OPTIMIZING DISCHARGEABLE EFFLUENT PRODUCTION FROM PALM OIL MILL EFFLUENT: AN EXPERIMENTAL RESEARCH

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ABSTRACT: *This paper describes the research findings conducted with palm oil mill effluent and Nano membrane. This research investigated the performance of the Nano membrane (NM) in separating total organic materials (TOM) from POME. The performance of NM is measured in the scale of productivity and efficiency in producing dischargeable effluent from POME. Three NM of different pore sizes and primary POME treatment machinery have been used for the conducting of the experiment. The feed pressure of POME to NM was from 60 psi to 120 psi. The research findings demonstrated the optimum performance of NM in separating TOM about 90% at operating pressure 80 psi. The findings of this research would be useful in producing environmentally friendly effluent from POME. The novelty of this research is to use a POME feedstock of pH 7.0 with a Nanomembranes system in optimizing dischargeable effluent production performance.*

Keywords: Palm Oil Mill Effluent, Biotechnology, Nano- Membrane, Environmental Sustainability, Climate change Productivity, Efficiency

1.0 RESEARCH BACKGROUND

This paper presents the research findings of Nano membrane (NM) used to treat palm oil mill effluent (POME) measured in terms of reduction of total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), and total dissolved solids (TDS). In this research, NM with three different pore sizes has been used to evaluate the effect of pore size on the quality of treated effluent.

Published reports suggested, palm oil mills in Sarawak have used open pond anaerobic digestion process to treat POME [1–3], but the performance of this method was found to be poor and was not economical and environmentally sustainable [1, 4, 5]. Thereby, the mills are looking for an alternative technology with higher performance, which suggests the research gap on treatment methods that produce better POME quality [6]. Indeed, this research was undertaken to reduce this gap. The novelty of this research is using NM with properties that enable the optimized POME quality as per the guideline published in SDG-6 and SDG-13 protocol.

1.1 Problem Statement

Palm oil processing emits greenhouse gases (GHG) and one of the primary drivers of climate change. The carbon (CO_2eq) emission potential of the CPO process and POME digestion is approximately $28m^3(\text{ton POME})^{-1}$. In this regard, Shahidul *et al*.[7] and Eugene *et al.* [2] revealed the carbon (CO_2eq) emission from palm oil mills contained about 65% Methane, which is about 25 times higher than global warming potentials (GWP) compared with carbon dioxide (CO_2) emission.

Wendy *et al*.[8] revealed a few mills discharged poor quality of POME to the water bodies, and it is due to the unavailability of appropriate technology at affordable cost. According to Azri et al. [9], palm mill managers are also struggling to comply with environmental regulations due to the lack of technological supports. Koyuncu *et al* [10], Shahidul *et al*.[5], and Chan and Chong [4] also revealed that the technologies available in the market are not fully able to produce quality effluent to meet the requirement of the department of environment (DOE).

It can be concluded here that the palm mills are struggling in meeting DOE requirements due to the lack of affordable green technology to produce good quality treated POME'.

To address this problem, the current experimental research with NM was done to evaluate whether NM can produce good treated POME. Thus, this study aimed to evaluate the performance of NM in separating total organic matter (TOM) from POME, hence producing dischargeable effluent that supports the achievement of SDG-6 on clean water and SD-13 on climate action [11].

1.2 LITERATURE REVIEW

This section presents the review on treatment methods to produce dischargeable effluent by separating organic materials from POME. The focus of this review is the update on the performance of NM so far to improve the quality of treated POME.

Palm oil processing uses a huge amount of water for crude palm oil (CPO) production as highlighted by Shahbandeh (2020) who reported that the global Crude Palm Oil (CPO) production potential was about 74.0 million metric tons in the marketing year 2019/2020 [14] and the estimated water consumption for CPO production is about $1.5m^3$/t of CPO [2, 12]. Ahmed *et al*. [9] reported the estimated water potential of POME in Malaysia is about 25 million m^3 a year [9].

POME, the effluent generated during the extraction of crude palm oil (CPO) from the fresh fruit bunch (FFB), contains water and a large number of organic materials [7], [9], including carbohydrates, proteins, lipid, and other micronutrients [15], which are responsible for pollution of the air, water, and soil. The properties of POME are listed in Table 1.

Table 1: Properties of the POME [8]

Parameter	Range
Organic Material (mg/L)	15,000–100,000
Total Solids (TS-mg/L)	11,500–79,000
Volatile Suspended Solids (VSS-mg/L)	9,000–72,000
Water	92%–96%

POME was found to contain a high quantity of organic materials, total solids, and volatile suspended solids that responsible for the pollution of the water, air, and soil contributing to an unsustainable environment for the future generation. It is also an identified source for biodiversity loss in many countries including Malaysia and Indonesia. To address these problems, Eugene *et al* [4] and

Shahidul *et al.* [8] suggested using green technology for the separation of pollutants and reclamation of water.

1.2.1 Nano Membrane in POME Treatment

NM in the filtration process is defined as using the membrane with pore size in Nano-meters (nm) (1×10^{-9} m). The NM has been used to remove small size ions (≥ Nano size diameter) from the fluid. The NM family has been used in fluid possessing to separate dissolved solids of molecular weight cut-off (MWCO) ranging from 200 Da to 500 Da [12]. NM has been used by scientists and engineers in recent years for the separation of dissolved solids from the fluid. Various membranes including ultrafiltration membrane (UFM) and microfiltration membrane (MFM) have been also successfully used as pre-treatment for the NM in fluid treatment applications [16, 17]. Abdur Rahman *et al*. and Espinoza-Gómez (2003) revealed that the NM is a potential separation means to reduce dissolved solids from bio-fluid-like POME [18, 19].

NM can remove compounds/ions with a molecular weight greater than 300–400 g/mol. Rejection of NM is mainly determined by molecular size, hydrophobicity, and charge; but the effects of the molecular shape and dipole moment are also a potential factor. The removal efficiency of NM for the salts of smaller molecular weight is up to 90 percent [13]. Most salts with monovalent anions (e.g., Cl^-) can pass through the NM, whereas multivalent anions (e.g., SO^{2-}) are retained. The pH of the fluid is also associated with salts removal performance [14]. The feed pressure of the fluid influences the performance of NM in separating dissolved salt and in producing the permeate from the POME. The permeate recovery performance from POME is from 40% to 90%. The recommended feed pressure to POME for NM is from 60 psi to 120 psi [15, 16].

2.0 Research Objective

The broad objective of this research is to model the performance of NM in producing good quality (dischargeable) POME. To achieve this goal, the work has divided into three specific objectives:

2.1.1 To characterize the input-output parameters of NM.

2.1.2 To optimize the production of quality effluent from the POME.

2.1.3 To evaluate the efficiency of the NM in quality effluent production from POME.

The scope of works for this study encompasses the collection of inputs and outputs data from laboratory-scale research. The inputs and outputs data have been used to estimate the productivity and the efficiency of the NM used. The optimum performance of the NM in separating TOM was evaluated concerning feeding pressure for membrane operating conditions.

3.0 MATERIALS AND METHOD

The methodology includes the sample collection of POME, experimental setup, conducting experiments as per outputs of Design of Expert (DOE) (version 2018) software, inputs-outputs data collection from experiments and data analysis for report writing. The Design of Expert (DOE) (version 2018) software was used to estimate required experimental runs [4].

3.1 Theoretical Framework in Evaluating POME Treatment Performance

The NM was used to separate TOM from POME treatment performance. Figure 1 shows the inputs and outputs configuration of NM for POME treatment [17].

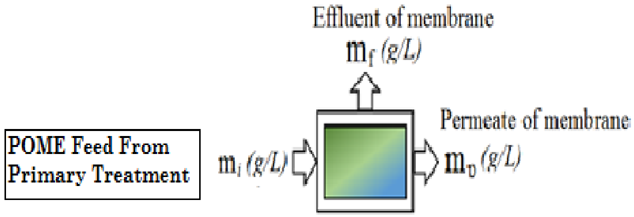

Figure 1: Nano Membrane

3.1.1 Mass balance in NM for POME

The mass balance across the NM for POME is illustrated in the equations below.

$$m_i = m_f + m_p \quad \text{Eq.(1)}$$

$$m_i(g/L)=[COD(g/L)]_i+[VSS(g/L)]_i+[TSS(g/L)]_i \quad \text{Eq (2)}$$

$$m_f(g/L)=[COD(g/L)]_f+[VSS(g/L))]_f+[TSS(g/L)]_f \quad \text{Eq (3)}$$

$$m_p(g/L)=[(COD(g/L)]_p+[VSS(g/L)]_p+[TSS (g/L)]_p \quad \text{Eq (4)}$$

Here,

m_i is effluent discharge from Anaerobic reactor and fed to the membrane.

The term above m_f is a mass in effluent discharge from the membrane

m_p is the mass in permeate of the membrane as quality effluent

VSS is then biomass of POME.

TSS is the total solid to be suspended from POME.

3.1.2 Membrane Efficiency in TOM Removal

The membrane efficiency is described by Equation 5.

$$\eta_m = \frac{mp}{m_i}.100 \quad \text{Eq. (5)}$$

Here, η_m is the tTOM removal efficiency of the membrane**.**

3.1.3 Productivity of NM in Separating TOM

Productivity is a measure of the output rate of the production process, described by Equation 6.

$$\Pr(L/hr) = m_p\ /\ T \quad \text{Eq .(6)}$$

Here, Pr (L/hr) is the productivity of the membrane in producing dischargeable effluent. The L is the amount of effluent produced by the membrane [19]. Then (T) is the time in an hour used to produce L by the membrane.

3.2 POME Sample Collection

POME was collected from Bau Palm Oil Mill and Felcra Jaya Palm Oil Mill. The samples were transported to the Operations Research laboratory of Universiti Malaysia Sarawak (UNIMAS) for experiments.

3.3 Experiment Setup

To achieve the research goal, pre-treatment and three sets of NM have been used. The feedstock was adjusted to pH 7 by adding sodium hydroxide (NaOH) and at a temperature of 35°C [2, 20].

3.4 NM for Waste Biomass Separation from POME

Properties of the NM are given in Table 2 similar to those used by several researchers in the solid separations process for industrial effluent [21, 22, 23].

Table 2: Properties of Nano Membrane Used

Membrane Type	Pore Diameter (nm)	Membrane CODE	Hydraulic Permeability (10^{-14} m)
NF270-4040	0.8	NM1	0.899
NF90 4040	0.68	NM2	0.929
GE NF4040	0.10	NM3	0.699

The experiments were carried out at a temperature of 35 °C, feed pressure from 60 psi to 120 psi, and cross-flow velocity at 0.9 m/s [24]. The outputs of NM such as the volumes and dissolved solids of concentres and permeate were determined as per the method suggested by Van and Olieman [25].

3.5 Steps of Conducting Experiments

Experiments were done using several items. Item 1, the sedimentation component to separate TSS, item 2, the sand and biomass granular filters, item 3, bio-degradation component to reduce BOD and COD, item 4, the biomass media filter, item 5, the feedstock preparation component, item 6, microfiltration and item 7, Nanofiltration. All items were set up in series. 20 experimental design was done using DOE software.

4.0 RESULTS AND DISCUSSION

Performance of NM was evaluated about the outputs effluent quality of primary treatment and the feedstock parameters, as listed in Table 3.

Table 3: Input-out data of Primary POME treatment

POME's parameter	Outputs of primary treatment	Feed Stock for Nano Membrane
COD (g/L)	33.2	33.2
VSS (g/L)	9	9
TSS (g/L)	5	5
Total loading (g/L)	47.2	47.2
pH	4.0	7.2

4.1 Inputs–Outputs Data of Experiments

The productivity and efficiency of NM in producing dischargeable effluent from POME were estimated from the input-output data listed in Table 4.

Data listed in Table 4 demonstrate that the separation of TSS and organic materials increased with the reduction of NM pore size. NM3 with pore size 0.1nm exhibited the highest separation performance compared with NM2 (0.68 nm) and NM1(0.68 nm?). The findings conclude that to achieve higher separation performance of dissolved solids from effluent, NM with lower pore size would be the best choice.

Table 4: Input-out data of NM in POME treatment; Average Output effluent's quality of 20 Experimental Runs

POME's parameter	Input to NM from Feedstock	NM1 0.8nm	NM2 0.68nm	NM3 0.10nm
COD g/L	33.2	5	3	1.5
VSS g/L	9	4	2	1.0
TSS (g/L)	5	1	0.5	-
Total* OM&TSS loading g/L	47.2	10.5	5.5	2.5
pH	7.2	7.0	6.9	6.8

* Organic materials and TSS

4.2 Optimizing Productivity in Quality Effluent Production

The feed pressure (as an independent) and the Productivity (as a dependent variable), and operating time have been used to evaluate the optimum productivity of the NM. Inputs-outputs data of the 20 experimental runs were used to estimate NM's productivity, as in Eq (6). The productivity and corresponding feed pressures were analyzed by the excel software for determining the optimum performance of NM. The findings have been plotted in Figure 2; where X-axis presents the feed pressure (as the independent variable), and Y-axis presents the productivity (as the dependent variable).

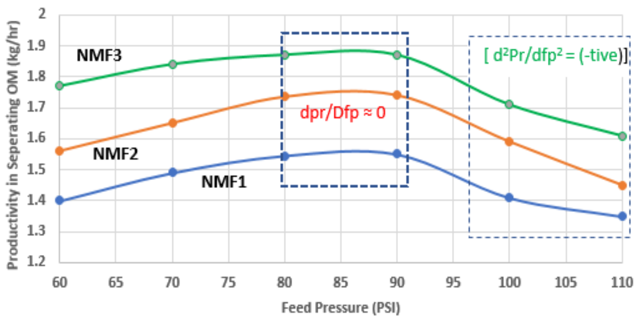

Figure 2: Productivity of NM

Figure 2 demonstrates optimum productivity of the NM was between the feed pressure 80 psi and 90 psi. But the productivity of the membranes has started to reduce from feed pressure 90 psi. Additionally, the maximum productivity of NM3 was recorded as 1.87 $m^3(hr)^{-1} (m^2)^{-1}$ at feed pressure 80 psi. From Figure 2, the relationship between productivity and feed pressure is presented in Table 5.

Table 5: The productivity matrix of NM.

NM	Optimum Productivity [$(m^3(hr)^{-1} (m^2)^{-1}$]	
	80 psi	90 psi
NM1	1.55	1.55
NM2	1.73	1.73
NM3	1.87	1.87

Data in Table 5 demonstrates that the pressure of more than 80 psi does not affect productivity. In this aspect, feed pressure of more than 80 psi is a non-valued added input. Eq.(7) presents the characteristics and relationship between feed pressure and productivity.

Pr ($m^3/hr/m^2$) = $-0.0003P^2 + 0.0455P+1.72$ Eq (7)

The negative [-ve] sign of Eq. (7) indicates, at higher pressure, the productivity of NM would be decreased further.

4.2.1 Model Validation

The first derivative and second derivative of Eq. (7) have been used to validate the model. The first derivative is presented by Eq. (8).

$$\frac{dpr}{dp}(80\,psi) = 0 \qquad \text{Eq.(8)}$$

Eq.(8) indicates the marginal productivity of the membrane is zero between the feed pressure 80 psi and 90 psi. These findings are the qualifying optimum conduction [27],[28]. The second derivative of Eq.(7) is presented by eq.(9)

$$\frac{d^2pr}{dp^2} = [-0.006] \qquad \text{Eq.(9)}$$

Eq.(9) indicates the second derivative of productivity is negative between the feed pressure 80 psi and 90 psi. Eq. (8) and Eq.(9) are also qualifying required optimum condition no 2 of the model developed [26], [27]. Thus, optimum productivity of the NM in separating TOM from POME is established.

4.3 Efficiency Evaluation in Producing Quality Effluent

The feed pressure (as an independent) and the efficiency (as a dependent variable) in producing quality effluent by the NM have been used to evaluate the optimum efficiency. The data of optimum effluent outputs the rate of the NM_{mp} and the effluent feed rate to the NM (as per the designed capacity of NM) have been used to estimate Eq. (5) for the evaluation of NM's efficiency. The findings are listed in Table 6.

Table 6: Separation of Efficiency of NM

Feed Pressure(psi)	Separation Efficiency		
	NM1	NM2	NM3
60	75	80	82.5
70	853	85	92.5
80	92	94.5	96
90	91.5	94	95.5
100	89	93	94
120	83	89.3	90

Table 6 shows that the effluent production efficiency depends on feed pressure and membrane pore size. The combination of feed pressure 80 psi and 90 psi; and the pore size 0.1 nm (NM3) has exhibited the highest efficiency of NM in producing quality effluent. The efficiency of NM3 (pore size 0.1nm) has appeared to be highest compared to the NM1(pore size 0.8 nm) and NM2(Pore size 0.68 nm). The recorded efficiency behavior of NM 3 is presented by Eq. (10) and Eq.(11):

ŋ(80psi) = ŋ (90psi) ≈ 98.5% Eq. (10)

ŋ(%) = $-0.010P^2+1.912P+9.97$ Eq. (11)

4.3.1 Model Validation

The first derivative and second derivative of Eq. (11) have been used to validate the model. The first derivative is presented by Eq.(12).

$$\frac{d\eta}{dp}(80\,psi) = 0 \qquad \text{Eq.(12)}$$

Eq.(12) indicates the marginal efficiency of NM is zero between the feed pressure 80 psi and 90 psi. This finding is the qualifying optimum conduction no 1 [27],[28]. The second derivative of Eq.(11) is presented by eq.(13).

$$\frac{d^2\eta}{dp^2} = [-0.006] \qquad \text{Eq.(13)}$$

Eq. (13) indicates the second derivative of efficiency is negative between the feed pressure 80 psi and 90 psi. This finding is qualifying optimum conduction no 2 [27], [28]. Thus, optimum efficiency of NM in producing quality effluent is established.

5.0 Scenario Analysis of Findings

The outcomes of the research can be summarized as follows.

5.1 The first outcome listed in Table 4 indicates that the NM can produce dischargeable effluent from the POME as per the environmental requirement of Malaysia [27]. It was found that NM has contributed to increasing TOM separation efficiency from 63.1% to 96%. The finding concludes that combined operation of primary treatment and NM in series would be a solution for producing environmentally friendly effluent from POME.

5.2 The Second outcome is presented in Figure 2 and Table 5. Findings demonstrate an optimum level of productivity in separating TOM has been achieved between feed pressure of 80 psi to 90 psi. The performances of all three NM used in this research have been listed in Table 7.

Table 7: Performance of NM in Producing Quality Effluent

NM	Productivity Achieved [kg(hr)$^{-1}$ (m^2)$^{-1}$]	Efficiency Achieved (%)
NM1(0.8 nm)	1.25	98*
NM2(0.68 nm)	1.73	95
NM3(0.10 nm)	1.87	92

* NM 01. nm exhibited the highest performance.

5.3 Third outcome is the model validation. The validated results are listed in Table 8.

Table 8: Validation for Optimization of NM3

Validation and Outcomes	Productivity	Efficiency
Models for Membrane NM3(0.1nm)	Pr = $-0.003P^2 + 0.0455P + 0.74$	Ŋ = $-0.011P^2 + 2.061P + 3.354$
Optimization Condition 1 Between 80- 90 psi	$\frac{dpr}{dp} = 0$	$\frac{d\eta}{dp} = 0$
Optimization Conduction 2	$\frac{d^2pr}{dp^2} = [-0.006]$	$\frac{d^2\eta}{d\eta^2} = [-0.022]$

Pr(kg/hr)-Productivity, ŋ (%)-Efficiency

6. Implications of Research Outcomes and Conclusion

The research findings listed in this paper have a few implications in the domains of effluent treatment and environment. Technologies and methods discussed in this paper would be a guideline in the reclamation of wastewater from POME and contribute to reducing carbon emission (CO2eq). Additionally, the method described in this paper would be useful to produce dischargeable effluent which would contribute to reducing the pollution level in the air, water, and soil. These findings would be a reference for engineers and researchers working with palm oil mills for the modeling of producing quality effluent from POME.

This study concludes that the research outcomes listed in this paper would be a guideline for policymakers and managers for implementing the developed technology in palm oil mills to reduce the pollution in the water, air, and soil contributing to the achievement of SDG-6 (clean water) and SDG-13 (climate actions) [2, 11, 30].

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