Investigation of unsteady thermal performance of multi-effect desalination with TVC

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ABSTRACT

Due to the high use of thermal desalination plants, there is a great tendency to simulate the behavior of them. Most of the researches are focused on modeling steady behavior, but to design control systems and evaluate their performance, we also need to study unsteady behavior. Also, few researches have studied system shut down. In this paper, steady and unsteady modeling of industrial multi-effect desalination plant with four effects, one condenser and a thermocompressor has been studied. The variable-step, variable-order method has been used to solve differential equations. Each evaporator is divided into three phases of vapor, tubes and brine then the equations of mass and energy conservation is used. Results have been validated with real plant data. The variables of temperature, vapor flow rate, brine flow rate and brine level were studied in unsteady modeling in starting, shutting down and steady state conditions. It was found that the largest change in the brine flow rate after shutting down is in the last effect, which increases by 42%. Also, the biggest change in the level of the brine is in the first effect, which after 800 seconds will reach 11 times the steady state that will cause flooding phenomenon.

Keywords

desalination plants, unsteady behavior, shut down, variable-step and variable-order, flooding phenomenon

1. Introduction

Modeling and simulation of the desalination process simplifies the design and operation of the MED-TVC device and gives us a better view for optimal operation and process control. Dynamic modeling will be very useful for solving problems related to unsteady behavior such as start-up and shutdown and the effects of disturbances. There are many studies on modeling in the steady state, but in the transient state the studies obtained have been very limited due to the complexity of the equations obtained. Cipollina et al. [1] presented a dynamic model for transient operation of a multi-effect desalination plant with a thermocompressor in 2017. Elsayed et al. In 2018 [2, 3] investigated the dynamic performance of the multi-effect desalination process in different forms of feed water into the system and the effect of perturbation on the MED-TVC. In 2019, Guimard et al. [4] considered new considerations along with a control strategy for modeling a multi-effect desalination plant with an ejector under dynamic conditions. In 2019, Dong et al. [5] connected an integrated pressurized water reactor with a multi-effect desalination process with thermal vapor compression. They developed a dynamic model for the design and optimization of control devices for nuclear desalination plants. In 2020, Hakim et al. [6] proposed a new algorithm to solve the problem of steady-state analysis of a multi-effect evaporator with forward feed, which consists of three effects. In 2021, Hua et al. [7] studied the dynamic response of state variables in the multi-effect desalination process. These variables include evaporation temperature, salinity, evaporation mass flow rate and brine level.

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According to the researches on multi-effect desalination plant with ejector, it is clear that most studies in this field have focused on modeling the steady-state behavior of this system and very little researches have been on the transient state model. However, in order to design control devices and especially principled planning with the least amount of losses and stress to the desalination system and its ancillary devices including ejector, pumps and heating supply system during start-up and shutdown, we need to model the transient behavior of desalination plant. In this study, the unsteady behavior of four-effect thermal desalination with an ejector is modeled. This modeling has been implemented by obtaining governing differential equations of evaporators, condensers and ejector, in order to obtain the relationship between the outputs and inputs of the system by using the thermophysical properties of water. One of the main differences between current modeling and others, especially Elsayed model [3], is in the dynamic model of the condenser, which is able to report the water level of the condenser. Also, the modeling of the ejector is based on gas dynamics equations in two algorithms of design and evaluate, which most articles use only one empirical equation. This type of ejector modeling makes it possible to use the design algorithm to obtain the geometrical characteristics of the ejector and then by using evaluate algorithm the reaction of the same ejector to start-up and shutdown of the system can be studied. While the existing experimental equations for the ejector examine the reaction of a general ejector under the new conditions. Also, most of the experimental equations of ejector, by changing the input and output conditions, offer a new ejector suitable for the new conditions, which is not suitable for unsteady modelling at all. In the end, with the results of the unsteady behavior of the four-effect thermal desalination plant with a ejector, it is possible to observe the course of changes in the thermophysical properties of the device from the start-up to stability and then shutting down the system.

2. Methodology

In this research, the first-order nonlinear ordinary differential equations for the condenser and each evaporator are solved simultaneously through MATLAB Simulink using the variable-order, variable-step method. First, the steady state response is obtained through the steady model and the results are placed in the required coefficients of the unsteady model. In the unsteady model, all variables are calculated at each time step for each effect, and the suction ratio of the thermal compressor at each time step is adjusted using the pressure values at the last effect and the motive vapor pressure through the ejector evaluation algorithm. To validate the steady and unsteady model of the MED-TVC, the experimental data of Tripoli MED-TVC plant located in Libya [8] have been used which indicates a very good agreement between the present modeling and experimental data.

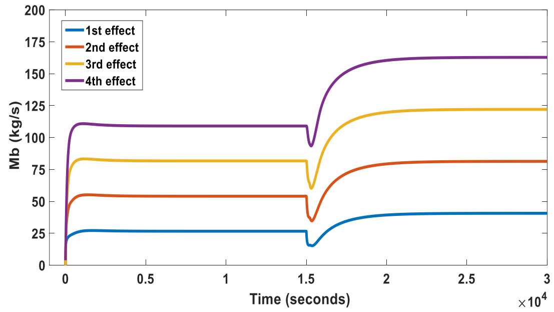

Figure 1. Output Brine mass flow rate changes from all effects

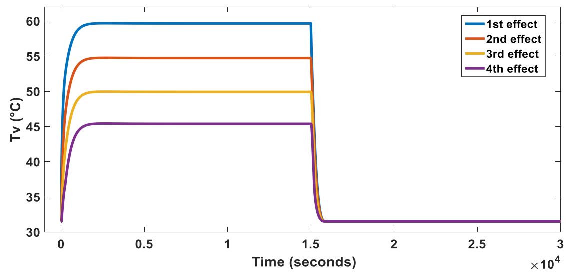

Figure 2. Vapor temperature changes in all effects in mode of on and off

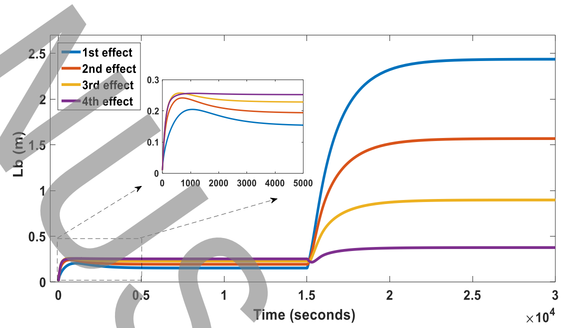

Figure 3. Brine level changes in all effects in mode of on and off

3. Results and Discussion

The desalination plant is simulated in both start-up and shutdown modes, first the system is turned on so that the thermodynamic parameters reach their steady values from the ambient condition, then the ejector motive steam closes after 15000 seconds, so the thermodynamic parameters return to their ambient condition. At the start-up, the heating steam enters the first effect tubes and gradually as the tubes heat up, the feed water begins to evaporate and the steam temperature rises (fig 1), then the generated steam enters the next effect and this process continues until the final effect. At this time, all steam flow and brine flow reach their steady state from zero and the level of brine will increase from zero to its steady state (fig 2, 3).

Then the shutdown occurs and the effects temperature returns to ambient temperature (fig 1). As shown in Figures 2 and 3, during the shutdown, the flow rate and the level of the brine increase in each effect, and the device can face flooding. The reason of this phenomenon is the reaction of the transient state of the system to the decrease of the saturation pressure in the effects and the lack of sufficient pressure for the brine to pass through the orifices. Therefore, the system provides the necessary pressure for the passage of brine flow through the orifices by increasing the brine level in the first effects compared to the last effects.

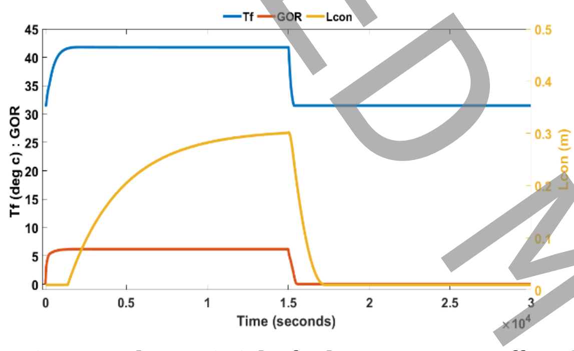

Figure 4. Changes in inlet feed temperature to effects, condenser fluid level and GOR ratio

As shown in Figure 4 in the condenser section, the level of the condensed water, feed water temperature and GOR start to increase with the start-up of the system, and after applying the shutdown, the temperature decreases to ambient temperature and GOR becomes zero. But the level of the condensed water reaches to zero with a delay of 2000 seconds. The reason for this delay is that after applying the shutdown in the system, there is still a small amount of steam left in the effects and the condenser, and enough time is needed for the condenser to drain completely.

4. Conclusions

From MED-TVC simulation during start-up to complete shutdown, the following results are obtained:

In the event of a sudden shutdown in the motive steam, the control system has a limited time (400 seconds) depending on the height of the effect to shut down the entire system without damage to the device, otherwise flooding occurs.

The time required for the device to reach steady state after start-up is longer than the time required for the device to reach ambient mode after shutdown.

Only in the unsteady model is possible to compute the exact level of the brine, and this can help to select the appropriate orifice and tube diameter for the design of the desalination plant, as well as the type of operation of the control valve (according to the control system and Bernoulli equations used for the flow).

5. References

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