Performance Optimization of Steam Jet Ejector Using CFD A Review

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Abstract - *Jet ejectors are popularly used in the chemical process industries because of their simplicity and high reliability. They are widely used to generate vacuums with capacity ranges from very small to enormous. Due to their simplicity, constant-pressure jet ejectors those are properly designed for a given situation are very forgiving of errors in estimated quantities and of operational upsets. The purpose of this project is to optimize the geometry of steam jet ejector used for refrigeration application in chemical plant. Exhaustive survey has been conducted on the influence of geometrical parameters on the efficiency of the ejector as well as critical flow parameters to improve the overall performance. The use of computational dynamics has been widely accepted by researchers to improve the performance of jet ejector. CFD gives detail insights on the flow characteristics, which allows accurately optimizing the ejector geometry. Since the ejector requires single point design for specific applications, using computer simulations early in the design process will significantly reduce the requirement of prototyping trials. The results obtained through CFD analysis will be used to optimize the geometry of the ejector, to achieve better efficiency by reducing pressure drop across the ejector geometry.*

***Key Words :* Steam Jet Ejector, Geometrical Parameters, Computational Fluid Dynamics(CFD)**

1. INTRODUCTION

Jet ejectors provide numerous advantages, like : They require little maintenance because there are no moving parts to break or wear. They have lower capital cost compared to mechanical devices because of their simple design. Their design is very straightforward. They are easily installed and require little supervision.

On the other hand, the major disadvantages of jet ejectors are : They are designed to perform at a particular optimum point. Deviation from this optimum point can dramatically reduce efficiency. They have a low thermal efficiency at high compression ratios.

1.1 Operating Principle :

As shown in Figure 1, the conventional jet ejector design has four major sections:

1. nozzle 2. suction chamber 3. Throat 4. diffuser

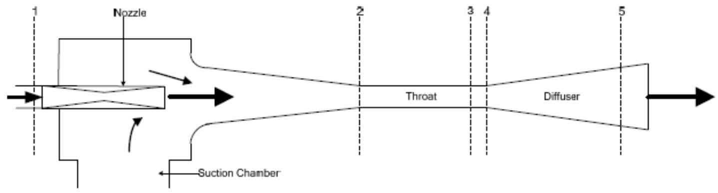

Fig – 1: Conventional Jet Ejector Design[7]

The operating principle of jet ejectors is described below: (1) Subsonic motive stream enters the nozzle at Point 1. It flows to the converging section of the nozzle, its velocity increases, and its pressure decreases. At the nozzle throat, the stream reaches sonic velocity. In the diverging section of the nozzle, the velocity increases to supersonic. (2) The entrained propelled fluid enters the ejector, flowing to Point 2. Its velocity increases and its pressure decreases. (3) The motive stream and entrained propelled stream begin to mix within the suction chamber; mixing is completed in the throat. (4) Inside the throat, a shock wave forms when the mixture velocity reduces to a subsonic condition. The back-pressure resistance can cause condensation at Point 3. (5) The mixture flows into the diverging section of the diffuser where the kinetic energy of the mixture is transformed into pressure energy. At Point 5, the pressure of the emerging fluid is slightly higher than at Point 3.

2. LITREATURE REVIEW

1. Natthawut Ruangtrakoon et al (2013) [1] in their study used CFD technique to investigate the effect of the primary nozzle geometries on the performance of an ejector used in the steam jet refrigeration cycle. In all cases, only one fixed geometry mixing chamber together with eight different primary nozzles was investigated numerically using the CFD package. The optimum condition was the primary nozzle with the throat diameter of 2.3 mm and exit Mach number of 4 operating with the boiler temperature of 120 ˚C at the evaporator temperature of 7.5 ˚C. From this study, it can be concluded that the CFD technique can be used as an efficient tool to predict the performance of a steam ejector. It can also be used to explain the mixing process which cannot be explained experimentally. The results show that geometries of the primary nozzles used and operating conditions have very strong effects on the ejector performance and therefore the system COP.

Table – 1: Dimensions of Primary Nozzle

Nozzle code	d (mm)	$(D:d)^2$	Calculated exit Mach number	Ejector's area ratio
d1.4M4	1.4	20:1	4.0	184:1
d1.7M4	1.7			124:1
d2.0M4	2.0			90:1
d2.3M4	2.3			68:1
d2.4M4	2.4			62:1
d2.6M4	2.6			53:1
d1.4M3	1.4	7:1	3.0	184:1
d1.4M5.5	1.4	88:1	5.5	

2. Szabolcs Varga et al. (2009) [2] in their study considered three geometrical factors, area ratio of the nozzle and area of constant section (r_A), nozzle exit position (NXP) and constant area section length (Lm) to study the influence of geometrical factors on steam jet ejector performance. The results indicated the existence of an optimal area ratio, depending on operating conditions. Nozzle exit position affected both the critical back pressure and entrainment ratio. The best location for the nozzle exit was found to be 6 cm from the converging section inlet plane resulting in a 5% and 12% increase in the entrainment ratio and critical back pressure, respectively. Increasing Lm up to 155mm increased the critical back pressure. A further increase did not affect the performance indicators; therefore, it can be considered as optimal for the present ejector

3. Hongqiang Wu et al. (2014) [3] in their study employed computational fluid dynamics (CFD) method to investigate the effects of the geometries of mixing chamber on the performance of steam ejectors used for multi-effect distillation systems. The internal flow characteristics of the steam ejector and the effects of the length and convergence angle of the mixing chamber were obtained. It is concluded that there is an optimum range of the mixing chamber length at which the ejector will achieve its largest entrainment ratio and the mixing chamber has an optimum convergence angle at which the steam ejector performance is the optimum.

4. E. Rusly et al. (2005) [4] have studied several ejector designs using finite volume CFD techniques to resolve the flow dynamics in the ejectors. The CFD results were validated with available experimental data. It is found that the maximum entrainment ratio happens in the ejector just before a shock occurs and that the position of the nozzle is an important ejector design parameter. From the investigation, it can be concluded that the constant area diameter increase will only improve ejector performance when it is operating in critical mode with a shock in the diffuser. It is found that in order to obtain maximum output, the constant area diameter can be continuously increased until the shock disappears but the secondary flow choking remains.

5. T. Sriveerakul et al. (2007) [5] in Part-1 of their study investigated the use of CFD in predicting performance of a steam ejector used in refrigeration applications. The effects of operating conditions and geometriecal parameters on its performance were investigated. The CFD's results were found to agree well with actual values obtained from the experimental steam jet refrigerator. The CFD was not only a sufficient tool in predicting ejector performance it also provide a better view in the flow and mixing processes within the ejector. Average errors of the predicted entrainment ratio and the critical back pressure were both found to be less than -7%. Note that negative sign indicates that the CFD calculated results were underestimated.

6. T. Sriveerakul et al. (2007) [6] in Part-2 of their study analyzed the flow phenomena inside the steam ejector when its operating conditions and geometries were varied. Using the applications provided by the CFD software, the flow structure of the modelled ejectors could be created graphically, and the phenomena inside the flow passage were explored. It can be seen that both entrainment ratio and critical back pressure can br varied simultaneously by adjusting 3 parameters, which are Primary fluid saturated pressure, Secondary fluid saturated pressure and Primary nozzle size. However, when adjusting the primary fluid saturated pressure and critical back pressure cannot be increased together. The only adjustment which can increase both parameters simultaneously, is the increase of secondary fluid saturated pressure.

7. Jianyong Chen et al. (2014) [7] has presented an ejector model to determine the optimum performance as well as design area ratio of an ejector in a refrigeration system. The entrainment ratio increases with increasing of generator temperature and evaporator temperature, while an increasing condenser temperature leads a gradual decrease in entrainment ratio instead of a sharp drop. The nozzle and mixing efficiencies have more effect on area ratio than the diffuser efficiency. Variable geometry ejectors play an important role in achieving optimum performance and widen the operating conditions.

8. Natthawut Ruangtrakoon et al. (2011) [8] constructed a 1 kW cooling capacity experimental refrigerator and tested. The system was tested with various operating

temperatures and various primary nozzles. The boiler saturation temperature ranged from 110 to 150 ˚C. The evaporator temperature was constant at 7.5 ˚C. Eight primary nozzles with difference geometries were used. Six nozzles have throat diameters ranged from 1.4 to 2.6 mm with exit Mach number 4.0. Two remained nozzles have equal throat diameter of 1.4 mm but difference exit Mach number, 3.0 and 5.5.

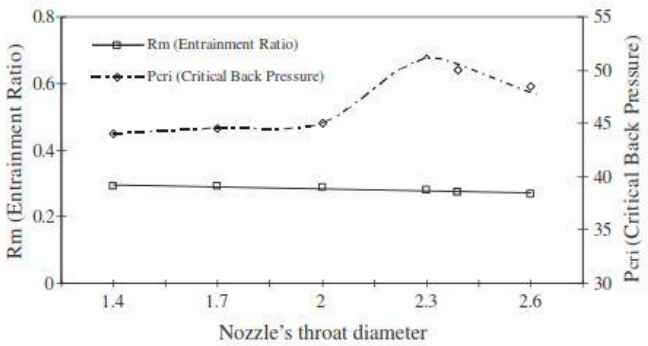

Chart – 1: Variation of the Entrainment Ratio and the Critical Back Pressure When Using Various Nozzles butFfix the Critical Mass Flow Rate and the Exit Mach Number.

For one particular primary nozzle, operated at a fixed evaporator saturation temperature, the critical mass flow rate through the nozzle is increased with the boiler pressure. But the nozzle exit Mach number is remained unchanged. When several nozzles with different throat diameters are used under a fixed boiler and evaporator saturation temperature, different amounts of critical mass flow rate through these nozzles are produced. From this study, it can be concluded that, geometrical parameters of the primary nozzle have strong effects to the ejector performance and the system COP.

9. R. Yapici et al [9] in their study, Experimental determination of the optimum performance of ejector refrigeration system depending on ejector area ratio, The performance of the ejector refrigeration system using ejectors with cylindrical mixing chamber is studied at operating conditions with choking in the mixing chamber. The study is performed over a range of the ejector area ratio from 6.5 to 11.5 at the compression ratio 2.47. In the study the experimental coefficient of performance of the system ranges from 0.29 to 0.41, as the optimum generator temperature increases from 83 to 103 ˚C. Similar results were also found in the parametric study when the efficiencies of the nozzle and diffuser are taken as 0.90. For a given ejector area ratio, there exists an optimum generator temperature at which maximum COP is obtained from the ejector refrigeration system. The COP of system undergoes a rather sharp drop when the generator temperature is lowered from the optimum temperature corresponding to its area ratio. The optimum area ratio nearly increases linearly with the generator temperature in the studied range.

3. CONCLUSIONS

The geometry of the ejector plays a vital role in improving the COP of the refrigeration system. Depending on the application, there exists an optimum mixing chamber length and convergence angle for maximum entrainment ratio. Entrainment ratio and critical back pressure can be varied by adjusting primary and secondary fluid pressure as well as nozzle size. Increase in generator and condenser temperature increases entrainment ratio. Optimizing nozzle geometry (throat diameter) strongly influences the steam jet ejector performance.

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