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Comparative Study of Methylene Blue Dye degradation by Ultrafiltration and Micellar Enhanced Ultrafiltration Membrane

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ABSTRACT: Ultrafiltration is a promising, environmental-friendly alternative to the physicochemical based Industrial Effluent. This research was done to know the feasibility for application of Magnetic Stirred UF cell as a clean technology for treatment and reclamation of dye house wastewater. The operating transmembrane pressure is in the range 1-2 kg/cm² and feed pH was 7, (as the reading were for blank). The membrane used is a flat sheet type made of polysulfone. It has a surface area of 15.90 cm². The characterization of effluent is based on Standard Method. Further works involve the characterization of dye concentration and colorant and their removal enhanced by Micellar Enhanced Ultrafiltration.

Therefore, the prior aim remains to not consider wastewater as a nuisance and focus on perceiving towards a resource not to be wasted. The UF and MEUF method was able to successfully extract the reactive dyes from an aqueous solution. For RR218 and MB dye, the maximum removal of dye rejection was 60.7% and 95.8% respectively by UF and 72.47% and 98.93%, respectively. By varying the RPM, observed dye rejections for RR 218 and MB for UF(without surfactant) by varying the RPM were 64.66% and 96.16% respectively.

Similarly the observed dye rejection for RR218 and MB for MEUF (with surfactant by varying the RPM were 74.66% and 99% respectively. The recovery of MB was observed to be more as compared to RR218.

KEYWORDS: Industrial Effluent, Magnetic Stirred UF, polysulfone membrane, Methylene blue, fouling, Micellar Enhanced Ultrafiltration, resource

I. INTRODUCTION

Increasing industrialization trend in the worldwide has resulted in the generation of industrial effluents in large quantities with high organic content, which if treated appropriately, can result in a significant source of energy. Industrial wastewater contains large amounts of suspended material, through the efficient separation membrane these suspended solids and turbidity of the wastewater come close to zero. In addition, due to the wastewater contains toxic substances, which easily lead to sludge swelling phenomenon occurs at the membrane separation, not resorted to water quality is affected Water is one of the most important components which are essential for life-line. Water is required for production of electricity, thermal energy, nuclear energy and growing bio-fuels. Irrigation in agriculture sector needs large quantity of water. Industries need water for different manufacturing processes. Fresh and safe water is needed for maintaining healthy life and healthy environmental conditions. But fresh water on the earth is decreasing very fast. Pressure is increasing on fresh water because of increasing population, urbanization and industrialization. So, reuse and recycling of water has become necessary. Government of different countries has become alert for this problem and are making strict environmental norms and ensuring compliance to save the situation. Investments and research in water sector are growing. As a result, many technologies for the water preservation and purification have been emerged. Industries have usually different production and large changes in product categories, which increase the difficulty of

industrial wastewater treatment. Industrial wastewater treatment methods commonly used chemical and biological methods. Among these methods, biological treatment is currently widely used in industrial wastewater treatment, which is the most economical and environment friendly. Every method has become the focus of research and application. Water released from textile industry is either used for irrigation purposes or it runs off into natural sources of water. Basic and reactive dyes are gently used in the textile industry because of their bright colors, being water soluble, easy to apply fabric and being economic.

The wastewater produced by the leather industry is considered to be one of the most contaminated wastes, since there is a considerable amount of organic material (mainly dissolved fat, protein, keratin, etc.) and inorganic chemicals (various salts, such as NaCl, Na₂SO₄, CaOH, etc)

The three main characteristics of effluent are classified below.

1. **Physical Characteristics:** Turbidity, Colour, Odour, Total solids, Temperature
2. **Chemical Characteristics due to Chemical Impurities:** Chemical Oxygen Demand (COD), Total Organic Carbon, Nitrogen, Phosphorus, Chlorides, Sulphates, Alkalinity, pH, Heavy Metals, Trace Elements, Priority Pollutants.
3. **Biological Characteristics due to Contaminants:** Biochemical Oxygen Demand (BOD), Oxygen required for nitrification, Microbial population

Classification of dye:-

1. Anionic dye: Direct dye, Acidic dye, Disperse dye 2. Cationic dye: Basic Dyes 3. Nonionic dye: Disperse Dyes

Some of the methods used for the removal of dyes are electrocoagulation, adsorption, enhanced softening, biosorption, UV-irradiated titania, Polyelectrolyte Enhanced Ultrafiltration, Reverse Osmosis and Nanofiltration are already registered as a good technique for the separation of several pollutants from wastewater. MEUF is a new technique used for the separation which is a step further than NF. MEUF can successfully remove toxic dye from wastewater.

II. LITERATURE SURVEY

Reverse osmosis (RO) in 2017 paper was shown to be effective at higher pressures (20–100 bar) and very small pore sizes (0.0001–0.001 microns), operating via diffusion mechanisms at 323 K. On the other hand, UF technology for wastewater treatment (2017 paper) performed best at 1–10 bar and 323–343 K using pores of 5–20 nm, with a preferential adsorption mechanism. In drinking water treatment (2013), UF at 2 bar and 2.8–24.1°C achieved 100% TDS and 98% COD removal with optimal conditions including pH 7.69 and conductivity of 15.3 mS/m. Earlier, in 2000, a combination of coagulation, adsorption, and UF under 1 bar pressure, pH 6, and 291 K achieved 82.7% COD removal and turbidity reduction.

In 2019 paper, ultrafiltration of oily wastewater at 100 bar and 333 K with a flow rate of 480 LPH achieved complete removal of oil content, TSS, and heavy metals. In the dairy industry (2012), UF operated at 1–10 bar, with pore sizes of 0.2–0.02 microns and flux between 30–300 L/m²·h, effectively rejecting proteins, polysaccharides, viruses, and macromolecules. Nanofiltration (2017) and microfiltration also contributed to wastewater treatment; nanofiltration worked best at 7–30 bar with 2–5 nm pores and electrostatic hydration, while microfiltration was effective between 100–400 kPa and pore sizes of 50 nm to 10 microns through sieving and adsorptive mechanisms. Finally, the treatment of distillery spent wash (2009) using UF and RO at 20 atm showed excellent performance with up to 99.7% sulphate, 97.9% COD and SS, and 96.8% TDS removal, showcasing the robustness of membrane technologies across industries.

III. METHODOLOGY

Ultrafiltration (UF): Ultrafiltration is a pressure-driven membrane filtration technology used to remove suspended solids, colloidal particles, and high molecular weight contaminants from water. It operates using semipermeable membranes with pore sizes typically ranging from 0.005 to 0.1 microns, effectively filtering out particles such as bacteria, viruses, proteins, and other macromolecules, while allowing water and smaller dissolved substances to pass through.

The membranes used in UF can vary based on the application, including micellar-enhanced and surfactant-based membranes for heavy metal and complex pollutant removal. These membranes are classified by their Molecular Weight Cut-Off (MWCO), which determines the size of the particles they can retain. For instance, a 100,000 Dalton MWCO membrane can retain particles approximately 0.05 microns in size.

UF systems typically use hollow fiber membranes through which feed water flows, either inside or around the fibers. Larger contaminants are retained, while treated water passes through. UF is similar to reverse osmosis, nanofiltration, and microfiltration but differs in the size range of molecules it filters.

Maintenance of UF systems involves regular cleaning to prevent fouling:

- 1.Organic contaminants: cleaned using medium alkaline detergent (0.6–1%) for 40–60 minutes.
- 2.Inorganic contaminants: cleaned using citric acid (up to 3%) for 1–3 hours; other acids like HCl or HNO₃ may also be used.

Key Benefits of Ultrafiltration:

- 1.No need for added chemicals like coagulants or disinfectants
- 2.Reliable removal of particles and microbes
- 3.Compact and automated system design
- 4.Consistent water quality
- 5.Environmentally friendly process

Ultrafiltration is an effective solution for treating water in both industrial and municipal settings, especially when removal of pathogens and turbidity is required without affecting dissolved solids.

Micellar Enhanced Ultrafiltration (MEUF) – is a surfactant-based membrane separation technique used to remove a wide range of contaminants from polluted water, including **metal ions, anions, and organic compounds** such as phenols and dyes. MEUF is an energy-efficient alternative to high-pressure processes like reverse osmosis (RO), operating at **lower pressure with higher membrane permeability**. MEUF uses **surfactants** that form micelles when their concentration exceeds the **critical micelle concentration (CMC)**. These micelles trap pollutants like **heavy metals and anionic contaminants** through electrostatic interaction or solubilization. The **metal-surfactant complexes** formed are large enough to be retained by **ultrafiltration membranes**, allowing clean water to pass through.

Pollutants Removed via MEUF: **1.Cationic metals:** Cu²⁺, Zn²⁺, Cr³⁺, Mn²⁺, Co²⁺, Pb²⁺, Ni²⁺, etc. **2.Anions:** chromate, phosphate, nitrate, permanganate, etc. **3.Organics:** phenol, nitrophenols, catechol, aniline, chlorophenol, etc. **4.Mixed pollutant systems** (both cations and anions) can be treated using **mixed micelle systems**.

Advantages: **Lower operating pressure** than RO, **Effective removal** of trace organics and heavy metals, **Selective targeting** of pollutants, **Less energy-intensive** and more economical, Possibility of **reusing surfactants** to reduce cost and environmental impact

Challenges: **High surfactant concentration** in treated water can degrade quality, **Surfactants are expensive**, so recovery and reuse are essential

Key Factors Affecting MEUF Performance: **Membrane properties:** Type, Material, MWCO, **Surfactant properties:** type (ionic/non-ionic), dosage, surfactant-to-solute ratio, **Operating conditions:** pH, temperature, pressure, filtration mode

IV. FINDINGS / RESULTS

The cell was pressurized using nitrogen. The membrane was compacted using distilled water for 24 hr. During membrane compaction, water flux was measured continuously until constant flux was achieved. Water flux was measured at different operating pressures, and from the slope of the flux vs. pressure curve, the membrane permeability (Lp) was determined. Operating pressure was maintained at 1kg/cm² at room temperature. For dye, feed solution for each experiment was prepared by weighing specific amounts of dye and surfactant and dissolving them in distilled water.

After filling the feed solution, the cell was pressurized at the operating pressure using a pressure regulator. Experimental setup was equipped with a magnetic stirrer to achieve the operating shear rate. The operating pressure was applied by air compressor. The total active area of the membrane is 15.90 cm^2 . The permeate from the bottom cell was collected, where the cumulative volume was continuously measured. The permeate concentrations were measured spectrophotometrically. After each run, the cell and the membrane were washed thoroughly with distilled water. The membrane permeability was checked. All experiments were conducted at room temperature ($32 \pm 2^\circ\text{C}$).



Experimental Setup

Filtration experiments are carried out in the 50 Millipore UF cell stirred batch with feed containing
1. Only dye
2. Mixture of dye and surfactant

Experimental procedure with absence of surfactant

- Take 40ml of 10ppm solution in the cell and run the setup.
- Discard the first 10 ml of permeate solution.
- After every regular intervals record the volume of permeate and ultimately find the permeate flux.
- Record the concentration of feed and concentration of permeate.
- Carry out the same procedure for different concentrations.

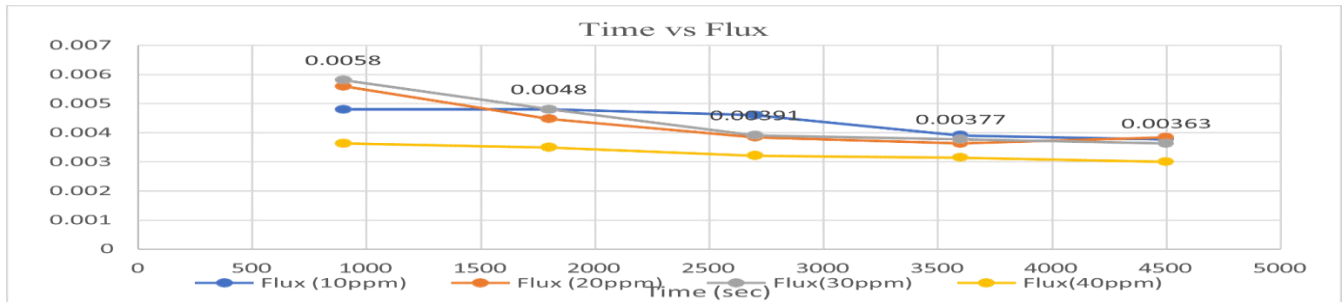
Experimental procedure with presence of surfactant

- In 40 ml of 10ppm solution add 6ml of SDS surfactant and let it rest for a period.
- Transfer the dye-surfactant mixture in the cell and run it.
- Again discard the first 10 ml and, after regular intervals, record the permeate and calculate flux rate.
- Also note down the concentration of feed and concentration of permeate.
- Carry out the same procedure for different concentrations.

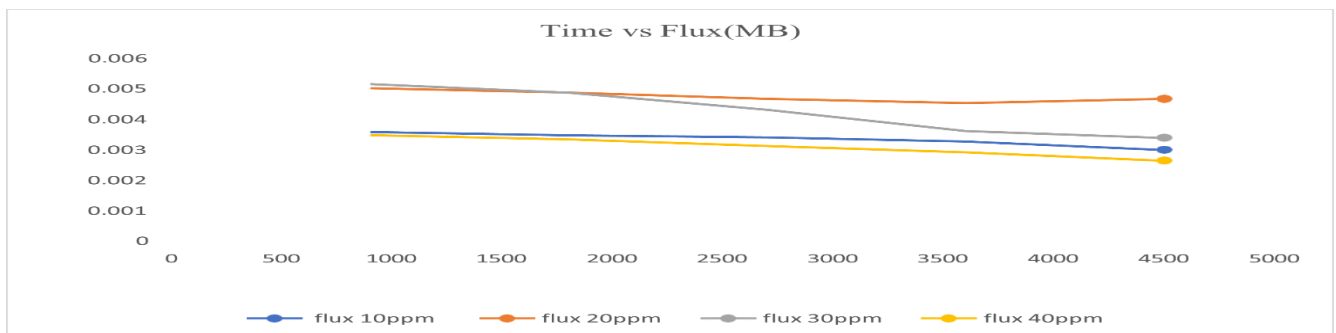
V. EXPERIMENTAL RESULTS

1. Using a UV-visible spectrophotometer, it was discovered that the reference wavelengths for the dyes Reactive Red 218 and Methylene Blue were 520nm and 665 nm, respectively. The absorbance was measured for a range of known dye solution concentrations based on the reference wavelength. Using these values, the calibration curve for both dyes was created. We can quickly determine any unknown dye solution concentration using this calibration curve

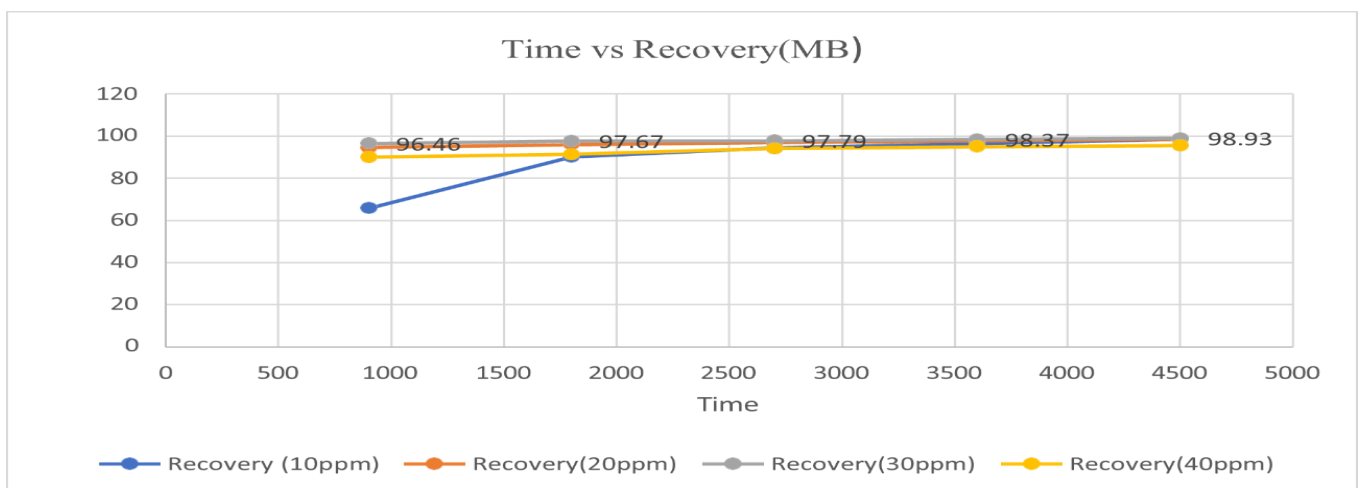
2. Variation Of Permeate Flux During Ultrafiltration Of Dye Solution In Absence Of Surfactant



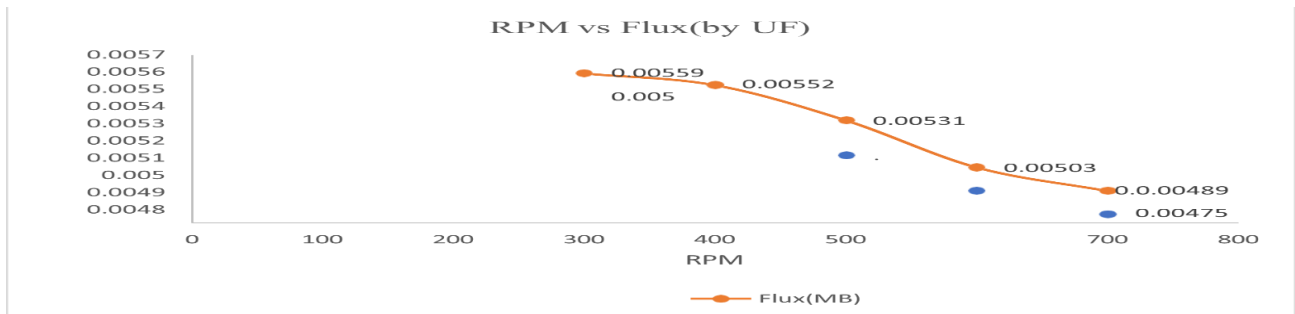
3. Variation Of Permeate Flux During Ultrafiltration Of Dye Solution In Presence Of Surfactant



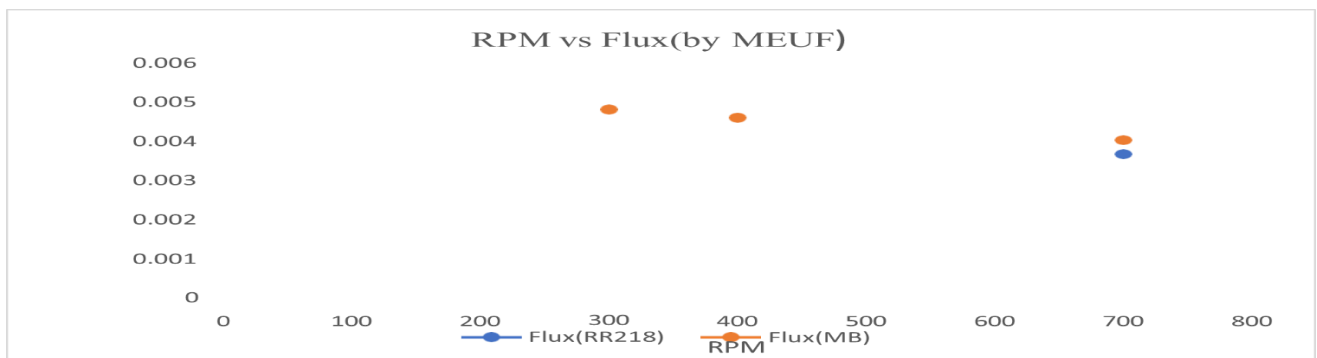
4. Variation Of Observed Dye Rejection During Ultrafiltration Of Dye Solution In Presence Of Surfactant



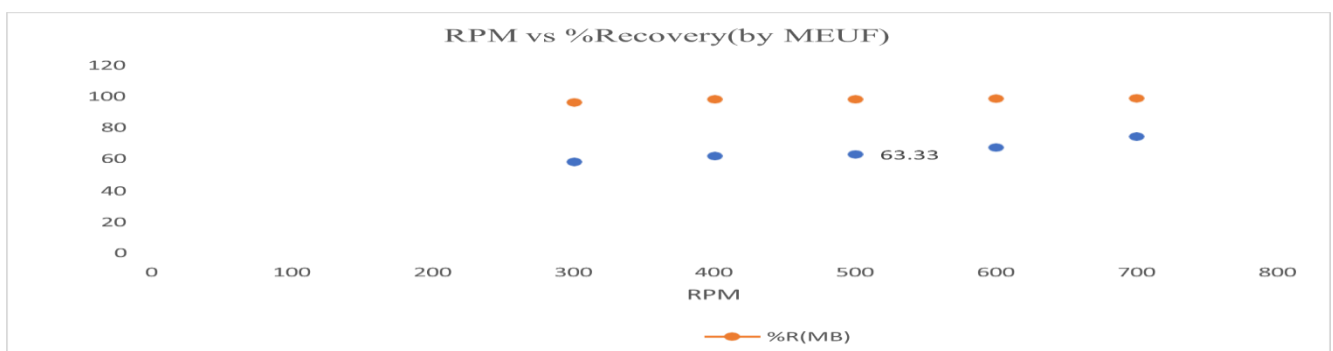
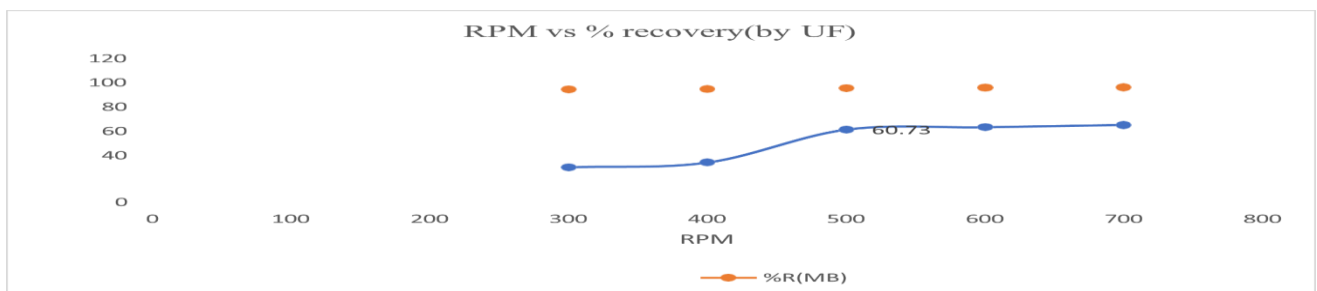
5. VARIATION OF PERMEATE FLUX DURING UF AND MEUF BY VARYING RPM :
observation of flux of 30ppm solution MB by UF by varying the RPM



6. Observation of flux of 30ppm solution MB by MEUF by varying the RPM



7. Variation Of Observed Dye Rejection By UF AND MEUF By Varying RPM



VI. CONCLUSION / SUMMARY

Magnetic Stirred Ultrafiltration Cell is highly recommendable for the removal of all those factors that make textile effluent a nuisance. A proposal for a new concept of water management in the textile industry including recycling. The performance of this membrane towards the treatment of an industrial textile wastewater sample are determined in terms of the permeate flux and the pollutants removal. The polysulfone UF membrane renovation was achieved using an alternative protocol based on acid-basic washing. MEUF could prove one of the alternate methods that promising higher rejection of contaminants from effluent. The knowledge of surfactant selection and MEUF process system is very important to enhance the effectiveness of this of this process. Considering the positive results of the experimental studies, the implementation of the technique on the industrial scale is considered technically and economically feasible, and it could reduce the freshwater drain and the wastewater discharge by half.

1.The parameters of ultrafiltration exhibited a significant variance The experimental results obtained from the blank readings gave a permeate flux of about 0.000001 (L/sec.kg) . The operating transmembrane pressure was in the range 1-2 kg/cm² and feed pH was 7, (as the reading were for blank). The membrane used was a flat sheet type made of polysulfone with a surface area of 15.90 cm². Expectations behold on this membrane process to be suitable for advanced treatments of textile wastewater for reuse.

2.The reported dye rejections and permeate flux characteristics of MB dyes under various experimental conditions are investigated and analysed. The UF and MEUF method was able to successfully extract the reactive dyes from an aqueous solution. For MB dye and RR218 dye, the maximum removal of dye rejection was 60.7% r by UF and 72.47% MEUF respectively.

3.By varying the RPM, observed dye rejections for MB for UF (without surfactant) by varying the RPM were 96.16% respectively. Similarly the observed dye rejection for MB for MEUF (with surfactant by varying the RPM were 99% respectively.

4.Ultrafiltration membrane treatment could be considered as one of the promising technologies for the treatment of Industrial Effluent. The research highlights the social dimension as a tool, a lens through which wastewater management and reuse can take on new dimensions.

MEUF have more rejection coefficient as compared to without surfactant ultrafiltration process. The permeate concentration is reduced to greater extent by MEUF than normal ultrafiltration.

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