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Process investigation of different locations of thermo-compressor suction in MED–TVC plants

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ABSTRACT

The desalting of seawater has been a vital issue in several countries around the world in which water shortage is a serious problem. Through the process of designing desalination systems, with consideration of energy crisis, amount of energy consumption is a very important economical factor. In multi-effect distillation systems with thermal vapor compression (MED–TVC), thermo-compressor plays a main role in energy consumption. The geometry and operating conditions of thermo-compressor can have a significant influence on energy consumption. In this research, the influence of changing the suction position of thermo-compressor on the amount of energy consumption of the plant is analyzed. Results of the study showed that variation in suction pressure of thermo-compressor has considerable effects on the entrainment ratio. However, in order to have the maximum entrainment ratio and consequently reduce energy consumption, integration of MED–TVC with MED desalination must be optimized into the position of thermo-compressor suction. It was found that changing the suction location of thermo-compressor from the last effect to the middle effects or increasing the suction pressure has a valuable role in decreasing the energy consumption of the system. Results showed that the optimum value of compression ratio of thermo-compressor is between 2 and 2.5.

1. Introduction

The issue of water shortage has led to the development of seawater desalination systems especially in countries around the Persian Gulf where using desalination systems are more common.

A noticeable part of production capacity of the desalination industry has been devoted to thermal desalination in the last decade and it is still increasing [1]. Since thermal desalination processes are very energy sensitive[2], creating an accurate modeling program that can simulate the performance of desalination systems enables the designers to select the best components and determine the optimal operating conditions in order to improve the performance of desalination plants, reduce the amount of energy consumption and as a result save money. To this end, several studies have been carried out in this field during the last decade [1–13].

Some modeling programs have been developed for MED system with shell and tube evaporators for horizontal tubes [1,2,4,6–8] and a simulation code for MED system with vertical tubes has been considered by Raach and Mitrovic [3]. In their simulation model conventional MED and MED–TVC systems have been investigated. In MED system, steam comes directly to the first effect with a very low pressure and there is no recycling of steam in these packages. In conventional MED–TVC systems steam is recycled and recompressed from the last effect to use in the first effect by a thermo-compressor. The GOR value in MED–TVC systems is greater than MED systems by result of decreasing in steam consumption with consideration of thermo-compressor in the system.

Habshi [9] also developed a mathematical model using a steady-state simulation program to analyze a MED–TVC plant. The effect of the thermodynamic losses on specific heat transfer area, specific flow rate of the cooling water and thermal performance ratio is studied in his research.

Recently, a computer simulation code has been developed by KouhiKamali et al. to simulate MED–TVC packages which were approved by MED–TVC packages installed in the south of Iran [11–13]. In this research, the model has been improved in order to simulate MED–TVC + MED package as well.

A simulation model has been presented by Alasfour et al. to investigate the combination of MED–TVC system and MED in comparison with conventional MED and MED–TVC units [14].

He has carried out a parametric study to investigate the MED–TVC integrated with a conventional MED system (MED–TVC + MED) with regenerative feed heaters in comparison with conventional MED–TVC units with regenerative feed water heaters (MED–TVC, FH) and without them. The analysis is based on the first and second law of

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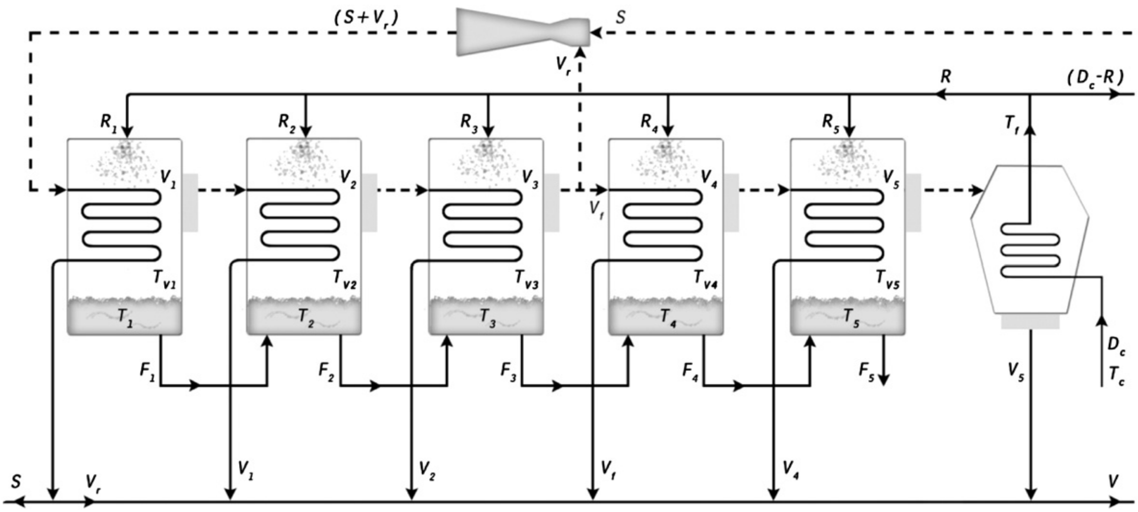

Fig. 1. Schematic flow diagram of a conventional MED–TVC system with five effects.

thermodynamics. The exergy analysis showed that irreversibilities in the steam ejector and evaporators are the main sources of exergy destruction in the three configurations. Results showed that when steam is supplied directly from the boiler to all configurations, the first effect was responsible for about 50% of the total effect exergy destruction. The study also showed that the decrease in exergy destruction is more pronounced than the decrease in the gain output ratio at lower values of motive steam pressure, and the MED–TVC + MED with regenerative feed heaters has two main features compared to two other configurations. First of all, it has a lower compression ratio, which makes the motive steam capable of compressing larger amounts of the entrained vapor; as a result, the amount of motive steam is reduced. Second, the configuration can be used for large-scale production.

Darwish and Al-Najem [15] conducted a parametric analysis using the first and second law of thermodynamics for single- and multi-effect TVC systems. Their work showed that the steam ejector and the evaporator are the main sources of exergy destruction. The study revealed that the increase in top brine temperature, while keeping the same last effect brine temperature, reduces the heat transfer surface area of each effect. On the other hand, the increase in the number of effects for the same values of top brine temperature and last effect temperature reduces the temperature difference across each evaporator and consequently increases the gain output ratio.

Hamed et al. [16] conducted and evaluated the performance of thermo-compressor, and compared against an actual plant. The exergy analysis was performed in their research and compared against conventional MED and mechanical vapor compression (MVC) desalination systems. Results showed that TVC system yields the least exergy destruction among the three systems. Exergy analysis showed that most of the exergy destruction occurs in the first effect of the TVC and in the thermo compressor. Increasing the number of effects and decreasing the top brine temperature can reduce the exergy losses.

The influence of variation in suction pressure of the thermo-compressor on energy consumption of the system in different combination of MED–TVC system and MED was investigated in the present study.

2. Process simulation

A schematic flow diagram of the MED–TVC system is shown in Fig. 1. The system consists of several evaporators, a condenser and a thermo-compressor.

Feed water leaves the condenser at T_f and is then divided equally between the effects. Steam from the thermo-compressor ($S+V_r$) is also directed to the inside of the tubes of the first effect as the heat source. In the first effect, as shown in Fig. 2, the pre-heated feed water at T_f is sprayed on the tubes' bundle and heated up to the boiling point temperature of the first effect (T_1). During the heat transfer, a part of the feed water of the first effect (R_1) is evaporated and generates vapor at T_{v1}. This generated vapor at the first effect (V_1) is directed to the second effect as the heat source at a lower pressure and temperature.

On the other hand, in order to utilize the energy of hot brine produced in the first effect, it flows to the second effect at P_2. The vapor generated by the evaporation of the feed water in the second effect and flashing brine is called V_2, and this iterative process is repeated to the end of the middle effect.

As shown in Fig. 3, part of the generated vapor in the middle effect, V_r, is recompressed in the thermo-compressor by the motive steam (S). The expanded motive steam and the recompressed vapor leaving the thermo-compressor ($S+V_r$) act as the first effect heat source and are condensed in it. The part of the condensate returns to the boiler, S, and the other part, V_r, joins the product water (Fig. 2).

The vapor released from the last effect passes the condenser and gives off its latent heat to the cooling seawater intake (D_c), and raises

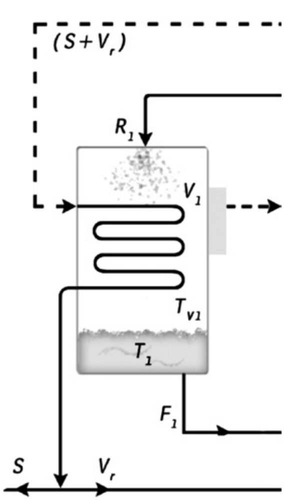

Fig. 2. The first effect as a control volume.