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Performance Analysis of Two-Phase Constant Pressure Ejector Used in Ejector Expansion Refrigeration System (EERS)

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Abstract

As the urgency to reduce high-grade energy consumption grows, it is crucial to investigate innovative alternatives to energy-intensive technologies like vapor compression refrigeration. One promising approach is the integration of a two-phase ejector in place of the traditional throttle valve, which can significantly lower power usage in standard vapor compression refrigeration systems. This study focuses on designing a constant-pressure two-phase flow ejector and assessing the performance of an ejector expansion refrigeration system using R134a as the refrigerant. To optimize performance, a simulation program was created to analyze how various operating and geometric parameters of the ejector affect system efficiency. A comparison with existing experimental data revealed that the developed model can accurately predict the system's coefficient of performance (COP). Notably, the COP improved by 8.86% when the evaporator temperature was raised from -25°C to 20°C and by 14% when the condenser temperature increased from 30°C to 70°C. Furthermore, the study provides correlations for sizing the key parameters of the ejector based on operating conditions, system cooling capacity, and ejector efficiencies.

Keywords: *Constant Pressure Ejector; Coefficient of Performance; R134a; Vapour Compression Refrigeration.*

1. Introduction

1.1. Ejector Expansion Refrigeration System

A two-phase ejector is a device used to handle two phases simultaneously—typically a gas (or vapor) and a liquid. These ejectors are widely used in various industrial applications where vacuum creation, gas compression, or mixing of gas and liquid streams is required. Two-phase ejectors operate based on the principle of momentum transfer. They utilize the high-velocity flow of a primary fluid to entrain and transport a secondary fluid. The primary fluid is expanded through a nozzle, creating a high-velocity jet that induces a suction effect on the secondary fluid, entraining it into the ejector and mixing the two phases. [6] In an ejector refrigeration system, the two-phase ejector is used to entrain and compress the refrigerant vapor (gas phase) coming from the evaporator. The primary fluid or another high-pressure fluid is used to drive the ejector. As the high-velocity primary fluid passes through the primary nozzle of the ejector, it creates a suction effect entraining in the low-pressure refrigerant vapor from the evaporator. The mixture of primary fluid and refrigerant vapor then passes through the diffuser section of the ejector, enabling the rise in static pressure. This increases the pressure of the refrigerant vapor to a higher suction pressure to be available at compressor inlet. This reduces the compressor work for the same cycle pressure ratio [7]. In figure 1 the high-pressure primary fluid (PF) expands and accelerates through the primary nozzle, reaching supersonic speeds and creating a low-pressure region relative to the low-temperature evaporator. This low-pressure zone, combined with the high-velocity primary fluid, draws in the secondary fluid (SF) through a channel linked to the low-temperature evaporator. While the two streams interact, mixing

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only begins at specific points along the length of the ejector. [1] (Figure 1,2)

Nomenclature	
EERS	Ejector Expansion Refrigeration System
COP	Coefficient of Performance
PF	Primary Fluid
SF	Secondary Fluid
ω	Entrainment Ratio
T_e	Evaporator Temperature
T_c	Condenser Temperature
P_e	Evaporator Pressure
P_b	Back Pressure
D_{mi}	Diameter of Motive Nozzle at Inlet
D_{mt}	Diameter of Motive Nozzle at Throat
D_{me}	Diameter of Motive Nozzle at exit
D_{ss}	Diameter of Motive Suction Section
D_{ms}	Diameter of Mixing Section
D_{de}	Diameter of Diffuser Section at Exit
L_{ss}	Length of Suction Section
L_{ms}	Length of Mixing Section
L_{ns}	Length of Nozzle Section
α_{ss}	Angle of Suction Section
α_{ds}	Angle of Diffuser Section
Subscript	
eec	Ejector Expansion Cycle
bc	Basic Cycle

Figure 1 Nomenclature

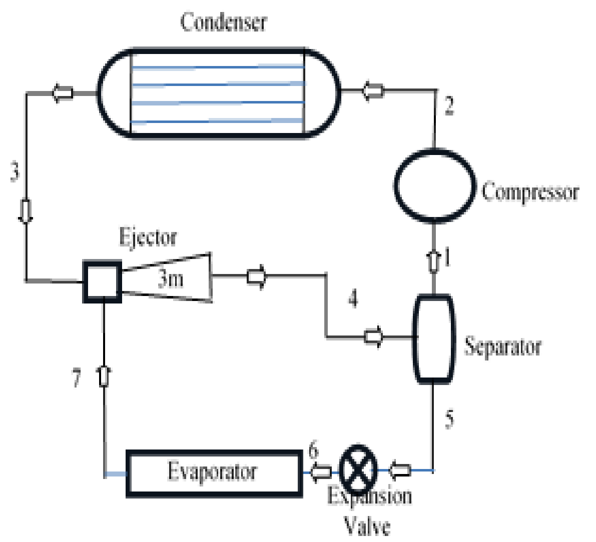

Figure 2 Layout of Ejector Expansion Refrigeration System

The SF continues to accelerate through a converging section and mixes isentropically with PF. It is assumed that mixing is completed by the end of the mixing chamber, which maintains a constant cross-sectional area. At this point, where mixing is anticipated to be finished, a thin shock wave typically forms due to the high back pressure at the diffuser exit, which aligns with the compressor inlet pressure. In the subsonic diffuser the velocity decreases and as pressure is partially restored, the flow stream experiences further compression. (Figure 3) [14]

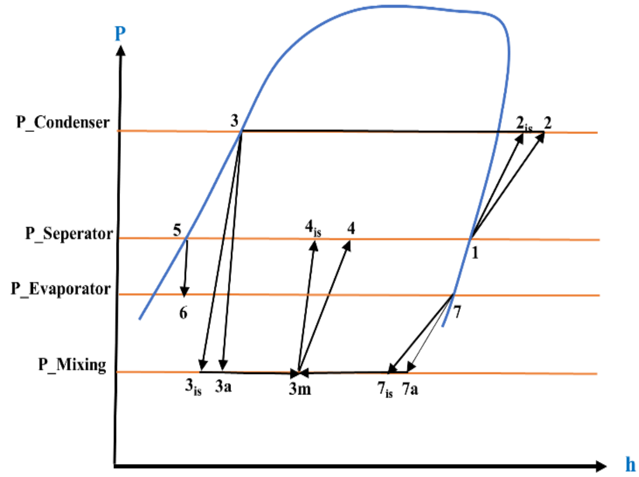

Figure 3 Shows the Variation in Pressure and Enthalpy of Primary and Secondary Fluid

2. Methodology

The methodology involved in the investigation of a 2-phase constant pressure ejector's in an Ejector Expansion Refrigeration System (EERS) using refrigerant R134a is outlined. The mathematical model is developed in Engineering Equation Solver (EES) to analyse the effects of operational and geometric parameters on Entrainment Ratio, Pressure Lift and ejector efficiency. EES (Engineering Equation Solver) is used to solve a variety of interconnected non-linear differential and algebraic equations through numerical methods. EES has built-in property functions for many refrigerants. Enthalpy, entropy, temperature, pressure and specific volume is computed by different mathematical equation with the help of thermophysical built in properties and finally COP for both basic cycle and ejector expansion refrigeration system is evaluated. (Figure 4) [15-20]

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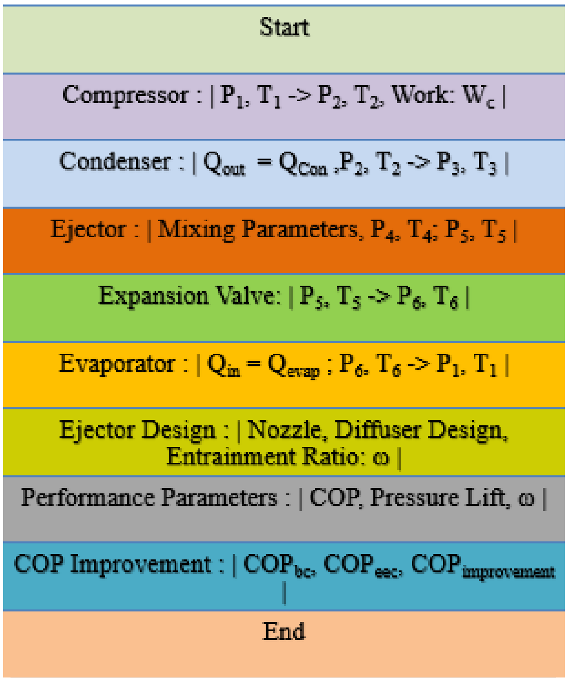

Figure 4 Flow Diagram for EES Software

Using the mathematical model described, the relative performance of the ejector expansion cycle is analyzed, influenced by the entrainment ratio (ω) and the secondary fluid pressure drop (Pe - Pb). (Table 2)

Table 2 Ejector's Geometrical Parameters

Refrigerant	D_{mi}	D_{mt}	D_{me}	D_{ss}	D_{ms}	D_{dse}	L_{ss}	L_{ms}	L_{ns}	α_{ds}	α_{ss}
R-134a	7	3	5	25	15	35	35	65	70	30	6

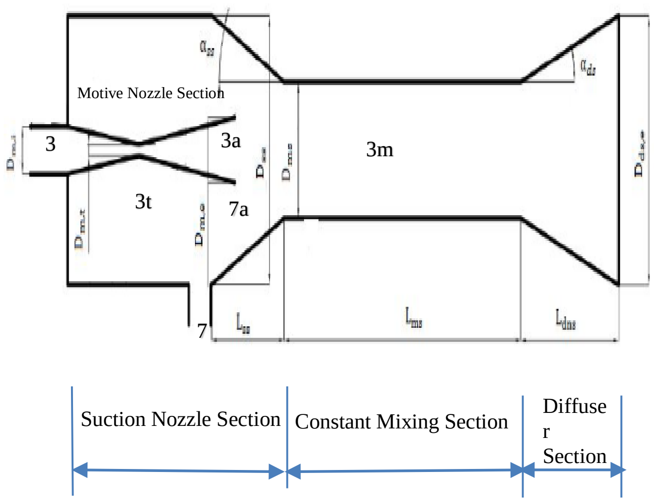

Figure 5 Ejector Design

3. Results

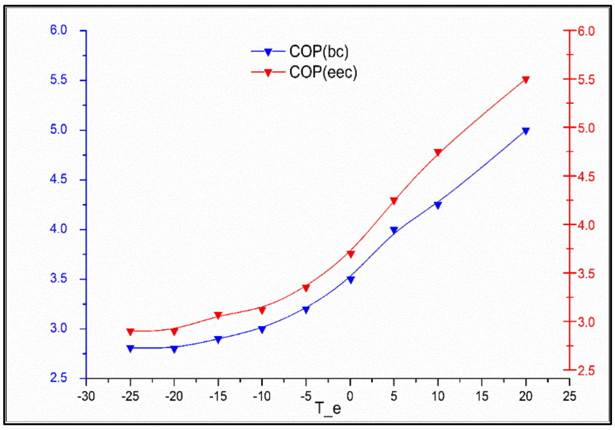

Figure 6 Variation of COP with Evaporator Temperature

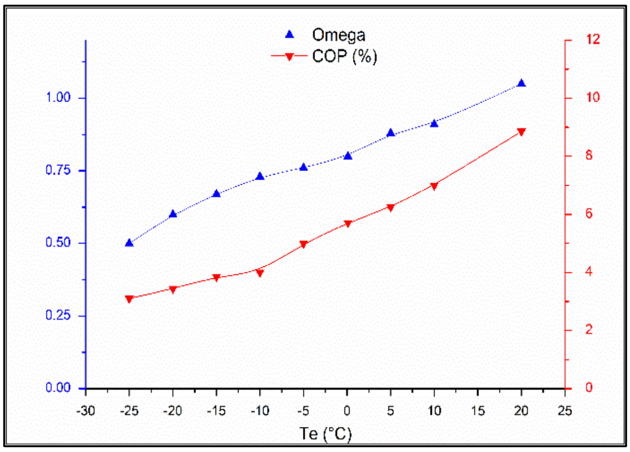

Figure 7 Variation of Percentage COP% and Entrainment Ratio with Evaporator Temperature

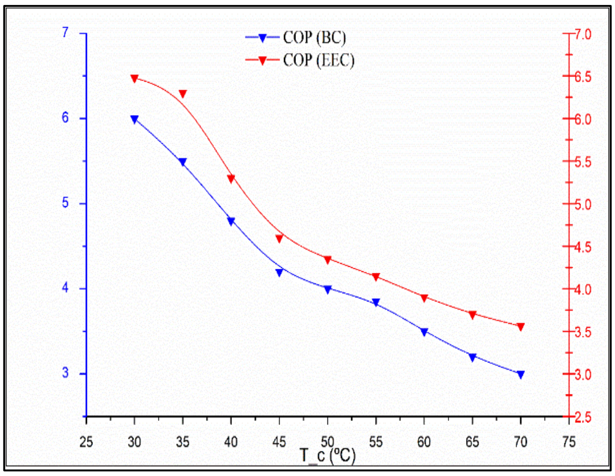

Figure 8 Variation of COP with Condenser Temperature

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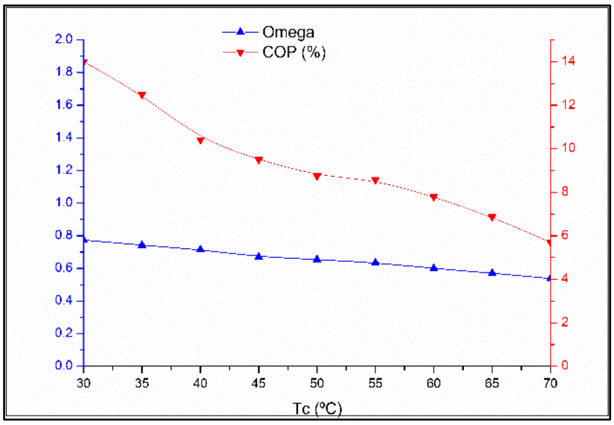

Figure 9 **Variation of Percentage COP% and Entrainment Ratio with Condenser Temperature**

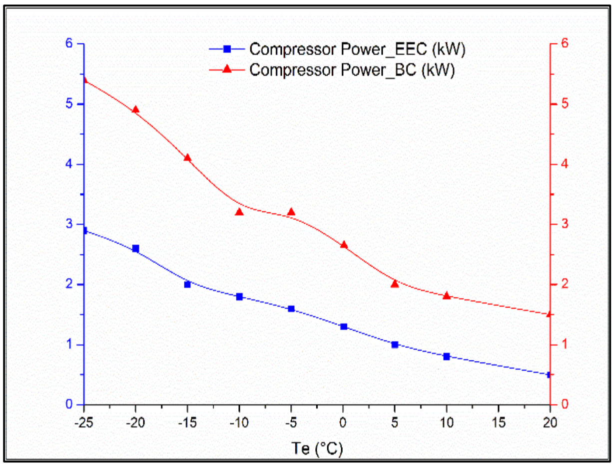

Figure 10 **Comparison of Compressor Work for Basic and Ejector Cycle Against Evaporator Temperature**

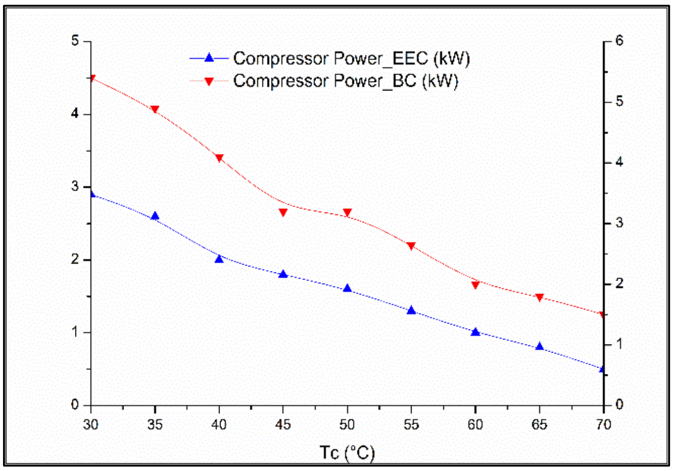

Figure 11 **Comparison of Compressor Work for Basic and Ejector Cycle Against Condenser Temperature**

Discussion

Figure 6 implicit the COP increases with increase in evaporator temperature, as the temperature in evaporator rises from -25°C to 20°C the variation of COP for both i.e., Basic Cycle (VCRS) and Ejector Expansion Cycle (eec) increase. Also, the higher COP can be achieved with eec. In Figure 7 result shows that increasing evaporator temperatures from -25°C to 20°C, COP and Entrainment Ratio both increases at Te =20°C maximum COP% change is 8.86 and entrainment ratio ω=1.05 can be achieved whereas at lower temperature Te = -20°C maximum COP% change is 3.10 at entrainment ratio (ω) =1.05 Figure 8 implicit the COP decreases with increase in evaporator temperature, as the temperature in condenser rises from 30°C to 70°C the variation of COP for both i.e., Basic Cycle (VCRS) and Ejector Expansion Cycle (EEC) decreases. Also, the higher COP can be achieved with EEC. In Figure 9, result shows that increasing condenser temperatures from 30°C to 70°C both COP% and Entrainment Ratio increases, at Tc = 30°C maximum COP% achieved is 14 with entrainment ratio 0.7. Also at Tc = 70°C, maximum COP% is 5.7 at entrainment ratio (ω) = 0.5. Figure 10 shows that as the temperature in evaporator increases from -25°C to 20°C compressor work decreases quantitatively, in ejector expansion cycle work done required is less as compared to basic cycle therefore the COP of ejector expansion cycle is higher. Figure 11 shows that as the temperature in condenser increases from 30°C to 70°C compressor work decreases quantitatively, also in ejector expansion cycle work done required is less as compared to basic cycle therefore the COP of ejector expansion cycle is higher. [21]

Summary

This study enhances the performance of EERS by analyzing geometric and operational parameters, achieving a significant improvement in system efficiency. Results indicate an increase in the ω from 0.5 to 1.05 and COP% from 3.1 to 8.86 as the evaporator temperature rises from -25°C to 20°C. Conversely, increasing the condenser temperature from 30°C to 70°C results in a reduction in COP from 14 to 5.7 and a 96% increase in compressor power (from 1.5 kW to 2.95 kW). The proposed system

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achieves a COP of 14%, outperforming previously reported values from studies. These findings contribute to improving industrial and commercial refrigeration systems by providing a framework for enhancing energy efficiency and sustainability in real-world applications.

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