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A Review on Water Filtration Approaches and Composite Membrane Engineering for Sustainable Separation

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Article Details

Key Words: Cellulose Polymer, Polymer Membranes, Fabrication Techniques, Segregation Method, Hydrophilicity, Oil Pollution

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ABSTRACT

Hydrocarbon-bearing wastewater with complicated compositions that contain hazardous and damaging contaminants is produced in significant quantities during the development and production of both local and international oil fields. The highest concentration of oil-water emulsion is seen in oily sewage generated during oilfield extraction. Concern over the separation of oily wastewater arose from last decade as a result of the increased demand for fresh water. For waste water separation, multifunctional membrane fabrication is the most dependable method and high potential technique due to its low cost, high separation efficiency, and single operating procedure. In addition to novel physical and chemical methods for membrane fabrication, this review article will also look at high potential separation strategies.

INTRODUCTION

Water is most irreplaceable and essential source of life existence on the earth. Without water the survival on planet is impossible. It is crucial for daily cleanliness, survival of living organism and to maintain ecosystem because from insect to human and even aquatic life totally depend on water. Out of 100% water, 97% are present inform of ocean and seas and total 3% are for human use but these 3% amount of water also polluted by human unnecessary activities.

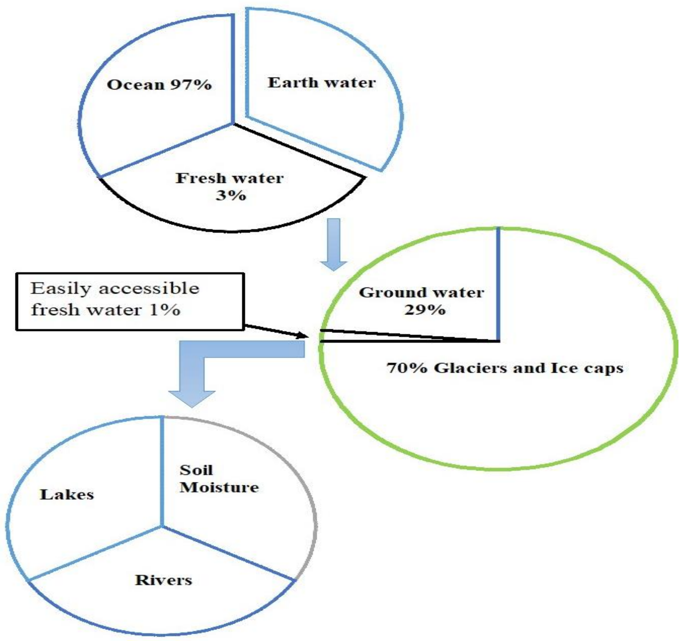


FIGURE 1: WATER COMPOSITION

The pollution of water mean addition of hazardous component which have negative effect on human (many disease) and any other living organism health. The addition of oil in water cause water pollution .In aquatic system it lead to depletion of oxygen and different reproductive issues. Various human activities is directly and indirectly effecting water like primary source is petroleum and oil extraction, industrial outlets or pipes which directly release oil and other contaminant in fresh water reservoirs. Natural oil spillage and leakage of oil tankers accidentally. Even a small spill of oil have vast and undeniable impact.

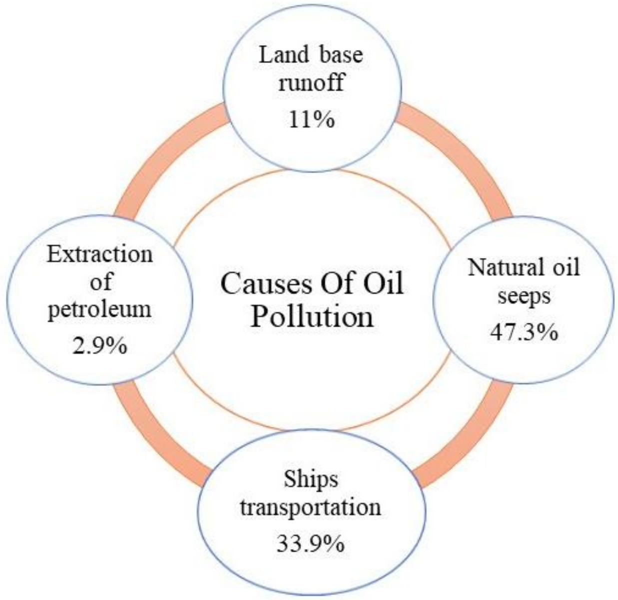


FIGURE 2: CAUSES OF OIL POLLUTION

Many working industries crude oil refining and petrochemical, metal processing, pharmaceutical, and even food processing sector release wastewater as by product, which is a hefty threat for human and aquatic life, also unsuitable for agriculture area. Different types of oil also used in automobiles, vehicles engine for oil changing cause water pollution [1]. When organic and inorganic contaminants encounter with water, it pollutes water cause serious health issue and Millions of people died every year [2]. Aliphatic and aromatic hydrocarbon are present 75% in concentration in oily sludge. Heteroatoms are also present but less as compared to asphalt and resin. [3]

To meet water demand with increasing growth of population, it is crucial to adopt a cost effective and advanced method to recycle the wastewater. Different conventional physical and chemical methods are available for oil water separation. Physical methods include adsorption, sand filter, evaporation and cyclone while oxidation, demulsifier, ionic liquid at room temperature and electrochemical processes are included in chemical method. These conventional methods have some disadvantages like high cost, use of toxic compounds and slow processing. [3]

Polymer with different additives and solvent are used to fabricate membranes with desire properties. Hydrophillic polymer such as Poly sulfone(PS), Polyether sulfone(PES), cellulose, chitin, cellulose acetate(CA), Poly imidazole, polyacrylonitrile (PAN) with different hydrophobic (acetate, propionate, butyrate) and hydrophilic (polyethylene glycol , polyethylene oxide , polystyrene , polyurethane, epoxies) additives investigated by their mechanical properties , water flux , structure and performance.[4] Different solvent dimethyl sulfoxide (DMSO), t-butanol, 1-propanol, acetone, Dimethyl formamide (DMF), N-Methyl pyrrolidone, N, N-dimethyl acetamide, methyl acetate, 2-propanol were used to prepared solution with different polymer. Nowadays polymeric material is utilized to design membrane for oil water separation. [5]

TYPES OF MEMBRANES

DENSE MEMBRANES

This membrane surface is free of pores. Oil water separation mainly depend upon membranes material and their interaction. Mostly these membranes are used to separate gases. Receiving pores in membrane lead to permit the gases without any separation. [6]

POROUS MEMBRANES

They have interconnected pores with size range of 0.01 to 10 microns .Ultrafiltration and nanofiltration techniques are used for these membranes to segregate the liquid emulsions like oil\ water or water\oil. Small pores size membrane show high efficiency in separation of emulsion. [6]

SYMMETRIC MEMBRANES

Supporting and separating layer are undistinguishable. Membrane performance can increase by decreasing the thickness of membranes. Membrane thickness has inverse relation with permeation rate. [7]

ASYMMETRIC MEMBRANES

Separating or skin layer and supporting layer both are distinguishable. Supporting layer are porous and thick. The material can be selected on the basis of properties. In asymmetric membranes if both layer fabricated by different material called Asymmetric composite membranes. [7]

Membrane separation is a hopeful technique to purify wastewater. [8] In polymeric membrane cellulose acetate-based membranes are frequently used because of their non-toxicity and bio compatibility. Most membranes are fabricated by phase inversion method due to easy processing. We can enhance the anti-fouling property, mechanical stability of cellulose acetate membranes by adding different organic and inorganic additives. Cellulose acetate-based membranes have shown effective progress in oil water separation and can also be used in energy storage, energy production, gas separation etc. A lot of toxic impurities and harmful microorganism suspended in oily wastewater, 90% of dreadful impurities can easily remove by ultra filtration. Meanwhile forward osmosis requires less energy for water purification than other methods. [9]

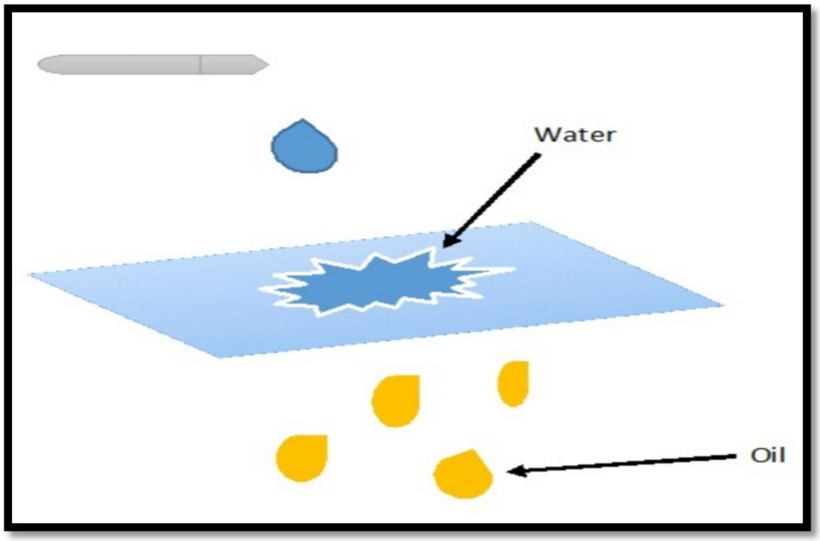


FIGURE 3: HYDROPHOBIC MEMBRANE

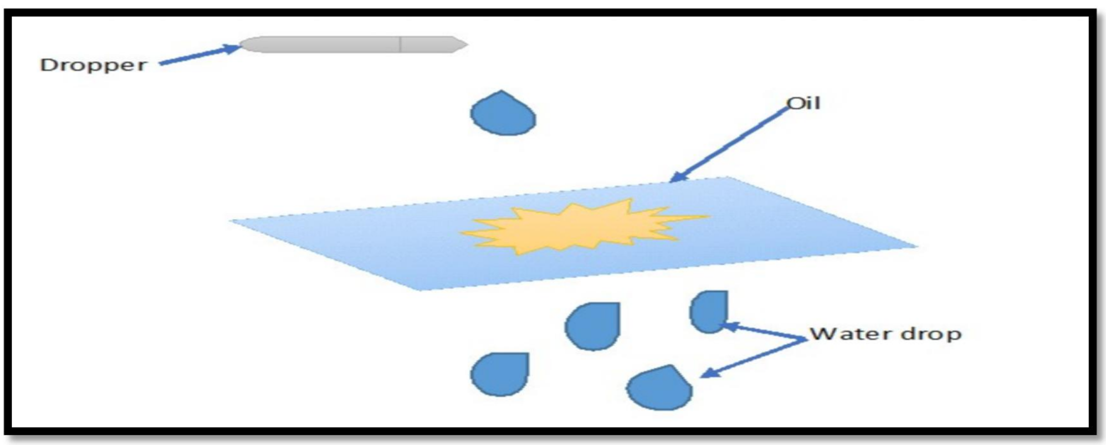
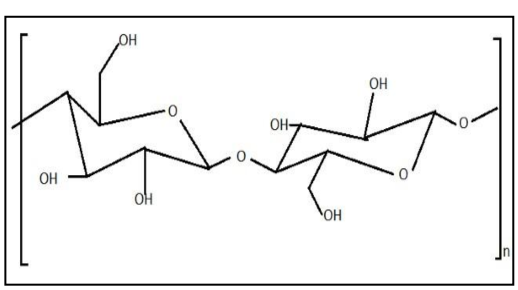


FIGURE 4: HYDROPHILIC MEMBRANE

CELLULOSE MEMBRANES

Cellulose is a natural, hydrophilic, nontoxic, biodegradable and biocompatible polymer. Cellulose acetate is derivative of cellulose. Cellulose acetate membranes are light weight, easily fabricated.



CELLULOSE

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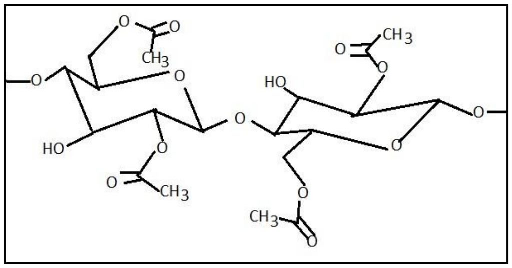

CELLULOSE ACETATE

TABLE 1.1: CA AND TITANIUM OXIDE NANOPARTICLES PROPERTIES COMPARISON [10] [11] [12]

PROPERTIES	CELLULOSE ACETATE (CA)	TITANIUM DIOXIDE (TiO_2)
Tensile strength (10^3 MPa)	6.6	333.3
Melting point (°C)	245	1843
Decomposition °C	450	400
Crystallinity %	27	(3-Phases)
Glass transition temperature °C	205	883
Density g\cm^3	1.3	2.9

It is used because of excellent film forming ability, eco-friendly, hydrophilic with high water flux and antifouling property. Cellulose acetate is soluble in acetone, methyl acetate etc., and insoluble in water. [9]

Suzana. Nunes uses hydrophilic ionic liquid in cellulose (EMIM) oAC doped solution for oil\ water separation. The result reported the complete removal of crude oil from water. Thinnest coating of cellulose show high permeance and flux recovery. Fouling affected by changing PH and charge on the droplet. [5]

HUSSAIN.A and coworker used cellulose acetate membranes doped with Nylon 6, 6 and formic acid as a solvent. Thermal properties were enhanced by addition of Nylon 6, 6. Degradation time of backbone was increased from 180°c to 320°c. Tensile strength increase, flux permeation 33L|mh and oil rejection of 95% achieved. [13]

G. Anthanareeswan and P. Thanikaivelan prepared the membranes by dissolving CA in dimethylformamide solution and zirconium oxide as additives. The result showed that water flux increased by increasing the increasing the concentration of zirconium oxide, but mechanical stability and membrane resistance decreased. A SEM study revealed that pore formation and anti-fouling property of membrane increased with increasing zirconium oxide particles. [14]

W. Chen et al synthesized membrane with grafting techniques. Polyacrylonitrile (PAN) GRAFTED on CA powder by free radical polymerization. Cerium ion was used as initiator. The comparison study of PAN, CA, CA-g-PAN confirmed that PAN increased the permeation property by enlarging the pore size. The hydrophilicity of CA-g-PAN was close to CA membrane. CA-g-PAN membranes show high antifouling property, good flux property and complete oil rejection. [15]

A. Mansourizadeh prepared asymmetric membrane by dissolving the PES and PEG-400 in NMP and lastly added to CA. PES|CA MEMBRANE show sponge like morphology and higher permeability with pore size of 0.15µm.[16]

Micah Belle and coworkers fabricated the cellulose acetate polydopamine mixed matrix membrane and investigated the performance of polydopamine in cellulose acetate. $CA_{PAD(0.2\%)\ Wt.}$ concentration shows better anti fouling property, high oil rejection (93-98%) with $771.98 lm^{-2}h^{-1}$ of water flux [17].

Jincui and his team prepared Janus polymer| CNT MEMBRANES showed good results by selective removal of organic compound and high separation efficiency for both oil water and water oil emulsion and promising flux. [18]

FABRICATION TECHNIQUE

Different fabrication methods are existing for preparation of membranes. Some are here concisely defined.

PHASE INVERSION METHOD

In this technique, a water insoluble polymer is first dissolved in solvent, polymer doped solution is formed. After degassing the doped solution cast on supporting material or glass slit with glass rod or doctor knife. Solvent evaporated when exposed to air for some time. After this membrane dipped in water for solvent exchange. Water move from lower to higher concentration and solvent move from higher to lower concentration gradient this leach out is responsible for pores formation in membrane. [19]

Three types of phase inversion method utilized for membrane fabrication. (1) Thermal induced phase inversion method (TIPS), (2) Non solvent phase inversion method (NIPS), (3) Vapour induced phase inversion method (VIPS). NIPS method are frequently used method in membranes fabrication. [19]

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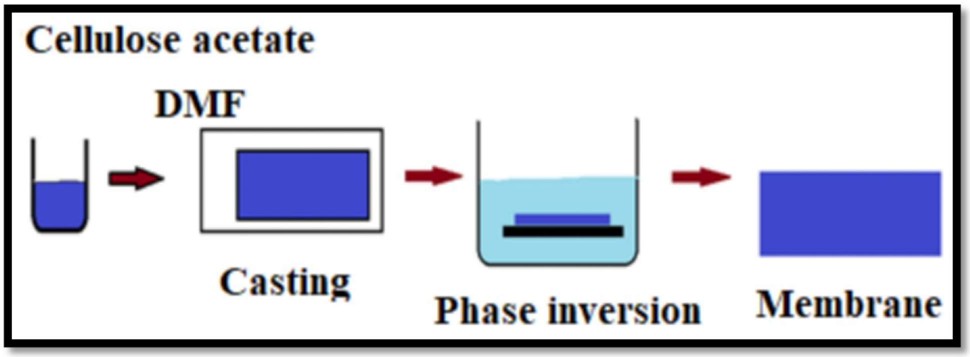

FIGURE 5: PHASE INVERSION METHOD

INTERFACIAL POLYMERIZATION

IP method is mostly used to fabricate a thin film composite. A membrane fabricated by this method has excellent permitted flux and impurity rejection. First substrate clamped on supporting material (a membrane module). Substrate surface permeated by aqueous diamine solution and further submerged in diacid chloride (an organic media).Later we dry membrane in oven, solvent evaporated and pores formed. This method is costly because of use of too much chemical solvent compared to phase inversion method. [20]

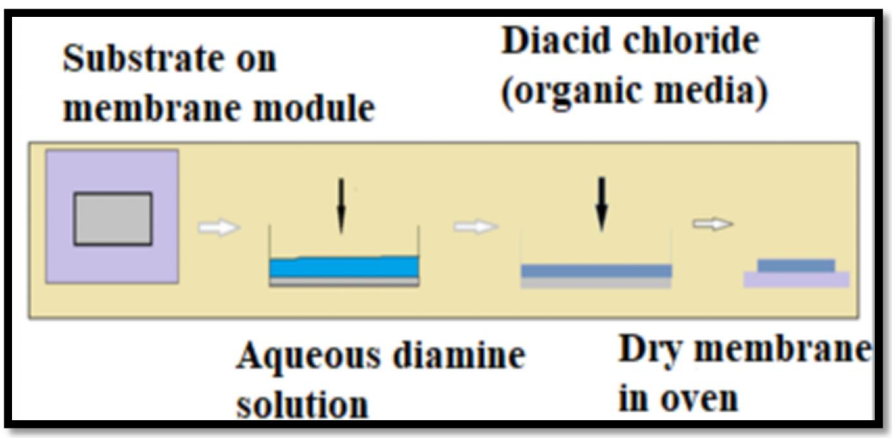

FIGURE 6: INTERFACIAL POLYMERIZATION

STRECHING

First in 1970; this method was used to synthesize polymeric membrane. This is non solvent technique.

The polymer is heated above its melting point and expelled to form a thin sheet with no use of solvent in fabrication process. Further force out the polymer to give membrane porosity. Porous structures are formed from amorphous region and crystalline region make polymeric membrane strong. Porosity and strength of membranes can be controlled by amorphous and crystalline region or by choice of particular polymer according to desired properties. Mostly two types of stretching are followed by cold stretching and hot stretching. Cold stretching is accountable for crystallization of membrane and hot stretching is utilized for development of pores on membrane surface. The process is cost effective as no additional solvent for emulsion preparation and coagulation is used. But high cold and hot temperature is compulsory to perform the process. [20]

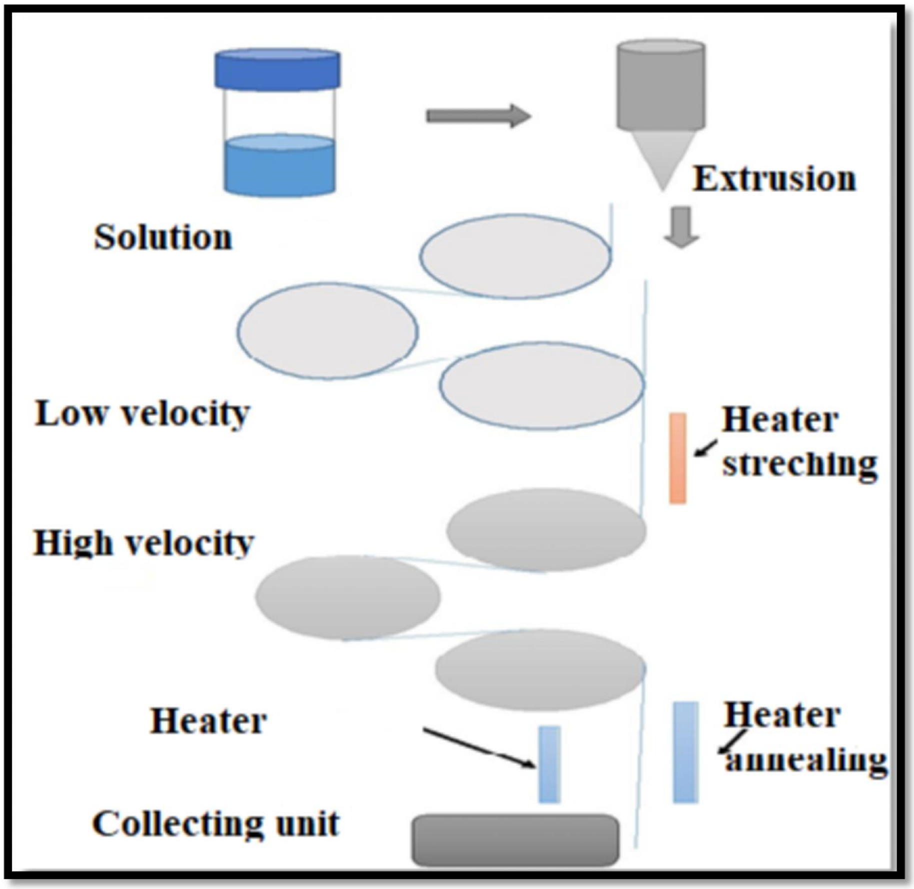

FIGURE 7: STRETCHING

ELECTROSPINNING

Electro spinning is an advanced technique as compared to other methods. First, prepared Polymer solution introduced in syringe. When high electric voltage is applied to the polymer solution when it's ejected from a syringe and cast on a collector. Solvent evaporated when polymer solution moves from needle to collector, polymer needed time when move from syringe to collector, after sometime dry membranes formed. By changing the needle shape and collector the structure of membrane also changed. [20]

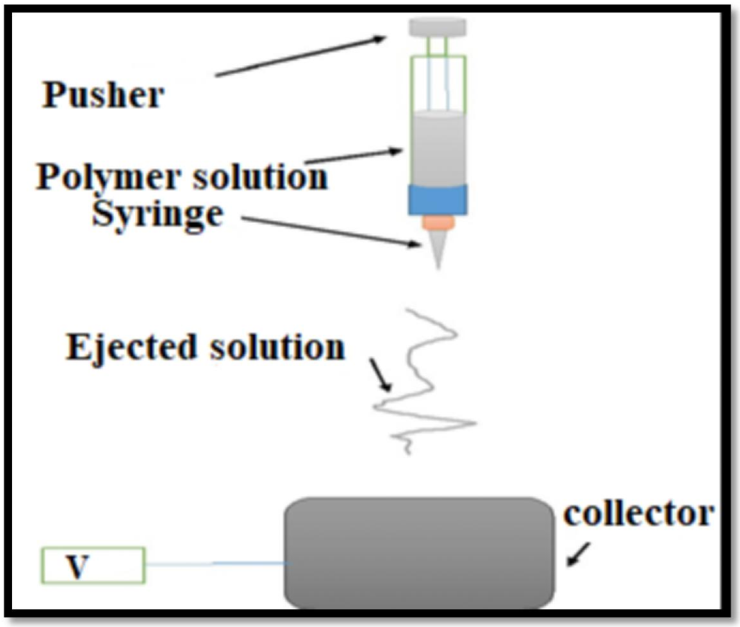

FIGURE 8: ELECTROSPINNING

TRACK ETCHING

A track etched polymeric membrane was first formed in 1970. Ionic radiation is used to engrave the membranes. Polymeric films are exposed to radiation in reaction, straight linear trail created over the X-rayed film or membrane. The porous membrane with desired property can be achieved by controlling density

and pore size.[20]

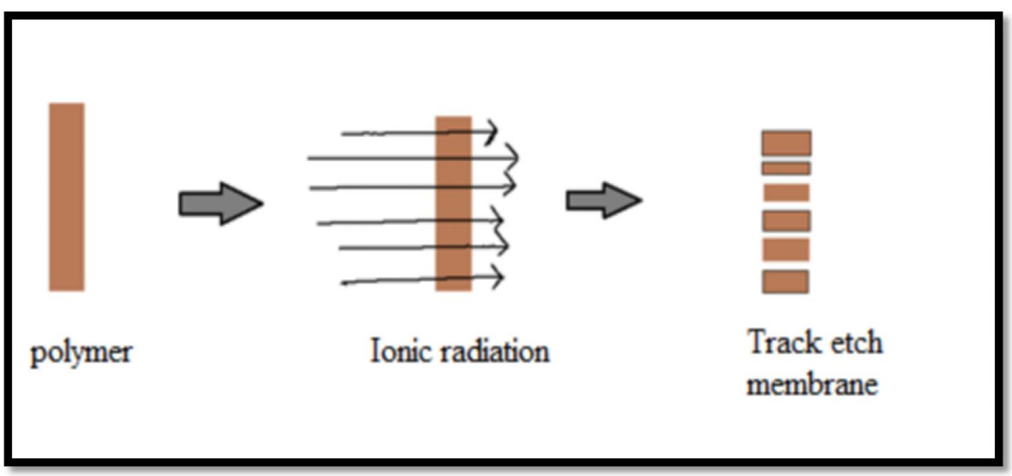

FIGURE 9: TRACK ETCHING

TECHNOLOGIES FOR OIL WATER SEPARATION

From past few decades, many novel technologies used for separation of oil water emulsion. Many membranes have been developed to be utilized in water filtration techniques for oil water separation. In this era new techniques are successfully evolved but these few are extremely used. [20]

MICROFILTRATION

Microfiltration is an attractive method for clarification of liquid, generally used in wastewater treatment. Widely used in separation process and to purify the water for drinking purpose. Macromolecules, colloids and particles are easily removed from water. Microfiltration is a pretreatment process to nanofiltration and reverse osmosis, used to enhance the removal of organic material from solution. This filtration technique separate particles in the range of 0.1-0.2μm and average pore diameter is 0.1-10μm. separation based upon the sieving process; the applied pressure is less than 2 bars. Many pharmaceutical and food processing industries used this method due to low cost and easy processing. [21]

INSTRUMENTATION

The equipment may differ dependent on category of microfiltration like

- Dead-end filtration
- Cross-flow filtration
- Tangential flow filtration

According to filtration application particular further component also comprised

- Pre-treatment process
- Post-treatment process
- Cleaning system
- Data acquisition system

General instrumentation of microfiltration contain following components

- Membrane module
- Feed pump
- Pressure gauge
- Flow meters
- Valves
- Membrane housing
- Tubing and fittings

- Control system
- Monitoring instrument [22,23]

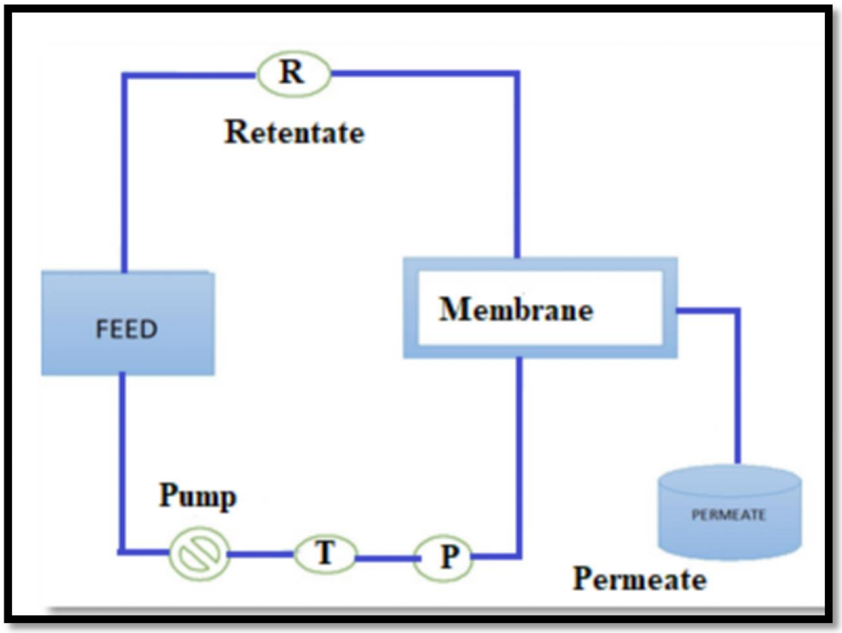

FIGURE 10: MICROFILTRATION

ULTRAFILTRATION

Ultrafiltration is the most dominant method for low energy consumption. It is used to remove suspended impurities, viruses, organic molecules, macro particles, harmful microorganisms from water but unable to remove inorganic material. It is a technique in which water passes through semipermeable membrane. Solid and higher weight molecules remain on one side and small molecules with water pass through the solution. Pore size is in the range of 0.1-0.01 micron. About 90% of pathogens and impurities can be removed by this method. Proper cleaning maintenance is crucial to prevent fouling. [24]

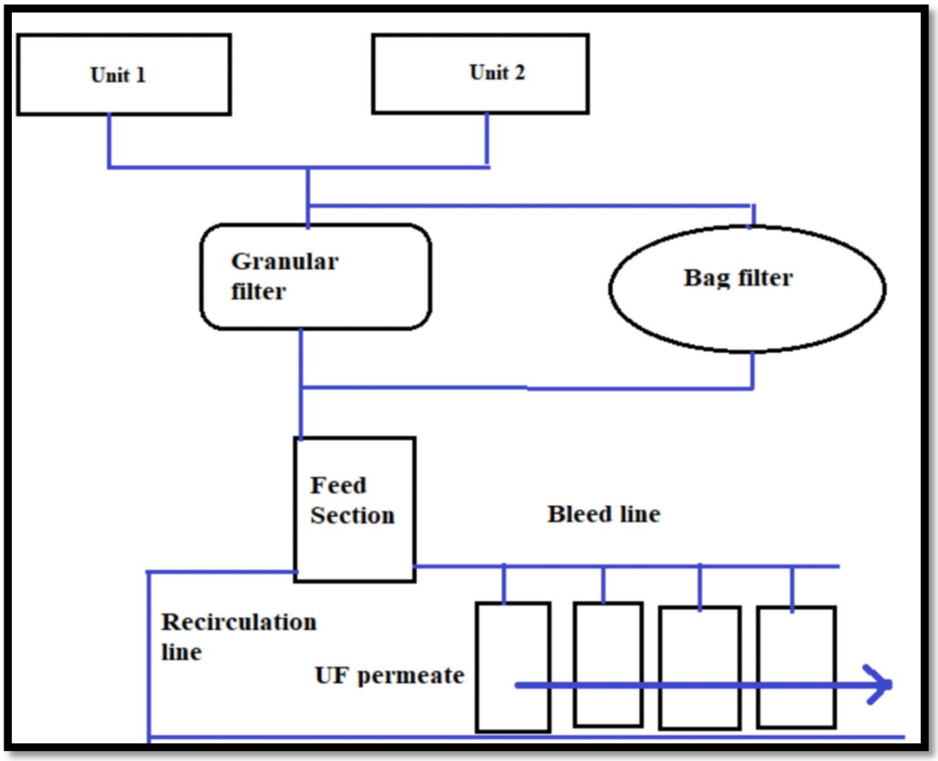

FIGURE 11 : ULTRAFILTRATION

NANOFILTRATION

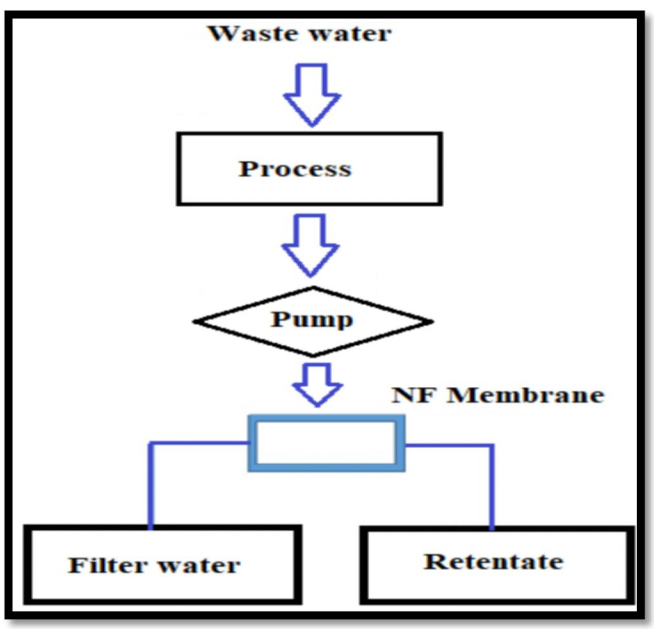

FIGURE 12: NANOFILTRATION

In nanofiltration no pretreatment is required. The NF membranes pore size range from 0.01 to 0.001. During filtration, pressure is applied to pass the contaminated water through the membranes. A 0.001-micron size impurity can be removed from water. All bacteria, viruses, divalent and 90% monovalent ions can also be removed from water. NF and RO are similar in design but different in percentage of removal. NF is used in many application-like textiles, recycling of acid solution wastewater treatment. [25]

INSTRUMENTATION

The instrumentation system of nanofiltration system is same as microfiltration system but monitoring system may vary because of its deep monitoring include four meters

- Conductivity meter
- Ph meter
- Turbidity meter
- Particles counter

Pre-treatment system further have two units

- Coagulation and flocculation units
- Sedimentation and filtration units

Post treatment system divided to 2 categories

- Disinfection unit
- Remineralization units

Data acquisition system analyze the data

Cleaning and sterilization of the system done by maintenance system. [26, 27]

FORWARD OSMOSIS

In FO filtration, solvent moves from a lower concentration region to higher concentration region. When, Raw or unfiltered liquid is passed through the FO membranes, 50-95% of water purified by this method. The membrane also has anti fouling properties. This process depends on osmotic pressure and needs less energy than other water treatment methods like hydraulic pressure method. [28, 29]

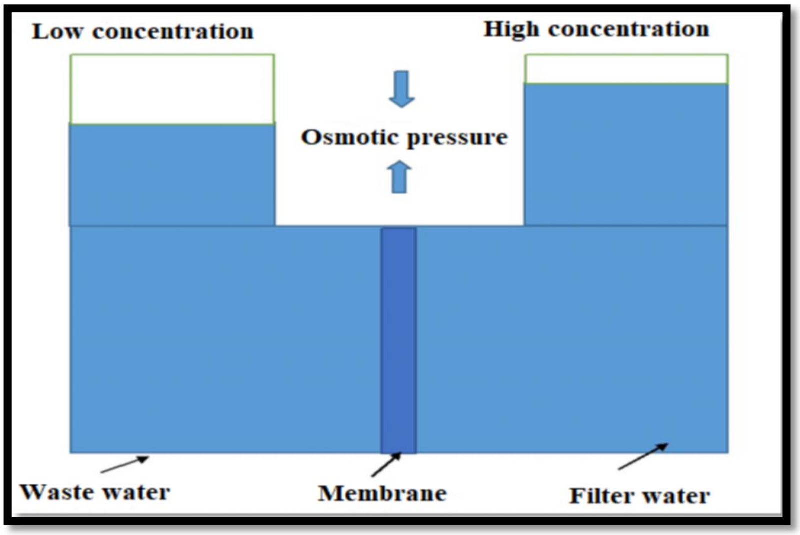

FIGURE 13: FORWARD OSMOSIS

REVERSE OSMOSIS

A semipermeable membrane is used to remove contaminants from unfiltered or raw water. Reverse osmosis also removes microorganisms and leaves pure water behind only. Water moves from higher concentration to lower concentration. When it passes through a filter the contaminants cannot pass through the filter. 99% of all contaminants can be removed even particles with 0.01-micron size can easily filtered by this method. It converts hard water into soft water at high pressure. The main disadvantage of RO is membranes fouling and high cost. [30]

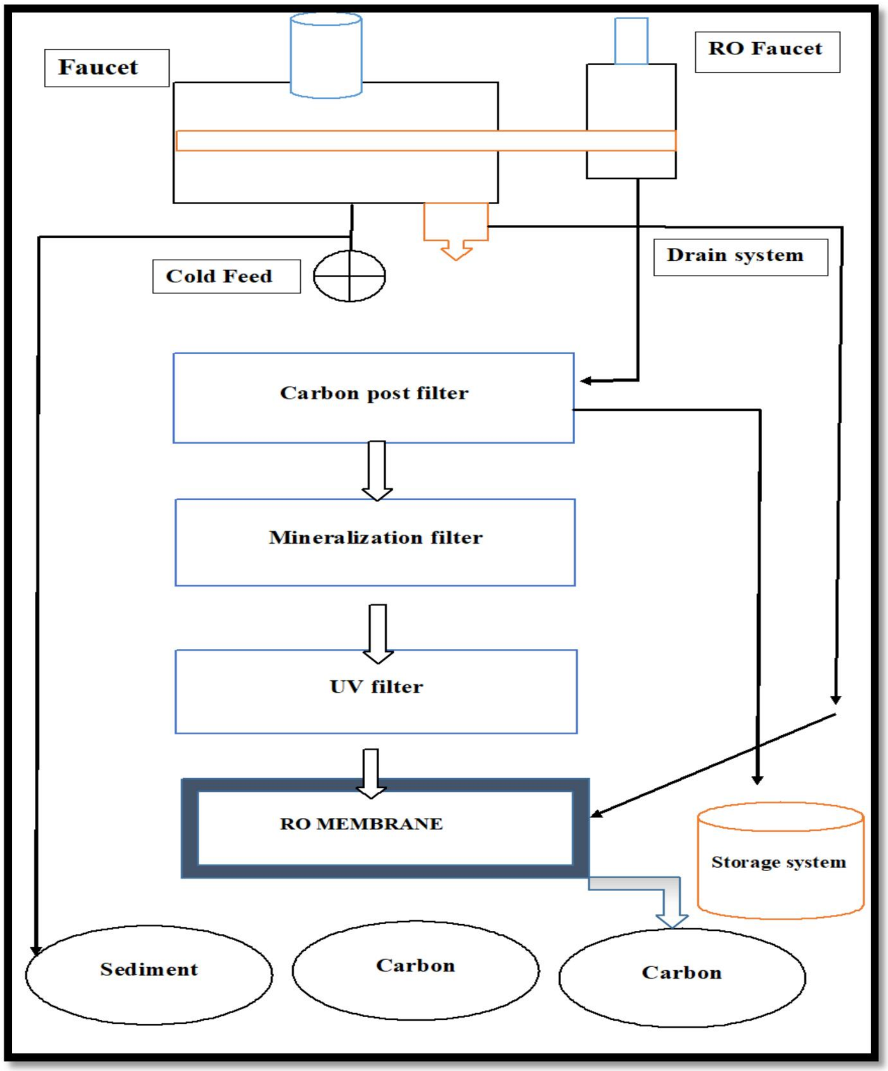

FIGURE 14: REVERSE OSMOSIS

CONCLUSION

This article reviews the techniques for creating membranes and their modifications for the separation of water-oil emulsions using commercial polymers like cellulose and other materials. It is recognized that there isn't a single altering method that reliably makes great results possible. In fabrication methods compared to interfacial polymerization and track etching, the phase inversion approach is more reliable. The Electrospinning and stretching techniques, however, cannot be disregarded. But, Electrospinning requires a significant amount of energy for membrane molding. Reverse osmosis removes 99 % of contaminants and nanofiltration removes 90 % of monovalent ions and pathogens, however membrane fouling is typically the main obstacle in filtration techniques.

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