Brackish water treatment for small community by using membrane technology

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Abstract. High salinity water, containing high TDS and chloride, is a common problem in coastal areas of Indonesia. The chloride content in water causes water to taste salty. It occurs in a small community of Tambak Cemandi Village, Sidoarjo. The groundwater has chloride content up to 3,694.3 mg/L, hardness 2,071 mg/L (CaCO3), and total coliform 7,100 MPN/100 mL. Membrane technology has been overgrowing all over the world in the water desalination process. This study aims to examine the basic concepts, principles, advantages, and disadvantages of membrane technology and its application in brackish water treatment for drinking purposes. This research was conducted by literature review, secondary data analysis, and application of case studies. The case study is applied to small scale drinking water treatment (flow rate 0.2 L/second) with brackish raw water from groundwater in Tambak Cemandi Village, where some of the population do not have access to safe drinking water. The study concludes that RO membranes with UF pre-treatment are adequate to treat 98%, 96%, and 100% of chloride content, hardness, and total coliform and fulfilled Indonesia Ministry regulation's drinking water quality standard. The treatment can serve 202 people with an operational cost of Rp. 1,198/peop
day.

1. Introduction
Lack of freshwater availability in coastal areas of Indonesia has been becoming an issue. For instance, in Tambak Cemandi, a rural area of Sidoarjo, some of the population do not have access to safe drinking water due to the unavailability of a piped water distribution system to the entire village [1] and the poor quality of the groundwater. Chloride, hardness, and coliform groundwater levels in Tambak Cemandi reach 3,694.3 mg/L, 2,071 mg/L (CaCO3), and 7100 MPN/100mL [2]. High levels of chloride in water cause water to taste salty. Ion exchange, zeolite, and UV irradiation technology can only reduce chlorine, hardness, and coliform levels by 45%, 32.7%, and 99.2%, thus it could not meet the drinking water quality standards Indonesia Ministry regulation [2]. Other treatment alternatives are needed to treat the high levels of chloride, hardness, and coliform content to provide drinking water for Tambak Cemandi’s population.

Membrane technology has been accepted and developed rapidly worldwide. Several studies show that membrane technologies are capable of treating brackish groundwater in coastal areas around the world. NF and RO membranes are capable of removing up to 99.5% of dissolved solids in feed water. MF and UF membranes are theoretically the best pre-treatment for desalination [3]. Therefore, a literature review needs to be conducted to determine the principle of membrane technology, its advantages and disadvantages, and its performance in brackish water treatment. As well as a case study...
of its implementation to treat groundwater quality in Tambak Cemandi, the study can be used as a reference for future research and plans.

2. Methodology

2.1. Literature review
This study is conducted through literature review, which includes reading, analyzing, and information selection related to membrane technology in brackish water treatment in the term of secondary data. The data are obtained from books, journals, researches, theses, dissertations, academic reports, websites, news, seminars, etc. Obtained data consists of:

1. Basic concepts and principle of membrane technology in drinking water treatment
2. Advantages and disadvantages of membrane technology in drinking water treatment
3. Performance (efficiency) of membrane technology in brackish water treatment
4. Characteristics of brackish water treatment.

2.2. Case study
Obtained data are then implemented in a case study to determine the feasibility of membrane technology in a small-scale (flow rate 0.2 L/s) brackish groundwater treatment in Tambak Cemandi. In this study case, additional data is required as follows:

1. Quality of groundwater in Tambak Cemandi treatment
2. The condition of water availability in Tambak Cemandi
3. Amount of population and drinking water requirement in Tambak Cemandi.

2.3. Calculation of treatment cost
The estimation of treatment costs on the case study is based on literature. Costs that will be calculated are investment cost, electrical cost, and production costs. Additional data is required to calculate treatment cost as follows:

1. The cost needed by chosen technology to operate or produce water (Rp/m³)
2. Electricity requirement of the chosen technology
3. The market price of chosen technology (chosen membrane element).

3. Results and discussion

3.1. Tambak Cemandi profile

3.1.1. General. Tambak Cemandi is a rural area in Sidoarjo located in the northern coastal area of East Java, Tambak Cemandi has a population of 3,779 with an area of 4.43 km². Most of the population are pond and fish farmers. Based on ‘Program Kota Tanpa Kumuh (KOTAKU)’ Sidoarjo, Tambak Cemandi is included in the category of slight slums, which some of the communities do not have private sanitation facilities [2]. The picture in Fig.1 shows the map of the Sedati sub-district where Tambak Cemandi is located.
3.1.2. Water Quality and Drinking Water Requirement. The water quality parameters of groundwater in Tambak Cemandi concern chloride, hardness, and coliform bacteria [2]. The comparison between the quality of groundwater and drinking water quality requirements based on Indonesia’s Ministry of Health regulation No. 492 of 2010 is given in Table 1.

| Parameter   | Value     | Unit       | Quality Requirement |
|-------------|-----------|------------|----------------------|
| Chloride    | 3,694.3   | mg/L       | 250                  |
| Hardness    | 2,071.5   | mg/L (CaCO₃) | 500               |
| Total Coliform | 7100 | MPN/100mL  | 0                    |

Based on Indonesia’s Ministry of Public Works and Public Housing No. 14 of 2010, the required amount for drinking water in rural areas is 60 L/people/day. Therefore, 226,740 litres per day is needed to meet all the drinking water requirements for Tambak Cemandi, with a population of 3,779. However, some of the population already have access to the piped water distribution system. Thus, the applied flow rate in the study case is based on the capacity of chosen membrane technology.

3.2. Treatment Alternatives

3.2.1. Main treatment. With the high levels of chloride and hardness content, the most supportive pressure-driven membrane technologies capable of removing dissolved solids are NF and RO. Meanwhile, MF and UF membranes can be used as pre-treatment alternatives. Comparison between NF and RO membrane based on its efficiency on chloride and hardness separation, assuming a membrane recovery rate of 100%, is given in Table 2.
Table 2. Removal efficiency by NF and RO membrane.

| Parameter | Feed Water Quality | Removal Efficiency | Permeate Quality | Quality Requirement |
|-----------|-------------------|--------------------|------------------|---------------------|
|           |                   | NF                 | RO               | NF                  | RO                  |
| Hardness  | 2,071.5           | 98% [4]            | 96% [5]          | 41.43 mg/L          | 82.86 mg/L          | 500                 |
| Chloride  | 3,694.3           | 79% [6]            | 98% [7]          | 775.8 mg/L          | 73.886 mg/L         | 250                 |

The calculation in table 2 concludes that NF membrane with a chloride removal efficiency of 79% was not sufficient to treat the groundwater in Tambak Cemandi to meet the chloride quality standard, which is 250 mg/L. RO membrane is needed to achieve chloride and hardness levels that meet the drinking water quality standard of Indonesia’s Ministry of Health No. 492 of 2010. However, the RO membrane cannot stand alone as the system does not allow coliform in the feed water. Thus, pre-treatment is needed to remove coliform bacteria, suspended solids, and other unwanted materials in the feed water. RO membrane-type BW30-4040 Filmtec is selected in this study case based on membrane capacity and availability. BW30-4040 has a capacity of 9m³/day.

3.2.2. Pre-treatment. Pre-treatment is needed to remove particulates, colloids, and other fouling materials as well as coliform bacteria. The application of membrane filtration for saline water pre-treatment has become popular in desalination technology due to its capability to remove TDS altogether. Comparison between MF and UF membrane based on its efficiency to remove suspended solids and coliform bacteria is given in table 3.

Table 3. Removal efficiency of TSS and Coliform by MF and UF membrane.

| Parameter | Removal Efficiency |
|-----------|--------------------|
|           | MF                 | UF                 |
| TSS (mg/L)| 100% [9]           | 100% [10]          |
| Total Coliform (MPN/100mL) | 63.57% [11] | 100% [12] |

Based on table 3, MF membrane with 63.57% coliform removal efficiency would not fulfil the drinking water requirement standard of total coliform, which is 0 MPN/100mL. Thus, a UF membrane is required as RO pre-treatment to treat groundwater in Tambak Cemandi. RO membrane with UF pre-treatment can remove 98% of dissolved solids in saline water [7] [5]. Another advantage of using UF membrane as RO pre-treatment is that it requires significantly lower energy consumption than all sedimentation-based pre-treatments (0.07 versus 0.22 kWh/m³) [13]. Hollow fibre polypropylene UF membrane, with a capacity of 23 m³/day, is selected as BW30-4040 RO pre-treatment as it is proven to remove ~98% of chloride and TDS content from brackish water [5].

3.3. Treatment scenario

3.3.1. Mass balance. Brackish groundwater treatment in Tambak Cemandi requires low operating and maintenance costs and low energy requirements. Thus, the treatment in this case study is set to 0.2 L/s flow rate with 70% of RO membrane recovery. The recovery rate of brackish water treatment with RO membranes operates at 70-90% [8]. Calculation of mass balance is conducted to determine chloride, hardness, and coliform content in permeate. The result is shown in figure 2.
When the feedwater passes through the UF pre-treatment, there is a 100% removal of particles along with colloids and coliform bacteria. RO membranes of 70% recovery rates produce concentrate in the form of brine and permeate water. Based on the calculation, the permeate water fulfilled the drinking water quality requirement of Indonesia’s Ministry of Health No.492 of 2010.

3.3.2. Treatment capacity and cost. Permeate flow from RO treatment of 70% recovery rate is 0.14 L/s or 12,096 m$^3$/day. In other words, brackish water treatment with a feedwater flow rate of 0.2 L/s will produce 12,906 L/day. Based on the calculation, this treatment can fulfill 5% of the drinking water requirement in Tambak Cemandi or about 202 people. Selected RO and UF membranes are designed to produce 9 m$^3$/day and 23 m$^3$/day. A feedwater flow rate of 0.2 L/s or 17.28 m$^3$/day requires ~2 RO membranes and ~1 UF membrane element. The average price for RO membrane per module (BW30-4040) is Rp. 1,171,174.00 and UF membrane per module Rp. 432,271.00. Therefore, the investment cost required for the membrane is Rp. 2,774,566.00.

Electricity requirement for low-salinity BWRO is 0.3 kWh/m$^3$ [8]. According to Indonesia’s Ministry of Energy and Mineral Resources, the electricity price for drinking water treatment is Rp. 972.00/kWh. Thus, the need for electricity costs for treating 17,28 m$^3$ brackish groundwater in Tambak Cemendi is Rp. 120,939.00/day. Meanwhile, the cost of water produced by low-salinity BWRO system is 0.7 $/m$^3$/day or Rp. 10,000.00/ m$^3$/day. So, for water production of 12,096 m$^3$/day, it takes Rp. 120,960.00 per-day. The total cost of electricity and water production is Rp. 241,899.00 per day to serve 202 people or Rp. 1,198.00/day. Compared to the PDAM Delta Sidoarjo’s tank water (Rp. 30,000-35,000.00/m$^3$), water from RO treatment costs less.

4. Conclusion
MF and UF membranes are not capable of removing dissolved solids (TDS) from feed water, so that in the desalination process or the removal of dissolved ions in water, NF and RO membranes are needed. RO membrane can remove monovalent ions, such as chloride ions, so it is widely used to treat water with a high level of salinity. However, membrane fouling potential is also higher for RO than other membranes. This study figured out the quality of brackish groundwater in Tambak Cemendi, the coastal area of Sidoarjo, East Java. Chloride levels of groundwater in Tambak Cemendi reached 3694.3 mg/L, hardness 2,071 mg/L CaCO$_3$, and coliform 7,100 MPN/100mL. Brackish water treatment with RO membrane is proven to treat 98% of chloride content and 96% of water hardness in various studies. It can be applied to treat brackish groundwater in Tambak Cemendi. However, it requires a UF membrane.
as a pre-treatment to meet the drinking water quality standard based on Indonesia's Ministry of Health No. 492 of 2010. With feed water flow rate of 0.2 L/s, the treatment can fulfil water needs for 202 people or 5% of the population with Rp. 1,998.00/people/day operating cost.

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