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Integrated Process of Palm Oil Mill Effluent using Electrocoagulation, Active Carbon Filter, Zeolite and Membrane Separation Technology

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Abstract

Palm Oil Mill Effluent (POME) is a type of agro-industrial organic originating from the by-products of the processing of fresh fruit bunches (FFB) of oil palm. Palm oil waste pollution decreases environmental quality which will indirectly be harmful to the environment and human health. This research aims to treat palm oil liquid waste using electrocoagulation process, activated carbon filter, zeolite and membrane separation technology in an integrated manner. The combination of palm ash and zeolite was found to be the most effective in reducing pH, TSS, COD, BOD, and fatty oils. The electrocoagulation method best conditions are at a voltage of 15 Volts and an operating time of 90 minutes. The system of integration of the electrocoagulation process, activated carbon filters, zeolite and membrane separation technology has proven to be very effective for processing palm oil mill wastewater. The treatment results meet the quality standards based on Governor of South Sumatra Regulation No. 8 of 2012 concerning Liquid Waste Quality Standards for Industrial, Hotel, Hospital, Domestic and Coal Mining Activities and based on Government Regulation no. 22 of 2021 concerning Implementation and Management of the Environment (Annex 6 National Water Quality Standards) with average results: pH 7.02 TSS 44.6 mg/L, COD 24 mg/L, BOD 2.89 mg/L and fatty oils 1.2 mg/L

Keywords: Palm Oil Mill Effluent, Electrocoagulation, Zeolite, UF Membrane, Fatty Oil

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Abstrak (Indonesian)

Limbah cair pabrik kelapa sawit (LCPKS) merupakan salah satu jenis limbah organik yang berasal dari hasil samping proses pengolahan tandan buah segar (TBS) kelapa. Pencemaran limbah kelapa sawit dapat menurunkan kualitas lingkungan yang secara tidak langsung akan berbahaya bagi lingkungan dan Kesehatan manusia. Penelitian ini dilakukan untuk mengolah limbah cair kelapa sawit dengan proses elektrokoagulasi, filter karbon aktif, zeolit dan teknologi separasi membran secara terintegrasi. Variasi abu kelapa sawit dan zeolit merupakan variasi yang paling baik untuk menurunkan nilai pH, TSS, COD, BOD dan Minyak Lemak. Pada metode elektrokoagulasi ini kondisi terbaik ada pada tegangan 15 Volt dan waktu operasi 90 menit. Sistem Integrasi proses elektrokoagulasi, filter karbon aktif,zeolit dan teknologi separasi membran terbukti sangat efektif digunakan untuk pengolahan limbah cair pabrik kelapa sawit. Hasil pengolahan memenuhi peraturan Gubernur No. 8 Tahun 2012 tentang Baku Mutu Limbah Cair Bagi Kegiatan Industri, Hotel, Rumah Sakit, Domestik dan Pertambangan Batubara dan berdasarkan Peraturan Pemerintah No.22 Tahun 2021 dengan hasil rata- rata sebagai berikut : pH 7,02 TSS 44,6 mg/L, COD 24 mg/L, BOD 2,89 mg/L dan minyak lemak 1,2 mg/L.

Kata Kunci: Limbah Cair Pabrik Kelapa Sawit, Elektrokoagulasi, Zeolit, Membran UF, Minyak Lemak

INTRODUCTION

Association Businessman Crude Palm Oil Indonesian reported that Indonesia's CPO production in 2021 is 47 million tons. This production increased from 2020 which was 43 million tons. The current rapid industrial development causes industrial waste to increase. As a result, the waste dumped into the environment is getting heavier. Even though nature's ability to accept waste loads is very limited.

Palm Oil Mill Effluent (POME), one of type waste organic agro industry as water, oil and solids organic origin formed from results processing plant of coconut fresh fruit bunches palm for produce Crude Palm Oil (CPO) [1]. Some of the reasons for the difficulty of treating POME: 1) Palm oil comes from plants, and is an element that is very difficult to decompose through biological processing. 2) Sludge with a high concentration and mixed oil, the oil content becomes difficult to float, so that the separation of oil-water becomes difficult. 3) In addition, when the temperature of the wastewater drops, the palm oil contained becomes easy to condense, for this reason the oil sticks to the sludge, the viscosity will increase, the surface becomes scam-shaped, so that the oil-water separation becomes impossible. 4) If wastewater with these conditions is delivered by means of a pump, the process of forming an emulsion from palm oil will take place, making it very difficult to separate the oil-water

Palm oil waste pollution can reduce environmental quality which will indirectly be harmful to the environment and human health. This is because palm oil mill wastewater has a high organic matter content with an average BOD of 26,222 mg/L, an average COD of 62,934 mg/L, is acidic in nature (pH 4.05-4.15), contains oil and suspended and other dissolved solids. So far, the process of treating palm oil mill wastewater uses aerobic and anaerobic ponds, but this system requires a very long hydraulic residence time. Seeing that the palm oil factory liquid waste treatment system is taking so long, we are looking for ways of processing that can be done for the palm oil factory liquid waste [2].

Palm Oil Mill Effluent (POME) is the largest waste from palm oil production process [3]. The average palm oil mill processes every ton of fresh fruit bunches (FFB) into 200-250 kg of crude oil, 230-250 kg of empty palm fruit bunches (EFB), 130-150 kg of fiber, 60-65 kg of shells, 55- 60 kg of kernels, and 0.7 m^3 of waste water [4]. POME has a high concentration and is dark brown in color and often causes pollution. Table 1 is listed the characteristics of POME.

Table 1. Characteristics of POME Entering the Waste Control Pond

No.	Parameter	Unit	Value
1.	BOD	mg/L	22,673
2.	COD	mg/L	38,164
3.	Suspended Solid	mg/L	10,016
5.	Oil and Fat	mg/L	96,8
6.	pH	-	4.45

Source: initial analysis result of POME

Table 1 shows that POME contains high organic matter which makes the levels of pollutant materials even higher. In general, the impact caused by the waste water of the palm oil industry is the contamination of the receiving water bodies, because almost every palm oil industry is located near rivers. If it is untreated, palm oil industry waste water will form ammonia, this is caused by the organic matter contained in the liquid waste decomposes and forms ammonia. Ammonia is formed which will affect the life of aquatic biota and can cause a foul odor [5].

The palm oil mill's wastewater possesses elevated temperatures, a brownish hue, and includes dissolved and suspended solids such as colloids and residual oils. Moreover, it exhibits high levels of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Discharging this wastewater directly into bodies of water can result in environmental pollution. The discharge would settle and decompose gradually, depleting dissolved oxygen levels, causing turbidity, emitting a pungent odor, and potentially causing harm to aquatic ecosystems [6].

Before wastewater from several palm oil industries in South Sumatra can be discharged into the environment. The initial step is to ensure that it undergoes the necessary treatment to meet the waste quality standards outlined in Point 4 on page 2 of Governor of South Sumatra Regulation No. 8 of 2012 dated 15 February 2012.

To reduce water and soil pollution in the environment due to the difficulty of treating POME, process and equipment modifications are needed so that the waste can be properly treated. This is what will be done in this research. The design of the device that will be carried out uses several stages, namely the initial stage of pretreatment (Sedimentation) then proceeds to the process of electrocoagulation, filtration (activated carbon and zeolite filters) and membrane separation (Ultrafiltration membranes).

The purpose of this research is to treat POME so that it meets the Wastewater Quality Standards so that it does not pollute the Environment and meets the

Wastewater Quality Standards for palm oil industrial activities. Design a POME Processing Tool.

In this research, the POME treatment process was carried out using the electrocoagulation method, Activated carbon Filters and Membrane Systems into a series of equipment from the POME pretreatment system to the use of Filters and Membranes. The Quality Standard for Palm Oil Industry Waste is expected to be impacted by the outcomes of the POME's processing process, according to South Sumatra Governor Regulation No. 8 for 2012.

MATERIALS AND METHODS

Materials

This Research use POME as much as 50 Liters originating from factory is located in South Sumatra. Equipment Set: Pipes, Pumps, Filter Media (Palm ash), Zeolite, Activated Carbon and Membranes Ultrafiltration

Methods

Preparation of POME (sedimentation stage)

The waste is put into the Storage Tank to be carried out in the sedimentation process for approximately 1-2 days to form 3 layers. taken the middle part in the form of liquid waste that has been separated from the solid particles.

Palm ash activation

Palm ash from the process of burning oil palm bunches is activated with NaOH solution for 2–3 hours, then the activated carbon is washed with distilled water until the pH is neutral and heated at high temperature.

Membrane manufacturing process

The membrane material was chosen based on the results of previous studies where variations of palm ash and zeolite were the best variations for reducing pH, TSS, COD, and BOD values [7]. The material will be printed in the form of a tube which will be used as a membrane media.

Manufacturing process of electrocoagulation equipment

The electrocoagulation apparatus used in this study was made from PVC pipe, the pipes used in the installation of electrocoagulation devices are at sizes of 1 inch and 4-inch. The 4-inch pipe is made into 4 parts of the same length and then perforated with a size of 1 inch to be connected with 4 pieces of 4-inch pipe. The PVC pipe that has been connected at the bottom of each pipe is closed using a 4-inch PVC pipe hubcap. At the top of each pipe is given anode and cathode which have been connected to the positive and negative currents in the power supply device. the positive part uses a metal plate made of aluminum and the negative part uses a metal plate made of iron. Then enter the POME using the pump and the power supply is turned on so that the anode/cathode in each pipe is electrified where it will come into contact with the POME and a reaction will occur. This research was carried out with various variations, which later after going through the electrocoagulation stages, the samples were taken and put into bottles for analysis in the laboratory.

Wastewater treatment process

Wastewater is treated using the sedimentation stage/pretreatment process by pumping it into the first tank, which will be separated into several parts. The results of the treatment process go to the electrocoagulation stage, enter the second tank which contains metal plates (anode/cathode) and then filter using activated carbon and filters. The results of this process will then be processed to the next stage.

Water resulting from the electrocoagulation process is then treated using a series of equipment that has been integrated using zeolite, activated carbon and using Ultrafiltration Membranes. The equipment for the POME treatment process uses the

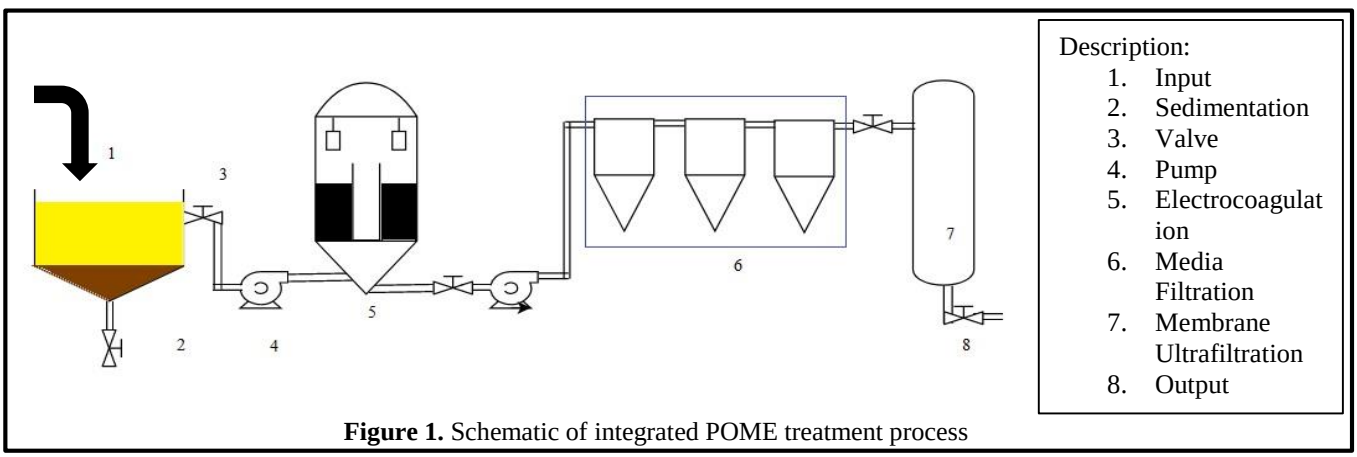


Figure 1. Schematic of integrated POME treatment process

Electrocoagulation Process, Activated Carbon Filters, Zeolite and Membrane Separation Technology, as seen in **Figure 1**.

The National Water Quality Standard based on Government Regulation No. 22 of 2021 concerning Implementation and Management of the Environment (Annex 6 National Water Quality Standards) listed in **Table 2**.

Table 2. National water quality standards according to Government Rule No. 22 Year 2021 (River Water Quality Standards) [8]

Parameter	Class 1	Class 2	Class 3	Class 4
pH	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0
TSS (mg/L)	40	50	100	400
COD (mg/L)	10	25	40	80
BOD (mg/L)	2	3	6	12
Oil and Fat (mg/L)	1	1	1	10

Table 2 classified water quality into 4 different types. The description of classes are as follows: Class 1 is water whose designation can be used for drinking water and/or other uses that require the same water quality as that use. Class 2 is water whose designation can be used for water recreation infrastructure/facilities, freshwater fish cultivation, animal husbandry, water for irrigating plantations, and/or other uses that require the same water quality as those uses.

Class 3 is water whose designation can be used for freshwater cultivation, animal husbandry, water for irrigating plants, and/or other uses that require the same water quality as those uses. Class 4 is water whose designation can be used to irrigate plantations and/or other uses that require the same water quality as that use.

Table 3. Results of analysis of the initial sample

Parameter	Unit	Governor of South Sumatra Regulation No. 8 of 2012	Results of Analysis of the Initial Sample
pH	-	6.0 – 9.0	4.45
TSS	mg/L	250	10,016
COD	mg/L	350	38,164
BOD	mg/L	100	22,673
Oil and Fat	mg/L	25	96.8

The analysis that will be carried out is as follows:

- Testing the Degree of Acidity (pH) SNI 6989.11: 2019.
- Testing of Chemical Oxygen Demand (COD) SNI 6989.2: 2019.
- Biochemical Oxygen Demand Test (BOD) SNI 6989.72: 2009.
- Testing for total suspended solids (TSS) SNI 6989.3: 2019.
- Determination of Oil and Fat SNI 6989.10: 2011.
- Determination of the value of Flux and % Rejection

RESULTS AND DISCUSSION

Results of analysis of the initial sample

The results of the analysis of the initial samples are shown in **Table 3**. The contents of pH, TSS, COD, BOD and Fatty Oil did not meet the requirements in Governor of South Sumatra Regulation No. 8 of 2012. The value is too high and very dangerous for the environment and ecosystem if the liquid waste is directly discharged into the environment.

Sedimentation process analysis results

After the sedimentation process, there was a decrease in the values of TSS, COD, BOD and Fatty Oil and an increase in the pH value which approached the limit value in Governor of South Sumatra Regulation No. 8 of 2012 but for other parameters such as TSS, COD, BOD and fatty oils, the results are still not close to the standards for waste that can be directly disposed of into the environment (Governor of South Sumatra Regulation No. 8 of 2012). This is shown in **Table 4**.

Table 4. Results of analysis of the sample after through the sedimentation process

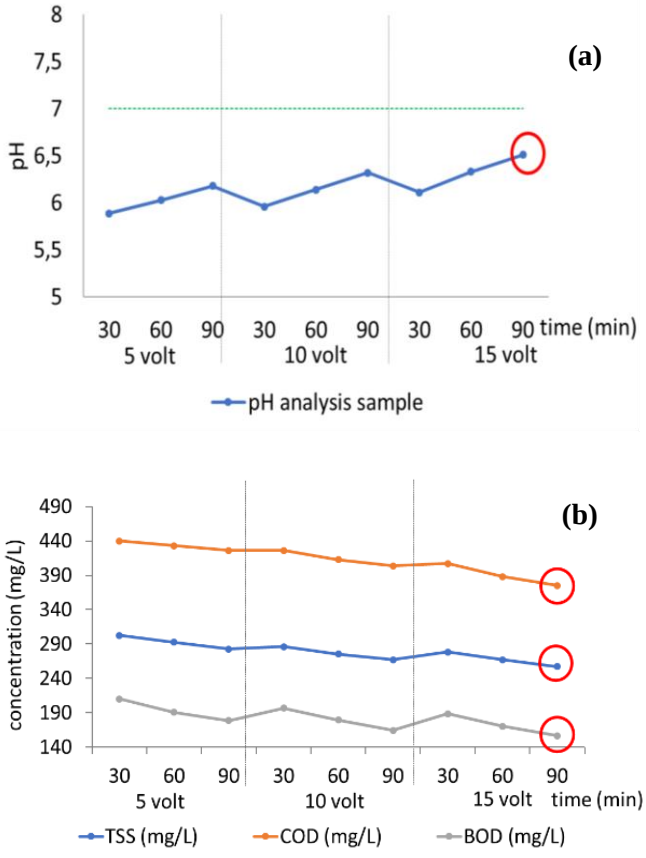
Parameter	Unit	Result of the Sedimentation Process
pH	-	5.47
TSS	mg/L	336
COD	mg/L	461
BOD	mg/L	243.5
Oil and Fat	mg/L	30

These results indicate that the sedimentation process can increase the pH value and decrease the TSS, COD, BOD and Fatty Oil values because the particles and impurities can be separated and settle by gravity.

Results of analysis of POME treatment using the electrocoagulation method

This electrocoagulation method is carried out with 3 variations of electric voltage and with different time variations, namely as follows 5, 10, and 15 Volt mains Voltage with 30, 60 and 90 minutes. The results of the analysis shown in **Figure 2**.

The results in **Figure 2** show that the optimal conditions are at a voltage of 15 volts for 90 minutes. This shows that the high voltage and long operating time of the coagulation method are able to treat waste properly and the value is close to the POME quality standard according to Governor of South Sumatra Regulation No. 8 of 2012.The longer the operating time and the greater the electric voltage, the pH level which was originally acidic slowly rose to a neutral pH due to the increasing release of OH- ions produced by reduction of water and the release of H_2 gas in the cathodic reaction.



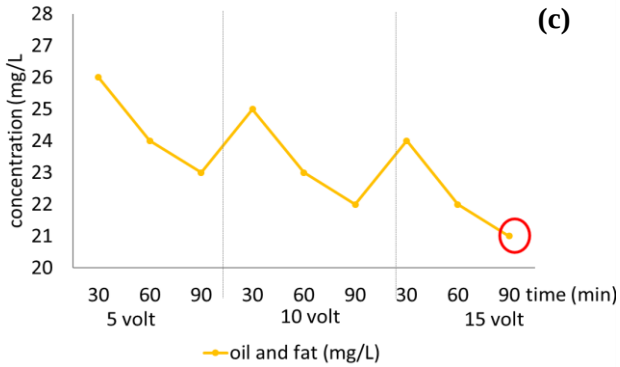


Figure 2. Results of (a) pH analysis; (b) TSS, COD, BOD analysis, (c) oil and fat analysis after the electrocoagulation method

The decrease in COD value is because the molecules of organic matter will experience destabilization by coagulants and also the electric field in solution, the physical bonds between organic molecules will be broken, allowing these molecules to be adsorbed by coagulant flocs and then precipitate after reaching sufficient weight. The lowest COD value is found at the highest voltage, which is 15 Volts and the longest time, which is 90 minutes.

A decrease in COD concentration indicates a reduction in organic compounds in the liquid waste. This is in accordance with the double layer theory that the innermost circle will be filled with positively charged coagulants which will absorb negative ions located in the outer circle. If the positive and negative charges meet, there will be a Van der Waals force (attraction) between the two ions resulting in a very strong bond and a coagulant is formed which will then form flocs which can reduce organic compounds in the waste, this also causes a decrease in value BOD and TSS samples. The electrocoagulation stage can be used as the initial stage of the pome treatment process [9].

Results analysis of advanced treatment (membrane method)

Advance treatment uses a membrane with a composition of 15% palm ashes, 15% activated carbon and 70% clay. At this stage, variations in the flow rate and with different time variations, namely as follow: Flow rate 2, 4 and 6 L/min with 30, 60 and 90 minutes. the results of the analysis shown in **Figure 3**.

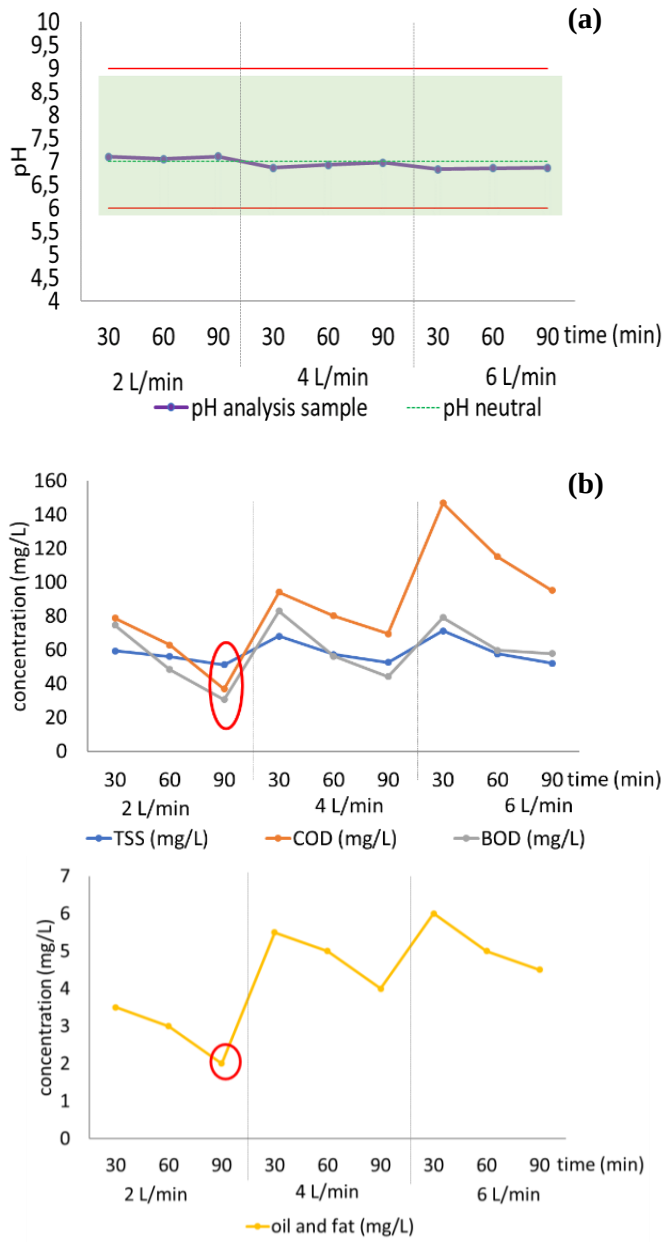


Figure 3. Results of (a) pH analysis; (b) TSS, COD, BOD analysis, (c) oil and fat analysis after membrane method

From **Figures 3**, it shows that the optimal conditions are at a flow rate of 2 L/minute and with an operating time of 90 minutes. This value meets the quality standards for liquid waste from the palm oil industry which may be disposed of into the environment based on Governor of South Sumatra Regulation No. 8 of 2012.

The decrease in TSS value is due to the function of the membrane to filter suspended solids in solution. The principle is that particles that have a large diameter will be retained by the membrane. At this stage the adsorption process also occurs due to the collision between the particles and the activated carbon. The large number of pores in the membrane can result in an effective adsorption process. The optimal condition for reducing TSS is at a flow rate of 2 L/minute and 90 minutes, this is in accordance with the theory that the higher the flow rate at the rate of water in the membrane, the lower the decrease or decrease in TSS value due to the greater flow rate, the faster contact time between waste and media so that the effectiveness of the media decreases. The same thing also applies to a decrease in the value of pH, COD, BOD and Fatty Oil [10].

Results of advanced process analysis (ultrafiltration membrane method)

At this stage using Ultrafiltration membranes as the media. The process is carried out three times to ensure the result. **Table 5** show the result of analysis. The results of the analysis shown in table 6 show that the average value of the sample after going through the processing using an ultrafiltration membrane is in class 2 of the National Water Quality Standard according to Government Regulation no. 22 of 2021 where the designated water can be used for water recreation infrastructure/facilities, freshwater fish cultivation, animal husbandry, water for irrigating plantations, and/or other uses that require the same water quality as those uses.

From these data this is in accordance with the theory where ultrafiltration membranes are a very effective membrane separation process technique for various solutes with high molecular weights, various colloids, microbes to suspended solids from aqueous solutions [11].

Table 5. Analysis results after ultrafiltration membrane

Parameter	Unit	Result
pH	-	7.05
TSS	mg/L	45.22
COD	mg/L	24.64
BOD	mg/L	2.92
Oil and Fat	mg/L	1.17

Results of integrated POME treatment analysis of electrocoagulation process, activated carbon filter, zeolite and membrane separation technology

The stages of the electrocoagulation process, activated carbon filters, zeolite and membrane separation technology were repeated 5 (five) times using optimal conditions at each stage of the process. The results show in **Table 6**.

Table 6. Analysis results after integrated process carried out

Parameter	Governor of South Sumatra Regulation No. 8 of 2012	Government Regulation No. 22 of 2021 Class 2	Result
pH	6.0 – 9.0	6.0-9.0	7.02
TSS	250	50	44.6
COD	350	25	24
BOD	100	3	2.89
Oil and Fat	25	1	1.2

The outcomes presented in **Table 6** display the findings of the sample analysis regarding pH, TSS, COD, BOD, and Fatty Oil values. These results adhere to the established standards of good quality as outlined in Governor of South Sumatra Regulation No. 8 of 2012 concerning Liquid Waste Quality Standards for Industrial, Hotel, Hospital, Domestic and Coal Mining Activities and based on Government Regulation no. 22 of 2021 concerning Implementation and Management of the Environment (Annex 6 National Water Quality Standards) where water signifies its suitability for various purposes, including water recreation infrastructure/facilities, freshwater fish cultivation, livestock, irrigation for plantations, and other applications. This signifies the effectiveness of the integrated system that employs the Electrocoagulation process, Activated Carbon Filter, Zeolite, and Membrane Separation Technology for treating Palm Oil Mill Effluent (POME) [12].

The Results of the Percentage Reduction in Value of TSS, COD, BOD and Fatty Oil Concentrations in Each of Methods Used.

At this stage, the percentage of impairment for TSS, COD, BOD and Fatty Oil concentrations in each process is determined. The result of all parameters was described in **Figure 4** and **Table 7**.

From **Table 7**, it shows that the highest percentage of reduction is in the stages of the sedimentation method and the membrane system, the sedimentation process is required at the initial stages of waste treatment and the membrane system method is very effective for use in POME treatment.

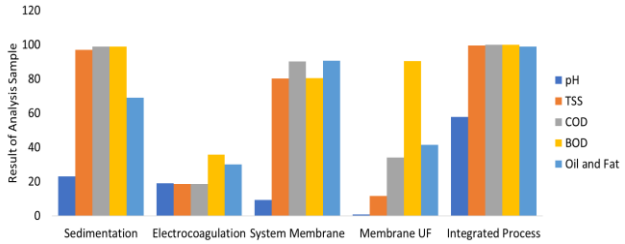


Figure 4. Percentage of decreased concentrations of TSS, COD, BOD and Fatty Oil

In **Table 7**, the pH parameters show that sedimentation and electrocoagulation have a high percentage of increasing pH, this is because sedimentation and electrocoagulation can separate and precipitate acidic floc particles. For TSS, COD and Fatty Oil Parameters, the highest percentage decrease was found in the Sedimentation Process and the Membrane System. In the presence of activated carbon which has chemical and physical properties that can absorb organic and inorganic substances. The membrane system also contains zeolite which has pores filled with K, Na, Ca, Mg ions and H_2O molecules to allow ion exchange to occur (zeolite is effective at absorbing cations which can cause environmental pollution) [13].

For the BOD parameter, the highest percentage decrease was found in the process of using UF membranes (Ultrafiltration) this is because UF membranes have very small pores so that UF membranes can remove various solutes with high molecular weight, various colloids, including microbes to suspended solids in solution water [14].

Comparison of flux to membrane

At this stage, the Flux value is determined to determine the performance of the membrane used, the results are as described in **Figure5**. **Figure 5** shows the smallest flux value at a flow rate of 2 L/minute and an operating time of 90 minutes where flux can be interpreted as the speed of a permeate, which is a parameter used to see the performance of a membrane in the membrane filtration process. The flux value in membrane filtration is affected by the media contained in the membrane, not only the media used but also the membrane density and the area of the membrane itself have an influence on the flux value of a solution and because of this we can see whether the membrane we have made has filtered properly efficient or not.

Table 7. Percentage of increase and decrease in pH, TSS, COD, BOD and fatty oil concentrations in each process

Parameter	Sedimentation	Electro coagulation	Membrane System	Membrane UF	Integrated Process
pH	22.92 [a]	19.01	9.22[b]	0,84 [b]	57,84
TSS	96.84	18.58	80.13	11,56	99,55
COD	98.79	18.59	90.19	34,00	99,94
BOD	98.92	35.77	80.42	90,47	99,98
Oil and Fat	69.01	30.00	90.48	41,50	98,76

Note: [a] Increase and [b] Decrease

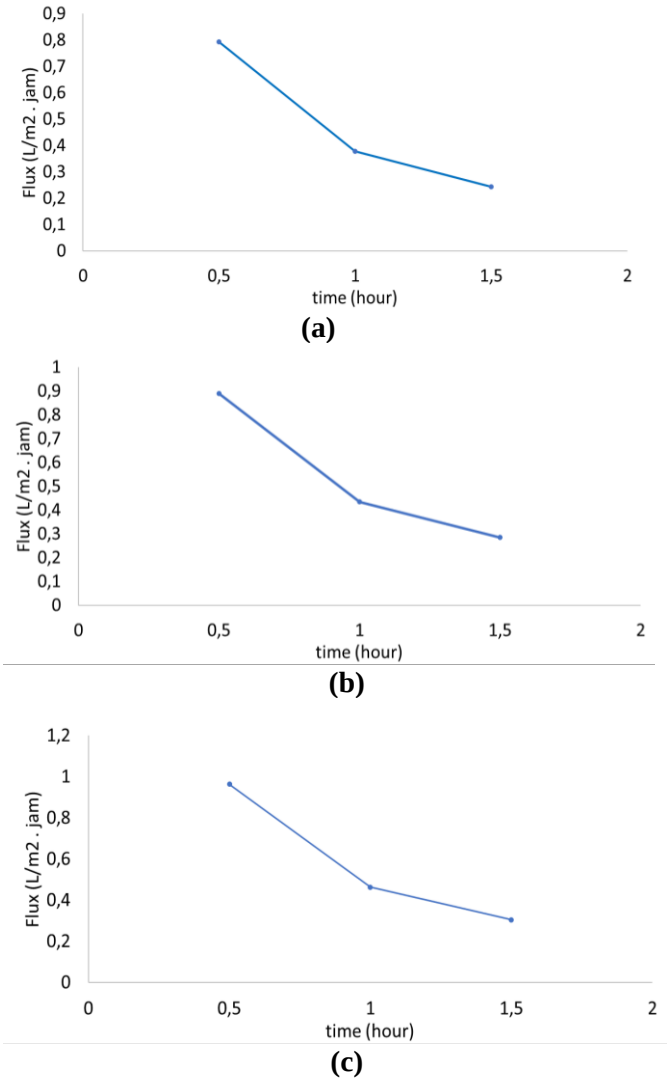


Figure 5. Comparison flux to membrane on time and flow rate variation (a) 2 L/min, (b) 4 L/min, and (c) 6 L/min

The decrease in the flux value which always decreases when the flow rate is increased is due to the faster contact time between the solution and the media so that the filtration does not run as effectively at a small flow rate. The flux itself has decreased because the substances retained by the membrane over time will collect and accumulate and then form fouling and this results in compression and resistance on the surface of the membrane. It can be concluded from these two theories that what affects the flux value is how much the membrane binds substances while at a high flow rate the membrane does not filter effectively because the contact time between the waste and the membrane is getting faster and this makes the flux at a high flow rate have high value [15].

CONCLUSION

Variation of palm ash and zeolite is the best variation to reduce the value of pH, TSS, COD, BOD and Fatty Oil. The electrocoagulation method is proven to be used in reducing the levels of TSS, COD, BOD and fatty oils. In this electrocoagulation method, the best conditions are at a voltage of 15 Volts and an operating time of 90 minutes. However, it is necessary to carry out further research to determine the effect of the membrane area and lifetime of the membrane and to consider and recalculate the efficiency of using this integration system compared to previous treatments.

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