Energy consumptions of the submerged UF system

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**Abstract**

Refinery wastewater treatment is needed especially in the oil-producing arid regions such as oil refineries due to water scarcity. One of potentially applicable processes to treat refinery wastewater is a submerged membrane technology due to water scarcity that is caused by producing oily wastewater. This study reports the energy consumption analysis of membrane for refinery wastewater treatment. Results showed that the invesment and production costs were estimated to be the total annual cost per year and costs for treated reuse water of RM 39,174.35 (USD 39,174.35) and RM 21.47/GPD (USD 7.02/GPD), respectively.

Keywords*:* Submerged membrane ultrafiltration; refinery wastewater; economic evaluation; energy consumption.

1. **Introduction**

The impact of membrane filtration versus conventional treatment in water and wastewater reclamation is a key point in the position of such new technology. Several studies have been performed in developing some researchs in the first half of this decade [1-4]. Meanwhile, the need of pure water throughout the world is constantly increasing, as well as insufficiency of supply due to limited stocks and pollution. As reported by Frioui and Oumeddour (2008), the world has experienced a six fold increase in the water usage since 1950 and the demand of freshwater increases also twice as fast as population growth from 6 billion in year 2000 to 8 billion during a period of 25 years [5]. Based on this situation, numerous manufacturers of membrane filtration, especially ultrafiltration membrane system are currently existing, 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 can be 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 development of water or wastewater filtration and their products have been tabulated in Table 1.

Table 1. Summary of the major UF/MF systems [3].

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 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 [6,7]. 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. The evaluation was made for a small production unit of 5 Gallon/day.

This kind of study addressed in the water purification industries to apply the system in order to simplify the operating steps thus minimized the overall energy consumption.

1. **Submerged membrane system for refinery wastewater treatment**

Submerged membrane system is defined as a membrene separation system, where the membranes are immersed in the feed water contained in an open tank. The modified hollow fiber membranes were prepared by dry-jet wet spinning method with the spinning dope of 19 wt.% PVDF in dimethylacetamide (DMAc). 0.98 wt.% of titanium dioxide (TiO2) and 0.50 wt.% of lithium chloride (LiCl) were added to the spinning dope in order to improve membrane hydrophilicity, mechanical strength, pore size, and porosity [8-10]. The properties of the modified PVDF hollow fiber membrane was tabulated in Table 2.

Table 2. Properties of modified PVDF hollow fiber membrane [10].

|  |  |
| --- | --- |
| **Parameter** | **Membrane** |
| Membrane material  Additives added | PVDF  LiCl, TiO2 |
| Outer diameter (mm) | 1.1 |
| Inner diameter (mm) | 0.55 |
| Outer pore size (nm) | 34.05 |
| Nodule size (S.D.) (nm) | 66.57 (±1.31) |
| Contact angle (o) | 54 (±0.93) |
| Tensile strength (MPa) | 3.37 ( ±0.13) |

The 60 pieces of hollow fiber membranes were assemblied to form a bundle with an effective hollow fiber length of 50 cm. Two bundles of fibers were submerged in the feed reservoir, where the fibers were allowed to be shaken by the air bubbles during the operation to dislodge the foulants deposited on the hollow fiber surface.. The filtration experiments were carried out in a vacuum pressure mode (0.5 bars absolute) and the permeate was withdrawn from the open end of fibers. The liquid level of 40 cm in the feed tank was maintained constant throughout the experiment. The air scouring bubbles also exerted shear stress upon the membrane surface to minimize the particle deposition.

The experimental set-up shown in Fig. 1 was used in this study. It was comprised of two main parts: the pretreatment tank and the membrane separation unit equipped with a fiber glass tank. The membrane filtration unit consisted of a feed reservoir of 14 L, two hollow fiber bundles, a peristaltic pump, a permeate flowmeter, a recycle pump and an effluent tank.



Fig. 1.  Scheme of the submerged membrane ultrafiltration (V1: wastewater valve, T1: pretreatment tank, V2:feed membrane reservoir valve, S: sparger, M: membrane module, T2: feed reservoir, T3: effluent tank,P1: peristaltic pump, P2: centrifugal pump, P3: air pump, QC: flow control, LC: liquid control, LI: level indicator, PC: pressure control [9,10].

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

*F = * (1)

where *F* is the pure water flux (l/m2 h), *V* is the permeate volume (l), *A* is the membrane surface area (m2), and *t* is the time (h).

Total suspended solids (*TSS)* concentrations was 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 daily. The total suspended solids (*TSS)* removal efficiencies was calculated by Eq. 2. [11],

*TSS removal %*  (2)

where *TSSo* and *TSS* are the initial TSS concentration of the synthetic refinery wastewater in feed and the TSS concentration of permeate produced.

At the air bubble flow rate, hydraulic retention time and mixed liquor suspended solids of 2.25 ml/min, 240 min and 3 g/L, respectively, the maximum flux, TSS removal were achieved as listed in Table 3.

Table 3. Optimum performance of submerged membrane UF for refinery wastewater treatment

|  |  |
| --- | --- |
| Parameter | Removal (%) |
| Total suspended solids (TSS) | 99.63% |

1. **Factors affecting energy consumption on submerged membrane filtration**

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 [12-15]:

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 associated with meeting local/state permits and regulatory requirements.
   1. *Energy consumption and capital cost*

Recently, the capital costs of submerged and encased membrane system have been reduced by several manufacturers in order to minimize the total capital investment. The capital costs consist of the membrane, compressors, pumps, piping, instrumentation, controls, and other necessary for a complete and operable system. The data is summarized in the Fig. 2, which shows that the bothencased and submerged systema are very competitive for systems up to 10 mgd (million gallon per day) and submerged systems are more cost-effective for systems larger than 10 mgd.

Fig. 2. The summarized capital costs for encased and submerged membrane systems bid and constructed from 2003 to 2011 in US Dollars (USD) per US Gallon (USG) of capacity [3,9,10,16].

Sorgini 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 [17].

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 4, as reported by Pressdee *et al*.[18].

Table 4. Impact of water treatment plant upgrades on water flowrates.

|  |  |
| --- | --- |
| Financial year | Percentage rate increase |
| 2003 | 10 |
| 2004 | 10 |
| 2005 | 10 |
| 2006 | 10 |
| 2007 | 10 |
| 2008 | 7 |
| 2009 | 5 |
| 2010 | 3 |
| 2011 | 2 |

The costs estimating models in Table 4 are currently available for estimating capital and operation costs of water treatment process including membrane process.

1. **Submerged membrane filtration performance evaluation**

The economics of submerged membrane filtration based on its energy consumption were evaluated based on the plant specification. 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 (USD 1.88/L). Plant specification was carried out using assumptions and financial arrangements described in Table 5 dan 6. The operating and maintenance costs of resuse water production from refinery wastewater has bees anlized and listed in Table 5.

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Direct and indirect costs | | Amount (kg) | Purchasing cost (RM) | |
| No | Item |
| 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/m2)** |  |  | **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 [19].

**Table 6.** The operating and maintenance costs (B) of reuse water production per year

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| No | Item | Amount | Purchasing cost (RM) | |
| RM/unit/kW hr/L | Cost/year |
|  | Operating costs |
| a | Utilities power (pump+mixer+compressor) | 267,858.90 | 0.0198 | 5303.60622 |
|  | 37.29+37.29+37.29+8.95+1.49=122.31 kW x 6 hr= 733.86 kW hr); | kW hr/year |  |  |
|  | 733.86 kW x 365 = 267,858.9 kW hr/year |  |  |  |
| b | Labor costs (500/month; average 8 hr/day) | 1 | 16.6 | 16.6 |
| c | Cleaning costs | 830.3 | 4 | 3321.2 |
| e | NaOH consumption | 825 | 8 | 6600 |
| f | **Total chemicals costs (c+d+e)** |  |  | **15,241.40622** |
| g | Maintenance cost |  | 2 % of TCI | 1378.721465 |
| h | **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 [20].

* 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 Gallon
* Cost for treated reuse water = RM 21.47/Gallon.

1. **Conclusion**

Submerged membrane ultrafiltration 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 UF has gained acceptance as a main filtration system with chosen pretreatment process for refinery wastewater treatment. It can be concluded from this feasibility study that the profitability of a submerged membrane UF system with cost of treated reuse water of RM 21.47/GPD is very interesting value for further application.

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