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Effect of design parameters on thermodynamic losses of the heat transfer process in LT-MEE desalination plant

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HIGHLIGHTS

- Thermodynamic losses in a large scale LT-MEE desalination plant were investigated.
- Effects of design parameters on the thermodynamic losses were analyzed.
- The operating characteristics of LT-MEE desalination plant were summarized.

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ABSTRACT

Thermodynamic losses caused by the flow resistances and the boiling point elevation (BPE) in low-temperature multi-effect evaporation (LT-MEE) desalination plant were investigated. The purpose is to provide detailed considerations for the design and modeling of LT-MEE process. Design parameters were analyzed to evaluate their effects on thermodynamic losses. Results indicate that on the premise of constant distillate production, as the sequence number of evaporator/condenser increases, each flow resistance decreases first and then increases, while the variation of corresponding temperature depression always performs a rising tendency. With the increase of tube length, the proportion of saturated temperature depression caused by the in-tube condensation flow resistance increases, and that caused by the inter-tube flow resistance decreases. The tube length for the lowest temperature depression occurs when two temperature depressions are in similar proportions. The thermodynamic losses caused by the flow resistances and the BPE account for considerable percentages, especially when under smaller temperature difference. The operating characteristics of LT-MEE desalination plant are summarized based on the analysis.

1. Introduction

In recent years, the shortage of freshwater resources has become a constraint to sustainable socio-economic development with economic development and population growth. The development of desalination technology is an important way to solve the shortage of water resources in coastal areas. Currently, the total installed capacity of desalination plant in the world is about 7.48×10^7 $m^3 \cdot d^{-1}$, and will reach 10^8 $m^3 \cdot d^{-1}$ until 2015 [1]. There are various large-scale commercial desalination technologies [2], such as reverse osmosis (RO), multiple stage flash (MSF) and low temperature multiple effect evaporation (LT-MEE). LT-MEE desalination technology cannot only be coupled with power plant and new energy such as nuclear and solar energy [3–5], but also has the features of high thermal efficiency, high purity water production and stable operation [6]. Therefore, its market share is growing rapidly and the current amount of installed capacity is over 8% of the world's total installed capacity of desalination [7].

The horizontal-tube falling-film evaporator (HTE) has been extensively utilized in LT-MEE desalination system because of significant advantages, such as high heat transfer rates under low flow rate and small temperature difference [8]. Different from general heat exchangers, the LT-MEE desalination plant makes the saturated temperature very sensitive to the variation of corresponding pressure because the unit heat transfer temperature difference is usually between 1.5 °C and 4 °C and its operation is in vacuum condition. Thus, it is very important to understand the effects of thermodynamic losses during the heat transfer process accurately to analyze and design the desalination plant. A lot of simulations and analysis on the LT-MEE desalination process have been carried out so far, but the thermodynamic losses in adopted models have received insufficient attention and have not been particularly discussed. Darwish et al. [9] and Kamali et al. [10,11] developed a simplified model of MEE, which ignored the flow resistance loss in the process and considered the boiling point elevation (BPE) as a constant. Aly et al. [12] developed a model of MEE with parallel feed, which

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assumed that the heat transfer coefficient and thermodynamic loss in each effect of evaporator/condenser were constant and ignored the flashing of the distillate. The model developed by El-Dessouky et al. [13] was one of the most comprehensive methods for the thermal calculation of LT-MEE desalination plant. The model considered the effects of BPE, the flow resistance of the steam flowing across the demister, the transmission channel and the condensation process. However, the inter-tube flow resistance was ignored and some adopted correlations were not suitable for the HTE in LT-MEE desalination plant.

In this paper, based on the experimental correlations corresponding to the HTE in LT-MEE desalination plant, the distributions of various thermodynamic losses including flow resistances and BPE in the whole plant have been presented. It shows a clear image of the thermodynamic losses in the evaporator/condenser. The design and operating variables were analyzed to perform their effects on the thermodynamic losses. The theory on the operating characteristics of LT-MEE desalination plant was summarized.

2. Thermodynamic losses in LT-MEE desalination plant

As shown in Fig. 1(a), LT-MEE desalination plant contains a series of evaporators/condensers and an end condenser. Other pieces of auxiliary equipment include brine and distillate expelling facilities, a seawater feeding facility, distillate flashing boxes and a venting system. The parallel feed mode was adopted for the analysis.

The seawater is fed to the end condenser to cool the steam generated in the last effect of evaporator/condenser. The seawater is divided into two parts: one part as the feed seawater is conducted to the system; the other part as the cooling water is discharged to the sea. The feed seawater is equally allocated to each effect of evaporator/condenser in the parallel feed mode, and then evenly sprayed onto the top row of heat transfer tubes by liquid distributor. The seawater falls in the form of thin film along the tube bundle.

In the first effect evaporator/condenser, the heating steam from an external heat source condensates inside the tube and supplies heat for the seawater preheating and partial evaporating. The condensate in the first effect evaporator/condenser either returns to the boiler or flows to the distillate evaporator/condenser flashing box, which depends on the system configuration. At the same time, a portion of vapor is generated because the feed seawater is heated to saturated state by the heating steam inside tubes during the falling film flow process. After that, the generated vapor flows into the heat transfer tubes of the next effect evaporator/condenser as the heating steam through the demister to remove entrained seawater droplets. The remaining brine falls to the bottom of the tank and, afterwards, flows to the brine space of the next effect evaporator/condenser with flashing because of the non-equilibrium allowance. The process repeats in subsequent effect evaporator/condensers and the brine is discharged at the last effect evaporator/condenser. The vapor generated in the last evaporator/condenser condenses in the end condenser. The condensates from the last condensate box and the end condenser are the product of desalination plant.

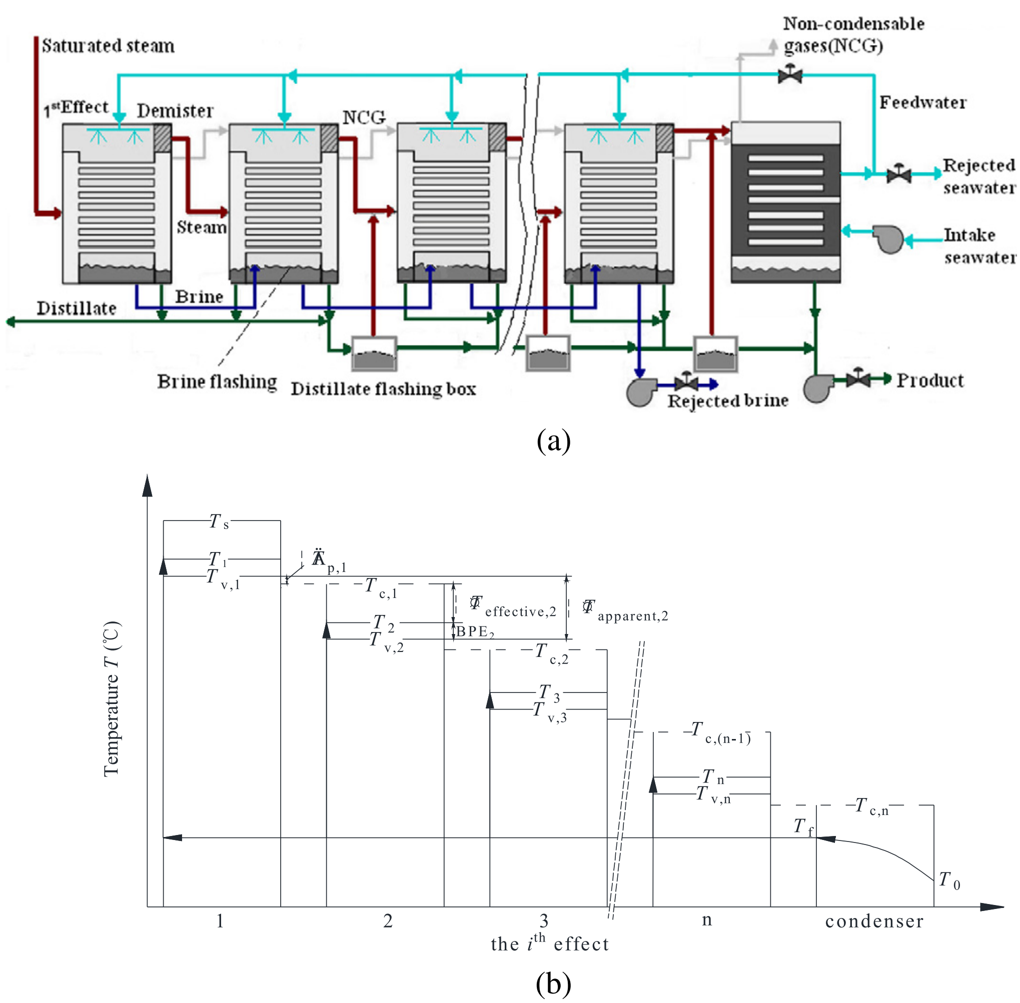

Fig. 1. (a) Schematic of LT-MEE desalination system; (b) temperature distribution in adjacent effects.