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BWRO DESALINATION FOR POTABLE WATER SUPPLY ENHANCEMENT IN COASTAL REGIONS

I Nyoman Widiasa [1], Vita Paramita [2], Heny Kusumayanti [2]*

[1] Dept. Chemical Engineering, Faculty of Engineering, Diponegoro University
[2] PSD III Chemical Engineering, Faculty of Engineering, Diponegoro University
Kampus UNDIP Tembalang, Jl. Prof. Sudarto, Tembalang, Semarang

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ABSTRACT

Most of coastal regions in Indonesia have experienced water scarcity where water resources are becoming more and more threatened due to the rapid growth of population, aquaculture industries and agricultures. Brackish water reverse osmosis (BWRO) desalination may be used to overcome the supply potable water problem in the coastal regions. Brackish water having total dissolved solids (TDS) content in the range of 1,000–10,000 ppm can be desalinated at a reasonable cost. This work was aimed to find valuable technical data for plant design and operation. Cost analysis also was conducted to obtain specific water cost. The results show that stable system performance was achieved. Based on a case study of small scale BWRO with capacity of 50 m^3/day, specific water cost was around of IDR 6,100/ m^3.

Key Words : Brackish water, Desalination, Coastal region, Reverse osmosis.

Correspondence* : Phone. +62-24-7460058, Fax. 62-24-76480675, email: widiasa@undip.ac.id

INTRODUCTION

Recently, a number of coastal regions in Indonesia have water resources with low quality because the high level of salts, hardness, or dissolved and suspended organics content. Available surface water resources have been obviously contaminated by industrial wastes as well as by domestic wastes. The rapid growth of population, aquaculture industries and agricultures has increased water demand, resulting in a mismatch between surface water resources and water demand. Consequently, millions people in coastal regions lack access to safe drinking water and good sanitation.

Brackish water reverse osmosis (BWRO) desalination provides an alternative for fresh water supply, treating water not accessible for irrigational or municipal use. The feasibility of BWRO desalination in many countries has been reported from technical and economical points of views (Frenkel and Gourgi, 1995; Mudaiheem *et al.*, 1998; Mohsen and A1-Jayyousi, 1999; Georgopoulou *et al.*, 2001; Goncharuk *et al*, 2001; Allama *et al.*, 2002, Talaat *et al.*, 2002; Ahmad and Schmid, 2002; Al-Zubari, 2003; Afonso *et al.*, 2004; Saadi and Ouazzani, 2004; Lashkaripour and Zivdar, 2005; Nederlof and Hoogendoorn, 2005; Walha *et al.*, 2007). Generally, it is reported that BWRO desalination is

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prospective for potable water supply at reasonable cost.

Recent development of the RO membranes have resulted dramatic improvements in the economics of reverse osmosis. Many patents claim that the newer membranes reject more salts and pass more water under a particular pressure, thus resulting in lower energy consumption (Hachisuka and Ikeda, 1998; Hirose *et al*, 2000; Hirose *et al*, 2004; Koo *et al*, 2009). It also is claimed that they are more durable, able to handle harsher feed water conditions, and more compatible to a wide range antiscalants and cleaning solutions. These improvements will drive the continuous growth of BWRO technology.

Before a BWRO system is designed, it is very important to understand the limitations related to feed water characteristics. The BWRO system permeate recovery and permeate quality, as well as maintenance requirements, will depend greatly on the quality of water source. Usually, the quality of potential water source has wide variety during the year that affecting the design of the RO itself. Therefore, the potential water source should be completely investigated, including its contaminants, its variability, and even its availability, to assist in designing RO pretreatment and RO system successfully.

MATERIALS AND METHODS

(Fig.1) illustrates the experiment set-up used in this study, which consisted of a stirred vessel, cartridge filter, a spiral wound RO membrane, a diaphragm pump (Puricom UP-8000, maximum flow rate of 4 lpm, maximum pressure of 105 psig, motor 48VDC/2A/50hz), a flow rate regulator (adjustable DC power supply), and one pressure regulator (regulator valve). The system was also completed with automatic temperature control and pressure indicator (FTB, 0–140 psig). RO membranes, FilmTec™ TW30-1812-100, were used.

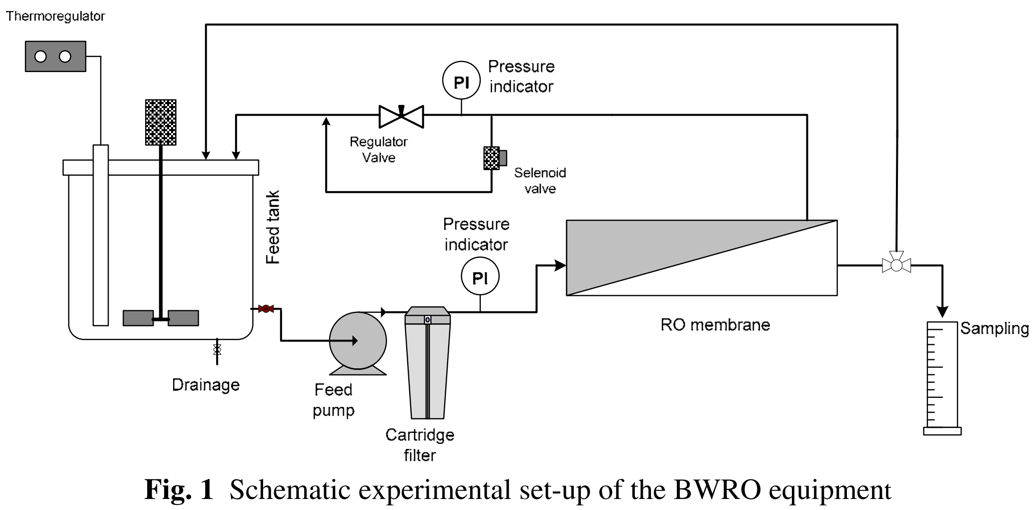

Fig. 1 Schematic experimental set-up of the BWRO equipment

In this study, the brackish water was taken from Morosari-Demak, Central Java. A total recycle operation mode was used, that is both permeate and retentate were returned to the feed tank to maintain the feed characteristic relatively constant. To avoid the effect of membrane compaction, deionized water was recirculated at pressure of 8 bars for 8 hours prior to the use of the brackish water. Experiments of the brackish water desalination were conducted at pressure and temperature 90±3 psig and 28±2°C, respectively. Two key performance

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parameters, i.e. flow rate and total dissolved solids of permeate, were observed.

For evaluating the effect of membrane fouling and/or scaling to the hydraulic resistance, the pure water fluxes were measured under the following conditions: (1) for a new membrane, (2) for a membrane which was exposed by brackish water, (3) for a membrane which was cleaned by 1% citric acid followed by 1% EDTA (ethylenediaminetetraacetate).

Cost evaluation was also done based on a case study of small-scale BWRO plant with capacity of 50 m^3/day. This cost analysis took into account both direct capital and operating costs. All elements of indirect capital cost elements were excluded.

RESULTS AND DISCUSSION

Feed water characteristic

It has been stated above that the quality of feed water greatly influences BWRO system permeate recovery and permeate quality, and maintenance requirements. Physical and chemical characteristics of the feed water are shown in Table 1. As can be seen that TDS content is relatively low, allowing the system is operated under feed pressure lower than 15 bar. This will reduce process equipments cost significantly.

Table. 1. Physical and chemical characteristics of the feed water

Parameters	**unit**	**Value**
Temperature	oC	28
pH	-	7.96
Total disolved solids (TDS)	mg/l	3850
Ca^{2+}	mg/l	115.9
Mg^{2+}	mg/l	228.9
$Na^{+}+K^{+}$	mg/l	993.2
HCO_3^-	mg/l	267.4
SO_4^{2-}	mg/l	493.8
Cl^-	mg/l	1693.0

Permeate flux and specific energy

(Fig. 2) shows the effect of feed pressure on both permeate flux and specific energy. The increase of feed pressure resulted in increase of the permeate flux. It is means that smaller membrane area is required for a given plant capacity; however, process equipments cost raises. While, specific energy decreased with the increase of feed pressure, subsequently lowering electricity cost.

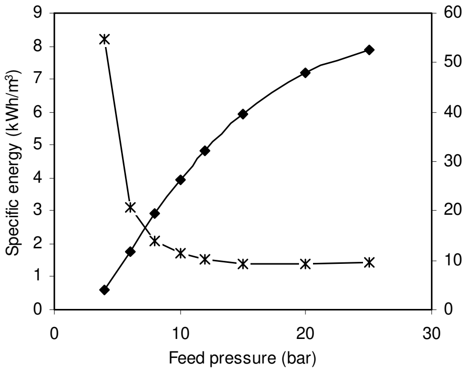

Fig. 2. The effect of feed pressure on permeate flux and specific energy

Membrane cleaning

Organic fouling, oxide fouling, biofouling and scale formation due to precipitation of sparingly soluble salts present in the feed water such as calcium carbonate, calcium sulfate, silica, and magnesium silicate remain a serious problem in BWRO desalination. The presence of dissolved organic carbon (DOC) contributes to organic fouling. DOC represents a range of organic compounds, such as polysaccharides, proteins, amino sugars, nucleic acids, humic and fulvic acids, organic acids, and cell components (Sciener *et al*, 1998).

Developing strategies for fouling control has always been a major challenge in membrane research. Chemical cleaning solution will remove foulant deposited on the membrane surfaces (Deqian, 1987; Ebrahim, 1994; Sadhwani and Vesa, 2001; Moghadam *et al.*, 2001; Moghadam *et al.*,

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2002; Laukkanen *et al.*, 2002). Membrane cleaning is conducted when there is a significant decline in permeate flux or salt rejection, or there is a need to increase the transmembrane pressure significantly to maintain the desired permeate flux (Osta and Bakheet, 1987). There are five categories of cleaning agents – alkaline solutions, acids, metal chelating agents, surfactants, and enzymes (Moghadam *et al.*, 2002). Commercial cleaning products are often a mixture of these compounds, but in most cases, the actual compositions are unknown.

(Fig. 3) shows permeate flux of new membrane, of fouled membrane, of acid-cleaned membrane, and of EDTA-cleaned membrane. Although it is not always effective, acid cleaning followed by EDTA cleaning was enough effective to restore membrane performance when scale was in the form of calcium salts. Cleaning efficiency may be improved by optimizing cleaning agent dose and pH solution.

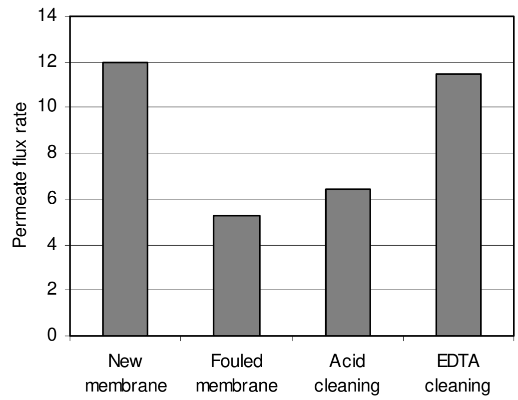

Fig. 3. Restore of membrane performance after cleaning

System design

An example of BWRO plant producing 50 m^3/day fresh water will be discussed. Figure 4 shows the process flow of the plant, consisting of one well, one feed break tank, two feed pumps (one standby), one antiscalant injection system, one RO system, one CIP system, one flush system. The system has five pressure vessels (PV) where there are two membrane modules in each pressure vessel. Feed water is passed through the pressure vessels in two pass with 3-2 arrangement.

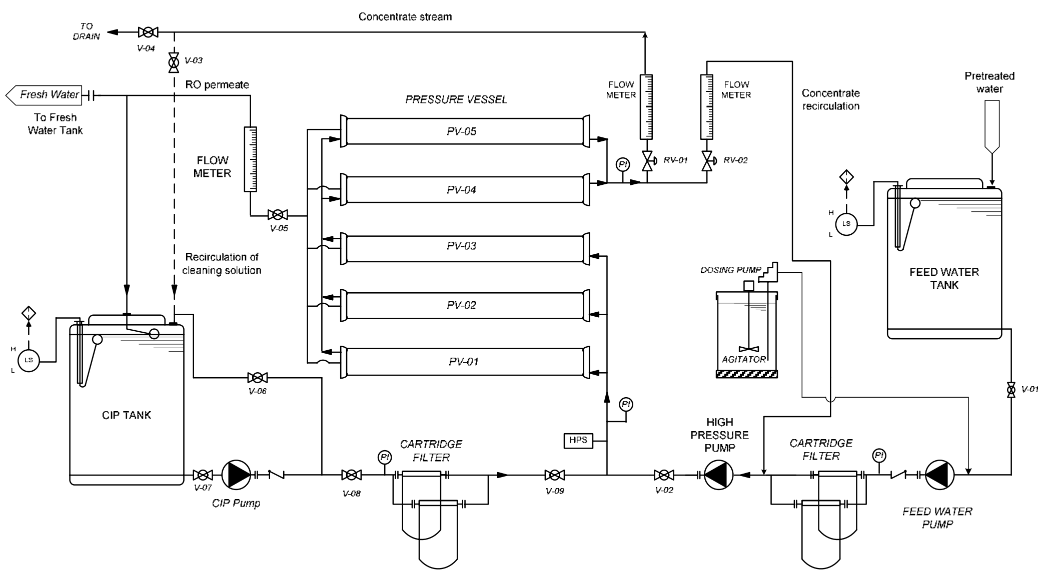

Fig. 4. Process and instrumentation diagram (P&ID) of the BWRO system

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Table 2. The input data used for system calculation to produce fresh water of 50 m^3/day

Feed data	
Water type	SDI < 3
Feed percentage	100%
Feed number	1
Feed stream	1
Total dissolved solids	3850
Temperature	25°C
pH	7.96
System configuration	
No. Passes	1
Current pass	1
Stages in pass	2
Fouling factor	0.85
Permeate flow	2.2
Recovery	50
Pressure vessel in stage 1	3
Pressure Vessel in stage 2	2
Total element in each stage	2
Membrane type	BW30LE4040
Back pressure	0.2 Bar
Blend permeate	none
Pass 2 conc. to pass 1 feed	0.0 m^3/h

For design and optimization calculations, free RO software, well known as ROSA 6.15, was used. The calculation based on assumptions that feed water has maximum TDS and turbidity of 5000 mg/L and 3 NTU, respectively. The input data used for the BWRO system calculation is shown in Table 2. Overall system recovery was fixed 50% to reduce scaling problem.

Table 3. The calculation results of system details

Feed flow to stage 1	4.4 m^3/h
Raw water flow to system	4.4 m^3/h
Feed pressure	11.4 bar
Osmotic pressure	
Feed	2.4 bar
Concentrate	4.7 bar
Average NDP	7.36 bar
Power	3.47 kW
Specific energy	1.58 kWh/ m^3

The system capacity may be increased up to 60 m^3/h by increasing feed pressure up to 13 bar and recycling the second pass concentrate to the first pass feed. However, this increases the specific energy consumption up to 1.71 kWh/m^3.

Table. 4 shows comparison between the produced fresh water quality and Indonesian drinking water standard. As can be seen that all parameters fulfill such standard. It should be emphasized that the produced fresh water is possible to be contaminated in distribution system, hence, further disinfection is needed to ensure the microbial safety.

Table 4. Comparison between produced fresh water and the Indonesian drinking water standard (Kepmenkes, 2002)

Parameters	**unit**	**Value**	**Standard**
pH	-	6.51	6.5 – 8.5
TDS	mg/l	67.7	1000
Hardness	mg/l	3.7	500
Na^+	mg/l	14.9	200
SO_4^{2-}	mg/l	3.9	250
Cl^-	mg/l	31.2	250

Cost analysis

Cost analysis for the BWRO desalination based on the cost structure as shown in (**Fig. 5**). Production cost was divided into direct and indirect capital costs and annual operating cost. Direct capital costs include the purchase cost of major equipment, auxiliary equipment, land and construction. In this cost analysis, costs for well supply, brine disposal, land, and building as well as all indirect capital cost elements were excluded.

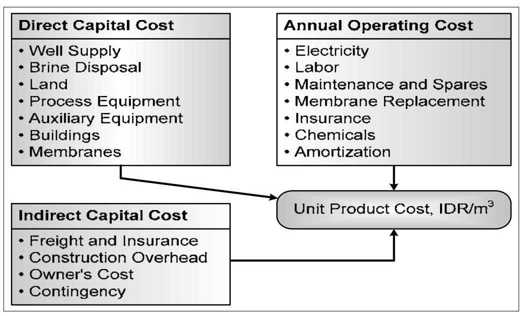

Fig. 5. Structure of cost analysis of a BWRO desalination

Annual operating costs are those expenditures incurred after plant commissioning and during actual operation. These include labor, energy, chemicals, spare parts and miscellaneous items. The calculations were based on the following assumptions:

- interest rate, i = 14%/yr
- plant life, n = 10 yr
- amortization factor, a = 0.2913/year
- plant availability, f = 0.9
- electricity cost, c = IDR 1,000/kWh

Table 5 shows a summary of the cost analysis. As the capacity is too small, the unit product cost of IDR 6,100/m^3 is high. Larger plant capacity will provide lower cost per unit product, despite a higher initial capital investment.

Table 5. Summary of cost analysis results of a given BWRO system with capacity of 50 m^3/day

Items	unit	value
Total product	m^3/yr	18,250
Capital cost	IDR	277,000,000
Electricity cost	IDR/yr	39,364,812
Membranes cost	IDR/yr	13,750,000
Manpower cost	IDR/yr	43,200,000
Maintenance cost	IDR/yr	13,850,000
Chemicals cost	IDR/yr	1,186,250
Annual operating cost, IDR		111,351,062
Specific operating cost, IDR/m^3		6,100

CONCLUSIONS

Technical and economical evaluations of BWRO desalination for enhancement of fresh water supply were conducted. The results show that the system performance was relatively stable. The effectiveness of acid cleaning followed by EDTA cleaning is important to obtain membrane lifetime over than 2 years. Finally, based on a case study of small-scale BWRO with capacity of 50 m^3/day, specific water cost around of IDR 6,100 per m^3 could be achieved.

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