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Performance Optimization of Multi-Effect Distillation-Thermal Vapor Compression Desalination Using Genetic Algorithm

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ABSTRACT: In the present study, a MATLAB computer code has been prepared for the simulation of a multi-effect desalination unit with thermal vapor compression. The first step is to obtain the parameters' effect on the performance, including motive steam flow rate, temperatures, and dimensions of the system. Comparison of the present simulation results with the data reported for an actual desalination system shows a good consistency. System performance in two different cases of extracted secondary vapor from the last effect and all effects is investigated. It is observed that a higher performance ratio and specific heat transfer area are obtained by receiving secondary vapor from the last effect. Finally, the genetic algorithm is used to maximize the performance ratio of the system which is considered as the fitness function. Optimization results show that one can achieve a performance ratio higher than 17 and specific heat consumption less than 107 kJ/kg for a system with 10 effects.

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1- Introduction

One of the main issues facing human beings in recent decades is distillate water crisis. Desalination of water can be considered as an appropriate solution used for solving this problem. In general, desalination methods are divided into two categories, namely membrane, and thermal methods. Due to low maintenance costs, simple geometry and low power consumption, thermal methods have attracted considerable attention with the most used method of Multi-Effect Distillation (MED).

On the other hand, considering the growing interest in energy efficiency, the design of a system with the lowest energy consumption while producing the highest amount of fresh water is very important. Extensive studies have been carried out to improve the thermal efficiency of desalination devices such as MED. The effect of various parameters on the performance ratio of a MED has been investigated by various authors [1-3].

In the present work, a MED system in combination with a thermal vapor compression is modeled and simulated using MATLAB code. Also, the effect of different parameters was investigated on cooling water mass flow rate and performance ratio. In this study, the effect of supplying secondary vapor by two different modes was investigated on the performance ratio and specific heat transfer area. Finally, this system was optimized using a genetic algorithm.

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2- Problem Description

Multi-effect evaporation systems which are combined with thermal vapor compression (MED-TVC) consist of several evaporators and one condenser. The schematic diagram of the process is shown in Fig. 1. As is observed in this figure, water, and feed water are pre-heated in the condenser and then a part of each one as well as cooling water is returned to the sea. The role of cooling water is to condense distillate water which is available in the condenser. This feed water is distributed equally among evaporators. In every evaporator, the feed water is sprayed on the evaporator tubes while a part of it is vaporized by absorbing heat produced in preceding effect or external heat source such as steam from the thermal power station, combined heat power, etc. Product steam is conducted to evaporator tubes of the next effect where it is used as a heat source to evaporate part of the feed water. Finally, it is condensed and saved as distillate water. In the present work, the series-parallel configuration is considered for which the brine water of every effect goes to the next effect and a part of it is vaporized as a result of the sudden drop pressure resulting in more distillate water production in every effect.

Approaching the last effect (evaporator), the temperature and pressure decrease. Apart of the produced vapor in the last evaporator is sent to the condenser and preheats the feed and sea water while the remaining part is sent to the steam jet ejector as the secondary steam. Using the motive steam, the ejector increases the secondary vapor pressure and finally output steam from the ejector that is called heating steam enters into the evaporator to provide energy for the first

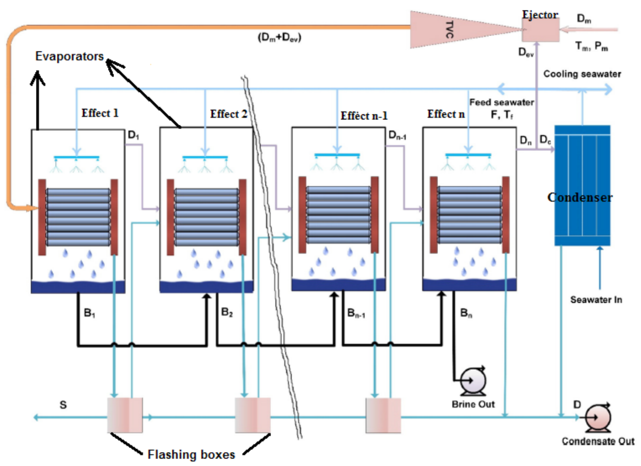

Figure 1. Schematic of MED-TVC series-parallel system

evaporator.

3- Optimization Using Genetic Algorithms

The aim of optimization is to find maximum performance ratio and minimum specific heat consumption while they are a function of heat steam temperature, feed water temperature, the temperature of the first and the last effect. Here, the aim is choosing optimum input values to optimize performance ratio as the fitness function. Genetic algorithm is used to optimize the performance ratio. It consists of different functions and operators, including Initialization, Selection, Crossover, Mutation, and Modification.

4- Methods

A computer code has been written based on mass and energy balances using MATLAB software in the present study. This code is a tool to design MED-TVC system and investigate the effects of various factors on the specific heat transfer area, specific cooling water flow rate and performance ratio. After validation, optimization is performed using a genetic algorithm. Decision variables are considered as heat steam temperature, feed water temperature, the temperature of the first and the last effect.

5- Results and Discussion

Validation of the present computations is performed using actual data of the Tripoli plant [4] which shows a good correspondence as discussed here. It is worth mentioning that reducing the entertainment ratio leads to an increase in the secondary steam and the heat steam mass flow rate that, in turn, increases the performance ratio.

The main results are as follows:

- As the temperature of the first effect increases, the feed water mass flow rate decreases resulting in the reduction of performance ratio. Also, it causes an increase in the temperature difference between the effects and specific area reduction will occur.
- Reducing heat steam temperature reduces entertainment ratio while increases the feed water mass flow rate, the result is an increase in the performance ratio.
- Increasing the number of effects increases feed water flow, which leads to a reduction in cooling water flow rate.
- In this section, two different combinations of the MED and TVC are investigated. In the first case, secondary steam is provided from all evaporators, while in the second case secondary steam is provided from the last evaporator. In the first case, less steam goes to next effect, thus the capacity of the evaporators decreases, while in the second case, just some of the steam of the last effect is sent to the ejector and the remained steam is sent to the condenser. Therefore, the performance ratio reduces in the first case (Fig. 2).

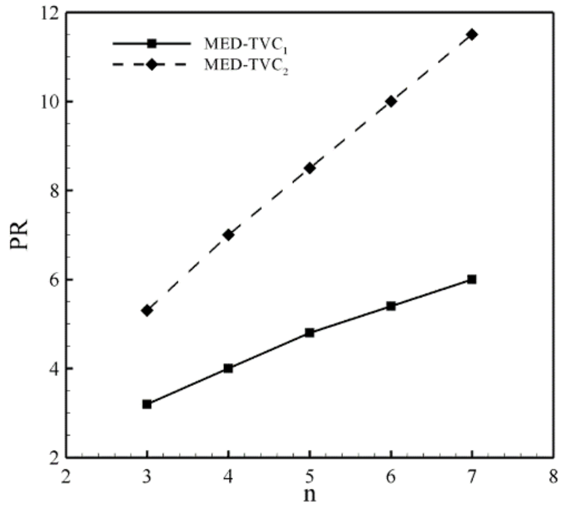

Figure 3. Performance ratio at different number of effects

- Here, optimization results are presented. In the present study, the feed water temperature, the heat steam temperature and the first and the last effect temperatures are decision variables. Using genetic algorithm, performance ratio and specific heat consumption can be obtained as 17.26 and 106.92 kJ/K. Using the feed water temperature, the first effect temperature and the temperature difference between the effects considered as 40°C, 63.1°C and 2.3°C, the amount of performance ration and specific heat consumption were obtained as 13.31 and 183.5 kJ/kg. Optimization results in different effects are shown in Table 1.

Table 1. Optimization results of MED-TVC series – parallel system using Genetic Algorithm (GA)

n	*Ts* (°C)	*T1* (°C)	*Tn* (°C)	*Tf* (°C)	*PR*	*Q* (kJ/kg)
6	55.69	54.61	43.76	41.71	12.49	147.72
8	53.30	50.17	40.19	38.19	15.63	118.11
10	55.07	52.12	39.40	37.90	17.26	106.92

6- Conclusions

The present MATLAB program can be used as an effective tool in designing a MED-TVC system based on the results which show a good correspondence with the experimental data. Results of the present computations showed that decreasing temperature of the first evaporator increases heat steam temperature, mixing ratio and performance ratio. In addition, it was observed that by supplying the intake steam by ejector from the last evaporators only, the performance ratio and the specific heat transfer area are increased. Finally, optimizing of this system was performed using a genetic algorithm with the most appropriate decision variables (feed water temperature, heat steam temperature at the outlet of the ejector, the temperature of the first and the last evaporator) was determined to find the highest possible performance ratio and the lowest special heat consumption. According to the condition listed and obtained results, performance ratio and specific heat consumption can be reached at 17 and 107 kJ/kg, respectively after optimization while their values were equal to 13.31 and 183.5 kJ/kg before doing optimization.

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