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Performance of thermal vapor compression

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HIGHLIGHTS

- Performance of TVC device has been carried out.
- The performance is represented in graphical and mathematical forms.
- The model presents a new form of Power's Chart.

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ABSTRACT

The choice of the steam jet ejector system, which transforms the thermal energy of motive steam, will primarily depend on the final vacuum to be achieved. The net result of these energy transformations is an increase of the absolute pressure of the mixture on discharge to several times the pressure at which it entered the ejector inlet. A new approach of mathematical correlations performance of thermal vapor compressor (TVC) is presented. The performance of TVC is studied. The results of the mathematical model of TVC mixing ratios and performance diagram are very close approach to the Power's lines.

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1. Introduction

The steam jet ejector or thermal vapor compression is a key system to increase the performance of thermal desalination processes such as multiple effect distillation (MED) and multi stage flash (MSF). Different desalination technologies have been commercially used including: 1) thermal technologies such as Multi Stage Flash (MSF) and Multiple Effect Distillation (MED); and 2) Membrane Technologies such as Sea Water Reverse Osmosis (SWRO), Brackish Water Reverse Osmosis (BWRO) and Electro Dialysis or Electro Dialysis Reverse (ED/EDR). Although RO currently represents the leading world market technology, mainly due to its lower specific energy consumption, however, thermal desalination (MSF and MED) still represents the main technology in the Gulf Council Countries (GCC) countries. This is mainly due to the Gulf water poor quality known as 4H: High salinity, High Turbidity, High temperature and High marine life [1].

Darwish [2,3] mentioned that the real potential of the vapor compression systems lies in its ability to increase the unit capacity and solve the problems associated with its maintenance. The gain output ratio of four effects MED-TVC is very close to that of 11 effects MED and 24 stages MSF desalting systems. Nevertheless, the MSF and MED are supplied with steam at low pressure, while the TVC requires high-pressure steam. The performance of the TVC system increases at higher motive steam pressures [4].

El-Dessouky [5,6] mentioned that a novel MSF configuration, which is based on thermal vapor compression, is proposed and evaluated as a function of the vapor compression mode and the operating conditions. Analysis of the results shows that the thermal vapor compression enhances the performance of the MSF system as a result of increase in the performance ratio and reduction in the specific flow rate of cooling water and the specific heat transfer area. Vapor compression from stages operating at higher temperatures in the heat recovery section gives higher performance ratios than for vapor compression from the heat rejection section. The specific heat transfer area for the vapor compression mode from the heat recovery section gives lower specific heat transfer area from the heat rejection section. The pipe diameter for the motive steam in MSF–TVC is lower than the diameter for the heating steam by an average of 60%.

2. Thermal analysis of TVC system

An ejector has two inlets: one to admit the motive steam (inlet 1), and the other to admit the vapor to be evacuated (inlet 2), as shown in Fig. 1. Motive steam, at high pressure and low velocity, enters the inlet 1 and exits the steam nozzle at design suction pressure and

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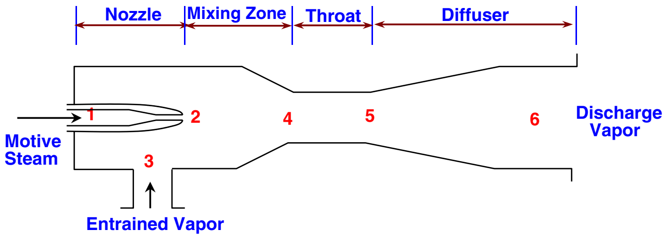

Fig. 1. Different processes in steam jet ejector.

supersonic velocity, entraining the vapor to be evacuated into the suction chamber through inlet 2. The nozzle throat diameter controls the amount of steam to pass through the nozzle at a given pressure and temperature. The entrained vapor flow and the motive steam flow mix while they move through the converging section of the diffuser, increasing pressure and reducing velocity. The velocity of this mixture is supersonic and the decreasing cross sectional area creates an overall decrease in pressure and an increase in velocity. The motive steam slows down and the inlet gas stream picks up speed and, at some point in the throat of the diffuser, their combined flow reaches the exact speed of sound. A stationary, sonic-speed shock wave forms there and produces a sharp rise in absolute pressure. The shock wave in the diffuser throat changes the velocity from supersonic to sub-sonic. Then, in the diverging section of the diffuser, the velocity of the mixture is sub-sonic and the increasing cross sectional area increases the pressure but further decreases the velocity [7].

The first requirement is to estimate the performance of TVC by answering questions such as, how much motive steam is required or what suction pressure or discharge pressure can be created. Power [8] introduced a graphical method to calculate the value of motive steam and entrained vapor as shown in Fig. 2 based on published data and it has been smoothed considerably. It is generally accurate to within 20% over the range of compression ratios up to 5, expansion ratios up to 1000, and motive/load (mixing ratios) ratios from 0.25 to 5 [8].

Fig. 2 is redrawn into scaling diagram as shown in Fig. 3 and written in equations form in Table 1. The mixing ratio ($M_r = M_{ms}/M_{ent}$) depends on the compression ratio ($C_r = P_d/P_s$) and expansion ratio ($E_r = P_{ms}/P_s$). The M_r as function of the compression ratio and expansion ratio can be calculated as cleared in Eqs. (1), (2) and (3) as follows:

$$\begin{aligned} M_r = {} & -1.93422581403321 + 2.152523807931 * C_r + 113.490932154749/E_r \\ & -0.522221061154973 * C_r{}^{\wedge}2 - 14735.9653361836/(E_r{}^{\wedge}2) \\ & -31.8519701023059 * C_r/E_r + 0.047506773195604 * C_r{}^{\wedge}3 \\ & +900786.044551787/(E_r{}^{\wedge}3) - 495.581541338594 * C_r/(E_r{}^{\wedge}2) \\ & +10.0251265889018 * (C_r{}^{\wedge}2)/E_r, \qquad \textit{if } E_r \geq 100 \end{aligned} \tag{1}$$

$$\begin{aligned} M_r = {} & -3.20842210618164 + 3.93335312452389 * C_r + 27.2360043794853/E_r \\ & -1.19206948677452 * C_r{}^{\wedge}2 - 141.423288255019/E_r{}^{\wedge}2 \\ & -22.5455184193569 * C_r/E_r + 0.12581268762412 * C_r{}^{\wedge}3 \\ & +348.506574704109/E_r{}^{\wedge}3 + 41.7960967174647 * C_r/E_r{}^{\wedge}2 \\ & +6.43992939366982 * C_r{}^{\wedge}2/E_r, \qquad \textit{if } 100 \geq E_r \geq 10 \end{aligned} \tag{2}$$

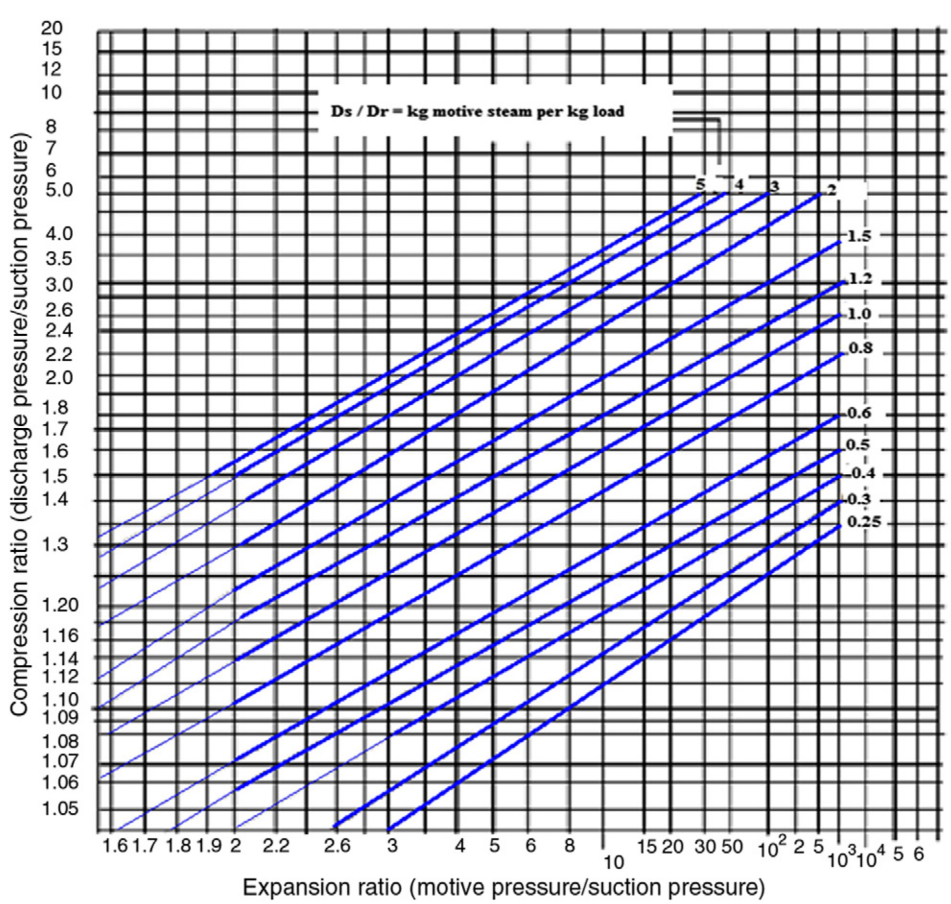

Fig. 2. Entrained ratio for different compression and expansion ratio [8].