CHEMICAL ENGINEERING TRANSACTIONS
VOL. 72, 2019

A publication of
AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Yi-Hsu Ju, Fusheng Li, Wira Wasista Hakun

**ISBN** 978-88-95608-69-3; **ISSN** 2283-9216

# The Economic Analysis of Submerged Membrane Palmoil Wastewater Filtration

Erna Yuliwati[a,*], Elfidiah[a], Kiagus Ahmad Roni[a], Ahmad Fauzi Ismail[b,c], Ani Melani[a]

[a] Department of Chemical Engineering, Faculty of Engineering, Universitas Muhammadiyah Palembang, Jalan Jendral Ahmad Yani 13 Ulu Palembang 30263, Indonesia

[b] Advanced Membrane Technology Research Centre Universiti Teknologi Malaysia, Universiti Teknologi Malaysia, 81310 UTM, Skudai Johor, malaysia

[c]Faculty of Petroleum and Renewable Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM, Skudai Johor, Malaysia

deeyuliwati@gmail.com; erna_yuliwati@um-palembang.ac.id

Palmoil industry is needed potentially applicable processes to treat its wastewater due to water scarcity and submerged membrane technology in one of the special system. However, the application of submerged membrane for industrial wastewater treatment is still in its infancy due to high operational costs. This study reports the economic analysis of submerged membrane for palmoil industry wastewater treatment. Energy consumptions and costs of this system are among the main parameters affecting water filtration system and permeate water final cost. A semi-empirical method was employed for determining operation and maintenance (O&M) and investment costs. PVDF fibers in a specially designed holder providing out-in feed were used in a lab-scale aerated membrane system. Results showed that the flux, total suspended solids (TSS) and sulfide removal of 148.82 L/m2h, 99.82 % and 89.2%, respectively, could be achieved by increasing the air bubbles flow rate due to increase of turbulence around fibers. Moreover, the invesment and production costs were estimated to be the total annual cost per year and costs for treated reuse water of USD 39,174.35 and 7.02/GPD, respectively. Therefore, the costs of engineering can be reduced considerably and as available option to design such wastewater treatment system.

## 1. Introduction

Environmentally acceptable disposal of oily wastewater is a current challenge to the palmoil industry. Nowadays, more attentions and studies focused on the techniques of palmoil wastewater filtration. Mohammad, et al. (2015), Li et al. (2014), Johnson et al. (2012) and Lau and Ismail (2009) identified various technical and management developments in order to treat oily wastewater such as oil industry, oil reining, oil storage and transportation and petrochemical industries. The development of wastewater treatment methods were summarised on six aspects namely; flotation, coagulation, biological treatment, membrane filtration, combined technology and advanced oxidation process (Li et al., 2014). The application of membrane filtration versus conventional treatment in water and wastewater treatment is also a key point in the position of such developed technology. Delcolle et al. (2017) studied a comparison between coagulation and ultrafiltration in order to treat the biodiesel production. They concluded that ultrafiltraion membrane showed the best result for turbidity removalat a transmembrane pressure.

It has been studied that wastewater streams typically contain many regulated inorganic and organic contaminants that can restrict its use or disposal thereof (Vargas and Ladino., 2017). Standards promulgated by state agency that regulate the maximum content of contaminants in wastewater streams disposed into publicly owned treatment works or discharged into waste injection wells have become increasingly more strict. Thus, processes for reducing the content of the inorganic and organic contaminants to an acceptable level in the wastewater streams employed to comply with these standards.

For instance, in Indonesia, the effluent discharged from industrial sectors should comply with the national primary regulatory of discharged standard from Regulation of The Minister Environment and Forestry of Republic of Indonesia Number: 5 Year 2014. To attain these limits, the palmoil wastewater treatment need additional tanks and equipment, but in many cases, the palm industries are located in populous areas with little space for expansion. Technologies, which can treat large quantities of wastewater with relatively small requirements, are important. The developed membrane technology is able to completely retain biomass and operate with high-suspended solids concentration. Based on this situation, numerous manufacturers of membrane filtration, especially ultrafiltration membrane system currently exist, each with their own proprietary technologies. The differences between proprietary systems present significantly varying design considerations. The technologies of commercially available UF membranes by major manufacturers are summarized as follows,
(1) submerged vs. encased membrane system; (2) crossflow vs. dead-end filtration; (3) inside-out vs. outside-in flow; (4) hollow fiber vs. flat sheet; (5) performance characteristics (flux, recovery, particle rejection, backwash procedures); (6) pretreatment requirements; (7) cost impacts; and (8) installed capacity summaries. Some of the major UF systems for developing of water or wastewater filtration and their products are tabulated in Table 1.

*Table 1: Summary of the major UF/MF systems (Younos,2005)*

| System Manufacturer s | System type | Pore size | Mode of operation | Cleaning method | Flux (gfd) | Recovery (%) |
|---|---|---|---|---|---|---|
| Koch | Encased UF (8"x48" or 8"x72") | 100,000 daltons | I/O DE and CF | Chemical soak | N/A | N/A |
| TriSep-SpiraSep | Spiralwound UF (8"x40") | 0.05 µm | O/I | Chemical backwash and air scour | Up to 80 gfd | >90% |
| US-Filter | Submerged and encased MF | 0.1 µm | O/I DE | Chemical caustic and acid air scour | 15-40 gfd | 90%-98.5% |
| Hydraunatics | Encased UF (8"x40" or 8"x60") | 150,000 daltons | I/O DE and CF | Chemical soak | 35-85 gdf | 95%-98% |
| Zenon Zee Weed 500 | Submerged UF | 0.04 µm | O/I CF | Continuous air scour, air and water backwash | 10-40 gfd | 85%-99% |
| Zenon Zee Weed 1000 | Submerged UF | 0.04 µm | O/I DE | Continuous air scour, air and water backwash | 10-40 gfd | 85%-99% |

Note: I/O – Inside-outside; O/I-Outside-inside; CF-Crossflow; DE-Dead-end.

The major task of membrane filtration engineers is to choose an appropriate process with reduced energy consumption and specific investment cost, long service time and high availability with low maintenance cost (Pilutti et al., 2003, Younos, 2005). The cost of producing a unit volume of product water has shown a continuous change over the last two decades. The objective of this study is to evaluate the cost to treat refinery wastewater based on the experimental data obtained in our laboratory using the in-house produced submerged hollow fiber membrane set-up for a small production unit of 5 gallon/day.

## 2. Experimental

### 2.1 Experimental setup and procedure

Yuliwati et al. (2015) described the properties of PVDF membranes used in this work in detail. As a semi-crystalline polymer, PVDF generally exhibits more complicated phase separation behavior than amorphous polymer. LiCl and $TiO_2$ were added to the spinning dope to improve thermodynamic/kinetic relations during the phase inversion process in the preparation of PVDF-based membranes, increase the surface hydrophilicity and thus to improve membrane water productivity (Lau and Ismail., 2009). Synthetic palmoil wastewater was prepared as feed solution in submerged ultrafiltration experiments.The lab-scale experimental set-up shown in Figure 1. The submerged membrane separation system consisted of a feed reservoir of 20 L volume, hollow fiber bundles, a peristaltic pump, a permeate flowmeter, and a permeate collector.

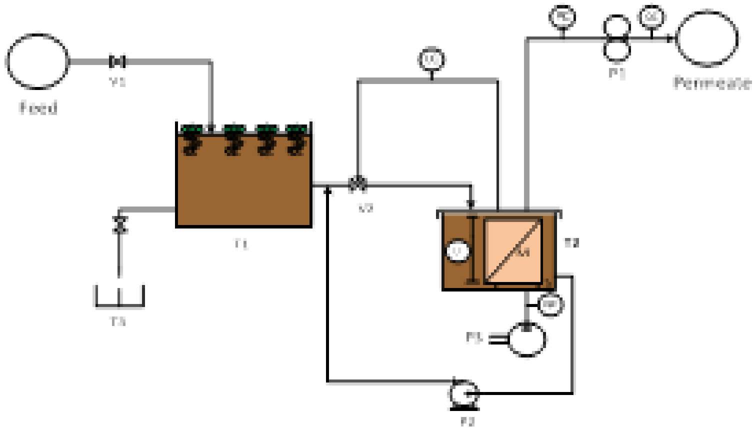


*Figure 1: Schematic diagram of membrane system for palmoil wastewater treatment ($V_1$: wastewater valve, $T_1$: pretreatment tank, $V_2$:feed membrane reservoir valve, S: sparger, M: membrane module, $T_2$: feed reservoir, $T_3$: effluent tank, $P_1$: peristaltic pump, $P_2$: centrifugal pump, $P_3$: air pump, QC: flow control, LC: liquid control, LI: level indicator, PC: pressure control*

The experiments were studied at room temperature and 0.5 Bar on the permeate side and treated using a peristaltic pump (Master flex model 7553-79, Cole Palmer). The transmembrane pressure of 0.5 bar was maintained to let water permeate from outside to inside of the hollow fiber. The continuous aeration produced turbulent flow that could decrease the cake layer thickness and the average particle size (Yuliwati et al., 2011).

**2.2 Analytical methods**

The membrane performance was tested as follows.Pure water permeation rate was measured after the steady state was reached, using the following equation

$$F = V/(At) \qquad (1)$$

where $F$ is the pure water flux (l/m$^2$ h), $V$ is the permeate volume (l), $A$ is the membrane surface area (m$^2$), and $t$ is the time (h).

Total suspended solids (*TSS)* concentrations were measured using a spectrophotometer (DR 5000, HACH) in accordance to the standard procedures of method 8006 (Photometric method). During the operation with high organic loading rates, the concentrations were evaluated correctly and the sampling was carried out three times a week again. The total suspended solids (*TSS)* and sulfide (*S*) removal efficiencies were calculated by Eq.(2) and (3) (Lau and Ismail., 2009).

$$TSS\ removal\ \% = \frac{T\,SS_0 - TSS}{TSS_0} \times 100 \qquad (2)$$

where $TSS_o$ and $TSS$ are the initial TSS concentration of the synthetic palmoil wastewater in feed and the TSS concentration of permeate produced.

$$COD\ removal\ \% = \frac{CODS^{0-}}{COD_0} \times 100 \qquad (3)$$

where $COD_o$ and $COD$ are the initial COD concentration of the synthetic palmoil wastewater in feed and the *COD* concentration of permeate produced.

$$S\ removal\ \% = \frac{S^{0-}}{S_0} \times 100 \qquad (4)$$

where $S_o$ and $S$ are the initial sulfide concentration of the synthetic palmoil wastewater in feed and the sulfide concentration of permeate produced.

At their bubble flow rate, hydraulic retention time and mixed liquor suspended solid of 2.25 ml/min, 240 min and 3 g/L, respectively. The maximum flux of 82,11 L/m$^2$h, TSS, COD and sulfide removal were achieved as listed in Table 2.

*Table 2: Optimum performance of submerged membrane for palmoil wastewater treatment*

| Parameter | Removal (%) |
|---|---|
| Total suspended solids (TSS) | 99.63 |
| Chemical oxygen demand (COD) | 90.08 |
| Sulphide | 89.20 |

### 2.3 Factors affecting submerged membrane filtration costs

According to the literature, several factors affect cost of submerged membrane system. Moreover, cost factors associated with implementing a submerged membrane system are site specific and depend on several variables (Delcolle et al., 2017). The data obtained from our experimental set-up described above and the assumptions usually made in the literature are used in this section to estimate the capital investment and the production costs of the submerged membrane. It should be noted that increasingly reliable and greater choice of equipment, processes and expertise in membrane technology are available commercially for a range of applications, reducing unit costs by up to 30-fold since 1990. Major cost variables are briefly described below:

(1) Quality of feedwater; The quality of feed water is a critical design factor. Low suspended solid concentration in feed water requires less energy for treatment compared to highly suspended solid feed water.
(2) Type of membrane material and configuration; The selected membrane materials and configurations have to be compatible with raw water quality, pretreatment requirements, and other operating conditions.
(3) System capacity; The system capacity is an important design factor. It affects the size of treatment units such as pumping, piping, water reservoir, water distribution system, and aeration system.
(4) Site characteristics; Site characteristics can affect water production cost. For example, availability of land and the land condition can determine cost. The proximity of system location to water source and concentrate discharge point is another factor.
(5) Regulatory requirements; these costs are associted with meetinglocal/state permits and regulatory requirements.

Ali et al. (1995) reported that the capital costs for the submerged system is lower than the encased system since the membrane area per unit is higher for the submerged system, and the necessary ancillary pipework, pump, and valve requirements are lower. On completion of construction, the annual rate increase will be gradually scaled back over a five-years period. The percentage increase in water rates to residential customers is summarized in Table 3, as reported by Pressdee et al. (2006).

*Table 3: Impact of water treatment plant upgrades on water rates*

| Financial year | Percentage rate increase |
|---|---|
| 2014 | 7 |
| 2015 | 5 |
| 2016 | 3 |
| 2017 | 2 |

## 3. Results and Discussion

### 3.1 The capital investment costs analysis

The economics of submerged membrane filtration were evaluated based on the plant specification, cost data of Total Capital Investment (TCI) and O&M costs per year as shown in Tables 4-6, respectively. It is further shown that this advanced membrane treatment process exhibited promising annual reuse water production of 1,825 Gallon and effective treatment cost of RM 21.47/Gallon or RM 5.66/L. Plant specification was carried out using assumptions and financial arrangements described in Table 4.

*Table 4: Plant specifications for reuse water production (Pilutti et al., 2003)*

| | |
|---|---|
| Plant capacity (GPD) | 5.00 |
| Filtrate flowrate (Q) (L/hr) | 257.069 |
| Flux (LMH) | 16.03 |
| Filtration area ($2\pi r\ell$) ($m^2$) | 1,800 |
| Estimated membrane length (km)) | 521.40 |
| Estimated occupied membrane volume ($\pi r^2\ell$) ($m^3$) | 0.495 |
| Operational transmembrane pressure (TMP) (bar abs) | 0.5 |
| Membrane life (year) | 4 |
| Workingdays ($D_w$) (days) | 365 |
| Annual reuse water production | 1,825 Gallon<br>6908 L according to US gallon, or<br>8297 L according to UK gallon |

The total capital invesment to process the refinery wastewater based on the plant capacity of 5 gallon per day (GPD) was obtained. This study produced water from wastewater palmoil using by membrane system. The produced water could be reuse as cooling water and the production consists of direct costs, indirect costs and general expenses were analysed that listed in Table 5.

*Table 5: The direct and indirect costs (A) of reuse water production per year*

| No | Item (Direct and indirect costs) | Amount (kg) | Purchasing cost (RM) | |
|---|---|---|---|---|
| A | Raw material costs | | | |
| | | | RM/kg | Cost |
| A | Polyvinylidene fluoride Kynar-760 | 132.088 | 50.015 | 6,606.38 |
| B | Lithium chloride monohydrate | 6.868 | 110.588 | 759.52 |
| | Titanium dioxide | 13.209 | 134.163 | 1,772.16 |
| C | N,N-dimethylacetamide DMAc-Merck | 43.035 | 120 | 5,164.20 |
| D | Post treatment Glycerol solution (20% of 200 L) | 40 | 18.5 | 740.00 |
| E | **Total bare module cost (Cbm) (a+b+c+d)** | | | 15,042.26 |
| F | Auxiliary facilities | | 30% of Cbm | 4,512.68 |
| G | Contingency and fees | | 10% of Cbm | 1,504.23 |
| H | **Total module cost (A)(Cmembrane) (e+f+g)** | | | **21,059.16** |
| I | **Total module cost/m2 (Cmembrane/m$^2$)** | | | **11.69** |
| J | Land, Building and service facilities | | 5% of Cmembrane | 1052.96 |
| K | Building improvements | | 5% of Cmembrane | 1052.96 |
| L | **Total off-site cost (j+k)** | | | 2105.92 |
| M | Pump (50 hp; 37.29 kW) | 3 | 5000 | 15,000 |
| N | Aeration compressor (12 hp;8.95 kW) | 1 | 2000 | 2,000 |
| O | Mixer (2 Hp; 1.49 kW) | 1 | 1500 | 1,500 |
| P | Reactor | 2 | 800 | 1,600 |
| Q | Holding tank | 2 | 200 | 400 |
| r | Purchased equipment installation | | 5% of Cmembrane | 1052.96 |
| s | Instrumentation and control | | 5% of Cmembrane | 1052.96 |
| t | Piping, fitting and controlled valve | | 10% of Cmembrane | 2105.92 |
| u | **Total on site cost (m+n+o+p+q+r+s+t)** | | | 24711.83 |
| v | Engineering and supervision | | 5% of Cmembrane | 1052.96 |
| w | Contingency | | 5% of Cmembrane | 1052.96 |
| x | **Total indirect cost (v+w)** | | | 2105.92 |
| y | **Total equipment capital (Cequipment) (l+u+x)** | | | 47,876.91 |
| z | **Total capital invesment (TCI) (h+y)** | | | **68,936.07** |

Total capital invesment to process 5 GPD of reuse water was calculated RM 68,936.07. The installed cost of equipment was adjusted to December 2011 using SRI's Process economics program (PEP) cost indexes (Pilutti et al., 2003)

### 3.2 The production costs analysis of reused water production

Total production costs consist of manufacturing and general expenses. The manufacturing are also termed operating costs and is generally divided into fixed, variable, and general costs. A semi empirical method is used to estimate the production cost. The detail of production costs analysis are listed in Table 6.

*Table 6: The operating and maintenance costs (B) of reuse water production peryear*

| No | Item | Amount | Purchasing cost (RM): RM/unit/kW hr/L | Purchasing cost (RM): Cost |
|---|---|---|---|---|
| | Operating costs | | | |
| a | Utilities power (pump+mixer+compressor)<br>37.29+37.29+37.29+8.95+1.49=122.31 kW x 6 hr= 733.86 kW hr);<br>733.86 kW x 365 = 267,858.90 kW hr/year | 267,858.90<br>kW hr/year | 0.0198 | 5303.60622 |

| | | | | |
|---|---|---|---|---|
| b | Labor costs (500/month; average 8 hr/day) | 1 | 16.6 | 16.6 |
| c | Cleaning costs | 830.3 | 4 | 3321.2 |
| d | NaOH consumption | 825 | 8 | 6600 |
| e | **Total chemicals costs (c+d)** | | | **15,241.40622** |
| f | Maintenance cost | | 2 % of TCI | 1378.721465 |
| g | **Total O&M costs (a+b+f+g)** | | | **21,940.33** |

The operating costs that include operating labor, supervision, maintenance and repairs, and indirect costs, which consist of overheads, storage and insurance and general expenses were estimated according to the standard procedures (Pilluti et al., 2003).

- Total annual cost per year (A+B) = (TCI/4 years) + O&M/year = RM 39,174.35
- Total reuse water production per year = 1,825 G
- Cost for treated reuse water = RM 21.47/Gallon.

## 4. Conclusions

Submerged membrane system is one of the most rapidly advacing water treatment technologies, which has gained wide acceptance in water and wastewater treatment industry due to their ability to produce a high-quality and consistent product water. More recently submerged membrane has gained acceptance as a main filtration system with chosen pretreatment process for refinery wastewater treatment. It can be concluded that the profitability of a submerged membrane UF system with cost of treated reuse water of RM 21.47/Gallon is very interesting value for further application. On the other hand, of course, the engineer or end user may be interested in other variety of existed technologies and the choice must also include the technology reliability and the plant availability

**Acknowledgements**

This research is funded by the grant from The Ministry of Research Technology and Higher Education through the “Penelitian Terapan Unggulan Perguruan Tinggi” program.

**References**

Ali, M.F., Hamdan A. J., Rahman F., 1995, Techno-economic evaluation of waste lube oil re-refining in Saudi Arabia, International Journal of Production Economics, 42, 263-273.

Andrade L.H., Mendes F.D.S., Espindola J.C., Amaral M.S.C., 2014, Nanofiltration as tertiary treatment for the reuse of dairy wastewater treated by membrane bioreactor, Separation and Purification Technology, 126, 21-29.

Delcolle R., Gimenes M.L., Fortulan C.A., Moreira W.M., Martins N.D.,Pereira N.C., 2017, A comparison between coagulation and ultrafiltration processes for biodiesel wastewater treatment, Chemical Engineering Transactions. 57, 271-276.

Frioui R, Oumeddour R., 2008, Investment and production costs of desalination plants by semi-empirical method, Desalination 223, 457-463.

Johnson D.J., Al Malek S.A., Al-Rashdi B.A.M., Hilal N., 2012, tomic force microscopy of nanofiltration membranes: effect of imaging mode and environment, Journal of Membrane Science, 389, 486-498.

Lau W.J., Ismail A.F., 2009, Polymeric nanofiltration membranes for textile dye wastewater treatment: preparation, performance evaluation, transport modelling, and fouling control- a review, Desalination, 245, 321-348.

Li Y., Su Y,, Dong Y., Zhao X., Jiang Z., Zhang R,. Zhao J., 2014, Separation performance of thin film composite nanofiltration membrane through interfacial polymerization using different amine monomers, Desalination, 333, 59-65.

Mohammad A.W., Teow Y.H., Ang W.L, Chung Y.T., Oatley-Radcliffe D.L., Hilal N., 2015., Nanofiltration membranes review: Recent advances and future prospects, Desalination, 356, 226-254.

Mosqueda-Jimenez, D.B., Narbaitz R.M., Matsuura T.,Chowdhury G., Pleizier, G., Santerre J.T., 2004, Influence of processing conditions on the properties of ultrafiltration membranes, Journal of Membrane Science. 231, 209-224.

Pilutti PE. M., Julia E., Nmeth PE., 2003, Technical and cost review of commercially available MF/UF membrane products, International Desalination Association Report, BAH03-029.

Pressdee J.R., Veerapaneni S., Shorne-Darby H.L., Clement J.A.,Van der Hoek J.P., 2006, Integration of membrane filtration into water treatment systems, American Water Works Association (AWWA) research foundation, USA,

Vargas A.N., Ladino J., 2017, Economic viability analysis on seawater desalination by electrodialysis as an alternative for water potabilization in Pueblo Viejo, Colombia, Chemical Engineering Transactions. 57, 493-498.

Younos T., 2005, The economics of desalination, Journal of Contemporary Water Research & Education, 132, 39-45.

Yuliwati E., Ismail AF., Matsuura T., Kassim M.A., Abdullah M.S., 2011, Effect of modified PVDF hollow fiber submerged membrane ultrafiltration membrane for refinery wastewater treatment, Desalination 283, 214-220.