EXPERIMENTAL INVESTIGATIONS ON AUTOMOBILE AIR CONDITIONERS WORKING WITH R134a AND R290/R600a AS AN ALTERNATIVE

by

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In this work, the performance of R134a based automobile air conditioning system has been evaluated by retrofitted with R290/R600a mixture (in the ratio of 50:50, by mass), as an alternative. The performance was evaluated at five different operating speeds (1000, 1500, 2000, 2500, and 3000, which covers the entire range of working conditions) with four different cabin load (100, 200, 300, and 400 W). The condenser inlet air temperature was varied in the range between 30 and 50 °C, which covers the entire climatic variations in Coimbatore city of India. The performance characteristics such as, refrigerating effect, coefficient of performance, compressor power consumption, and compressor discharge temperatures were considered for comparison. The results showed that, hydrocarbon mixture has faster cooling rate due to its high latent heat of vaporization, 5% higher coefficient of performance due to higher refrigeration effect, 8-10 K lower compressor discharge temperature due to its lower specific heat ratio with 5% lower compressor power consumption due to its lower viscosity and lower liquid density. The charge requirement of R290/R600a mixture is about 50% less compared to R134a. However, the mixture composition is considered as an interment replacement in automobile air conditioners due to composition shift under leakage conditions. Hence, R290/R600a mixture is considered as an interim energy efficient and environment friendly option in R134a automobile air conditioners to extend its life.

Key words: *automobile air conditioners; R290/R600a mixture*

Introduction

Automobile air conditioners are working on vapor compression cycle using halogenated refrigerants. The halogenated refrigerants are having good thermodynamic, thermophysical and chemical properties. However, their environmental properties are poor due to its ozone depletion potential (ODP) and global warming potential (GWP) [1]. According to Montreal protocol 1987, the use of R12 in refrigeration, air conditioning and heat pump sys-

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tem have been phase-out due to its high ODP and GDP. The R134a has taken up the position of R12 in automobile air conditioners during the year 1995 due to its zero ODP and low GWP of 1300. In 1997, Kyoto protocol has identified six green house gases, which includes hydroflurocarbons (HFC) using as refrigerant in refrigeration, air conditioning and heat pump systems [2]. In 2016, more than 190 countries around the world have agreed to reduce to the consumption of HFC refrigerants in refrigeration, air conditioning and heat pump system due to its high GWP. More than 90% of the existing automobile air conditioning in India is working with R134a as a working fluid due to its good thermodynamic and thermophysical properties. However, R134a has high GWP of 1430. Hence, it is essential to identify a new energy efficient and environment friendly to meet the current requirements in automobile sector. During last two decades, many research and development investigations have been reported on environment friendly alternative refrigerants for automobile air conditioners, which are summarized in earlier published review articles [3, 4]. The review work confirmed that, R152a, hydrocarbon based mixtures (such as, R290/R600/600a, R134a/R290/R600a), and R744 as possible alternatives to R134a based automobile air conditioners. However, these refrigerants have certain drawbacks in retrofitting in the existing systems due to mismatch in operating pressure. The hydrocarbon refrigerants are possible alternatives to R134a in automobile air conditioners [5, 6]. The refrigerant R1234yf has been proposed as a possible alternative to phase out R134a by many researchers around the world due to its zero ODP and low GWP [7]. The R1234yf has similar thermodynamic and thermophysical properties with R134a. Hence, it is possible to replace R1234yf in R134a systems without major modifications [8]. Another possible alternative is R1234ze, which can similar thermodynamic and thermophysical properties with R134a. Hence, it is possible to replace R134a in automobile air conditioning systems using R1234ze without major modifications [9]. The hydrofluroolefins will form tri-fluro-acedic acid, which are more harmful to aquatic. From cited review, it is observed that many research and developments have been investigated on the performance evaluation of automobile air–conditioning systems. However, the possibility of using locally available R290/R600a hydrocarbon mixture in automobile air conditioner is not reported in open literature. Hence, an attempt has been made in this research work to explore the possibility of using locally available hydrocarbon refrigerants in automobile air conditioning systems and explored its feasibility for retrofitting.

Characteristics of refrigerants

In fig. 1, the vapor pressures of different refrigerants with reference to temperatures are illustrated. Refrigerant R290 has a higher saturation pressure than the existing refrigerant for the working temperature range. Refrigerant R600a and hydrocarbon mixture (R290:R600a 50:50, by mass) has working pressure below R134a. Generally for selection of the alternate refrigerants, the saturation or the vapor pressure should not exceed the value of the existing system and it should be greater than the atmospheric pressure. It is clear that the refrigerant R290 cannot be used as an alternative refrigerant as replacement for R134a. The latent heat of the refrigerants considered in this research work is illustrated in fig. 2. From fig. 2, it is con-

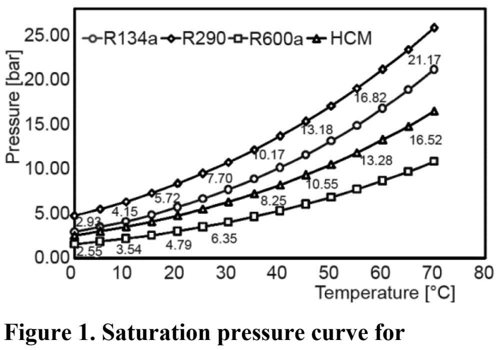

Figure 1. Saturation pressure curve for different refrigerants

firmed that hydrocarbon refrigerants have high latent heat of vaporization. Higher cooling rate can be expected with hydrocarbon refrigerants when compared with R134a. The liquid densities of investigated refrigerants are shown in fig. 3. Lower the liquid density is preferable to reduce the refrigerant change requirement. From fig. 3, it is observed that, the hydrocarbon refrigerants are having lower liquid density when compared to R134a, which confirms that, hydrocarbon charge requirement is low.

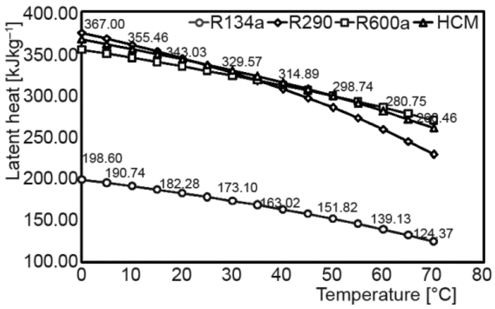

Figure 2. Latent heat of investigated refrigerants

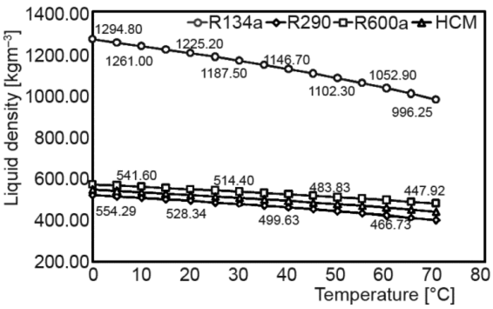

Figure 3. Liquid density of different refrigerants

Experimentation

The details of experimental set-up, instrumentation and experimental procedure are described in this section.

Experimental set-up

The schematic diagram of an experimental set-up and its photographic view are depicted in figs. 4 and 5, respectively. The experimental set-up consists of Maruthi Suzuki made Alto LXI model car, 3 HP three phase AC induction motor fitted with variable frequency drive,

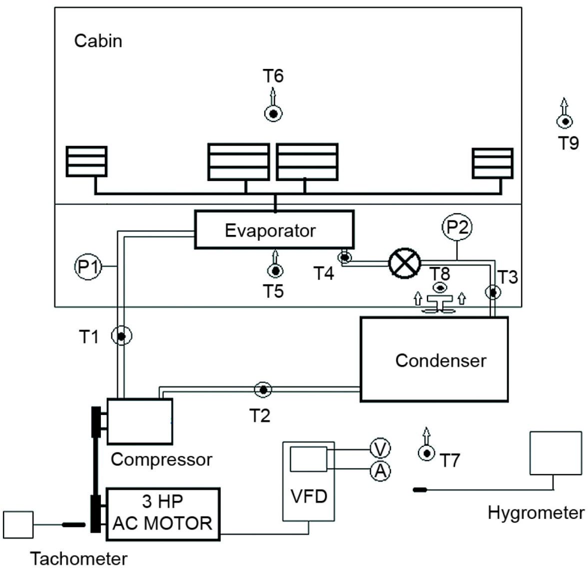

Figure 4. Schematic diagram of vapor compression refrigeration in automotive air conditioning;
T1 – compressor inlet temperature,
T2 – condenser inlet temperature,
T3 – condenser outlet temperature,
T4 – evaporator inlet temperature,
T5 – evaporator air inlet temperature,
T6 – evaporator air outlet temperature,
T7 – condenser air inlet temperature,
T8 – condenser air outlet temperature,
T9 – ambient temperature,
P1 – suction pressure,
P2 – discharge pressure,
VFD – variable frequency drive

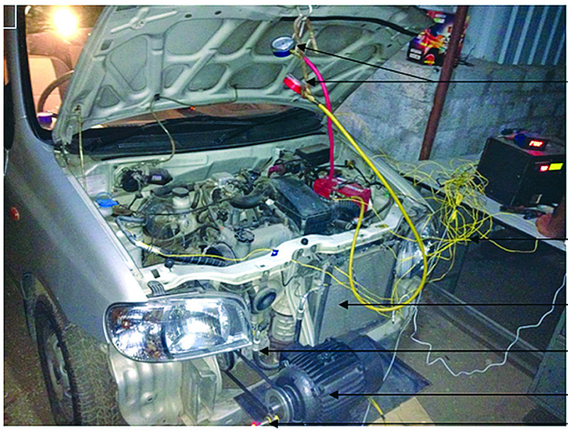

Figure 5. Photograph of experimental set-up

heater for loading the car cabin and another heater loading the environmental chamber. The compression refrigeration cycle used in the air conditioning system consists of six piston radial piston compressor, air cooled condenser, expansion valve and an evaporator. The temperature inside the vehicle cabin was controlled using thermostat. The heat infiltration into the vehicle cabin was controlled using transparent film in the wind screen. The air velocity approaching the condenser was varied using a 0.75 kW centrifugal blower. The entire system was kept inside a room of 3.35 × 8.22 × 3.25 m. The compressor is used to pressurize and pump the refrigerant from evaporator to the condenser side. The high pressure refrigerant gets condensed in the air cooled condenser. The condensed liquid refrigerant is then expanded in expansion device and gets evaporated in the evaporator. The vapor refrigerant then enters into the compressor for further cycle. Speed of the compressor is controlled with the help of the variable frequency drive.

Four (K-type) thermocouples were used to measure the temperatures at salient points in the refrigeration cycle, another four thermocouples with same specifications were used for measuring the air temperatures at different locations inside the car cabin and two thermocouples were used for measuring temperature at inlet and outlet of condenser for measuring the air temperature at condenser inlet and outlet. All the thermocouples are having similar accuracy of ±0.2 °C and similar technical specifications. Two pressure gauges with an accuracy of ±0.1 bar were installed at compressor suction and discharge to measure the suction and discharge pressures of the system. Two Wattmeters were used for measure the compressor power consumption and heater load separately. The speed of the motor is measured with help of the digital tachometer with an accuracy of ±5 rpm.

Experimental procedure

Initially, the system was flushed with nitrogen gas to remove the impurities and other non-condensable gases inside the system. Then, high pressure nitrogen gas was released and subjected to vacuum using vacuum pump. The required R134a quantity (about 400 g) was charged in the system according to the manufacturer recommendation. The experiments were carried out according to the procedure described in earlier experimental work [10]. The charge quantity was ensured with the electronic scale with an accuracy of ±0.1 g. Experimental observations were made by varying the speed of the motor, load inside the cabin and condenser inlet air temperature. In order to ensure the reliability of experiments, five trial experiments have been conducted at every operating condition. During, experimentation, the pressure and temperature at typical locations in the refrigerant circuit, air flow measurements through the condenser, air temperature measurements at different locations inside the vehicle cabin and compressor power consumption were measured. After baseline tests with R134a, the refrigerant was recovered and the required quantity of hydrocarbon mixture (HCM) composed of R290 and R600a (in the ratio of 50:50, by mass) was charged. The required quantity of R134a was determined based on liquid density. The HCM quantity was estimated as 140 g based on comparison of liquid density. While retrofitting with HCM, the same polyolester was retained. The experimental trials with HCM have been made similar to the procedure followed in R134a experimentation. All the experimental observations have been made after the system has reached the steady state conditions under each operating conditions. The evaporator cooling capacity was predicted using following equation:

$$Q_{\text{evap}} = m_{\text{a}} c_p (T_{\text{out}} - T_{\text{in}}) \tag{1}$$

The coefficient of performance, *COP*, is calculated by:

$$COP = \frac{Q_{\text{evap}}}{PC_{\text{measured}}} \tag{2}$$

The uncertainties in experiments are estimated using [11]:

$$w_r = \sqrt{\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2} \tag{3}$$

where R is a given function, w_r – the total uncertainty, x_1, x_2,…x_n are independent variables, w_1, w_2,…, w_n are the uncertainties in the independent variables. The uncertainties in evaporator cooling capacity and *COP* are estimated as ±2.5% and ±3.1%, respectively.

Results and discussion

The results obtained from series of experiments made in an experimental set-up are presented in this section.

The variations of evaporator pressure against compressor speed (using R134a and HCM as refrigerants) are depicted in fig. 6. It is observed that, compressor suction pressure of both the refrigerants gets decreased with increase in the compressor speed due to pumping of refrigerant from low pressure side to high pressure side. About 6-9% higher evaporator pressure was observed for HCM when compared to R134a. The pressure inside the evaporator was observed less than 10%, which ensures that the evaporator designed for R134a is quite good for retrofitting with HCM. Similarly, the condenser pressure variations of R134a and HCM during experimentation are compared in fig. 7. It is observed that, the compressor discharge pressure of both the refrigerants gets increased with increase in compressor speed. An increase in compressor speed pumps more quantity of refrigerant to the condenser, which enhances the compressor discharge pressure. The compressor discharge pressure of HCM was about 8-9% higher when compared to R134a. The high condenser pressure ensures better condensation in the condenser. Moreover, it is observed that, the condenser design is safe to withstand the difference in operating pressure while retrofitting with HCM.

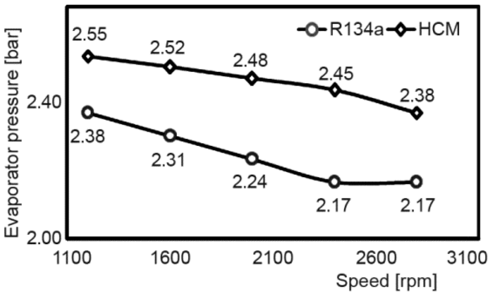

Figure 6. Evaporator pressure variation against compressor speed

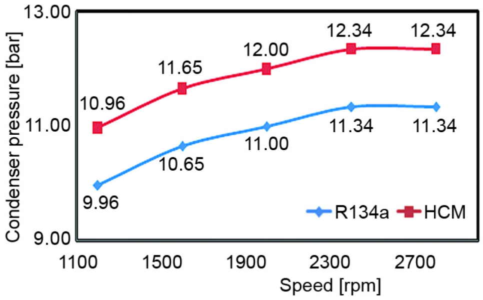

Figure 7. Condenser pressure variation against compressor speed

The compressor discharge temperature is main factor considered for selecting an alternative refrigerant. The experimental observations of compressor discharge temperature are depicted in fig. 8. It is observed that, compressor discharge temperature gets increased with increase in the compressor speed due to increase in refrigerant mass flow rate through the compressor. An increase in compressor discharge temperature ensures better condensation. The difference in compressor discharge temperature was observed within 5-7 °C. The lubricant used in the compressor is not affected due to rise in 5-7 °C, which ensures that, operation of compressor using HCM is safe without degradation of lubricant. Moreover, it is observed that, the condenser heat load of both the refrigerants is equal, which ensures the existing condenser used for R134a is compatible for HCM. The compressor power consumption of R134a and HCM are at different compressor operating speeds are compared in fig. 9. It is observed that compressor power consumption of both the refrigerants gets increased with increase in compressor speed. The compressor power consumption of HCM was observed to be higher by about 26% when compared to R134a. The high compressor consumption for both the refrigerants are observed due to increase in refrigerant mass flow rate through the compressor at high operating speed.

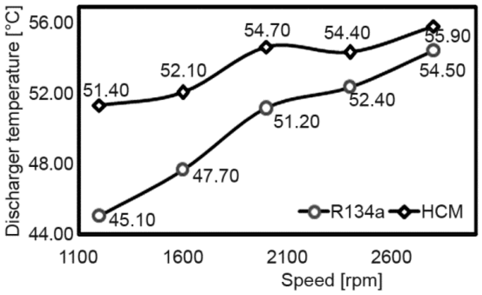

Figure 8. Variation of compressor discharge temperature against compressor speed

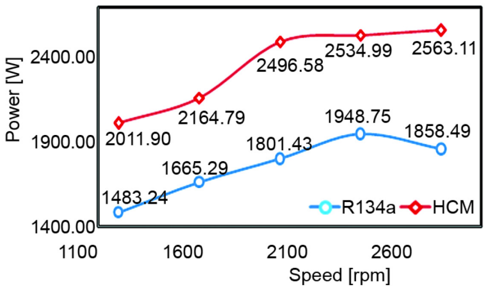

Figure 9. Compressor power consumption against speed

The variation of refrigerating effect of R134a and HCM are compared in fig. 10. It is observed that, the refrigeration capacity of both the refrigerants gets increased with increase in compressor operating speed. The refrigeration effect of HCM was about 30% higher when compared to R134 due to high latent heat of evaporation. Due to high latent heat of evaporation, the HCM is capable of providing faster cooling when compared to R134a. Moreover, the HCM exhibits higher transfer coefficients in evaporators due to its lower liquid density, lower viscosity when compared to R134a. Further, the variations of COP of both the refrigerants against the compressor speed are compared in fig. 11. The COP of HCM was observed to be higher when compared to R134a in all operating speeds. It is observed that COP of both the refrigerants gets decreases with increase in compressor speed. The COP variations for both the refrigerants were observed in the range between 0.9 and 1.03 and in the range between 0.94 and 1.12 for R134a and HCM, respectively. The compressor power consumption and refrigeration capacity gets increased with increase in compressor speed. The refrigerant mixture is compatible with synthetic lubricant, which is commonly used lubricant in HFC based automobile air conditioning systems. Hence, change of lubricant is not essential in the case of HCM retrofitting. The results observed in this work is similar to the earlier work reported by Wongwises, *et al.* [7] for the ternary hydrocarbon refrigerant mixture composed of R290/R600a/R600. The R290/R600a mixture is a readily available binary HCM in Indian market for retrofitting. Since, the HCM will not form flammable mixture even under leakage conditions due to less charge inside the system. However, it is essential to use sealed controls while retrofitted with HCM. Moreover, this mixture is an environment friendly and compatible with all the components of the system.

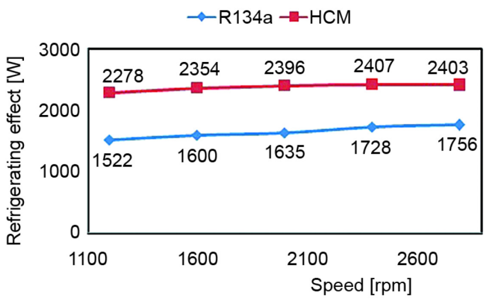

Figure 10. Variation of refrigeration effect against speed

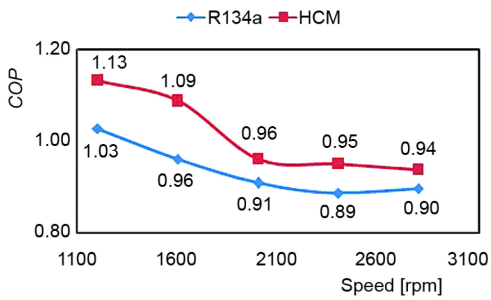

Figure. 11. Variation of COP against speed

Conclusions

The following major conclusions are drawn based on the experimental investigations.

- The refrigerant charge requirement of HCM was about 40% when compared to R134a.
- The operating pressures levels in compressor suction and discharge are slightly higher when compared to R134a. However, the existing condensers used for R134a is more safe for retrofitting with R134a.
- The HCM is having high latent heat of vaporization, which ensures better refrigeration effect when compared to R134a.
- The *COP* of HCM was found to be higher by about 5% when compared to R134a.
- The HCM has negligible GWP with zero ODP, which ensures that HCM is more environmentally sustainable.
- Due to the flammable nature of HCM, it is essential to use sealed control units to avoid flammable risk.

This investigation confirms that HCM is a good option for replacing R134a in the existing automobile air conditioners to extend its life.

Nomenclature

h – enthalpy, [kJkg^{-1}]
m_a – air mass flow rate, [kgs^{-1}]
N – compressor speed, [rpm]
PC – compressor power consumption, [W]

p – pressure, [bar]
Q_{evap} – refrigeration capacity, [W]
RE – refrigerating effect, [W]
T – temperature, [°C]

Acronyms

COP – coefficient of performance
GWP – global warming potential, (CO_2 = 1)
HCM – hydrocarbon mixture
HFC – hydrofluorocarbon
ODP – ozone depletion potential (CFC = 1)
POE – polyolester oil

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