EXPERIMENTAL EVALUATION OF INTERNAL HEAT EXCHANGER INFLUENCE ON R-22 WINDOW AIR CONDITIONER RETROFITTED WITH R-407C

by

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The performance of one ton of refrigeration window air conditioner working with R-22 and retrofitted with eco friendly alternative refrigerant R-407C is experimentally investigated An internal heat exchanger is also added to the same air conditioner to provide liquid overfeeding operation. When retrofitting the R-22 system with R-407C, the coefficient of performance is found to drop by 7.28%, however when internal heat exchanger is included the performance is improved. It is observed that the inclusion of internal heat exchanger has increased the coefficient of performance by 5.86% when running on R-22 and 6.18% when running on R-407C, under the given conditions

Key words: *window air conditioner, internal heat exchanger, R-407C*

Introduction

Global concern over ozone depletion and global warming have resulted Montreal and Kyota protocols, respectively, according to which , the use and production of chlorofluorocarbons (CFC) and hydro chlorofluorocarbons (HCFC) have to be ceased in all over the world by the year 2010 and 2030, respectively. The environmental problems caused by CFC and HCFC have been encouraging engineers and researchers to develop new alternative refrigerants with highly efficient machines which have the capability to reduce energy consumption [1]. It has been reported that R-407C is a close match to R-22 with respect to energy efficiency and other performance parameters such as compressor discharge temperature and pressure [2, 3]. R-407C is the blend of R-32, R-125, and R-134a that has properties similar to R-22 (tab. 1). New systems built with R-407C must have polyolester (POE) lubricants, and retrofitted R-22 systems would need the residual oil flushed with POE. Yang *et al*. [4] have used refrigerant mixtures whose performance is close to that of R-22. Jabaraj *et al*. [5] have reported that HCFC 407C/HC blends are superior to R-22. The experimental investigation, on the performance of R-407C un-

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der retrofit conditions, as a substitute to R22 for window air conditioners by Devotta *et al*. [6], has shown a lower cooling capacity (2.1-7.9%), higher power consumption (6-7%), lower coefficient of performance (COP) (8.2-13.6%), higher discharge pressures (11-13%) and lower pressure drops. Alternatives to R-22 have been suggested by various investigators [7, 8].

Table 1. Thermo-physical properties of selected refrigerants

Properties		Refrigerant	
		R-22	R-407C
Molecular weight	g/mol	86.5	86.2
Normal boiling point	°C	–40.9	–43.6
Critical temperature	°C	96.2	86.7
Critical pressure	bar	50.5	46.2
Latent heat	kJ/kg (at 25 °C)	180.3	185.8
Bubble pressure	bar (at 25 °C)	10.4	12.0
Saturated liquid density	kg/m^3 (at 25 °C)	1191	1140
Saturated vapor density	kg/m^3 (at 25 °C)	44.8	43.2
Temperature glide	K (at 1 bar)	0.0	7.3
Saturated liquid specific heat	kJ/kgK (at 10 °C)	1.29	1.54
	kJ/kgK (at 50 °C)	1.46	1.79

The influence of adopting an internal heat exchanger on the coefficient of performance has been studied by Aprea *et al*. [9], assuming adiabatic device and negligible pressure drops. Meyer *et al*. [10] have developed a mathematical model for a coiled type heat exchanger accumulator applicable on a small window air conditioning system working on R-22 to provide liquid overfeeding operation for the full use of evaporator thereby reducing the evaporator size by 15%. The incorporation of liquid overfeeding accomplishes several purposes like providing additional liquid sub cooling at the exit of the condenser which reduces the risk of vapor formation in the expansion valve, 100% wet evaporator and increased compressor efficiency. A saturated or near saturated vapor is supplied to the compressor thus increasing the mass flow rate and also a lower compressor discharge temperature is observed. The experimental results of Navarro-Esvi *et al*. [11] show that the adoption of internal heat exchanger on a refrigeration system has a positive effect on the overall plant energy performance. Internal heat exchanger is used to serve the purpose of providing a near 100% wet evaporator bringing a situation similar to liquid overfeeding system in larger plants. Bivens *et al*. [12] have investigated the performance of mixtures of R-32/R-125/R-134a in systems with accumulators or flooded evaporators. Capillary tube suction line heat exchangers have been reported by a few authors [13, 14].

Experimental studies on small capacity (one TR) window air conditioners, widely used in India retrofitted with R-407C are rare, and are attempted in the present study. Ton of refrigeration (TR) is equal to the heat removal required to freeze one metric tonne of water at 0 °C into ice in 24 hours (1 TR = 3.52 kW). In addition, the effects of using internal heat exchanger are attempted, which are also presented in this paper.

Experimental test facility

The basic configuration and thermodynamic cycle of vapor compression refrigeration system with internal heat exchanger are presented in figs. 1 and 2. The cycles 1-2-3-4-5-6-1 and 1'-2'-3-4-5'-6'-1-1' are the system without internal heat exchanger, and with internal heat exchanger, respectively. The liquid refrigerant is sub cooled from state 5 to 5' while the vapor gets superheated from state 1 to 1'.

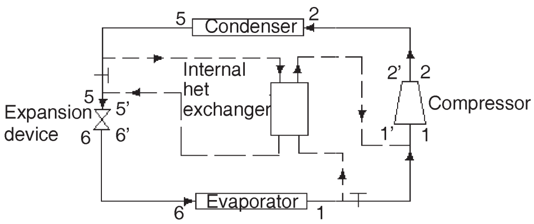

Figure 1. Schematic diagram of vapor compression system with internal heat exchanger

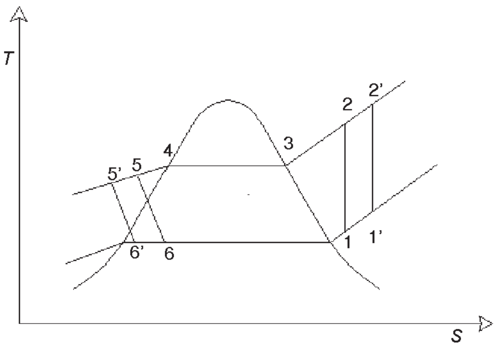

Figure 2. T-S diagram of vapor compression system with internal heat exchanger

The present study involves the testing of one TR window air conditioner with and without internal heat exchanger using R-22 as refrigerant followed by retrofitting the system with R-407C.

The schematic diagram of the experimental test facility is shown in fig. 3. It consists of a window air conditioner of one TR capacity, environmental chambers to simulate the indoor and outdoor conditions and the necessary instrumentation.

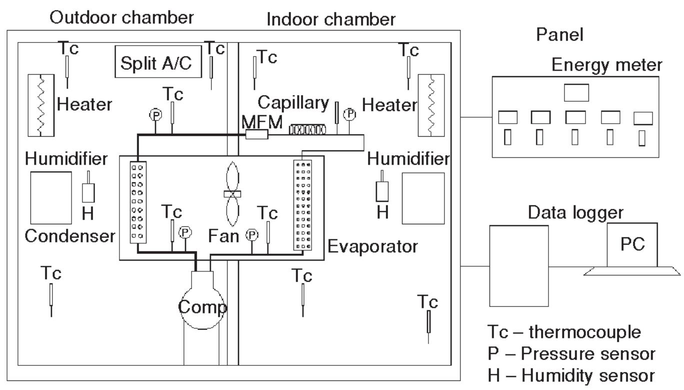

Figure 3. Schematic diagram of the test facility

Environmental chambers

The indoor and outdoor simulation chambers are made of double skin polyurethane foam (PUF) insulated walls and the dimensions are chosen as per BIS: 1391-1992 [15]. The heat load is provided by a 3000 W heater placed in the indoor chamber which is controlled by a variac. A wattmeter of ±0.5% accuracy is provided to measure the power supplied to the heater. To ensure uniform temperature distribution within the chambers air circulating fans are provided. A 2 TR split air conditioner is placed in the outdoor chamber to dissipate the heat from condenser. Humidifiers are provided to maintain the required relative humidity.

Window air conditioner

Test air conditioner is of one TR capacity with specifications as in tab. 2. 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. A shell and coil type internal heat exchanger is fabricated as shown in fig. 4, with dimensions as listed in tab. 3.The shell and coil heat exchanger is the perfect choice whenever high heat transfer rates, compact design and low maintenance costs are high priorities. In the present study a small capacity window air conditioner is used and the space available for installing an internal heat exchanger is limited. Hence a shell and coil type internal heat exchanger is chosen. The location of the internal heat exchanger in the existing system is shown in fig. 3. The internal heat exchanger is sized using the design procedures of Meyer *et al.* [10]. Valve arrangements are provided to carry out the experimentation with or without internal heat exchanger. About 15% of the evaporator is insulated while conducting experiments with internal heat exchanger.

Table 2.Technical data of experimental compressor

Model	Kirloskar AHR 13
Cooling capacity	3.5 kW
Refrigerant	R-22
Displacement rate	29.91 cm^3 per revolution
rpm	2875

Table 3. Physical dimensions of internal heat exchanger

Internal diameter of tube, d_i	8.1 mm
External diameter of tube, d_o	9.5 mm
Coil winding diameter, D_{cw}	100 mm
Length of tube, L	2.198 m
Total number of turns	7
Shell diameter, D_s	118 mm
Core diameter, D_c	82 mm

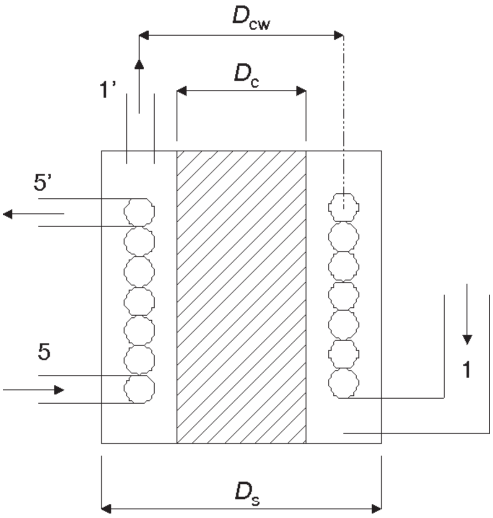

Figure 4. Internal heat exchanger

Instrumentation

Mass flow rate of refrigerant is measured using a corialis type flow meter of accuracy ±0.25%. To measure the compressor power, a digital wattmeter of accuracy ±0.5% is provided. Pressure transducers with ±0.25% accuracy and J-type thermocouples with ±0.1% accuracy are provided to measure the respective refrigerant pressures and temperatures at salient points. Thermocouples are also placed inside the chambers to measure the average room temperatures. The relative humidity is measured using humidity sensor of accuracy ±0.1%. All sensors are connected to a computerized data acquisition system (AGILENT 34970 A).

Experimentation

Tests are conducted according to BIS: 1391-1992 [15]. Test conditions for the present study along with that of Devotta *et al*. [6] and Meyer *et al*. [10] are listed in tab. 4.

Table 4. Test conditions – comparison with the earlier studies

Variable	Present study		Meyer *et al*. [6]	Devotta *et al*. [5]	
	R-22	R-407C	R-22	R-22	R-407C
T_o [°C]	6, 9, 12	6,9,12	7	5.5	8.9
T_k [°C]	50	50	50	57	57
Indoor DBT	27	27	25	27	27
Indoor WBT	19	19	–	19	19
Outdoor DBT	35	35	25	35	35
Outdoor WBT	30	30	–	30	30
Inlet pressure of air [kPa]	101.325	101.325	n. a.	101.325	101.325
Mass flow rate of air [kg/min.]	10	10	7.2 evaporator 21.6 condenser	20	20
Humidity [%]	50-60	50-60	50-60	69.5	69.5
Cooling capacity [kW]	3..5	3..5	3.780	5.13	5.13

Before carrying out the actual experimentation, a heat infiltration test is done to assess the infiltration rate of the chambers. For a temperature difference between the average chamber temperature and the atmosphere ranging from 15 °C to 0 °C, the time temperature graph is plotted to calculate the heat leakage into the chambers. It is ensured that the infiltration is within 5% of the capacity of the air conditioner. The infiltration heat load of the indoor chamber is added to the evaporator load at each test condition. Also, internal heat exchanger optimization is done using five different coil lengths. The COP of the air conditioning system is the maximum with a coil length of 2.198 m (7 turns) and hence this size of the internal heat exchanger coil is chosen for experimentation.

Tests are conducted using R-22 without internal heat exchanger. The condenser temperatures are varied over a range viz. 40, 45, 50, and 55 °C during the experimentation, while the evaporator temperature is held constant at 7 °C. In each test condition, three trials are carried out and the average values are used for further calculations. Then the tests are repeated with internal heat exchanger by insulating approximately 15% of the evaporator area. After completion of all tests with R-22, the air conditioner is retrofitted with R-407C and poly ester oil, as discussed by Devotta *et al.* [6]. All tests are repeated with R-407C.

Results and discussions

By varying the condenser temperatures the experiments are carried out, with and without internal heat exchanger, for both the refrigerants R-22 and R-407. The performance parameters such as refrigerant mass flow rate, compressor power consumption, refrigerating effect, COP, and compressor pressure ratio are compared between R-22 and R-407C. The results are encouraging as they closely agree with the earlier studies by Devotta *et al*. [6] (R-22 *vs*. R-407C) and Meyer *et al*. [10] (R-22 with and without internal heat exchanger).

Effect of internal heat exchanger

With R-22 the variations in refrigeration effect, refrigerant mass flow rate, compressor pressure ratio, compressor power consumption, and COP when the internal heat exchanger is added to the vapor compression system are shown in fig. 5 to fig. 9. The percentage variations of

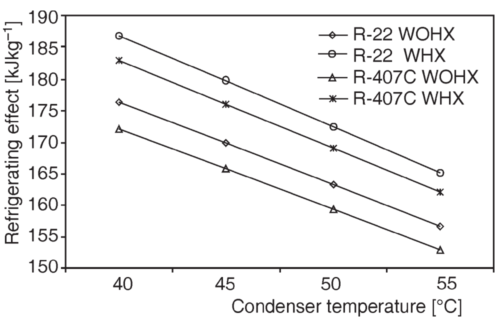

Figure 5. Effect of condenser temperature on refrigerating effect

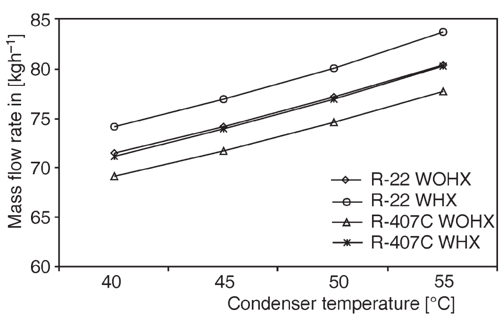

Figure 6. Effect of condenser temperature on mass flow rate

the performance parameters with the inclusion of internal heat exchanger, at a condenser temperature of 50 °C and evaporator temperature of 7 °C are shown in fig. 10. The inclusion of internal heat exchanger in R-22 system increases the refrigerating effect, refrigerant mass flow rate and COP by 5.59, 3.85, and 5.87%, respectively, whereas the compressor power consumption and pressure ratio are reduced by 2.5% and 1.5%, respectively.

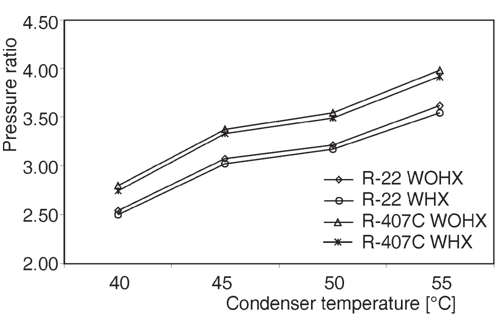

Figure 7. Effect of condenser temperature on pressure ratio

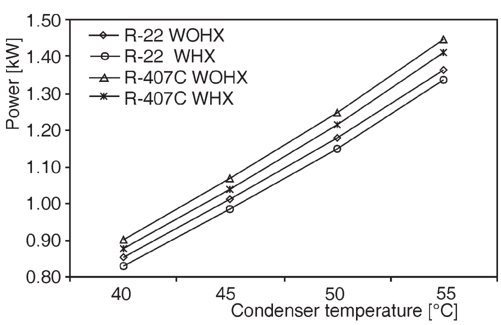

Figure 8. Effect of condenser temperature on power consumption

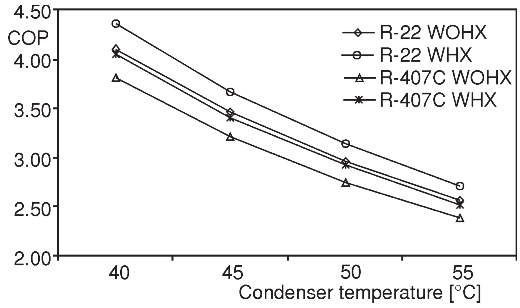

Figure 9. Effect of condenser temperature on COP

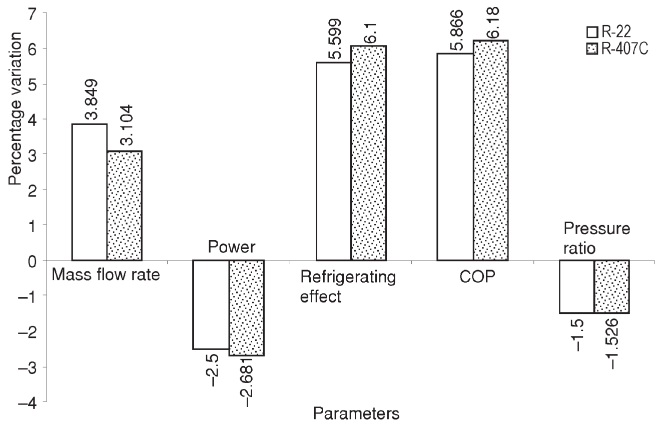

Figure 10. Effect of inclusion of internal heat exchanger

Effect of retrofitting with R-407C

The percentage variations in various performance parameters when the system is retrofitted with R-407C, with and without internal heat exchanger are shown in fig. 11. At a condenser temperature of 50 °C and an evaporator temperature of 7 °C, in the case of system without internal heat exchanger (baseline experimentation), retrofitting with R-407C increases the pressure ratio and compressor power by 10.1% and 5.9%, respectively, whereas the refrigerant

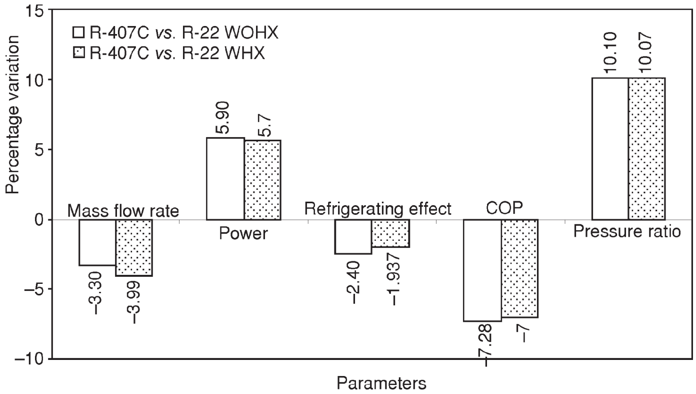

Figure 11. Performance comparison of R-407C with respect to R-22

mass flow rate, refrigerating effect, and COP are observed to be reduced by 3.3, 2.4, and 7.28%, respectively.

In the case of system with internal heat exchanger, the pressure ratio and compressor power are, respectively, 10.07% and 5.7% higher for R-407C, and the refrigerant mass flow rate, refrigeration effect, and COP are, respectively, 3.99, 1.94, and 7% lower, when compared to R-22. Obviously the use of internal heat exchanger improves the performance of window air conditioner when retrofitted with R-407C.

Conclusions

From the experimental study to evaluate the influence of internal heat exchanger on one TR capacity R-22 window air conditioner, retrofitted with R-407C, the following conclusions are drawn.

- Whether the system uses R-22 or R-407C, the use of internal heat exchanger increases the refrigerating effect, refrigerant mass flow rate, and COP and reduces the compressor power requirement and pressure ratio.
- While retrofitting the R-22 system with R-407C, the refrigerating effect, refrigerant mass flow, rate and pressure ratio are found to decrease and the pressure ratio and compressor power are found to increase.
- When the internal heat exchanger is included, the enhancement in COP is slightly higher with R-407C when compared to R-22.
- In general there is a drop in COP observed for the retrofitted system but this drop is less in the system with an internal heat exchanger compared to the one without internal heat exchanger.

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Nomenclature

D_c – core diameter, [mm]
D_{cw} – coil winding diameter, [mm]
D_s – shell diameter, [mm]
d_o – outer diameter of tube, [mm]
d_i – inner diameter of tube, [mm]
L – length of tube, [m]
T_k – refrigerant temperature in the condenser, [°C]
T_o – refrigerant temperature in the evaporator, [°C]

Acronymes

BIS – Bureau of Indian standards
CFC – chlorofluorocarbons
DBT – dry bulb temperature
HCFC – hydro chlorofluorocarbons
WBT – wet bulb temperature
WHX – with internal heat exchanger
WOHX– without internal heat exchanger

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