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Development of Desalination Technology using Reverse Osmosis Membrane for the Provision of Clean Water in DKI Jakarta

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Abstract. Ensuring the availability of water in a future is a primary concern of government in the world nowadays. As one of the countries involved in the Sustainable Development Goals (SDGs) commitment, Indonesia required drafting development programs, one of which is to ensure the availability of clean water. The amount of clean water available is not proportional to the needs of the community as the population increases. As an example, Jakarta is still heavily dependent on groundwater and river water that heavily polluted by residents' wastes. Due to the lack provision of clean water, one of the alternatives emerged is to get clean water through the desalination process using Reverse Osmosis (RO) membrane. Reverse osmosis development can be an opportunity for overcoming the crisis of water supply. The development including advanced membrane materials, modules and process design, and energy recovery will reduce the cost burden that will draw attention to its commercial applications. Currently, the government has designed water supply fulfilment using the technology but is constrained by several factors such as expensive technology installation cost, energy consumption and the problem of membrane treatment.

INTRODUCTION

The quality of raw water used for the fulfilment of clean water needs in Jakarta is alarming because of the high organic and inorganic particles contamination in the river water and groundwater [1]. In 2016, Jakarta is classified as one of the ten countries with the lowest Water Sustainability Index in the world, which is 42.5% [2]. As many as 80% of groundwater in the Jakarta Basin Area (CAT) does not meet the Minister of Health's standard no. 492 of 2010 on Water Quality Requirements. There are 16 out of 85 samples of well locations on free aquifer layers that meet quality standards, and for distressing aquifer locations, there are only 12 out of 69 areas that meet the quality standards to serve as raw water [3]. The river water in Jakarta is already in the contaminated condition of bacteria that comes from the population waste (Table 1).
TABLE 1. The Quality Value of 13 River water in Jakarta Based on the Biological Parameters [4]

<table>
<thead>
<tr>
<th>Location</th>
<th>Biological Parameter</th>
<th>Total Coliform Value (JPT/100 mL)</th>
<th>Coliform Feces Value (JPT/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saluran Tarum Barat Bendungan Curug</td>
<td></td>
<td>$4 \times 10^3$</td>
<td>$1.1 \times 10^3$</td>
</tr>
<tr>
<td>Syphon Bekasi</td>
<td></td>
<td>$2.1 \times 10^3$</td>
<td>$6 \times 10^4$</td>
</tr>
<tr>
<td>PAB Cawang</td>
<td></td>
<td>$3.3 \times 10^5$</td>
<td>$1.7 \times 10^4$</td>
</tr>
<tr>
<td>Kali Ciliwung (Pejaten)</td>
<td></td>
<td>$1.2 \times 10^6$</td>
<td>$6 \times 10^5$</td>
</tr>
<tr>
<td>Setu Babakan</td>
<td></td>
<td>$1.7 \times 10^5$</td>
<td>$1.3 \times 10^4$</td>
</tr>
<tr>
<td>Kali Krukut (Cilandak)</td>
<td></td>
<td>$4 \times 10^5$</td>
<td>$2 \times 10^6$</td>
</tr>
<tr>
<td>Kali Pesanggrahan (DCR 5)</td>
<td></td>
<td>$9 \times 10^5$</td>
<td>$9 \times 10^4$</td>
</tr>
<tr>
<td>Kali Pesanggrahan (DCR 4)</td>
<td></td>
<td>$6 \times 10^5$</td>
<td>$7 \times 10^4$</td>
</tr>
<tr>
<td>Cengkareng Drain</td>
<td></td>
<td>$2.7 \times 10^6$</td>
<td>$4 \times 10^5$</td>
</tr>
<tr>
<td>Kanal Banjir Barat Jembatan Besi</td>
<td></td>
<td>$2.2 \times 10^6$</td>
<td>$1.7 \times 10^5$</td>
</tr>
<tr>
<td>Kanal Banjir Barat Hutan Kota</td>
<td></td>
<td>$2.2 \times 10^5$</td>
<td>$1.7 \times 10^4$</td>
</tr>
<tr>
<td>Kanal Banjir Timur Marunda</td>
<td></td>
<td>$2.2 \times 10^5$</td>
<td>$2.6 \times 10^4$</td>
</tr>
<tr>
<td>Danau Sunter</td>
<td></td>
<td>$7 \times 10^5$</td>
<td>$2 \times 10^5$</td>
</tr>
</tbody>
</table>

*Maximum Threshold Value for Total Coliform is $10^4$ JPT/100 mL.

** Maximum Threshold Value for Coliform Feces is $2 \times 10^7$ JPT/100 mL.

Based on Table 1, of the 13 samples of river water under study, only 2 rivers meet the requirements of government quality standards. This condition needs to get attention because there are still many people who use river water and well water as the primary source of daily activities, plus government water company only able to serve 60.27% from total population in Jakarta [4]. Therefore, the Indonesian government, especially the government in Jakarta should begin to search for alternative water sources for the provision of clean water. Adequate brackish water sources and seawater sources of unlimited quantity are good alternatives, but these two types of water are of inferior quality due to their high salt content or Total Dissolved Solid (TDS) [5]. Therefore, a process of reducing the salt content in water to produce water is feasible, this process known as desalination [6], [7].

METHODS

This study uses literature study based on journal reviews and reviews related news about the development of clean water needs, especially in DKI Jakarta and surrounding areas by using membrane desalination technology.

RESULT

Desalination is a technology that can reduce salt and other minerals from raw water such as seawater, brackish water or industrial wastewater [8]. In another definition, desalination is the processing of brine or brackish water into clean water (drinkable water) through the reduction of its dissolved solids content [9]. The most commonly used desalination technology is thermal desalination using Multi-Stage Flash Distillation (MSF) and membrane desalination [7], [10]. Although the water quality of the product produced by MSF desalination is better than the RO membrane, it requires a higher installation and operation costs. Therefore, a possible route to more sustainable
clean water production offered by Membrane Technology, whose core aspect meets the requirements of Process Intensification.

RO is the most commonly used membrane type in the desalination process because of its ability to reject almost all dissolved solids to produce pure water [7], [11], [12]. It is a design aimed at generating tangible benefits in manufacturing and processing, substantially shrinking equipment sizes, improving plant efficiency, saving energy, reducing capital costs, minimising environmental impact, improving safety, using remote control and automation, etc. [13].

A very fundamental difference is shown in the pressure required to process raw materials into the clean water. This is due to a large amount of shelled solids contained in seawater causing high-pressure requirements [18]. The second difference is the number of stages required in the desalination process. In designing RO can use single stage system or multiple stage system. In RO membrane design with raw water feed from seawater usually only use a single stage, while in brackish water can use single stage and multiple stages [20]. Multiple stages design is frequently used than the single stage to increase its recovery.

![Fig 1](image)

**FIGURE 1.** (a) Design of Single-stage RO Membrane for Desalination; (b) Design of Multi-stage RO Membrane for Desalination [7], [12], [16]

**DISCUSSION**

**Problems of Desalination using RO membrane**

**Fouling and Scaling**

Fouling is a clogging event in the pores or solute adsorption on the membrane surface which can decrease the membrane performance [11]. Fouling can be caused by several factors: chemical foulants, physical foulants or particulate matter (organic or inorganic) that can create the disposition of particles on the membrane surface, natural organic matters that can react with membranes and biological foulants such as bacteria and fungi can form biofilm layers that degrade membrane performance [15], [16].

The RO membrane has a small pore size so that it rejects particulates that potentially cause fouling and scaling. Therefore, pre-treatment technology is necessary to reduce membrane fouling, in order to improve the effluent quality and control membrane fouling economically and environmentally [19]. Two methods are used as pre-treatment of RO, mainly membranes conventional pre-treatment (i.e. chemical coagulants and filter) and Membrane pre-treatment membrane (e.g. Microfiltration, Ultrafiltration, and Nanofiltration) [16],[21]. Currently, membrane pre-treatment is mostly applied to the desalination plant RO compared with conventional pre-treatment [10], using Ultrafiltration (UF) because it has smaller pores than Microfiltration (MF) and has a higher flux than Nanofiltration (NF) [22].

One example of membrane pre-treatment application is in the case of pre-treatment in Tampa Bay, Florida, where there are operational problems in the desalination process [7]. Desalination plants built with a capacity of 94000 m$^3$/day initially use conventional pre-treatment with in-line coagulation and 2-stage sand filters. However, the treatment result of pre-treatment cannot meet the value of Silt Density Index (SDI) for feed water on RO membrane to accelerate the occurrence of fouling on the membrane. This leads to the use of high chemicals, high energy consumption and a more frequent period of membrane replacement resulting in increased operating costs. Based on Table 2, when the pre-treatment type on the installation of its SWRO membrane is changed to UF membrane, the quality of the treated water into the feed can meet the standard thus reducing the risk of fouling and scaling on the
RO membrane. Although UF membrane life is shorter than a sand filter, it able to produce a higher flux permeate and reduce RO membrane replacement period so that operating cost can be more controlled [7].

**TABLE 2.** Comparisons between Membran Pre-treatment and Conventional Pre-treatment to Sea Water Desalination Process [7]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Membran Pre-Treatment **</th>
<th>Conventional Pre-Treatment***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of Feed Water</td>
<td>SDI &lt; 2.5, 100% of the time (Usually &lt; 1.5)</td>
<td>SDI &lt; 4, 90% of the time</td>
</tr>
<tr>
<td>SWRO Average Flux</td>
<td>~18 L/m²h</td>
<td>~14 L/m²h</td>
</tr>
<tr>
<td>SWRO Cleaning Frequency</td>
<td>~1-2 times per year</td>
<td>~4-12 times per year</td>
</tr>
<tr>
<td>SWRO Replacement Rate</td>
<td>~ 10%</td>
<td>~ 14% per year</td>
</tr>
<tr>
<td>Lifetime</td>
<td>Membrane: 5-10 years</td>
<td>Sand Filters: 20-30 years</td>
</tr>
<tr>
<td>Pre-treatment footprint</td>
<td>~30-60% of conventional</td>
<td>100%</td>
</tr>
</tbody>
</table>

*SDI stands for Silt Density Index to measure fouling capacity of raw water in RO system

** Using Hollow Fibre Ultrafiltration Membrane

*** Using In-line Coagulation and 2-stage Sand Filters

A similar case occurred in membrane installations constructed by the government in Seribu Island, Jakarta. In 2015, where 8 RO membrane units damaged due to fouling and scaling [23]. Installation of desalination built with a capacity of 210 m³/day by 2015 is not maintained by the government so it can only run with a capacity of 50 m³/8 hours, even if forced to run with a capacity of 100 m³/10-12 hours [24]. The water quality generated from this plant is still considered to be unfit for drinking water standards (TDS ± 385 mg / L from the previous 15,000 mg / L), so residents only use the water for daily use [24]. This is because raw water in the form of brackish water contains high iron metal so that with pre-treatment at the installation of RO Desalination which currently only use an ordinary filter is not able to filter the raw material to the maximum [24]. This makes the load of RO membrane process heavier that can accelerate the fouling process in membrane. The government at that time only prepared the budget for the membrane installation, but not with the maintenance cost to make the membrane performance worse [23],[24]. In 2018 the government plans to replace the RO membrane with SWRO and will install pre-treatment membranes in the form of UF membranes to meet the needs of residents in the area [25]. However, desalination installations in other parts of Jakarta are still in a proposal due to cost constraints [24],[25].

**Energy Consumption**

Desalination using RO membranes requires a massive energy consumption because in the process it needs a high-pressure range above the osmotic pressure of the raw water. However, as the developments of technology continues to grow, emerging some of the methods that can reduce energy consumption during the desalination process, one of them is the Energy Recovery Device (ERD).

Energy Recovery Devices (ERD) use the remaining hydraulic energy from the brine (retentate) to provide pressure to feed raw water. There are two types of ERD namely Pressure Exchanger and Turbine System [7], [26]. If in a membrane desalination process the energy needs of 6-8 kWh / m³ will reduce to 4-5 kWh / m³, even more, reducing to 2 kWh/m³ by using ERD for seawater [11] and <1 kWh / m³ for brackish water [7].

Pressure exchanger directly transfers pressure from concentrate on some feed raw water with an efficiency of about 96% - 98%, while the turbine system converts potential energy from concentrate into mechanical energy supplied to the pump as additional power or directly to raw feed water with an efficiency of 90% [26]. The use of pressure exchangers requires other equipment such as high-pressure circulation pumps that need a high cost of installation, operation and maintenance [7]. If assessed concerning cost, the use of turbine systems will be cheaper than pressure exchangers [27], [28]. Another disadvantage of pressure exchangers is to increase salinity in feed water by about 3-5% and cause an increase in osmotic pressure and thus require a higher pressure in the desalination process of RO [7], [30]. However, the turbine system has a lower operating efficiency value compared to the
Desalination Water Cost

In general, the costs required for the RO desalination process are influenced by several factors, namely the quality of the raw water source being the feed, the characteristics, the location and the capacity of the plant, the energy consumption required and the interest rate at the time of budgeting for the construction of the plant [32], [33]. Plantlife, energy, and interest rates have a major impact on RO unit cost of clean water ($/m^3) compared to the energy and chemical factors required in operation and maintenance [34]. However, the presence of several technological development factors on the membrane material (higher flux, higher salt rejection rate, lower hydrostatic pressure and lower price) helps to reduce energy consumption and RO membrane desalination costs [16]. On the other hand, the quality and characteristics of the raw water that feeds on the desalination process of RO membranes also play an important role in determining the price of water, in addition to the capacity and energy required [16], [34].

The cost of RO desalination water from year to year has decreased. In 1988, the price of water for desalination reached 1.75 - 3.55 $ / m^3, due to the limited resources. However, along with the development of commercial membrane technology, the required cost for desalination process also decreases, reaching 1 $/m^3 or less [14], [16], [35]. It is also predicted in the next five years that SWRO desalination water costs will fall back to 0.6-1.0 $ / m^3 and in the next 20 years will reach 0.3-0.5 $/m^3 [29], [38].

Each country has a difference in the cost of water even though it was built in the same year, due to plant capacity and RO membrane technology used, different values of economic parameters such as interest rate, water tax and labour cost [36]. In Indonesia, especially in Jakarta, the development of desalination using new RO membranes has been successfully implemented by private parties. PT. Pembangunan Jaya Ancol Tbk (PJA) is one of the companies that apply RO membrane technology with the capacity of 5000 m^3 / day which requires water cost around Rp 4,700 or equivalent 0.36 $ /m^3 to fulfil the clean water needs in Jaya Ancol Dreamland, Jakarta [37]. This fee is much cheaper than the price of clean water they usually pay which is around Rp 12.000 / m^3 or equivalent 0.92 $ / m^3 [37]. Meanwhile, the government-administered desalination in Seribu Island with a capacity of 50 m^3 / 8 hours from the previous 210 m^3/day sold at Rp 2000 - 3000 per gallon or equivalent from 0.15 to 0.22 $. For the needs of 1m^3 / day, the community must spend around Rp 100,000 or equivalent to 7.69 $ / m^3.

CONCLUSION

The condition of raw water coming from the river water and groundwater was contaminated with biological and chemical particles which come from the residents waste. The use of desalination technology with RO membranes is commercially increasing globally. The existence of technological developments from both membrane components to energy recovery innovations makes the cost of membrane desalination decreased. Since 2015, the Jakarta government has made a desalination system using RO membranes but failed because of inefficient pre-treatment. This causes membrane performance to become susceptible to fouling and scaling. Meanwhile, the implemented RO desalination system by the private sector namely PT. Pembangunan Jaya Ancol Tbk is successfully fulfilling the
clean water needs in that area. Pre-treatment used is UF membrane and turbine for energy recovery to save energy and cost. Therefore, if the government of Jakarta again repair and build membrane installation, it is better to reconsider the choice of pre-treatment process in designing RO membranes based on the quality of the raw water resources. Also, the government need to consider the cost of maintenance for membranes to work optimally for the fulfilment of clean water needs in Jakarta.

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