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DESIGN ANALYSIS AND PERFORMANCE TESTING OF EJECTOR SPLIT AIR CONDITIONER USING HC-290 AS AN ALTERNATIVE REFRIGERANT TO HCFC-22

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Abstract— Isenthalpic expansion is one of the major source of irreversibility in a typical split air conditioners (SAC). This paper presents the design analysis and experimental results of an ejector split air conditioner (ESAC). An ejector is employed in the SAC instead of a standard expansion device to recover expansion losses while improving cooling capacity and minimizing energy usage. A 5.2 kW nominal capacity SAC that was originally designed for HCFC-22 was used for performance testing. Initially, a baseline performance test was conducted in a psychrometric test chamber as per Indian standard IS 1391 part 1. The COP of the original SAC using HCFC-22 was 3.2, while the COP of modified ejector split air conditioner (ESAC) was increased by 28.12 % and found to be 4.1. With drop-in test, HC-290 gave the COP of 4.6 which is 43.75 % higher compared to original SAC. Thus, use of HC-290 is an energy efficient and climate friendly alternative to HCFC-22 in Ejector split air conditioner.

Index Terms— Split air conditioner, HC-290, HCFC-22, Ejector expansion, Energy efficiency, Low GWP, Alternative refrigerants, Environment friendly refrigerant.

1. INTRODUCTION

Air conditioning provides the basic essence for comfort living. In AC applications, generally Evans-Perkins vapor compression cycle has been most commonly used for accomplishing the cooling. But, the isenthalpic expansion process shown in the Evan-Perkins cycle is irreversible resulting in limiting the cycle cooling and at the same time increases the work input compared to Carnot cycle shown in Fig. 1. This loss in the cycle is termed as throttling loss which reduces the cycle productivity, when estimated by the COP. [1]

To distribute the refrigerant from the high pressure side to the low pressure side of the system, the economical and reliable devices being used in the conventional VCC are valves, capillaries and diaphragms etc. But these devices allow isenthalpic expansion rather than isentropic expansion to take place which causes the throttling loss as described above. To decrease the throttling losses, a device with provision for creating an isentropic expansion as opposed to throttling process in which liquid enthalpy is changed over into mechanical work, is required. This work done by the expander is utilized to legitimately enhance the task of the compressor, along these lines lessening the work costs required for the cycle. Such expansion devices which expands the

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cooling limit of the cycle and builds the proficient system have either a complex design or expensive to use in VCC. Hence ejector is other alternative which is potentially simpler and less costly in which the secondary fluid is compressed with the help of enthalpy released by the expanding fluid. The main objective of this research is to integrate ejector as an expansion device into the vapor compression system and investigate its performance compared to conventional capillary tube VCC.

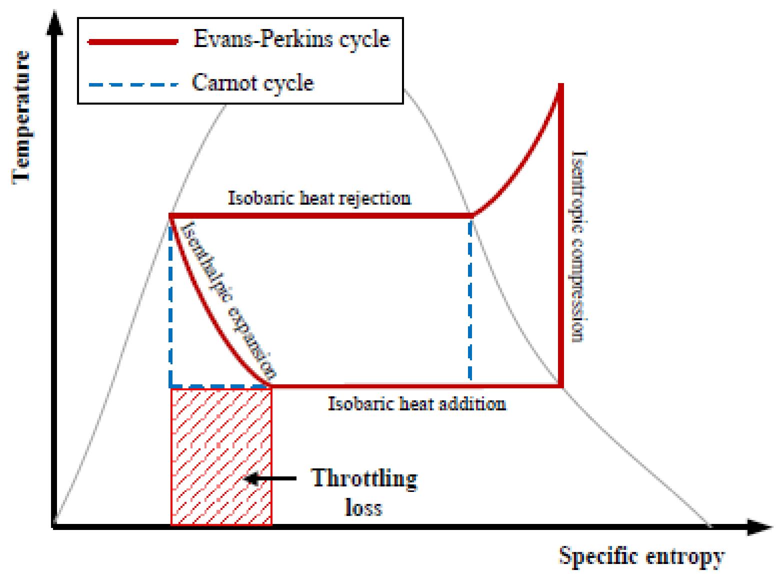

Fig. 1 Comparison of Evan-Perkins cycle and Carnot refrigeration cycle [1]

During the expansion of high pressure refrigerant the released enthalpy can be utilized by an ejector to compress the refrigerant at low pressure. The flow of fluid in ejector is shown in the Fig. 2. The high pressure (primary or motive) fluid is expanded in the primary nozzle at low pressure and high momentum and gets mixed with fluid at low pressure. The velocity of mixed flow is then reduced in diffuser and total momentum is converted into static pressure. Hence the suction fluid is received at the exit at higher pressure. The expansion process taking place here is isentropic because the enthalpy of the motive fluid is transformed to kinetic energy, which is transmitted to the suction fluid, reducing the enthalpy of the motive stream as it moves through the ejector. Isentropic expansion process is ideal case in which there is no irreversibility present and neither entropy generation takes place. Also ejector does not involve any moving parts hence they are inexpensive and robust option to the capillary tube in VCC.

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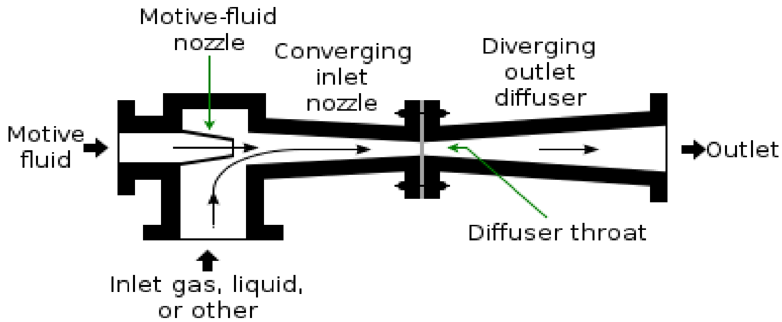

Fig. 2 Fluid flow zones in an ejector [2]

An ejector's performance is often measured in terms of entrainment ratio and suction pressure ratio. The main objective of this research is to use ejector in VCR cycle to restore development work and increase the energy efficiency of SAC system.

Using a constant-area ejector mixer as an expansion device, Jahar Sarkar [1] performed a thermodynamic analysis and comparison of refrigeration vapour compression cycles based on ammonia, HC-290, and isobutane. The geometrical parameter of the ejector is optimized for optimal cooling efficiency and enhanced performance under a variety of operating circumstances. Ammonia has the largest ideal geometrical characteristics, while refrigerant iso-butane has the smallest. Isobutane enhanced the maximum efficiency for HC-290 (17.9%) and ammonia (11.9%) by 21.6 percent by using an ejector as an expansion device.

Elbel [2] demonstrated the performance of a normal two-phase injection cycle in transcritical mode by varying the mixing zone lengths of the ejector. The study found that the shorter the mixing zone, the higher the ejector's coefficient of suction pressure, and the greater the ejector's efficiency. The length of the mixing zone appears to have a greater impact on the ejector's performance than the ejector's angle.

Sumeru et al. [3] investigated the performance of an ejector as a novel form of expansion mechanism for a split air conditioner. The findings revealed that an increase in COP caused by higher ambient temperatures was more dependent on compressor power than on increased cooling capacity. In a split-room air conditioner, replacing the capillary tube with an ejector with a modified ejector cycle a can enhance efficiency dramatically, especially at higher ambient temperatures. This demonstrates that the use of an ejector for expansion purposes has been determined for geographic areas with high outside temperatures. The numerical research provides a high drag coefficient for COP enhancement; however, an experimental study yields a low drag coefficient.

HC-290 was tested with both constant speed and inverter air conditioners by a number of researchers. Padalkar et al. [6] used HC-290 to evaluate the performance of a retrofitted, 5.1 kW capacity, SAC with constant speed compressor. In comparison to HCFC-22, cooling capacity

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increased by 2.8 percent and EER decreased by 1.1 percent with a 10% increase in compressor capacity. Padalkar et al. [8] studied the performance of HC-290 as an alternative to HCFC-22 in a 5.1 kW split air conditioner. Main goal was to reduce the charge of HC-290 in order to solve its flammability problem. With a 360g charge, the greatest EER achieved with HC-290 was 3.70.

Improvements in the use of an ejector for expansion work in vapor-compression cycles have been made in last decade. Another advantage of using an ejector is that it can supplement the compressor's power by using the ejector's pressure lift to raise the suction pressure. As a result, the general goal of this project is to build a two-phase ejector that may be used in a vapor-compression cycle to maximize efficiency.

2. EJECTOR ANALYSIS

In this study ejector is design with high drag coefficients so that it can be implemented in air conditioners. When the diameter of the nozzle and the angle of the diffuser are considered, it was determined that a well-designed nozzle can increase frame efficiency by more than 14.5 %. The stream flow in the ejector is analyzed using ANSYS fluent version 15.0. Pressure, temperature, and velocity changes could be predicted by simulating multiphase flows. The purpose was to design a two-phase constant area ejector for a 5.2 kW split air conditioner. The ejector was designed in a CAD tool and then tested in ANSYS. The simulation was conducted to determine the pressure drop across the ejector.

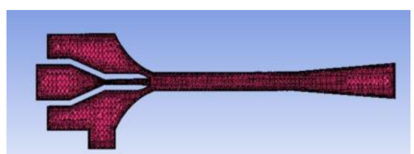

Fig. 3 Mesh model of Ejector

2.1 Velocity counters at mid cross section

The figure 4 shows the velocity variations along the ejector length. The velocity of liquid at the motive nozzle inlet is zero. As the liquid refrigerant passes through the throat the velocity increases

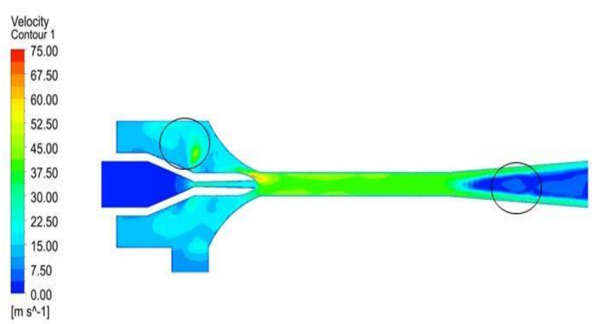

Fig. 4 Velocity variations along the ejector

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and it goes on increasing up to 45 m/s to 50 m/s in the constant area mixing zone. As the mixture passes through the diffuser, the total velocity is converted to static pressure. Thus at the end, we get the higher pressure at the diffuser exit.

The recirculation zones are visible in the suction nozzle and diffuser parts as shown in figure 5. This is due to the turbulence caused by the high-velocity vapours rushing inside. The pressure drops at that location as a result of the recirculation.

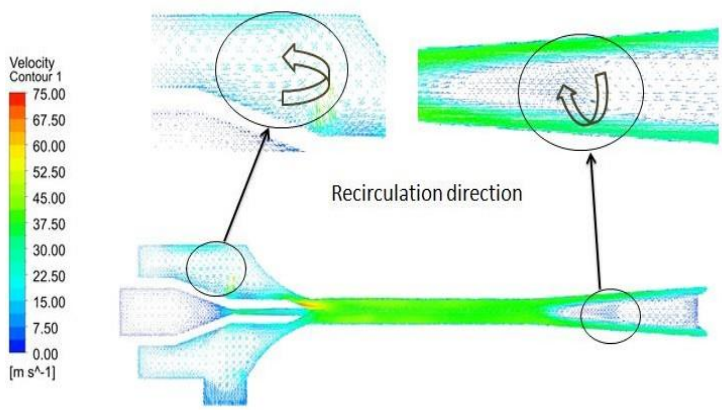

Fig. 5 Velocity vectors at mid-cross section

2.2 Pressure contour at mid cross section

The pressure changes along the length of the ejector are depicted in the figure 6. The pressure at the motive nozzle inlet is roughly 7.5 bars, whereas the pressure at the diffuser's end is nil. This indicates a 7.5 bar pressure drop along the length of the ejector.

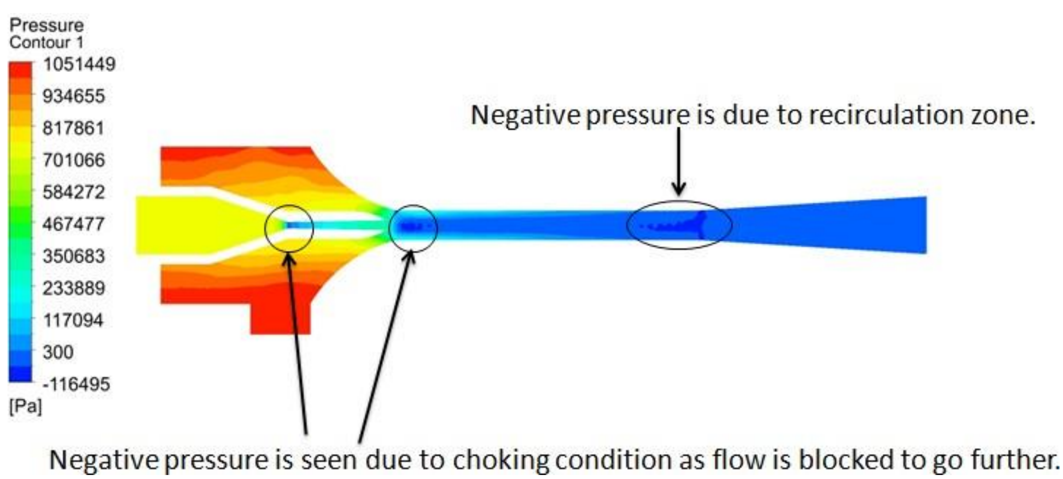

Fig 6 Pressure contour along mid cross section

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2.3 Ejector Specifications

The range for diffuser angle for the ejector was recommended by Lawrence and Elbe [8]. A big diffuser angle can cause the flow to split, whereas a small diffuser angle causes friction losses. Both lead to a reduction in pressure recovery. The table no 1 gives the different diameters obtained for a 2-phase refrigerant ejector. The lengths and angles are taken into consideration according to ASHRAE (1983) recommendation.

Table 1: Ejector dimensions

Sr. No	Description	Symbol	HCFC-22	HC-290
1	Motive nozzle throat dia.	d_t	1.1 mm	1.3 mm
2	Motive nozzle exit dia.	det	2.9 mm	3.7 mm
3	Suction nozzle exit dia.	dsn	15.1 mm	18.2 mm
4	Mixing area dia.	d_m	3.8 mm	5.0 mm

3. TESTING OF EJECTOR SPLIT AIR CONDITIONER

The modified ejector system is built to evaluate the performance and compare it with original ac system. A split air conditioner with a rated cooling capacity of 5.2 kW originally designed for HCFC-22 was used and performance testing is done as per the Indian standard IS 1391 part 2 in the psychometric chamber at the research facility.

The ESAC also includes a separator, which separates the liquid and vapour combination that leaves the ejector as shown in figure 7. It is built in such a way that a minimal quantity of liquid refrigerant is constantly present at the bottom, ensuring that the flow through the evporator is

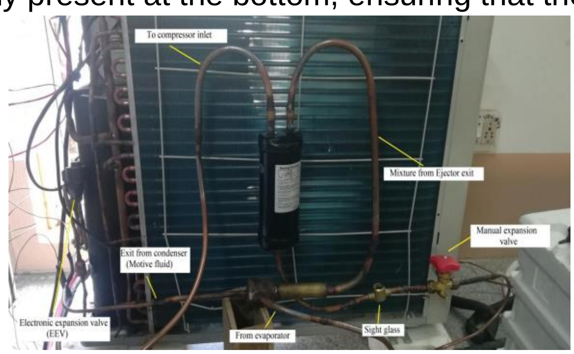

Fig. 7 Ejector split air conditioner (ESAC)

never interrupted. A sight glass is also placed at the evaporator intake to confirm that there is flow taking place to evaporator. A manual hand valve is also included in the system to regulate the amount of flow to the evaporator.

In original ac cycle, the electronic expansion valve (EEV) is operated by the controller's inputs. It

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maintains consistent superheat by controlling the flow of refrigerant by measuring the refrigerant temperature at the input and exit of the evaporator. The EEV is replaced with an ejector in this work.

4. RESULTS AND DISCUSSION

A sizing program was developed in Engineering Equation Solver Version 9.478 to design and analyze the performance parameters of ejector for original ac cycle. The experimental results with modified ESAC for both the refrigerants HCFC-22 and HC-290 are presented below.

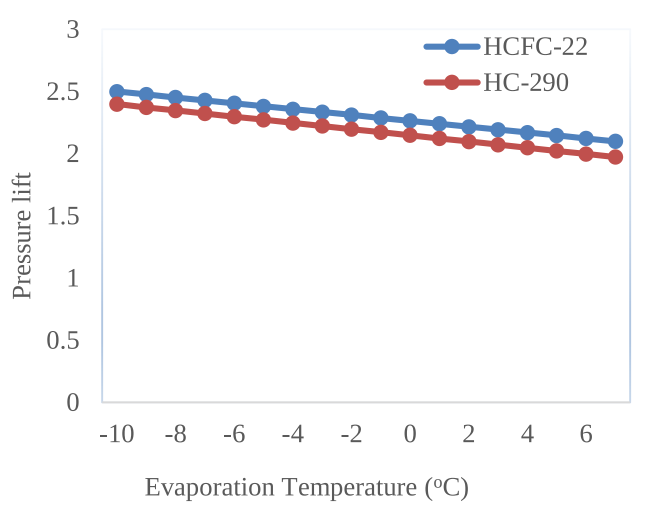

Fig. 8 Pressure lift against evaporation temperature

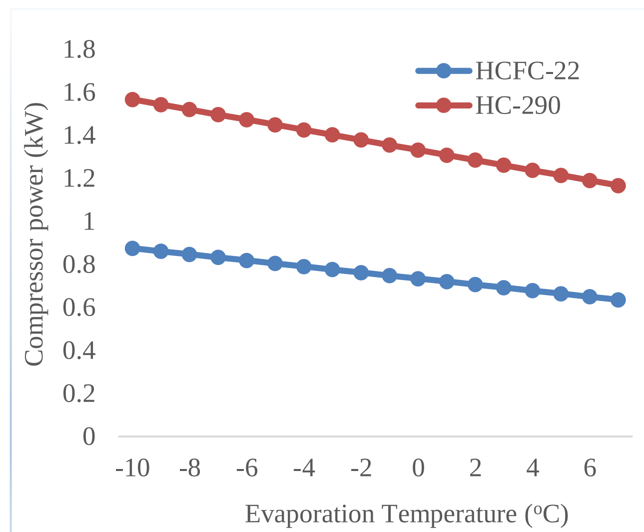

Fig. 9 Compressor power against evaporation temperature.

The figure 8 shows the effect of evaporation temperature on the pressure lift. The pressure lift decreases as the evaporation temperature goes on increases. From the curve it is seen that both the curves approaches towards each other as the evaporation temperature increases.

According to the pressure-enthalpy chart of the ejector cycle, when the condenser pressure remains constant, power consumption decreases as the evaporation temperature rises as shown in figure 9. As the evaporation temperature increases from -10 ºC to 7 ºC for HCFC-22, the compressor's energy consumption lowers from 0.8 kW to 0.6 kW for HCFC-22 and from 1.5 kW to 1.1 kW for HC-290.

The pressure lift ratio is the ratio of pressure at diffuser exit to that of inlet suction pressure. The figure 10 depicts the pressure lift as a function of condensing temperatures. As the temperature of the condensing fluid rises from 40 ºC to 60 ºC. The pressure lift for both refrigerants increases somewhat from 1.5 to 1.9.

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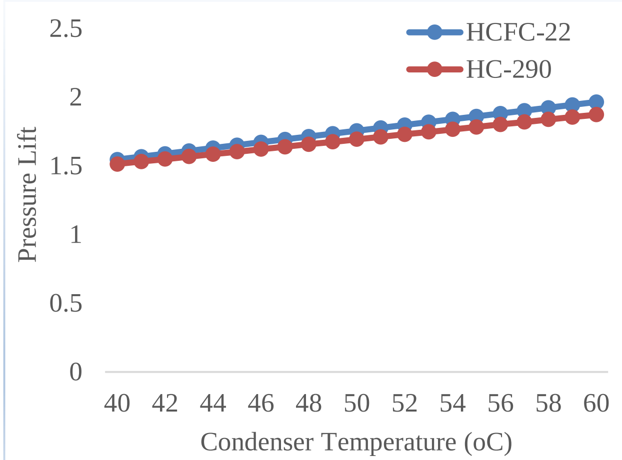

Fig. 10 Pressure lift against condenser temperature

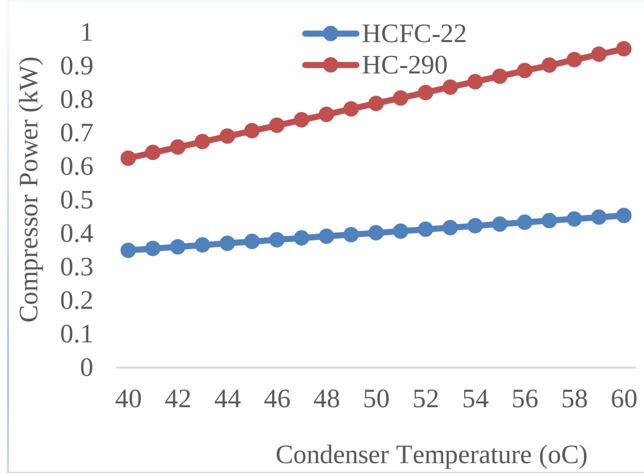

Fig. 11 Compressor power against condensing temperature

Figure 11 shows the work done by compression for compressing the gas in kW. The increase in compressor work is more in the case of HC-290 refrigerant. With increased condenser temperature and decreasing evaporator temperature, the testing findings exhibits an increase in efficiency relative to the original cycle. The effect of both refrigerants on the change in condensation temperature is the same. The COP value decreases from 8 to 5 as the temperature rises as shown in figure 12.

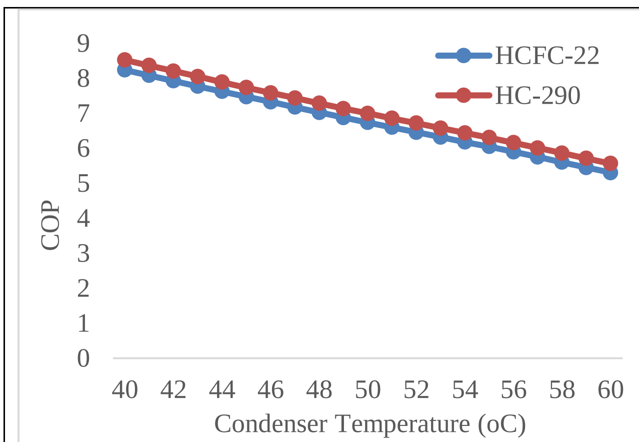

Fig. 12 COP against condensing temperature

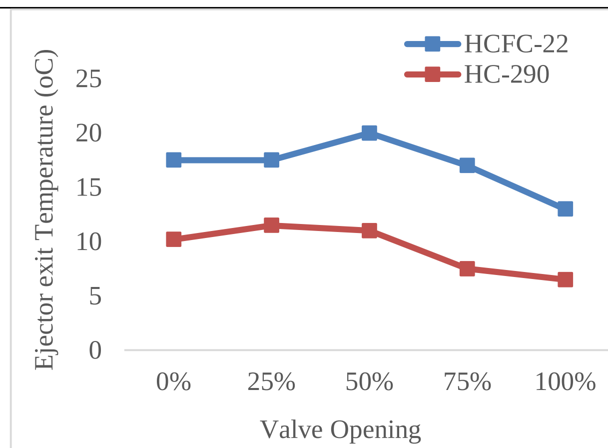

Fig. 13 Ejector exit temperature against valve opening

The temperature at the ejector exit seems to be in decreasing manner for both the fluids The HCFC-22 shows higher value at all the valve positions compared to HC-290. The highest

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temperature for HCFC-22 was achieved at 50% of the valve opening and for HC-290 the highest temperature was achieved at 25 % opening of valve as shown in figure 13.

For the modified ejector system, several valve opening positions were studied and parameters such as compressor suction pressure, discharge pressure, compressor inlet temperature, discharge temperature, ejector exit temperature etc. were recorded.

The suction pressure and the discharge pressure for HC-290 was less compared to HCFC-22 as presented in figure 14. The pressure for both the refrigerants reduced initially for 0% to 25% valve opening and then it again increased for HCFC-22 greatly but not that much for HC-290 which was nearly constant till the end. The discharge pressure was higher for HCFC-22 and both the curves were parallel till 75% valve opening afterwards got diverted

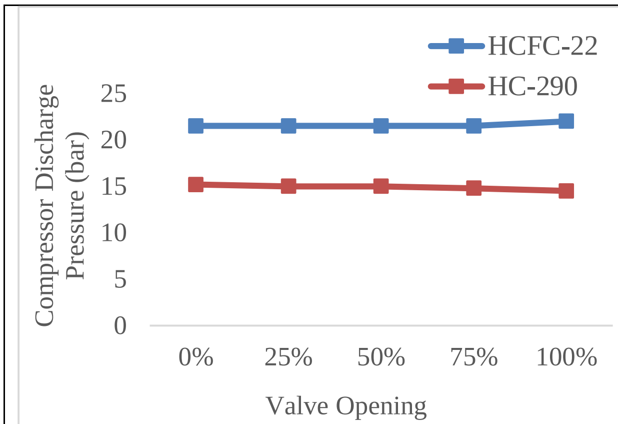

Fig. 14 Compressor discharge pressure against the valve opening

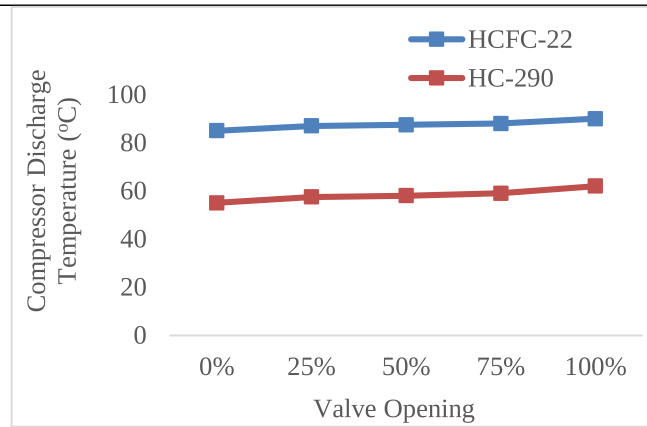

Fig. 15 Compressor discharge temperature against valve opening

The figure 15 represents that the discharge temperature is a function of discharge pressure and is directly proportional. The temperature of HCFC-22 was observed between the ranges of 80 ^oC to 90 ^oC whereas for HC-290 it was in the range of 50 ^oC to 65^oC. Both the fluids showed increase in temperature with respect to increase in valve opening.

5. CONCLUSION

The replacement of capillary tube with an ejector in ac cycle was done successfully, with the primary goal of increasing cooling capacity and reducing compressor work. The evaporating and condensing temperatures were used to design and build the 2-phase ejector. To compute the diameters of ejectors and their performance characteristics, an ejector size software was created in engineering equation solver. In fluent, the flow in the ejector was analyzed, and it was discovered that the pressure drop over the ejector was 7.5 bar. The experimental COP of the original SAC was 3.2, whereas the ESAC had a COP of 4.1. The COP of the modified system increased by 28.12 percent when compared to the original SAC for HCFC-22. Under drop-in test, when HCFC-22 was replaced by HC-290, the COP of the ESAC system was found to be 4.6. The experimental results showed that COP of HC-290 system raised by 43.75 % as compared to the original SAC. It demonstrates that in split air conditioners, HC-290 is a more energy-efficient and environmentally friendly alternative to HCFC-22. The sole drawback to use HC-290 is that it is flammable, yet it is permitted for use in small capacity air conditioners.

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