

Effect of Refrigerant Charge Variation and Operating Conditions in a Split Air Conditioner Retrofitted with R290

A. Lalitha Saravanan and D. Mohan Lal

Department of Mechanical Engineering, College of Engineering, Anna University, Chennai 600025, India
e-mail: irttshane@gmail.com, mohanlal@annauniv.edu

Abstract

A widely used hydrochlorofluorocarbon (HCFC) refrigerant R22 in the split air conditioner is being phased out in all countries under Montreal Protocol. Propane (R290) is a promising substitute for R22. The effect of refrigerant charge variation from 90% to 110% of optimum charge on the performance of a split air conditioner is reported. A 5.25 kW split air conditioner designed for R22 was retrofitted with R290 and tested under five different operating conditions. Results indicate that R22 is more sensitive to deviations in charge level. The influence was greater for undercharging than for overcharging. A decrease in charge level of about 7% reduced the system refrigeration capacity and coefficient of performance by 7.1% and 4.8%, respectively with R22, while with R290 it reduced by 6.3% and 3.3% only. The TEWI analysis showed that R290 has very little environment effect and is suitable as a retrofit refrigerant for the R22 system.

1. Introduction

R22 is widely used as a refrigerant in air conditioning and heat pump applications. In view of ozone depletion and global warming phenomena, Montreal and Kyoto protocols restrict the use of HCFCs. The Montreal protocol schedules have been advanced to phase out the production and use of HCFCs by 2020 in developed countries and by 2030 in developing countries [1]. In India, R290 Air-conditioners are available in market. Many research works have been performed worldwide. Mastrullo et al. [2] studied the possibility of replacing R404A in light commercial vertical freezer with R290. Fernando et al. [3] experimentally investigated 5 kW water-to-water heat pump performance at Swedish operating conditions. By using mini-channel aluminium heat exchangers, the heat pump was run with 200 g of propane. Devotta et al. [4] experimentally assessed R290 refrigerant as a drop-in substitute to R22 in window air conditioners. Their results indicate that the cooling capacity and energy consumption of R290 were lower in the range of 6.6%-9.7% and 12.4-13.5%, respectively. The COP was higher in the range of 2.8%-7.9%. Padalkar et al. [5] experimentally assessed a 5.13 kW split air conditioner designed for R22 that was retrofitted with R290. In the drop-in test, the cooling capacity with R290 was lower by 6% and COP was higher by 14%. The optimized charge of R290 was about 50% of R22 by weight. Park and Jung [6, 7] studied the performance of two pure hydrocarbons and seven mixtures to substitute R22 in residential air conditioner and heat pump applications. Compared to R22, R290 showed 11.5% reduction in capacity, but 1.9% improvement in COP

and compressor discharge temperature was reduced by 17.3°C. Teng et al. [8] experimentally investigated the feasibility of replacing R22 in a window air conditioner with R290 for different charge quantities and test conditions. It was reported that the optimum R290 charge was approximately 50-55% of the R22 charge and improvement in the energy efficiency ratio (EER) was 20%. Zhou and Zhang [9] experimentally investigated the performance of split air conditioner with R22 and R290. Similar cooling capacity was achieved and the COP of R290 was 8.5% higher than that of R22, and the refrigerant charge was 44% of R22 charge. Saravanan et al. [10] experimentally studied 5.25 kW split air conditioner with R22 and R290. The possibility of charge reduction was studied with condenser tube diameter and capillary length modification. Corberan et al. [11, 12] conducted experimental studies on water-to-water heat pump and analyzed the effect of refrigerant charge on the system performance. It was concluded that the system performance was highly dependent on refrigerant charge quantity for capillary systems. It would be also possible to retrofit existing R22 air conditioners with R290 possibly with minor modifications. When such retrofitting is done in the field one can expect a shift in the charge levels. The performance is also subject to operating conditions.

The objective of the study was to quantify the system performance parameters (cooling capacity, mass flow rate, power consumption and COP) of a 5.25 kW residential split air conditioner designed for R22 and retrofitted with R290 refrigerant. The optimum charge quantity was arrived at for 5 test conditions as per Indian Standard (IS). The performance with

±7% variation in charge quantities was compared with R290 and R22 to understand the effect of charge variations at different conditions.

1.1. Refrigerant Properties

Table 1 compares the typical thermodynamic properties of R22 and R290. R290 refrigerant has superior thermodynamic properties like low density, high latent heat of vaporization along with zero ODP, negligible GWP. The saturation vapour pressure curves as seen in Figure 1 overlap at lower saturation temperatures. At higher saturation temperatures, the saturation pressure of R290 is lower and hence a lower compression ratio prevails. The P-T curve and thermodynamic similarity indicate that R22 compressor can be charged with R290 without changing the original design. However, because of its flammable nature, charge quantity is to be reduced in appliances to satisfy the safety standards. Corberan et al. [13] have reviewed the various existing safety standards for air conditioning applications. Charge quantity limitations are set considering the fact that the concentration should be far below the lower flammability limit (LFL), even if the whole charge leaks and diffuses into the conditioned space. The European standard EN 378 allows R290 in a broad range of applications, if safety requirements are fulfilled.

Table 1: R22 vs R290 properties comparison

Properties	R290	R22
ODP	0	0.055
GWP (100 Year)	5	1780
Normal boiling point (°C)	-42.1	-40.8
Critical temperature (°C)	96.7	96.1
Pressure at 0°C in bar (absolute)	4.71	4.98
Liquid density at 0°C (kg/m ³)	529	1282
Vapour density at 0°C (kg/m ³)	10.4	21.23
Enthalpy of vaporization at 0°C (kJ/kg)	374	205
Pressure at 55°C in bar (absolute)	19.1	21.8
Toxicity/flammability	A3	A1

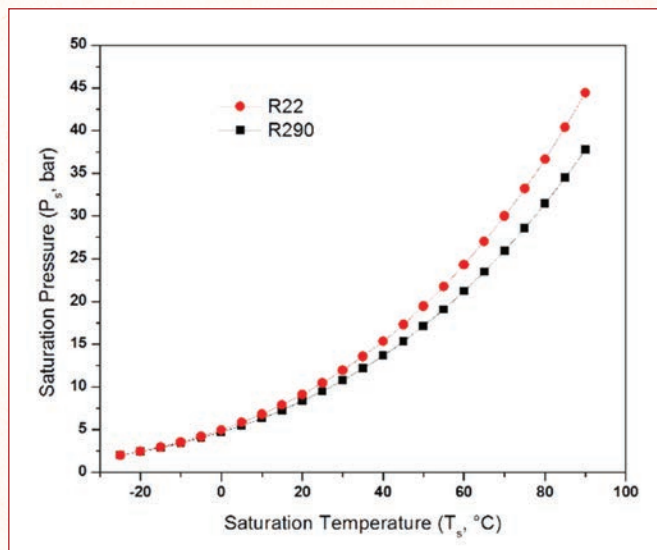


Figure 1: P-T diagram for R22 and R290 refrigerant

2. Experimentation

The air conditioner was tested in a psychrometric test facility as per IS 1391 Part 2 [14]. The facility consists of an indoor room and an outdoor room as shown in Figure 2 and 3. The indoor unit of the test air conditioner was fixed on the partition wall between the rooms, and the outdoor unit was kept in the outdoor room. Both the rooms have separate AHUs with cooling coil, air heater and humidifier to maintain the required test condition as per IS [14] and ASHRAE [15] standards. The room conditions were monitored continuously to maintain temperature uniformity within ±0.5°C. An airflow measuring device was used to measure the volume flow rate of air as per ASHRAE 41.2-1987 [16]. The power consumed by the compressor was logged into a data logger.

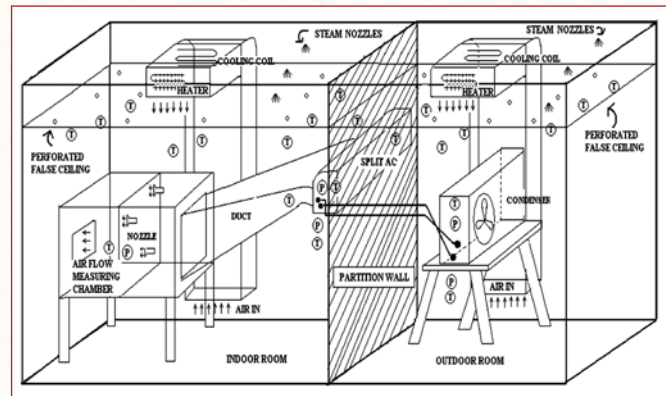


Figure 2: Schematic diagram of experimental test facility



Figure 3: Photographic view of indoor room with air flow measuring chamber

2.1. Measurements and Uncertainty Analysis

The testing procedure included the measurement of temperatures, pressures, power consumption and nozzle air pressure difference. The cooling capacity and actual COP were calculated, based on the measured parameters. Measured quantities with their uncertainties are listed in Table 2. The uncertainties in cooling capacity and COP were analyzed based on the method by Moffat [17] and were found to be in the range of 1.18 to 1.74% and 2.65 to 4.06%, respectively.

Table 2: Measured quantities and their Uncertainty

Quantity	Range	Uncertainty
Temperature	0-100° C	±0.15%
Pressure	0-40 bar	±0.1%
Nozzle pressure drop	0-10 mbar	±0.1%
Power	0-5000 W	±0.25%

2.2 Experimental Procedure

The tests were conducted for five different test conditions as per IS1391 part 2 (1992) [14], which are listed in Table 3. The DT and ETA are usually referred as the lower operating conditions and ETB, MDT and META as the higher operating conditions. Seven charge levels were considered for each test condition. Thus, for each refrigerant (R22 and R290), 35 different tests were considered. Supply air and return air enthalpy values were calculated from measured DBT and WBT. The associated flow rates and enthalpies were used to calculate the cooling capacity. Equations (1)-(4) were used for performance calculation.

$$COP = RC / W_c \tag{1}$$

$$RC = m * (h_r - h_s) \tag{2}$$

$$m = Q_e * \rho_s \tag{3}$$

$$Q_e = (C_1 * A_1 + C_2 * A_2) * Y * \sqrt{2 * \Delta P / \rho_s} \tag{4}$$

Table 3: Capacity rating test operating conditions as per IS 1391 part 2 (1992)

Test Type	Indoor		Outdoor	
	DBT (°C)	WBT (°C)	DBT (°C)	WBT (°C)
DT	27	19	35	30
ETA	27	19	35	24
ETB	29	19	46	24
MDT	35	24	46	27
META	32	23	43	26

First, the air conditioner was charged with R22. The charge quantity was optimized as the system flow volume had changed due to the alterations made for fixing the mass flow meter and sight glass. The charge quantity of R22 was varied from 820 g to 980 g. While testing, the conditioning equipment with PID controllers for indoor and outdoor rooms was switched ON along with the unit under test (UUT). The conditioning equipment and the UUT were run at least for one hour, to allow the room conditions to reach steady state. After attaining steady state, the temperatures of air at the inlet and exit of condenser as well as evaporator were recorded for 30 minutes at an interval of 1 minute. The mean value of the reading for the period of 30 minutes was used for calculations. The power consumed by the compressor, the mass flow rate, and the suction and discharge pressures were also recorded. The same test was repeated for 7 different charge quantities (ranging from 820 g to 980 g) to arrive at the optimum charge that yields maximum COP. The same test procedure to obtain the optimized charge was repeated for the 5 different test conditions. After the completion of all tests with R22, the refrigerant was recovered and without making any modification the air conditioner was

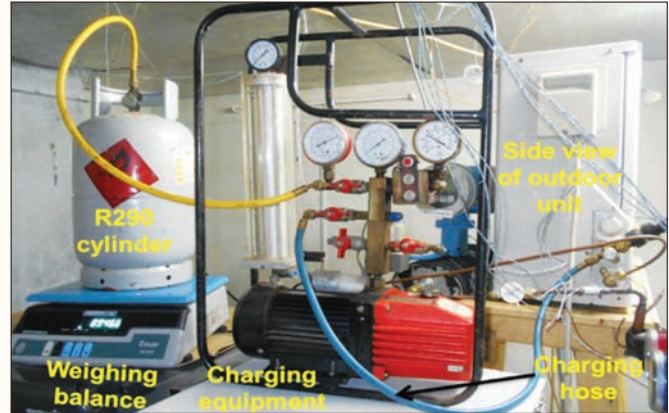


Figure 4: A photographic view of charging equipment in the test facility

charged with R290. Based on the published literature [3, 5, 6, 7, 8, 9, 10], 50% of the R22 charge quantity was considered as an approximate equivalent charge for R290. Hence the charge was varied from 410 g to 490 g. The same procedure was repeated to obtain the optimum charge for all the different test conditions. A photographic view of charging equipment inside the indoor room is shown in Figure 4. Each test was repeated two times to confirm repeatability and accuracy of the data.

3. Results and Discussion

A split air conditioner designed for R22 was charged with R290 as a retrofit refrigerant and tested at different operating conditions. The results are compared in this section. For each of the five test conditions, charge optimization was made to maximize COP. The optimum charge for each condition is given in Table 4. The performance parameters namely, cooling capacity, mass flow rate, power consumption and COP are presented in this section. The charge variation has been made from 90% to 110% of the optimum charge and performance is studied. The performance degradation with charge variation is typically discussed for ±7% deviation.

Table 4: Performance test data for the optimum charge condition of R22 compared with R290

Test condition	Refrigerant	Mass flow rate (kg/hr)	Suction pressure (bar)	Discharge pressure (bar)	Cooling capacity (kW)	Power consumption (W)	COP
DT	R22 (920 g)	112.80	5.25	18.8	4.97	1920	2.59
	R290 (460 g)	56.52	5.04	14.2	4.58	1685	2.72
ETA	R22 (920 g)	115.30	5.35	19.2	4.94	1975	2.50
	R290 (460 g)	57.70	5.16	14.5	4.57	1719	2.66
ETB	R22 (880 g)	116.32	5.35	21.9	3.64	2142	1.70
	R290 (440 g)	56.87	5.03	17.4	3.23	1878	1.72
MDT	R22 (880 g)	118.53	5.49	22.5	3.42	2225	1.54
	R290 (440 g)	57.61	5.18	17.8	3.14	1941	1.62
META	R22 (880 g)	114.25	5.17	21.3	3.85	2188	1.76
	R290 (440 g)	56.24	4.88	17	3.50	1905	1.84

3.1 Cooling Capacity

The variation of cooling capacity under different refrigerant charge quantities and test conditions is shown in Figure 5.

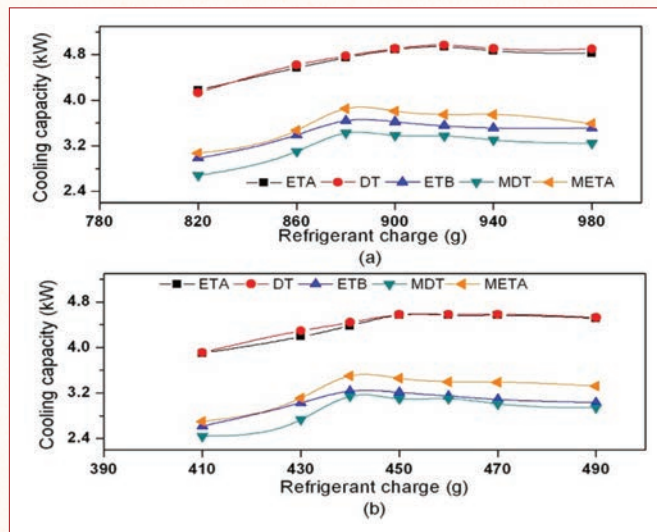


Figure 5: Variation of cooling capacity as a function of refrigerant charge (a) R22 (b) R290

In undercharged condition, the cooling capacity was low and increases as charge increases up to optimum charge level. Then the curve plateaus and drops with a decreasing trend. This indicates that the cooling capacity degrades significantly due to undercharging than for overcharging. For undercharged condition, the cooling capacity reduces significantly due to lower mass flow rate and compressor efficiency. In undercharged condition, the lower evaporator pressure and low refrigerant flow rate results in the evaporator being occupied with superheated vapour. This results in significant reduction of evaporator efficiency at undercharged condition compared to overcharged condition. In overcharged condition, the cooling capacity is reduced due to rise in evaporator pressure and, in turn, temperature that leads to reduced evaporator temperature difference. O'neal and Farzad [18, 19] conducted an experimental study with 10.6 kW split air conditioner with capillary tube expansion at different charge levels and outdoor conditions. It was observed that the performance degradation was greater in undercharged condition. The seasonal COP (SCOP) dropped from 2.77 to 2.20 for 20% undercharging while it dropped to 2.48 only for 20% overcharging. Choi and Kim [20, 21] investigated the effect of performance of off-design R22 refrigerant charge from -20% to +20% of design charge on water-to-water heat pump with electronic expansion valve (EEV) and capillary. The performance of capillary system was more sensitive to charge deviation than EEV system. The degradation of performance was higher at undercharged than at overcharged system for capillary system. Raj and Lal [22] experimentally analyzed the effect of refrigerant charge on a 5.25 kW window air conditioner with R22 and M20 (80% R407C/20% HC blend) refrigerant with different outdoor conditions. It is observed that R22 is more sensitive to

deviations in charge levels as compared to the M20 refrigerant mixture.

The optimum charges for test conditions DT and ETA are different from ETB, MDT and META test conditions. Thus, the charge quantity that produced the best performance at one test condition produced sub-optimal performance at other conditions. For DT and ETA, the maximum cooling capacity was achieved at 920 g, whereas for ETB, MDT and META the maximum capacity was at 880 g charge itself. It shows that the charge giving maximum cooling capacity of the system depends on outdoor condition also. The maximum cooling capacity of R290 is realized at 460 g charge quantity for DT and ETA condition, whereas for ETB, MDT and META, the maximum cooling capacity was realized at 440 g. At DT condition, the cooling capacity of R22 in a 7% undercharged condition is 7.1% lower than the maximum, whereas the cooling capacity of R290 is 6.3% lower than the maximum for the same undercharged condition. The cooling capacity of R22 in a 7% overcharged condition is 1.4% lower than the maximum; whereas the cooling capacity of R290 is 1.2% lower than the maximum for the same overcharged condition. At higher operating conditions, the performance degradation due to charge variation of R290 is lower than that of R22. The cooling capacity at the optimum charge condition of R22 at DT condition is 26.8% higher than that at ETB condition, whereas the cooling capacity of R290 is 29.5% higher than that at ETB condition. It is seen that the influence of test condition on the performance of R22 is lower than on R290. The lower cooling capacity for R290 compared with R22 was due to its lower volumetric cooling capacity than R22 for the retrofitted condition. Even though the latent heat capacity of R290 is higher than that of R22, due to reduced charge quantity, the cooling capacity is lower, as the mass flow rate realized is also lower than that of R22.

3.2 Mass Flow Rate and Power Consumption

The variation of mass flow rate under different refrigerant charge quantities and test conditions is shown in Figure 6.

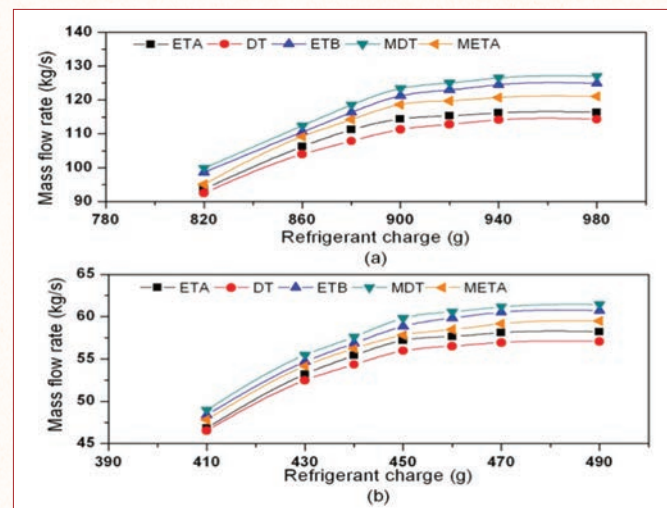


Figure 6: Variation of mass flow rate as a function of refrigerant charge (a) R22 (b) R290

The mass flow rate is found to increase as the charge quantity is increased from the lowermost level up to the optimum charge, and then it plateaus. As the charge quantity increases, the condensing pressure also increases, which increases the flow through the capillary as long as the pumping rate of the compressor is commensurate with the capillary flow. But, as the condensing pressure increases, the volumetric efficiency decreases and hence the flow rate reduces, which characterizes the optimum charge for the system specific to the refrigerant. Generally, the refrigerant flow rate through the capillary tube is strongly dependent on condensing pressure, while it is insensitive to evaporating pressure due to choking (Choi et al. [20]). As the temperature of air entering the condenser is increased, the mass flow rate passing through the capillary also increases due to the rise in pressure difference across the capillary. The same trend is reported by Choi et al. [20, 21], and Raj and Lal [22]. The mass flow rate of R22 at a 7% undercharged condition is 7.8% lower than the optimum, whereas the mass flow rate of R290 is 7.2% lower than the optimum for DT test condition. It is observed that the mass flow rate of R22 at 920 g DT operating condition is 8.3% lower than at ETB condition, whereas the mass flow rate of the R290 refrigerant in 460 g DT condition is 5.5% lower than at ETB condition. The variation in the power consumption with respect to charge quantity and test condition for R22 and R290 are shown in Figure 7. As the refrigerant charge increases, the power consumption increases slowly due to rising compression ratio and mass flow rate. The increase in the suction pressure and temperature in the compressor with refrigerant charge results in lower specific volume and higher mass flow rate. The power consumption of R22 when 7% undercharged is 2.3% lower than at the optimum charge condition, whereas for R290 the power consumption is 3.2% lower than that of the optimum in DT condition. It is also seen that at DT condition the power consumption at a 7% overcharged condition is 3.1% higher than at the optimum in R22 and 2.6% higher in the

case of R290. The power consumption of R290 is lower than of R22 for all equivalent charge level and test conditions, since pressure ratio and the vapour specific volume of R290 is lower than that of R22 (Table 1).

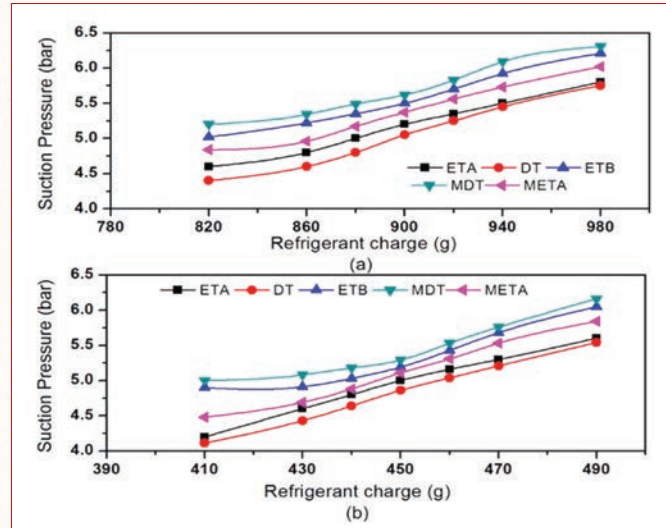


Figure 8: Variation of suction pressure as a function of refrigerant charge (a) R22 (b) R290

3.3 Suction pressure and Discharge pressure

The suction pressure increases gradually with refrigerant charge as shown in Figure 8. It is observed that at the DT condition for a 7% undercharged condition, the suction pressure of R22 is 12.4% lower than at the optimum condition, whereas the suction pressure of R290 is 12.1% lower than at the optimum condition. Similarly, at a 7% overcharged at DT condition, the suction pressure of R22 is 9.5% higher than at the optimum condition, whereas the suction pressure of R290 is 9.9% higher than at the optimum condition. The refrigerant charge variation has almost the same influence on the suction

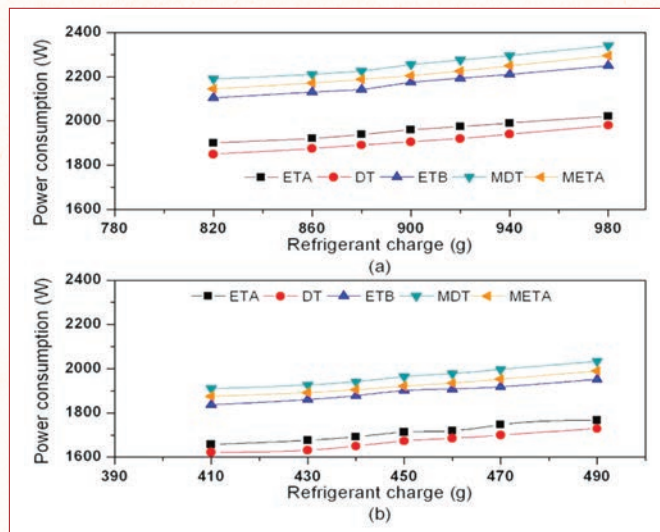


Figure 7: Variation of power consumption as a function of refrigerant charge (a) R22 (b) R290

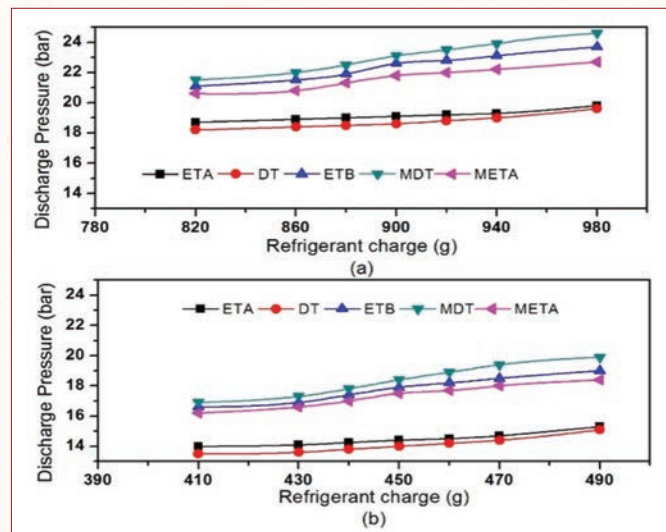


Figure 9: Variation of discharge pressure as a function of refrigerant charge (a) R22 (b) R290

pressure when R22 system is retrofitted with R290. The suction pressure increases steadily with charge quantity due to increasing mass flow rate.

The variation of discharge pressure under different charge quantities and test conditions are shown in Figure 9. It is seen that in DT condition at a 7% undercharged condition, the discharge pressure is 2.1% lower than at the optimum

condition, whereas the discharge pressure of R290 is 4.2% lower than that at optimum condition. Similarly, at a 7% overcharged condition it is 4.7% higher than at optimum condition, whereas the discharge pressure of R290 is 4.9% higher than that at optimum condition. The charge quantity variation has almost the same impact on the discharge pressure of R22 as well as R290 systems. However, it can be observed that the drop in these pressures due to reduced charge is more pronounced in R22 system while the rise due to overcharge is more pronounced in R290 system.

3.4 COP

The variation of COP under different refrigerant charge quantities and test conditions is shown in Figure 10. In the undercharged and overcharged condition, the COP is reduced. The reduction in COP is more pronounced in undercharged condition than in overcharged condition, because the cooling capacity drops significantly at undercharged condition. It can be observed that at higher ambient conditions (i.e. ETB, MDT and META), the COP falls significantly for all charge quantities. This is

Table 5: Performance comparison data for shift in charge quantity for ±7% of R22 and R290

Parameter	Charge quantity	DT		ETA		ETB		MDT		META	
		R22	R290	R22	R290	R22	R290	R22	R290	R22	R290
SP	-7%	-12.4%	-12.1%	-10.3%	-10.9%	-6.2%	-2.6%	-5.3%	-3.5%	-6.4%	-8.2%
	+7%	+9.5%	+9.9%	+8.4%	+8.5%	+10.7%	+12.9%	+10.9%	+11.2%	+10.8%	+13.3%
DP	-7%	-2.1%	-4.2%	-1.6%	-2.7%	-3.7%	-4.6%	-4.4%	-5.1%	-3.3%	-4.7%
	+7%	+4.7%	+4.9%	+3.1%	+4.8%	+5.5%	+6.3%	+6.2%	+9.0%	+4.2%	+5.9%
CC	-7%	-7.1%	-6.3%	-7.5%	-8.3%	-18.1%	-18.8%	-21.6%	-22.3%	-20.3%	-22.9%
	+7%	-1.4%	-1.2%	-2.2%	-1.2%	-3.6%	-4.4%	-3.5%	-4.1%	-2.6%	-3.2%
MR	-7%	-7.8%	-7.2%	-7.9%	-7.7%	-15.2%	-15.0%	-15.8%	-15.0%	-16.8%	-15.0%
	+7%	+1.3%	+1.0%	+0.9%	+1.0%	+7.0%	+6.4%	+6.7%	+6.2%	+5.7%	+5.2%
PC	-7%	-2.3%	-3.2%	-2.8%	-2.5%	-1.7%	-2.2%	-1.6%	-1.6%	-2.0%	-1.6%
	+7%	+3.1%	+2.6%	+2.4%	+2.8%	+3.2%	+2.1%	+3.2%	+2.9%	+2.8%	+2.5%
COP	-7%	-4.8%	-3.3%	-4.8%	-5.9%	-16.7%	-17.0%	-20.4%	-21.0%	-18.7%	-21.6%
	+7%	-4.4%	-3.8%	-4.5%	-3.9%	-6.5%	-6.4%	-6.5%	-6.8%	-5.3%	-5.6%

because of higher power consumption due to higher discharge pressures, which also reduces the volumetric capacity of the compressor. It is seen that the optimum charge level for DT and ETA conditions is 920 g for R22 and 460 g for R290, whereas for ETB, MDT and META conditions the optimum was 880 g for R22 and 440 g for R290. The optimum charge of R290 is found to be 50% of the optimum charge of R22 at the respective test condition.

The COP of R22 and R290 in a 7% undercharged condition is 4.8% and 3.3% less than at the optimum, respectively, at DT condition. It is also seen that the COP of R22 and R290 in a 7% overcharged condition is 4.4% and 3.8% lower than that of the optimum at DT condition. At ETB condition the COP of R22 and R290 falls below the COP at DT condition by 34.4% and 40.1%, respectively. Hence, the performance degradation due to high ambient condition will be more severe for R290 than for R22. A consolidated comparative table of the variation in these performance parameters for a shift in charge quantity of +7% and -7% are presented in Table 5.

3.5 Environmental Effect

The Total Equivalent Warming Impact (TEWI) is the sum of the direct (chemical) and indirect (energy) emission of greenhouse gases from a certain equipment during its useful life. (Maykot et al [23]). The TEWI is calculated in accordance with the equation:

$$TEWI = GWP \cdot m \cdot L_{annual} \cdot n + GWP \cdot m \cdot (1-a) + n \cdot E_{annual} \cdot \beta$$

Where,

GWP – Refrigerant global warming potential, relative to CO₂ (GWP CO₂ =1)

L_{annual} – Annual leakage rate (%)

n – System operating life (years)

m – Refrigerant charge (kg)

a – Recycling factor (%)

E_{annual} – Energy consumption per year (kWh/year)

β – CO₂ emission factor (kg CO₂/kWh)

The following assumptions are made for calculations:

- Annual leakage rate for typical split air conditioning (single and multi) system is 4% [24] and for window air conditioner/wall units and portable system is 2%.

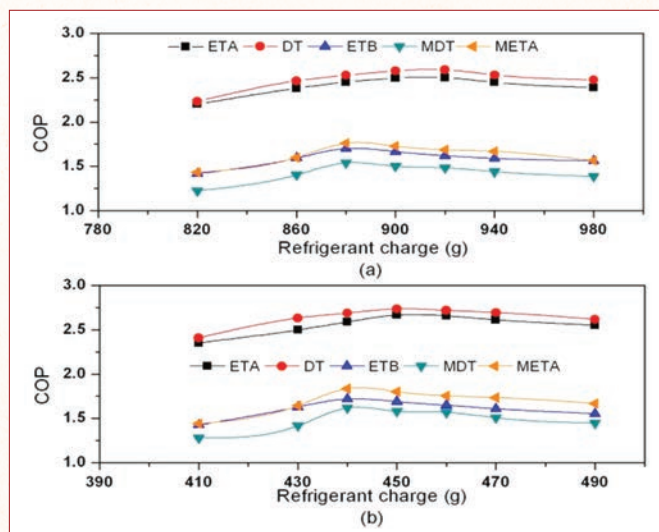


Figure 10: Variation of COP as a function of refrigerant charge (a) R22 (b) R290

- The service life of household air conditioner is 15 years.
- The Intergovernmental Panel of Climate Change (IPCC) issued good practice caused the recycling factor of 75% for household application. That means 75% of the refrigerant charge is recovered at the end of the equipment useful life.
- The carbon dioxide emission factor is 0.83 (kg CO₂ /kWh) for India [25].
- The hot and dry climatic conditions regions like India, the air conditioner operates upto 7 months per year. The operating hours of the system are assumed to be 8 hours per day.

R22 has ODP as well as high GWP value. R290 has null ODP and negligible GWP value. The Total Equivalent Warming Impact (TEWI) for R22 and R290 with various charge quantities under different test condition is shown in *Figure 11*. The TEWI includes both direct effect and indirect effect. The direct effect contributes approximately 2.6-3.4% of the total impact for R22, whereas for R290 the direct effect is only 5 * 10-7% only. R22 global warming contribution more than R290 due to high energy consumption results higher corbondioxide emissions for electricity production. R22 consumes more energy to run the system under all equivalent charge condition compared with R290. Under all test conditions, the TEWI value for R290 is 14.9-15.9% less than that of R22. The refrigerant charge used for R22 double the amount of R290 charge. The COP value for R290 is better than R22. TEWI analysis concluded that R290 is the best substitute for replacing R22 in environmental point of view.

4. Conclusions

The effect of refrigerant charge and test conditions on the performance of an R22 split air conditioner retrofitted with R290 was studied and compared with the original system by varying the refrigerant charge from 90% to 110% of the optimum charge. The study was conducted in a Psychrometric test facility at five different test conditions of IS 1391. Based on the study, the following conclusions are drawn.

- (1) For undercharged condition the suction pressure drop is more significant at lower operating conditions, while the rise in suction pressure due to overcharging is more pronounced at higher operating conditions. This effect is by and large the same in R22 and R290.
- (2) The discharge pressure drop and rise due to undercharged and overcharged condition, respectively, is more pronounced in R290 than in R22.
- (3) The cooling capacity drops for undercharged as well as overcharged conditions, and it is more pronounced at higher operating conditions. The drop is more in case of R22 at lower operating condition and for R290 at higher operating condition.
- (4) The power consumption drop or rise due to charge variations is by and large the same for all operating conditions.
- (5) The loss in COP for both R22 and R290 is very high due to undercharged condition at higher operating conditions,

while it is moderate at lower operating conditions. The drop in COP is considerably higher for undercharged condition as compared to overcharged condition.

- (6) The R22 system, if retrofitted with R290 as a drop-in substitute, operates with a 7.8% reduction in cooling capacity, while the COP rises by 5% at DT condition.
- (7) The TEWI analysis showed that R290 has very little environment effect and is suitable as a retrofit refrigerant for an R22 system.

Acknowledgements

The authors thankfully acknowledge the grant from DST-FIST and TEQIP projects for developing the experimental test facilities. The propane refrigerant was provided by GTZ, India which is also acknowledged thankfully.

Symbols	
<i>A</i>	area (m ²)
<i>C</i>	nozzle discharge coefficient
<i>COP</i>	coefficient of performance
<i>DBT</i>	dry bulb temperature (°C)
<i>E</i>	energy consumption per year (kW h)
<i>h</i>	enthalpy (kJ kg ⁻¹)
<i>L</i>	annual leakage rate per year (%)
<i>m</i>	refrigerant charge (kg)
<i>n</i>	system operating life (years)
<i>Q</i>	volume flow rate (m ³ s ⁻¹)
<i>RC</i>	refrigeration capacity (kW)
<i>W</i>	work consumption (kW)
<i>WBT</i>	wet bulb temperature (°C)
<i>Y</i>	expansion factor
Greek Symbols	
<i>α</i>	recycling factor (%)
<i>β</i>	CO ₂ emission factor (kg CO ₂ /kWh)
<i>ΔP</i>	density (kg m ⁻³)
<i>ΔP</i>	pressure drop across nozzle (N m ⁻²)
<i>m</i>	mass flow rate of air (kg s ⁻¹)
Subscripts	
<i>1</i>	nozzle 1
<i>2</i>	nozzle 2
<i>annual</i>	year
<i>c</i>	compression
<i>e</i>	evaporator
<i>r</i>	return air
<i>s</i>	supply air

Abbreviations

ASHRAE	– American Society Of Heating Refrigerating and Air-Conditioning Engineers
DT	– Domestic capacity rating test condition
ETA	– Export test A capacity rating test condition
ETB	– Export test B capacity rating test condition
IS	– Indian Standard
MDT	– Maximum domestic capacity rating test condition
META	– Maximum export test A capacity rating test condition
UUT	– Unit under test

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