

## CFD analysis on the performance of steam ejector in multi effect desalination process

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**ABSTRACT:** The purpose of this paper is to study the influence of geometry parameter on the ejector performance. The CFD results were verified with available experimental data. Flow field analysis was also carried out in this study. Variation on the geometry parameter was made by varying the angle of converging duct those are 0.5°, 2.0° and 3.5°. The converging duct with an angle of 0.5° gives the highest value of entrainment ratio that is 0.941. Furthermore, from this study it can be concluded that the entrainment ratio decreases with respect to the increase of angle of convergence duct.

**Key words:** CFD, TVC, desalination, steam, ejector

### Nomenclature

$\dot{m}_d$  discharge mass flow rate,  $kg/s$

$\dot{m}_m$  motive mass flow rate,  $kg/s$

$\dot{m}_s$  suction mass flow rate,  $kg/s$

$\dot{m}_g$  gross distillate production,  $kg/s$

P Pressure, *bar*

### Greek letters

$\alpha$  angle of converging duct

$\omega$  entrainment ratio

### 1. Introduction

Owing to its enormous capacity, MSF (multi stage flashing) types are the most of the desalination facilities installed in the Middle

East during 60s and 70s. Unfortunately, MSF needs a huge specific energy consumption rate that contradicting the merit of MSF in producing fresh water. Compare to MSF, by employing TVC (thermal vapor compressor) makes MED (multi effect desalination) more energy-efficient and competitive and the recent development of the large capacity MED over 10 MIGD (million imperial gallon per day) inspired the great interest in MED process. Moreover, as the lifetime of the mass-produced MSF in the Middle East is coming to the end, the demand for MED plant is expected to rise. TVC is a dominant element governing total process of MED. The accurate prediction of the TVC performance promotes the reliability of the process and the enhancement of the TVC entraining efficiency improves the performance of MED significantly by reducing the amount of motive steam. TVC is a kind of typical steam ejector which entrains low pressure steam using the shear forces of

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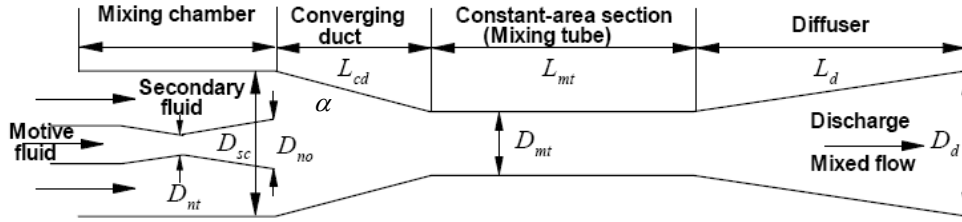


Fig. 1. Schematic diagram of conventional ejector.

supersonic flow made by a small supersonic nozzle mounted in the center of a large converging-diverging duct. Fig. 1 shows the schematic diagram of conventional ejector.

Many researchers [1–3] have presented the various ejector analysis models applying the one-dimensional gas dynamics equations. Since these analysis models are based on the inviscid and isotropic flow assumption, many empirical coefficients are applied to compensate the loss by friction and mixing. Moreover, the assumption that the flow choking occurs in hypothetical throat formed by the primary flow and ejector wall, caused the premixing of the primary flow and the suction flow to be overlooked and limited the accuracy of ejector analysis.

Recently, the accurate design procedure based on the numerical analysis has been developed. Riffat [4] discovered the optimal position of the primary nozzle through the parametric study, considering its axial position as a major factor of performance.

In this study, CFD (computational fluid dynamics) analysis based on the finite volume method was employed to investigate the influence of angle of converging duct on the ejector performance. The using of CFD method allowed not only the accurate prediction of the performance but also the identification of the shock/expansion wave, the circulation zone, and the pressure distribution of the axial direction. Verification with experimental data also carried out at various operational conditions. The final objective of this study is to obtained optimum

design of ejector employed in MED.

## 2. Multi effect desalination and thermal vapor compressor

The multi effect thermal vapor compression seawater desalination process in its simplest form is illustrated schematically in Fig. 2. The MED plant has 3 evaporation effects and sucks low pressure steam from 3rd effect. In MED plant, seawater is sprayed into each evaporation effect and flows down as a liquid film along the outside wall of the tube horizontally installed in the effect. The hot steam (motive steam) that is externally provided from a boiler or power plant, flows into the tube inside, evaporates the seawater film flowing down on the tube outside walls, and is simultaneously condensed in the tube inside. The steam evaporated from seawater like the former effect. The performance of MED plant is represented by GOR (gained output ratio) defined by the ratio of gross fresh water production to the motive steam supplied externally, as follows[5]:

$$GOR = \frac{\dot{m}_g (\approx n \times \dot{m}_g)}{\dot{m}_m} \quad (1)$$

Therefore, the entrainment ratio of  $(\omega = \dot{m}_g / \dot{m}_m)$  TVC is directly related with GOR of MED plant. Here,  $\dot{m}_g$  represents the gross distillate production,  $\dot{m}_g (= \dot{m}_m + \dot{m}_s = (1 + \omega) \cdot \dot{m}_m)$  the mass flow rate of the discharged steam of TVC, and  $n$  the number of effects of MED. The fresh water production depends on the number of effects and the discharge flow rate

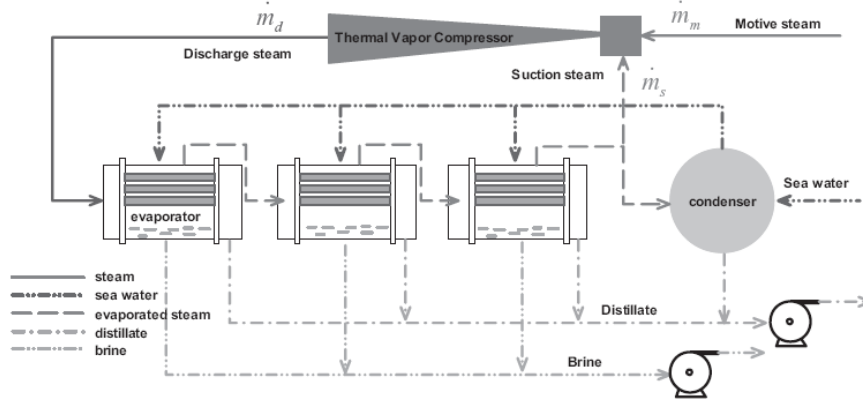


Fig. 2. Schematic diagram of MED plant with 3 evaporator effects. TVC sucking steam from 3rd effect.

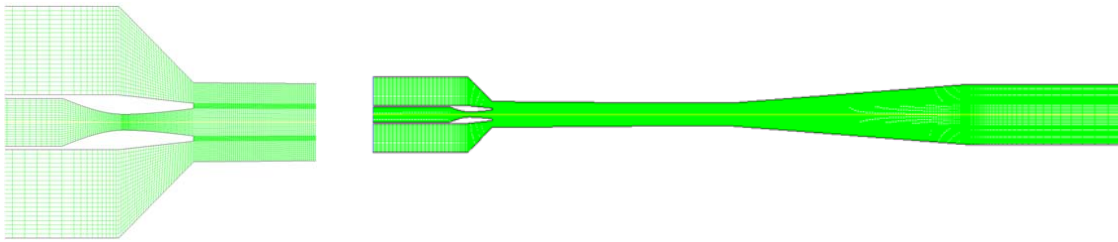


Fig. 3. Calculation domain and grid structure of the ejector CFD model.

of TVC as discribed in Equation (1). In order to improve GOR as well satisfy the required fresh water production, the high efficiency TVC that can save the motive steam and increase the amount of suction steam, should be designed.

### 3. Computational method

The problem under investigation here involved the supersonic flow inside the flow passage of steam ejector. In order to simulate this particular situation, Gambit and FLUENT were used as grid generator and the CFD solver, respectively.

Gambit was used to create the calculation domain and grid elements of the model. The mesh and model was created in a two dimension (2-D) domain. However, the axisymetric solver was applied and therefore, the three dimensional effect (3-D) was taken

into account in the simulation. The mesh was made of 24,000 structured quadrilateral elements, as shown in Fig. 3.

For an axisymetric turbulent compressible flow, the governing equations of continuity, momentum and energy are solved simultaneously with the constraint, the ideal gas law. The standard  $k-\varepsilon$  model was selected to model the turbulent viscosity with applying "coupled-implicit" solver. The near wall treatment was left as the "standard wall function", which gave reasonably accurate results for the wall bounded with very high Reynolds number flow.

Boundary conditions of two faces entering a primary nozzle and ejector were set as pressure-inlet, whilst the one leaving ejector was set as pressure-outlet. These parameter were varied with the same operating condition as was conducted in the experiments.

Table 1. Comparison of Entrainment Ratio between Experimental and CFD Results

$p_1$ (bar) (motive)	$p_2$ (bar) (suction)	$p_3$ (bar) (discharge)	$m_1$ (kg/s)		$m_2$ (kg/s)		$m_3$ (kg/s)		$\omega$		error (%)			
			exp	CFD	exp	CFD	exp	CFD	exp	CFD	$m_1$	$m_2$	$m_3$	$\omega$
2.67	0.16	0.29	0.1	0.099	0.1	0.101	0.200	0.200	1.000	1.020	-1.0	1.0	0.0	2.0
2.67	0.146	0.205	0.1	0.1	0.086	0.089	0.186	0.189	0.860	0.890	0.0	3.5	-1.6	3.5
2.67	0.135	0.174	0.1	0.099	0.083	0.087	0.183	0.186	0.830	0.879	-1.0	4.8	-1.6	5.9
2.67	0.124	0.155	0.1	0.099	0.078	0.081	0.172	0.180	0.780	0.818	-1.0	3.8	-4.7	4.9

The values of each boundary were assigned as the saturation properties (temperature and pressure) each operating condition. Since the velocity of the flow entering and leaving the domain was thought to be relatively small compared with the supersonic speed during the flow process of the ejector; there was no difference between an input of the stagnation pressure and static pressure.

#### 4. Results and discussion

Before getting into discussion on the influence of design parameter on the performance of ejector, the CFD results is verified to the experimental data available firstly. Table 1 shows the comparison of entrainment ratio between experimental and CFD results for various suction and discharge pressures at a fixed motive pressure. It is seen that the discrepancy of the entrainment ratio is within 6%. It can be said that the CFD results agree well with experimental observations. The quantitatively good agreement confirms that the present CFD modeling is sufficiently accurate in simulating the compressible mixing flow.

Fig. 4 illustrates the static pressure and velocity magnitude distribution on the centerline of base ejector. The distributions were taken at operating condition where  $P_1$ ,  $P_2$  and  $P_3$  at 2.67, 0.163 and 0.29 bars absolute respectively. From this figure, it can be seen that a series of shock waves occur inside the mixing tube, starting from converging to constant area mixing tube. The region where the series of shocks occurs is known as a shock train region. These shock waves consist of normal and/or oblique shock and involving a pressure rise.

Fig. 5 presents the influence of angle of converging duct on the pressure distribution along the centerline of the ejector, plotted from the primary nozzle outlet to the diffuser outlet. The increase of converging angle affects on the increase of static pressure field inside of mixing duct. However, the outlet pressure of diffuser is remains the same. In this condition, the motive suction and discharge pressures are the same as the operating condition of base ejector.

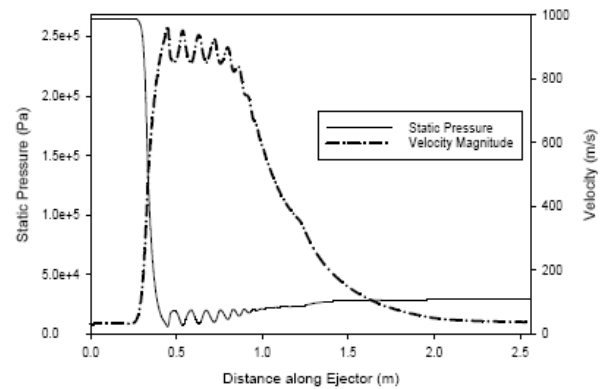


Fig. 4. Static pressure and velocity magnitude distribution along the centerline of the ejector.

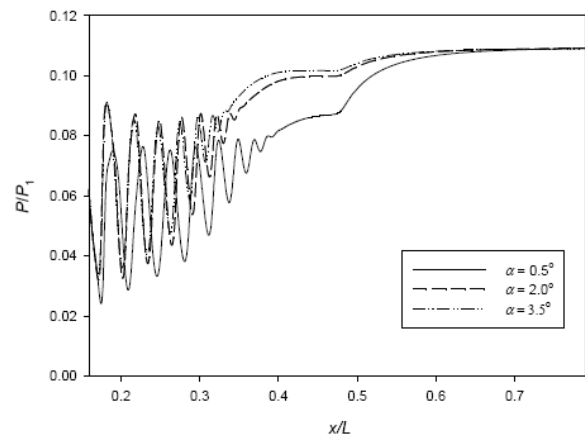


Fig. 5. Axial static pressure distribution. Effect of converging angle of mixing tube.

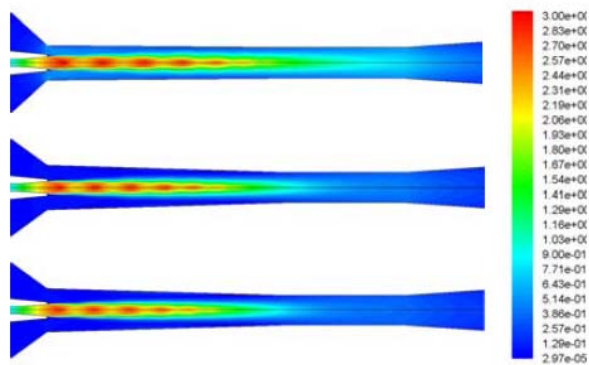


Fig. 6. Filled contours of Mach number.

Fig. 6 illustrates the contour of Mach number and shock waves phenomena inside the converging duct to mixing tube. It is seen that the length of shock train region is influenced by the angle of converging duct. In this research, the longest is at  $\alpha=0.5^\circ$  and the shortest is at  $\alpha=3.5^\circ$ .

The performance of ejector is determined by the entrainment ratio and compression ratio ( $P_3/P_2$ ), where  $P_3$  is the statics pressure of the discharge and  $P_2$  the suction pressure.

Depending on the cases it is necessary to maximize one of them or to optimize their combination. In this research, the task is to maximize the entrainment ratio with the shape variables provided the mass flow rate of motive steam and compression ratios remains constant. Both motive and suction steams are assumed to be saturated. The stagnation pressure of motive and suction steams are constants at 2.66 and 0.163 bar, respectively. The discharge pressure is 0.25 bar. The converging angle ( $\alpha$ ) of mixing tube was set varies at  $0.5^\circ$ ,  $2.0^\circ$  and  $3.5^\circ$ . Fig. 7 shows the entrainment ratio for various models of ejector. It is observed that the entrainment ratio is influenced by the angle of converging duct. Ejector with  $\alpha=0.5^\circ$  gives the highest value of  $\omega$  and then decreases with respect to the increase of converging angle. It is because the converging angle has significant influence on the area of hypothetical throat, consequently the entrainment property. By increasing the converging angle, it means increasing the area

between jet mixing layer and tube wall (hypothetical throat). Consequently, this 'enlarged' area produces low velocity and increasing pressure, an adverse gradient. If the increasing pressure is too large, adverse gradient is excessive and the boundary layer will separate at one or both walls, with backflow, increased losses resulting in the decrease of suction flow. Fig. 8 illustrates the separation condition occurs on the ejector with larger converging angle.

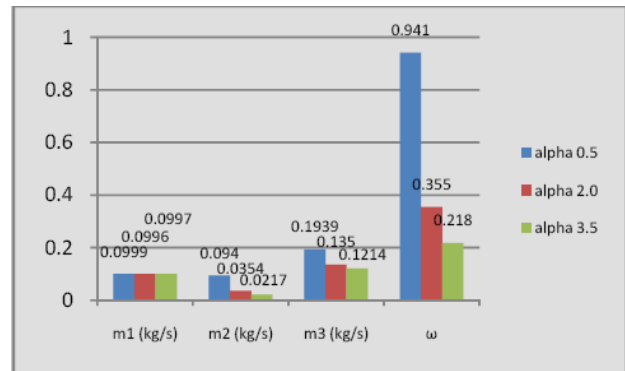


Fig. 7. Comparisons of mass flow rate and entrainment ratio for various convergence angles.

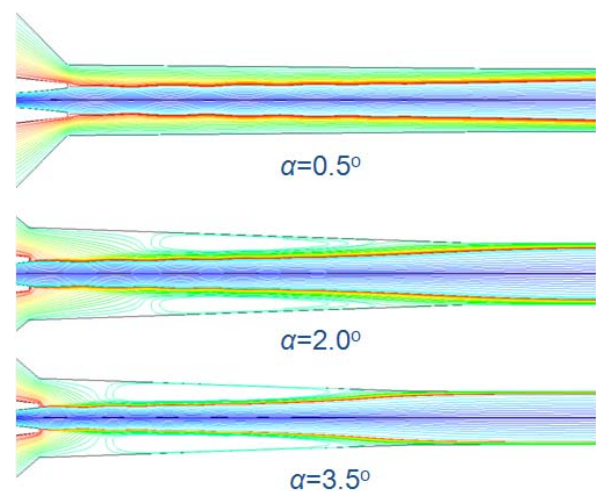


Fig. 8. Contour of path lines. Circulation occurs on the convergence angle of  $\alpha=2.0^\circ$  and  $\alpha=3.5^\circ$ .

## 5. Conclusion

The CFD analysis was performed for the supersonic flow in the constant-pressure mixing

ejector. The CFD result was validated with experimental data. The discrepancies are within 6%. From this validation, it can be concluded that CFD simulation has a good agreement with experimental results. The simulation was continued to investigate the influence of angle of converging duct, on the ejector performance. In this study, the mixing tube with converging angle of  $0.5^\circ$  gives the highest value of entrainment ratio that is 0.941. Furthermore, from this study it can be concluded that the entrainment ratio decreases with respect to the increase of angle of convergence duct. In order to obtain the optimum design of ejector, regarding converging duct, it is still necessary to analyse more models with different angle.

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#### Reference

1. J.C. Dutton and B.F. Carrol, "Optimal supersonic ejector designs", *J. Fluids Eng.*, 108 (1986) 414-420.
2. H. Christensen, "Application of gas-dynamic functions for steam ejector design", *Heat Transfer Eng.*, 4 (1983) 83-105.
3. B.J. Huang, J.M. Chang, C.P. Wang and V.A. Petrenko, "A 1-D analysis of ejector performance", *Int. J. Refrigeration*, 22 (1999) 354-364.
4. S.B. Riffat and S.A. Omer, "CFD modelling and experimental investigation of an ejector refrigeration system using methanol as the working fluid", *Int. J. Energy Res.*, 25 (2001) 115-128.
5. I.S. Park, S.M. Park, and J.S. Ha, "Design and application of thermal vapor compressor for multi-effect desalination plant", *Desalination*, 182 (2005) 199-208.