ECONOMICAL AND THERMAL STUDY OF A MECHANICAL VAPOR COMPRESSION DESALINATION UNIT

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Résumé

The Mechanical Vapor Compression (MVC) desalination technology offers an interesting alternative for small-scale desalination of seawater to produce high quality distilled water with competitive cost. This paper presents an economical and thermal study of single-effect mechanical vapor compression unit. The aim of this work is to define, the parameters influencing on the behavior of the desalination unit, to develop a knowledge base on the total cost of pure water in different range of operation. The proposed approach is based on MVC components and cost models. The results demonstrate the influence of the MVC unit capacity and temperature difference between condensing vapor and boiling brine ΔT on the total cost of clean water. A high ΔT value reduces the cost of heat transfer area, but simultaneously increases the cost of electric consumption. This study confirms that the MVC desalination cost heavily dependent on operating parameters. A good control of these parameters can significantly reduce the total cost of pure water.

Mots clefs: *Desalination; Mechanical vapor compression; Cost;*

1. Introduction

As freshwater scarcity continues to increase with the increasing continuous of population, desalinating seawater is becoming a necessity for meeting freshwater needs especially in the North Africa and other regions. Water scarcity is a threat to over 40% of the global population [1]. The two major types of technologies that are used around the world for desalination can be broadly classified as either membrane such as reverse osmosis (RO) or thermal including single effect evaporation (SEE), multiple effect evaporation (MEE), multi-stage flash (MSF), thermal vapor compression (TVC) and mechanical vapor compression (MVC) [2,3]. Both technologies need energy to operate and produce fresh water. The inception of commercial mechanical vapor compression (MVC) units dates back to the early 1970s [4,5]. MVC units have been evolved to become a mature technology over past decades. However, initial costs, system design and energy consumption remain challenging problems. An early report by Matz and Fisher [4] in 1981 showed that either the RO or MVC system has a definitive edge regarding total production cost. However, expansion of the MVC process remained limited. In 1994, only 200 MVC units with very small unit capacity are reported by Zimmerman [6]. The minimum theoretical energy required for separating the salts-desalination, to produce freshwater is 0.7 kWh/m^3 [7]. In practice, much higher energy is required by the currently available desalination technologies. Calculations of unit product cost depend on the process capacity, site characteristics and design features. Thermoeconomic design for a MEE–MVC desalination process and exergy are developed and presented by A.S. Nafey [8].

This work presents an economical and thermal analysis for a MVC desalination unit. The effect of the MVC unit capacity and temperature difference ΔT on the total cost of clean water is investigated.

2. System description

Figure 1 shows the sequence of operations in an MVC system. The main components of the MVC unit are the mechanical vapor compressor, evaporator/condenser heat exchanger, and a circulation pumps. The demister serves to filter the water vapor before joining the compressor. The feed preheater is a plate type heat exchanger, which recovers part of the sensible heat found in the distillate and brine stream to heat the intake seawater. The thermal energy recovered is then sprayed over the evaporator tubes of the evaporator/condenser. The feed temperature is further increased to the brine boiling temperature and subsequently evaporation commences. The produced steam is drawn through the demister to the compressor in order to add an additional amount of superheat, increases the pressure and temperature of the steam by compression. The superheated vapor that has passed through the condenser heat exchanger tube releases its latent heat, which can be the heat source of the evaporator. At the same time, the vapor is condensed into purified water. The condensed distillate product and the brine stream flow through the preheaters where it exchanges heat with the intake stream.

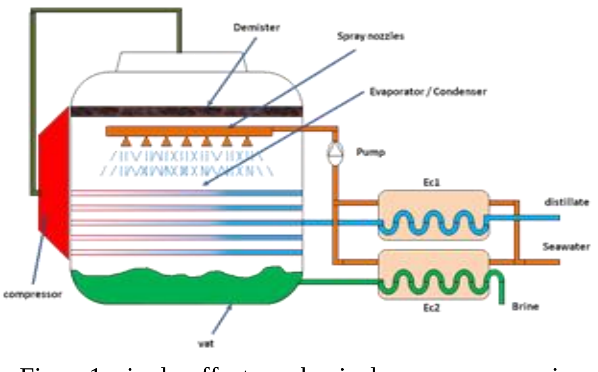

Figure1: single-effect mechanical vapor compression desalination unit

3. Process modeling

At this step, an economic and thermal analysis was performed in order to calculate the produced unit volume cost of the fresh water. The global model consists of the MVC components and cost models.

3.1 The MVC heat transfer model

Specific power consumption (W) is expressed in terms of the enthalpy difference of the compressed superheated vapor H_s and the inlet vapor H_v.

$$W = (H_S - H_V)(1000/3600) \quad (1)$$

The heat transfer area of the evaporator, feed and distillate preheater are calculated respectively from the following relationship:

$$A_e = \frac{M_d \lambda_d + M_d C_{pv}(T_s - T_d)}{U_e (T_d - T_b)} \quad (2)$$

$$A_{bh} = \frac{M_b C_{pb}(T_b - T_o)}{U_{bh}(LMTDbh)} \quad (3)$$

$$A_{dh} = \frac{M_d C_{pd}(T_d - T_o)}{U_{dh}(LMTDdh)} \quad (4)$$

The total heat transfer area is given by equations (5):

$$A_{Tot} = A_e + A_{bh} + A_{dh} \quad (5)$$

3.2 The water production cost model

The method adopted for calculating the unit production cost C_u is the same as that used in [9,10]. The costs included the unit electrical energy cost C_{uee}, the unit labor cost C_{ulab} and the unit chemical cost C_{uchem}. The unit production cost were analyzed using plant life =30 years, a plant availability f =0.9, and amortization factor a =0.05783, with the interest rate=4%.

The unit production cost C_u is calculated by:

$$C_u = \frac{aC_{TC}}{365 f V_{MVC}} + C_{uee} + C_{ulab} + C_{uchem} \quad (6)$$

Where C_{TC} is the total capital cost.

The total capital cost is calculated by:

$$C_{TC} = 1.15 \times \left(C_C + C_{pl} + C_{rest}\right) \quad (7)$$

Where C_c is the compressor cost, and C_{pl} is the cost of heat exchanger plates (evaporator, feed and distillate), and C_{rest} is the other direct costs (auxiliary equipment, land, building construction and well construction).

4. Results and discussion

An important aspect that can affect the sustainability of the model described above is to evaluate which are the resulting costs of the water. The parameters used in the evaluation process are giving in Table 1.

TABLE I. INPUT VARIABLES OF THE GLOBAL MODEL

Input variables	*Values*
Intake seawater temperature, °C	25
Boiling brine temperature °C	90
X_f/X_b	0.7
Efficiency of the vapor compressor	0.6
C_{ulab}, €m-3	0.1
C_{uchem}, €m-3	0.02

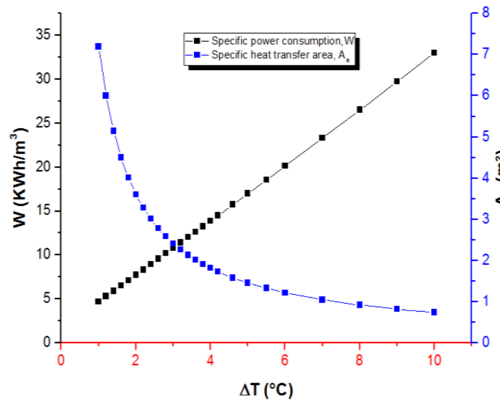

Figure 2: Influence of the temperature difference on the specific power consumption and the heat transfer area.

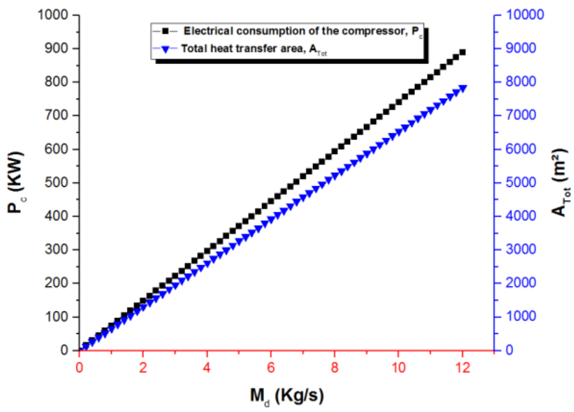

Figure 3: Influence of the product flow rate on the power consumption and the total heat transfer area

Figure 2 shows the heat transfer area of the evaporator A_e and the specific power consumption of the compressor W versus the difference between condensing vapor and boiling brine temperature ΔT for M_d=20 l/h. As can be seen, A_e decreases strongly accordingly with the increased value of ΔT, and in the same time W increases linearly with the increase of ΔT, which is also consistent with the results reported in the literature [11,12]. However, according to the previous works [11], the operations with an elevated brine boiling temperature is desirable since it reduces W and decreases slightly A_e. This figure shows that the choice of ΔT is an important parameter from the economic point of view.

In order to give more details on the parameters influencing the MVC unit, Figure 3 shows the power consumption and total heat transfer area as function of the product flow rate M_d for ΔT =8°C. It can be seen that A_{tot} and P_c both increase linearly with the increases of M_d, which means that an economic study including the costs of the compressor and the heat exchangers is necessary to bring out the propitious choose of product flow rat of the MVC unit.

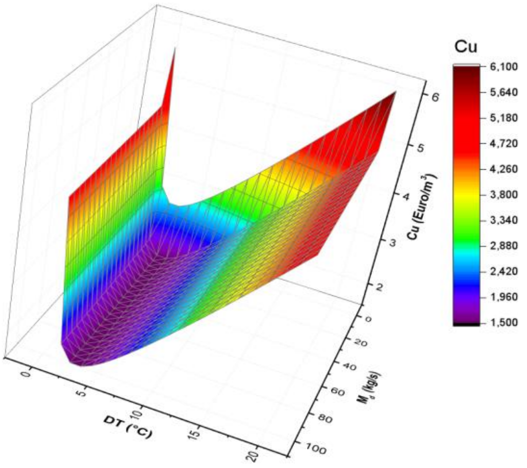

Figure 4: Influence of the product flow rate and temperature difference on the water unit production cost

Figure 4 is a synthesis, which gives an idea of the parameters influencing the behavior of the desalination unit cost, in order to develop a knowledge base on the total cost of pure water. In addition, Figure 4 shows the influence of the product flow rate and temperature difference on the water unit production cost. The variation of the distillate flow rate as a function of the water unit production cost define three areas: high, medium and constant variation of the cost. These results are in concordance with the values reported in literature [10]. According to the study made above, the lowest ΔT value means a huge A_e value (i.e. high C_{pl}), small W value (i.e. small C_{uee}, C_c), and vice versa. The variation of C_u as a function of ΔT reflects the importance of the choice of this parameter. As a summary, the operation with temperatures differences ranged between 2 to 8 °C, drastically decreases the overall unit product cost. However, the operation with a ΔT=3°C and M_d =6.94 Kg/s, gives the better results of C_u=1.5 €m^{-3}.

5. Conclusion

An investigation on the cost of a MVC desalination system is presented in order to provide a knowledge base on the total cost of pure water in different range of operation. Several conclusions can be drawn:

- The power consumption and the total heat transfer area increase linearly with the increases of the product flow rate. That means that is necessary to bring out the propitious choose of product flow rat of the MVC unit.
- The operations with a high value of ΔT reduce the heat exchange area, therefore the cost of the evaporator reduced too, but increase the power consumption. This inferred that an optimization study is needed to find a compromise between the congestion (investment cost) and electric energy consumption to design an efficient desalination unit.
- The costs of water unit production can be significantly reduced by the application of the developed knowledge base, which is 1.5 €m^{-3} for the considered desalination case.

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