

# Studies on seawater desalination by reverse osmosis at the Badak natural gas liquefaction plant, Bontang, East Kalimantan

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## Abstract

Seawater desalination by reverse osmosis was studied as an alternative process for the production of fresh water to supply 20,000 m<sup>3</sup>/d of drinking and boiler feed water at the Badak natural gas liquefaction plant and community housing. Seawater resources will be taken off shore from the Bontang Sea near the plant site. The chemical and physical analysis of seawater will be made at several locations in the Bontang Sea, which contains around 33,000 ppm TDS without any special characteristics. The Hydranautic RO design will be used for pre-design of the RO system. Data input needed for simulation are characteristics of seawater, production of fresh water and the price of energy at the local site. Total water cost ranges from US\$ 0.46–0.64 based on an energy price of US\$ 0.038 kWh at Badak. By simulation, product water had TDS 452 and boiler water feed TDS 15. Total investment cost based on 20,000 m<sup>3</sup>/d product ranges from US\$ 8–16 million, depending on local site conditions. The area needed for a seawater RO plant is around 2500 m<sup>2</sup>. This study describes an idea and an illustration about other fresh water resources before implementation of RO seawater desalination at Badak before the fresh water resources dry out. The pre-design gave satisfactory results in the prediction of total water cost and total investment for the RO plant.

*Keywords:* Reverse osmosis; Bontang, Indonesia

## 1. Introduction

Seawater desalination by reverse osmosis (RO) is an alternative technology to produce fresh water for drinking and boiler feed water as

the time when a shortage of raw water supply is approaching. At present, raw water is sufficiently supplied from several deep wells located near the plant site at the Badak natural gas liquefaction plant. Seawater at the site is clear, relatively free from contaminants such as oil and colloidal matter. Total dissolved solids range between

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30,000 to 34,000 ppm. Since 1976 seawater has been used as cooling water for a heat exchanger at the refrigeration system [1].

## 2. Reverse osmosis

RO needs a high operating pressure to overcome the osmotic pressure of the feed solution. In general, every 1000 TDS concentration in seawater raises the osmotic pressure 1 bar. For seawater with 35,000 TDS, the osmotic pressure is almost 35 bar. Desalination of seawater with concentration a 35,000 TDS needs almost 100 bar applied pressure to overcome the osmotic pressure. The development of a new generation of RO membranes reduces the operating pressure and consumes less energy. To produce fresh water from very saline water, a multi-permeator is needed for desalination [2–4].

## 3. Seawater desalination at the Badak NGL plant

The desalination of seawater was studied to produce 20,000 m<sup>3</sup>/d fresh water for drinking to supply community housing and boiler feed water for high-pressure steam [1]. A simulation with the Hydranautics RO design was done to determine the system performance, operating conditions, RO configuration, power requirements per m<sup>3</sup> fresh water product, product water quality, feed flow rate, and pressure needed in the system. The input data needed for simulation [5–7] are:

- product permeate water flow rate (m<sup>3</sup>/d or gal/d)
- recovery ratio (%)
- seawater feed composition (mg/L or ppm)
- seawater feed temperature (°C or °F)
- membrane type
- percentage of flux decline rate per year (%)
- percentage of salt passage increase per year (%)

The simulation was done by varying the most important variables, i.e., seawater TDS, recovery ratio, and system configuration. Besides these three variables, the graphic plot by RO design is useful for predicting the influence of seawater temperature on the operating pressure and product water salinity. The influence of the recovery ratio on product salinity and operating pressure can be predicted.

## 4. Seawater quality

Using the chemical parameters of seawater in the Bontang Sea, the results of the RO design simulation are:

- seawater TDS: 33,208 ppm
- osmotic pressure: 24.7 bar
- Stiff & Davis Stability Index (S&DSI): 0.1
- saturation value of CaSO<sub>4</sub>: 14.5 %
- saturation value of SiO<sub>2</sub>: 0.9 %
- saturation value of BaSO<sub>4</sub> and SrSO<sub>4</sub>: 0%
- ionic strength: 0.683

Pretreatment was designed based on the seawater feed quality. The proper pretreatment is important to the performance and continuation of the RO system and longer membrane lifetime. From the results of the RO design, parameter S&DSI is negative. This means that CaCO<sub>3</sub> scaling is relatively low. Silica and sulfate were below the limiting saturation value. Saturation limit for dissolved silica was 100%, CaSO<sub>4</sub> 230%, BaSO<sub>4</sub> 6000% and SrSO<sub>4</sub> 800% [7].

## 5. Pre-design seawater RO system

The alternative technology of seawater desalination by RO at the Badak NGL plant is based on the following fixed parameters [5–7]:

- seawater TDS: 33,208 ppm
- production capacity of fresh water: 20,000 m<sup>3</sup>/d
- recovery ratio: 40%

- feed water system: open sea intake
- feed temperature: 24°C
- membrane type: Hydranautics spiral wound, 8040-HSY-SWCI; size 8"×40", total number of elements, 2100
- fresh water quality standard TDS: ≤500 ppm (WHO standard)
- system configuration: 2 array – 1 pass with concentrate circulation and booster pump
- flux decline percentage per year: 7%
- percentage of salt passage increasing rate per year: 10%

Note: The parameters are fixed by considering the condition at PT. Badak, references, and vendor information.

To calculate energy demands and total water cost (TWC) using RO, it is necessary to make the following assumptions [2,3,8]:

- pump and engine efficiency: 83%
- energy recovery turbine efficiency: 83%
- investment cost: US\$ 8,000,000–16,000,000
- interest: 6%
- electricity (local site): US\$ 0.038/kWh
- plant factor: 90%
- maintenance cost and pretreatment cost: 5% investment cost
- plant lifetime: 10 y
- membrane lifetime: 5 y
- membrane price/module: US\$ 2,000

The results of simulation using RO are given in Table 1.

Attention should be made to prevent fouling due to the fluid flow in the piping system and membrane module. For example, the Hydranautics 8040-HSY-SWCI, diameter 8", maximum allowable flow rate, is 17 m<sup>3</sup>/h. It is fixed to produce a turbulent flow in the piping system and in the membrane module ( $Re=4000$ ). The Reynolds number is determined by physical parameters: seawater viscosity, density, fluid flow and the diameter of the pipes.

Table 1  
Results of the RO design simulation

Parameter	Pre-design value	
TDS, ppm:		
Permeate	451.9	
Concentrate	55,010.6	
Osmotic pressure, bar:		
Feed	26.2	
Concentrate	41.8	
Operation pressure, bar	58.4 <sup>a</sup>	
Booster pump pressure, bar	5	
Pumping flow rate, m <sup>3</sup> /h	2293.4	
Permeate flow rate, m <sup>3</sup> /d	20,000	
Feed flow rate, m <sup>3</sup> /d	50,000	
Recovery ratio, %	40	
Recirculation rate conc., m <sup>3</sup> /d	5,000	
Stiff & Davis Saturation Index:		
Feed	−0.14	
Permeate	−5.23	
Concentrate	0.35	
Langelier Saturation Index (LSI):		
Feed	0.87	
Permeate	−5.28	
Concentrate	1.35	
<b>Investment costs (US thousands):</b>	8,000	16,000
Capital cost, US\$/m <sup>3</sup>	0.13	0.25
Maintenance cost, US\$/m <sup>3</sup>	0.06	0.12
Chemical cost, US\$/m <sup>3</sup>	0.02	0.02
Membrane replacement cost, US\$/m <sup>3</sup>	0.13	0.13
Energy cost, US\$/m <sup>3</sup>	0.13	0.13
Total water cost, US\$/m <sup>3</sup>	0.46	0.64

<sup>a</sup>Recommendation: 61.1

Based on RO design calculation, the LSI and S&DSI specifications in the concentrate flow are satisfied: LSI = 1.35 and S&DSI = 0.35, under the limiting values of scaling and corrosion in the brine disposal piping system. LSI and S&DSI of the permeate flow are −5.28 and −5.23, respectively. In this condition scaling tendency is low but the corrosion potential is relatively high for the permeate piping distribution system. Post-treatment is necessary by pH adjustment with

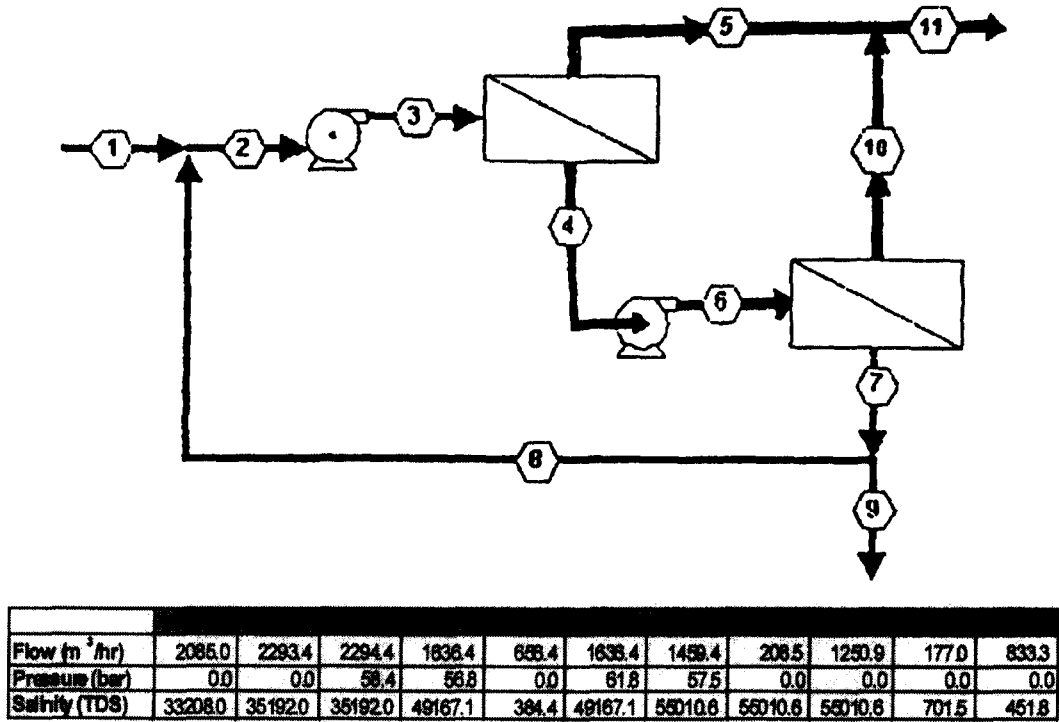


Fig. 1. Process flow diagram of the RO system.

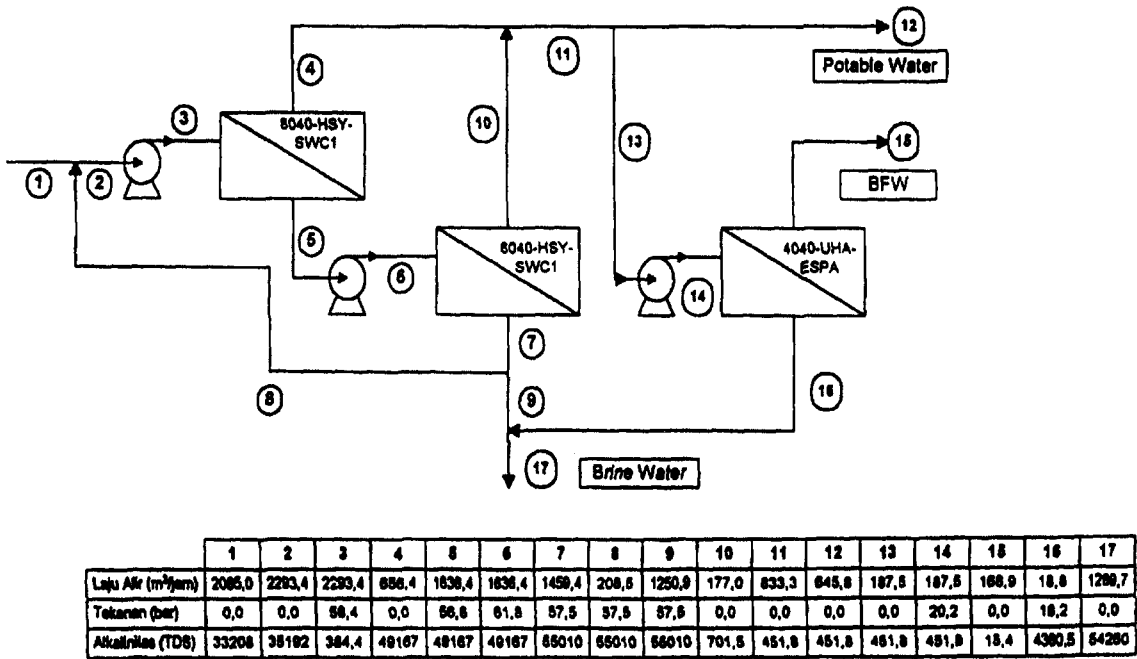


Fig. 2. Process flow diagram for the RO system for the production of boiler feed water.

NaOH or the addition of lime [5,6] to increase the LSI and S&DSI to a proper value under the limiting corrosion potential.

The process flow diagram of the RO system by RO-design simulation is shown in Fig. 1.

## 6. RO system for boiler feed water production

Boiler feed water (BFW) for high-pressure steam needs high-quality water. To produce BFW with specific requirements, an additional RO process is needed. The process flow diagram of the RO system by simulation is shown in Fig. 2. The simulation by RO Design for production of BFW was done based on the following fixed parameters:

- fresh water product from RO system I TDS: 451.9 ppm (is used as the feed water for RO system II)
- production capacity BFW: 4,050 m<sup>3</sup>/d
- recovery ratio: 90%
- feed water temperature: 24°C
- membrane type: Hydranautics, spiral wound 4040-UHA-ESPA; size 4"×40", total number of elements, 330
- product water quality standard for high-pressure steam, TDS: ≤20 ppm

The results of the simulation are given in Table 2.

## 7. Conclusions and recommendations

1. The pre-design RO system by Hydranautic RO design is based on the seawater quality in the Bontang Sea and fresh water production of 20,000 m<sup>3</sup>/d with a TDS of ≤500 ppm. Production of boiler feed water can be achieved by further processing of product fresh water from RO system I to RO system II after passing through an ion-exchange unit. The TWC of US\$0.46–

Table 2

Results of the RO design simulation for boiler feed water

Parameter	Pre-design value for BFW	
TDS, ppm:		
Permeate	15.4	
Concentrate	4,380.5	
Osmotic pressure, bar:		
Feed	0.3	
Concentrate	3.2	
Operation pressure, bar	20.2 <sup>a</sup>	
Booster pump pressure, bar	—	
Pumping flow rate, m <sup>3</sup> /h	187.6	
Permeate flow rate, m <sup>3</sup> /d	4,050	
Feed flow rate, m <sup>3</sup> /d	4,500	
Recovery ratio, %	90	
Recirculation rate conc., m <sup>3</sup> /d	—	
Stiff & Davis Saturation Index:		
Feed	−5.23	
Permeate	0	
Concentrate	−2.58	
Langelier Saturation Index (LSI):		
Feed	−5.28	
Permeate	0	
Concentrate	−2.44	
<b>Investment costs (US thousands):</b>	162	324
Capital cost, US\$/m <sup>3</sup>	0.01	0.03
Maintenance cost, US\$/m <sup>3</sup>	0.01	0.01
Chemical cost, US\$/m <sup>3</sup>	0.00	0.00
Membrane replacement cost, US\$/m <sup>3</sup>	0.07	0.07
Energy cost, US\$/m <sup>3</sup>	0.03	0.03
Total water cost, US\$/m <sup>3</sup>	0.12	0.14

<sup>a</sup>Recommendation: 22.2.

0.64/m<sup>3</sup> fresh water was calculated based on an energy price of US\$0.038/kWh at the Badak plant site.

2. The pre-design is useful as a reference and input knowledge for a feasibility study before implementing the process in the near future. The

assumption and the fixed variables for calculation must be reviewed to get the proper values. From the reference *Desalination and Water Reuse*, the investment cost of seawater desalination by RO with a product capacity of 20,000 m<sup>3</sup>/d at the Badak plant is between US\$ 8,000,000– 16,000,000, depending on local site conditions. Further study is needed before implementation of this technology in the near future. Simulation by the Hydranautic RO design is useful to calculate mass and energy balance, system configuration, P&ID and selecting unit processes and operation equipment.

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