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Effect of liquid suction heat exchanger on hydrocarbon refrigerant mixture R290/R600a and refrigerant R134a used in a domestic refrigerator

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ABSTRACT

In the present work, an experimental study of effect of liquid suction heat exchanger on hydrocarbon refrigerant mixture R290/R600a in the ratio of 50:50 by weight and R134a used as working fluid in domestic refrigerator has been done. The refrigerant R134a and hydrocarbon refrigerant mixture R290/600a have been used in a domestic refrigerator of capacity 220 litre. Also, an attempt is made to improve the system performance with the use of liquid line suction line heat exchanger (LSHX). With use of heat exchanger the refrigerant R134a and hydrocarbon mixture R290/R600a has more refrigeration effect than without use of heat exchanger by about 36.37 % and 14.9 % respectively. Also compressor work done with use of heat exchanger for the refrigerant R134a and hydrocarbon mixture R290/R600a is less than without the use of heat exchanger by 9.38 % and 9.98 % respectively. With use of heat exchanger the refrigerant R134a and hydrocarbon mixture has more coefficient of performance than without use of heat exchanger by 50.51 % and 27.65 % respectively. Also with use of heat exchanger the refrigerant R134a and hydrocarbon mixture has more discharge temperature than without use of heat exchanger by 2.9°C and 5.7°C respectively.

Keywords : *Coefficient of performance, Compressor discharge temperature, Compressor work done, Liquid suction heat exchanger, Refrigeration effect.*

1. Introduction

Refrigerants have undergone radical development due to the environmental issues like ozone depletion and climate change concerns. The selection of suitable refrigerant for various applications is now very crucial which satisfies the factors like, chemical properties, physical properties, transfer properties of substance and the most important is the substance ozone depletion potential (ODP) and global warming potential (GWP). For this reason the production and eventually the use of most popular refrigerants such as HFC 134a (R134a) will be terminated in the near future [1]. Mohanraj et al. [2] experimented with hydrocarbon refrigerant mixture composed of R290/R600a in the ratio of 45.2:54.8 by weight as an alternative to R134a in domestic refrigerators. Discharge temperature for HCM was found to be lower than that of R134a. For power consumption it is observed that HCM 50 and HCM 60 were found to be lower than that of R134a. The COP of HCM 50 was lower than that of R134a by about 2.4 to 2.59 %.

Richardson and Butterworth [3] investigated the performance of hydrocarbon refrigerants in vapour compression refrigeration system and compared the coefficient of performance between R12 and hydrocarbon refrigerants mixture R290/R600a with different compositions like 56:44 and 43:57 for various evaporator temperatures -40°C, -30°C, -20°C, -10°C, 0°C, 10°C, and 20°C. For this 56:44 mixture has a COP greater than that of R12 throughout the range of temperatures investigated while 43:57 mixtures only achieves a better COP at temperature above about -10°C. Mani et al. [4] studied vapour compression refrigeration system with new R290/600a refrigerant mixture and compared with CFC12 and HFC 134a. The refrigerant mixture R290/R600a 68/32 had higher refrigerating capacity than R12 and R134a. The energy consumed by the system with R290/R600a 68/32 mixture was higher by 6.8 to 17.4 % than R12 and 8.9 to 20 % higher than R134a for all operating conditions. Further the coefficient of performance of R290/R600a 68/32 mixture was 3.9 to 25.1 % higher than R12 at the lower evaporating temperature below - 8°C.

Joaquin et al. [5] experimented for the influence of an internal heat exchanger on the performance of vapour compression system using R1234yf as drop in replacement for R134a. The cooling capacity increases with the internal heat exchanger adoption with increase between 0 to 5 % for R134a and 2 to 9 % for R1234yf. Due to the internal heat exchanger adoption there is an increase in the discharge compressor about 4K to 11k for both refrigerants increasing with compression ratio. Nurhasenah [6] studied the effect of subcooling on vapour compression refrigeration system with cooling load variation. Refrigerant R134a and R600a were used. Greater cooling load increases subcooling and there is greater decrease in temperature. The compressor work without subcooling with R134a as a refrigerant is 35.57 kJ/kg, with subcooling increase to 36.71 kJ/kg if valve is half open and 37.58 kJ/kg if valve is full open.

Cabello et al. [7] presented experimental comparison between R152a and R134a working in a refrigeration facility. At the same working conditions R152a yields lower compressor power consumption than R134a. This reduction in power consumption is assessed in the range between 5.52 and 16.03 %. It was found that R152a has always a discharge temperature higher than R134a. The maximum difference registered between R152a and R134a was 4.49 K. Furthermore, the use of R152a instead of R134a improves the COP of the refrigeration cycle.

Prayudi et al. [8] studied the effect of the effectiveness of liquid suction heat exchanger to performance of cold storage with refrigerant R22, R404A and R290/R600a. The use of mixture refrigerant R290/R600a results in an increase in refrigeration capacity greater than using refrigerant R22 and R404A. Also, the effect on work of compressor with liquid suction heat exchanger subcooling, for refrigerant R22, R404A and R290/R600a is 47.59 KJ/kg, 40.15 KJ/kg and 84.20 KJ/kg. respectively. The liquid suction heat exchanger subcooling leads to increase in compressor work. Now, effect of liquid suction heat exchangers subcooling on COP for R22, R404A and mixture of R290/R600a 2.63, 3.18 and 3.38 respectively.

In the present work, an experimental study of effect of liquid suction heat exchanger on hydrocarbon refrigerant mixture R290/R600a and R134a used as working fluid in domestic refrigerator has been done in a domestic refrigerator of capacity 220 litre under ambient temperature of 29°C with constant evaporator temperature of -25°C and condenser temperature of 42°C.

2. Experimental Setup

Test rig of liquid suction heat exchanger domestic refrigentor is shown in Fig. 1 mainly consists of four major components which are compressor, condenser, expansion device and evaporator as in basic vapour compression refrigeration system. The refrigeration system used for experimentation was of 220 litre capacity originally designed for the refrigerant R134a. Along with the major components this system consist of counter flow heat exchanger i.e. LSHX, rotameter 1 and rotameter 2 as a fluid flow measurement devices i.e. for the measurement of mass flow rate of vapour refrigerant and for liquid refrigerant respectively, temperature sensors for the measurement of temperatures at two different locations, pressure gauges for the measurement of compressor suction and discharge pressure.

An energy meter was used for the measurement of compressor power consumption. In this, these are two different systems one is simple vapour compression refrigeration system and other one is LSHX vapour compression refrigeration system.

These two different systems are controled with the help of five valves. These five valves are placed at five different positions in order to regulate the flow of refrigerants for the completion of system. These valves are in red colour. The names of valves are V1, V2, V3, V4, and V5, the actual positions of these five valves are shown in Fig. 1. Compressor used is of a single cylinder hermetic reciprocating compressor design and manufactured by LG. It is originaly by designed for only R134a, such type of compressor is used in almost every domestic refrigerator system. Condenser used is of wire and tube type and it has serpentine shape. Next one is evaporator of coil and shell type that is used. It is a box type of heat exchanger which is made up of aluminium. Capillary tube is used as an expansion device.

3. Experimental Procedure

Initially the system was flushed with nitrogen gas to eliminate moisture, foreign materials and other

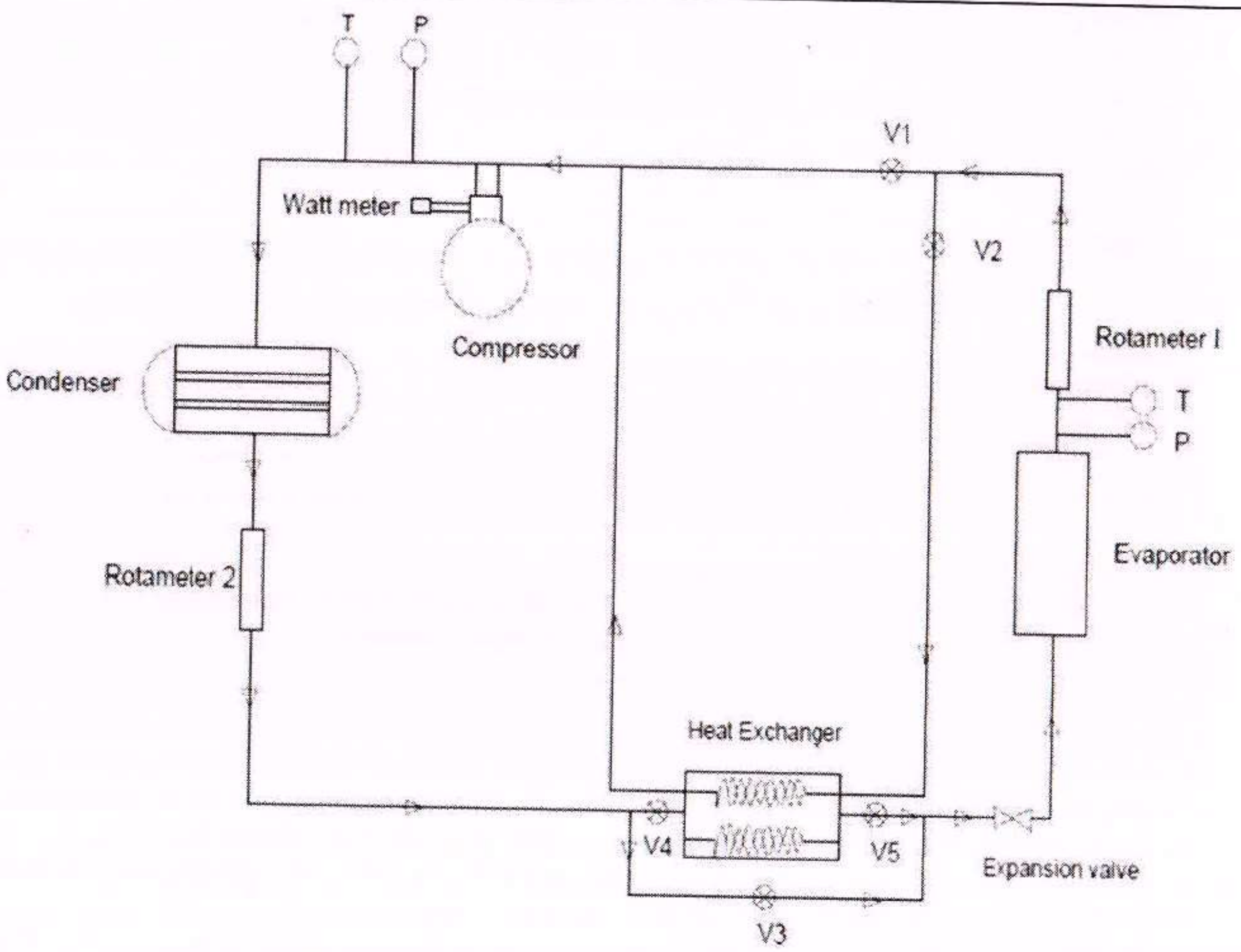

Fig.1. Schematic diagram of domestic refrigerator experimental setup

impurities which are available inside the system. As per the manufacturer's recommendation 190 gm of mass charge of R134a was charged in the refrigerator system for conducting the baseline test. From Fig. 1 there are five valves are provided in order to regulate the system, this regulation will help to convert the simple vapour compression refrigeration system in to the LSHX vapour compression refrigeration system. Among the five valves V2, V4 and V5 were closed and V1 and V2 were open to form simple vapour compression refrigeration cycle.

During experimentation with R134a 3 metre capillary tube length was used. After the completion of the baseline reference test with R134a as a refrigerant in simple vapour compression refrigeration cycle then turned off the refrigerator switch and operated the valves V1 and V3 in closed position which were initially open for simple cycle. After that opened the valves V2, V4 and V5 simultaneously, with this the baseline system gets converted into liquid suction heat exchanger vapour compression cycle. After operating the valves, allowed the compressor to completely cool up to the surrounding temperature after then switched on the system and the same procedure was followed for the liquid suction heat exchanger vapour compression refrigeration system running with refrigerant R134a similar with simple vapour compression refrigeration system.

After recording of the experimental data of simple vapour compression refrigeration system and liquid suction heat exchanger vapour compression system recovered the refrigerant R134a from the refrigeration system. Then system was charged with hydrocarbon mixture refrigerant and the running test was repeated for HCM R290/R600a (50:50) same as the simple vapour compression refrigeration system of R134a. Similarly with same charge amount of hydrocarbon mixture refrigerant, running test was repeated for HCM R290/R600a (50:50) same as liquid suction heat exchanger vapour compression refrigeration system of refrigerant R134a. After this the experimental data were recorded for the same system.

4. Results and Discussion

This paper presents the results of the experimental performance that was conducted on

R134a and mixture of R290/R600a with 50:50 by weight for simple vapour compression refrigeration system i.e. without use of heat exchanger and with the use of heat exchanger under the same operating conditions of evaporation pressure, condensation pressure and the ambient temperature. The results of the experimental work are given in following subsections.

4.1 Refrigeration effect: In Fig. 2 the actual refrigeration effect for simple vapour compression refrigeration system without using heat exchanger with R134a as a working fluid is 0.24 kW and for the simple vapour compression refrigeration system with use of heat exchanger working as a same refrigerant R134a is 0.33 kW.

It is observed in this actual refrigeration effect that effect of simple vapour compression refrigeration system with use of heat exchanger is greater than simple vapour compression refrigeration system without using heat exchanger. This increment of actual refrigeration effect is about 36.37 %. Now from Fig. 3 the actual refrigeration effect for simple vapour compression refrigeration system without using heat exchanger with hydrocarbon refrigerant mixture R290/R600a 50:50 as a working fluid is 0.32 kW and for the system with using heat exchanger working as same refrigerant R290/R600a 50:50 is 0.37 kW.

In this the actual refrigeration effect of simple vapour compression refrigeration system with the use of heat exchanger is greater than simple vapour compression refrigeration system without using heat exchanger. This increment of actual refrigeration effect is about 14.9 %.

4.2 Compressor work done: With reference to Fig. 4, the actual compressor work done for simple vapour compression refrigeration system without using heat exchanger with R134a as a working fluid is 0.19 kW and for the simple vapour compression refrigeration system with use of heat exchanger working as a same refrigerant R134a is 0.17 kW. In this actual compressor work done of simple vapour compression refrigeration system with using heat exchanger is less than simple vapour compression refrigeration system without using heat exchanger. This decrement of actual compressor work done is about 9.38 %.

Now from Fig. 5 the actual compressor work done for simple vapour compression refrigeration system without using heat exchanger with hydrocarbon refrigerant mixture R290/R600a 50:50 as a working fluid is 0.20 kW and for the system without using heat exchanger working as same refrigerant R290/R600a 50:50 is 0.1875 kW.

In this the actual compressor work done by simple vapour compression refrigeration system with use of heat exchanger is less than simple vapour compression refrigeration system without use of heat exchanger. This decrement of actual compressor work done is about 9.98 %.

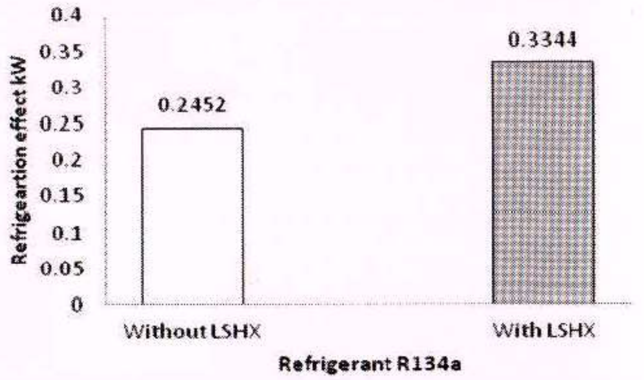

Fig. 2. Refrigeration effect with and without LSHX for R134a

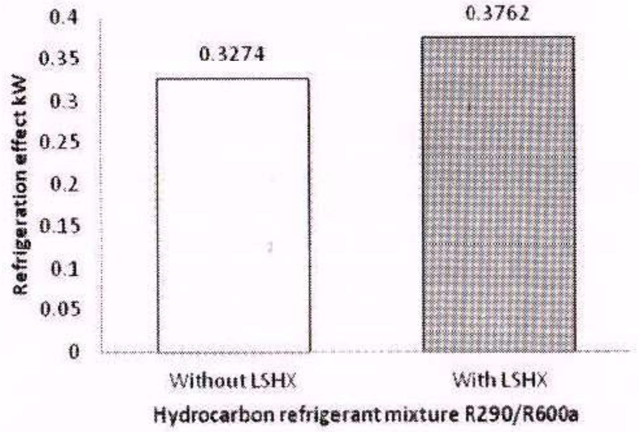

Fig. 3. Refrigeration effect with and without LSHX for R290/R600a

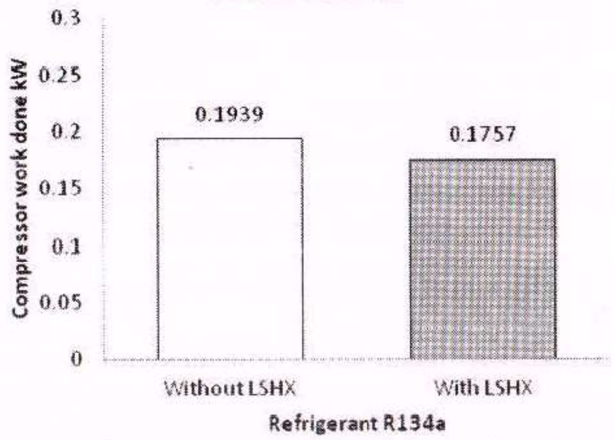

Fig. 4. Compressor work done with and without LSHX for R134a

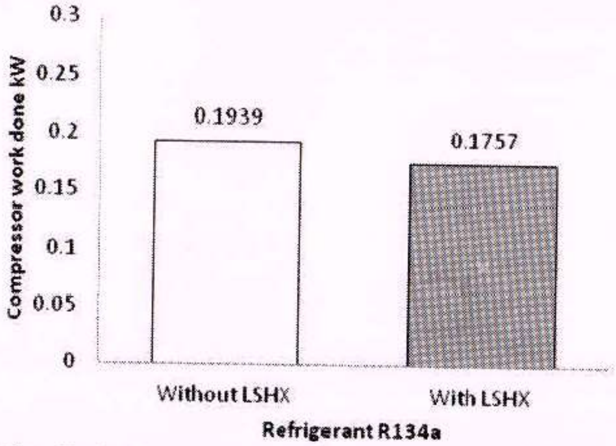

Fig. 5. Compressor work done with and without LSHX for R290/R600a

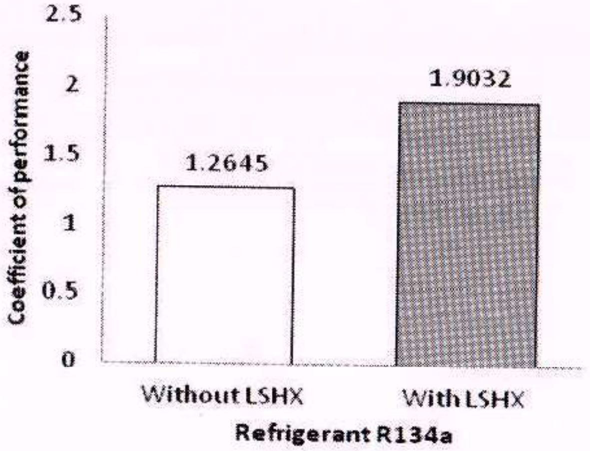

Fig. 6. Coefficient of performance with and without LSHX for R134a

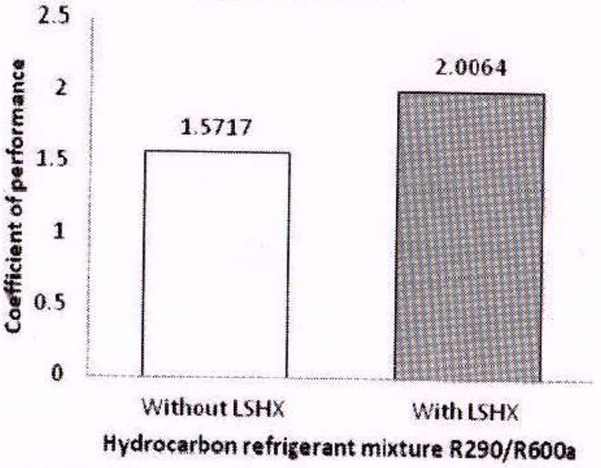

Fig. 7. Coefficient of performance with and without LSHX for R290/R600a

4.3 Coefficient of performance: From Fig. 6 the actual coefficient of performance for simple vapour compression refrigeration system without using heat exchanger with R134a as a working fluid is 1.26 and for the simple vapour compression refrigeration system with the use of heat exchanger working as a same refrigerant R134a is 1.90.

In this actual coefficient of performance of simple vapour compression refrigeration system with the use of heat exchanger is greater than simple vapour compression refrigeration system without using heat exchanger. This increment of actual coefficient of performance is about 50.51 %. Now from Fig. 7 the actual coefficient of performance for simple vapour compression refrigeration system without using heat exchanger with hydrocarbon refrigerant mixture R290/

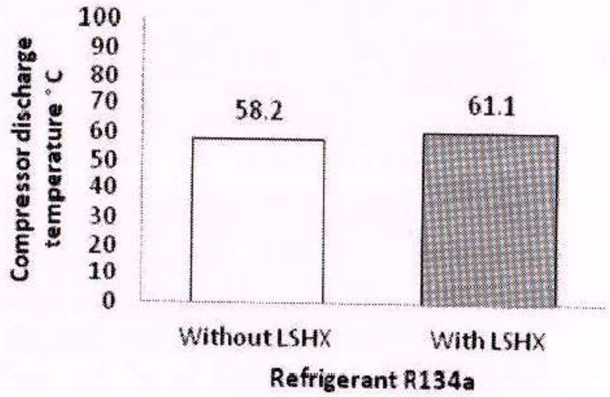

Fig. 8. Compressor discharge temperature with and without LSHX for R134a

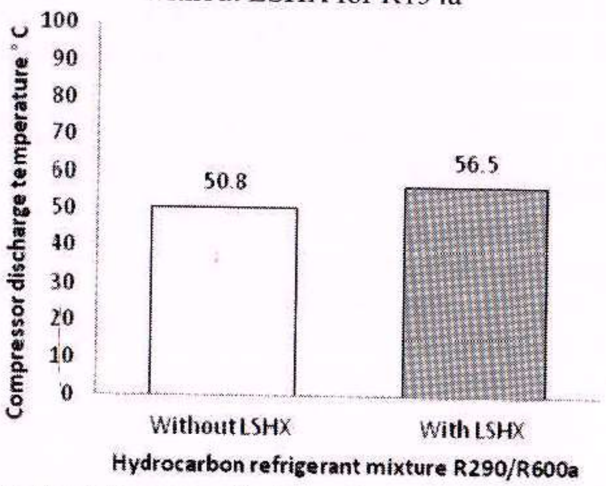

Fig. 9. Compressor discharge temperature with and without LSHX for R290/R600a

R600a 50:50 as a working fluid is 1.57 and for the system with using heat exchanger working as same refrigerant R290/R600a 50:50 is 2.01.

In this the actual refrigeration effect of simple vapour compression refrigeration system with use of heat exchanger is greater than simple vapour compression refrigeration system without using heat exchanger. This increment of actual refrigeration effect is about 27.65 %.

4.4 Compressor discharge temperature

From Fig. 8 the actual discharge temperature for simple vapour compression refrigeration system without using heat exchanger with R134a as a working fluid is 58.2°C and for the simple vapour compression refrigeration system with use of heat exchanger working as a same refrigerant R134a is 61.1°C. In this actual discharge temperature of simple vapour compression refrigeration system with use of heat exchanger is greater than simple vapour compression refrigeration system without using heat exchanger.

This increment of actual discharge temperature is about 2.9°C. Now from Fig. 9 the actual discharge temperature for simple vapour compression refrigeration system without using heat exchanger with hydrocarbon refrigerant mixture R290/R600a 50:50 as a working fluid is 50.8°C and for the system with use of heat exchanger working as same refrigerant R290/R600a 50:50 is 56.5°C.

In this the actual discharge temperature of simple vapour compression refrigeration system with use of heat exchanger is greater than simple vapour compression refrigeration system without using heat exchanger. This increment of actual discharge temperature is about 5.7°C.

5. Conclusion

Experimental performance of a domestic refrigerator of working fluid R134a is experimentally tested with hydrocarbon refrigerant mixture R290/R600a (50:50) by weight and the following conclusions are drawn.

1. The mass charge of hydrocarbon refrigerant mixture of R290/R600a (50:50) requirement is significantly lower which is almost half of the refrigerant mass charge of R134a.

2. The refrigerant R134a with use of heat exchanger in system exhibits higher actual refrigeration effect than R134a without use of heat exchanger in system. Also the refrigerant R290/R600a with use of heat exchanger in system exhibits higher actual refrigeration effect than R290/R600a without use of heat exchanger in simple system.

3. The refrigerant R134a with use of heat exchanger in system exhibits less actual compressor work done than R134a without use of heat exchanger in system. The refrigerant R290/R600a with use of heat exchanger in system exhibits less actual compressor work done than R290/R600a without use of heat exchanger in simple system.

4. The refrigerant R134a with use of heat exchanger in system exhibits higher coefficient of performance than R134a without use of heat exchanger in system. Also the refrigerant R290/R600a with use of heat exchanger in system exhibits higher coefficient of performance than R290/R600a without use of heat exchanger in system.

5. The refrigerant R134a with use of heat exchanger in system exhibits higher actual discharge temperature than R134a without use of heat exchanger in system. Also the refrigerant R290/R600a with use of heat exchanger in system exhibits higher actual discharge temperature than R290/R600a without use of heat exchanger in system.

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