

# WITHDRAWN: An integrated process of methanol coagulation and side-stream membrane bioreactor for the treatment of rice gruel wastewater

**Shaik Nazia**

"RMIT University"

**Karishma Mishra**

Indian Institute of Chemical Technology

**Veeriah Jegatheesan**

"RMIT University"

**Suresh K Bhargava**

"RMIT University"

**Sridhar Sundergopal**

[sridhar11in@yahoo.com](mailto:sridhar11in@yahoo.com)

Council for Scientific and Industrial Research Natural Resources and the Environment

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## Research

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## EDITORIAL NOTE:

The full text of this preprint has been withdrawn by the authors while they make corrections to the work. Therefore, the authors do not wish this work to be cited as a reference. Questions should be

directed to the corresponding author.

# Abstract

Significant demand for water supply was to expect forthcoming decades. Production of reusable water from industrial and domestic wastewater is a feasible, cost-effective, and significant positive benefit to the environment. In the present study, the domestic rice gruel wastewater (RGW) treated with aqueous methanol coagulation integrated aerobic membrane bioreactor (AMBR). Hydrophilized (HF) spiral wound 5 kDa ultrafiltration (UF) membrane used in the bioreactor for the effective removal of pollutants from RGW. Furthermore, the RGW pretreated with various coagulants such as methanol, ethanol, and HCl. The obtained pretreated RGW subjected to the HF-UF 5 kDa side stream AMBR for reusable water production. The experiments conducted to determine the turbidity, conductivity, total dissolved solids (TDS), and chemical oxygen demand (COD) found to be 96%, 91%, 91%, and 94.6%. The overall process was feasible, compact, environmentally free, cost-effective, eco-friendly.

## Introduction

Water demand is officially looking for few substitutional resources to satisfy for enhancing affirmation. Due to the augmenting population, urbanization, population growth, expansion of integrated agricultural, etc. [1]. Hence, it has become a particular interest in arid and water-scarce countries such as Iran, India, Italy, Iraq, Portugal, etc. [2]. Most of the water resources contaminated by domestic and industrialization for urban development. The treatment of wastewater is an essential factor for environmental application, whereas domestic wastewater is considered a strategic method for reusable water production.

Moreover, two-thirds of the entire world population consumed rice as a staple food, mostly 95% of rice consumed by oriental countries like India, Bangladesh, China, Japan, Korea, Philippines, Malaysia, Indonesia, Thailand, Sri Lanka, etc. The cooking of rice produced large rice gruel (RG) and discharged to land as wastewater [3, 4]. The RG is one of the domestic wastewaters; it consists of a significant amount of starch, protein, lipids, and suspended solids that need to separate before discharge into water sources. Amylose and amylopectin were two components of starch with an average range molecular weight of 5,200 (5 kDa) to 872,300 (870 kDa). In contrast, Amylose is a long, straight starch molecule that does not gelatinize during cooking. In comparison, amylopectin is a highly branched starch molecule responsible for making rice viscous and sticky. It also evolves a foul odor due to bacterial growth when exposed to the environment.

Hence, the Rice gruel wastewater (RGW) is directly discharged into water bodies by restaurants, hotels, hostels, households, monasteries, etc. [5, 6]. Most conventional wastewater treatment processes such as ion exchange, adsorption, electrochemical treatment, chemical precipitation, adsorption, solvent extraction, and flotation used to extract the significant component starch present in the RGW. However, the conventional processes have some limitations due to the high-power consumption, considerable space requirements, additional chemicals, or solvents for separation and phase change [7]. Therefore, there is a need to develop an alternative technology for the treatment of domestic wastewater reclamation.

Membrane separation processes such as reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), microfiltration (MF), membrane bioreactor (MBR) for the treatment of various domestic wastewaters [8]. Among those, MBR is widely-enhancing technology for domestic wastewater treatment in aerobic and anaerobic conditions. The anaerobic treatment system can remove chemical and biological oxygen demand and carbohydrates, proteins, and other constituents. The generation of biomethane from the anaerobic treatment can be another significant product as an energy supplement. However, anaerobic processes have their limitations, including foul production, odor, low reduction in turbidity, and total dissolved solids (TDS), etc. Hence, most researchers have used aerobic treatment to supply enough oxygen to support the bacteria, reducing organic and inorganic compounds.

MBR in aerobic conditions can extensively use for sustainable and energy-efficient for domestic wastewater such as laundry, kitchen [9], Bathroom [10], washing machine water for reproducibility of water. The aerobic membrane bioreactor (AMBR) can be further integrated with the conventional process to achieve high energy consumption, massive operation, and less maintenance. A very few studies were reported on domestic RGW by AMBR. Mananta and Bhattacharya extracted the rice starch from parboiled rice starke in the thermal degradation process [11]. Choudhary et al. used the electrocoagulation process to treat rice mill effluent [12].

From the literature survey, this is the first kind of study for the treatment of RGW using coagulation processes integrated with AMBR. Pretreatment of RG with different coagulants such as methanol, ethanol, and HCl for sedimentation of heavy suspended solids. Further, the RG treated with HF - UF AMBR for reproducibility of potable water. Experiments conducted to estimate the turbidity, chemical oxygen demand (COD), TDS, pH, and conductivity on membrane performances. From the experimental results, the process was scaled up and calculated the cost of the process.

## Materials And Methods

### 2.1. Material

Polyethersulfone (PES) polymer purchased from Solvay, Vadodara, India. Polyvinyl alcohol (PVA), polyethylene glycol (PEG) of different molecular weights, ethanol, methanol, hydrochloric acid (HCl), glutaraldehyde (GA) and dimethylformamide solvent (DMF), sodium hydroxide (NaOH), ethylene diamine tetraacetic acid (EDTA), sodium lauryl sulfate (SLS), and sodium metabisulphite (SMBS) procured from SD. Fine Chemicals Ltd., Mumbai, India. The non-woven polyester fabric purchased from Miki Tokushu Paper Mfg. Co. Ltd., Japan, to be used as the support for casting the HF-UF membranes. Hi-Media Lab. Pvt. Ltd supplied the nutrient broth and agar, Mumbai, India. Indigenous HF-UF membrane synthesis spirally wound with Permionics Pvt. Ltd., Vadodara, India. Glass wear such as a conical flask, beakers, Petri dishes, and measuring cylinders used to prepare the agar broth and analyze sample collected from Vasco scientific, Hyderabad, India. Equipment such as autoclave (Equitron Medica Instrument, Mumbai, India), laminar flow chamber (Lab Tech, Mumbai, India), weighing machine (Sartorius, Hyderabad, India), Refractive Index (AntonPaar, Type: Abbemat 200, Mumbai, India) and incubator supplied by

Secunderabad India. The hardware items such as aerator, pressure gauge, valves, pump, T – joint, telfon, cotton, tubing, parafilm, strips, and the MBR system supplied by SVS water solution for experimental setup, Hyderabad, India. Deionized water for water bath prepared using the laboratory ultrapure cascaded RO system.

## 2.2. Methods

### 2.2.1. *Synthesis of HF-UF 5 kDa membrane*

HF-UF membrane synthesized using the immersion precipitation method by phase inversion technique. The blend polymer solution for casting prepared by adding the 2 wt% of PVA and 23 wt% of PES and 0.5 mL of GA to the 74.5 mL of DMF solvent (wt/vol as per polymer weight) under continues stirring for 12-18 h at 50 °C. The mixture was kept stagnant at room temperature ( $30 \pm 2$  °C) to remove excess bubbles in the polymer solution. The bubble-free solution was poured on the polyester non-woven fabric support fixed on a glass plate using the doctor's blade for the desired thickness and immediately immersed in the non-solvent bath (pure water) ( $30 \pm 2$  °C) to obtain HF-UF 5 kDa membrane.

### 2.2.2. *Effect of molecular weight of PEG*

PEG with molecular weights of 6,000 and 4,000 Da dissolved in deionized water to prepare 1 L aqueous solutions to assess molecular weight cut off (MWCO) and rejection of solvents through synthesizing HF-UF membrane. Rejection measurements were performed at a 3 bar pressure using the PEG solution as the basis for feed. The concentration of feed, permeate, and retentate solution determined via Refractive Index.

### 2.3. *Sample collection*

RGW used in the present work obtained from the Akshaya Patra Foundation, Hyderabad, India. Initially, the sample pretreatment with alcohol and HCl before subjected membrane filtration. The overall experimental manifold provided in (Fig. 1a).

### 2.3.1. *Treatment of cold and hot RGW by spiral-wound HF-UF 5 kDa membrane*

RGW, which was at room temperature and warm temperature (80 °C), passed through the spiral wound UF membrane with an area of 1.2 m<sup>2</sup> for 3 h and the feed, permeate, and retentate sample used for the physicochemical study.

### 2.3.2. *Pretreatment of RGW with coagulants*

Wastewater treatment processes involve a series of physical, chemical, and biological treatment techniques that further classified into the pretreatment, primary and secondary treatment. In the present study, the coagulation pretreatment for RGW domestic wastewater pretreated for soluble removal of organic matter. The coagulation step was carried out by alcohol and acids to stabilize the starchy

colloidal content, eliminating moderate levels of TDS, COD, pH, conductivity, and turbidity. During the pretreatment step, the hot raw RGW was allowed to cool at room temperature, and 6.5 L feed was collected in a container and treated with a 1% HCl solution. The reaction mixture was stirred at 250 rpm for about 30 min and allowed 2 h to sedimentation, as shown in (Fig.1b). The same experiments repeated with methanol and ethanol as pretreatment coagulants. Among that methanol, coagulant shows higher removal efficiency in suspended from RGW.

### *2.3.3. Experimental setup for spiral wound UF membrane*

After the preliminary pretreatment with the methanol, the supernatant liquid passed through the spiral wound HF-UF membrane module membrane area  $1.2 \text{ m}^2$  at 3 bar pressure using 300 gpd (gallons per day) pumps. The experiments performed continuously by measuring the permeate flux to time, whereas the concentrate was recycled back to the feed tank. The UF process flow diagram was provided in (Fig.1c) the pretreatment method and UF experimental system.

## *2.4. Preparation of culture and nutrient agar*

Microbial consortia developed to prepare a culture media using a nutrient agar and broth. The agar medium made by dissolving 28.0 g of agar in 1L distilled water and sterilized using autoclaved at a pressure of 15 lbs for 45 min by maintaining the temperature  $121^\circ\text{C}$  for sterilization. The agar medium was allowed to cool for 1 h at room temperature and poured into a petri dish under laminar airflow until it solidifies. The medium was subsequently streaked on the petri dish and kept in an incubator at  $37^\circ\text{C}$  for 24 h

### *2.4.1. Preparation of nutrient broth*

13.0 g of nutrient broth was uniformly mixed with 1L of distilled water and subjected to the autoclave for sterilization at  $121^\circ\text{C}$  using 15 lbs pressure for 30 min. The grown culture (50 mL) from nutrient agar was added to the nutrient broth and kept in the incubator for 24 h at  $37^\circ\text{C}$ . The culture was added to the feed tank and allowed to stay overnight for further microbial growth, which aid bacteria to adapt with the RGW environment.

## *2.5. Experimental setup and procedure for pretreatment coagulation and integrated AMBR*

In this experimental study, after the preliminary pretreatment of the RGW step with the chemicals (HCl, ethanol, and methanol), the supernatant was passed through the side-stream AMBR to remove suspended solids, turbidity, and color. Fig. 1d represents the process flow diagram AMBR, where the feed tank capacity of 2.5 L connected to the spiral UF membrane module with membrane area  $1.2 \text{ m}^2$  connected to 300 gpd pressure pumps. The module arranged in a cross-flow manner, and the permeate collected into the permeate tank, the retentate was fed back to the feed tank with the pressure gauge and control were fixed at the retentate line.

Initially, a mixed culture aerobic medium added to the pretreated RGW wastewater. A micro-bubble diffuser assembled in the feed tank to provide the oxygen and control the aerobic conditions for the growth of biomass. The feed fed to the membrane by maintaining the feed pressure of 3 bar throughout the experiments. Initially, feed, permeate, and retentate samples collected for the analysis. The operations were continued for 18 days in aerobic conditions to remove the TDS, color, conductivity, and COD.

### *2.6. Membrane characterization*

Indigenous membranes were characterized by fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD) analysis, and scanning electron microscope (SEM). For SEM studies, the membrane was cut into the liquid nitrogen and subjected to the SEM (JEOL JSM 5410, Japan) with a model number for 20 and 200  $\mu\text{m}$ .

The X-ray pattern of the membrane was determined by XRD D 5000 (NJ, USA) to understand the crystalline nature of the polymer membrane. The X-ray diffract gram was obtained by the Bragg's equation to determine  $2\theta$  valves of the polymer.

FTIR spectroscopy carried out using a Shimadzu, Japan instrument for analyzing the formation of new functional groups and intermolecular interactions after membrane formation.

### *2.7. Membrane fouling*

The membrane fouling caused by suspended particles, microbes, inorganic and organic components present in the feed that can accumulate, salts, and organic compounds present in the feed water collected on the surface of the membrane and pores. Therefore, the membrane fouling was reduced by removing the module from the system and cleans at regular time intervals after every batch experiment using chemical washing followed by water washing at low pressure. The chemical washing conducted using 1% citric acid, 1% NaOH + 0.5% EDTA + 0.1% SLS for 30 min followed by water wash (30 min) after acid and alkaline wash. After chemical cleaning, the scalant have been completely removed from the surface of the membrane [13, 14]. After chemical cleaning, the membranes stored in SMBS (0.5% w/v) aqueous solution to avoid further biological fouling and extend the life span of the membrane.

### *2.8. Analytical methods*

Raw industrial wastewater, pretreated supernatant (after coagulation), permeate samples were analyzed to pH, color, conductivity ( $\text{mS cm}^{-1}$ ), turbidity (FAU), TDS ( $\text{mg L}^{-1}$ ) according to the standard procedure for wastewater analysis. The sample pH determined through a digital pH-meter (model DPH-504) at room temperature. Color (Co-Pt), turbidity (FAU) analysis performed at (DR 800, HACH), TDS determined using TDS meter with model HM TDS 0-999, Hyderabad, India, and conductivity measured using model DCM900 conductivity meter obtained from Global Electronics, Hyderabad, India.

### *2.9. Mathematical tools*

### *2.9.1. Permeate flux*

During the separation process, the permeate volume determined by considering the active membrane area and time, as shown in Eq. (1).

**See equation 1 in the supplementary files section.**

Where  $J$  is the permeate flux ( $\text{L m}^{-2} \text{ h}^{-1}$ ),  $V$  is the collected volume of permeate (L) in time  $T$  (h), and  $A$  is the membrane area ( $\text{m}^2$ ).

### *2.9.2. Porosity*

We calculated the overall porosity ( ) of the membrane by gravimetric method, as defined in the following equation Eq. (2):

**See equation 2 in the supplementary files section.**

Where  $m_1, m_2$  is the weight of the wet and dry membrane respectively, whereas  $s_1$  is the surface area,  $\delta$  is the cross-section thickness, and  $\rho$  is the density of the demineralized water.

### *2.9.3. Rejection efficiency*

Rejection is another factor in which the membrane separation performance was evaluated by considering the turbidity, COD, and PEG rejection in the permeate by Eq. (3).

**See equation 3 in the supplementary files section.**

The percentage rejection denotes as  $R$ ,  $C_p$ , and  $C_f$  are the solute concentration in permeate and feed ( $\text{mg L}^{-1}$ ).

### *2.9.4. COD*

The quantity of the pollutants present in the permeate was determined after wastewater treatment is known as COD. The presence of higher organic contaminates presents in the water the higher value of COD. Hence, the COD can calculate from Eq. (4).

**See equation 4 in the supplementary files section.**

$B, S$  is the volume consumed with blank and sample preparation 8000 being the equivalent weight of oxygen per L;  $N$  is the normality of standardized ferrous ammonium sulfate solution;  $D.F$  and  $V$  specified as dilution factor and sample volume (mL).

## **Results And Discussion**

### *3.1. Membrane characterization*

### *3.1.1. Structural analyses by FTIR*

Fig.2a represents the FTIR spectra of PES blended PVA cross-linked with the GA membrane. The peak at  $1117.78\text{ cm}^{-1}$  and  $1435\text{ cm}^{-1}$  have attributed the ether ( $\text{C=O}$ ) and sulfonated ( $\text{SO}_2$ ) group of PES. Due to the stretching vibration of the aromatic ether. The peaks at  $1582.63\text{ cm}^{-1}$  denoted the aromatic benzene ring. In addition to this, the board peak at around  $3227\text{ cm}^{-1}$  indicates the starching vibration of the hydroxyl group of PVA. The formation of new acetol linkage was attributed at  $1070\text{ cm}^{-1}$ , representing the cross-linking between the GA and the hydroxyl group of PVA. The possible reaction mechanism provided in scheme 1.

### *3.1.2. SEM*

The morphology of surface and cross-section morphology of the HF-UF membrane provided in Fig.2b. The surface morphology of the membrane observed to be porous with uniform distribution of pores throughout the membrane. The blended PVA and PES substrate was interpenetrated into the polyester non-woven fabric support layer by forming a finger-like structure shown in Fig.2b. From surface and cross-sectional morphologies, the membrane successfully formed a porous layer on the support.

### *3.1.3. XRD*

The nature of the polymer membrane was studied by X-ray diffraction pattern, as depicted in Fig.2c. The membrane appeared semi-crystalline, where the amorphous nature was 0 to 37 on  $2q$  without intensity. On the other hand, the sharp peaks found to be 38 and 48 on  $2q$  represent the polymer's crystalline nature due to the crosslinker. Therefore, the HF-UF membrane shows semi-crystalline and aptly suitable for the study.

### *3.1.4. Effect of PEG concentrations on membrane compositions*

The membrane was passed through a 2 wt% of aqueous PEG solution to analyze the MWCO for the UF membrane. From Fig.3a, b it can be seen that a linear relationship with two different PEG solutions i.e., 4,000 Da & 6,000 Da. However, a higher rejection efficiency of 90% achieved with 4,000 Da of PEG solution, which accomplished with 2 wt% of the solution compared with 6,000 Da. Feed, permeate, and retentate refractive index shown in Fig.3c, where the refractive index for PEG 4,000 concentration lead to the highest %rejection, and when the MWCO of PEG was 6,000 Da, therejection decreased slightly. There was no further difference in the %rejection efficiency with changes in molecular weight. Hence, this experiment demonstrates rough ideation, on average MWCO of 5000 Da. The calculated value of the 5 kDa membrane's porosity was 34.68%, concluding that the membrane MWCO was 5kDa.

## *3.2. Experimental results for the treatment of RGW*

### *3.2.1. Effect of direct filtration using spiral-wound HF - UF membrane*

Experiments were carried out based on the feed temperature to know the membrane performances. Initially, 5 L of RGW without coagulation was fed directly to the spiral wound HF-UF membrane with an operating pressure of 5 bar at room temperature ( $28 \pm 2^\circ\text{C}$ ). From Table 1, the parameters, namely pH, TDS, turbidity, conductivity, and COD values in the permeate at room temperature found to be 3.34,  $56,330 \text{ mg L}^{-1}$ , 1,200 FAU,  $84.3 \text{ mS cm}^{-1}$ , and  $20,000 \text{ mg L}^{-1}$ , respectively. Further, the effect of operating time on permeate flux provided in Fig.4a, where the average flux decreased from  $8.33 \text{ L m}^{-2} \text{ h}^{-1}$  by proceeding the operating time from 0 to 30 min, respectively. The reason might be the formation of a scalant on the membrane surface by direct filtration. Initially, the RGW 4.60 pH and removal efficiency of TDS, turbidity, conductivity, and COD found to be  $62,330 \text{ mg L}^{-1}$ , 1,325 FAU,  $34.3 \text{ mScm}^{-1}$ , and  $24,000 \text{ mg L}^{-1}$ , respectively, after membrane treatment. In the second series of experiments in hot conditions, i.e., the temperature of the feed held at  $80^\circ\text{C}$  was passed through the HF-UF membrane.

Moreover, from Fig.4a, the average flux decreased from  $7.14 \text{ L m}^{-2} \text{ h}^{-1}$  with time from 0 to 30 min of the experimental run. The flux declination was due to the acceleration of membrane fouling by suspended solids present in the effluent in hot conditions [15]. The feed and permeate characteristics of RGW in the room and hot conditions provided in Table 1. From the results, the treatment of RGW using the HF-UF membrane shows better performance at room temperature than in hot conditions. Therefore, further experiments conducted using RGW effluent at room temperature.

### *3.2.2. Coagulation based integrated HF – UF membrane system*

The RGW pretreated with various coagulants such as methanol, ethanol, and HCl, and after treatment with HF-UF processes were studied. Initially, the color of the RGW found to be milky white at room temperature, and the feed and permeate characteristics of TDS, turbidity pH, conductivity, and COD in integration with HCl + HF-UF, ethanol + HF-UF and methanol + HF-UF efficiencies provided in Table 2. From the experimental results, the methanol integrated UF membrane permeates characteristics found to be  $4,200 \text{ mg L}^{-1}$  TDS, 70 FAU,  $7.23 \text{ mS cm}^{-1}$ , and  $6,000 \text{ mg L}^{-1}$  COD. On the other hand, the effect of operating time on permeate flux and %rejection efficiencies provided in Fig.4b. The overall permeate flux, % removal efficiencies of TDS, turbidity, conductivity, and COD for HCl, ethanol and methanol integrated process found to be 7.7, 8.2 and  $13.62 \text{ L m}^{-2} \text{ h}^{-1}$  with operating time 30 min, respectively, which is due to the formation of scalant on the membrane surface. Further, from Fig.4b the %efficiencies of TDS, turbidity, conductivity, and COD were noted as 87.4, 99.7 87.4 and 28.6% for HCl integration, 36.3, 93.77, 99.93, 36.3, and 53.6% for ethanol integration and finally 93.77, 95.4, 93.9, 78.6% for methanol integration processes, respectively. The reason could be, after pretreatment of HCl, the effluent can damage the surface of the membrane. In contrast, ethanol has vander wall force between the molecules, and suspended solids may take a longer time to settle down. Therefore, methanol has opted as a coagulant for further experimental studies in integration with HF-UF membrane through aerobic membrane bioreactor (AMBR).

### *3.2.3. Influence of coagulant on AMBR*

The RGW effluent was pretreatment with methanol followed by treatment with HF-UF membrane bioreactor under the aerobic condition in continuous recirculation for 18 days. The effect of operating time on permeates flux provided in Fig.5a. Permeate flux decreased from 4.87 to 3.4 L m<sup>-2</sup>h<sup>-1</sup> an operating time from 0 to 30 min, the formation of scalant on the surface of the membrane by a continuous experimental run, respectively.

Further, from Fig.5b-5e, it can see that the removal efficiency of turbidity, conductivity, TDS, and COD in permeate reduced from 1500 to 60 FAU, 105.3 to 9.5 mS cm<sup>-1</sup>, 392 to 5,760 mg L<sup>-1</sup>, and 28,000 to 1500 mg L<sup>-1</sup> with several days from 1 to 18. The pH of the effluent after treatment with AMBR increased from 4.85 acidic to neutral medium (pH -7.04) (Fig. 5f) with 18 days of operation. The overall percentage removal efficiency of the membrane with respect for turbidity, TDS, conductivity, and COD was 96.0, 91.0, 91.0, 91.0 and 94.6%, respectively. In this sense, methanol pretreatment, along with AMBR, is the best-suited system as this system will remove residual methanol entering the AMBR biologically. From Fig.5b - 5f can be seen the AMBR becomes stable after 18 days of operation.

### *3.2.4. Effect of membrane washing on pure water flux*

The membrane efficiency depends on the chemical washing, which effects on pure water flux. After effluent treatment using the UF membrane, it was washed thoroughly with organic and inorganic chemicals to determine the absolute water flux for understanding the washing efficiency. Fig.6a reveals the decrease in the pure water flux from 136 to 87 L m<sup>-2</sup>h<sup>-1</sup>, whereas, after membrane cleaning, the flux was increased from 27.27 to 80.35 L m<sup>-2</sup>h<sup>-1</sup> with time from 0 to 3 min, respectively. After membrane washing, the pore on the membrane effectively removes the scalant and particulates from the pores on the membrane surface.

### *3.3. Construction of the molecular dynamic (MD) simulation*

A PES polymer chain for the MD simulation carried out with repeating monomer units that were constructed and simulated using the Accelrys commercial software using the condensed phase optimized molecular potential for atomistic simulation study (COMPASS) force field [16]. The 3 D structure of the PES, PVA, and DMF as showed in (Fig.6b, c, d). The amorphous builder module used to construct the system and minimization. PES has been built by monomer PVA with repeating units and minimized by steepest – descent method.

Several cycles of energy minimization (EM) and MD simulation repeated to allow the polymer chain to fold until the polymer structure had a density of 1.0003 g cm<sup>-3</sup>, very close to the experimental frequency of PES, which was 1.37 g cm<sup>-3</sup> under ambient conditions. After the first EM and MD simulation performed at a constant, elevated temperature at 298 K in the NVT (where the amount of N, volume (V) and Temperature (T)) statistical ensemble to speed up the process of folding of the polymer chain. The minimized PES/PVA blend membrane structure at different hydration levels and an annealing MD

simulation followed at the ambient conditions and the final composition of the PES bulk polymer model shown in Fig. 6e.

### 3.3.1. Energy minimization

From Fig. 6f shown that the potential energy increases during the process of molecular minimization. Due to the energy replacement of (OH) hydroxyl group from PVA. The amorphous systems constructed with a periodic boundary condition and density of  $1.0003 \text{ gcm}^{-3}$  after the minimization of each molecule. The minimization energy of the amorphous system with potential energy is  $-227.549 \text{ kcal mol}^{-1}$ . Fig. 6f provides information about how the water molecules help to increase the total strength of the system.

### 3.3.2. Economic estimation for integrated MBR

Usually, the conventional processes required enormous space, high energy consumption, chemical usage, and labor cost compared to the membrane process [17]. However, by considering environmental engineering drawbacks in low-pressure membrane processes for potable water production in various applications. Table 3 represents where a detailed description of the materials used in the present study for the installation of an experimental setup. The possible economic estimation carried out for  $1000 \text{ L h}^{-1}$  pilot-scale provided in Table 4 includes operating and maintenance cost. The process capital investment was 5501.84 USD (INR 4.20 Lacs), with a payback period of 2.72 years.

## Conclusions

In the present study reveals the feasibility of methanol coagulant for pretreatment followed by side-stream AMBR to effectively remove the turbidity, conductivity, TDS, moderate level COD present in RGW for water recovery and its reuse. Synthesis of HF-UF membrane used in AMBR. The membranes were indigenously synthesized and characterization to illustrates the structural, nature, and surface and cross-sectional morphologies of the membrane. Before subjecting to AMBR, the RGW effluent pretreated with HCl. Methanol and ethanol coagulant and integrated laboratory HF-UF module to know the coagulant and membrane performance. The methanol coagulation process integrated with HF-UF achieved 78.6% COD. Therefore, the method successfully integrated with AMBR. The methanol and pre-treatment followed by AMBR remove 96% turbidity, and 91% conductivity, 96.4% COD. Further, the effluent pH was increased from acidic medium to neutral (7.04) for membrane longevity and safety. Finally, the cost estimation of the pilot-scale process was calculated and for 15 h operating time of the bioreactor.

## Declarations

### Availability of data and materials

No other source of data and materials used in these studies.

### Competing interests

There are no competing interests

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## Authors' contributions

All authors contributed in experimental work and paper drafting, corrections to the final structure

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## Authors information

<sup>1</sup>Membrane Separations Laboratory, Process Engineering &Technology Transfer Division,  
CSIR - Indian Institute of Chemical Technology, Hyderabad, India-500007.

<sup>2</sup>School of Engineering, RMIT University, Melbourne, VIC 3000, Australia

<sup>3</sup>School of Science centre f Advanced Materials and Industrial Chemistry at RMIT University, Melbourne, VIC 3000, Australia.

## References

1. Jin Z, Gong H, Temmink H, Nie H, Wu J, Zuo J, Wang K. Efficient sewage pre – concentration with combined coagulation microfiltration for organic matter recovery. *Chem Eng J.* 2016; 292:130 -
2. Koning JD, Bixio D, Karabelas A, Salgot M, Schafer A. Characterization and assessment of water treatment technologies for reuse. 2018; 218: 92-104.
3. Wakte K, Zanan R, Hinge V, Khandagale K, Nadaf A, Henry R. Thirty-three years of 2-acetyl-1-pyrroline, a principal basmati aroma compound in scented rice (*Oryza sativa L.*): A status review. *J Sci Food Agric.* 2017; 97:2: 384-395.
4. Mingyai S, Kettawan A, Srikaeo K, Singanusong R. Physicochemical and antioxidant properties of rice bran oils produced from coloured rice using different extraction methods. *J Oleo Sci.* 2017; 66:6:565-572.
5. Kimberly S, Eveline IPV, Mathieu S, Mark CMVL. Resource recovery and wastewater treatment modeling. *Environ Sci: Water Res Technol.* 2019; 5:631-642.
6. Zeng Z, Liu J, Savenije HHG. A simple approach to assess water scarcity integrating water quantity and quality. *Ecol Indic.* 2013; 34: 441-

7. Brunetti A, Macedonio F, Barbieri G, Drioli E. Membrane engineering for environmental protection and sustainable industrial growth: Options for water and gas treatment. *Environ Eng.* 2015; 20:4: 307-
8. Krzeminski P, Tomei MC, Karaolia P, Langehoff A, Almeida CMR, Felis E, Gritten F, Andersen HR, Fernandes T, Manaia CM, Rizzo L, Fatta-Kassinos D. Performance of secondary wastewater treatment methods for the removal of contaminants of emerging concern implicated in crop uptake and antibiotic resistance spread: A review. *J Sci Total Environ.* 2019; 15: 1052 -
9. DeCarolis JF, Adham S. Performance investigation of membrane bioreactor systems during municipal wastewater reclamation, *Water Environ. Res.* 2007; 79: 2536 -
10. Hey T, Bajraktari N, Davidsson A, Vogel J, Madsen HT, Helix-Nielsen C, Jansen JC, Jonsson K. Evaluation of direct membrane filtration and direct forward osmosis as concepts for compact and energy-positive municipal wastewater treatment. *Environ Technol.* 2018; 39: 3: 264-276
11. Mahanta CL, Bhattacharya KR. Thermal degradation of starch in parboiled rice. *Starch – Stärke.* 1989; 41: 91-94.
12. Choudhary M, Majumder S, Neogi S. Studies on the treatment of rice mill effluent by electrocoagulation. *Sep Sci Technol.* 2014; 50: 505-511.
13. Kawasaki K, Matsuda A, Tanabe S, Katagiri N, Irtiani E. Effect of suction pressure and aeration pressure on the hollow fiber microfiltration of excess activated sludge. *Process Saf Environ.* 2007; 85: 176–180.
14. Chang IS, Le-Clech P, Jefferson B, Judd S. Membrane fouling in membrane bioreactor for wastewater treatment. *J Environ Eng.* 2002; 128:11:1018–1029.
15. Sioutopoulos DC, Yiantzios SG, Karabelas AJ. Relation between fouling characteristics of ro and uf membranes in experiments with colloidal organic and inorganic species. *J Membr Sci.* 2010; 350: 62–82.
16. Shi TF, Wei J, An LJ, Li BY. Molecular dynamics simulation of sub-transition for polyethersulfone, *MacromolTheor Simul.* 2001; 10:232–236.
17. Venkata Swamy B, Madhumala M, Prakasham RS, Sridhar S. Processing of biscuit industrial effluent using thin film composite nanofiltration membrane. *Des Monomer Polym.* 2016; 19:1:47 – 55.

## Tables

**Table 1** Feed water characteristics of RGW effluent after treatment with HF - UF membrane in cold and hot conditions

Parameter	Feed	Feed at room temperature	Feed at 80 °C
pH	4.85	3.34	4.60
TDS (mg L <sup>-1</sup> )	67,392	56,330	62,330
Turbidity (FAU)	1,500	1,200	1,325
Conductivity (mS cm <sup>-1</sup> )	105.3	84.3	34.3
COD (mg L <sup>-1</sup> )	28,000	20,000	24,000

**Table 2** Water quality parameters in feed and after coagulation integrated UF membrane process

Parameters	TDS (mg L <sup>-1</sup> )	Turbidity (FAU)	pH	Conductivity (mS cm <sup>-1</sup> )	COD (mg L <sup>-1</sup> )	Color (Pt-Co)
RGW (feed) after cooling to room temperature	67,392	1,500	4.85	105.3	28,000	Milky White
HCl (1 %) + HF-UF	8,512	4	1.61	13.3	20,000	-
Ethanol (1 %) + HF-UF	42,880	1	3.34	67.4	13,000	-
Methanol (1 %) + HF-UF	4,200	70	7.23	6.528	6,000	-

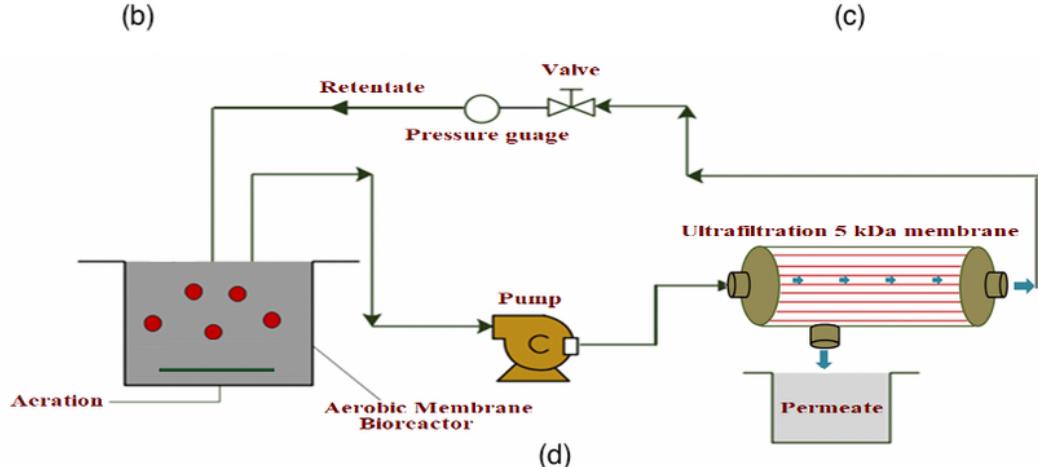
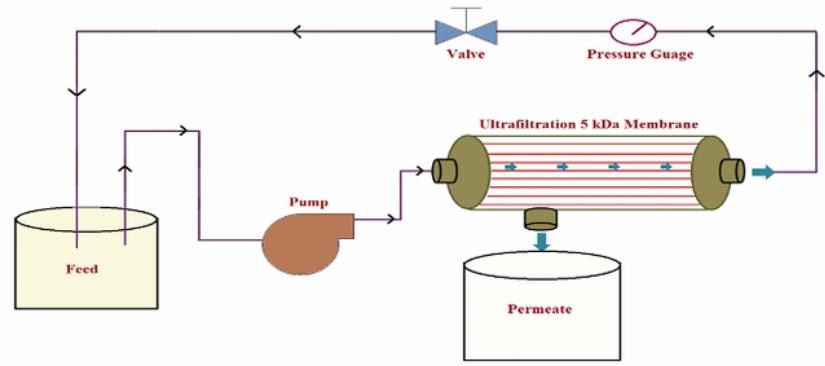
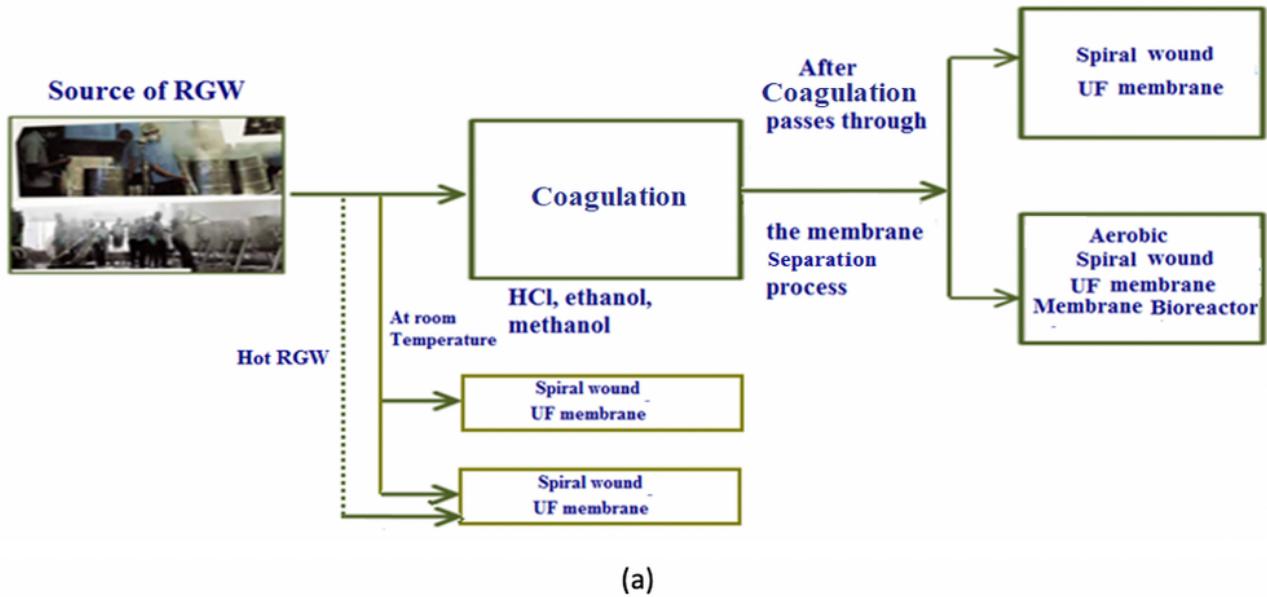
**Table 3** List of items and capital equipment cost

S. No	Item	Specifications	Material	Qty. No	Total Cost INR	Total Cost USD
1	Feed tank	2000	Plastic	1	10500	138.16
2	Feed pump	1 HP 1000 LPH	Nil	1	3500	46.05
3	Skid	plant	SS	1	2500	32.89
4	Multiport valve	Nil	Nil	1	950	12.50
5	Pressure vessel	3m long	FRP	1	2800	36.84
6	Sand (Bag)	Nil	Granular	1	250	3.29
7	Carbon (Bag)	Nil	Granulated	1	450	5.92
8	Jumbo pre-filter	Nil	Thread	2	600	7.89
9	Jumbo pre-filter housing	Nil	Nil	2	800	10.53
10	Bioreactor unit	Nil	Polyacrylic	1	300000	3947.37
11	High pressure pump	1.5 HP	SS	1	17000	223.68
12	Membrane housing	1m long 4"dia x 40" long	Nil	4	8800	115.79
13	Membrane module		UF	4	46000	605.26
14	Control panel	Nil	SS	1	5800	76.32
15	Flow meter	Nil	Nil	2	1300	17.11
16	Pressure gauge	Nil	Nil	1	725	9.54
17	TDS meter	Nil	Nil	1	1200	15.79
18	Permeate tank	1000	Plastic	1	7000	92.11
19	Dosing pump	0.025 HP	Nil	1	4500	59.21
20	Piping (lot)	Nil	CPVC	1	5500	72.37
				Total	420175	5528.62

**Table 4** Operation and maintenance cost of UF system

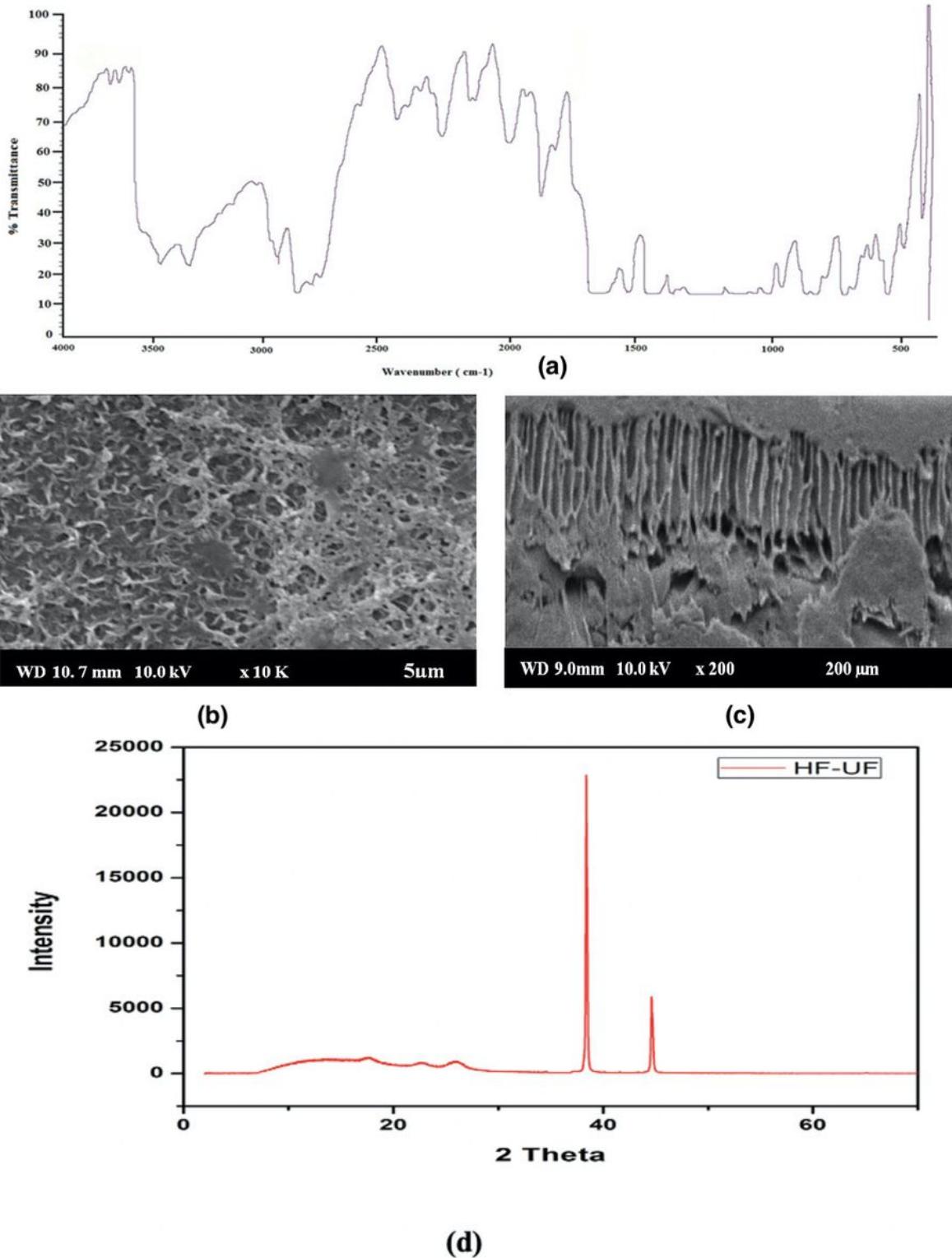
<b>Cost component</b>	<b>MBR</b>
Feed capacity (lph)	1000
Permeate capacity (lph)	550
% Recovery	0.55
<b>Operating cost</b>	
<b>Membrane module replacement cost</b>	
No. of membrane modules (4" x 40" long)	4
Price per membrane module (USD)	151.32
Total membrane module replacement cost (USD)	605.28
Duration of replacement (years)	3
No. of working hours per day	15
Cost/h (USD)	0.037
<b>Cartridge replacement cost</b>	
No. of cartridges	2
Price per cartridge (USD)	3.95
Total cartridge replacement (USD)	7.9
Duration of replacement (days)	30
No. of working hours per day	15
Cost/h (USD)	0.018
<b>Power cost</b>	
Feed pump (kW)	0.745
High-pressure pump (kW)	1.12
Dosing system (kW)	0.02
Total power consumption (kW)	1.885
Total power cost (USD) (@Rs 6 unit)	0.15
<b>Chemical consumption</b>	
Antiscalant dosing (ppm)	5
Dosage (L h <sup>-1</sup> )	0.01
Cost/L (USD)	2.105
Cost/h (USD)	0.021
<b>CIP chemicals (Citric acid, EDTA, NaOH)</b>	
Frequency (days)	7
Hourly cost of cleaning chemicals (USD)	0.028
Total cost of CIP per hour (USD)	0.049
Labor cost per hour (USD)	0.29
Total operating cost per hour (USD)	0.542
Total operating cost per year (USD)	3957.84
Depreciation cost (assuming 10% of capital cost) (USD)	772
Interest (10% of capital cost) (USD)	772
Total cost per year (USD)	5501.84
<b>Permeate</b>	
Quantity (LPH)	550
Operation time (h)	15
Quantity of permeate generated in 1 year (L year <sup>-1</sup> )	3,011,250
Cost of permeate per liter (USD)	0.00183
Cost of permeate per liter (Paisa)	12.42
If sold at $2.5 \times 10^{-3}$ USD per L, then	7528.125
Annual profit (USD)	2026.29
Payback period (years)	2.72

## Figures



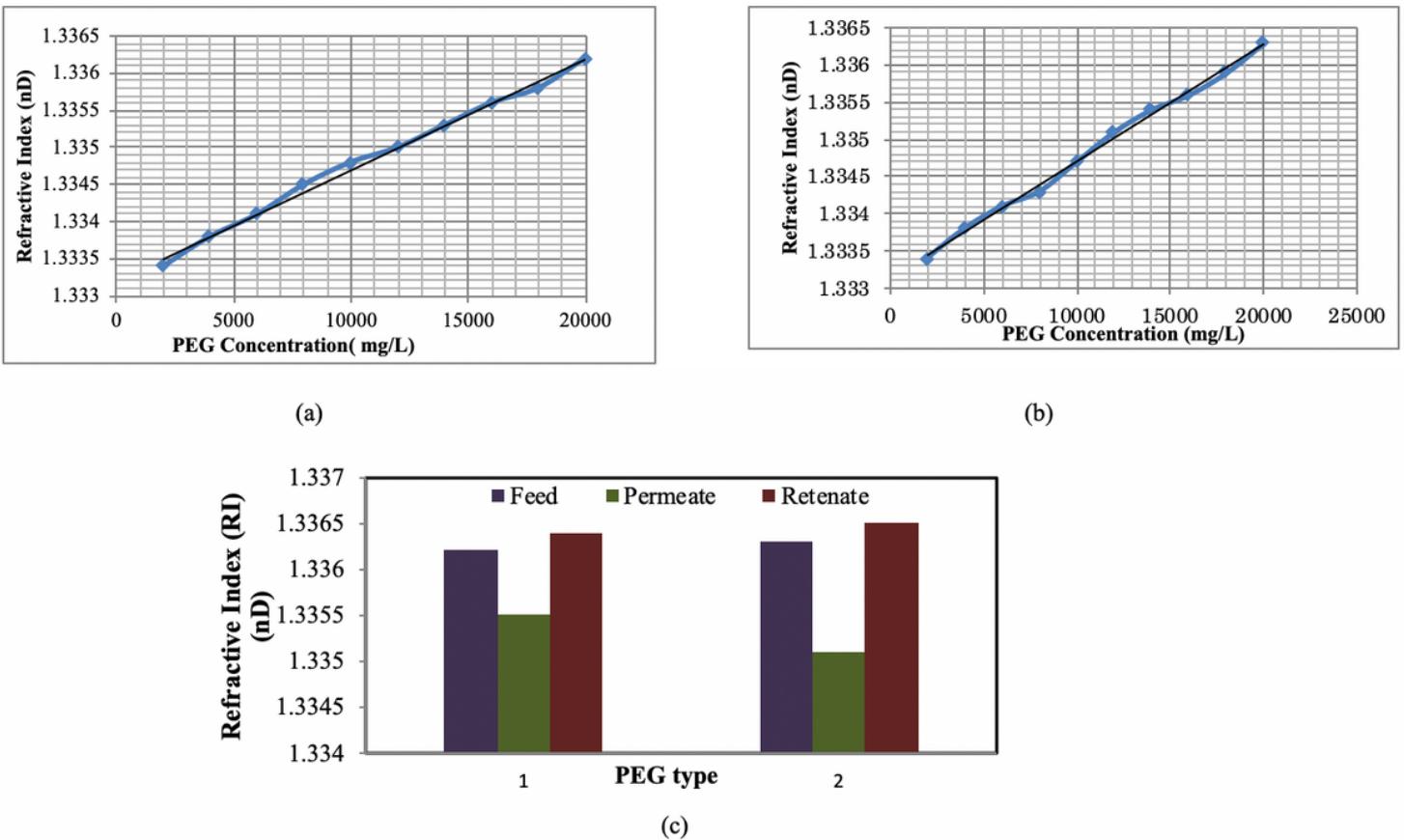
**Figure 1**

(a) Overall process flow diagram for the treatment of RGW, (b) RGW after pre-treatment with methanol, Process flow diagram of (c) spiral wound UF system and, (d) AMBR system



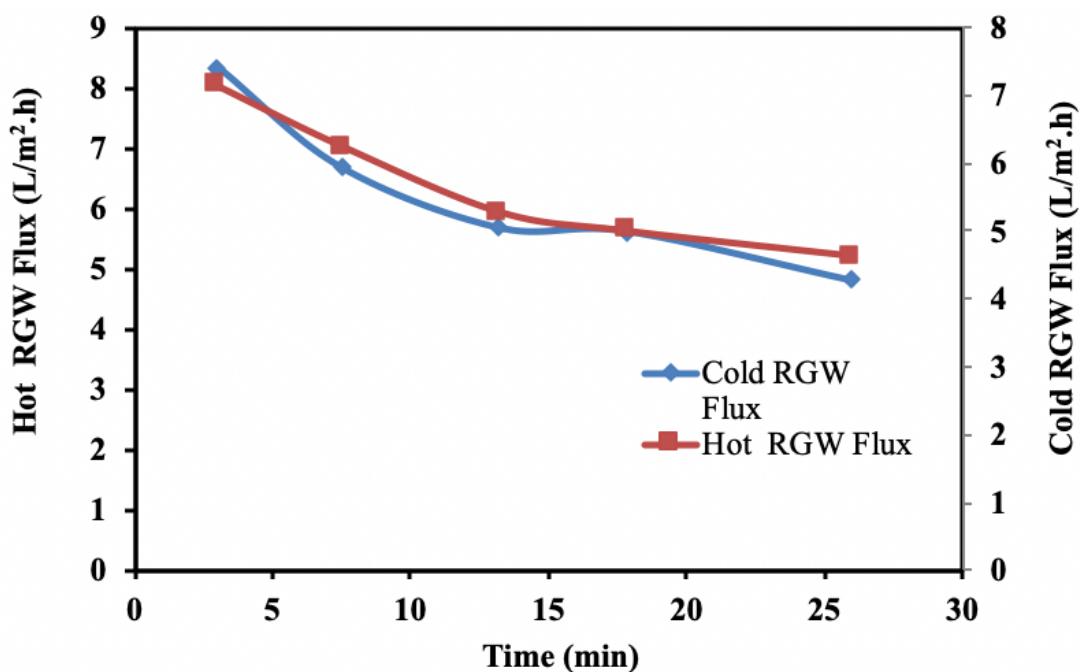
**Figure 2**

(a) FTIR, (b) SEM image of surface (c) cross-sectional of HF – UF membrane and (d) XRD pattern of HF-UF membrane

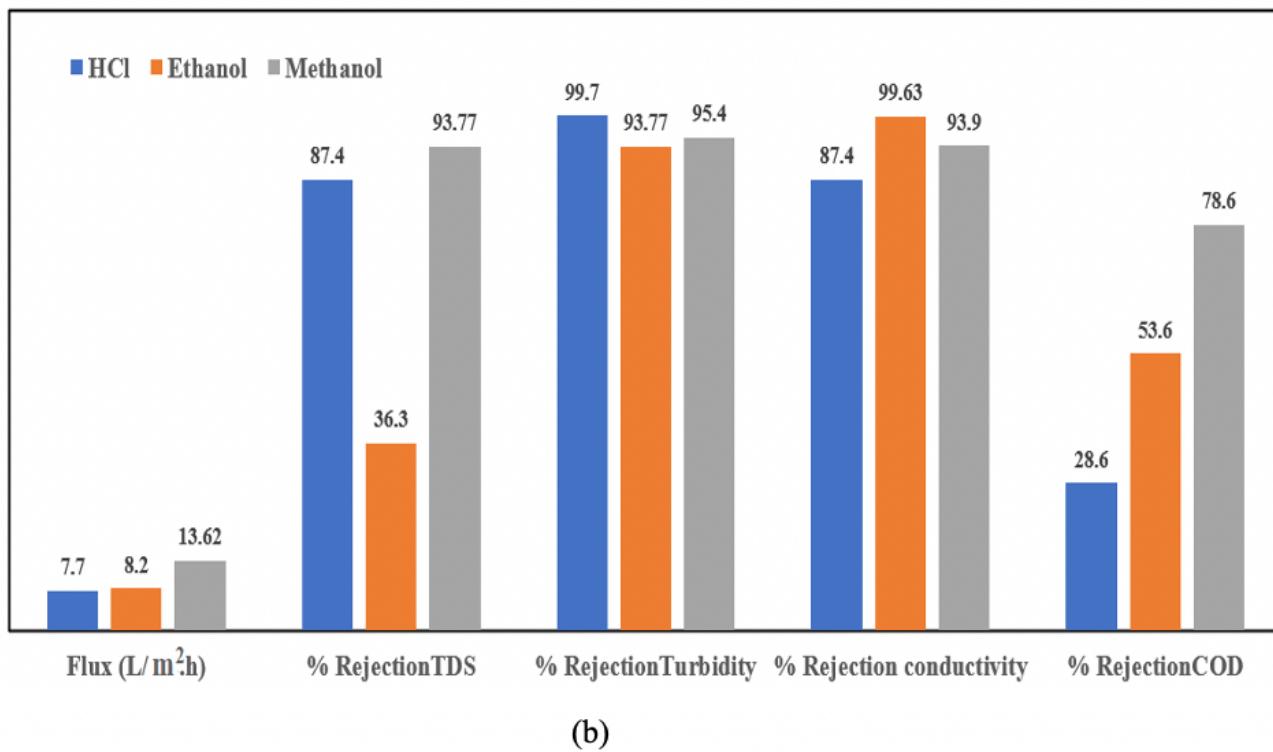


**Figure 3**

Effect of PEG concentration with Refractive Index (a) 6,000 (b) 4,000 and (c) Effect of Parameters with the Refractive Index (1 and 2 denote the PEG type 6,000 and 4,000 Da, respectively)



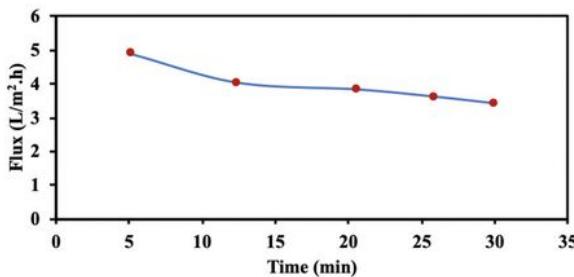
(a)



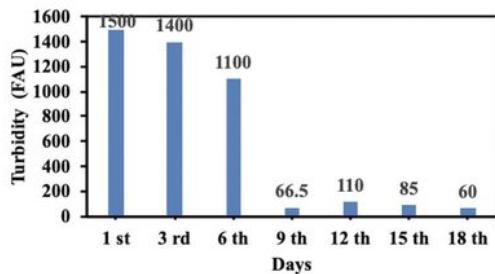
(b)

**Figure 4**

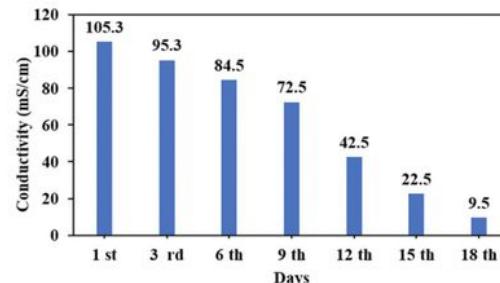
(a) Effect of operating time on permeate flux at room temperature and 80 °C, (b) Permeate flux and% rejection parameters after coagulation integrated HF-UF membrane.



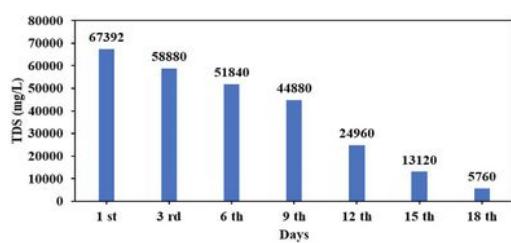
(a)



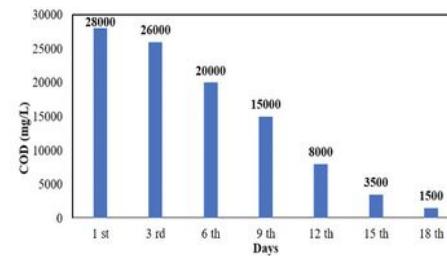
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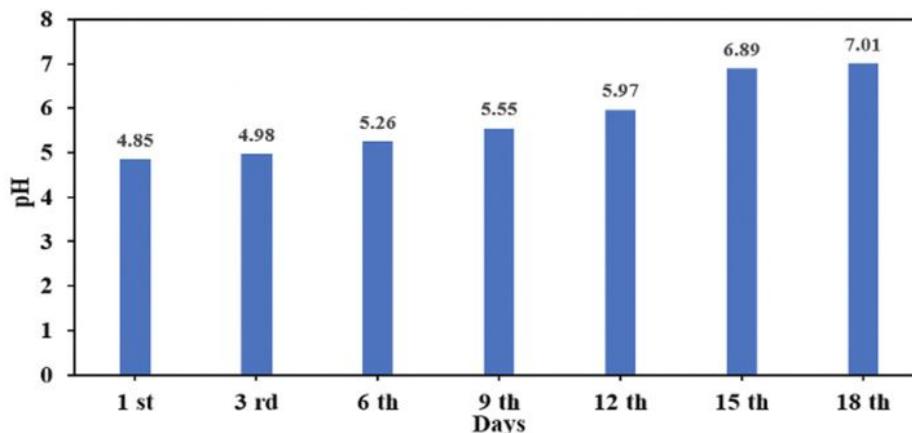
(c)



(d)



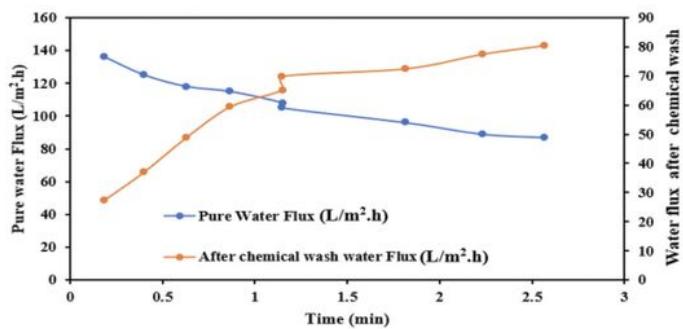
(e)



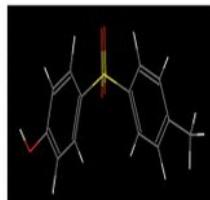
(f)

**Figure 5**

(a) Effect of operating time on permeate flux, effect of operating days on (b) Turbidity (c) conductivity (d) TDS (e) COD and (f) pH in permeate by AMBR process



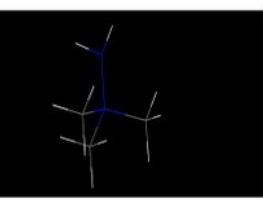
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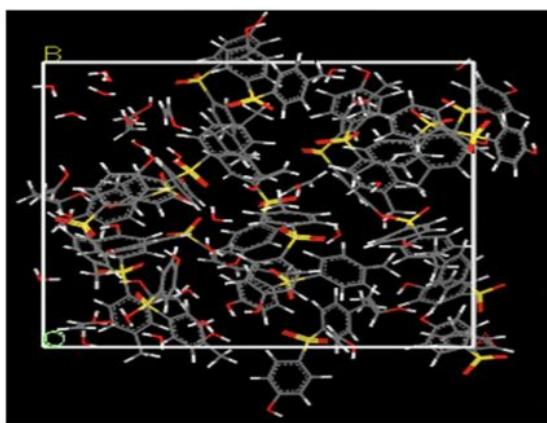
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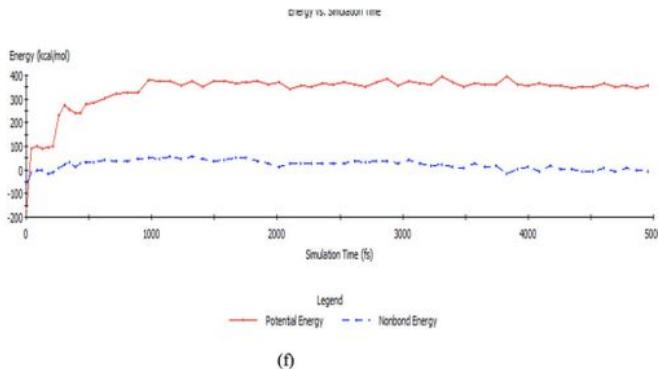
(c)



(d)



(e)



(f)

**Figure 6**

(a) Effect of operating time on pure water flux and water flux after chemical wash, 3 D structure of (b) PES, (c) PVA, (d) DMF, (e) a minimized structure of PES/PVA and (f) Minimization energy of PES/PVA structure

## Supplementary Files

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