

INFLUENCE OF ELECTRONIC EXPANSION VALVE ON THE PERFORMANCE OF SMALL WINDOW AIR CONDITIONER RETROFITTED WITH R407C AND R290

by

**Chennuchetty CHINNARAJ^{a*}, Palanisamy GOVINDARAJAN^a
and Raghavan VIJAYAN^b**

^a Department of Mechanical Engineering, Government College of Engineering, Salem, India

^b Sona College of Technology, Salem, India

Original scientific paper

UDC: 697.975:532.66

DOI: 10.2298/TSCI100629081C

The objective of this study is to investigate the influence of electronic expansion valve on the performance of window air conditioner retrofitted with R407C and R290. The window air conditioner applying the electronic expansion valve is tested by varying the compressor inlet superheat from 0 °C to 20 °C. The eco friendly refrigerant R407C has the similar thermodynamic properties as those of R22 with an exception of temperature gliding during the phase change at constant pressure. R290 is a hydrocarbon which also exhibits properties very close to R22 which enables this to be used as a potential alternative to R22. The electronic expansion valve affords a precise, fast, and stable flow control for a wide range of flow rate due to its use of an electronic control method based on an advanced control algorithm. The electronic expansion valve controls the refrigerant flow through the evaporator by means monitoring pressure and temperature at the outlet of the evaporator and hence it shows good overall performances comparing the capillary tube system. The coefficient of performance of R290 is the maximum among the three refrigerants tested and also for all the three refrigerants, the coefficient of performance is low at higher degree of superheat.

Key words: window air conditioner, coefficient of performance, electronic expansion valve, tonne of refrigeration

Introduction

The electronic expansion valve (EEV), driven by stepping motor controlled pulse signal generator, has widely used in refrigeration systems. This can afford a precise adjustment to valve opening. Though thermostatic expansion valve (TEV) is a useful expansion device, it reveals some characteristics that can limit versatility and performance of machines. Some kinds of plants are more sensitive to negative aspects of TEV regulation, because of plant specifics, kind of duty or distribution of cooling load during the year. To overcome these disadvantages of TEV, the electronically controlled valve that allow a quicker response to variations in operating conditions and a greater facility of regulating the superheating setting is developed by manufacturers. The type of EEV considered is a solenoid valve linked to an electronic controller.

* Corresponding author; e-mail: chinnaraj58@yahoo.co.in

The performances of the EEV has been examined at different conditions when the experimental plant works with R22 and with substitute a non-azeotropic blend R407C that is chlorine free. Indeed the HCFC designated as R22 contains chlorine that is harmful for the ozone layer and must be replaced in the future.

Adopting EEV in air conditioners enables an appreciable energy saving with respect to the same installations equipped with traditional TEV. According to Lazzarin *et al.* [1], this is due to the fact that EEV allow a lower condensation pressure in systems equipped with air cooled condensers, which is adjusted to variations in outside air temperature.

Choi *et al.* [2] state that the performance of the capillary tube system is more sensitive to off-design charge than that of the EEV system. As the refrigerant charge deviates from the full charge, the R407C EEV system shows a much lower degradation of the capacity and of the coefficient of performance (COP) as compared to the R22 and R407C capillary tube systems due to an optimum control of superheat by electronically adjusting the EEV opening. In addition, the R407C EEV system shows more a stable compressor discharge temperature at off-design charge than the R407C capillary tube system.

Park *et al.* [3] in their work prove that the applications of EEV in multi-type heat pumps and inverter heat pumps in building air-conditioning systems have increased for comfort environmental control and energy conservation.

Study by Aprea *et al.* [4] shows an overall better performance of EEV compared with the TEV under transient conditions, while under steady state conditions both the valves are equal in performance.

According to the studies by Kang *et al.* [5], the flash gas generation at the expansion device inlet in multi-air-conditioners causes rapid reduction of refrigerant mass flow rate and irregular distribution of refrigerant into multi indoor units. As the EEV inlet condition changed from the sub cooled to the two-phase state, the refrigerant flow rate decreased rapidly due to the flash gas generation at the EEV inlet. At two-phase inlet conditions, the system operating parameters, such as mass flow rate, suction and discharge pressures, fluctuated periodically with time. As the flash gas ratio increased, the average COP decreased and the discharge temperature increased, degrading the system performance and reliability more severely.

Ma *et al.* [6] have developed a correlation on the basis of the experimental data of EEV for R22 and its alternatives, R407C (R32/125/134a, 23/25/52 wt.%) and R410A (R32/125, 50/50 wt.%). Liu *et al.* [7] have developed an 1-D model, in which the evaporation wave theory is employed, to investigate the choking flow characteristics in EEV.

A mass flow correlation for R134a through an EEV has been developed by Xue *et al.* [8], from the extensive experimental data. The refrigerant mass flow characteristics of the EEV are an important issue in heat pump/refrigeration system operation because the valve regulates the refrigerant flow to match various operating conditions. Based on the throttling mechanism and thermodynamic analysis, the mass flow rate is a function of various parameters.

Experimental test facility

An experimental set-up is designed to measure the performance of the window air conditioner under variable operating conditions. The nominal cooling capacity of the window air conditioner is 3.5 kW using R22 and R407C as working fluids. The window air condition-

er consists of a hermetic type compressor, two heat exchangers (condenser and evaporator), expansion devices (such as capillary, TEV and EEV), and environmental chambers to simulate the indoor and outdoor conditions and the necessary instrumentation. It is modified to accommodate various sensors and mass flow meter. The arrangement is done in such a way that any component can be replaced without refrigerant loss. The detailed specifications of the major components of the tested window air conditioner are given in tab.1, and fig.1 shows the photograph of the test facility.



Figure 1. Photograph of test facility

Environmental chambers

The indoor and outdoor simulation chambers are made of double skin poly urethane foam (PUF) insulators walls and the dimensions are chosen as per bureau of indian standards (BIS): 1391, year 1992 [9]. The heat load is provided by a 3000 W heater placed in the indoor chamber which is controlled by a variac. There is a wattmeter of 0.5% accuracy provided to measure the power supplied to the heater. To ensure uniform temperature distribution within the chamber, air circulating fan are provided. A two tonne of refrigeration (TR) split air conditioner is provided in the outdoor chamber to dissipate the heat from condenser. Humidifiers are provided in both the chambers to maintain the required relative humidity.

Instrumentation

The mass flow rate of refrigerant is measured using a coriolis type flow meter of accuracy $\pm 0.25\%$. To measure the compressor power, a digital wattmeter of accuracy 0.5% is provided. Pressure transducer with $\pm 0.25\%$ accuracy and J-type thermometer with $\pm 0.1\%$ accuracy are installed to measure the refrigerant pressure and temperature at salient points.

Table 1. Specification of the main components of the system

Component	Specification
Compressor	Manufacturer: Kirloskar Model no: AHR 13 Type: Hermetic(scroll) Rated capacity: 3.5 kW
Capillary tube	Diameter: 1.63 mm Length: 1860 mm
Thermostatic expansion valve	Manufacturer: Danfoss Orifice diameter: 1.2 mm Orifice length: 2.5 mm
Electronic expansion valve	Manufacturer: Danfoss Step: 0-480 pulse Orifice diameter: 1.4 mm Orifice length: 3 mm

Thermocouples are also placed inside the chamber to measure the average room temperatures. The relative humidity is evaluated using humidity sensor of accuracy $\pm 0.1\%$. All sensors are connected to a computerized data acquisition system (AGILENT 34970A).

Experimentation

Before conducting the actual experimentation, preliminary tests were conducted to determine the heat infiltration into the indoor chamber. Also charge optimization tests were conducted to find out the optimum charge quantities of all refrigerants under study.

Tests conditions were maintained according to BIS: 1391 standards. For all tests the infiltration heat load is added to the readings obtained from the energy meter to compute the actual capacity of the system under a particular degree of superheat. Tests were conducted for different degree of superheat at the exit of the evaporator from the values of 0 to 20 °C. Indoor and outdoor conditions were maintained by adjusting the power supply to the heaters and controlling the humidifiers.

Refrigerant side and air side readings were noted and the average values were used for computing various performance parameters, for better accuracy. However for mass flow rate only, refrigerant side measurements could be obtained. For calculating the refrigerant side values of capacity and compressor power, the enthalpy values at salient points were obtained from thermodynamic property tables using the pressure and temperature readings.

After conducting experiments for a particular refrigerant the compressor was retro-fitted with another refrigerant following the procedure adopted by Devotta *et al.* [10]:

- (1) R22 was recovered from the air conditioner,
- (2) the compressor was taken out from the air conditioner and the mineral oil was drained and the quantity was measured.
- (3) the compressor was charged with a small quantity of fresh polyol ester oil and run dry; the oil was then drained; this was repeated twice,
- (4) the compressor was reinstalled in the system and then system was checked for leak with dry nitrogen at a pressure of 12.41 bar,
- (5) the system was kept for evacuation for an hour,
- (6) a fresh charge of polyol ester oil of 950 ml was charged,
- (7) the system was evacuated to a vacuum of 500 μm . Then system was charged with R407C; the charge of R407C was 95% of the original charge of R22, and
- (8) since R290 is compatible with mineral oil, the same procedure was repeated for R290 by using the mineral oil as lubricant.

All the three refrigerants under study were tested and the results were analyzed.

Results and discussion

By varying the degree of superheat, the experiments are carried out for the refrigerants R22, R290, and R407C. The performance parameters such as mass flow rate of refrigerant, cooling capacity, compressor exit temperature, compressor power, volumetric efficiency, and COP were compared between the refrigerants with the use of EEV.

Figure 2 shows the variation of mass flow rate for R22, R290, and R407C using EEV with different degree of super heat. The mass flow rate of all the refrigerants decreases with the increase in degree of superheat and at 6 °C superheat, the mass flow rate of R22 EEV system is higher by 5% than that of R407C and 49% than that of R290. The

reduction in mass circulation rates for the refrigerants R407C and R290 can be attributed to the lower liquid density of these refrigerants compared to R22.

Refrigeration capacity was calculated based on the average values of airside measurements and refrigerant side measurements. In case of airside measurements, the refrigerant capacity was obtained using the direct energy supplied to the heater and the infiltration load. In case of refrigerant side measurements, the refrigeration load was calculated using the measured mass flow rate of refrigerant and the enthalpy corresponding to the temperature and pressure of refrigerant measured. Figure 3 shows the variation of cooling capacity for R22, R290, and R407C using EEV as a function of different degree of super heat. At 6 °C superheat, the cooling capacity of R22 system is higher by 2% than that of R407C and 12% than that of R290. For R407C and R290 the latent heat is observed to be more in the evaporating temperature ranges and less in the condensing temperature ranges. The reduction of latent heat in the condensing temperature ranges are more predominant compared to the marginal increase in the evaporating temperature ranges. The combined effect of these is to reduce the overall heat carrying capacity of R407C and R290 thereby reducing the cooling capacities. As the degree of superheat increases since the volumetric efficiency and mass flow rates are getting reduced, the cooling capacity also is coming down for all the three selected refrigerants.

Figure 4 shows the variation of compressor outlet temperature for R22, R290, and R407C using EEV as a function of different degree of super heat. At 6 °C superheat, the compressor outlet temperature of R22 is higher by 11% than that of R407C and 25% than that of R290. For all the refrigerants, the compressor outlet temperature is increasing with the increase in degree of superheat. For the same compressor inlet temperature, the discharge temperatures of R407C and R290 are lower due to less increase in temperatures undergone by these refrigerants in the compression process.

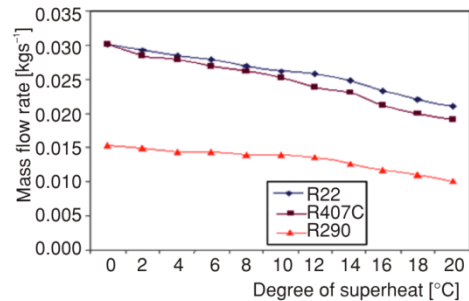


Figure 2. Variations of mass flow rate with degree of super heat for R22, R407C, and R290

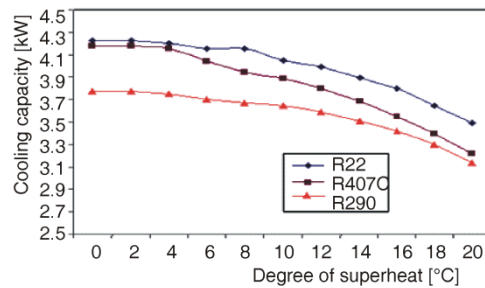


Figure 3. Variations of cooling capacity of R22, R407C, and R290 with degrees of superheat

The combined effect of these is to reduce the overall heat carrying capacity of R407C and R290 thereby reducing the cooling capacities. As the degree of superheat increases since the volumetric efficiency and mass flow rates are getting reduced, the cooling capacity also is coming down for all the three selected refrigerants.

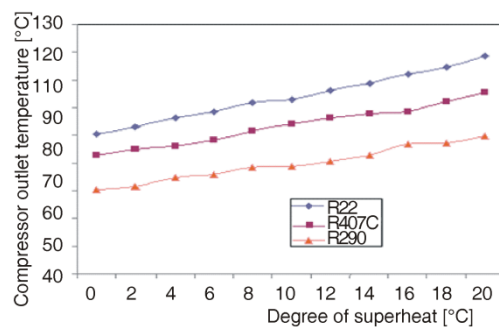


Figure 4. Variations of compressor outlet temperature with degree of superheat for R22, R407C, and R290

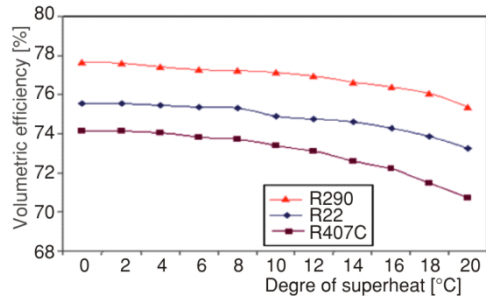


Figure 5. Variation of Volumetric efficiency with degree of superheat for R22, R407C, and R290 (color image see on our web site)

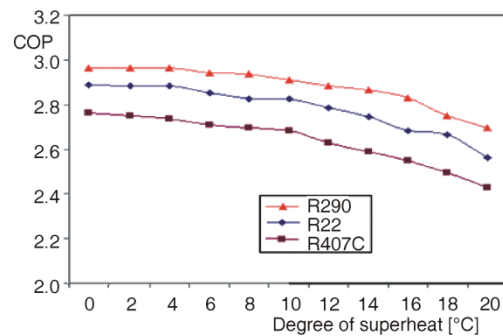


Figure 6. Variations of COP with degree of superheat for R22, R407C, and R290 (color image see on our web site)

values for the entire range of superheat. Comparing the power consumption by R22 and R407C, at lower degrees of superheat there is a marginal increase for R407C whereas it is slightly less at higher degrees of superheat. At all operating conditions R290 shows a reduction in power consumption by 14% compared to R22. COP for R407C is 3 to 7% lower than that of COP for R22. Cooling capacity of R407C is higher than R290 whereas power consumption is the minimum for R290 at all conditions which results in better COP for R290 than R22 and R407C. Hence COP is the maximum for R290 out of the three refrigerants tested.

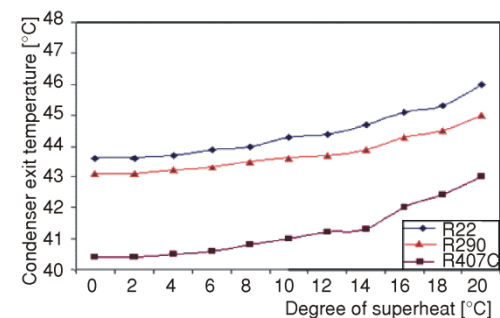


Figure 7. Variations of condenser exit temperature with degree of superheat for R22, R407C, and R290 (color image see on our web site)

Figure 5 shows the variation of volumetric efficiency for R22, R290, and R407C using EEV as a function of different degree of super heat. For all the refrigerants, the volumetric efficiency is decreasing with the increase in degree of superheat. At 6 °C superheat, the volumetric efficiency of R290 is higher by 3% than that of R22 and 4% than that of R407C. R407C is observed to exhibit the minimum value of volumetric efficiency. One of the reasons for reduction in actual volumetric efficiency of R407C is the smaller superficial tension of the polyol ester oil used with R407C. Polyol ester oil is not an effective seal between cylinder and piston likened with mineral oil.

Figure 6 shows the variation of COP for R22, R290, and R407C using EEV as a function of different degree of super heat. For all the refrigerants, the COP is decreasing with the increase in degree of superheat. At 6 °C superheat, the COP of R290 system is higher by 4% than that of R22 and 7% than that of R407C. COP is found to be the maximum with R290. Even though the cooling capacity and mass flow rate are found to be less for R290, a considerable reduction in compressor power, effects in improved COP for R290 than R22 and R407C. Hence COP is the maximum for R290 out of the three refrigerants tested.

Figure 7. shows the variation of condenser exit temperature for R22, R290, and R407C using EEV as a function of different degrees of super heat.

For all the refrigerants, the condenser exit temperature is increasing with the increase in degree of superheat. At 6 °C superheat, the condenser exit temperature of R22 system is higher by 3% than that of R290 and 6% than that of R407C.

Conclusions

From the experiments carried out to compare the performances of R22, R407C, and R290 using EEV in a small window air conditioner of 3.5 kW capacity the following conclusions have been drawn.

- Mass flow rate of refrigerant and cooling capacity of R407C and R290 are always less than that of R22.
- Power consumption by R407C is marginally higher at lower superheats and lower at higher degrees of superheat.
- For R290, the COP is high at all operating conditions; system operates with R407C, the COP decreases by 3 to 7% compared with R22 due to higher power consumption.
- Compressor outlet temperature is minimum for R290 and maximum for R22.
- Volumetric efficiency is maximum for R290 and minimum for R407C.
- For all the refrigerants, mass flow rate and COP are decreasing with increase in degree of superheat; hence for better performance the system, the EEV should be operated at lower degree of superheat.
- R290 shows overall better performance in terms of energy efficiency.
- The only drawback associated with the hydrocarbon R290 is its flammability. This can be overcome by carefully designing leak proof systems.
- Due to the ozone depletion concerns since R22 has to be phased out, R407C and R290 can be used as drop in substitutes; out of these two R290 is a better choice in terms of energy efficiency and ozone friendliness.

Acronyms

BIS – Bureau of Indian standards
COP – coefficient of performance
EEV – electronic expansion valve

PUF – poly urethane foam
TEV – thermostatic expansion valve
TR – tonne of refrigeration

References

- [1] Lazzarin, R., Noro, M., Experimental Comparison of Electronic and Thermostatic Expansion Valves Performances in an Air Conditioning Plant, *International Journal of Refrigeration*, 31 (2008), 1, pp. 113-118
- [2] Choi, J., Kim, Y., Influence of Expansion Device on the Performance of a Heat Pump Using R407C under a Range of Charging Conditions, *International Journal of Refrigeration*, 27 (2004), 4, pp. 378-384
- [3] Park, C., et al., Mass Flow Characteristics and Empirical Modeling of R22 and R410A Flowing through Electronic Expansion Valve, *International Journal of Refrigeration*, 30 (2007), 8, pp. 1401-1407
- [4] Aprea, C., Mastrullo, R., Experimental Evaluation of Electronic and Thermostatic Expansion Valves Performances Using R22 and R407C, *Applied Thermal Engineering*, 22 (2002), 2, pp. 205-218
- [5] Kang, H., Joo, Y., Kim, Y., Effect of Flash Gas Generation at the Expansion Device Inlet on the Dynamic Characteristics of a Refrigerant System, *International Journal of Refrigeration*, 31 (2008), 3, pp. 396-403
- [6] Ma, S., et al., Experimental Research on Refrigerant Mass Flow Coefficient of Electronic Expansion Valve, *Applied Thermal Engineering*, 25 (2005), 14-15, pp. 2351-2366
- [7] Liu, J., Chen, J., Chen, Z., Investigation of Chocking Flow Characteristics in Electronic Expansion Valves, *International Journal of Thermal Sciences*, 47 (2008), 5, pp. 648-658

- [8] Xue, Z., Shi, L., Ou, H., Refrigerant Flow Characteristics of Electronic Expansion Valve Based on the Thermodynamic Analysis and Experiment, *Applied Thermal Engineering*, 28 (2008), 2-3, pp. 238-243
- [9] ***, Bureau of Indian Standards. Room Air Conditioners Specification, Part 1: Unitary Air Conditioners, BIS 1391, New Delhi, 1992
- [10] Devotta, S., Padalkar, A. S., Sane, N. K., Performance Assessment of HCFC-22 Window Air-Conditioner Retrofitted with R-407C, *Applied Thermal Engineering*, 25 (2005), 17-18, pp. 2937-2949