A Numerical Study on Ejector Refrigeration System With Special Reference To Geometrical Parameters

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ABSTRACT

Vapour compression refrigeration system consumes high grade energy which is utilized to get the desired output and the remaining part is rejected as waste heat. This waste energy is used to drive an ejector refrigeration system. This work describes the numerical study on the effect of geometrical parameters like nozzle exit position, convergent angle of suction chamber, divergent angle of diffuser on the performance of ejector. Analysis is done for all the design with fixed operating conditions and the entrainment ratio variation corresponding to each geometrical parameter are analysed. The design which gives the maximum entrainment ratio is considered as the optimum design.

Key Words: Ejector, Nozzle, Entrainment ratio.

1. INTRODUCTION

Ejector refrigeration system has become a topic of research interest for the reasons that it is utilizing low-grade energy such as solar energy; waste heat rejected from industries etc., the system can be operated successfully with environmentally friendly refrigerants. On the other hand, the performance of this cycle is lower than vapour absorption refrigeration system due to the complex compressible fluid flow in ejector which is the heart of the entire system. . A typical ejector consists of three different parts namely, a convergent-divergent nozzle, suction and mixing chamber and a diffuser. The geometry and the operating condition of this ejector play a vital role in the performance of the entire system. . The working fluid used in this work is steam. The steam has zero ODP, zero GDP, and good thermodynamic and transport properties as compared to banned halocarbon refrigerants, non-flammable, and abundant and easily available. In this work the optimization of ejector performance is done by varying the nozzle exit position, convergent angle of suction chamber, divergent angle of diffuser which is the most influencing geometrical parameters over the performance of ejector and performance of this system is directly proportional to the entrainment ratio of the ejector.

2. DESCRIPTION OF THE EJECTOR REFRIGERATION CYCLE

The Schematic diagram of ejector refrigeration system is as shown in Fig. 1. The system composed of a generator, ejector, condenser, expansion device and pump. Generator is used to generate high-pressure primary vapour by electrical energy. This vapour is allowed to expand in the convergent–divergent nozzle of the ejector. An ejector is shown in Fig.2 consists of a converging- diverging nozzle which allows the high-speed jet exiting the nozzle to become supersonic. This high-speed jet coming from the nozzle starts interacting with the secondary fluid coming from the evaporator in section chamber where its momentum is shifted from the primary fluid which results in an acceleration of the secondary fluid. The two streams are mixed in mixing section. The mixture flows into the diffuser which is used to recover the kinetic energy and convert it into potential energy, so increasing the static pressure. So, the ejector acts as pump which is used to elevate the pressure of the entrained fluid. Then vapour leaving the ejector is condensed inside the condenser. A portion of refrigerant is pumped to the generator and the remaining refrigerant is expanded in an expansion device to the evaporator.

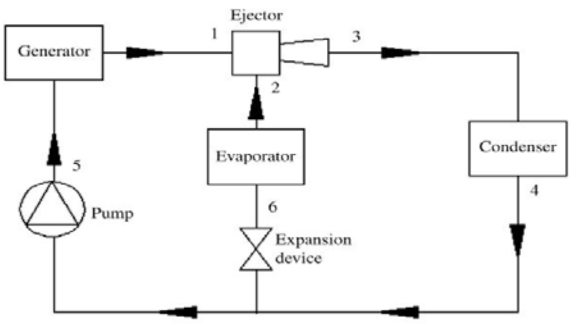

Fig 1: Ejector refrigeration cycle

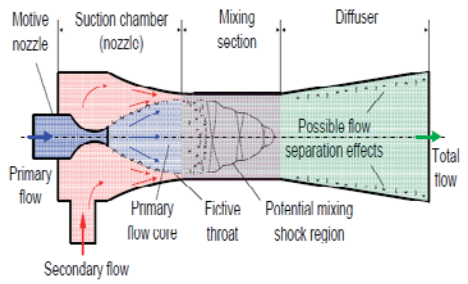

Fig 2: Ejector

3. PERFORMANCE OF EJECTOR

The performance of an ejector is expressed by the term Entrainment ratio. It is the ratio of secondary vapour flow rate (Δh_e) to the primary vapour flow rate (Δh_g). Entrainment ratio is expressed as µ.

$$\text{COP}=\mu\left(\frac{\Delta he}{\Delta hg}\right)$$

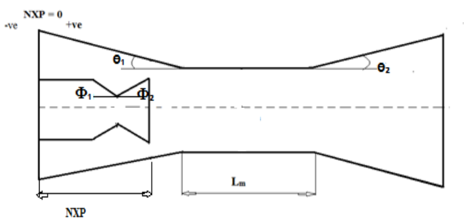

Fig 3: Geometrical parameters of ejector

COP and entrainment ratio are directly proportional, so entrainment ratio has to be improved to enhance the performance of ejector. Performance of ejector depends on geometrical parameters like:

- NXP = Nozzle exit position
- θ_1 = Convergent angle of the suction Chamber
- θ_2 = Divergent angle of diffuser
- Φ_1 = Convergent angle of nozzle
- Φ_2 = Divergent angle of nozzle
- Lm = Length of mixing chamber

4. EXPERIMENTAL PROCEDURE

In this present work the design of ejector is analysed by changing the converging angle of suction chamber, nozzle exit positions, divergent angle of diffuser, divergent angle of nozzle and mixing chamber length and the detailed procedure is done by CFD SOFTWARE and model used for the analysis with the help of GAMBIT software.
The CFD code selected for the simulation is GAMBIT 2.3 and ANSYS 13. The grid modelled from the GAMBIT had quadrilateral structure. The solving method was couple implicit. The governing equation for compressible fluid can be written in the compact Cartesian form as:

$$\frac{\partial\rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \quad (1)$$

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j} \quad (2)$$

$$\frac{\partial}{\partial t}(\rho E)+\frac{\partial}{\partial x_i}(u_i(\rho E+\rho))=\nabla.\left(\alpha_{eff}\frac{\partial T}{\partial x_i}\right)+\nabla.\left(u_j(\tau_{ij})\right) \quad (3)$$

Where,

$$\tau_{ij}=\mu_{eff}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\frac{2}{3}\mu_{eff}\frac{\partial u_k}{\partial x_k}\delta_{ij} \quad (4)$$

The turbulence model selected in this paper is k-ε turbulence. This model relies on the Boussinesq hypothesis. This hypothesis is used in Spalart-Allmaras, k-ε and k-w models. The main advantage of this approach is low computational cost associated with the determination of the turbulent viscosity. The operating conditions are selected as shown in table.

Table1: Operating conditions

Generator temperature	403 K
Generator pressure	2 bar
Evaporator temperature	283 K
Evaporator pressure	0.061598 bar
Condenser temperature	383.13 K
Condenser pressure	0.0445264 bar

4.1Specification of Ejector

Experiments were conducted by varying geometrical parameters at fixed operating conditions.

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Table 2: Specification of Ejector

Nozzle throat diameter	8.691 mm
Nozzle inlet diameter	10.8 mm
Mixing chamber diameter,D_m	60.9 mm
Ejector inlet diameter	102.15 mm
Ejector exit diameter	$2D_m$ mm
Nozzle exit diameter	33.4 mm
Mixing chamber length, L_m	$5.5D_m$ mm
Convergent angle of nozzle(Φ_1)	22.2^0
Divergent angle of nozzle(Φ_2)	6^0
Convergent angle of suction chamber (θ_1)	4^0
Divergent angle of diffuser(θ_2)	5^0

The geometrical parameters which are varied for the analysis is as shown in table 3.

Table 3: Geometrical Parameters Varied

Converging angle of suction chamber	6^0 to 20^0 (1^0 increment)
Nozzle exit positions	0–130mm (10mm increment)
Divergent angle of diffuser	5^0 to 11^0 (1^0 increment)

5. RESULTS AND DISCUSSION

5.1 VARYING THE NOZZLE EXIT POSITION

The convergent angle of the suction chamber is varied from 6^0 to 20^0 and for each converging angle the nozzle exit position is varied from 0 – 130mm. All the other dimensions of the ejector remain same as shown in table 2. Entrainment ratio corresponding to each angle's NXP is analyzed. From the analysis it is found that ejector with converging angle 18^0 and nozzle exit position 20mm, maximum entrainment ratio of 0.2545 is obtained. The nozzle exit position that gives the maximum entrainment ratio corresponding to each converging angle of suction chamber is represented in the graph.

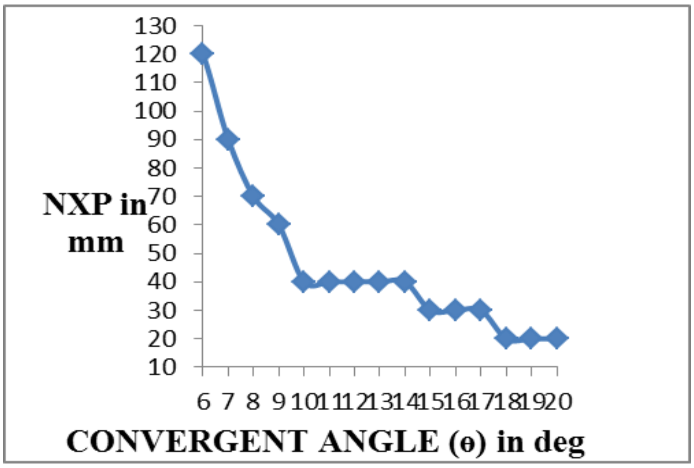

Figure 4: Convergent angle Vs NXP

Table 4: Entrainment ratio for each NXP

NXP	ENTRAINMENT RATIO (μ)
(mm)	**Converging angle 18^0**
0	0.2500
10	0.2515
20	0.2545
30	0.2038
40	0.1970
50	0.2045
60	0.1997
70	0.2000
80	0.2010
90	0.2036
100	0.2037
110	0.2062
120	0.2088
130	0.2075

5.2 VARYING THE DIVERGENT ANGLE OF THE DIFFUSER

The divergent angle of the diffuser is varied from 5^0 to 11^0. The convergent angle is fixed as 18^0 and NXP 20mm. All other dimensions remain the same.

Table 5: Varying the divergent angle of diffuser

DIVERGENT ANGLE OF DIFFUSER(Φ)	ENTRAINMENT RATIO (μ)
5^0	0.2363
6^0	0.2241
7^0	0.2130
8^0	0.2545
9^0	0.2440
10^0	0.2342
11^0	0.2268

From the above analysis it is found that ejector with converging angle 18^0, nozzle exit position 20mm and divergent angle of diffuser 8^0 gives the maximum entrainment ratio 0.2545.

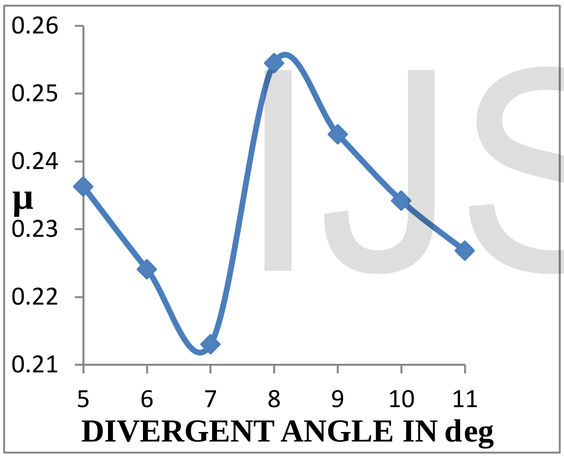

Figure 5: Divergent angle Vs entrainment ratio

6. CONCLUSION

Variation in the performance of ejector is evaluated experimentally by varying the geometrical parameters with the help of FLUENT software. The numerical study shows that ejector designed with converging angle 18^0, nozzle exit position 20mm, divergent angle of diffuser 8^0 gives the maximum entrainment ratio of 0.2545 for the selected operating condition.

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