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Processing Coal Mine Acidic Water Using Nanofiltration Membrane in West Aceh

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ABSTRACT

Acidic water from the coal of mining pool has been polluted from the surrounding coal stockpile stocpile industry. Water quality in mining ponds can threaten the biota in it. During this time, coal mining pool the local community uses water extensively for everyday requirements like drinking, washing, and bathing. More than time it turns out that coal mine acidic water has been polluted. This problem needs to be sought a solution, one of which is required treatment technology for creating water quality that satisfies requirements for drinking water quality. This research tries to use NF270 membrane type Nanofiltration membrane technology to eliminate COD, TSS, TDS, and metal parameters (Fe, Mn). This research was conducted by analyzing the influence pressure (4, 5, and 6 bar) on each component's rejection rate and flux each parameter. The results of the study show the processed results as follows; Turbidity, Color, COD, TSS, TDS, Fe and Mn at pressures 4, 5, and 6 bar of acid mine rejection water values, namely; Turbidity (96.23%; 98.7%; 100%), Color (79%; 98%; 100%), COD (57.9%; 63.7%; 83.19%), TSS (73, 3%; 87.2%; 95.8%), TDS (62.7%; 66%; 70.19%), Fe (36%; 74.5%; 100%), Mn (100%; 100 %; 100%). Acidic water treatment in coal mining ponds can be turned into drinking water using nanofiltration membranes producing the best percentage of rejection at pressures of 5 and 6 bar. Water treatment with Nanofiltration membrane technology has produced treated water in accordance with drinking water quality standards required by Priest of Wellbeing Pronouncement of the Republic of Indonesia No. 907/Menkes/Sk/VII/2002 and Clergyman of Climate Pronouncement the Decree of the Minister of Environment No. 492 / IV / 2010 / MENKES / PER. NF 270 membrane can remove heavy metals and other impurities in acidic water by more than 90%.

Keywords: coal acid mine water, membrane NF270, filtrasi, flux, rejection.

INTRODUCTION

Natural resources abound in Indonesia, particularly coal. In Aceh Province, one of the coal mining regions is situated in Meureubo District, West Aceh Regency [Kiswanto et al., 2021a]. Coal of mining activities are carried out using open pit mining techniques so that many leave holes that have been dug up. The former pit of mining coal if left unchecked will become an artificial lake Kiswanto et al., 2018a; Alghifary et al., 2020]. Ex-coal mining pits which are done by open-pit mining with mining systems are called hydraulic mining [Nugraha et al., 2020; Said et al., 2021a]. Giant holes formed as ex-mining land form a small lake with a depth of up to 40 meters [Ekwule et al., 2019]. Over time, coal mining pits will form lakes, filled with water and have an average depth of 4 to 5 meters, but some reach up to 40 meters, giant holes will produce ponds which can change the environment both physically, chemically, and biologically, it will affect the water quality and also the biota in the pond [Abdullah et al., 2018]. Changes in the pH of soil and water during the mining process are caused by exposure to rock strata, which increases the solubility of micro elements, so that the environment is not in accordance with its designation [Talukdar et al., 2016; Said et al., 2021b]. During the dry season, acid water in the former coal mining ponds is widely used by the surrounding community for washing, bathing and drinking water needs. Surface water has chemical properties and composition that changes with the changing seasons and after rain [Yildirim et al., 2019; Kiswanto et al., 2022].

In the process of treating raw water into drinking water, treatment is needed that meets existing quality standards, so that the resulting product is of high quality and does not endanger human health [Arifin et al., 2019; Setiawan et al., 2018]. Water treatment is currently carried out conventionally such as coagulation, flocculation, sedimentation and filtration. Currently water treatment can be carried out using membrane technology (specifically nanofiltration and / or reverse osmosis) [Hidayah et al., 2018; Kiswanto et al., 2020]. Drinking water treatment that has been implemented in Indonesia in the form of conventional treatment consists of Coagulation-Flocculation, Sedimentation and Filtration. However, conventional processing has limitations such as requiring large areas of land, operations and complex maintenance to the quality of water that is still below standard [Vatral et al., 2023; Kiswanto et al., 2019]. This raises the thought to develop even further to modify it with new technology. Lately, one technology that is widely used in developed countries is Membrane Technology [Wenten., 2015]. This technology is a clean technology that is environmentally friendly because it does not cause adverse effects on the environment. This membrane technology can reduce organic and inorganic compounds that are in water without the use of chemicals in its operation [Kiswanto et al., 2020 ; Theron et al., 2008] As one of the separation techniques, membrane technology in its application can be aimed at concentration, purification, fractionation, and reaction intermediaries [Ghazem et al., 2023].

Scarcity and decline in the quality of fresh water accompanied by increasing water demand from both the community and industry is a driver of the need for quality water treatment technologies that are environmentally friendly [Munirasu et al., 2016]. Water treatment is thus a great opportunity for membrane technology applications. As a relatively new technology, membrane processes offer benefits that are not obtained from conventional processes. One of the advantages of applying membrane technology is the low energy used. The membrane process, especially nanofiltration, is even the Best Available Technology for water treatment. In waste treatment, membrane technology can be applied directly and indirectly. The nanofiltration process resounds hardness, removes bacteria and viruses, removes color due to organic substances without producing harmful chemicals such as chlorinated hydrocarbons [Istirokhatun et al., 2021]. Nanofiltration is suitable for low dissolved total solid water, softened and removed organic. Its rejection properties are typical of ion types: dualival ions are removed more quickly than the equivalent, according to when the membrane is processed, formulation like a maker, temperature, annealing time, and so on [Tan et al., 2024]. The basic formulation is similar to reverse osmosis but the operational mechanism is similar to ultrafiltration. So nanofiltration is a combination of reverse osmosition and ultrafiltration [Ramos et al., 2020].

Nanofiltration is sometimes referred to as “loose RO” due to the greater gap size and lower pressure needs for RO [Ysulat et al., 2023]. Although it does not have the ability to filter monovalent ions like RO, the NF process has the ability to exclude organic compounds. For hospital wastewater treatment applications, the NF process is able to set aside COD, NH3-N, and PO4-P to 92%, 88%, and 68% [Kiswanto et al., 2023; Tan et al., 2024]. Other uses, for example in wastewater. Nanofiltration is a relatively new membrane filtration process that is frequently used in conjunction with water that has a low total dissolved solids content to soften (remove polyvalent cations) and remove disinfection byproducts, such as natural and synthetic natural substances [Munirasu et al., 2016]. Nanofiltration is one membrane that operates on the basis of pressure as a driving factor [Ang et al., 2015 ; Bodzek et al., 2015]. Based on type, nanofiltration membrane has a structure asymmetric consisting of a thin membrane skin layer (0.005-0.3 μm) lining the sublayer (100–300 μm) which provides porous support [Li et al., 2017]. Nanofiltration has pores that are roughly 1–5 nm [Bodzek et al., 2015]. Nanofiltration membrane process can eliminate natural organic debris, uspended solids, bacteria, viruses, salts, and divalent ions which are contained in water. Nanofiltration operates at lower pressure than reverse osmosis, between 50–150 psi [Abdulghader et al., 2021; Tan et al., 2024]. The membrane used in nanofiltration operates on the principle of diffusion of its solution, However, unlike in microfiltration or ultrafiltration, where pore size prevents ions from flowing through the membrane, monovalent ions diffuse through the membrane [Li et al., 2017]. For example, color, sugar, and dye removal, as well as precursor, hardness, and sulfate removal, can all be accomplished by nanofiltration THM from water supplies or waste water sources such as acid mine drainage (AMD) [Kiswanto et al., 2021a; Qu et al., 2018]. The new innovation that will be carried out for coal mine acid water treatment is treatment using Nanofiltration membrane technology to obtain water with a much better quality that can even be consumed directly.

RESEARCH OF METHODS

Materials

The materials used are;

1. Synthetic acid from coal mining ponds is adjusted to the characteristics of coal acid water taken from coal mining pools in West Aceh.
2. NF-270 Nanofiltration Membrane (DOW FilmtecTM Membrane Production)

Tools

The instrument used in this research is the Nanofiltration membrane reactor:

1. Membrane filtration equipment
2. Genesys 105 UV-VIS Spectrophotometer from Thermo Scientific USA with accuracy of 0.001
3. COD Reactors from HACH USA
4. Model 210 VGP AAS (atomic absorbtion spectrophotometer) from Buck Scientific USA.
5. TDS meters from HM Digital USA
6. Turbidimeter Portable Micro TPW field from HF Scientific USA
7. SEM (scanning electron microscopy)
8. FTIR (Fourier transform infra red) from Shimadzu Japan
9. pH meter

Set of tools

The series of tools used looks like Figure 4.2 which uses a Reverse Osmosis Presurer Buster Micron Water Purifier pump with the following specifications:

- voltage – 220–240 VAC,
- current – 0.22 AMPS,
- open flow – 0.31 GPM,
- presure – 100 Psi.

Research procedure

Before the filtration process was carried out with Nanofiltration, the instrument was compacted for 30 minutes using Aquades. Next, coal acid water is made in an artificial solution. After an artificial solution is made as a synthetic solution

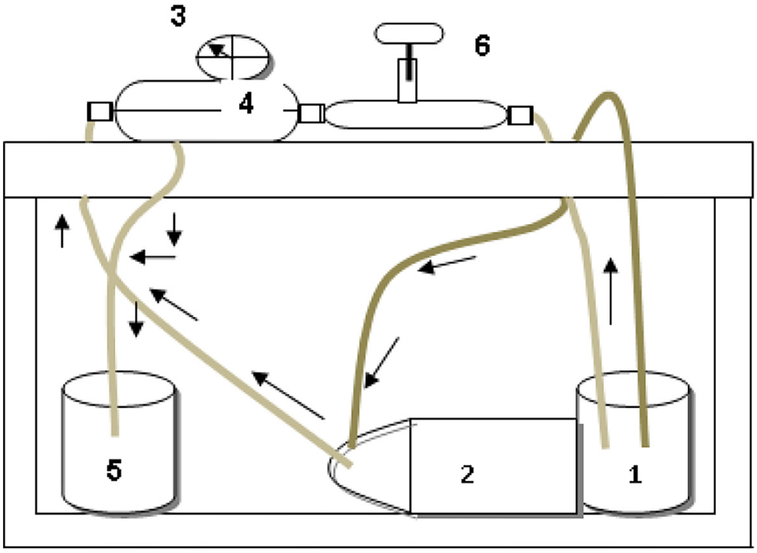

Figure 1. Schematic work of membrane filtration [16]; Information: 1 – feed tank; 2 – pump; 3 – valve; 4 – pressure gauge; 5 – membrane compartment; 6 – permeate tank

of coal acid water then it is stirred using a homogenizer. This synthetic coal acid water solution as feed to be flowed in a 270 variable Nanofiltration membrane device used is the difference in operating pressure (4 bar, 5 bar and 6 bar) and time (0, 15, 30, 45, 60, 75, 90, 105, 120 minutes).

Analysis of results

The analysis carried out are: membrane flux and membrane rejection, turbidity, color, COD, TSS, TDS, Fe and Mn.

Flux calculation

The feed is channeled into membrane filtration at 4 bar, 5 bar and 6 bar pressure for 120 minutes. Sampling is done every 10 minutes with a shelter for 5 minutes, so a total of 15 minutes. This membrane was obtained from Alfa Laval, Sweden and printed with a diameter of 4.22 cm and To stabilize the structure of the pore and membrane, it is compressed for 30 minutes. The study was conducted by cross flow filtration and carried out for 3 hours with permeate taking time every 15 minutes.

Flux is calculated from data of sample volume (V), sampling time and membrane surface area (A). From the volume and time of sampling data (t), the permeate volumetric flow rate (Q) is obtained ($Q = V/t$). After obtaining the data, the flux calculation is then performed as follows;

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

Membrane rejection

Rejection analysis is done by comparing the concentration of parameters contained in the produced water and permeate feed produced. The equation of rejection calculation is as follows;

$$\% R = 1 - \frac{Cp}{Cp} \times 100\% \quad (2)$$

pH analysis

The pH analysis is carried out using a pH meter HI 96107, before measuring for the sample, the instrument is calibrated first using a pH buffer solution 7. Then for measuring the tool sample is put into the sample solution to a certain height limit.

COD analysis

Chemical oxygen demand (COD) analysis is carried out using a COD meter. The first step is sample preparation. If a dilution is required, a dilution is carried out first, then each sample of 2 ml is mixed into a regen tube using COD reactor HI 839800 for 2 hours at 150 °C. After the sample is heated, let it sit first until it warms up for about twenty minutes, then it is then adjusted and allowed to stand until it is completely cold. After that the reading of the sample is done with a photometer.

TSS analysis

TSS analysis is carried out using gravimetry.

TDS analysis

TDS analysis is done by using a HM digital USA TDS meter

Fe analysis

Fe analysis was carried out using AAS (Atomic Absorbtion Spectrophotometer) Model 210 VGP from Buck Scientific USA

Mn analysis

Mn analysis was carried out using Buck Scientific USA's AAS (Atomic Absorbtion Spectrophotometer) Model 210 VGP.

RESULTS AND DISCUSSION

This research will examine whether nanofiltration Technology is applicable to acid water in coal mines treatment so that it meets specified quality standards. From the results of the study, raw water was analyzed to determine its characteristics. The parameters analyzed were pH, temperature, color, turbidity, TSS, TDS, COD, Fe, Mn and *E. coli*. Table 1. below shows the characteristics of raw water taken from a former coal mining pond in West Aceh.

From the results of the analysis above shows that the acidic water quality in the former coal mining ponds does not meet drinking water quality standards [Kiswanto et al., 2028b; Ministry of Environment., 2021] especially for the parameters of pH, turbidity, color, TSS, TDS, COD and Fe, and therefore need to be processed first. For E. coli it is not found in coal mine acidic water.

Table 1. Results of analysis of characteristics of acid water in coal mining ponds

Parameter	Unit	Raw water (coal mining ponds)				KEPMENKES 907/2002
		Station 1	Station 2	Station 3	Avarage	
pH	-	4.2	4.3	5.0	4.5	6.5–8.5
Temperature	°C	26.5	26.3	26.6	26.5	25–28 °C
Color	Mg/LPtCo	5.74	5.74	2.59	4.7	Maxs 15
Turbidity	NTU	15	9.8	7.6	10.8	Maxs 5
TSS	mg/L	376	272	132	260.0	Maxs 50
TDS	mg/L	256	221	167	214.7	Maxs 500
COD	mg/L	252.8	253.2	82.9	196.3	100
Fe	mg/L	8.24	3.03	2.76	4.7	0.03
Mn	mg/L	0.01	< 0.01	< 0.01	0.01	0.1
E. coli	MPN/100 mL	–	–	–	–	–

Note: N.B.: – did not undertake.

Feed flux test

A profile of the feed flux in the form of acidic water in a coal pool as it passes through the nonofiltration membrane is presented in Figure 2. The flux normalization profile (J/J_o) at various pressure variations can be seen in Figure 2. In general, after fifteen minutes of nanofiltration, the flux value has decreased. This is because at the beginning of the nanofiltration membrane there were no particle deposits on the membrane surface. The longer the time the more particles are stuck on the membrane surface so that the occurrence of fouling. The effect of deposition of solids on the membrane surface on the initial flux reduction is quite significant. Increased filtration time makes the displacement of the eyerial foulant on the membrane surface relatively reduced so that the effect on decreasing flux is also reduced.

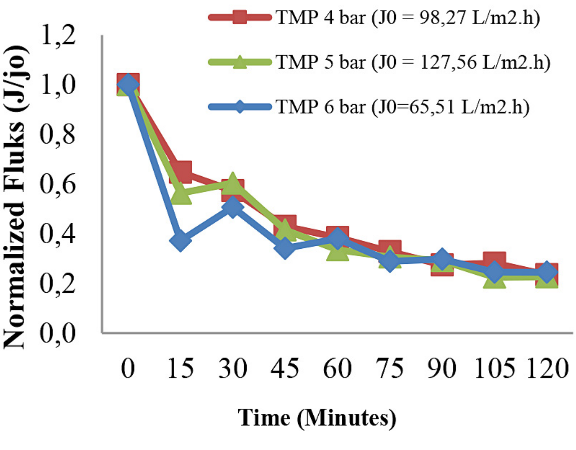

Figure 2. Flux profile (J/J_0) on filtration using NF270 nonofiltration membrane

From the picture above it can be seen that the addition of pressure affects the decrease in flux. The higher the pressure, allowing the bait to pass through the membrane quickly and the more foulan that accumulates on the membrane surface and membrane structure, causing pore blockage more quickly than at low pressure [Zoka et al., 2020]. The sieving mechanism occurs during the waste treatment process using a membrane unit which causes a separate feed based on size according to the pore size of the membrane used. Figure 2 shows the bait flux profile which is affected by the membrane pore size. Fouling is a result of the deposition of particles on the membrane will be faster. Different pore sizes can affect the value of the resulting flux [Ysulat et al., 2023]. The length of time of operation also affects the amount of flux produced. The longer the operating time, the smaller the flux produced. According to [Alkhudhiri et al., 2013], this is caused by fouling which includes concentrations of polarization, adsorption, formation of gel layers, and pore blockages.

Membrane rejection

Membrane performance is also determined by the ability of rejection of several parameters, namely turbidity, color, COD, TDS, TSS, Fe and Mn. From Figure 3. visually visible turbidity, color, COD, TSS, TDS, Fe and Metal rejection experienced a significant decrease in each trans membrane pressure (TMP). The decrease in rejection occurs along with the increase in TMP. This is because at high pressures a high diffusion rate results in faster feed interactions and the membrane is difficult to hold the diffuse feed

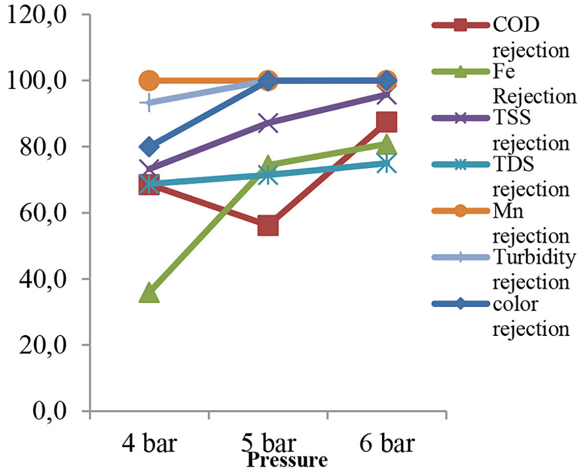

Figure 3. Results of coal mine acid water rejection at various transmembrane pressures

through the membrane so the rejection coefficient is low. Transmembrane pressure in the nanofiltration process serves as the driving force and is one of the most important operating parameters in the membrane separation process. High rejection means that the molecule or dissolved particles are blocked by the membrane and cannot diffuse against the membrane. Coal mine acid water rejection can be set aside very well. Membrane performance is also determined by the ability of rejection of several parameters, namely turbidity, color, COD, TSS, TDS, Fe and Mn.

Turbidity

The coal mine acid water wastewater feed has a turbidity parameter value of 10.8 NTU. Pretreatment or prefiltration is necessary if the turbidity value of the feed is above 10 NTU and is done to reduce the concentration of dissolved solids before entering the membrane unit [38]. The turbidity parameter value after passing through the prefiltration is 7.95 NTU. The values of turbidity parameters for feed and permeate after being treated with membrane units are presented in Table 2. Based on Table 2 shows the resulting rejection rate for turbidity parameters at all operating pressures reached 96.23–100%. This research results, Nanofiltration membranes are able to produce permeats/products with low turbidity values. Membrane pores also affect the rejection of turbidity parameters. Another factor that influences the level of turbidity rejection is pressure.

Table 2. Turbidity rejection in nanofiltration membranes with pressure variations

Membrane	Pressure (bar)	Turbidity (NTU)	Rejection (%)
NF 270	4	0.33	96.23
	5	0.1	98.7
	6	0	100

Decreased rejection rate that occurs in the Nanofiltration Membrane is caused by the addition of thrust to the bait to pass through the pore membrane causing the permeate to increase the amount of solute concentration and a decrease in the rejection level. This is consistent with research [Kiswanto et al., 2021b] that the higher the operating pressure will cause the lower the rejection parameters.

Color

Coal mine acid wastewater feed has color parameter values for three stations with an average of 4.7 pt.co. The values of the feed and permeate color parameters after processing with the Nanofiltration membrane unit are presented in Table 3.

Table 3. Color rejection in nanofiltration membranes with pressure variations

Membrane	Pressure (bar)	Color Pt-Co	Rejection (%)
NF 270	4	1	79
	5	0.1	98
	6	0	100

COD (biochemical oxygen demand)

The COD value in the acid water feed in the coal mining pond is 196.3 Mg/L. COD is still above the quality standard so it is still dangerous for drinking water quality standards water. Table 4 shows the COD rejection for the F 270 membrane at 4, 5, and 6 bar working pressures

From the results of the study shown in Table 4. it can be seen that the pore size expressed in molecular weight cut off (MWCO) influences the removal of COD parameters. Nanofiltration membranes have better COD parameter rejection rates than Microfiltration and Ultrafiltration according to research conducted by [Ang et al., 2015] that the smaller the pore size, the COD parameter rejection rate will increase. This is due to organic substances that are It will remain larger than the membrane pore in the membrane pore so

Table 4. COD rejection of nanofiltration membranes with pressure variations

Membrane	Presure (bar)	COD (mg/L)	Rejection (%)
NF 270	4	82.6	57.9
	5	71.3	63.7
	6	33	83.19

that the content of organic humat acid substances in the permeate is reduced.

Another factor influencing the rejection rate of COD parameters is pressure. The increase in the level of rejection of the nonofiltration membrane at 4, 5, and 6 bar pressure is caused by the addition of pressure resulting in the rapid formation of fouling on the surface and membrane structure so that it can reduce membrane's pore size and expand the membrane's ability to revise COD parameters [Istirokhatun et al., 2021; Munirasu et al., 2016]. The level of rejection which decreases with the addition of pressure can be caused when the pressure is added, the process of reducing the pore on the surface and the pore of the membrane is inhibited thereby reducing the performance of the membrane in the sieving mechanism [Kiswanto et al., 2029].

Total suspended solid

For TSS parameters in the NF270 nanofiltration membrane the rejection rate was 73.3%; 87.2% and 95.8% for pressures 4, 5, and 6 bars (Table 5). From the results of the study, Nanofiltration membranes are able to produce permeats / products with low total suspendet solid (TSS) values. Membrane pores also affect the TSS parameter rejection.

Another factor influencing the level of rejection of TSS parameters is pressure. The decrease in the rejection rate that occurs in the NF270 Nanofiltration Membrane is caused by the addition of thrust to the bait to pass through the pore membrane causing the permeate to increase the amount of solute concentration and a decrease in the rejection level. This is consistent with research [Munirasu et al., 2016] that the higher the operating pressure will cause the high the rejection parameters.

Table 5. TSS rejection of nanofiltration membranes with pressure variations

Membrane	Pressure (bar)	TSS (mg/L)	Rejection (%)
NF 270	4	69.5	73.3
	5	33.2	87.2
	6	10.9	95.80

Total dissolved solid)

For TDS parameters, NF270 membrane is able to produce permeats with a fairly low TDS value. From this study the TDS obtained was a range of 62.7%; 66%; and 70.19% for 4, 5, and 6 bar pressures, respectivel. The results showed the level of rejection produced is higher in addition to applying more pressure. This is in line with the investigation of [Parashar et al., 2022] which states that as flow increases, so will the degree of salt rejection (NaCl) [Ang et al., 2015]. Mentioned, for the level of rejection of Cl-membrane NF270 can reach 40.2–83.1% based on temperature, pH, pressure, and bait concentration. Furthermore, the rate of chloride ion transfer causes the chloride ion rejection rate to rise as operating pressure rises.

Iron metal

For Fe parameters, The NF270 nanofiltration membrane has the ability to extract Fe metals with a rejection rate of 36%; 74.5%, and 100% at 4, 5 and 6 bar pressure. The level of rejection produced is higher along with the greater pressure used. This proves that the performance of NF270 nanofiltration membranes is indeed good for removing multivalent metals as mentioned by [40] that nanofiltration is usually used for removal of heavy metals and mixed solutions containing multivalent ions. At 6 bar pressure the Fe metal ion can reach up to 100%.

Table 7 shows the lowest value of decreasing Fe content which is 36% at a pressure of 4 bar processing time 120 minutes while the highest value decreasing Fe content is 100% at a pressure of 6 bar processing time 120 minutes. The best reduction of Fe content reaches 0.01 mg / L. Based on the Decree

Table 6. Rejection of TDS in nanofiltration membranes with pressure variations

Membrane	Pressure (bar)	TDS (mg/L)	Rejection (%)
NF 270	4	80	6.7
	5	73	66.0
	6	64	70.19

Table 7. Rejection of Fe in nanofiltration membranes with pressure variations

Membran	Pressure (bar)	Fe (mg/L)	Rejection (%)
NF 270	4	3.01	36.0
	5	1.2	74.5
	6	0	100.0

Table 8. Rejection of mn in nanofiltration membranes with pressure variations

Membrane	Pressure (bar)	Mn (mg/L)	Rejection (%)
NF 270	4	0	100
	5	0	100
	6	0	100

of the Minister of Environment No. 492/MENKES/PER/IV/2010 regarding the maximum levels of Fe in coal processing waste is 7 mg/L.

At low concentrations of iron can cause taste or odor of metals in drinking water, therefore for drinking water the levels of iron allowed are respectively 0.3 mg/l [Malinovic et al., 2022]. Drinking water quality standards in Indonesia based Predicated on Environment Minister's Decree No. 492/MENKES/PER/IV/2010 stipulate the maximum permissible levels of iron in drinking water of 0.3 mg/l. Whereas for drinking water based Predicated on Environment Minister's Decree No. 492/MENKES/PER/IV/2010 the allocation of water resources, water quality parameters for group I for Fe content is 0.3 mg/l.

Mangan

For Mn parameters, Mn metals may be removed using NF270 Nanofiltration membrane with a rejection rate of 100%; 100% and 100% at 4, 5 and 6 bar pressure. The level of rejection produced at pressures 4, 5 and 6 bar is able to repel the Mn metal ions to 100%. This proves that the NF270 nanofiltration membrane's performance is indeed good for removing multivalent metals as mentioned by [Almazan et al., 2015] that nanofiltration is usually used for removal of heavy metals and mixed solutions containing monovalent / multivalent ions. At 6 bar pressure the Fe metal ion can be revised up to 100% (Table 8). The research showed that the best concentration of Mn at all pressures decreased to 100%. So that the levels in zero percent permeate. Based on data from the Minister of Environment Decree No. the Minister of the Environment's Decree No. 492/MENKES/PER/IV/2010 that the maximum allowable content is 4 mg/ L, so this result is in accordance with the allotment for drinking water. which is desired. Manganese can cause a taste or odor of metals in drinking water, therefore for drinking water levels of manganese are allowed 0.05 mg/l [Kiswanto et al., 2020; Kiswanto et al., 2023; Almazan et al., 2015]. Drinking water quality standards in Indonesia based on Ministry of Health Decree No. 907 of 2002 stipulates the maximum allowable manganese content of 0.1 mg/l.

Fouling characterizations of membrane surface characterization by SEM

Figure 4 demonstrates the surface fouling's existence of the membrane used to treat coal mine acid water. Fouling occurred due to formation of a gel/cake layer. This gel/cake layer was formed from humic acid. The formation of this layer also caused an increase in the screening mechanism shown in Figure 5, the particles were attached to the gel layer. The presence of kaolin and salt in the feed also affected the contamination process. In addition, the presence of NaCl and $FeCl_3$ can form an electrolytic double layer (EDL) on the surface of kaolin, which can reduce the charge of kaolin, so that the stability

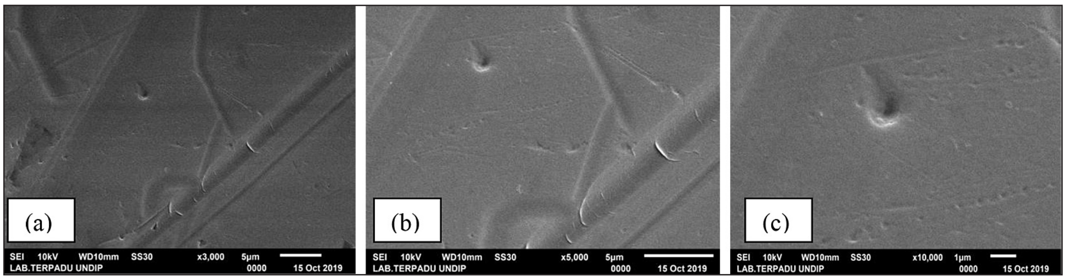

Figure 4. SEM analysis of used fresh membrane in different magnifications (a) 3,000x, (b) 5,000x, (c) 10,00

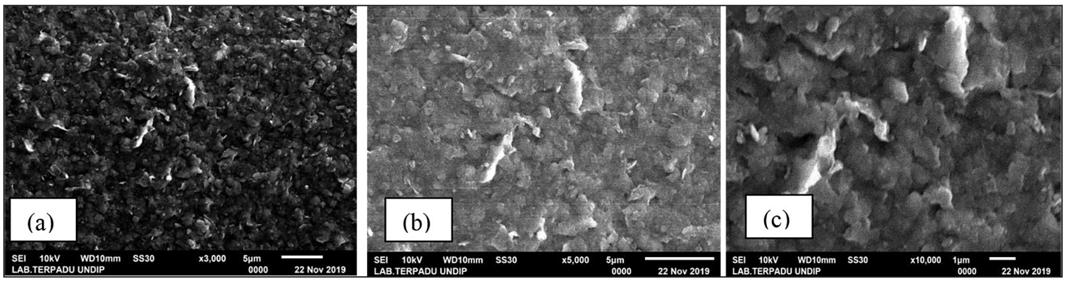

Figure 5. SEM analysis of used treat membrane AMD from West Aceh in different magnifications (a) 3,000x, (b) 5,000x, (c) 10,000x

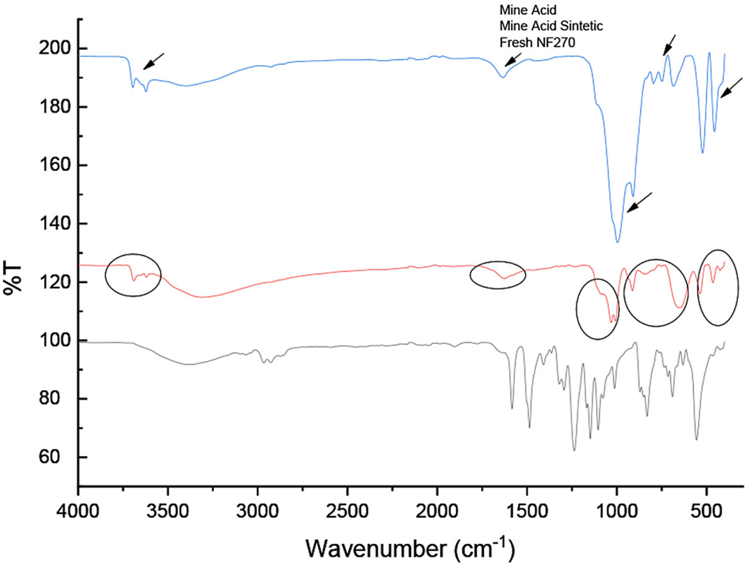

Figure 6. Spectrum FTIR from fresh membrane and fouling membrane (acid water from coal mines sintetic and acid water from coal mines)

of colloids is improved disturbed which in turn formed aggregates between kaolin particles.

Because of the cation exchange with the system's H^+, the presence of a monovalent cation may make the zeta potential more negative. [Munirasu et al., 2016]. Because of the ion exchange that took place, the EDL's thickness increased. Fe^{3+}, a divalent cation, caused kaolin's zeta potential to be lower than that of monovalent cations. The lower the zeta potential, the thinner the EDL, and the higher the ion concentration or more valence of the ion. Reaction between colloids and cations could affect fouling and rejection rates. The more cations adsorbed on kaolin the higher salt rejection rate. This phenomenon resulted fouling in membrane surface. The formation of this gel layer was caused by several things. One of them was because of the suspended solids that had not been removed from the initial screening. In addition, Other organic and inorganic substances also contributed significantly to the fouling formation process due to their enabling properties. the occurrence of each component reactions. Possible interactions were organic compounds with colloids, organic compounds with metals, and metals with colloids [Arifin et al., 2019; Hidayah., 2018]. stated that fouling on NF270 membranes could be caused by precipitation of inorganic compounds, colloidal fouling, adsorption of organic compounds, and/or biofouling.

Characteristics with FTIR

The decrease in flux is due to the fouling that occurs due to adsorption and deposition of particles on the membrane. To prove the existence of this fouling, FTIR analysis is needed to see the foulan functional groups on the membrane surface. Figure 10 is the result of testing the new NF270 membrane (fresh membrane), synthetic mining acid water, and original mine acid water using FTIR. Fouling characteristics that occur on the membrane surface are indicated by the emergence of new peaks or a shift from the previous peaks. In the picture above there is a difference in the peak of the synthetic acid mine fouling water membrane (marked with a circle) at peaks 465,06 cm^{-1}, 2787–3664 cm^{-1}, 913 cm^{-1}, 1031 cm^{-1}, 1107 cm^{-1}, and so on. It shows the presence of M – X (M = metal, X = halogen) at a wavelength of 465,06 cm^{-1} because it is in the range of M – X 100–750 cm^{-1} as mentioned by [Ntshangase et al., 2022]. This peak indicates the presence of $FeCl_3$ or NaCl on the membrane surface. At a wavelength of 913 cm^{-1} there is an Al-OH group originating from kaolin. This is in line with research [Onstad et al., 2008] which states Al-OH appears at peaks 911–915 cm^{-1}. At 1041 cm^{-1} and 1107 cm^{-1} showed the presence of Si-O groups originating from kaolin as stated by [Ntshangase et al., 2022; Oluwasola et al., 2022]. As for Humic Acid, IR frequency is indicated at wavelengths of 1058–960 cm^{-1}. At frequencies 600–1500 cm^{-1} indicate the presence of C-O and C-C groups. 2900–3450 cm^{-1} indicates the presence of C-H and O-H groups. Whereas at 3618–3712 cm^{-1} can indicate the presence of O-H groups originating from kaolin [Mena et al., 2016 ; Sayed et al., 2024].

In the original acid mine water fouling membrane there is also a peak difference at 457 cm^{-1}. 1014 cm^{-1}, 1637 cm^{-1}, 2912–3915 cm^{-1} (marked with an arrow). The wavelength of 457 cm^{-1} indicates the presence of inorganic molecules M – X (M = metal, X = halogen) because it falls in the range of M = X 100–750 cm^{-1} as mentioned by [Kiswandono et al., 2024]. Wavelength of 911 cm^{-1} indicates the presence of Si-O groups originating from TSS. In Stuart [Mahardika et al., 2012], a wavelength of 1637 cm^{-1} in the original coal acid mine indicates the presence of a primary amide group (NH_2). Whereas the wavelengths of 2912–3915 cm^{-1} indicate the presence of O-H, C-H, and N-H groups. According to Mistry [Ministry of Environment., 2021], at frequencies 2500–3335 cm^{-1} can indicate the presence of OH groups from carboxylic acids. In general, the differences that occur in the fresh membrane and membrane fouling indicate that there is indeed fouling on the membrane surface that comes from organic and inorganic compounds. The FTIR results show that there was indeed a foulan deposition on the membrane surface.

CONCLUSIONS

The higher operating pressure produced higher flux and affects the rejection rate. Flux for the coal acid mine’s feed water experience d a sharp decrease within the first 15 minutes insignificantly afterwards. This sharp decrease occurred due to rapid deposition of foulant on the membrane surface resulting in fouling as indicated by the results of membrane characterization with FTIR and SEM.

Acidic water rejection in turbidity parameters for 4, 5 and 6 bar pressures was 96.23%, 98.7%, 100%, respectively. In the color parameters for pressures 4, 5 and 6 bars respectively 79%, 98%, 100%. In the COD parameters for pressures 4, 5 and 6 bars respectively 57.9%, 63.7%, 83.19%. TSS parameters for 4, 5 and 6 bar pressures were 73.3%, 87.2%, 95.8%, respectively. The TDS parameters for 4, 5 and 6 bar pressures were 62.7%, 66%, 70.19%, respectively. Fe metal parameters for pressure 4, 5 and 6 bar respectively 36%, 74.5%, 100%. Mn metal parameters for pressures 4, 5 and 6 bars were 100%, 100%, 100%, respectively. It can be concluded that the NF270 nanofiltration membrane can be used for treating coal mine acid water into drinking water. For acid mine drainage water pressure of 5 and 6 bar is needed so that the permeate is obtained better results. Because without the prefilterization process the results of the permeate value are above the water quality standard for the Drinking Water Company. The difference in the level of rejection due to variations in pH and concentration in acid mine water feed. A neutral pH will make the rejection process easier than an acidic pH. Nanofiltration Membrane 270 will be able to remove heavy metals in acidic water waste up to 90%.

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