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SEAWATER DESALINATION PLANT – A CASE STUDY

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Abstract: *This article is focused on two main methods of seawater desalination. Each method is analyzed separately. Municipal solid waste (MSW) is used as energy source. Coupling of waste to power and seawater desalination plant is discussed in this paper. The case study presents a touristic area where this process could by worthy. The main goal of this article is to calculate the unit product cost as main parameter in desalting plants.*

Keywords: ***Desalination, MED, RO, energy, cost.***

1. Introduction

To live is to use water. Unfortunately, fresh water is becoming an ever-more precious commodity, again because the arid regions of the world appear to be expanding. This gap is expected to widen in the near future, due mainly to the high rate of population growth and the urbanization. Desalination of seawater is the logical or the only available solution to safe supplies of fresh water. This process consumes large amounts of energy while municipal solid waste (MSW) may be transformed to produce electricity and thermal energy (Dajnak et al., 2000). Waste treatment is an extraneous term in Albanian towns and their thermal utilization is encouraged. Seawater desalination can help to resolve local problems of water supply, which, especially in arid areas, can risk the development and the life of people. Since desalination involves high specific consumption of energy per m^3 of distilled water, the adoption of economic and efficient desalination technologies is desirable. The evaluation of unit product cost is considered in this paper.

2. Reverse Osmosis (RO)

Reverse osmosis is a membrane based desalination process. The membrane is capable of separating salt from water with a rejection of 98–99.5%. Reverse osmosis is based on a property of certain polymers called semi-permeability. While they are very permeable for water, their permeability for dissolved substances is low. By applying a pressure, difference across the membrane the water contained in the feed is forced to permeate through the membrane. In order to overcome the feed side osmotic pressure, fairly high feed pressure is required. In seawater desalination, it commonly ranges from 5.5 MPa to 7 MPa.

3. Multi-effect distillation (MED)

The MED process takes place in a series of vessels called effects and uses the principle of reducing the ambient pressure in the various effects. In a MED process the feed water enters the first effect and is raised to the boiling point after being preheated in tubes. The tubes are heated by steam from a boiler/turbine which is condensed on the opposite sides of the tubes. Only a portion of feed water applied to the tubes in the first effect is evaporated. The remaining fed water is fed to the second effect, where it is again applied to a tube series. The tubes are in turn being heated by the vapor created in the first effect. The vapor is condensed to distillate while giving up heat to evaporate a portion of remaining feed water in next effect. The main feature of the MED process is that it operates at low top brine temperature 60-70^{o}C (Al-Salahi et al., 2006).

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4. The case study

An Albanian touristic area of 100 000 inhabitants is considered in our case. The typical present day per capita content of MSW is evaluated 450 – 550 kg/year. MSW calorific value is considerable, 8.5-13 MJ/kg (Reimann, 2006). For our calculations have accepted LHV_{waste}=11 500 kJ/kg, from which results that nominal thermal power in boiler is Q_{boiler}=32.5 MW_{th} and electricity generated E= 9 MW_{el}.

4.1. Reverse Osmosis power by waste firing plant

First, we consider that the total energy production of 9 MW_{el} is used to supply RO desalting plant. In order to calculate the unit product cost is necessary to make some assumptions:

- Steady state operation
- Isothermal operation. Therefore the temperatures of the feed, brine and permeate are equal.
- The membrane selectivity is constant and is equal for various types of salts.

In the scheme below is examined a 2 000 m^3/d desalination plant. This assumed value is much higher than last achievements in the membrane technology. The main design variables in RO systems are:

- the recovery rate,
- the salt rejection, S_R = 99 %
- the operating pressure,
- the permeate flux, both in terms of overall product rate and specific rate.

For a given salt rejection of the membranes used, technical feasibility of single-stage systems for potable water production is expressed by the following condition:

$$TDS_p = (1 - S_R/100) * TDS_f \leq 500\,ppm \qquad (1)$$

TDS_f- salinity of feed water, ≈ 40 000 ppm (typical value of Mediterranean seawater)
TDS_p- salinity of product water, ppm

In order to decrease the power consumption a pressure exchanger is appropriate for energy recovery. These work exchangers directly transfer brine hydraulic energy to feed hydraulic energy. In any case, cost reduction rarely exceeds 10 % of water cost (Lamei, et al., 2007). A RO layout and with parameters is shown in Fig. 1. The results from the calculations are summarized in Tab. 2.

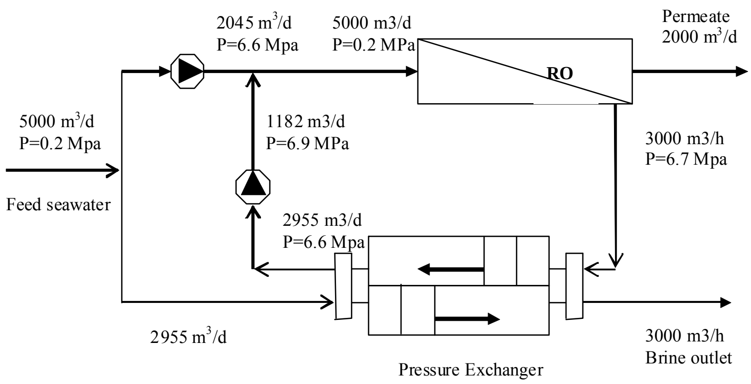

Fig. 1: Single RO desalination scheme.

4.2. Multi-effect distillation process coupled with waste firing plant

Waste firing plant supplies with heat and electricity the MED plant. Desalting capacity is accepted 2 000 m^3/d with 6 effects. For our calculations is accepted specific heat consumption 10 kWh/m^3 distillate. Specific electric energy consumption is assumed 2.5 kWh/m^3. Particularly for the MED section El-Dessouky et al., (1998) assume equal heat transfer area in each effect, and equal heat transfer coefficient. Equal temperature drop between effects as well equal specific heat for the brine, and feed water have been assumed.

The design of MED parameters starts with the definition of the temperature drop across all effects, which is obtained from equation (2).

$$\Delta T_{tot} = T_s - T_{bn} \tag{2}$$

Brine temperature in the first effect is obtained from the relation

$$T_{b1} = T_s - \Delta T_1 \tag{3}$$

Distillate flow rate in the first effect can be calculated from the evaporator energy balance (Jirouš, 2010) :

$$M_s \lambda_s = M_f c_p (T_{v1} - T_f) + D_1 \lambda_1 \tag{4}$$

Distillate flow rate in effects 2 to n:

$$D_{i-1} = \frac{M_f c_p (T_{vi} - T_f) + D_i \lambda_i}{\lambda_{i-1}} \tag{5}$$

Brine flow rate in effects 1 to n:

$$B_i = D_i \frac{X_f - X_d}{X_b - X_f} \tag{6}$$

The overall mass balance (Jirouš, 2010):

$$M_f = M_d + M_b \tag{7}$$

The evaporator heat transfer area, for the first and next effects are written as

$$A_e = \frac{M_s \lambda_s}{U_e (T_s - T_b)} \tag{8}$$

In Tab. 1, are shown the results for each effect of MED process. The enthalpies of brine and vapor are obtained from the formulas given in terms of the vapor and brine temperatures.

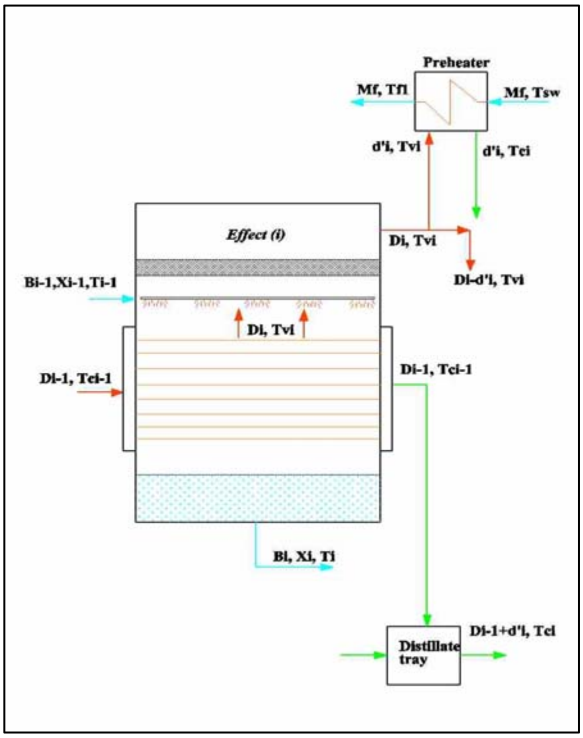

Fig. 2: Layout of the i^{-th} effect of MED plant.

Tab. 1: Parameters of MED profile.

Effect	1	2	3	4	5	6
U (kW/m^2K)	2	2	2	2	2	2
ΔT (°C)	4.16	4.16	4.16	4.16	4.16	4.16
T_b (°C)	70.84	64.68	58.52	52.36	46.2	40
T_v (°C)	68.84	62.68	56.52	50.36	44.2	38
λ_v (kJ/kg)	2335.92	2350.6	2365.46	2380.51	2395.77	2411.28
D (kg/s)	3.039	2.262	1.618	1.1048	0.7196	0.46
A (m^2)	902.04	902.04	902.04	902.04	902.04	902.04
B (kg/s)	8.201	8.978	9.622	10.1352	10.5204	10.78
F (kg/s)	11.24	11.24	11.24	11.24	11.24	11.24
X_b (ppm)	64 000	64 000	64 000	64 000	64 000	64 000

In Tab. 2, are summarized the data of cost analysis for each desalination process. The economic analysis is based on cost equation of the total cost C_t;

$$C_t = C_c + C_e + C_{ch} + C_l + C_m \tag{9}$$

Where, C_c is the yearly capital cost [€/year]:

C_e - cost of energy [€/year];

C_{ch} - cost of chemicals [€/year];

C_l - the yearly cost of labor [€/year];

Tab. 2: Unit cost production of each desalination process.

	RO section		*MED Section*	
Plant capacity, m^3/d		2 000		2000
Recovery rate (RO), % and conversion rate (MED), %		40		38
Direct capital cost, €m^3/d		1350		1400
Chemical consumption, kg/m^3		0.28		0,1
Chemical cost, €/kg		0.18		0,18
Specific (labour +maintenance), €/m^3		0.0645		0,022
Membrane replacement , €/m^3		0.034		N/A
Specific thermal energy consumption, kWh/m^3		N/A		10
Specific electric power consumption, kWh/m^3		4.5		2,5
Specific electric energy cost, €/kWh		0.05		0,05
Interest rate	5%			5%
The annual fixed cost, €/year	209 637		168 000	
The annual chemical cost, €/year	32 256		11808	
The annual operation + maintenance, €/year	41 280		14432	
The annual membrane cost, €/year	21 760		N/A	
The annual energy cost €/year	144 000		410000	
Total	448 933		604 240	
Unit product cost €/m^3	***0.74***		***0.921***	

5. Conclusions

Two different methods of desalination have been discussed in this article. RO requires high pressures and the total electricity production of 9 MWel, is used for desalination plant. The second attempt is coupling power plant with MED section. Design parameters of MED, operating parameters and some data cost have been evaluated. Unit product cost of RO is slightly lower than thermal desalination unit product cost, due to higher energy requirement of MED. In the end, could say that results are interesting and encouraging mainly, when desalting plants are powered by a waste firing plant.

Symbols

A - Area of evaporator, m^2

B - Brine flow rate from each evaporation effect, kg/s

λ - Latent heat for evaporation, kJ/kg

PR - performance ratio, PR=Md/Ms,

T - Temperature, ^oC

n - Number of effects,

T_v - Vapour temperature in each effect, ^oC

U - Heat transfer coefficient, $kW/m^2\,^oC$

X - Salinity, ppm

D - Amount of vapour formed in each flashing stage or effect

F - Feed flow to each effect, kg/s

M - Mass flow rate, kg/s

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