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Analysis of plate multi-effect distillation system coupled with thermal power generating unit

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HIGHLIGHTS

- The practical potential of plate exchanger as evaporator in MED seawater desalination system.
- Physico-mathematical model is developed for plate MED system coupled with thermal power generating unit.
- The design of MED system with different plate evaporators is conducted and compared with tubular system.
- Off-design performance of plate MED system is obtained under various conditions of feed brine and extracting vapor from turbine.

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ABSTRACT

In order to explore the practical potential of plate exchanger as evaporator in multi-effect distillation (MED) system, the physico-mathematical model is established for a plate MED system coupled with thermal power generating unit. A MED seawater desalination system with shell and tube evaporator in operation producing freshwater 10,000 ton/day is selected as comparison. The system design with different types of plate evaporators and off-design operating performance are conducted. The results indicate that the overall area can be significantly reduced with plate evaporator compared with that of shell and tube evaporator. The plate MED system can achieve a greater gain of ratio (GOR) than that of original tubular system by selecting suitable entrainment ratio of the last effect. The performance of the plate MED system can be improved by reducing the length of single plate of evaporators, for more channels with shorter plate can enhance heat transfer in evaporator and restrain the boiling point evaluation of evaporating brine. Influences of inlet temperature and flow rate of feed brine, flow rate of extracting source vapor from steam turbine under off-design conditions on the performance of plate MED system are investigated either. The investigations may provide a reference for the application of plate MED technology coupled with waste heat utilization of thermal power generating unit.

1. Introduction

The energy consumption is the core portion of the cost of water production by large-scale seawater desalination. On the other hand, thermal power generation is one of the most efficient technologies of fossil fuel utilization at present. Nevertheless, most of the energy is exhausted into the environment as the low-grade waste heat during thermal power generation, leading to tremendous energy waste. It has been found that the energy demand for seawater desalination and the residual heat of thermal power plant can be complementary, and the energy efficiency can be increased from 40% to 60% by combined water and electric power generation [1].

Dominating thermal technologies of seawater desalination include that of multi-stage flash (MSF) and multi-effect distillation (MED). The research of MSF technology at present is mainly focus on the further improvement of system performance and connection with reverse osmosis (RO) technology, etc. El-Dessouky et al. [2] proposed a new structure of multi-stage flash (MSF) system for reducing the residual heat taken away by seawater, increasing the utilization of the energy. El Din et al. [3] discussed some principles of MSF systems design to avoid or reduce the effects of corrosion, improve efficiency and performance. Maheshwari et al. [4] indicated that the combine of multi-stage flash (MSF) and reverse osmosis (RO) is an effective way to improve power plant operating efficiency and reduce energy consumption. Recently, multi-effect

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Nomenclature

A	heat transfer area, m^2
c_p	heat capacity at constant pressure, J/(kg K)
D_0	flow rate of extracting vapor from turbine, kg/s (or t/h)
h	heat transfer coefficient, W/(m^2 K)
K	overall heat transfer coefficient, W/(m^2 K)
L	the width of plate, m
M	mass flow rate, kg/s (or t/h)
$\dot{m}$	mass flow rate, kg/s (or t/h)
R_f	fouling resistance, m^2 K/W
T	temperature, K
ΔT_m	logarithmic mean temperature difference
x	flash rate
z	length, m
γ	latent heat of vaporization, J/kg
δ	thickness, m
λ	thermal conductivity, W/(m K)

Subscript

B	brine
con	condensation
e	effect
eva	evaporation
i	*i*th effect
in	inlet
p	plate
pre	preheat
s	saturation
V	vapor
W	water

distillation (MED) has become a priority because of its high gain of ratio (GOR) compared with MSF [5]. The techno-economic analysis has revealed that the multi-effect distillation (MED) with reverse osmosis (RO) (MED-RO) technology has superiority on improving energy efficiency and reducing freshwater cost while integrating seawater desalination with gas-steam combined cycle [1,6]. And the multi-effect distillation coupled with the low-grade heat source of thermal power plant has higher economical efficiency than that by reverse osmosis [7].

Falling film evaporation has a lot of advantages, including that of short contact time, high heat flux, low static pressure loss and low temperature difference of heat transfer [8,9]. These features endow MED seawater desalination with excellent water production performance. The inherent defect of MED is that the heating and evaporation of seawater are at the same process, which leads to fouling on seawater heat transfer surface. Low temperature MED (LT-MED) with medium top brine temperature (TBT) lower than 70 °C can suppress fouling to some extent. However, while combining MED desalination and thermal power generating unit, significant exergy loss by throttling can be resulted in order to reduce the high temperature and pressure of extracting source steam from turbine. At the same time, the increase of effects is limited by the top brine temperature, and hence the gain of ratio (GOR) of seawater desalination is reduced. These contradictions become the main technical bottlenecks for the improvement of seawater desalination performance by MED approach.

Plate heat exchanger uses the corrugated plate as the main heat transfer element. As shown in Fig. 1, the heat exchanger is made up by series of plates side by side. Cold and hot fluids flow in different sides of the plate to complete heat exchange [10]. Plate heat exchanger has been widely used in the corrosive operating environment with high temperature and high pressure. High specific surface area endows the plate heat exchanger with high heat transfer performance, because of which, the temperature difference of plate heat exchanger used as seawater evaporator can be small enough and hence inhibits brine fouling to some extent [10,11]. Combing plate falling film evaporator with technique of suitable seawater pretreatment and metal material surface process, high-temperature multi-effect distillation technology coupled with coal-fired power generating unit may be of great potential [12–15].

In the present study, base on the design parameters of an operating low temperature MED (LT-MED) seawater desalination system coupled with 2 × 300 MW coal-fired power generating units, physico-mathematical model with plate falling film evaporator is established for the optimization of the seawater desalination system and operating performance analysis under off-design conditions. The results are compared with the performance of the original seawater desalination system with shell and tube evaporators. The investigations may provide a reference for the design of the multi-effect distillation system with plate evaporators coupled with waste heat utilization of thermal power generating unit.

2. Physico-mathematical model

Fig. 2 shows the device flowchart of LT-MED seawater desalination system original designed by SIDEM Co. The system with no preheater uses the process of spray falling brine film distillation outside the horizontal tube bundles. It includes four effects, in which the temperature and pressure decrease successively from left to right, as shown in Fig. 2. The heat source of the first effect contains the vapor extraction from steam turbine of power generating unit and the vapor ejector from the last effect. The pressure is 0.55 MPa and the temperature is 320 °C of the vapor extracted from the turbine. The brine film is heated to the top temperature in each effect and releases secondary vapor, which condenses inside the horizontal tube bundles for heating the brine in next effect. Secondary vapor condenses to produce freshwater. Producing water in each effect flows to flash tank with lower pressure, which flashes

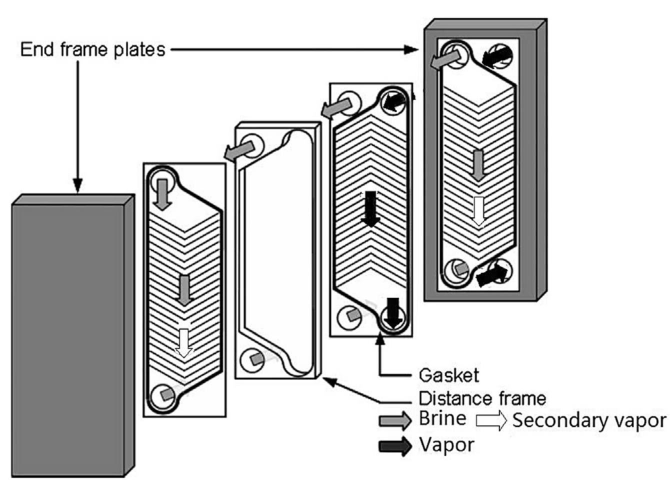

Fig. 1. Schematic diagram of the plate heat exchanger.