International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 07 | July-2016 www.irjet.net p-ISSN: 2395-0072

Performance Analysis of Automobile Air Conditioning System using Propane (R290)

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Abstract - *Automobile air conditioning (AAC) system contribute directly and indirectly to the problems of global warming and ozone depletion. The impact of air conditioning systems on environment can be reduced by the use of alternative ecofriendly refrigerants which are less harmful to the atmosphere. Since propane has negligible effect on global warming and zero ozone depleting substance, use of propane (R290) as a refrigerant is a good opportunity to develop environmental friendly system for an AAC. This paper discusses the theoretical aspects of R-290 (propane) as a potential substitute for R-22. The main aim of the study is to evaluate the performance of propane (R290) in AAC system theoretically and experimentally. For theoretical analysis purpose, thermodynamic evaluation of standard Vapor Compression Refrigeration System (VCRS) was carried out and a MS-Excel spreadsheet was developed to evaluate performance parameters like refrigeration effect, compressor work, coefficient of performance, mass flow rate, volumetric refrigerating capacity and power per tons of refrigeration. For experimental analysis purpose, an experimental set up was developed using components compatible with propane and instrumented. Theoretical analysis shows that the thermo physical properties and environmental properties of HC-290 is much better than HCFC-22 hence making it feasible for replacement. Experimental results showed that propane has higher refrigerating effect, marginally less COP but high compressor work which could be further lowered by specially designing compressor for propane. Hence, propane could be effectively used in AAC system.*

Key Words: Alternative refrigerant, Automotive air conditioning system, Propane (R290), Refrigeration.

1. INTRODUCTION

Refrigerants are the working fluids in refrigeration, air-conditioning and heat pumping systems which absorb heat from an air-conditioned space and reject it into outdoors, usually through evaporation and condensation process respectively. Refrigeration and air conditioning systems provides many benefits to the society, but these benefits carries environmental and societal consequences, many of which stem directly from the refrigerant chosen for each application. Throughout the history of air conditioning and refrigeration, numerous substances have been used as refrigerants. However, choosing a refrigerant has become more complex in recent years. Earlier generations of refrigerants-chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) contributed to the depletion of stratospheric ozone and are being phased out under international treaty. CFCs and HCFCs largely have been replaced with hydro fluorocarbons (HFCs). Some of these HFCs have high global warming potentials (GWP) and are becoming subject to use restrictions in some countries. Recently, lower GWP natural refrigerants such as propane and R600a have been introduced for the application of water coolers, freezers, etc [1].

According to the American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE), air conditioning is the science of controlling the temperature, humidity, motion and cleanliness of the air within an enclosure [2]. The open literature on the AAC systems is very limited. Few researchers had done research on substitution of different alternative refrigerants in place of R22 and R134a.

Recent attention to depletion of stratospheric ozone, by chemicals containing bromine and chlorine along with climate change, by greenhouse gases, resulted in an international accord to halt the production of these chemicals. Chemical and equipment manufacturers mounted aggressive research and development programs to introduce alternative and transition refrigerants [3]. Hydrocarbons, such as propane, R290, and isobutane, R600a, present a potential simultaneous solution for the two problems, owing to their good properties. Such refrigerants are being used for refrigeration as pure substances or in blends and also alongside non-hydrocarbons in mixtures. Such refrigerants are advantageous in respect of their performance, mineral oil compatibility, low toxicity and negligible environmental impact. The most important issue regarding hydrocarbons as refrigerants, either in their own right or as part of a blend formulation, is their flammability [4]. While it is an emotive subject, it should be remembered that millions of tonnes of hydrocarbons are used safely throughout the world every year for cooking, heating, powering vehicles and as aerosol propellants. In such industries, procedures and standards have been developed and adapted from scientific data, test methods, common use practices and experiential judgement to ensure the safe use of the product. The same approach is now being followed by the refrigeration industry [4].

In the present study, performance analysis of propane (R290) in an automobile air conditioning system is carried out theoretically and experimentally. The study is assessed over a wide range of evaporating temperature, with condensing temperature fixed and accordingly, various performance parameters are evaluated.

2. THEORETICAL CYCLE ANALYSIS

2.1 Thermodynamic properties of R290 refrigerant

The basic thermodynamic properties of propane (R290) as well as safety and flammability data are shown in table 1.

Table 1: Properties of R-290. [3]

Refrigerant	R290
Molecular Weight	44.10
Normal B.P. ⁰C	-42.1
Critical Temp. Tc⁰C	96.7
Critical Press MPa	4.25
Latent heat of Evap kJ/kg	425.4
Atm. life (Years)	0.041
ODP(R11=1)	0.000
$GWP_{100yr(CO2=1)}$	20
Safety class	A3
LFL by volume %	2.1

2.2 Theoretical cycle analysis procedure

AAC system works on Vapour Compression Refrigeration (VCR) cycle. The representation of cycle on schematic and (p-h) diagram is shown in figure 1 and 2 respectively when the vapor at the end of compression is assumed to be superheated.

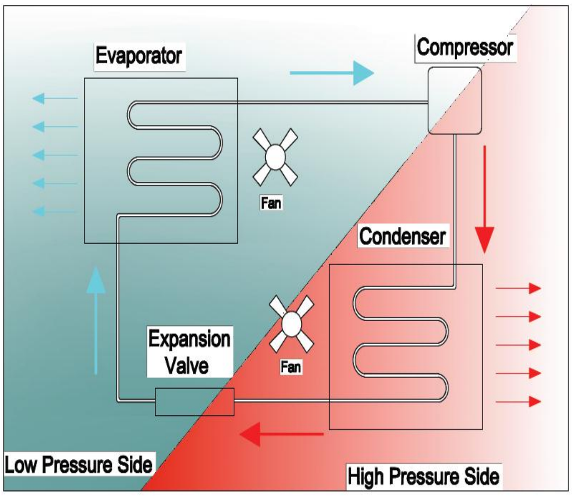

Figure 1: Schematic diagram of VCRS

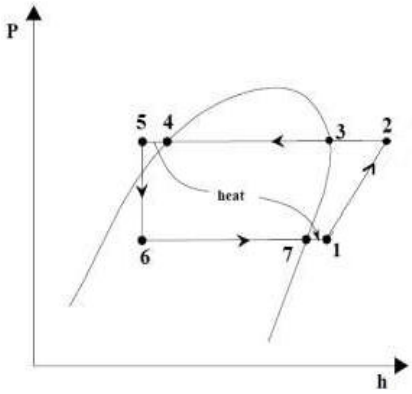

Figure 2: Pressure-Enthalpy chart of VCRS [5]

Assuming that 1 *kg* of refrigerant flows in the system, it can be analyzed for the system as follows with help of steady flow energy equation. Thermodynamic analysis of system is as follows [6].

(i) Compressor work, W_c *(kJ/kg)* : $W_c = h_2 - h_1$

(ii) Refrigerating effect, q_o *(kJ/kg)* : $q_o = h_1 - h_6$

(iii) Heat rejected at condenser, q_c *(kJ/kg)* :

$$q_c = h_3 - h_4$$

(iv) $$COP = \frac{\text{Re } frigerating\ effect, q_o}{Compressor\ work, W_c}$$

$$COP = \frac{h_1 - h_6}{h_2 - h_1}$$

(v) Mass of refrigerant to be circulated, m_r *(kg/sec)* :

$$m_r = \frac{Q(kJ/sec)}{q_e(kJ/kg)}$$

(vi) Compressor power, P_c *(kW)* : $P_c = m_r(h_2 - h_1)$

(vii) Expansion device : $h_5 = h_6$

2.3 Input data

The rating conditions are an evaporating temperature of 7.2 *℃* and a condensing temperature of 55 *℃*. For mixtures, CYCLE_D computes the condensing temperature as the mean of bubble and dew point temperatures. Similarly, the evaporating temperature is the mean of evaporator inlet temperature and the dew point temperature. Evaporator temperature (T_7) = 7.2 *℃*, condenser temperature (T_3) = 55 *℃*, volumetric efficiency = 85%, isentropic efficiency of compressor = 85%.

2.4 Theoretical cycle analysis

By using input data and by making evaluation in MS-Excel spreadsheet, the theoretical analysis of R290 was carried out by varying its evaporator temperature for the given cooling capacity. Condenser temperature is 55 *℃* and evaporator temperature (T_E) varies from 5 *℃* to 15 *℃*. For different evaporator temperature, each performance parameter like refrigerating effect (*RE*), compressor work (W_c) coefficient of performance (*COP*) and mass flow rate of refrigerant per ton (m_r) is measured. Table 2 presents the calculated theoretical (thermodynamic) data of R290 refrigerant.

Table 2: Calculated theoretical results of R-290

T_E (°C)	RE (kJ/kg)	W_C (kJ/kg)	COP	m_r (kg / s per TR)
5	244.11	61.20	3.988	0.01441
6	245.19	59.76	4.103	0.01434
7	246.26	58.29	4.224	0.01428
8	247.33	56.86	4.350	0.01422
9	248.39	55.44	4.481	0.01416
10	249.45	54.01	4.618	0.01410
11	250.51	52.59	4.763	0.01404
12	251.55	51.19	4.914	0.01398
13	252.60	49.81	5.071	0.01392
14	253.63	48.45	5.235	0.01387
15	254.67	47.05	5.413	0.01381

3. EXPERIMENTAL CYCLE ANALYSIS

3.1 Experimental setup

The experimental automobile air conditioning system mainly consists of the original components from an automobile air conditioning system, as shown in figure 3. Some auxiliary equipment like temperature sensors, motor, blower, etc was used for testing the system under the required conditions. The refrigeration circuit of the system consists of compressor, condenser and evaporator with blower.

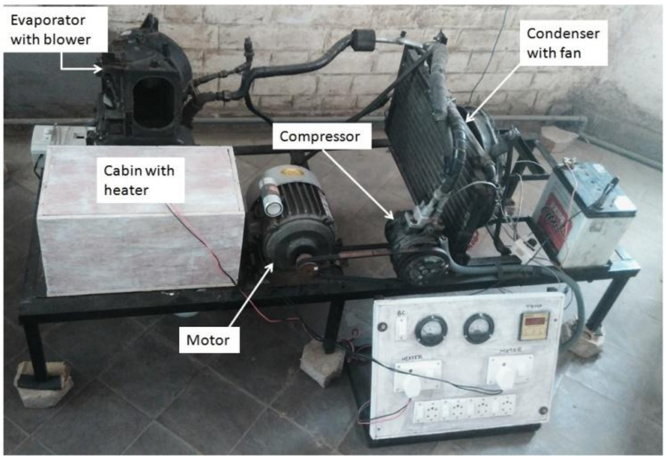

Figure 3: Experimental setup

The experimental set up consists of fan driven by an electric motor. The compressor was belt driven by an electric motor. The air flow passing through the condenser and evaporator can be achieved by fans and blower respectively. The refrigerant temperatures were detected by the thermocouples attached to the tube. The suction and discharge pressures of the compressor were measured by bourdon tube gauges. Pressure drops in the evaporator and condenser as well as in the connecting lines were neglected. With the use of a photoelectric tachometer, the motor speed was measured. The air velocity at the outlet of the evaporator and condenser was measured by anemometer. Different temperature state points of refrigerant side are as follows-

T_1 - Temperature at compressor suction,
T_2 - Temperature at compressor discharge,
T_3 - Temperature at condenser outlet,
T_4 - Temperature at expansion outlet,
T_5 - Temperature of evaporator.

3.2 Experimental results

Table 3 shows the experimental result performed on the test setup. During experimentation, evaporator temperature was kept constant in range of 5 °C to 18 °C by regulating the condenser fan and blower speed of evaporator.

Table 3: Experimental results of R-290

T_E (°C)	RE (kJ/kg)	W_C (kJ/kg)	COP	m_r (kg / s per TR)
5.2	240.82	73.20	3.290	0.01460
6.1	241.19	69.71	3.460	0.01458
7.2	241.76	65.82	3.673	0.01455
9.2	243.31	59.68	4.077	0.01445
11	245.21	56.89	4.310	0.01434
13.5	247.51	52.94	4.676	0.01421
16.2	250.29	47.20	5.302	0.01405
18.6	252.72	45.40	5.566	0.01392

4. RESULTS AND DISCUSSIONS

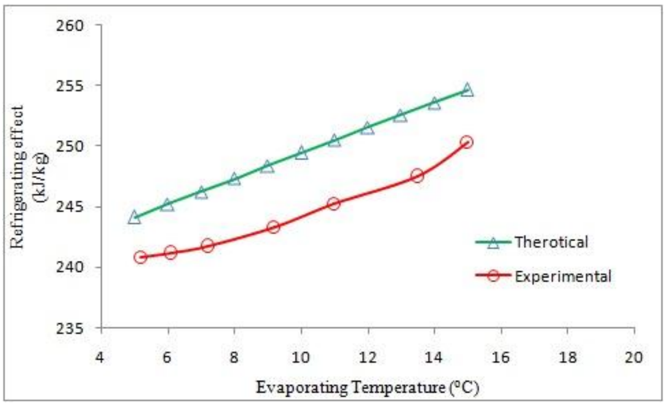

Figure 4: Effect of evaporating temperature on refrigerating effect

Based on the theoretical and experimental evaluation of propane as a refrigerant in AAC, the obtained results were discussed. Figure 4 shows the variation of refrigerating effect which is 1.82% lower for experimental evaluation as compared to that of theoretical. This is because the losses and power consumption by auxiliary components are not considered in theoretical evaluation.

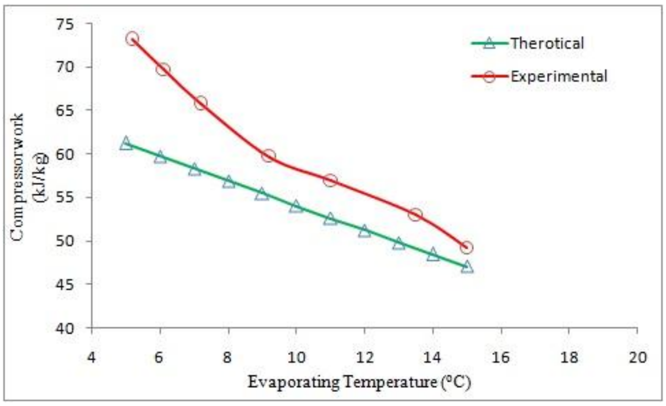

Figure 5: Effect of evaporating temperature on compressor work

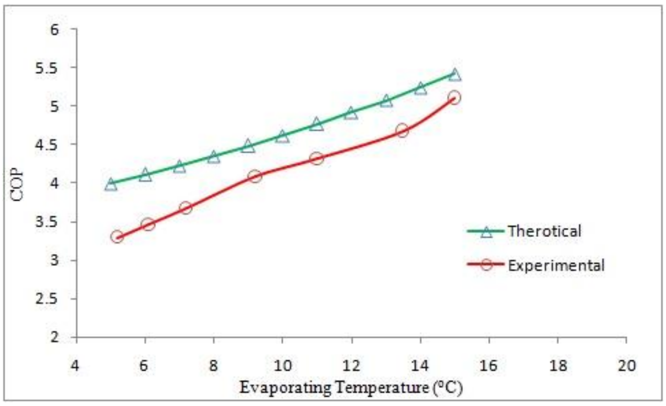

Figure 6: Effect of evaporating temperature on COP

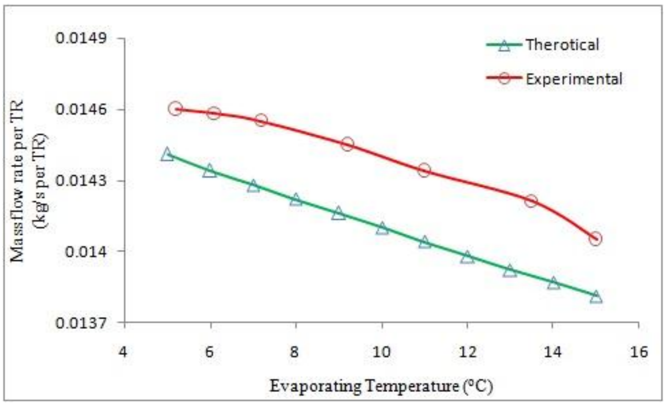

Figure 7: Effect of evaporating temperature on mass flow rate per TR

Figure 5 shows the variation in compressor work which is 7.91% higher for experimental evaluation than that of theoretical at 7 ^oC evaporating temperature due to power consumption by motor and other losse. COP is 8% lower whereas mass flow rate per ton of refrigerant is 1.89% higher for experimental evaluation than that of theoretical which is shown in figure 6 and figure 7 respectively. Variation in experimental and theoretical values is due to consideration of ideal cycle working and neglecting losses in theoretical evaluation.

5. CONCLUSIONS

Variation in refrigerating effect and mass flow rate per tons of refrigerant is well within 2% whereas compressor work and coefficient of performance also have deviation upto 8% . Hence the agreement between theoretical and experimental result is well within 8% and hence propane can be effectively used in automobile air conditioning system.

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