 Calculation of design brackish water reverse osmosis and Its financial analysis at Pamekasan coastal area

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Abstract. The minimal availability of fresh water during the dry season seems to be a classic problem that occurs in Pamekasan Regency. Based on data from the Regional Disaster Management Agency (BPBD) of the Pamekasan Regency Government, it shows that the drought that occurred in Pamekasan in 2019 was 325 hamlets in 82 well-known villages in 11 sub-districts. This data shows that most of the coastal areas in Pamekasan Regency are still experiencing a fresh water crisis. Therefore, alternative water treatment is needed to help provide fresh water in this area. Desalination is an important technology for coastal areas far from fresh water sources. The main objective of this study is to create a mini design for reverse osmosis desalination (RO) production in coastal areas to supply fresh water at the hamlet scale. The RO design for fresh water production of 5 m³/day is compact with brackish water well as raw material which has a TDS ranging from 5,000-10,000 ppm. In addition, this study also analyzes the economics of small-scale desalination based on the Revenue Cost Ratio (RC Ratio) with an RC Ratio value of 5.03, a Payback Period value of 0.17 years (2 months), and a production Break Event Point (BEP). Amounting to 149,007 liters (7843 gallons) and a BEP price of IDR 79.47 / liter, the small-scale desalination business is declared profitable and feasible to be realized.

1. Introduction

Pamekasan is one of the areas on the island of Madura with a wide coast. The large population in Pamekasan causes a very large consumption of groundwater, this affects the condition of the surrounding environment. The classic problem of Pamekasan residents in coastal areas during the dry season is the scarcity of fresh water. Based on data from the Regional Disaster Management Agency (BPBD) of the Pamekasan Regency Government, it was stated that the scarcity of fresh water that hit Pamekasan in 2019 was 325 hamlets in 82 villages spread over 11 sub-districts, especially the southern coastal area of Pamekasan which is a salt farming center area causing several negative impact. One of the biggest impacts of the conversion of coastal land into salt ponds is the vulnerability...
of groundwater resources where some of the residents’ groundwater wells have turned into brackish to salty.

In long dry conditions and seawater intrusion, the quality of shallow groundwater decreases, so that the water becomes salty due to the high salt content. In this condition, the salt content (Total Dissolved Solid) reaches more than 12,000 ppm. Therefore, the area is in dire need of a water treatment plant capable of processing salt water into fresh water. One of the possible ways to fulfill clean water, especially drinking water, is the construction of a water treatment plant unit that is in accordance with the condition of raw water. Based on raw water quality data, the processes that must be applied include oxidation, filtration and desalination of salt water with a Reverse Osmosis system. The salt water treatment plant with a reverse osmosis system is designed according to the socio-economic level and the drinking water needs of the local community.

In many parts of the world, RO membrane technology is widely used to produce high quality water, both on a large and small scale. Small-scale RO membrane technology is a development that has future prospects for practical and economical community ownership. RO membranes can separate water from discarded components such as organic, inorganic, bacteria, viruses, particulates, and dissolved ions or salts. This technology has several advantages compared to conventional water treatment technologies such as flocculation, sedimentation, ion exchange, distillation, and adsorption. This paper aims for technical design and analysis of technical economic feasibility for saltwater treatment technology with a small production Reverse Osmosis system to fulfill fresh water needs on a village scale.

2. Materials and methods

2.1. Study location
The location of this small-scale desalination design implemented in Padelegan Village, Pademawu District, Pamekasan Regency. The location of Pademawu District is not far from the coast, so the height of the area in Pademawu District is not more than 10 meters. The altitude of the study area is almost uniform and can be classified as an alluvial plain or coastal area with an altitude ranging from 0-50 m above sea level. In addition, this study area is one of the central areas for people's salt production. From groundwater data in the study area, according to Gemilang’s research [1] that the ratio values of Na/Cl and Cl/HCO₃ indicate that in the groundwater of the study area there has been a process of mixing seawater into the aquifer with the category of seawater infiltration slightly to somewhat high. Locations with poor water and very poor water categories are in resident water wells close to the coastline and salt ponds. The characteristics of groundwater data according to Gemilang’s research are as shown in the picture below:

2.2. Design
The RO desalination design is based on the freshwater demand plan for rural areas such as remote coastal areas, which includes 1000 people. The standard of eligibility for drinking water from the health aspect is 2 liters/capital/day. RO is designed for desalination of brackish water with a salinity range of 5000-10,000 ppm in the form of total dissolved solids (TDS) permitted in water is 500 mg/L or less, which refers to WHO [2] and Minister of Health RI No. 492/MENKES/PER/IV/2010 [3]

The RO technical calculation follows the RO membrane design method, in accordance with the RO membrane technical specifications and ROSA design software. The results of this software calculation can be used as a reference to obtain the best design based on the conditions of the feed water and processed water as desired so as to avoid failure (design errors) in the system.

This design includes preliminary treatment or what is called pretreatment consisting of several units of a filtration system process using a fast sand filter, a zeolite manganese filter, an activated carbon filter and a cartridge filter. Furthermore, for the main treatment, namely the reverse osmosis system, where the system design will be integrated between pretreatment and main treatment in one compact system.
Figure 1. Groundwater Classification Based on TDS Value (mg/L) [1]

Figure 2. Software Reverse Osmosis System Analysis (ROSA)
2.3 Business feasibility financial analysis

To determine the feasibility of a brackish water desalination business with a reverse osmosis system, a profit analysis is carried out using the following formula:

\[ \pi = TR - TC \]

**Remarks:** \( \pi \) = Profit (IDR/production period), \( TR \) = Total Revenue (Rp), \( TC \) = Total Cost (Rp)

Meanwhile, to determine business feasibility, RCR (Return Cost of Ratio), PP (Payback Period), and BEP (Break Event Point) are used. RCR analysis is a comparison (ratio or ratio) between revenue (revenue) and costs [4], can be expressed in the following formula:

\[ RC - Ratio = \frac{TR}{TC} \]

**Remarks:** RC-Ratio = Return Cost of Ratio, \( TR \) = Total Revenue, \( TC \) = Total Cost (TC = FC + VC)

**Decision criteria:**
- RC-Ratio > 1, Profits
- RC-Ratio < 1, Loss
- RC-Ratio = 1, Break even

The payback period method is an assessment technique for the period of return of an investment in a business [4], calculated by the formula:

\[ Payback \ Period = \frac{Total \ Investment}{Total \ Profit} \times 1 \ year \]

Break Event Point (BEP) analysis is an analysis that informs a situation where the volume of activity (as measured by sales results) does not generate profits but also does not cause losses [5], which can be calculated with 2 approaches, namely:

\[ BEP \ Production = \frac{Total \ Operating \ Cost}{Output \ Selling \ Price} \]

\[ BEP \ Price = \frac{Total \ Operating \ Cost}{Total \ Production} \]

3. Results and discussion

3.1. The reverse osmosis (RO) system

The reverse osmosis (RO) system is capable of separating dissolved ions from the feed stream in the RO system, the feed water is divided into two streams: one has no salinity (low) and the other has high salinity. Low salinity streams are known as ‘permeate or product water’ while high salinity streams are known as brine, or rejects.

To obtain good product water, the system design must pay attention to the quantity of water (\( Q_w \)) flowing through the membrane in proportion to the feed-permeate differential pressure (\( \Delta P \)), membrane surface area (A) and membrane permeability (\( K_w \)). This relationship looks like the following equation [6]:

\[ Q_w = \frac{dV}{dt} = (\Delta P - \Delta \pi) . K_w . A \]

**Remarks:** \( Q_w \) = permeate flow (m\(^3\)/hour), \( V \) = total volume (permeate) (L or m\(^3\)), \( t \) = time (hour, minute, second), \( \Delta P \) = differential pressure (feed pressure - permeate pressure) (bar), \( \Delta \pi \) = difference in osmotic pressure (bar), \( K_w \) = permeability constant for water (m\(^3\) m\(^{-2}\)/s/bar), A = membrane surface area (m\(^2\)), \( \Delta P - \Delta \pi \) = net driving pressure (NDP) (bar)
The RO membrane system is designed to consider the basic principles of membrane characteristics, then the calculation of the RO design with ROSA software. ROSA stands for Reverse Osmosis System Analysis and is widely used in the design of reverse osmosis desalination for both brackish and seawater [7], [8], [9], [10], [11], [12], [13], [14] includes the characteristics of the feed water, the quantity of feed water (feed flow), the quantity of treated water (permeate flow), the type of membrane and the allowable pump pressure according to the membrane characteristics will be used.

![Figure 3. RO System Design with ROSA Software](image)

This study uses the assumption of a feedwater concentration with a Total Dissolved Solid (TDS) of 5,000-10,000 ppm based on field data (in situ) research by Wisnu AG [2]. The design of a feed flow capacity of 10 m\(^3\)/day with a TDS concentration of treated water (permeate) below 300 ppm is in accordance with WHO standards [3] for fresh water. For this type of membrane use type BW30-4040 with a pump pressure below 20 bar. The selection of this type of membrane considers the ability to reject the salt content in the feed water while for the pump selection considers energy consumption and investment costs.

**Table 1. Reverse Osmosis Simulation Calculation Results**

| Stage | Element     | Feed | Permeate |
|-------|-------------|------|----------|
|       |             | TDS  | TDS |
|       |             | Flow | (mg/L) | Flow | (mg/L) | Pressure | Power | Status |
|       |             | (m\(^3\)/day) | mg/L | (m\(^3\)/day) | mg/L | bar | kWh/m\(^3\) | |
| 1     | BW30-4040  | 10   | 5,000 | 5   | 85   | 17.78  | 1.26 | TDS<300 |
|       |             | 10   | 10,000| 5   | 170  | 27.61  | 1.94 | mg/L [3] |

Based on the RO system design for brackish water using ROSA software, some data are obtained as follows:

a. Feed water capacity 10 m\(^3\)/day
b. TDS is simulated into 2 assumptions, namely TDS 5000 mg/L and TDS 10,000 mg/L, this aims to determine the ability of the RO system to reduce salt or minerals if there is a change in the concentration of TDS in the feed water. The processed water (permeate) has a TDS value of 85 mg/L from 5000 mg/L TDS feed water and 199 mg/L treated water (permeate) from 10,000 mg/L TDS feed water.
c. The pump pressure in the feeder system is 17.78 bar for TDS 5000 mg/L feedwater and pump pressure for TDS 10,000 mg/L is 27.61 bar with a recovery factor of 50%. As for the design with the assumption of a recovery factor of 30% at 10,000 mg/L TDS feed water, an operating pressure of 17.57 bar is required.

d. The treated water capacity for TDS 5000 mg/L and TDS 10,000 mg/L is 5 m³/day

The RO system design is made with the assumption that the feed water is in accordance with in situ data using ROSA software which takes into consideration several factors, including the characteristics of the feed water and the type of membrane which indicates that the BW30-4040 membrane type can be used for feed water with a TDS range of 5,000-10,000 mg/L. However, the ability of permeate flow or the capacity of treated water has a difference where the TDS 5000 feed water can produce a permeate flow of 5 m³/day while in the condition of the TDS 10,000 feed water the permeate flow decreases, which is 3 m³/day. From the results of this simulation, it shows that the feedwater concentration factor is a function of membrane recovery in salt rejection where the membrane recovery is the permeate flow rate divided by the feed flow rate multiplied by the percent [7]. The high salt concentration in the feed solution increases the osmotic pressure, which in turn reduces the Net Driving Pressure (NDP). As a result, the product water flow rate is reduced and the salinity of the treated water (Concentrate Permeate) is increased [15].

Salt rejection increases with the increase in operating pressure, this can be seen from the simulation data which shows that with a TDS of 10,000 and permeate capacity remaining at 5 m³/day, the operating pressure requirement increases to 27.61. This shows that the operating pressure difference is almost 10 bar from the feed water with a TDS of 5000 mg/L. The effect of salt rejection on the increase in operating pressure is because the RO process can take place if the hydrostatic pressure in a high concentration solution is greater than the osmotic pressure [16], [17], [18].

In the ROSA simulation, the simulation data obtained, it can be concluded that the selection of the type of membrane and pump in this system is correct, where the ability of salt rejection from feed water with a recovery rejection requirement at TDS 5,000 of 50% will produce a TDS permeate of 85 mg/L and recovery rejection at TDS 10,000 of 30% will produce a TDS permeate of 199 mg/L where both of these treated water products are still within the WHO standard. The advantage of this system design is that users do not need to change the type of membrane and pump if there is a change in the TDS concentration in the feed water with a range below 10,000 mg/L so that this small-scale desalination system can operate effectively and efficiently.

Figure 4. Small Scale Brackish Water RO System Design

The RO system design uses a functional approach for treating brackish water into drinking water with several main components that have functions such as:

1. Multimedia filters
This multimedia filter functions as a pretreatment to remove turbidity, odor, color, iron or manganese that is still contained in the feed water used.

2. Microfilter
   The function of the microfilter is to remove materials such as sand, silt, clay or organic matter from the water. This microfilter has a size of 1 m and 5 m.

3. High Pressure Pump
   A high pressure pump in the RO series which functions to increase the required water pressure according to the characteristics of the osmotic pressure of the RO membrane used. With the increase in water pressure can increase the rejection and product flow rate.

4. Reverse Osmosis Circuit
   Reverse osmosis with a membrane size of 0.0001 microns can separate components unwanted components such as organic components, inorganic components, bacteria, viruses, particulates, and dissolved ions or salts.

5. Ultraviolet Lamp
   Ultraviolet lamps emit radiation rays that function to kill germs, viruses, bacteria and protozoa in the water so the water is safe for consumption.

   In this design using several planning assumptions, the production of fresh water is 5m$^3$/day with an operational period of 10 hours per day so that the water production is 208 liters per hour or 750,000 liters per year. This assumption is needed to calculate the economic analysis of the design of a small-scale brackish water RO system that can be implemented in the field.

3.2. Business feasibility of small scale desalination with brackish water reverse osmosis

Based on Table 2, with an investment cost of Rp. 40,000,000.00, a fixed cost of Rp. 4,000,000.00 and a variable cost of Rp. 55,602,760.00, the revenue is Rp. 300,000,000.00. This calculation resulted in a net profit of Rp 240,397,240.00 per period. From the various costs incurred and the receipts obtained, the Revenue Cost Ratio value is 5.03. Brackish water desalination business with a small-scale reverse osmosis system is declared feasible because the R/C value is greater than 1 [5], which is 5.03. R/C value of 5.03 means that from every production cost incurred of Rp. 1,000,000.00, an income of Rp. 5,030,000.00 will be obtained. The payback period or the period of return on investment in this business is 0.17 years or 2 months.

Table 2. Business Feasibility of small scale desalination with Brackish Water Reverse Osmosis

| No. | Description                | Value       |
|-----|----------------------------|-------------|
| 1.  | Income                     |             |
|     | • Production (liter)       | 750,000     |
|     | • Price (Rp/litre)         | 400         |
|     | • Income (Rp)              | 300,000,000 |
| 2.  | Cost                       |             |
|     | • Investion (Rp)           | 40,000,000  |
|     | • Fixed (Rp)               | 4,000,000   |
|     | • Variable (Rp)            | 55,602,760  |
| 3.  | Profit (Rp)                | 240,397,240 |
| 4.  | Business Feasibility       |             |
|     | • R/C Ratio                | 5.03        |
|     | • Payback Period (year)    | 0.17 (2 months) |
|     | • BEP Price (Rp)           | 79.47       |
|     | • BEP Production (liter)   | 149,007     |

Remarks:
BWRO Desalination Capacity is 5 m³/day atau 208.33 liter/hour and operational time for 10 hours/day. Electricity Price for R-2/TR (3500-5500 VA) is Rp 1,444.7 per kWh [19].

The rate of return on capital of a business is categorized as fast if the value of PP < 3 years, the rate of return on capital is categorized as moderate if the value of PP is 3 years < PP < 5 years, and is said to be in the category of slow rate of return if the value of PP is > 5 years [20]. This means that the brackish water desalination business with a small-scale reverse osmosis system is very feasible because the investment payback period is relatively fast, far below 3 years. Based on the results of the analysis in Table 2, the BEP value of production is 149,007 liters, indicating that the break-even point or business conditions of no profit or no loss will be achieved at the time of business production of 149,007 liters of fresh water. The BEP value of Rp. 79.47 indicates that the break-even point or the condition of the company not making a profit or not losing will be reached when the selling price of fresh water is Rp. 79.47 per liter. Based on the analysis of production BEP and price BEP, a small-scale reverse osmosis desalination business in Pamekasan Regency – East Java is profitable and feasible to develop because the BEP value of production obtained is below the annual production level of 750,000 liters of fresh water and the BEP value is below the prevailing selling price of Rp. 400,00 [6].

4. Conclusion
The RO design for fresh water water production of 5 m³/day is compact with brackish water well as raw material which has a TDS ranging from 5,000-10,000 ppm and the economics of small-scale desalination based on the Revenue Cost Ratio (RC Ratio) with an RC Ratio value of 5.03, a Payback Period value of 0.17 years (2 months), and a production Break Event Point (BEP) amounting to 149,007 liters (7843 gallons) and a BEP price of IDR 79.47/liter, the small-scale reverse osmosis desalination business is declared profitable and feasible to be realized.

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