fouling rate in 45_{min}-15_{min} was less as compared to other filtration modes. Membrane fouling was caused by the formation of biofilm/cake layer however, as membrane fouling increased its removal efficiencies were also increased because of decrease in pore size; therefor, cake layer acted as secondary membrane.

As the filtration cycle increased irreversible fouling also increased. Membrane cleaning and operation very much depends on irreversible fouling. Firstly, operation was stopped at <50 kPa to avoid irreversible fouling; Secondly, chemical cleaning with NaOCl (0.03%w/v) was performed for 6 hr. to remove consolidated layer from the surface of membrane. It was also observed that chemical cleaning found effective in term of removing irreversible fouling then physical cleaning because in physical cleaning pores of membrane remained block.

WFMF membrane was also investigated for water treatment and found that WFMF membrane can effectively treat the low turbidity (< 30 NTU). *E. coli* removal was 90% as filtration started and reached to 99% however treated water was disinfected with sodium hypo chloride (NaOCl) to meet National Drinking Water Standard and WHO guidelines.

5.2 Recommendations

Some of the recommendations are follow to carry on this research work,

1. Aeration around membrane module is recommended to further decrease membrane fouling by scouring effect and improve membrane filtration recovery.
2. WFMF membrane can be used as treatment option for drinking water treatment where raw water exhibits high organic content but low turbidity (< 30 NTU).
3. Irreversible fouling can be further reduced by introducing maintenance cleaning (MC) in WFMF membrane.

Chapter 6

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