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Performance study on a mechanical vapor compression evaporation system driven by Roots compressor

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ABSTRACT

The thermal performance of a mechanical vapor compression (MVC) system was investigated. This work presented describes the mathematical and experimental study of the MVC system, focusing on mathematical models that were established based on the energy and mass balance equations as well as correlations of the thermophysical properties and heat-transfer coefficients. As a result, a MVC experimental platform, which can handle 100 kg/h evaporation rate was designed, with a falling film evaporator heater area of 10 m^2. A Root compressor was selected as a vapor compressor, utilizing a power of 18 kw. This paper has studied the feed temperature, evaporation pressure, compressor speed and vapor pressure increment effect on evaporation rate, Specific Moisture Extraction Rate (SMER) and power consumption, as to evaluate the MVC system performance. It was found that feed temperature reach the optimal conditions for saturated liquids. Evaporation pressure should be controlled in low level to ensure that SMER can reach high values and it was furthermore observed that the compressor speed determines the evaporation rate whilst SMER variations showed very subtle effects.

1. Introduction

In recent decades, the world has faced a resource shortage of both water and energy, which can be ascribed to the poor utilization of production methods with high energy consumption. Evaporation, which is a process of high energy consuming is one of the most important unit operation stages in chemical production processes and is widely used in desalination of seawater [1–3], wastewater treatment [4,5], Fermentation industry [6], Chemical Engineering [7–9] as well as other industries [10].

Several studies have been reported in the literature regarding the system design and performance evaluation, with Ettouney et al. [11] and Mabrouk et al. [12] used a MVR compressor as an external heating source in a single-effect vacuum evaporator. In turn, Nafey et al. [13] combined an MVR compressor with a vacuum evaporator to produce an external heating source. The MVR technology has also been applied to recover wastewater in an oil production factory. Ling et al. [7] proposed a double-effect MVR system to treat waste water, and the minimum specific power consumption was obtained when the emission concentration of the first effect is approximately 32%. Shen et al. [14] reported that MVC systems using water-injected twin screw compressors were a very promising technology for a water product capacity of less than 600 m^3/d. Pang et al. [15] examines the operating characteristics of MVR under low evaporation conditions. Mathematical models of the MVC system have been widely reported. The study by Darwish [16] included a simple mathematical model that provided a useful and rapid estimation of various system properties, such as thermal vapor compression (TVC) and mechanical vapor compression (MVC). The models by Aybar et al. [17,18] provided an evaluation of the performance, with a demonstrated 35.4% reduction based on models of the heat transfer and product water costs. A great deal of research has been done on MVC evaporation systems in recent years. However, it has not been widely applied in industry due to various technical barriers. The main reason is how to control the MVC node parameters to maintain the stability of system operation and better energy saving? Meanwhile, performance study on a MVC evaporation system driven by Roots compressor is less. In this paper, a MVC experimental platform is established and the performance of MVC system is studied from the point of industrial operation. Methods for optimizing MVC evaporation performance is proposed.

Improvement in energy efficiency is an important part in the field of energy systems research, given the financial consequences implicated. The defining characteristic of MVC is the re-use of the energy of vapor produced in the evaporator or flasher [5,19]. The advantages of MVC can be summarized as follows: (1) high

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thermodynamic efficiency; (2) no requirement for an external heat source or condenser and (3) low-temperature operation. In this study, the factors that influence the mechanical vapor compression system were discussed more comprehensively.

2. System description and process modeling

Mechanical Vapor Compression (MVC) denotes an efficient and energy-saving evaporation technology along single-effect evaporation, multi-effect evaporation and Thermal Vapor Compression (TVC). The principle of MVC is as follow: the feed enters the evaporator after being pre-heated, secondary vapors are generated upon heat transfer between vapor and feed. These vapors would then enter the liquid-gas separator for further purification. The pure secondary vapors are sucked by the Roots Compressor, where compression increases the pressure and temperature of the vapor. After that, the secondary vapors once saturated, enter the evaporator to replace the fresh vapor. Therefore, only a small amount of fresh steam is required at the start-up stage of system. The potential of the secondary vapors is used fully, thus achieving energy saving and emission reduction. The flow pattern and experiment platform of MVC are illustrated in Figs. 1 and 2.

During the modeling, the following considerations were adopted: (1) Except for the startup period, the system works under steady-state conditions. (2) The operating medium is water without any concentration change. (3) The leakage and dissipation heat of the system are negligible. (4) No recycle is considered. (5) The concentrated water leaving the shell sides of both heaters is in the saturated liquid phase.

The MVC model includes mass and energy balance equations for the evaporator, compressor and pre-heater. It also incorporates, heat transfer equations to determine the heat transfer areas of the evaporator and pre-heaters, and a compressor model to determine the compressor power.

The mass balances are given by Eqs. (1) and (2) below:

$$F_{in} = W_{in} + W_{out} \tag{1}$$

where F_{in} denotes the feed mass flow rate, W_{in} represents the secondary vapor mass flow rate formed in evaporator and W_{out} is the mass flow rate of concentrate. with the subscripts in/out representing the feed inlet/outlet respectively.

The total vapor mass flow rate can be expressed as illustrated in Eq. (2).

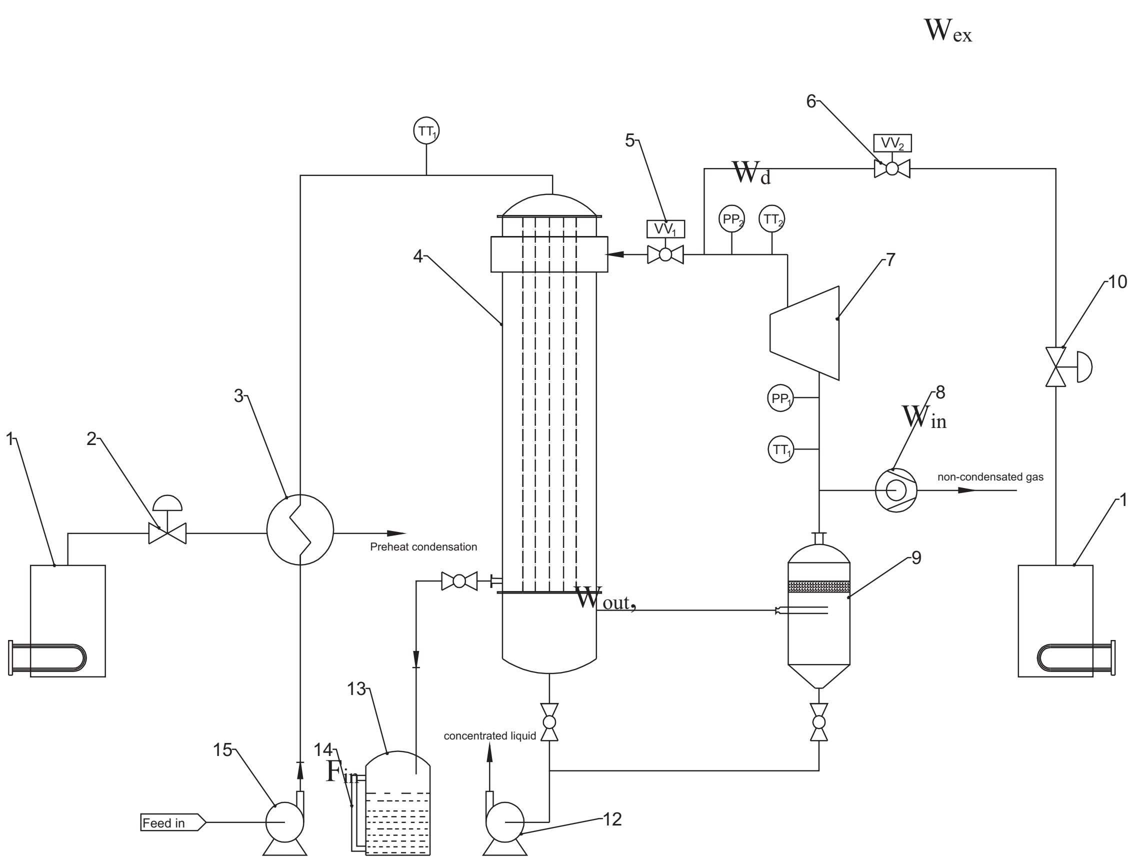
$$W_d = W_{in} + W_{ex} \tag{2}$$

where W_d and W_{ex} denote the total vapor mass flow rate which used for heat exchange and the additional supplement vapor mass flow rate from steam generator respectively.

The calculation of energy balance for the falling film evaporation can be calculated using the following Eq. (3):

$$Q_e = W_d(H_{vd} - H_{vs}) = F_{in}C_{pd}(t_{Tb} - t_{Tf}) + W_{in}\lambda_{Tv} + Q_L \tag{3}$$

where Q_e and H_{vd} represent the rate of heat transfer and the superheated steam enthalpy from the compressor discharge respectively.



1, 11.Steam generator 2, 10. Motorized valve 3.Preheater 4.Falling film evaporator 5,6. Vortex flowmeter 7.Roots compressor 8.Vacumme pump 9.liquid-gas separator 12, 15. Centrifugal pumps 13. Condensate tank 14. Liquid-level meter

Fig. 1. schematic diagram of the MVC system.