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STUDY AND PERFORMANCE ANALYSIS OF ECO-FRIENDLY REFRIGERANT FOR RETROFITTING R22 IN RESPECT TO BANGLADESH

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Abstract- *A split type room air conditioner designed to work with R-22 was used as a test unit to assess the possibility of using hydrocarbons and their blends as refrigerants. Propane like R290 and the different mixtures of propane with pure gas were used as refrigerants. The energy consumption of the air-conditioner during experiment with hydrocarbons and R22 was measured. The results show that the compressor consumed 5.29% and 6.5% less energy than that of HCFC-22 at 29°C ambient temperature when propane and mixture of propane were used as refrigerants respectively. The effects of condenser temperature and evaporator temperature on COP, refrigerating effect, condenser duty, work of compression and heat rejection ratio were investigated. The energy consumption and COP of hydrocarbons and their blends shows that hydrocarbon can be used as refrigerant in the domestic air-conditioner. The COP and other result obtained in this experiment show a positive indication of using HC as refrigerants in domestic split air-conditioner.*

Keywords: R22, R407c**,** Propane, Energy consumption, & ODP.

1. INTRODUCTION

R22 has been the dominant refrigerant in residential and commercial air conditioning and industrial process cooling. Worldwide attempts are being made to phase out the production and consumption of chlorofluorocarbons, as these chemicals are responsible for depletion of stratospheric ozone layer. Bangladesh is populated developing country. Day by day the uses of air conditioning are increased. More than 90% air conditioning system used R22 refrigerant.

Table1: Refrigerant Used in Bangladesh

Equipment	Refrigerant	Price /Kg	ODP	GWP
Room AC	R22	350tk	.05	1700
	R410a	1000tk	0	1720
	R407C	800tk	0	1600
Fridge	R12	320tk	0.82	10600
	R134a	1200tk	0	1300
	R404a	1200tk	0	4.1
	R600a	600tk	0	8
Cold storage	R502C	800tk	0.283	4.1
	R134a	1200tk	0	1300
Car AC	R134a	1200tk	0	1300

Recently some refrigerant R410a, R407c, R600a etc used in air conditioning system. Air conditioner, refrigeration and heat pumps sectors are one of the principal users of these chemicals. During the last decade, the number of refrigerants likely to be used in refrigerating machines has dramatically increased as a consequence of the elimination of the CFC's and HCFC's. According to Montreal Protocol and European Community countries (accelerated plan as per EC 2037-2000 regulation) has established a requirement for the worldwide phase out of ozone depleting HCFCs as per schedule. For, European countries stop the production all equipment's for R22 around 2002. Reduction 75% supplies of R22 for existing equipment's around 2008 and also stop production 100% around 2010, only recycling will going on. Finally around 2015, totally ban of use R22. In our subcontinent area 10% reduction in supplies of R22 around 2015,35% reduction in supplies of R22 around 2020, 67.5% reduction in supplies of R22 around 2025 and total ban of use is around 2030. A lot of people still use R22 for their different purpose. So it is necessary to search alternative refrigerant which serve their purpose and also safe for environment. This paper also presents the study of comparative thermodynamic analyses of R22 and three of its alternatives natural refrigerants for air conditioner units operating under different outdoor temperatures. These natural substances have the dual advantage of very low global warming, nearly zero and zero depletion. Table 2 presents the environmental data of selected refrigerants.

Table 2: Environmental data of different refrigerants

Group	Refrigerant	Atm. Life	ODP	GWP
CFC (Cl,F,C)	R11	130	1	4000
	R12	130	1	8500
HCFC (H,Cl,F,C)	R22	15	.05	1500
HFC (H,F,C)	R134a	16	0	1300
	R404a	16	0	3260
	R410a	16	0	1720
	R507	130	1	3300
HC (H,C)	R290	< 1	0	8
	R600a	< 1	0	8
R717	NH3	-	0	0
R744	CO_2	-	0	1

In this experiment a domestic split type air conditioner designed to work with R22 & R290 were investigated without modification.

2. LITERATURE RIVEW

Many researchers have done several investigations in order to determine the efficiency of potential substitutes to R22 due to refrigeration capacity because refrigeration capacity depended on mass flow rate through evaporator. Devotta *et al.* [1] selected HFC-134a, HC-290, R-407C, R-410A, and three blends of HFC-32, HFC-134a and HFC-125 and found that HFC-134a offers the highest COP, but its capacity is the lowest and requires much larger compressors. The characteristics of HC-290 are very close to those of HCFC-22, and compressors require very little modification. Therefore, HC-290 is a potential candidate provided the risk concerns are mitigated as had been accomplished for refrigerators. J U Ahamed *et al.* [2] used different mixture of R290& R22 for the possible replacement of R22 based on energy, exergy and heat transfer performance. But it is of liquid R290 [3]. Sekhar *et al.*[4] investigated an experiment to retrofit a CFC12 system to eco-friendly system using of HCFC134a/HC290/HC600a without changing the mineral oil and found that the new mixture could reduce the energy consumption by 4 to 11% and improve the actual COP by 3 to8% from that of CFC12. C. Henderson et al. [5] compared the performances of a domestic and commercial heat pumps working with R22 and its alternatives R410A and R290 and suggested that R410A is a good substitute compared to R290 to replace R22 in domestic and commercial heat pump due to increase in performance and comparable global warming potential.
So according to different research study, Hydrocarbons (HCs) are an environmentally proper alternative for CFCs and HCFCs. HCs as a refrigerant have been known and used since the beginning of this century. The development of the inert CFCs in the 1930s put the HC technology in the background. CFCs have been applied since then in numerous refrigeration equipments (United Nations Environment Programme, 1991). Studied the literature the candidate of alternatives to R22 shown in table 3

Table 3: Selected alternative refrigerants to R22

Refrigerant	Mol. Wt. Kg/Kmol	Boiling Point (^{0}C)	ODP	GWP
R22	86.47	-40.80	0.034	1700
R404A	97.60	-46.60	0	3260
R410A	72.58	-51.60	0	1730
R410B	75.57	-51.51	0	1830
R407C	86.20	-43.80	0	1530
R417A	106.75	-38.00	0	2200
R507	98.60	-47.10	0	3300
R717	17.03	-33.30	0	<1
R744	44.01	-78.40	0	1
R290	44.10	-42.20	0	.01

3. RESEARCH METHODOLOGY

The experimental set up for split type room air conditioner was built up to measure energy and heat transfer parameters by using refrigerant R22 and blend of HC(R290) at Thermodynamic lab, Chittagong University of Engineering & Technology Faculty of Engineering(CUET). A split type air conditioner was used for the experiment, and the model is General AOG12ASMC. The compressor was rotary sealed type. Specifications of the evaporator, condenser and capillary tube are shown in Appendix A. For measuring the necessary data, some apparatuses were used, and all are described briefly in this chapter. Data were collected using the equipment such as ammeter, two pressure gauges, two thermocouples (K-type), and hygrometer etc. Thermo-physical properties of the refrigerants were found using the commercial software REFPROP 7 at different operating conditions. Temperatures of the refrigerants inlet and outlet of the evaporator, compressor, condenser and expansion valve as well as inlet and outlet pressures of the compressor were also measured for different environmental conditions. For energy analysis, coefficient of performance (COP), energy usage, work of compression, refrigeration effect and condenser duty were calculated with the measured data of temperatures, pressures. For heat transfer analysis, the heat rejection rate in the condenser, cooling capacity of evaporator, heat transfer coefficients in the evaporator were calculated with the measured data using some mathematical formulae. All the data were collected at Thermodynamic lab, Chittagong University of Engineering & Technology (CUET). The size of the room used for testing was 10 X10 ft^2. During the experimental works, relative humidity of the room was 55%-60% and room temperature is 29 ^{0}C.

3.1 Experimental Apparatus

In this section the list of apparatus and their functions used in this experimental work is tabulated and show a brief description of the facilities developed for conducting experimental work on the air conditioner. Refrigerants were selected based on the justification described in the literature review. The techniques of charging and recovery of refrigerant into/from the air conditioner are discussed here. The apparatuses used in the experiments are listed in table 4.

Table 4: List of apparatuses and their functions, used in this experimental work.

Apparatus	Purpose
REFPROP 7	To find the thermo-properties of the refrigerant
Room air conditioning unit	To comparative study with different refrigerants
Vacuum pump	To discharge and evacuate the system and make moisture free
Digital electronic charging scale	To measure weight of different refrigerants
Pressure gauges	To measure the pressure at desired location
Digital temperature gauges	To measure the temperature
Digital Ammeter	To measure the current
Hygrometer	To measure the humidity of the room
Charging hose and pipes	To help for charging gas from cylinder

3.2 Test Unit

The air conditioner has been used in this experiment is General AOG12ASMC 12000 BTU 1 ton split air Conditioner. This air conditioner has the capacity of 1 ton. The air conditioner is a non-inverter type which is a standard model. The specifications of the air conditioner used in this research are presented in table

Table 5: Descriptions of the air conditioner used in the experiment.

Specifications	**Range or value**
Model	AOG12ASMC
Capacity	3.40-3.45 KW (11600 -11800 BTU/hr)
Type	Split type air conditioner
Power type/voltage/phase	220 -240V, 50 Hz
High Pressure (Max^m)	390 psi
Low Pressure (Max^m)	115 psi
Refrigerant	R-22
Refrigerant amount (kg)	0.75 Kg
Power input	1.27- 1.33 KW
Current	6.10-6.20 amp

3.3 Experimental Setup

In this test rig a split-type-air conditioner is installed which uses R22 as refrigerant. The main loop of the system under study consists of five basic components (compressor, evaporator, condenser, capillary tubes and liquid line filter–drier). The experimental set-up is located in a closed psychometric loop. Two Digital thermometers are installed to measure the inlet and outlet the temperature of the compressor. There are also two digital thermometers to measure the outlet and inlet temperature of condenser and evaporator respectively. Mass flow meter is of magnetic type that can detect the flow rate of refrigerant through the evaporator. A multi-meter with ±0.5 % accuracy was installed to measure power consumption of the compressor, evaporator and condenser fan. Room temperature was measured with the help of precision thermometer with an accuracy of ±0.01 ^{0}C. To know the condition of the room, a hygrometer is set in the room to detect the atmospheric condition i.e. relative humidity, dry bulb and wet bulb temperature. The air conditioner was instrumented with two pressure gauges at the inlet and outlet of the compressor for measuring the suction and discharge pressure. Some other measuring and controlling components are used in the system, such as an electrical switch, a digital thermostat for controlling the evaporator temperature, bourdon tube type low pressure gauge and high pressure gauge, 'K' type thermocouples and indicator and gas flow control valves. In order to have a uniform temperature throughout the room, a ceiling fan of 60 watt power installed in the centre of room was used to circulate the air inside the room.

3.4 Experimental Procedure

All refrigerants and mixture should be charged through the inlet port. Yellow jacket digital electronic scale was used to weigh accurately the different refrigerants. At first, the system was to be charged with R22 then the experiment will be performed. Then record data for the reference. In this experimental investigation, equivalent hydrocarbon charge of HFC 22 was considered approximately 10% by mass(shown figure1)

Fig.1: Charging mixture in compressor

The amount of charging R22 was 700 gm. For the refrigerant X_7, the amount of R22 was 610 gm and the amount of R290 was 90 gm. The next mixture X_6 , the R22 is 85 % by mass are maintained. The amount of refrigerant was adjusted by knowing the pressure inside the service port. The refrigerant was poured up to 5.15 bar pressure and observing whether there was sufficient cooling occurred in the room or not. During experimental work, the room temperature was maintained at approximately 25-26°C.

4. EQUATIONS & CALCULATIONS

Power consumption depends upon the number of hours. A typical split 1 ton AC has a rating of around 1.3 kW. The units are energy consumed, which is measured in KWh (Kilo-Watt-Hour).Now the whole split AC package consists of 2 units. The indoor unit, which is called the evaporator and the outdoor unit which called the compressor. The indoor unit is around 100 watts or say 0.1 kW. The Outdoor unit consumes the bulk of power which is rated at around 1250 watts or 1.25kW. Hence the total comes out to be around 1.3kW. In this experimental 1 ton General split AC, the indoor unit is constantly on, but the compressor doesn't run the whole time. It only starts when the indoor temperature begins to rise and stops once the required temperature is achieved. So, in an hour, the compressor runs only for about half the time. So total no of units consumed per hour would be, Equation,

P = VI Cosθ (Cosθ = 1, for single phase) ---------------(1)

P = √3VICosθ (Cosθ = .80, for single phase)-----------(2)

(wattage x hrs used)/ 1000 x unit price = cost of electricity ---(3)

[(1.24KW x 'P' hrs) + (0.033 KW x 1 hr)] = KWh, Where, P is variable for different hour------------------(4)

COP = $\frac{h_1-h_4}{h_2-h_1}$, Where, h is enthalpy---------------------(5)

In this equation,

$h_1 - h_4$ = Refrigerating effect (RE)
$h_2 - h_1$ = Compression work

When the temperature increases, the amount of molecular interactions also increases. When the number of interactions increases, then the internal energy of the system rises. According to the first equation given, if the internal energy (U) increases then the ΔH increases as temperature rise.

ΔH = ΔU + pΔV --(6)

$C_p = \left(\frac{\Delta H}{\Delta T}\right)_p$--(7)

As the hydrocarbon R290 can be used mixing with R22 to increase the performance. Thus, the energy usage will also be reduced. Energy savings can be treated as follows:

$$AES\% = \frac{AEU_{R22}-AEU_{Mixture}}{AEU_{R22}} X\ 100\%\text{------(8)}$$

Where,

AES= Average energy savings (%)
AEU= Average energy use (kWh)

The mixture of R22 and R290 can be a candiate in replacement of R22 for air conditioning system which will provide less GWP. If the proposed mixture is R22:R290 (85:15), the GWP will be changed. For the mixture (X_6), GWP can be calculated as follows:

$GWP(X_6) = 0.85\times GWP(R22) + 0.15\times GWP(R290)$-----(9)

So, as increases R290 ratio decreases GWP.

5. DISCUSSION & RESULTS

In Bangladesh generally, R22 is used as refrigerant in the air conditioner for the domestic purposes. Now due to global warming problems, it has been found from the literature that R22 would be replaced by R290, R407C, and R410A. R290 can be used as a substitute of R22 which occupies zero GWP and zero ODP. From the literature and using REFPROP 7 software, some properties (thermal and chemical) of the proposed refrigerants are tabulated in table 6.

Table 6: Determination properties of the refrigerants used in the vapor compression system

Refrigerant/ Mixer	Chemical Formula/ratio	CT (^{0}C)	CP (MPa)	NBP (^{0}C)
R290	$CH_3CH_2CH_3$ (Propane)	96.675	4.2471	-42.19
R22	$CHClF_2$	96.145	4.99	-40.80
R134a	$CH_2F\ CF_3$	101.06	4.0593	-26.07
R410A	R32:R125 (50:50)	72.50	4.950	-51.60
R407C	R32:R125: R134a (23:25:52)	87.30	4.6298	-43.80
X_1	R22:R290 (50:50)	84.40	4.3995	
X_2	R22:R290 (60:40)	85.51	4.4299	
X_3	R22:R290 (70:30)	85.710	4.4876	
X_4	R22:R290 (75:25)	86.021	4.5334	
X_5	R22:R290 (80:20)	86.786	4.5943	
X_6	R22:R290 (85:15)	88.101	4.6726	
X_7	R22:R290 (90:10)	90.058	4.7687	

In this table, it is clear that mixture X_6 and X_7 is near with the R22, so we can easily use that in existing air conditioning system for energy calculation.
The power consumption and the readings of the temperature sensor and pressure gauge are taken within some intervals during day time from 09.00 am to 6.00 pm. Power consumption is varied with day time because the outside or ambient temperature is increased with time up to noon. In the morning it is lower and in the afternoon, the atmospheric temperature was decreased. After that, the ambient temperature and power consumption is decreased. So, power consumption as well as ambient temperature is increased after 9.00 am to 2.00 pm (shown in figure 2). The data regarding energy consumptions by using power meter in the experimental facility section. At first, data has been taken for the refrigerant R22.

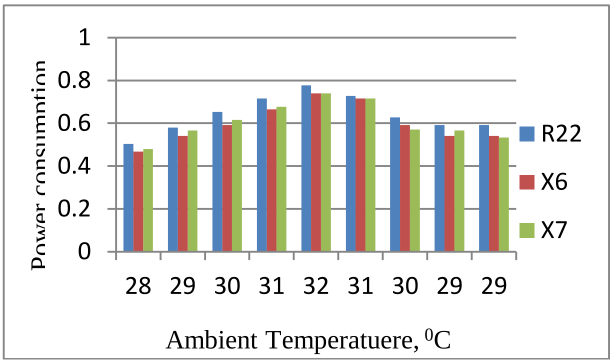

Fig.2: Variations of power consumptions with R22

So, it is clear that the power consumption depends on atmospheric temperature or dead state temperature. In this experiment, ambient temperature is not controlled manually but it is changing with nature. If reduced total power consumption for the period 09.00 am to 6.00 pm (9 hours) in day is around 5.0 to 6.0 kWh. It also varies for refrigerants types and their charges. May be the power consumption for the HC blends will be minimum compared to the R22. The power consumption also can be plotted in fig. 2 for different refrigerants.

Table 7: Setting room temperature at 26 ^{0}C and Refrigerant R22

Day Time (9 hrs)	Ambient Temperature (^{0}C)	Compressor running hrs (hrs)	Power Consumption (KWh)
9.00-10.00	28 ^{0}C	0.38	0.504
10.00-11.00	29 ^{0}C	0.44	0.579
11.00-12.00	30 ^{0}C	0.50	0.653
12.00-13.00	31 ^{0}C	0.55	0.715
13.00-14.00	32 ^{0}C	0.60	0.777
14.00-15.00	31 ^{0}C	0.56	0.727
15.00-16.00	30 ^{0}C	0.48	0.628
16.00-17.00	29 ^{0}C	0.45	0.591
17.00- 18.00	29 ^{0}C	0.45	0.591
	Total	4.41	5.765

Table 8: Setting room temperature at 26 ^{0}C and Refrigerant Mixture (X_6)

Day Time (9 hrs)	Ambient Temperature (^{0}C)	Compressor running hrs (hrs)	Power Consumption (KWh)
9.00-10.00	28 ^{0}C	0.35	0.467
10.00-11.00	29 ^{0}C	0.41	0.541
11.00-12.00	30 ^{0}C	0.45	0.591
12.00-13.00	31 ^{0}C	0.51	0.665
13.00-14.00	32 ^{0}C	0.57	0.739
14.00-15.00	31 ^{0}C	0.55	0.715
15.00-16.00	30 ^{0}C	0.45	0.591
16.00-17.00	29 ^{0}C	0.41	0.541
17.00- 18.00	29 ^{0}C	0.41	0.541
	Total	4.11	5.39

Table 9: Setting room temperature at 26 ^{0}C and Refrigerant Mixture (X_7)

Day Time (9 hrs)	Ambient Temperature (^{0}C)	Compressor running hrs (hrs)	Power Consumption (KWh)
9.00-10.00	28 ^{0}C	0.36	0.4794
10.00-11.00	29 ^{0}C	0.43	0.566
11.00-12.00	30 ^{0}C	0.47	0.615
12.00-13.00	31 ^{0}C	0.52	0.677
13.00-14.00	32 ^{0}C	0.57	0.739
14.00-15.00	31 ^{0}C	0.55	0.715
15.00-16.00	30 ^{0}C	0.46	0.570
16.00-17.00	29 ^{0}C	0.43	0.566
17.00- 18.00	29 ^{0}C	0.42	0.553
	Total	4.42	5.46

Running the air conditioner outdoor unit and set auto mode with the 26 ^{0}C, record data by pressure gauge and temperature sensor at different point and plotting table (table 7,8,9,10,11,12) with mollier chart, it easy to calculate COP and compared between them.

Table 10: COP changes with different evaporator temperature changes for R22

Dis. Pr^r,(bar)	h_1 (kj/kg)	h_2 (kj/kg)	h_3 (kj/kg)	Evap Temp (^{0}C)	COP
16.87	410	450	270	12.5	3.50
16.53	410.5	453	276	10.4	3.16
15.83	411	455	280	8.7	2.97
15.76	411.5	457	285	8	2.78
15.76	412	457	292	6.5	2.66

Table 11: COP changes with different evaporator temperature changes for Mixture X_6

Dis. Pr^r,(bar)	h_1 (kj/kg)	h_2 (kj/kg)	h_3 (kj/kg)	Evap Temp (^{0}C)	COP
16.83	417	457	275	13	3.55
16.50	417.5	459	277	12.9	3.38
15.79	418	461	278	10	3.25
15.74	418.5	462	280	9.5	3.18
15.74	420	464	282	9.3	3.13

Table 12 : changes with different evaporator temperature changes for Mixture X_7

Dis. Pr^r,(bar)	h_1 (kj/kg)	h_2 (kj/kg)	h_3 (kj/kg)	Evap Temp (^{0}C)	COP
16.85	415	455	274	12.9	3.525
16.52	415.5	457	276	11	3.36
15.80	416	460	278	9.5	3.13
15.75	416.5	462	280	8.8	3.0
15.75	417	463	281	7.5	2.95

The COP of the split air conditioner, using R22 as a refrigerant is considered as standard and the COP of R290 and their blend were compared. The COP versus evaporator temperature is plotted for mixture X6, X7 and R290 at 29°C ambient temperatures in the same graph. The results displayed in Figs. 3 show a progressive increase in COP as the evaporating temperature increases

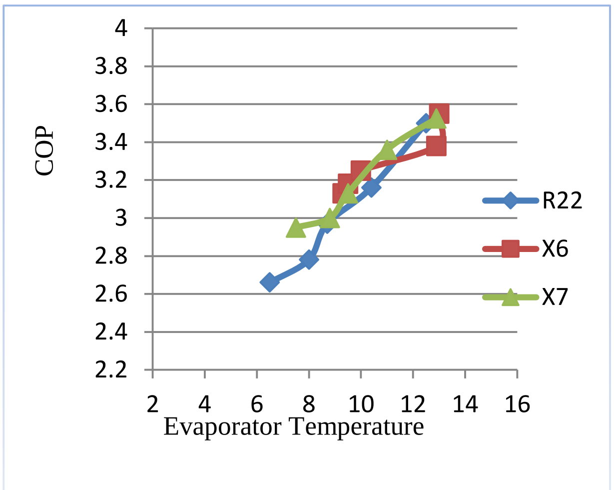

Fig.3: Variation of COP on different evaporator Temperature

6. CONCLUSION

This project investigated an ozone friendly, energy efficient and cost-effective alternative refrigerant for R22 in air conditioning systems. After the successful investigation on the performance between R22 and blends of HCs as refrigerants, it is observed that the COP of HCs blend is more than that of R22. The energy consumption of the HCs and blends is 5.29% to 6.5% less than that use of R22. The air conditioner unit charged with 610g R22 with 90 g R290 and no parts changed or modified of this unit.

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8. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	^{0}C
P	Pressure	Bar
h	Enthalpy	KJ/Kg
P	Power consumption	KWh
C_p	Specific heat	kJ/kgK
RE	Refrigerating effect	kJ/kg
COP	Coefficient of performance	
NBP	Normal Boiling Point	^{0}C
CT	Critical Temperature	^{0}C
CP	Critical Pressure	MPa
GWP	Global warming potential	
ODP	Ozone depletion potential	
CFC	Chlorofluorocarbon	
HCFC	Hydro Chlorofluorocarbon	
HFC	Hydro fluorocarbon	
HCs	Hydrocarbons	
R22	Monochlorodifluoromethane	
R290	Propane	