Design of a steam ejector by co - operating the ESDU design method and CFD simulation

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Abstract

This paper presents the procedure of designing the steam ejector for refrigeration system for air conditioning application. This study focuses on the influence of ejector geometries on its performances under the specified operating condition. The Engineering Sciences Data Unit (ESDU) and the Computational Fluid Dynamic (CFD) are used as the tools for this design. Firstly, the Constant Pressure Mixing (CPM) type ejector is selected and its basic geometries are determined by the Engineering Sciences Data Unit (ESDU). Those are convergent wall angles of 2°, 4°, 6°, 8°, and 10°, divergent wall angles of 3°, 4°, and 5°, and ejector throat lengths of 69, 103, and 137 mm. Then, the flow characteristics of the ejectors flow and performance are simulated by the CFD. The water (R-718b) is used as working fluid (or refrigerant) in this cycle. The simulating conditions are specified, according to the application, as, generator pressure of 5.5 bar, evaporator pressure of 12.3 mbar, and condenser pressure of 75 to 100 mbar. It was found that, the optimum dimensions of the steam ejector for this study are convergent wall angle of 2°, divergent wall angle of 3°, and ejector throat length of 137 mm. These parameters will be used in the experimental test ring and validated in the near future.

Keywords*:* ejector, CFD, ejector refrigeration, air conditioning

1. Introduction

In 1901, the ejector is invented by Sir Charles Parson and used in the first steam jet refrigeration system by Maurice Leblanc in 1910 [1]. The advantage of this system is the possibility of using the low grade energy sources such as solar energy, waste heat, and geothermal energy [2-3]. And it can use the environmental friendly refrigerants such as water, R152a, R134a etc [4]. However, it usually has a low coefficient of performance (around 0.2 to 0.3).

The ejector refrigeration system is unlike the conventional refrigeration system that compressor is replaced by an ejector, generator, and recalculating pump. The system consists of an ejector, a generator, an evaporator, a condenser, an expansion valve, and a circulating pump (as shown in Fig.1).

Working fluid is vaporized at a high pressure in the generator and used as the primary fluid for the ejector. Ejector entrains the low pressure vapour from the evaporator as its secondary fluid. This combined flow is then compressed to an intermediate pressure equal to that of the condenser. Part of liquid accumulated in the condenser is fed to the generator by circulating pump, whilst the remainder is returned to the evaporator via an expansion valve.

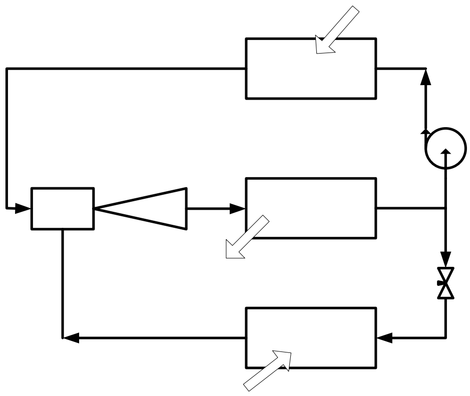


Fig. 1 Schematic diagram of ejector refrigeration system.

In the past, the effect of ejector's geometries, nozzle's geometries, and operating conditions have already been researched in ejector refrigeration system. Such as, Ian W. Eames *et al.* [5] has investigated the effects of primary nozzle geometries on jet pump performance. A. J. Meyer *et al.* [6] has investigated the possibility to run a steam jet ejector on generator temperature below 100°C. They are mainly experimental works and are quite limited in the testing conditions.

For many years, with the rapid development of numerical solution method, some researchers have applied the Computation Fluid Dynamics (CFD) to investigate the flow characteristic of ejector in order to develop a high performance ejector. T. Sriveerakul [7-8] used the CFD in predicting the performance of a steam ejector refrigeration system. Randheer L. Yadav *et al.* [9] presented the optimization of the geometry of the suction chamber using CFD simulation. MyoungKuk Ji *et al.* [10] are investigated the flow structure into steam ejector by using CFD. The effect of the angle of converging duct geometries are investigated numerically. K. Pianthong *et al.* [11] employed CFD technique to investigate the flow phenomena and performance of ejector used in refrigeration system. The simulation approach is validated by comparison with experimental results. E. Rusly *et al.* [12] simulated the flow in ejector by CFD. The CFD results are validated with experimental data. It found that, the CFD results closer to the experimental results than the one-dimensional analysis. It has shown that CFD is extremely for predicting the flow characteristics in ejector.

In this paper, the ejector is designed by the Engineering Sciences Data Unit (ESDU) and the flow characteristics of the ejectors flow and performance should be simulated by CFD.

2. Ejector design

In this study, the Constant Pressure Mixing (CPM) type ejector is selected and its proposed geometries are preliminary determined by the Engineering Sciences Data Unit (ESDU). The design conditions are generator pressure of 5.5 bar, evaporator pressure of 12.3 mbar, condenser pressure of 75 mbar, and refrigeration capacity of 3.5 kW. The diameter of nozzle throat (D_{th}), nozzle exit (D_{ex}), and ejector throat (D_m) can get from direct calculation. The shape and length of ejector determine by using Eqs. (1) – (4). The Fig. 2 shows the principal dimensions of an ejector.

$$L = 2 \text{ to } 4D_m \quad (1)$$

$$S = 10D_m - L \quad (2)$$

$$\phi_1 = 2° \text{ to } 10° \quad (3)$$

$$\phi_2 = 3° \text{ to } 5° \quad (4)$$

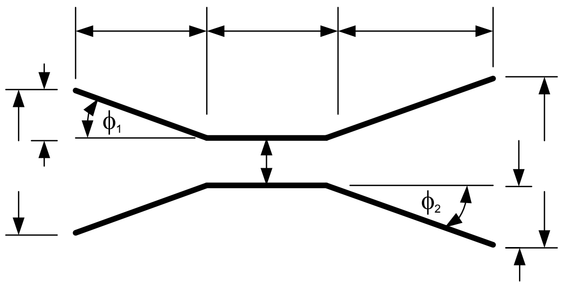


Fig. 2 Principal dimensions of an ejector

From Eqs. (1) – (4), the basic shape and length of the ejector can possibly be various sizes. Thus, the flow characteristics of the ejectors flow and performance should be simulated by CFD to finally determine the optimum geometry of the ejector which gives the best performance under certain operating conditions.

3. Performance characteristics of the steam ejector

The important parameter used to describe the performance of a steam ejector is an entrainment ratio (*Rm*).

$$Rm = \frac{\text{mass flow of secondary fluid}}{\text{mass flow of primary fluid}} \quad (5)$$

Fig. 3 show typical performance curves of the steam ejector. There are three regions: choke flow, unchoke flow, and reversed flow of the secondary fluid. There are distinguished by critical back pressure and break down back pressure. Under the choke flow region, where the back pressures are below the “critical value”, the ejector entrains the same amount of secondary fluid. This causes the entrainment ratio to remain constant. Under the unchoke flow region, where the back pressures are increased higher than the critical value, the secondary flow is no longer choked. The secondary flow reduces and causes the entrainment ratio to fall of rapidly. Under the reversed flow region, where the back pressures are above the “break down value”, the flow will reverse back into the secondary flow inlet and the ejector loses its function completely.

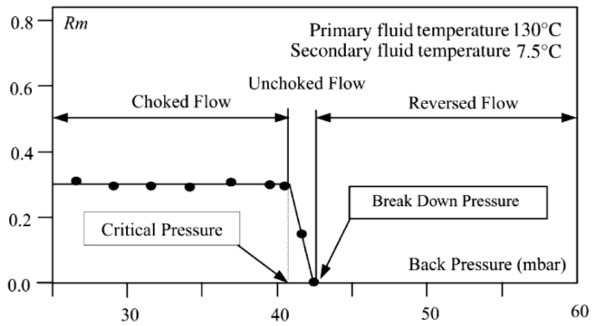


Fig. 3 Performance characteristics of a steam ejector based on experimental data provided by Eames *et al.* [7]

The flow characteristics of ejector flow are simulated by CFD show in Fig. 4 – 6. In Fig. 4 show the velocity contours of choke flow characteristic. The size of the primary jet core remained constant and it is bigger than the primary jet core of unchoke and reversed flow. Because the back pressure will not affect to the mixing behavior of the two fluids. The velocity contours of unchoke flow show in Fig. 5. The primary jet core is smaller and shorter than the primary jet core of the choke flow. Because the secondary flow is no longer choked. Fig. 6 show the velocity contours of reversed flow characteristic. The primary fluid flow will reverse back into the secondary flow inlet. Because the back pressures are above the break down value.

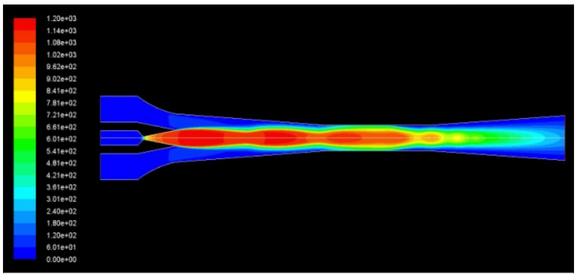


Fig. 4 Velocity contours of choke flow characteristic

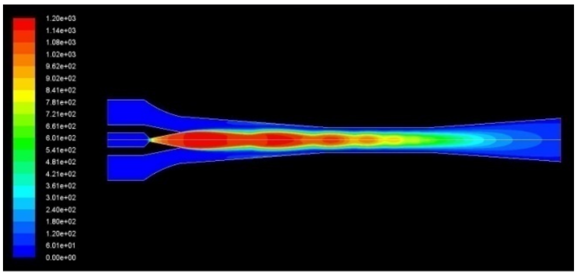


Fig. 5 Velocity contours of unchoke flow characteristic

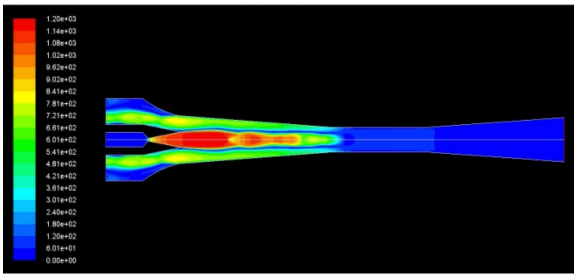


Fig. 6 Velocity contours of reversed flow characteristic

4. Experimental procedure

In this study, the flow characteristics of the ejectors flow and performance are simulated by CFD (FLUENT v.6.3.26). The ejector geometry is set as axisymmetric, shown in Fig. 7. Around 48000 nodes of quadrilateral mesh are used. The solving method is couple implicit. The realizable k - $\mathcal{E}$ turbulence model is selected. The energy equation is included, while the fluid property is defined as an ideal gas. The conditions of simulation are generator pressure (Primary inlet) of 5.5 bar, evaporator pressure (Secondary inlet) of 12.3 mbar, and condenser pressure (Pressure outlet) of 75 – 100 mbar. The water (R-718b) is used as working fluid in this cycle.

Constant the divergent wall angle (ϕ_2) and ejector throat length to investigate the effect of convergent wall angle (ϕ_1). The convergent wall angles of 2°, 4°, 6°, 8°, and 10° are tested.

Constant the convergent wall angle and ejector throat length (L) to investigate the effect of divergent wall angle. The divergent wall angles of 3°, 4°, and 5° are tested.

Constant the convergent wall angle and divergent wall angle to investigate the effect of ejector throat length. The ejector throat lengths of 69, 103, and 137 mm. are tested.

From Eq. (2), when the ejector throat length (L) is increased, the length of mixing duct entry (S) is decreased.

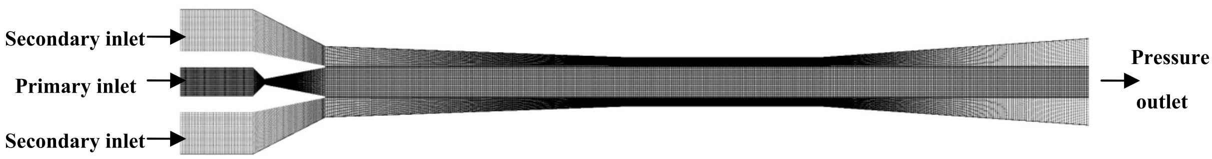


Fig. 7 Ejector geometry used in the CFD simulation.

5. Results and Discussion

5.1 Effect of convergent wall angle

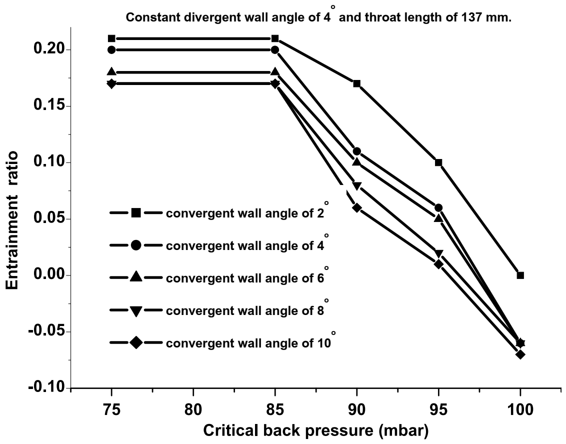


Fig. 8 Variation of calculated entrainment ratio of an ejector, effect of convergent wall angle.

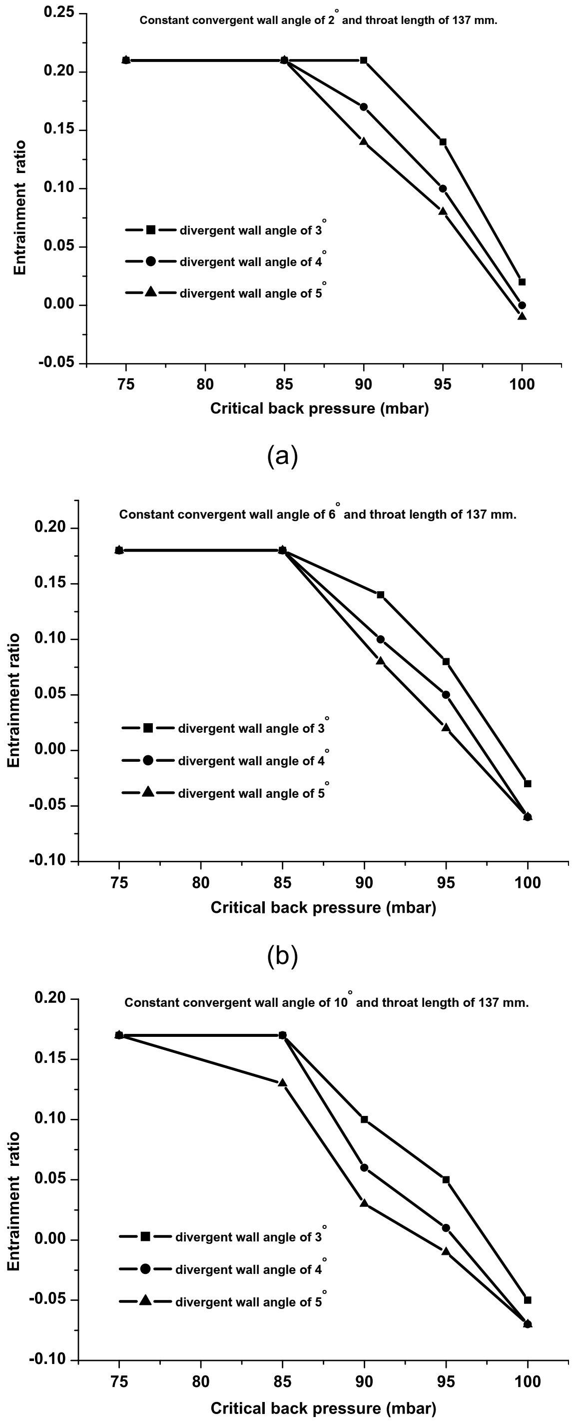
From Fig. 8, when the convergent wall angle is increased, the decrease of an entrainment ratio is found. The maximum an entrainment ratio is obtained, at the convergent wall angle of 2°. The same critical back pressure value of all ejectors is obtained at 85 mbar.

It is obviously that the convergent wall angle has no effect on the critical back pressure. But it has effect on the entrainment ratio.

5.2 Effect of divergent wall angle

Fig. 9 (a) – (c) shows the variation of calculated entrainment ratio of an ejector, effect of divergent wall angle. Under the choke flow region, the same entrainment ratio is obtained. Under the unchoke flow region, when the divergent wall angle decreased, the increase of entrainment ratio is obtained.

From Fig. 9 (a), the maximum critical back pressure value is obtained (90 mbar), at the convergent wall angle of 2°, and divergent wall angle of 3°, and ejector throat length of 137 mm. From Fig. 9 (c), the minimum critical back pressure value is obtained (75 mbar), at the convergent wall angle of 10°, divergent wall angle of 5°, and ejector throat length of 137 mm.



(a)

(b)

(c)

Fig. 9 Variation of calculated entrainment ratio of an ejector, effect of divergent wall angle.

It found that the best performance of ejector is obtained, at lowest convergent and divergent wall angle.

5.3 Effect of throat length

From Fig. 10 (a) under the choke flow, when the ejector throat length is decreased, the entrainment ratio is increased. But when the ejector throat length is decreased, the critical back pressure value is decreased.

Under the choke flow, when the ejector throat length is increased, the entrainment ratio is increased.

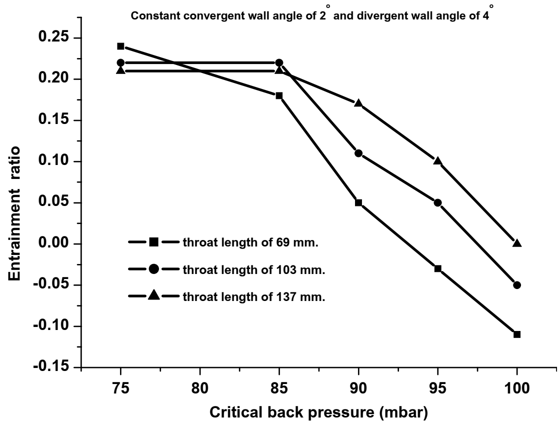
The highest entrainment ratio (0.24) and lowest critical back pressure (75 mbar) are obtained, at the ejector throat length of 69 mm. The highest critical back pressure value (85 mbar) is obtained, at the ejector throat length of 103 and 137 mm.

From Fig. 10 (b) and (c), when the ejector throat length is increased, the entrainment ratio and critical back pressure value are increased. The maximum an entrainment ratio and critical back pressure are obtained, at the ejector throat length of 137 mm.

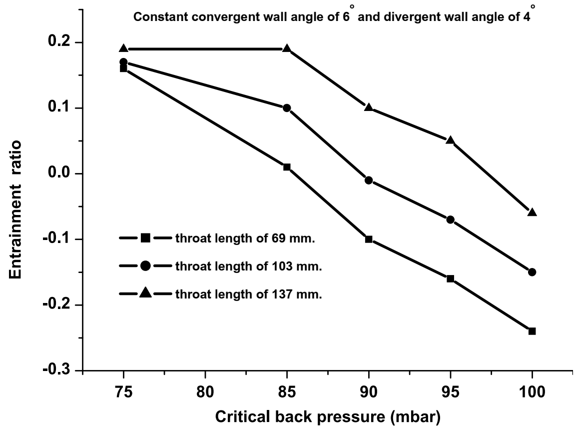
It found that the best performance of ejector is obtained, at the ejector throat length of 137 mm.

6. Conclusions

This study focuses on the influence of ejector geometries on its performances under the design operating condition. The Engineering Sciences Data Unit (ESDU) and the Computational Fluid Dynamic (CFD) are used as the tools for this design. The important parameters used to describe the performances of a steam ejector are an entrainment ratio (*Rm*) and critical back pressure value. It was found that, the convergent wall angle has no effect on the critical back pressure. But it has effect on the entrainment ratio. The maximum an entrainment ratio is obtained, at the convergent wall angle of 2°.



(a)



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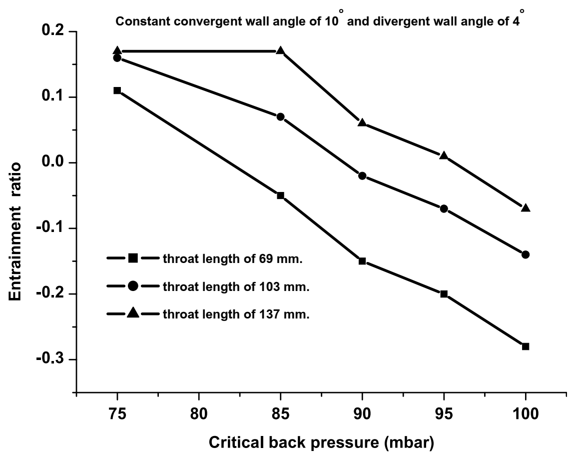

(c)

Fig. 10 Variation of calculated entrainment ratio of an ejector, effect of throat length.

When the divergent wall angle decreased, the increase of entrainment ratio is obtained. The maximum an entrainment ratio and critical back pressure value are obtained, at the divergent wall angle of 3°.

When the ejector throat length is increased, the critical back pressure is increased. The maximum critical back pressure value is obtained, at the ejector throat length of 137 mm.

In this study, the operating conditions are generator pressure of 5.5 bar, evaporator pressure of 12.3 mbar, and condenser pressure of 75 mbar. The optimum of ejector dimensions are convergent wall angle of 2°, divergent wall angle of 3°, and throat length of 137 mm. These parameters will be used in the experimental test ring and validated in the near future.

7. Acknowledgement

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