Design of hybrid RO/NF permeate staging for the supply of clean water in Tanjung Lame Village

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Abstract. The groundwater sources from community wells in Tanjung Lame village, Pandeglang district, are very salty, so they are not suitable for consumption. Reverse osmosis (RO) and nanofiltration (NF) membrane are alternative desalination technologies for treating clean water from saltwater wells. However, the pressure required on a conventional single-stage RO filtration system is very high. The purpose of this study is to design a hybrid RO/NF filtration system that can operate at low pressure. The designed hybrid RO/NF permeate staging has proven to be able to produce clean water from saltwater wells in Tanjung Lame village at low pressure. To obtain optimum results, the designed hybrid RO/NF permeate staging is operated at the first and second stage pressure of 6 and 3 bar, respectively. At that pressure, the salt rejection and TDS of permeate is 97.06% and 85 ppm, respectively. The water recovery rate and permeate flow rate is 31% and 1.55 liters/minute, respectively.

1. Introduction
Tanjung Lame is one of the villages in Ujung Jaya, Sumur District, Pandeglang Regency, Province of Banten. Tanjung Lame village is located on the coast. In the Selat Sunda tsunami of 2019, Tanjung Lame village was one of the affected areas. The location which is very close to the beach and the tsunami has made the ground water from the community wells are very salty. In the rainy season, the TDS of water from community wells can reach 2890 ppm. In the dry season, the TDS of the water can increase due to groundwater evaporation. This makes the source of water from the community wells are not suitable for consumption. One alternative technology for treating clean water from salt water is a reverse osmosis (RO) filtration system.

RO filtration system is one alternative water treatment technology that uses semipermeable membrane to remove impurities such as ions, molecules, and particles that are larger than water. RO filtration systems are easier to operate compared to the evaporation and ion exchange methods, making them easier to apply to the rural areas. However, the pressure required in a conventional single-stage RO system is very high which causes high the electrical energy requirements for pumps [1]. In the case of seawater desalination, the required pump pressure is usually above 40 bar, while water recovery is around 40-50% [2].

Some modifications to RO filtration system have been developed to decrease the pressure, one of which is a two-stage concentrate staging. This configuration succeeded in decreasing operating pressure but the TDS of combined permeate stream was still relatively high. Moreover, the fouling rate of second stage RO higher because the membrane recycles the rejection stream [3]. The purpose of this study is to design the permeate staging configuration. In this RO filtration system, permeate stream on the first RO...
as a feed on the second RO, so it can reduce operating pressure and the TDS of clean water produced. To increase water recovery rate, NF membrane will be combined with the RO membrane at the first filtration stage. NF membranes have higher flux so that they can increase the permeate flow rate [4]. In some brackish water desalination projects, the NF membrane has replaced the RO membrane due to lower energy consumption and higher flux rates [5]. Thus, the replacement of part of RO membrane with NF membrane is expected to increase the value of water recovery from the designed reverse osmosis filtration system.

2. Materials and method

2.1. Feed water and membrane modules
The experiments used feed water from saltwater well in Tanjung Lame village, Pandeglang district. Water from the well is collected in the feed tank so that the TDS of the feed is constant during the experiment. The TDS of feed is 2890 ppm. The membrane modules used in this experiment are RO TCF membrane ULP-3013-400 type for the first stage RO membrane, RO membrane type WW-2012-100 for the second stage RO membrane, and NF membrane Kusatsu type NF-2812-500 for the first stage NF membrane. There are three and six membrane in the first stage and second stage, respectively.

2.2. Experimental installation and procedure
The experimental setting used in this study was hybrid RO/NF permeate staging filtration system. Figure 1 shows a schematic diagram of the experimental settings for this study.

![Schematic diagram of experimental setup for hybrid RO/NF filtration system](image)

**Figure 1.** The schematic diagram of experimental setup for hybrid RO/NF filtration system.

In this configuration, three UF membranes are used as pretreatment stage. Permeate stream from the UF membrane is flowed to the first stage pump. The first stage pump, which consists of three pumps, will pump water to the first stage RO/NF membrane. The first stage RO/NF consists of two RO membranes and one NF membrane. Permeate stream from the first RO/NF membrane flow to the second stage pump. The second stage pump, which consists of three pumps, will pump water to the second stage RO membrane. The second stage RO consists of six RO membranes. Rejection stream from each RO
membrane is connected to the valve and pressure gauge to control the pressure on the membrane. The permeate stream from each stage is connected to the rotameter to measure the volumetric flow rate. Feed flow rate is set constant at 5 liters/minute. Permeate stream from the second RO membrane is collected in the clean water tank. Variation of transmembrane pressure used in the first and second stage are 5, 6, 7 bar and 3, 4 bar, respectively.

3. Result and Discussion

Performance of designed hybrid RO/NF permeate staging filtration system is evaluated by the effect of transmembrane pressure on salt rejection and water recovery rate.

3.1. Effect of transmembrane pressure on salt rejection

Salt rejection is one of the parameters to determine the performance of the designed RO/NF filtration system. The salt rejection (in%) is the ratio between the concentration of salt that can be rejected into the rejection stream and the concentration of salt in the feed stream at each stage of filtration. The higher the salt rejection, the better the performance of the RO/NF filtration system. The effect of transmembrane pressure on the salt rejection in this study is shown in Figure 2 and Table 1.

![Figure 2](image-url)  
**Figure 2.** Effect of transmembrane pressure on the salt rejection.

| Pressure (bar)  | Salt rejection (%) | TDS of clean water (ppm) | Volumetric flow rate of clean water (liters/minute) |
|----------------|--------------------|--------------------------|---------------------------------------------------|
| **First stage RO** | **Second stage RO** | **First stage RO** | **Second stage RO** | **Final value** | **TDS of clean water (ppm)** | **Volumetric flow rate of clean water (liters/minute)** |
| 5  | 3  | 65.50 | 92.78 | 97.51 | 72 | 1.00 |
| 6  | 3  | 64.01 | 91.83 | 97.06 | 85 | 1.55 |
| 6  | 4  | 63.67 | 84.57 | 94.39 | 162 | 2.40 |
| 7  | 3  | 60.90 | 86.73 | 94.81 | 150 | 1.95 |
| 7  | 4  | 60.55 | 84.12 | 93.74 | 181 | 2.60 |

**Table 1.** Effect of transmembrane pressure on the salt rejection.
Figure 2 and Table 1 show that the salt rejection will decrease when the transmembrane pressure increases. This is caused by the variation in pressure used which has passed its optimum pressure to separate the salt. The presence of the NF membrane in the hybrid RO/NF permeate staging makes the required optimum transmembrane pressure lower than the optimum transmembrane pressure in the configuration RO permeate staging. This is because the operating pressure of the NF membrane is lower than the RO membrane [6]. In the case of brackish water desalination using NF membranes, divalent and multivalent ions will be filtered, while monovalent ions will diffuse with the water molecules to the permeate flow [4]. When the transmembrane pressure continues to increase beyond its optimum condition, the salt flow in the feed stream will be forced to diffuse through the semipermeable membrane with a diffusion rate that exceeds the salt flow rate in the rejection stream so that more salt will diffuse towards the permeate stream [7]. When the salt passage increases, the salt rejection will decrease. Transmembrane pressure that exceeds the mechanical strength of the semipermeable membrane on the RO/NF membrane will also cause mechanical damage to the membrane, so that the semipermeable membrane cannot be a good separator between salt and water solution [8]. This will also increase the salt passage value and decrease the salt rejection.

To obtain the maximum salt rejection, the designed hybrid RO/NF filtration system is operated at the first and second stage RO/NF pressure of 5 and 3 bar, respectively. At that pressure, the value of salt rejection and TDS of permeate is 97.51% and 72 ppm, respectively. The salt rejection and TDS of the permeate close to the result at the optimum pressure at the first and second stage RO/NF pressure of 6 and 3 bar, respectively. At that pressure, the value of salt rejection and TDS of permeate is 97.06% and 85 ppm, respectively. The designed RO filtration systems with the configuration of hybrid RO/NF permeate staging has proven to have better performance in salt rejection.

3.2. Effect of transmembrane pressure on water recovery rate
Another parameter that shows the performance of the designed RO/NF filtration system is water recovery rate. The water recovery rate (in%) is the ratio between the permeate flow rate and the feed flow rate at each stage of filtration. The higher water recovery rate, the better the performance of the RO/NF filtration system. The effect of transmembrane pressure on the water recovery rate in this study is shown in Figure 3 and Table 2.

![Figure 3. Effect of transmembrane pressure on the water recovery rate.](image-url)
The results shown in Figure 3 and Table 2 show that the water recovery rate is directly proportional to the transmembrane pressure. The higher the transmembrane pressure, the more volume of water is forced to diffuse from the feed stream to the permeate stream. As explained in the previous section, this is because the increase in transmembrane pressure will increase the diffusion flux value in the RO/NF membrane so that the water recovery rate in the RO/NF filtration system also increases [7]. When the pressure increases, the permeate flux will also increase until the salt concentration in the permeate flow reaches its equilibrium value in the RO/NF membrane [9].

The presence of the NF membrane in first stage makes the water recovery rate of the first stage filtration higher than the second stage. Because the NF membrane contains a negatively charged hydrophilic group, the NF membrane has a higher water flux than the RO membrane [4]. In this study, the highest water recovery value was obtained at the first and second stage RO/NF transmembrane pressures of 7 and 4 bars respectively, which is 52%. However, in this pressure, the salt rejection is very low. The salt rejection that can be achieved is only 93.74% with the TDS of clean water is 181 ppm. In the pressure of the highest salt rejection, the water recovery rate that can be achieved is only 20%. At the first and second stage RO/NF transmembrane pressures of 6 and 3 bars, respectively, the decrease in the salt rejection produced is not too significant compared to its highest value (less than 0.5%). However, the water recovery rate that can be achieved has increased significantly. The salt rejection under these pressures only decreased by 0.45% from 97.51% to 97.06%. However, the water recovery rate has increased by 11% from 20% to 31%. Thus, the optimum pressure chosen in this study are at the first and second stage RO/NF transmembrane pressures of 6 and 3 bar, respectively. At the optimum operating conditions chosen, the value of water recovery that can be achieved is 31% with a flow rate of clean water products produced at 1.55 liters/minute.

Based on experimental study, the optimum condition for operating the machine is 12 hours per day with a time lag of 30 minutes after the machine is operated for 4 hours. It is aims to avoid pump damage due to overheating pump temperatures. If the machine is operated for 12 hours per day, clean water that can be produced is 1116 liters/day. It is enough to meet the clean water needs of 105 families in Tanjung Lame village. The average clean water requirements for drinking and cooking per family is 10 liters/day, so the average clean water needs for drinking and cooking for Tanjung Lame village is 1050 liters/day [10]. Thus, the volume of clean water produced can meet the needs of the people of Tanjung Lame with water quality that still meets WHO standards.

4. Conclusion
Design of hybrid RO/NF permeate staging configuration consisting of two RO membranes and one NF membrane on the first stage RO/NF and six RO membranes on the second stage RO/NF is proven to be able to produce clean water from saltwater well. The volume of clean water produced is able to meet the needs of the people of Tanjung Lame village, Pandeglang Regency, Banten. To obtain optimum results, the configuration is operated at the first and second stage RO/NF operating pressures of 6 and 3 bar, respectively. At that pressure, the salt rejection and TDS of permeate is 97.06% and 85 ppm, respectively. water recovery rate and permeate flow rate is 31% and 1.55 liters/minute, respectively.
The designed hybrid RO/NF permeate staging has proven to be able to produce clean water from saltwater wells in Tanjung Lame village at low pressure. The volume of clean water produced can meet the needs of the people of Tanjung Lame.

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