An Integrated Process of Methanol Coagulation and Side Stream Membrane Bioreactor for Treatment of Rice Gruel Wastewater

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Abstract

The demand for water supply is expected to be raised significantly in 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) was treated with aqueous methanol coagulation integrated aerobic membrane bioreactor (AMBR). Initially, the RGW which is at room temperature was treated with spiral wound hydrophilized - ultrafiltration (HF – UF) 5 kDa membrane module to determine the removal efficiency. Furthermore, the RGW was pre-treated with various coagulants such as methanol, ethanol and HCl. The obtained pre-treated RGW was subjected to the HF – UF 5 kDa side stream AMBR for production of reusable water. The experiments were conducted to determine the turbidity, conductivity, total dissolved solids (TDS) and chemical oxygen demand (COD) were found to be 96 %, 91 %, 91 % and 94.6 %. The overall process was feasible, compact, environmental free, cost effective, eco-friendly.

Introduction

In recent decades, water demand is officially looking for few substitutionally resources to satisfy the enhancing affirmation due to the augmenting population, urbanization, population growth, expansion of integrated agricultural etc., [1, 2]. Hence, it has become a special interest in arid and water-scarce countries such as Iran, India, Italy, Iraq, Portugal etc., [3]. Most of the water resources are contaminated by domestic and industrialization for urban development. The treatment of wastewater is an important factor for environmental application whereas, the domestic wastewater is considered as a strategic method for production of reusable water.

Moreover, two-thirds of the entire world population was consumed rice as a staple food, mostly 95% rice is being consumed by oriental countries like India, Bangladesh, China, Japan, Korea, Philippines, Malaysia, Indonesia, Thailand, Sri Lanka, etc. Cooking of rice produces a large amount of rice gruel and discharged to land as a wastewater [4, 5]. The Rice gruel (RG) is one of the domestic wastewater, consists of a significant amount of starch, protein, lipids and suspended solids which need to be separated before discharge into water sources [6]. Amylose and amylopectin are two components of starch ranging in average molecular weight from 5,200 (5 kDa) to 872,300 (870 kDa). While Amylose is a long, straight starch molecule that does not gelatinize during cooking whereas amylopectin is a highly branched starch molecule that is responsible for making rice gelatinous and sticky. It also evolves foul odour due to bacterial growth when exposed to environment.

Hence, the Rice gruel wastewater (RGW), is directly discharged into water bodies by restaurants, hotels, hostels, household, monasteries etc., [7, 8]. Most of the conventional wastewater treatment processes such as ion exchange, adsorption, electrochemical treatment, chemical precipitation, adsorption, solvent extraction, flotation were used to extract the major component starch which was present in the RGW [9, 10]. However, the conventional processes have some limitations due to the high-power consumption, large space requirements, additional of chemicals or solvents for separation, phase change [11].

Therefore, there is need to develop an alternative technology for treatment of domestic wastewater reclamation.

Advanced membrane separation processes include reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), microfiltration (MF), membrane bioreactor (MBR) were extensively used for treatment of domestic wastewater [12]. Among those MBR is widely enhancing technology for domestic wastewater treatment in aerobic and anaerobic condition. Anaerobic treatment system can remove chemical and biological oxygen demand along with 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 the production of foul, odour, low reduction in turbidity and total dissolved solids (TDS) etc., [13]. Hence, most of the researchers have been used aerobic treatment process to supply enough oxygen to support the bacteria which can reduce the organic and inorganic compounds.

MBR in aerobic condition can be extensively used for sustainable and energy efficient for domestic wastewater such as laundry [14], kitchen [15], Bathroom [16], washing machine water [17] for reproducibility of water. The AMBR can be further integrated with the conventional process to achieve high energy consumption, huge operation and less maintenance cost. A very few studies were reported on domestic RGW by AMBR. Boykin et al 2005 studied concentrating of starch from rice cooker wastewater using MF membrane [18]. Sayanthan and Thusyanthy 2018 reviewed rice parboiling and effluent treatment model [19]. Bovas and James developed membrane bioreactor in anaerobic conditions for rice mill effluent treatment with less energy conservation [20]. Mananta and Bhattacharya 1989 extracted the rice starch from parboiled rice starke in thermal degradation process [21]. Choudhary et al., 2015 used electrocoagulation process for the treatment of rice mill effluent [22].

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 was treated with HF - UF AMBR for reproducibility of potable water. Experiments were conducted to estimate the turbidity, COD, TDS, pH and conductivity on membrane performances. From the experimental results, the process was scaled up and calculated the cost of the process.

Material And Methods

Material

Polyethersulfone (PES) polymer was 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) were purchased from S.D. Fine Chemicals Ltd., Mumbai, India. The non-woven polyester fabric was procured from Miki Tokushu Paper Mfg. Co. Ltd., Japan to be used as the support for casting the hydrophilized (HF) – UF (ultrafiltration) membranes. The nutrient broth and agar were supplied by Hi-Media Lab. Pvt. Ltd. Mumbai, India. The indigenous

synthesized HF – UF membrane was spirally wound with assistances of Permionics Pvt. Ltd., Vadodara, India. Glass wear such as a conical flask, beakers, Petri dishes, measuring cylinders, were used to prepare the agar broth and analysis of the collected samples obtained from vasco scientific from Hyderabad, India. Equipment's 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 were supplied by Secunderabad India. The hardware items such as aerator, pressure gauge, valves, pump, T – joint, teflon, cotton, tubing, parafilm, strips, for installation of MBR system which was supplied by SVS water solution for experimental setup, Hyderabad, India. Deionized water for water bath was prepared using the laboratory ultrapure cascaded reverse osmosis (RO) system.

Methods

Synthesis of hydrophilized (HF) – ultrafiltration (UF) 5 kDa membrane

HF – UF membrane was synthesized using immersion precipitation method by phase inversion technique. The blend polymer solution for casting was 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 ± 2 °C) to remove the presence of 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) at room temperature (30 ± 2 °C) to obtain HF – UF membrane.

Effect of molecular weight of Polyethylene glycol (PEG)

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

Sample collection

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

Treatment of cold and hot RGW by spiral wound HF – UF 5 kDa membrane

The RGW which was at room temperature and hot (80 °C) were passed through the spiral wound UF module with membrane area 1.2 m² for 3 h and the feed permeate and retentate samples were used for physicochemical analysis, respectively.

Pretreatment of RGW with coagulants

Wastewater treatment (WWT) processes involves a series of physical, chemical and biological treatment techniques were further classified into pretreatment, primary and secondary treatment [23]. In the present study, the coagulation pretreatment for RGW domestic wastewater was pretreated for soluble removal of organic matter. The coagulation step was carried out by alcohols and acids to stabilize the starchy colloidal content, which eliminates moderate levels of total dissolved solids (TDS), chemical oxygen demand (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 1% HCl solution. The reaction mixture was stirred at 250 rpm for about 30 min and allowed for 2 h to sedimentation as shown in Fig.1b. The same experiments were repeated with methanol and ethanol as pre-treatment coagulants. Among that methanol, coagulant shows higher removal efficiency in suspended from RGW.

Experimental setup for spiral wound UF membrane

After the preliminary pretreatment with the methanol the supernatant liquid was passed through the spiral wound HF – UF membrane module membrane area 1.2 m² at 3 bar pressure using 300 gpd (gallon per day) pump. The experiments were performed in a continuous mode, by measuring the permeate flux with respect 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.

Preparation of culture and nutrient agar

For the development of microbial consortia, it is necessary to prepare a culture media using a nutrient agar and broth. The agar medium was prepared by dissolving of 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°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 37⁰C for one day.

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°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 one day at 37⁰C. The culture was added to the feed tank and stayed overnight for further microbial growth followed by adaptation within the RGW environment.

Experimental setup and procedure for pretreatment coagulation and integrated aerobic membrane bioreactor (AMBR)

In this experimental study, after the preliminary pretreatment of RGW step with the chemicals (HCl, ethanol, and methanol) the supernatant was passed through the side-stream AMBR for to remove suspended solids, turbidity, color. Fig. 1d represents the process flow diagram AMBR where the feed tank capacity of 2.5 L was connected to the spiral UF membrane module with membrane area 1.2 m² connected to 300 gpd pressure pumps. The module was arranged in a cross-flow manner and the permeate was collected into 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 was added to the pre-treated RGW wastewater present in the feed tank (2L). A micro-bubble diffuser was assembled in the feed tank for providing oxygen and controlling the aerobic conditions for the growth of biomass. The feed was fed to the membrane by maintaining the feed pressure of 3 bar throughout the experiments. The initially feed, permeate and retentate samples were collected for the analysis. The experiments were continued for 18 days in aerobic condition to remove the TDS, colour, conductivity and COD.

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 µm.

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 θ values of the polymer.

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

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 that accumulate on surface of membrane and pores. Therefore, the membrane fouling was reduced by removing module from the system and clean at regular time intervals, after every batch experiment using chemical washing followed by water washing at low pressure. The chemical washing was conducted using 1 % citric acid, 1% sodium hydroxide (NaOH) + 0.5 % ethylene diamine tetraacetic acid (EDTA) + 0.1% of sodium lauryl sulfate (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 [24,25,26,27]. After chemical cleaning the membranes was stored in sodium metabisulphite (SMBS) (0.5 % w/v) aqueous solution to avoid further biological fouling and extend the life span of the membrane.

Analytical methods

Raw industrial wastewater, pretreated supernatant (after coagulation), permeate samples were analysed in relation to pH, colour, Conductivity (mS/cm), turbidity (FAU), TDS (mg/L) according to the standard procedure for wastewater analysis [28]. Sample pH was determined through a digital pH – meter (model DPH-504), at room temperature. Colour (Co- Pt), Turbidity (FAU) analysis was performed at (DR 800, HACH), TDS was determined using TDS meter with model HM TDS0-999, Hyderabad, India and Conductivity was measured using model DCM900 conductivity meter obtained from Global Electronics, Hyderabad, India.

Mathematical tools

Permeate flux

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

$$J = \frac{V}{A \times T} \quad (1)$$

Where J is the permeate flux (L/m².h), V is the collected volume of permeate (L) in time T (h) and A is the membrane area (m²).

Porosity

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

$$\epsilon = \frac{(m_1 - m_2)}{s_1 \times \delta \times \rho} \quad (2)$$

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

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).

$$R = \left[1 - \frac{C_p}{C_f} \right] \times 100 \quad (3)$$

Where % rejection denotes as R , C_p and C_f are the concentration of the solute in permeate and feed (mg/L).

Chemical oxygen demand (COD)

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

$$\text{COD (mg/L)} = \frac{(B-S) * N * 8000 * D.F}{V} \quad (4)$$

Where B is the blank volume consumed in titration, S is the volume consumed in titration with sample preparation 8000 is the equivalent weight of oxygen per L, N is the Normality of standardized ferrous ammonium sulfate solution, $D.F$ and V is known as dilution factor and the volume of the sample (ml).

Results And Discussions

Membrane characterization

Structural analyses by fourier transform infrared spectroscopy (FTIR)

Fig.2a represents the FTIR spectra of PES blended PVA cross - linked with GA membrane. The peak at 1117.78 cm^{-1} and 1435 cm^{-1} have attributed the ether ($\text{C}=\text{O}$) and sulfonated (SO_2) group of PES. This might be due to the stretching vibration of the aromatic ether. The peaks at 1582.63 cm^{-1} was denoted the aromatic benzene ring. In addition to this the broad peak at around 3227 cm^{-1} indicates the stretching vibration of the hydroxyl group of PVA. The formation of new acetal linkage was attributed at 1070 cm^{-1} which represent the cross - linking between GA and hydroxyl group of PVA. The possible reaction mechanism was provided in scheme 1.

Scanning electron microscopy studies (SEM)

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

X-ray diffraction analysis (XRD)

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

Effect of Polyethylene glycol (PEG) concentrations on membrane compositions

The membrane was passed through a 2 wt % of aqueous PEG solution to analyse the molecular weight cut off (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 % was achieved with 4,000 Da of PEG solution, which was accomplished with 2 wt % of the solution compared with 6,000 Da. Feed, permeate and retentate refractive index were shown in Fig.3c, where the refractive index for PEG 4,000 concentration lead to a highest % rejection, and when the MWCO of PEG was 6,000 Da the % rejection was decreased slightly. There was no further difference in the % rejection efficiency with changes in molecular weight thereafter. Hence, this experiment demonstrates a rough ideation on average MWCO of 5000 Da. The calculated value of the porosity of 5 kDa membrane was found to be 34.68 %, which concludes that the membrane MWCO was 5kDa.

Experimental Results For Treatment Of Rgw

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 ± 2 °C). From Table 1, the parameters namely pH, TDS, turbidity, conductivity and COD values in the permeate at room temperature were found to be 3.34, 56,330 mg/L, 1,200 FAU, 84.3 mS/cm and 20,000 mg/L, respectively. Further, the effect of operating time on permeate flux was provided in Fig. 4a, where the average flux decreased from 8.33 to 4.81 L/m².h by proceeding the operating time from 0 to 30 min, respectively. The reason might be the formation of scalant on the membrane surface by direct filtration. In the second set of experiments the RGW was passed through the HF – UF membrane in hot condition i.e., the feed temperature was maintained at 80 °C. Initially, the pH of the RGW was 4.60 and removal efficiency of TDS, turbidity, conductivity and COD were found to be 62,330 mg/L, 1,325 FAU, 34.3 mS/cm and 24,000 mg/L after membrane treatment, respectively. Moreover, from Fig. 4a the average flux was decreased from 7.14 to 4.63 L/m².h with time from 0 to 30 min of experimental run, respectively. The flux declination was due to the accelerate of membrane fouling by suspended solids present in the effluent in hot condition [29]. The feed and permeate characteristics of RGW at room and hot conditions were provided in Table 1. From the results

the treatment of RGW using HF – UF membrane shows better performance at room temperature than hot condition. Therefore, further experiments were conducted using RGW effluent at room temperature.

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)	67,392	56,330	62,330
Turbidity (FAU)	1,500	1,200	1,325
Conductivity (mS/cm)	105.3	84.3	34.3
COD (mg/L)	28,000	20,000	24,000

Coagulation Based Integrated Hf – Uf Membrane System

The RGW was pretreated with various coagulants such as methanol, ethanol and HCl and after treatment with HF – UF processes were studied. Initially, the colour of the RGW was 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 were provided in Table 2. From the experimental results, the methanol integrated UF membrane permeate characteristics were found to be 4,200 mg/L TDS, 70 FAU, 7.23, 6.528 mS/cm and 6,000 mg/L COD. On the other hand, the effect of operating time on permeate flux and % rejection efficiencies were provided in Fig. 4b. The overall permeate flux, % removal efficiencies of TDS, turbidity, conductivity and COD for HCl, ethanol and methanol integrated process were found to be 7.7, 8.2 and 13.62 L/m².h 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 whereas, ethanol has vanderwall force between the molecules and suspended solids may take longer time to settle down. Therefore, methanol has opted as a coagulant for further continuation of experimental studies in integration with HF – UF membrane through aerobic membrane bioreactor (MBR).

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

Parameters	TDS (mg/L)	Turbidity (FAU)	pH	Conductivity (mS/cm)	COD (mg/L)	Colour (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	-

Influence of coagulant on aerobic membrane bioreactor (AMBR)

The RGW effluent was pretreatment with methanol followed by treatment with HF – UF membrane bioreactor under the aerobic condition in continues recirculation for 18 days. The effect of operating time on permeates flux was provided in Fig.5a. The permeate flux decreased from 4.87 to 3.4 L/m².h with operating time from 0 to 30 min, which is due to the formation of scalant on the surface of membrane by continues experimental run, respectively.

Further, from Fig.5b – 5e it can be clearly seen that the removal efficiency of turbidity, conductivity, TDS and COD in permeate were reduced from 1500 to 60 FAU, 105.3 to 9.5 mS/cm, 392 to 5,760 mg/L and 28,000 to 1500 mg/L with a number of days from 1 to 18, respectively. 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 were 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.

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 UF membrane was washed thoroughly with organic and inorganic chemicals to determine the pure water flux for understanding the washing efficiency. Fig.6a reveals the decreased in the pure water flux from 136 to 87 L/m².h whereas, after membrane cleaning the flux was increased from 27.27 to 80.35 L/m².h with time from 0 to 3 min, respectively. After membrane washing the pore on the

membrane was effectively remove the scalant and particulates from the pores on the surface of the membrane.

Construction of the molecular dynamic (MD) simulation

A PES polymer chain for the MD simulation was 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 [30]. The 3 D structure of the PES, PVA and DMF as shown in (Fig.6b, c, d). The amorphous builder module was used to construct the system and minimization. PES was constructed by monomer PVA with repeating units and minimized by steepest – descent method.

Several cycles of energy minimization (EM) and MD simulation were repeated to allow the polymer chain to fold until the polymer structure had a density of 1.0003 g/cm^3 , very close to the experimental density of PES, which was 1.37 g/cm^3 under ambient conditions [31]. After the first EM and MD simulation was performed at a constant elevated temperature at 298 K in the NVT (where the amount of N, volume (V) and Temperature (T)) statistical ensemble in order to speed up the process of folding of the polymer chain. The minimized structures of PES/PVA blend membrane at different hydration levels and an annealing MD simulation followed at the ambient conditions and the final structure of the PES bulk polymer model was shown in Fig. 6e.

Energy minimization

From Fig.6f shown that the potential energy increases during the process of molecular minimization. This is due to the energy replacement of (OH) hydroxyl group from PVA. The amorphous systems were constructed with a periodic boundary condition and density of 1.0003 g/cm^3 after the minimization of each molecule. The minimization energy of the amorphous system with potential energy is -227.549 kcal/mol. Fig.6f provides the information about how the water molecules are help for the increasing the total energy of the system.

Economic Estimation For Integrated Membrane Bioreactor

Usually, the conventional processes required enormous space, high energy consumption, chemical usage and labour cost compared to membrane process [32]. However, by considering environmental engineering drawbacks in low – pressure membrane processes for the production of potable water 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 was carried out for 1000 L/h pilot scale was provided in Table 4 include operating and maintenance cost. The capital investment of the process was 5501.84 USD (INR 4.20 Lacs) with a payback period of 2.72 years.

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	Nil	1	3500	46.05
3	Skid	1000 LPH plant	SS	1	2500	32.89
4	Multiport valve	Nil	Nil	1	950	12.50
5	Pressure vessel	3 m 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	1 m long	Nil	4	8800	115.79
13	Membrane module	4"dia × 40" long	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

Cost component	MBR
Feed capacity (lph)	1000
Permeate capacity (lph)	550
% Recovery	0.55
Operating cost	
Membrane module replacement cost	
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
Cartridge replacement cost	
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
Power cost	
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
Chemical consumption	
Antiscalant dosing (ppm)	5
Dosage (L/h)	0.01

Cost component	MBR
Cost/L (USD)	2.105
Cost/h (USD)	0.021
CIP chemicals (Citric acid, EDTA, NaOH)	
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
Permeate	
Quantity (LPH)	550
Operation time (h)	15
Quantity of permeate generated in 1 year (L/year)	3,011,250
Cost of permeate per liter (USD)	0.00183
Cost of permeate per liter (Paisa)	12.42
If sold at 2.5×10^{-3} USD per liter, then	7528.125
Annual profit (USD)	2026.29
Payback period (years)	2.72

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 was used in AMBR. The membranes were indigenous synthesised and characterization to illustrates the structural, nature and surface and cross-sectional morphologies of the membrane. Before subjecting to AMBR the RGW effluent was 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 process was successfully integrated with AMBR. The methanol and pre-treatment followed by AMBR was 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

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Authors' contributions

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

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Availability of data and materials

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

Competing interests

There are no competing interests

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Figures

Figure 1

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

(a)

(b)

(c)

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)

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)

(b)

(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.

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 structures of PES/PVA and (f) Minimization energy of PES/PVA structure