Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 7 ~ Issue 6 (2021) pp: 29-36
ISSN(Online) :2348-2532
www.questjournals.org

Research Paper

Physical method of Wastewater treatment-A review

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ABSTRACT:
As the water resources are diminishing due to increasing domestic, industrial and agriculture water usage, the role of wastewater treatment is becoming important. The cost and disposal of wastewater together with strict discharge regulations have resulted in lesser level of contaminant in waste stream. These conventional wastewater methods were used but they are not much effective in the current scenario. Therefore, to overcome these problems novel method for waste water treatment is developed which are discussed in this chapter. This includes various physical method such as nanofiltration, forward osmosis, microfiltration and reverse osmosis. This method proved to be reliable compared to the conventional one as they are cost effective and easy to manage.
KEYWORDS: *wastewater, nanofiltration, reverse osmosis, forward osmosis.*

Received 28 May, 2021; Revised: 08 June, 2021; Accepted 10 June, 2021 © The author(s) 2021. Published with open access at www.questjournals.org

I. INTRODUCTION

As the water resources are diminishing due to increasing domestic, industrial and agriculture water usage, the role of wastewater treatment is becoming important. The cost and disposal of wastewater together with strict discharge regulations have resulted in lesser level of contaminant in waste stream (Bhargava ,2016). According to the World Health Organization, 40 million m^3 of wastewater are recycled in the world every day ("Wastewater Management," n.d.). But in the developing countries the 80-90% of the wastewater in urban area remained untreated or not sufficiently treated when discharged ("Percentage of wastewater flows treated to national standards [and reused] – to be developed – Indicators and a Monitoring Framework," 2012). In Indian the amount of faecal waste generated in a day is about 1.7million tonnes. The official data illustrates that 78% of the generated sewage remains untreated, which is released directly into the rivers, lakes and groundwater. There are different sources through which contamination occurs in water, but two major sources are industrial and sewage waste. As the Indian population increasing day by day as well as its industrial area with a tremendous speed, the volume of wastewater generated rising at an alarming rate. In India, the situation of wastewater treatment is not satisfactory as only 1/3rd wastewater is treated, which leads to the high burden of water borne diseases such as jaundice, diarrhea, hepatitis etc. While urban water access is high on average, which leads to significant gaps across the country and the national average of the wastewater treatment remains around 33%. The large wastewater generated states in India are Maharashtra, Uttar Pradesh, Gujarat and Punjab. The total wastewater is also generated from processing operations. Wastewater from processing operations originated from boiler blowdown, steam-stripping operation, pump-gland cooling and desalting crude oil. As this water also comes in contact with oil, it becomes contaminated.

As the runoff water from surface is intermittent, which include constituents from spills, equipment leakage and material accumulated in drain. It also includes water from crude and product storage tank roof drain (U.S.EPA,1995). So, the efficiency of waste water treatment must be made efficient and sufficient so that they would be capable of eliminating different contaminants such as suspended and dissolved ones to obtain a safe water which can be easily discharged into the environment or suitable to be apply for the agriculture as a sludge, which is used as a fertilizer. So as to attain this condition the use of advanced technology must be made and ultimately it would be probable to re-use water after treatment for agricultural purposes, industry, or even as drinking water. This novel physical method discussed in this paper to enlighten our knowledge of wastewater treatment.

II. TREATMENT TECHNOLOGY FOR WASTEWATER:

The different types of wastewater method for physical process include nanofiltration, reverse osmosis, forward osmosis, microfiltration, electrodialysis. These all method has their own advantage and disadvantages; besides this they remove the contaminant by different process and are based on different principles. Nanofiltration based on the principle of difference in charge effect and particle size, while reverse osmosis works when pressure more than osmotic pressure is applied on the high concentration area, resulted in water flow to be reversed. Forward osmosis works on the mechanism of drawing water from low concentration feed solution side to high concentration solution driven by the osmotic pressure difference., while microfiltration works on the separation of one particle from other driven by pressure. Electrodialysis remove salt from solution by the ion exchange membrane. These all method are recently developed and can be effectively applied for the wastewater treatment processes.

III. PHYSICAL METHOD OF WASTE-WATER TREATMENT

3.1 Physical method

Physical method eliminates solids from wastewater as it flows through screens or filter media, or solids are removed by gravity settling or air flotation. Particles entrapped with air float to the surface and can be removed. They still form the base of most method flow systems for wastewater treatment. The advance used physical processes are:

(a) Nanofiltration:

The term nanofiltration (NF) seems to have been first utilized during the 1980s to describe membranes with characteristics that fall between ultrafiltration (UF) and reverse osmosis (RO). Nanofiltration has demonstrated high dependability in many wastewater treatment processes (Cheryan,1998; Tchobanoglous *et al*., 2003; Labbez *et al*., 2003; Ku *et al*., 2005). It is a proficient color removing technology, decreasing the volume of generated wastewater, recycling valuable constituents and recovering them. It works on the mechanism of solution diffusion and pore size flow (Wijamins and Baker, 1995; Anim-Mensah *et al*., 2008). In nanofiltration the size of membrane pores is nominally $\sim$ 1 nm due to which even minute solutes are rejected but the surface electrostatic properties allow single charge ions to be easily transmitted with polyvalent ions mostly retained. These features make nanofiltration membranes really useful in the fractionation and selective removal of solutes from complex process streams. It is one of the novel technologies for surface water treatment of inorganic and organic pollutant.

Mechanism of separation in Nanofiltration:

Pollutant separation by nanofiltration membrane depends on differences in charge effect and particle sizes, which is due to effects of electrostatic and steric interaction based on donnan exclusion. The component with low molecular weight is separated by mechanism of charge effect and diffuse solution, unlike high molecular weight component separated by mechanism of sieving. Following five steps are given by Macoun (1998) for nanofiltration rejection.

1- Wetted surface- Water forms hydrogen bonding with the membrane and molecules that form hydrogen bonds with membrane are transported.

2- Capillary rejection / Preferential sorption-membrane is microporous and heterogenous also electrostatic repulsion happens due to dissimilar electrostatic constant of membrane and solution.

3-Solution diffusion – membrane is non-porous and homogenous, the solvent and solute dissolve in the active membrane layer and transport of the solvent arises due to diffusion through layer.

4- Charged capillary – rejection decided by the pores in the electric double layer. Due to streaming potential counter ions are rejected and similar charged ions as attracted.by membrane.

5-Finely porous – Because a membrane is solid material with pores in it. The separation of pore and bulk fluid determines the transport.

The features of nanofiltration membranes lies between the porous ultrafiltration membranes (where rejection is due to electrostatic charge effects and size exclusion) and the non-pores reverse osmosis membrane (rejection due to solution-diffusion mechanism. Therefore, rejection of charge molecules dominated by electrostatic interactions and size exclusion, while that of uncharged molecules by size exclusion (Shon *et al*., 2013). Jin *et al*. (2012) developed a new composite nanofiltration membrane in which SiO_2 nanoparticles are incorporated for removal of salt from oily wastewater. There is 50% increase in the permeation efficiency of polyamide (PA)-SiO_2 membrane and no salt rejection loss, when adding 1% (wt) nano-SiO_2.The rejection of inorganic salts was in order as follows: Na_2SO_4 > $MgSO_4$ > $MgCl_2$ >NaCl; which revealed that (PA)- SiO_2 membrane and

PA(polyamide) were negatively charged. The higher stability flux was found in (PA)- SiO_2 membrane, which could remove approximately 50% of salts in oily wastewater in one cycle filtration.

Advantage
1- It requires less energy and operation cost than reverse osmosis
2- Nanofiltration compared to reverse osmosis has greater water permeability and works on low pressure range between 7 to 30 bar.

Disadvantage
1- Nanofiltration is also susceptible to membrane fouling (process in which contaminants are deposited on the surface of a filtration membrane) that could be due to inorganic precipitation or scaling, colloidal fouling, organic adsorption and/or biofouling.

(b) Reverse osmosis:
It is also knowns as the hyperfiltration as it is not porous and selectively allows liquid but retain most of the ions and solutes. It has high operating pressure in the range of 20 to 100 bar. It consists of two types: aromatic polyamide and cellulose ester. Reverse osmosis comprises of plate and frame, tube, roll and hollow fiber type. It can eliminate a variety of organic matter, dissolve inorganic salts and impurities. It is also efficient in salt elimination and reuse rate of water. But high pretreatment of feed water is required. It also separates organic compounds such as oxygen and nitrogen, colloid with <3.10 μm, ions and pesticides ((Lee *et al*., 2011; Teodosiu, 2001).

Principle of reverse osmosis
It has capacity of generating fresh water by putting large pressure into feed side enclosed by semi-permeable membrane. If P > OP i.e., pressure and osmotic pressure is applied to the high concentration, the direction of water flow through membrane can be reversed known as RO (reverse osmosis). The quantity of fresh water produce depends upon: concentration of salt in feed water and properties of membrane such as permeability and selectivity (Anqi *et al*.,2016). A set up of reverse osmosis plant for waste water treatment is illustrated in Figure.1. It is described in following steps:
1- Chemical and mechanical treatment of feed water is done to decrease settlement of mud, dust, fouling material and calcium and magnesium like compounds, non-condensable gases come out and it needed desceration.
2- Feed pump is used to maintain water pressure followed by high-pressure feed stream enters in the membrane, dissolved salts are rejected and fresh water passes via membrane.
3- Turbines recovered the brine having high-pressure energy followed by product water treated to sustain its neutrality of pH (Alatiqi.1999).

Advantage:
1-Reverse osmosis is cost effective if the price of fuel rises and regarded as best for wastewater treatment.
2- If wastewater treatment is of large scale than its efficiency is higher having greater flux and rejection over longer period of operation.

Disadvantage
1- It requires more energy and operation cost.
2- Reverse osmosis is also susceptible to membrane fouling

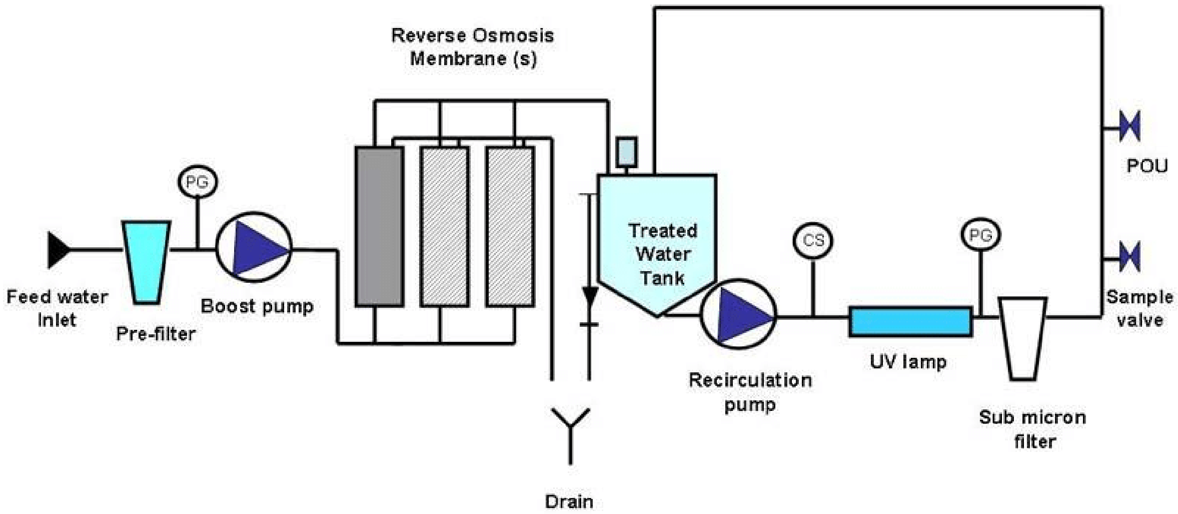


Figure.1. Set up of reverse osmosis plant for wastewater treatment (Source: Agarwal *et al*. 2016)

(c) Electrodialysis (ED)

It is generally a process of membrane separation and is generally used in the treatment of waste water processes. It combines electrolytic and dialysis diffusion process, which on action of direct current electric field allows anions and cations of dissolved salt in wastewater to move to anode and cathode. This leads to the reduction in cation and anion concentration in intermediate compartment, which results in its separation and recovery. Anions are passed through the membrane having positive charge and vice versa for cations. Alternately compartment is concentrated and diluted. The efficacy of electrodialysis process depend on the current density, cell structure, flow rate, properties of ion exchange membrane, pH and feed water ionic concentration.

Principle

The chief purpose of this method is to remove salts from aqueous solution, which is done by passing an aqueous solution via ion exchange membrane illustrated in Figure.2. The cell separated into chambers by placing the membrane of cation and anion exchange between the two electrodes which act as cathode and anode, when direct current is applied between these two electrodes. Taking example of feed solution of NaCl passes via electrodialysis system and concentrated in 1 chamber. Anion are restricted while cation passes through cation exchange membrane. Anion passes through anion exchange membrane limiting passage of cation. In the adjacent compartment concentration of salt increase while it decreases in another compartment. As a result, salt concentration decreases in some compartments while increasing in others. In the adjacent compartment, the concentrated brine as well as salt present in water exit out. The applied electric potential serves as driving force in the electrodialysis process. At low salt concentration preferred process is electrodialysis as it has higher energy efficiency. The quantity of (I) electric current required depend upon the no of ions that passes by membrane of ion exchange.

$I = QxFxZx\ \Delta C/£$

F=Faraday's constant; Q=feed solution flow rate; ΔC=change in solute concentration; £=Current utilization factor that accounts for energy efficiency; Z=charge on ion.

Various types of ion exchange membrane used in electrodialysis such as bipolar, amphoteric, inorganic-organic, homogenous etc.,

Advantage

1- Electrodialysis uses less energy and pharmaceutical consumption.
2- It causes less environmental pollution.
3- It is easy to operate and automate.

Disadvantage

1- Electrodialysis can only remove salt from water.
2- It usually has lower desalination efficiency.
3- It is also susceptible to the membrane fouling.

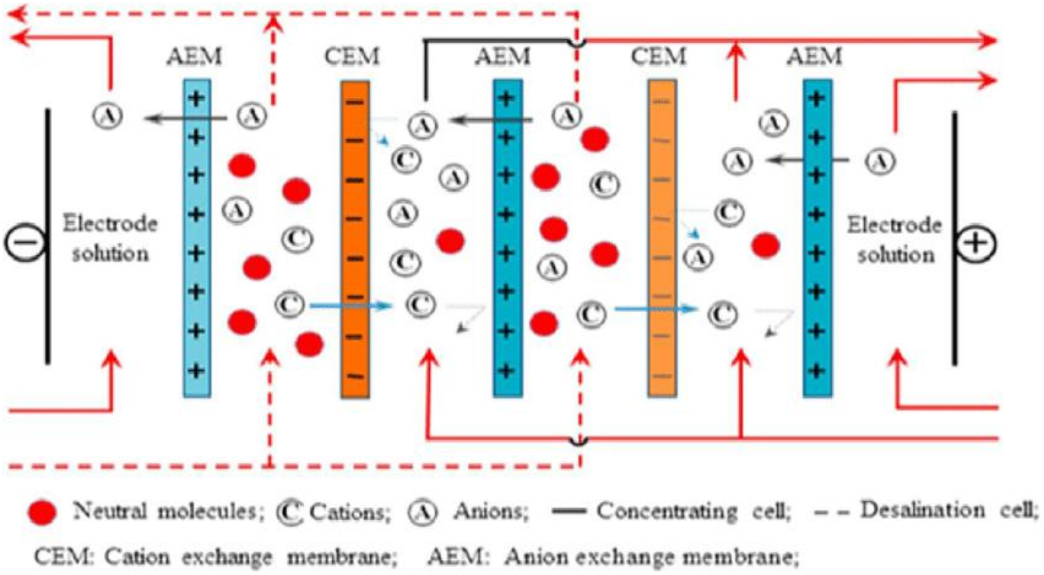


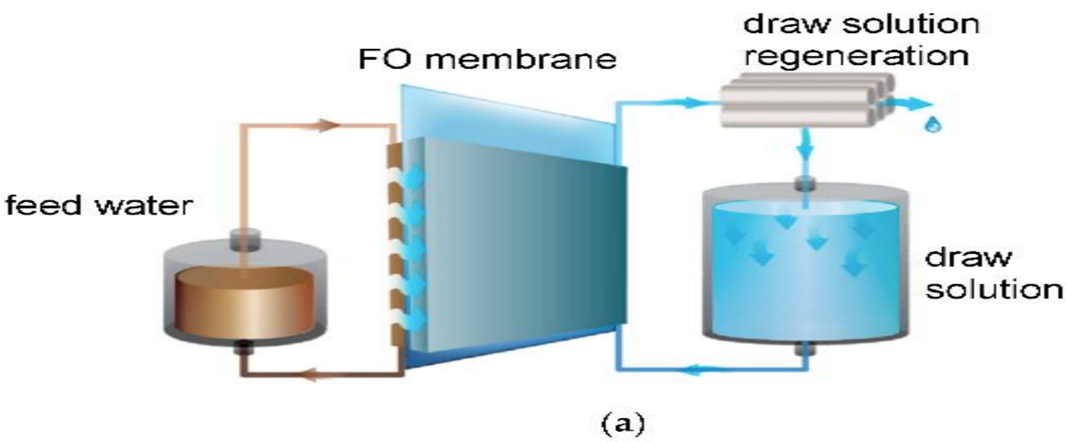
Figure 2: Basic principle of electrodialysis. (Source: Akhter,2018)

(d) Forward Osmosis

It is a membrane process that is propelled by the natural osmotic pressure formed when drawing feed solution and solution of various concentration separated by a semi-permeable membrane as shown in Figure 4. It does not require hydraulic pressure to be applied from outer source and is installable with a low-cost and required only low-pressure apparatus, that ultimately reduced the capital cost of pumping system. It has various application in desalination, treatment of secondary and tertiary effluent for sewage, digested sludge and municipal wastewater. This new technology is a potent and cheap alternative of various conventional wastewater technologies. Different modification of these techniques to be developed in the future scenario.

Principle in Brief

Forward osmosis uses the driving force induced by the osmotic pressure difference across the membrane active layer to draw water from low concentration feed solution side to the high concentration solution side. The hydraulic pressure difference across membrane is zero (ΔP). It can be regulated in two modes: (a) active layer facing draw solution (AL-DS) (b) active layer facing feed solution (AL-FS). In general membrane water flux in active layer facing draw solution (AL-DS) is greater w.r.t water flux of active layer facing feed solution (AL-FS), leading to reduced internal concentration polarization (ICP) (Zhao *et al.*, 2012). Specific solute flux (Js/Jw) is an important parameter for membrane efficacy. Lesser value indicates greater selectivity in forward osmosis process, where forward solute flux selectivity increased (Hancock and Cath, 2009). In every forward osmosis application, the penetration of solutes which diffuse into draw solution accumulate over time, leading to precipitation in draw solution which resulted in maintaining less (Js/Jw) value and its importance in forward osmosis.



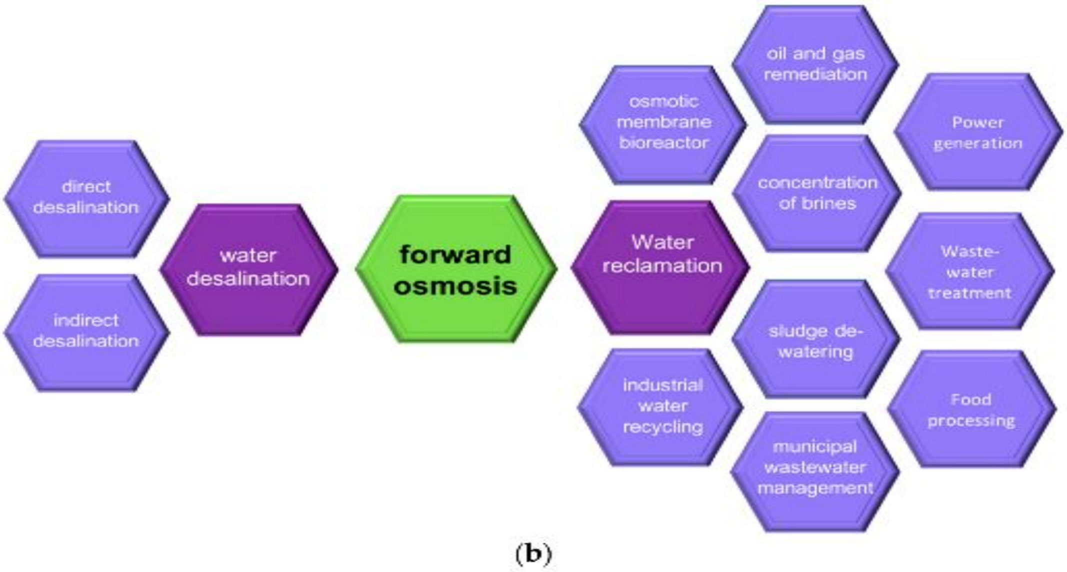


Figure 4. (a) A typical forward osmosis process is depicted schematically with the membrane, feed, draw solution tank and reconcentrated system (Cosay and Cath,2014) (b)Major applications of forward osmosis in different sectors.

Forward Osmosis Membranes

Variety of forward membrane are present in which the first-generation membrane includes (HT-NW) non-woven and (HTI-ES) is embedded support. These membranes are cellulose triacetate (CTA) membrane marketed by HTI company. They are produced by casting cellulose triacetate with an embedded polyester mesh to develop a dense active layer. The thickness of active layer membrane minimized in order to enhance membrane water permeability without compromising membrane integrity. Li *et al*. (2018) found out that in the field tests cellulose triacetate (CTA) membrane not achieved the expected salt and water rejection, also vulnerable in high or low pH conditions. To overcome these bottlenecks of cellulose triacetate (CTA) membrane second generation membrane are developed by HTI and oasys water, which are generally thin film composite (TFC). This membrane has comparable rejection as well improves the water flux to 30-40 L m^{-2} h^{-1} from 10 L m^{-2} h^{-1} for cellulose triacetate membrane (Linares *et al*.,2014). Advancement in technology leads to development of aquaporin spiral wound configuration (Blandin *et al*.,2016; Cosay and Cath,2014).

Advantage

1- Forward osmosis is installable with a low-cost and required only low-pressure apparatus, which decreases the capital cost link with pumping system (Linares *et al*., 2013).
2- Forward osmosis is sustainable and cost-effective solution compared to conventional membrane technologies such as membrane distillation and reverse osmosis.
3- It has ability to reject nearly all suspended as well as solute solids, which operates at particular temperature.

Disadvantage

1- Because of the reduced concentration gradient across the membrane rejection layer, concentration polarization (CP) is known to significantly reduce membrane performance.
2- Forward osmosis membrane should preferably limit the passage any dissolved draw solute into the feed solution. Small amounts of dissolved solute, however always leak into the feed solution due to phenomena reverse salt diffusion.
3- It suffers from different types of membrane fouling such as biofouling, organic, inorganic fouling and colloidal fouling (Ly *et al*., 2019; Bogler *et al*., 2017).

(d) Microfiltration

In this process particles of one size are separated from other size which are in the range of 0.01 µm to 20 µm (Manimekalai *et al*.,2017). It is driven by pressure and is thus effective for removal of suspended solids. In this fluid either be gas or a liquid. Microfiltration media are available with different variety of manufactures and materials. They are rated as nominal or absolute depending upon the % (percentage) of the capture of particles of similar size or greater than retention rating of media. Membranes of microfiltration categorize into two groups depending upon pore structure. They are called as screen membrane, because of capillary -type pores.

Membrane with tortuous-type pores known as depth membrane. Microfiltration consists of two modes of filtration:

1- Dead end filtration: here feed is forced normal to membrane The entire feed flow is forced through the membrane and filtered matter accumulates on the membrane's surface. It is a batch process as the filtration capacity reduces with accumulation of matter in the filter, due to clogging. A subsequent process step is required to remove the accumulated matter. It is an effective method for concentrating compounds.

2- Cross flow filtration: feed is forced tangential membrane. In this process membrane used are tubes with a membrane layer on the inside wall of the tube. The feed flow through the membrane tube has a high flow speed to create turbulent conditions and elevated pressure as the driving force for the filtration process. Because the feed flow and filtration flow direction are at 90-degree angle the process referred to as cross flow. It is an effective method for filtering liquid containing a high concentration of filtrable matter.

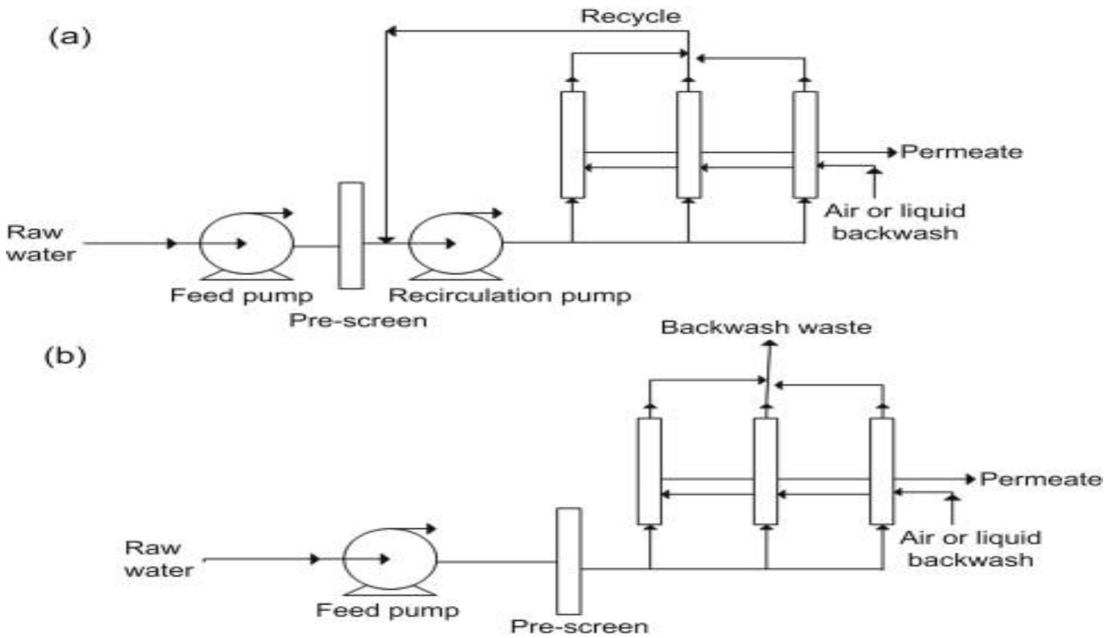


Figure 3. (a) Cross-flow configuration MF and (b) dead-end filtration for microfiltration (MF). Reprinted from Jacangelo, (1997)

Description of Technology

It has largest pore size (0.1-3 micron) of different membrane filtration system. In terms of pore size, it fills the gap between granular media filtration and ultrafiltration. The particle size of microfiltration lies between the lower portion of conventional clay and upper half of range of humic acid, which is smaller than size of algae, bacteria and cyst and greater than that of viruses. It is used to eliminate suspended solids, turbidity reduction and other microorganisms. It operates in dead end filtration and crossflow separation. In crossflow separation, only feed stream part is treated, while remaining water passes untreated through membrane. In dead end separation, all feed water treated nothing remain untreated. They also have two pump configuration which is vacuum type or pressure driven. In pressure driven membrane, flow is fed from pump and housed in vessel, while vacuum type membrane driven by vacuum developed on product side and submerged in non-pressurized tanks. The factor affecting membrane selection such as percent recovery, percent rejection, cost, pretreatment requirement and raw water characteristics.

Advantage

1- Microfiltration with ceramic filter (0.8μm) is effective in removing the turbidity due to the suspended solids.
2- Most microorganisms can be removed and recovery of enzymes in waste-water.
3- Can typically produce water of satisfactory turbidity.
4- Microfiltration membrane used to achieve very low turbidity effluent.

Disadvantage

1- All pressure-driven filtration processes including microfiltration requires a degree of pressure to be applied to the feed liquid stream as well as imposed electrical concerns.
2- It is also susceptible to membrane fouling.

IV. CONCLUSION

According to this study, it can be concluded that the use of these novel method will enhance the wastewater treatment processes to a great extent. But these methods have their own limitation which implicate that they are used under some specific conditions. The unique characteristics of different methods will revolutionize the water and wastewater treatment technologies in the current scenario.

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