Simulation on performance of CPM and CRMC Steam Ejectors Using CFD Technique

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Abstract

Steam ejector refrigeration has been studied and improved continuously for many years. In this study, the flow behavior of the steam ejector is thoroughly investigated. The Computation Fluid Dynamics (CFD) code (FLUENT) is employed to describe the flow behavior, mixing characteristic, and also predict the ejector performance. The flow geometry is assumed to be axissymmetry while the steam property is set as a perfect compressible gas. Flow characteristics of two kinds of ejectors; called CPM and CRMC, are investigated and compared. The entrainment ratio, pressure lift ratio and static pressure profile along the ejector are the main interest. Moreover the velocity manitude profile of CRMC and CPM ejector are plotted and analyzed.

1. Introduction

An ejector is a simplified type of vacuum pump or compressor which has no pistons, valves, rotors or other moving parts. It consists essentially of a nozzle which discharges a highvelocity jet (or primary flow) across a suction chamber that is connected to the fluid to be delivered (or secondary flow) or to the equipment to be evacuated. The secondary flow is entrained by the primary flow and carried into a venturi-shaped diffuser which converts the velocity energy into pressure energy at a pressure between the two incoming pressures. Nozzles are devices in subsonic flow that have a decreasing area and accelerate the flow to supersonic at its diffuser. They convert pressure energy to velocity energy. A minimum area is reached when velocity reaches sonic flow. In supersonic flow, the nozzle is an increasing area device. A diffuser in subsonic flow has an increasing area and converts velocity energy into pressure energy.

Tremendous interests have been owing to many advantages of ejector such as simplicity and reliability, low installation and operation costs, thermally powered system. The energy sources can be any low grade and environmentally friendly sources such as solar energy, waste heat etc.

Lately, ejectors have been employed in the refrigeration cycle. Its function is to replace the mechanical compressor to pump the refrigerant to circulate in the system. A liquid pump, a boiler (or heat generator), and an ejector are used in place of a compressor [1]. Thermal energy has to be provided substituting the electrical energy that runs the compressor. This can be obtained from a boiler or a generator powered by many alternative heat sources.

For many years, the steam ejector used in steam ejector refrigeration are usually designed based on two conventional assumptions either constant pressure mixing (CPM) or constant area mixing (CAM) at mixing region as shown in Figure 1. Lately, there is an experimental study confirms that CPM ejector gives the better performance than that of CAM ejector. However, it seems that the performance of CPM ejector is still very low and there is no sign of improvement in this ejector so far. Lately, Eamse [2] presented the novel prescription for the design of supersonic ejector called constant rate of momentum change (CRMC) method and described it would increase entrainment ratio and gradually increase the static pressure along the ejector axis (i.e. avoiding the total pressure loss associated with the shock wave effect in the diffuser).



Figure 1 Conventional CPM and CAM ejector

This study employs computational fluid dynamics (CFD) technique to elucidate the flow characteristics on the ejector flow of both conventional CPM and CRMC ejectors. Moreover the ejector performance can be predicted, enhanced, and simulated at various conditions. The some aspects on performance of both ejectors are compared. These will also give us some idea how CFD can help engineers to improve the ejector refrigeration while saving operating time and costs due to experiments, although some actual tests are still required.

2. Ejector characteristics

Flow characteristics inside the ejector directly affect the coefficient of performance (COP) of the ejector refrigeration. Therefore understanding the flow behavior is very important and will lead to enhancement of COP. Ejector consists of mainly 4 parts; (1) primary nozzle, (2) mixing chamber, (3) throat, and (4) mixing chamber as shown in Figure 2. The velocity and pressure profile along the ejector axis are also shown in this figure.



Figure 2 Typical steam ejector and flow characteristic in the ejector.

At the boiler, the liquid water is heated and becomes superheated vapor at high pressure. The superheated vapor flows though the primary nozzle and choked at the nozzle throat, then it becomes supersonic in the nozzle diffuser (or divergence section). At the exit of the nozzle, the superheated vapor (primary fluid) flows at supersonic speed and cause the static pressure around the its exit or mixing chamber very low, this will induce the water vapor (secondary fluid) from the evaporator. Those two fluid mix and flow through the throat while their velocity reduces to subsonic, finally, they expands at the diffuser. Here, the velocity or dynamic pressure converts to be static pressure and force the fluid to circulate along the cycle. The design concept and theoretical analysis of steam ejector maybe found are usually related to 3 basic equation i.e. energy equation, momentum equation, and continuity equation. But the two important parameters represented the ejector performance are;

Entrainment ratio
$$R_m = \frac{mass \ of \ sec \ ondary \ flow}{mass \ of \ primary \ flow}$$
 (1)

Pressure lift ratio
$$PLR = \frac{static \ pressure \ at \ diffuser \ exit}{static \ pressure \ of \ secondary \ flow}$$
 (2)

The entrainment ratio will directly affect COP of the system. However it is limited by the "critical back pressure" or condensing pressure of the system which the pressure that the ejector can maintain its entrainment ratio. Ejector geometry and other operating condition also affect the ejector performance as well.

3. CFD modeling

Geometries of CPM and CRMC ejector, also the mesh geometry, used in the simulation are shown in Figure 3. The variables of CPM ejector are the length of the ejector throat and the nozzle exit position (NXP)[3]. The operation conditions are listed in Table 1.



Figure 3 Geometry of ejector (a) mesh geometry (b) CPM geometry (c) CRMC geometry

Table. 1 Operating conditions

Boundary	Pressure	Temperature
	(Pascal)	(K)
Secondary Fluid Inlet	1227.6	283
Primary Fluid Inlet	270100	403
Ejector Exit	4000	302
Fluid	Water-Vapor (Ideal-gas)	

Geometry or shape of the CRMC ejector, especially the diffuser, is designed base on the prescription provided by Eames [4], however the operating conditions were according to Table 1. The profile of the diffuser designed by using CRMC method is shown in Figure 4.

CFD commercial package (FLUENT 6.0) is used as the tool to simulate the ejector flow characteristics. Ejector geometry is assumed to be axis-symmetry with quadrilateral mesh element. The mesh was densely created at the area of high shear flow and mixing layer. The material of the refrigerant (steam) is water vapor and set as ideal gas. Turbulence model is realizable k- \mathcal{E} with the couple-implicit solver for non-linear equations. Inlet pressure and outlet pressure were used as boundary conditions at the entrance of the nozzle and at the exit of the ejector respectively.



Figure 4 Profile of the diffuser of CRMC ejector

4. Results

Some of particular cases of CFD simulations were validated with the experiments in our previous works [4] and they show good agreement well with the experimental results.

4.1 Constant - pressure mixing ejector

4.1.1 Effect of throat length

Length of the ejector throat was varied from 10 mm to 170 mm while the operating conditions are fixed. It is found that the entrainment ratio increase when the throat distance is increased from 10 mm to 70 mm as shown in Figure 3(a). But further increase of throat distance gives roughly the same entrainment

ration (from 80-170 mm). The profiles of the static pressure and the pressure jump position (or shock condition) are also related to the throat distance as shown in Figure 4(b). Contours of Mach number at various throat distances are shown in Figure 4.



(b)

Figure 5 (a) Throat distances with entrainment ratio (b) Throat distances with static pressure.



Figure 6 Contour of Mach number at different throat distance

4.1.2 Effect of nozzle exit position

Nozzle exit positions (NXP) were varied for 9 positions from -34.3 mm to +15 mm. From Figure 5(a), when the NXP is decreased the entrainment ratio tend to increase. It seems that the furthest NXP (-34.3 mm) is the best position for highest

entrainment ratio while the static pressure profile from each NXP are quite similar as shown in Figure 5(b).



(b)

Figure 7 (a) Effect of the NXP to entrainment ratio (b) Static pressure with changes of NXP.



Figure 8 Contour of Mach number at different NXP

4.2 CRMC ejector

From Figure 8, we will see that the static pressure along the ejector axis is gradually increased as suggested by Eames. This behavior will reduce the loss of total pressure caused by shock pressure (or shock wave at the diffuser). This advantage helps the CRMC ejector to be able to operate at the higher critical back pressure (i.e. condensing pressure). However, the entrainment ratios given by CRMC ejector are quite similar to those obtained from CPM ejector. Case of 15 mm mixing chamber distance seems to give the best pressure profile while the 50 mm case has a strong fluctuation of pressure (i.e. higher pressure loss)

which is not desirable for the ejector design. Contour of Mach number in CRMC ejector are shown in Figure 9 where Figure 10 shown the plot of velocity magnitude (at axis position) along the ejector. It shows that the CRMC give a constant velocity at a longer distance which agrees well with the concept of constant rate of momentum change. This is one of the evidence that CRMC would enhance the pressure loss in the diffuser.



Figure 9 CRMC's Static pressure along ejector axis



Figure 10 Contour of Mach number for CRMC ejectors



Figure 11 Velocity magnitude along the CRMC and CPM ejector

5. Concluding remarks

CFD can be successfully employed to investigate the flow characteristic inside the steam ejector. The entrainment ratio and the static pressure profile can be examined. This leads to the better understanding of ejector performance and will help in enhancing is performance. The novel design concept ejector (CRMC) is also investigated and analyzed its flow behavior. The results are then examined referring to its 1D theoretical design and also compared with the CPM ejector. However further studies such as using wider operating conditions and comparing with the experimental results should be performed in the near future.

6. Acknowledgement

This research is financially supported by the Thai Research Fund (TRF). Contract no. MRG4680175).

7. References

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