Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 06, June - 2017

# 3d Analysis on Supersonic Ejector

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***Abstract*: Ejectors are being used since decades for refrigeration application. Nowadays development in technologies has resulted in reducing energy consumption by using low grade waste heat energy. Lack of moving parts and simplicity in functioning make ejectors attractive in energy saving researches. This paper deals with CFD analysis of an ejector under various operating condition .Analysis shows that geometry and operating conditions has a tremendous impact on the working of the ejector. The different geometrical parameters associated with ejector analysis includes length and radius of constant area section ,nozzle exit radius ,nozzle exit position. The results of this study reveals that CFD is a useful tool in design and optimization of ejectors used in refrigeration applications.**

***Key words: Ejector , entrainment ratio, CFD.***

## 1. INTRODUCTION

Ejector system using normal or renewable thermal energy to run environment-friendly refrigerants is a promising and different option for current frameworks. Compared to normal system, ejector system has many advantage because of their reliability, simplicity, low installation and operational cost. Their regularly low COP of around 0.2 can be enhanced considerably when combined with vapour absorption or compression system. (Aphornratana et al [1], Sun [2]). Ejector system involves four particular parts: a convergent–divergent nozzle, a suction chamber joined to a constant area duct and a diffuser. The normal procedures inside an ejector start with a high temperature and high pressure stream from the generator entering the ejector through the convergent–divergent nozzle. This stream is accelerated and expanded to supersonic pace at the nozzle exit. The secondary flow is accelerated to sonic velocity and mixes with primary fluid in the constant area duct. The region of supersonic flow is ended by a normal shock wave further down the duct or in the diffuser. During the process the pressure increases but the mach number reduces to subsonic value. The mixed stream then enters the subsonic diffuser where it experiences a re-compression process to reach the back-pressure (condenser pressure) at near zero velocity.

Studies on vapour-jet ejectors can be summed up into two categories, experimental or numerical studies. While the literature contains only few experimental results, numerical studies are a great deal more copious, particularly depictions of one-dimensional models. Detailed numerical descriptions of the fluid flow and heat transfer inside ejectors, such as those that may be found in Computational Fluid Dynamics (CFD) models of ejectors, are of great value as they provide a more complete simulation of the physics inside the ejectors than is possible with 1D models, although this comes with an increased computational cost. Once a CFD model of an ejector has been validated with experimental results, it becomes possible to have high confidence in the results of numerical "experiments" of ejectors that are performed with these CFD models. The costs associated with designing, fabricating and assembling experimental test benches can be reduced by maximizing the use of CFD models to perform much of the screening of ejector design prior to the assembly of prototypes. In addition, CFD models, using only "virtual" refrigerants, have no potential for environmental damage due to leakage from the test bench. Also, numerous refrigerants can be investigated without concern of the flammability or toxicity issues associated with some refrigerants.

Theoretical analyses of ejectors often use one dimensional point of view and have principally been utilized to compare different refrigerants and assess system attributes under varying working conditions (Eames et al. [3], Huang et al. [4], Sun [5]). At the point when further elements of the system are required, this technique is often inadequate.

Another way to deal with ejector modelling is to use computational fluid dynamics (CFD) that is equipped for creating points of interest of the flow field and fluid properties taking into account of numerical solutions of the flow domain. Particular types of flow including heat exchange, radiation, turbulence, and so on at any given working conditions or model geometry can be analysed using CFD. Information that is hard to acquire in an exploratory set up can be effectively examined utilizing CFD.

Later CFD concentrates on ejectors that modelled the flow as incompressible discounted the flows supersonic nature (Smith et al. [6]); others regarded it as compressible however falied to catch some key parts of the flow, such as the secondary flow choking and the shock wave(S.B.Riffat et al. [7]).

This paper deals with CFD analysis of an ejector under various operating condition .Analysis shows that geometry and operating conditions has a tremendous impact on the working of the ejector. The different geometrical parameters associated with ejector analysis includes length and radius of constant area section ,nozzle exit radius ,nozzle exit position.

## 2 EJECTOR REFRIGERATION SYSTEM

A basic vapour absorption refrigeration system is shown in the fig 1. First, the refrigerant flows through an evaporator where it absorbs energy and changes phase from liquid to vapour.This vapour is absorbed by absorbent in absorber and is pumped to generator.The high temperature refrigerant leaving the generator rejects heat to environment in the condenser. With the help of an ejector cycle, this waste heat energy can be utilized to increase COP of refrigeration system.

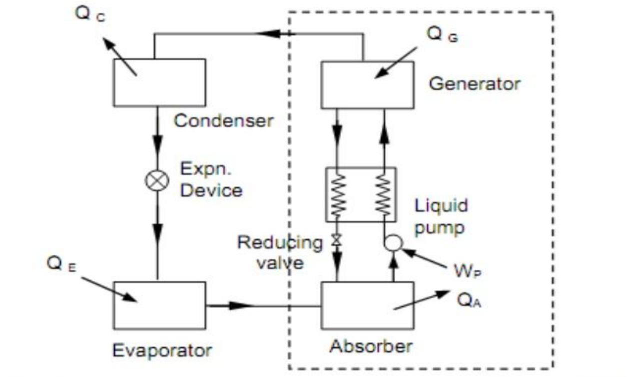



Fig 1. Simple vapour absorption system

Fig. 2 shows the vapour absorption system with an ejector . The system functioning can be explained as follows

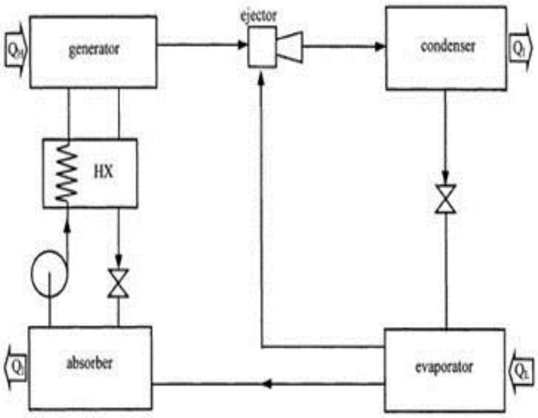



Fig. 2. Vapour absorption system with ejector

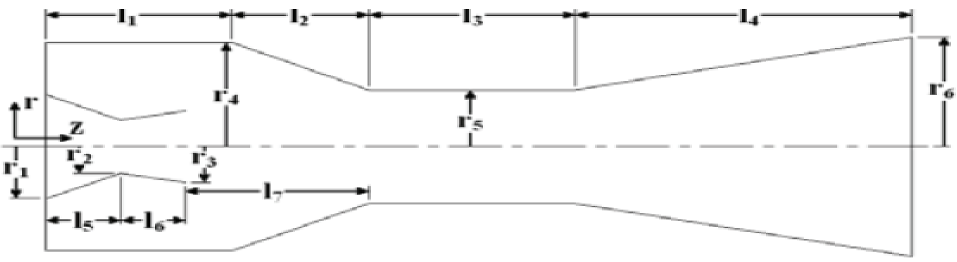
1. The high pressure high temperature vapour from the generator enters the ejector through primary nozzle that is a convergent divergent nozzle. During flow the energy of vapour is converted to kinetic energy in the form of supersonic velocity flow of gas.
2. The secondary stream from the evaporator is then entrained into the ejector due to low pressure generated by the expansion of primary stream.
3. The momentum transfer from primary stream to secondary stream takes place along the surface of contact between the two. The two streams mix properly at the constant area section of the ejector. The resulting flow then moves to diffuser.
4. In the diffuser the kinetic energy is converted into pressure energy. The outlet of ejector then enters the condenser.

The ejector cycle is best characterized by the entrainment ratio. The entrainment ratio is defined as the ratio of secondary mass flow rate that comes from the evaporator to the primary mass flow rate from the generator.

## 3. MODELING OF THE PROBLEM

### *3.1 Geometry*

A schematic drawing of a vapor-jet ejector that demonstrates the major measurements utilized as a part of this study is shown in Fig. 3. It has been assumed that the ejector is axi symmetric along the z-axis, therefore just a slim cut of an ejector is displayed. Basically, the ejector comprises of two annular converging diverging nozzles. Gas from the evaporator enters axially into the space outside the primary nozzle through outer nozzle. The secondary flow is accelerated through the length $l_2$ until it mixes with primary flow in $l_3$. The mixed flow is expanded through diffuser along length $l_4$ until it exit ejector.




### *3.2 Boundary Conditions*

The geometry of the ejectors used in the CFD model varied in the different cases considered. In all cases, the walls were considered to be adiabatic, no-slip boundaries. The fluids at the primary and secondary inlets were considered to be gasses with very little superheat. A constant pressure was applied at the ejector outlet. The dimensions and the properties of the refrigerant used in the basic ejector are summarized below .

| GEOMETRY | PARAMETER NAME | VALUE (mm) |
|---|---|---|
| P1 | L1 | 40 |
| P3 | L3 | 55.6 |
| P4 | L4 | 56.94 |
| P5 | L5 | 18.32 |
| P6 | L6 | 18.32 |
| P7 | R1 | 6.65 |
| P8 | R2 | 1.32 |
| P9 | R3 | 2.25 |
| P10 | R5 | 3.67 |
| P11 | R6 | 7.04 |
| P12 | L2 | 32.24 |
| P13 | R4 | 11.55 |

Table 1:Dimensions of the ejector

| PARAMETER NAME | VALUE | UNIT |
|---|---|---|
| Density | 1234.1 | $Kgm^3$ |
| Specific heat | 1153.7 | J/KgK |
| Thermal conductivity | 0.0906 | W/mK |
| Viscocity | 0.0004 | Pas |
| Evaporator pressure | 0.047 | Mpa |
| Generator pressure | 0.4006 | MPa |
| Evaporator temperature | 12 | C |
| Generator temperature | 78 | C |
| Outlet pressure | 0.06 | MPa |
| Outlet back flow temperature | 15 | C |

Table 2: Properties and working conditions

### *3.3 Governing Equation*

The flows in the presented vapour-jet ejectors model are considered to be incompressible, steady-stated, three dimensional and axi-symmetric Under steady-state conditions, the general form of the governing equations are:

THE MASS CONSERVATION EQUATION

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\overrightarrow{v}) = S_m$$

$S_m$=mass added to the continuous phase from dispersed second phase

For 2D axisymmetric geometries continuity equation is given by

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial r}(\rho v_r) + \frac{\rho v_r}{r} = S_m$$

$v_x$=axial velocity

$v_r$=radial velocity

x =axial coordinate

r=radial coordinate

THE MOMENTUM CONSERVATION EQUATION

$$\frac{\partial}{\partial t}(\rho\overrightarrow{v}) + \nabla.(\rho\vec{v}\,\vec{v}) = -\nabla P + \rho\vec{g} + \vec{F}$$

P=static pressure

$\rho\vec{g}$=gravitational body force

$\vec{F}$=external body force

For 2D axisymmetric geometries the axial and radial momentum conservation equation is given by

$$\frac{\partial}{\partial t}(\rho v_x) + \frac{1}{r}\frac{\partial}{\partial x}(r\rho v_x v_x) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r v_x) = -\frac{\partial P}{\partial X} + F_x$$

and

$$\frac{\partial}{\partial t}(\rho v_r) + \frac{1}{r}\frac{\partial}{\partial x}(r\rho v_x v_r) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r v_r) = -\frac{\partial P}{\partial r} + F_r$$

where

$$\nabla.\vec{v} = \frac{\partial v_x}{\partial x} + \frac{\partial v_r}{\partial r} + \frac{v_r}{r}$$

ENERGY EQUATIONS

Conservation of energy is described by

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\left(\vec{v}(\rho E + p)\right) = -\nabla.\left(\sum_j h_j J_j\right) + S_h$$

### *3.3 Calculation Procedure*

The Mesh was generated on a Tetrahedral dominant mesh settings in addition to hexahedral, prism and wedge elements. Fine Relevance center with 5 layers of Inflation provided elements of higher quality also with higher aspect ratio near the boundaries for proper prediction of wall conditions.

The material properties were used from REFPROPv9 and while the problem was run with different fluid models, the Invicid flow proved to be the best in predicting the working of the supersonic ejector.

A coupled pressure velocity coupling scheme was used with second order spatial descretization for pressure momentum and energy, with Pseudo Transient setting. Further the mesh was initialized using hybrid Initialization.

## 4. RESULT AND DISCUSSION

The design of a Supersonic Ejector used in the Vapour Absorption Refrigeration System has a huge impact on its overall performance. Though there have had been a lot of studies regarding the performance of Supersonic Ejectors, this study defines the variation of the Entrainment ratio of the flow with change in different parameters such as Back pressure from the Condenser, Nozzle exit radius, The length of the Nozzle Diffuser and its position from the Venturi neck of the Ejector, the Length of the Ejector Venturi throat, the diameter of the Venturi throat and the Generator Pressure inducing the Entrainment.

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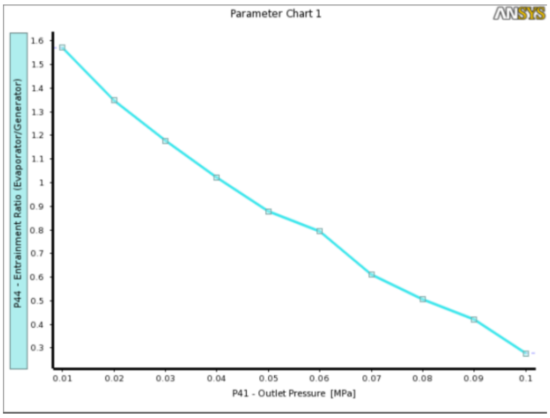


Fig X-1

From Fig X1, we see that the Entrainment Ratio decreases with increasing back flow pressure, this is true as, when higher back flow occurs in the condenser, the system requires higher Generator pressure to keep up the suction of the Evaporator fluid constant. But when it is not possible to provide additional Generator pressure, the entire entrainment ratio decreases and hence there will be a fall in the Refrigeration System Performance

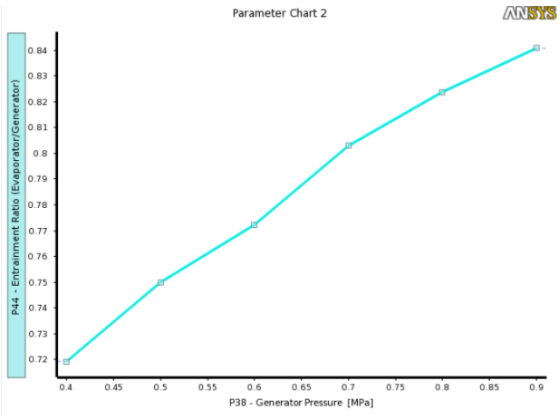


Fig X-2

As seen from Fig X2, with increase in Generator Pressure the Entrainment ratio rises. This can be accounted for by the drop in pressure in the Ejector, due to increase generator fluid flow velocity. Because of this drop in pressure inside the ejector, it leads to more suction for the Evaporator fluid, hence leads to higher performance of the system.

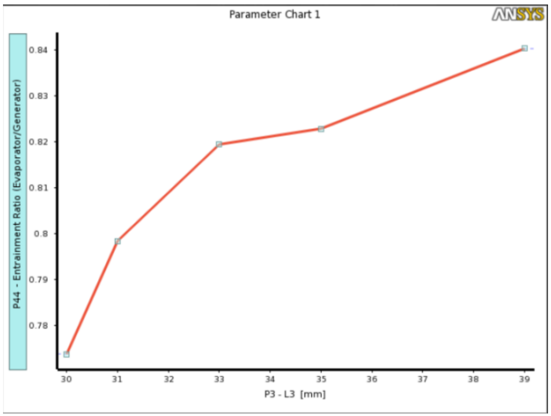


Fig X-3

The Figure X3 shows variation of Entrainment Ratio with increase in Throat Length of the Ejector. Now as seen from the graph, the Entrainment Ratio increases with increase in Ejector Throat length however the limitation exists as we cannot increase the throat length indefinitely. Hence only an optimum value of Ejector throat length need to be found out for effective gain in system performance.

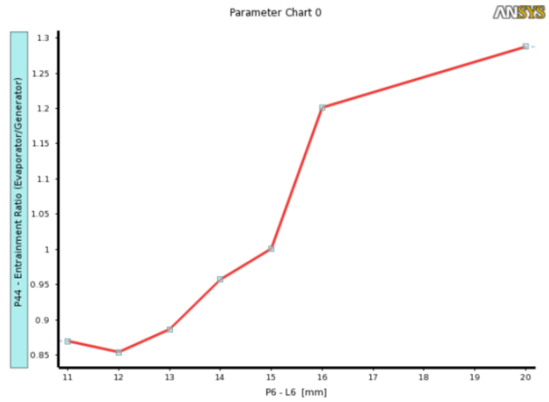


Fig X-4

Figure X4 depicts the variation of Supersonic Nozzle diffuser length to entrainment ratio. As the Nozzle diffuser length increases the net effective cross section area of the ejector used for the entrainment decreases, and hence the net mass flow into the ejector from the evaporator increases. However this also has a limitation that it can only be increased to a point which meets the minimum area, beyond which the entrainment ratio is expected to fall. As from the Geometry, the sum of L5 and L6 should be less than 75% of the sum of L1 and L2 lengths.

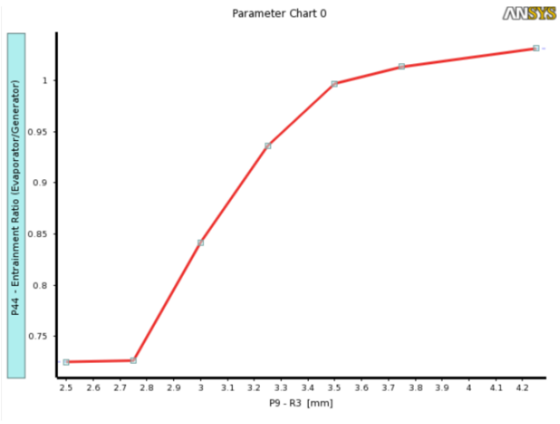


Fig X-5

Similar to the increase in length of the Nozzle diffuser, the increase in radius of the nozzle diffuser, also reduces the effective cross sectional area used for the entrained flow, hence exactly similar to the variation of the diffuser length, the variation of radius increases the entrainment ratio, to an extent until it start to decrease.

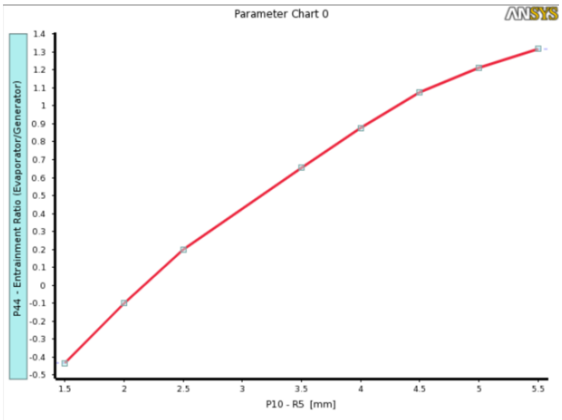


Fig X-6

As seen in figure X6 the increase in throat diameter of the Ejector can lead to increased entrainment ratios, but as the throat diameter increases, the obstruction in the flow path of the Nozzle reduces and hence the suction efficiency of the nozzle increases thereby entraining more evaporator fluid into the primary flow, leading to a net increase in Entrainment ratio. However we predict that as the radius becomes nearly equivalent to the inner and outer radii of the Ejector, the Entrainment ratio becomes constant where as the Ejector's Outer Nozzle and Diffuser becomes useless.

## 5. CONCLUSION

The present study has utilized a CFD model of ejectors working with R141b to investigate the effects by varying geometric parameters on the execution of the ejector at various working conditions .Three parameters examined were length and radius of constant area section ,nozzle exit radius and nozzle exit position. The study shows that progressions to these parameters do affect the performance.

The study shows the helpfulness of CFD models in investigations of ejectors; once a model is accepted, the stimulations can be keep running in a moderately brief timeframe

## 6. REFERENCE

[1] Aphornratana, S. and Eames, I.W., 1997. A small capacity steam-ejector refrigerator: experimental investigation of a system using ejector with movable primary nozzle. *International Journal of Refrigeration*, *20*(5), pp.352-358.

[2] Sun, D.W., 1997. Solar powered combined ejector-vapour compression cycle for air conditioning and refrigeration. *Energy Conversion and Management*,*38*(5), pp.479-491.

[3] Eames, I.W., Aphornratana, S. and Haider, H., 1995. A theoretical and experimental study of a small-scale steam jet refrigerator. *International Journal of Refrigeration*, *18*(6), pp.378-386.

[4] B.J. Huang, V.A. Petrenko, I.Y.A. Samofatov, N.A. Shchetinina, Collector selection for solar ejector cooling system, Sol Energy 71 (4) (2001) 269–274.

[5] Sun, D.W., 1999. Comparative study of the performance of an ejector refrigeration cycle operating with various refrigerants. *Energy Conversion and Management*, *40*(8), pp.873-884.

[6] Smith, S.J., Riffat, S.B., Wu, S. and Eames, I., 1997. Low-pressure ejectors: prediction of performance by computational fluid dynamics.*Building Services Engineering Research and Technology*, *18*(3), pp.179-182.

[7] S.B. Riffat, P. Everitt, Experimental and CFD modelling of an ejector system for vehicle air conditioning, J Inst Energy 72 (1999) 41–47.

[8] Rusly, E., 2004. Ejector cooling with reference to combined ejector-vapour compression system.

[9] Chang, Y.J. and Chen, Y.M., 2000. Enhancement of a steam-jet refrigerator using a novel application of the petal nozzle. *Experimental Thermal and Fluid Science*, *22*(3), pp.203-211.

[10] Hong, W.J., Alhussan, K., Zhang, H. and Garris, C.A., 2004. A novel thermally driven rotor-vane/pressure-exchange ejector refrigeration system with environmental benefits and energy efficiency. *Energy*, *29*(12), pp.2331-2345.

[11] Keenan, J.H. and Neumann, E.P., 1942. A simple air ejector. *ASME J. Appl. Mech*, *9*(2), pp.A75-A81.

[12] Al-Khalidy, N. and Zayonia, A., 1995. *Design and experimental investigation of an ejector in an air-conditioning and refrigeration system* (No. CONF-950624--). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA (United States).

[13] Keenan, J.H., 1950. An investigation of ejector design by analysis and experiment. *Journal of Applied Mechanics*, *17*, p.299.

[14] Henzler, H.J., 1982. Design of ejectors for single-phase material systems. *Chemie Ingenieur Technik*, *54*(1), pp.8-16.

[15] Sokolov, M. and Hershgal, D., 1993. Optimal coupling and feasibility of a solar-powered year-round ejector air conditioner. *Solar Energy*, *50*(6), pp.507-516.