Analysis of Constant Pressure and Constant Area Mixing Ejector Expansion Refrigeration System using R-1270 as Refrigerant

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Abstract - *It is established that the Ejector Expansion Refrigeration system achieves the significant improvement in coefficient of performance as compared to other system. Use of an ejector as expansion device is one of the alternative ways. The performance of a vapour compression system that uses an ejector as an expansion device is investigated. Ejector Expansion Refrigeration systems are analysed in this article using constant pressure and constant area mixing ejector as an expansion device. This paper provides a comparison between constant pressure and constant area model using R-1270 as a refrigerant. In the analysis, a two-phase constant area and constant pressure ejector flow model was used. Pressure variation along the length of the ejector is obtained for constant area model. The pressure variation is found to be higher for constant area ejector model compared to constant pressure model.*

Key words: Ejector, vapour compression cycle, R-1270 refrigerant, Coefficient of Performance

1. INTRODUCTION

Use of ejector as an expansion device by replacing the throttling valve in the vapour compression refrigeration cycle seems to be one of the efficient ways to reduce the throttling loss or the expansion irreversibility in the refrigeration cycle. Ejector also reduces the compressor work by raising the suction pressure to a level higher than that in the evaporator leading to the improvement of Coefficient of Performance (COP). Kornhauser [1] analysed the thermodynamic performance of the ejector-expansion refrigeration cycle using R-12 as a refrigerant based on constant mixing pressure model and found a COP improvement of up to 21% over the standard Cycle under standard operating conditions. Ejector operation relies on the principle of interaction between two fluid streams at different energy levels, in order to provide compression work. The stream with high total energy is the primary stream or motive stream while the other, with the lowest total energy, is the secondary or induced stream. There is a mechanical energy transfer from the primary stream to the secondary stream; imposing on it a compression effect. Ejector reduces the compressor work by raising the suction pressure to a level higher than that of Evaporator, which in turn improves COP of the system. It also enables to reduce size of the evaporator. Ejector Expansion Refrigeration system is much more efficient than conventional VCR system. Raman in their work, using heat exchanger in the

constant pressure ejector found that R1270 yields a maximum COP improvement of 42.85%.

Nomenclature

V	fluid velocity (m/s)
COP	coefficient of performance
h	specific enthalpy (kJ/kg)
P	pressure (kPa)
q_e	specific cooling effect (kJ/kg)
t	temperature (°C)
w_c	specific work (kJ/kg)
x	vapor quality
η	isentropic efficiency
μ	entrainment ratio
Ø	ejector area ratio
PLR	pressure Lift Ratio

Subscripts

b	basic cycle
c	compressor
ej	ejector

II Literature Review

Kornhauser [1] analysed the thermodynamic performance of the ejector expansion refrigeration cycle using R-12 as a refrigerant based on a constant mixing pressure model.
Sarkar[3] has carried out thermodynamic analyses and comparison of three natural refrigerants based on compression refrigeration cycle(ammonia, isobutene, and propane) and found that the effect of using internal heat exchanger in ejector expansion refrigeration cycle is not profitable.

Sarkar[4] analysed and compared the ammonia, propane and isobutene based vapour compression refrigeration cycle using constant area mixing ejector as an expansion device. Sarkar[5] analysed a two phase ejector and their applications in vapour compression refrigeration system. Chaudhary and Singh[6] did the work on the performance improvement in ejector expansion refrigeration system by using liquid vapour heat exchanger in constant mixing chamber

III. Model Description

In Ejector Expansion Refrigeration System there are two models.

1. Constant Pressure Mixing Model
2. Constant area Model

Constant Pressure Model:

The constant pressure mixing ejector-expansion vapour compression Refrigeration cycle is shown in Figure 1 along with the Corresponding P–h diagram in Figure 2. The primary stream from the condenser (state 3) and the secondary fluid from the evaporator (state 8) are flowing through primary and the secondary nozzles, respectively, 3-4 and 8-9 to mixing chamber at constant pressure. after the mixing of the flow is discharged to diffuser (10–5) section of the ejector and then separated in forms of vapour (state 1) and liquid (state 6) so that this ratio should be matched with the inlet ratio of primary and secondary flows. Then, the liquid circulates through expansion valve (6–7) and evaporator (7–8), whereas the vapour circulates through compressor (1–2) and condenser (2–3). Three ejector parameters, entrainment ratio (secondary mass flow to primary mass flow), pressure lift ratio (diffuser exit pressure to secondary nozzle inlet

Pressure) and geometric area ratio (mixing chamber area to primary nozzle exit area) significantly influence the system performance with an optimum ratio.

The ejector-expansion vapour compression refrigeration cycle has been modelled based on the mass, momentum and the energy conservations in each component. To simplify the theoretical model and setup the equations per unit total ejector flow, the following assumptions have been made:

(i) Neglect the pressure drop in the condenser, evaporator, separator and the connection tubes.

(ii) No heat transfer with the environment for the System except in condenser.

(iii) The refrigerant conditions at the evaporator and condenser outlets are saturated.

(iv) The vapour stream from the separator is saturated vapour and the liquid stream from the separator is saturated liquid.

(v) The flow across the expansion valve or the throttle valves is isenthalpic.

(vi) Both the motive stream and the suction stream reach the same pressure at the inlet of the constant area mixing section of the ejector. There is no mixing between the two streams before the inlet of the constant area mixing section.

(vii) The expansion efficiencies of the motive stream and suction stream are given constants. The diffuser of the ejector also has a given efficiency.

(viii) Kinetic energies of the refrigerant at the Ejector inlet and outlet are negligible

Constant Area Ejector Expansion Refrigeration System:-

The Schematic diagram of constant area ejector-expansion vapours compression Refrigeration cycle is shown in Figure 3 along with the corresponding P–h diagram as shown in Figure 4. The primary flow from the condenser (state 3) and the secondary flow from the
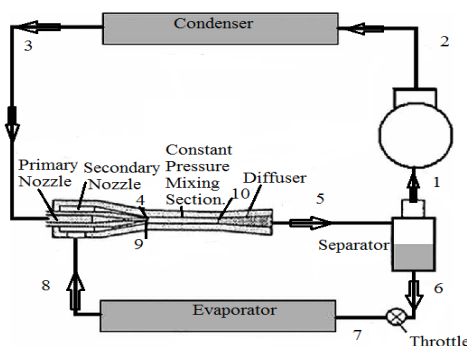

Figure1 Schematic Diagram of Constant Pressure Mixing Ejector expansion Refrigeration cycle

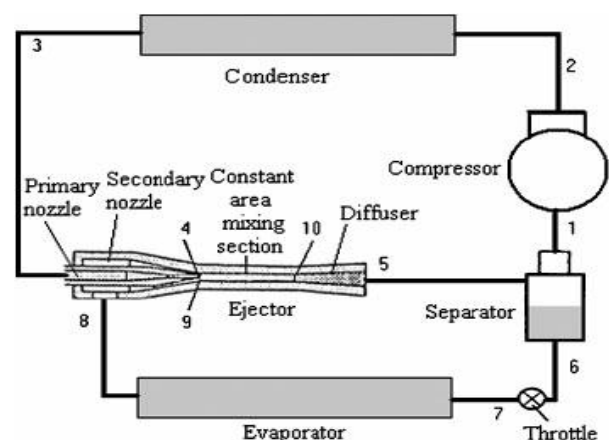Figure2 P-h Diagram of Constant pressure Refrigeration cycle

Figure3 Schematic Diagram of Constant Area Mixing Ejector expansion Refrigeration cycle
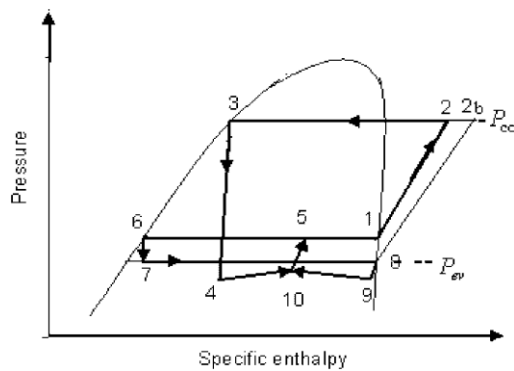
Figure4 P-h Diagram for Constant Area Ejector Expansion Refrigeration

evaporator (state 8) are going through primary and secondary nozzles, respectively, constant area mixing and diffuser (10–5) sections of the ejector and then separated in forms of vapour (state 1) and liquid (state 6) so that this ratio should matched with the inlet ratio of primary and secondary flows. Then, the liquid circulates through expansion valve (6–7) and evaporator (7–8), whereas the vapour circulates through Compressor (1–2) and condenser (2–3). Three ejector parameters, entrainment ratio (secondary mass flow to primary mass flow), pressure lift ratio (diffuser exit pressure to secondary nozzle inlet pressure) and geometric area ratio (mixing chamber area to primary nozzle exit area) significantly influence the system performance with an optimum ratio.

The Parameters used in expansion refrigeration cycle are as follows.

Entrainment Ratio (μ): It is the ratio of secondary mass flow rate of refrigerant coming out from the evaporator (Vapor) to the primary mass flow rate of refrigerant coming out from the condense (liquid).

$$\mu = m_v/m_l$$

$$m_v = \frac{1}{(1+\mu)}$$

$$m_l = \frac{\mu}{(1+\mu)}$$

Geometric area ratio($\emptyset$): It is the ratio of mixing chamber area (a_4+a_9) to primary nozzle exit area (a_4).

$$\Phi = \frac{(a_4 + a_9)}{a_4}$$

$$a_4 = \frac{1}{(1+\mu)\rho_4 C_4}$$

$$a_9 = \frac{1}{(1+\mu)\rho_9 C_9}$$

Compressor work: It is the amount of high grade energy which is required to run the compressor.

$$w_c = \frac{1}{1+\mu}(h_2 - h_1)$$

Refrigeration Effect: It is the amount of heat which is to be taken from the evaporator.

$$q_{ev} = \frac{\mu}{1+\mu}(h_8 - h_6)$$

Coefficient OF Performance: it is the ratio of refrigeration effect to work required.

$$COP = \frac{q_{ev}}{w_c}$$

IV. METHODOLOGY

For the analysis of Ejector expansion Model, Computational Fluid Dynamics (CFD) Software is used and Procedure was as given below:

1. Design the ejector as per proposed calculations [6].
2. Design a boundary model of the ejector.
3. Import the geometry in Ansys flow dynamics.
4. Start the fluent flow solver.
5. Set the inlet conditions as pressure inlet, set inlet pressures in Pa and temperature in k.
6. Set outlet conditions as pressure outlet and define outlet pressure and temperature.
7. Define walls and allot material to it (aluminium).
8. Define the flowing fluid (in this case propylene).
9. Define no. of iteration to be run.
10. Specify ambient conditions.
11. Run the solver.
12. Open the result window.
13. Define the type of result display (i.e. pressure, temperature, velocity).
14. Set the number of contours required in the display graph.
15. Display and interpret the results.

V. Results and Analysis

Study for the analysis was carried out based on the following two bases.

1. Analysis based on COP
2. Analysis based on position of the primary nozzle

Based on coefficient of Performance:

COP of constant pressure ejector expansion refrigeration cycle was evaluated by developing thermodynamic model, and found that COP of Constant pressure EERS as compared to conventional VCRS. The COP of EER with constant pressure mixing ejector was 6.80 where as in case of VCRS it was 4.90. So % increase in COP is 38.7.

Based on the position of primary nozzle:

Changing the position of primary nozzle, different pressure Contours has been developed and the Following observations has been made.

- From figure 5 to 8 are the pressure contours which show the pressure variation along the length of ejector.
- As the primary nozzle position varies, there is change in the pressure for different segments.
- In Fig.5 primary nozzle is advanced by 5mm towards the mixing chamber and found that the pressure at the exit of primary nozzle reaches to 1.30×10^5 [Pa] when exit pressure of diffuser is 5.41×10^5 [Pa] .
- In Fig 6 there is 10mm advancement and pressure at the exit of primary nozzle is found to be less as compared to previous case.
- Fig7 shows the pressure variation for 15 mm advancement of the primary nozzle. In this case the Pressure increases at the exit of primary nozzle with respect to the case of 10mm.
- In Fig 8 it is found that the pressure variation is almost negligible when primary nozzle is advanced with 20mm.
- By this analysis obtained results it is clear that after 20mm advancement of the primary nozzle there is no significant change in the pressure which results no more change in the performance of the cycle.
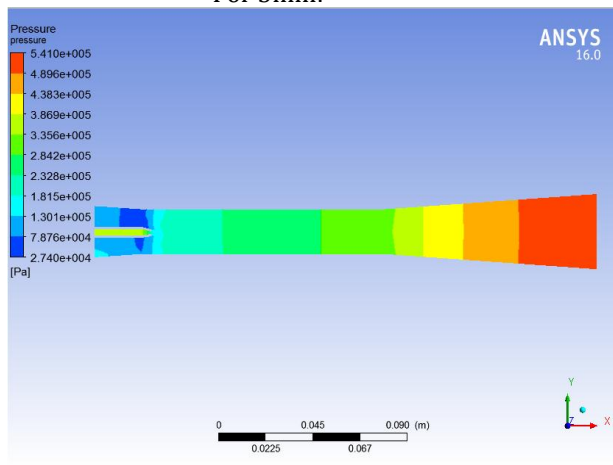
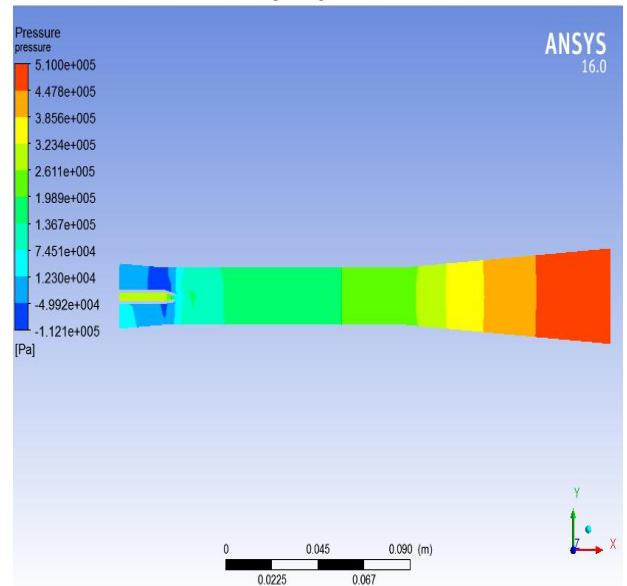Pressure variation with 5mm advancement of the nozzle

For 10mm-

Fig:-6

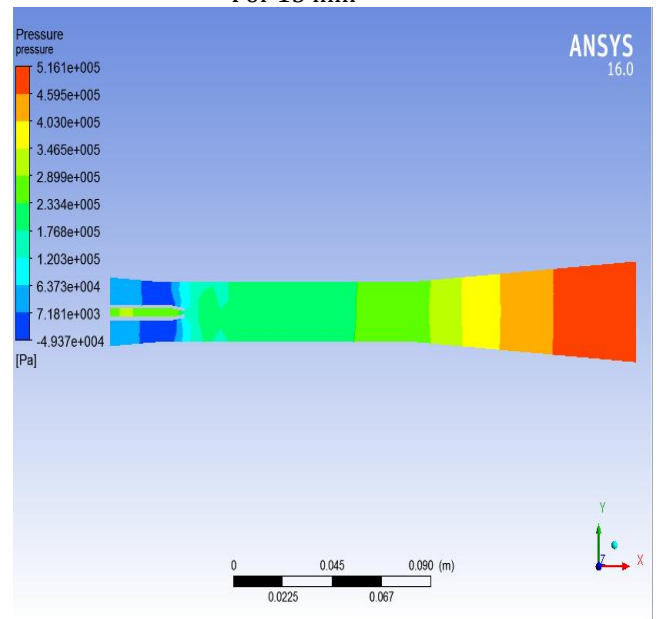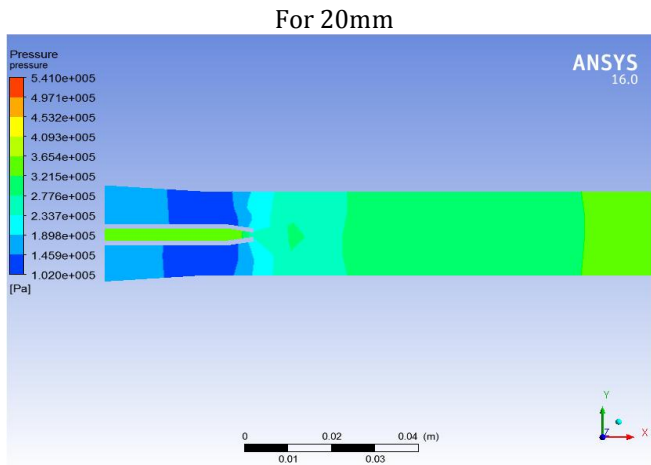Pressure variation with 10mm advancement of the nozzle

For 15 mm

Fig:-7

Pressure variation with 15mm advancement of the nozzle

For 5mm:

Fig:-5

For 20mm

Fig:-8

Pressure variation with 20mm advancement of the nozzle

VI. Conclusion

This paper provides the thermodynamic and CFD analysis of ejector expansion refrigeration cycle. Thermodynamic analysis for Constant pressure model using R-1270 as refrigerant is carried out whereas for constant area mixing ejector model, different pressure contours are developed using CFD software. In the analysis of Constant pressure model it is found that there is a significant improvement of COP as compared to conventional Vapor compression refrigeration system. In case of constant area mixing model, developed pressure contours gives the idea of pressure variation and mixing pattern of primary and secondary fluid streams when the primary nozzle is advanced at different positions. This pressure variation is justified with the previous work carried out by researchers. By the analysis and obtained results it is found that there is no significant change in the pressure after 20mm advancement of the primary nozzle, which results no more change in the performance of the constant area mixing ejector expansion cycle.

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