Experimental Performance Comparison of R134a and R600a Refrigerants in Vapour Compression Refrigeration System

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Abstract

This experimental work focuses on the performance comparison of refrigerants used in domestic vapour compression refrigeration systems. The experimental work uses two refrigerants like hydro fluorocarbon refrigerant R134a($C_2H_2F_4$) and a hydrocarbon refrigerant as R600a(C_4H_{10}) for comparison. Refrigerators used for domestic as well as household uses were chosen for conducting the experiments. R134a is the most widely used refrigerant in domestic refrigerators. It must be phased out soon according to Kyoto protocol due to its high global warming potential of 1250. The achieved results show that 89g of R600a produces the same output as produced by R134a.Based on the results, R600a performance compressor coefficient, charge amount and condenser evaporator were chosen for the analytical design. Out of the various outcomes, the variance result supported the view that R600a charge amount was the most notable parameter. At conditions which are optimal the charging amount necessary for R600a was found to be 89g which was 46.06% lesser than R134a.

Key words: Domestic refrigerator, Compressor, Condenser, Capillary tube, Evaporator and Coefficient of performance.

1. INTRODUCTION

Refrigerators have become a part and parcel of the common man's life. Almost all domestic refrigerators work on the mechanism of vapour compression. Hence for the purpose of analysis, refrigeration cycle of vapour compression is considered. The main components of such a cycle include evaporator, compressor, condenser and the expansion valve. The compressor function is to compress the refrigerant and to uphold its pressure. As pressure increases, temperature increases proportional to it thereby making the respective temperature higher than that of the cooling medium. In short the refrigerator pressure is increased from evaporator pressure to condenser pressure.

The cycle of vapour compression refrigeration can also be defined as a procedure that cools a closed space to a temperature lesser than the surroundings. To achieve this, heat must be removed from the space enclosed and dissipated into the surroundings. Heat has a tendency to flow from a high temperature area to that of a lesser temperature. The chlorofluorocarbons of refrigerants (CFCs) and hydro chlorofluorocarbons (HCFCs) contribute to ozone layer depletion and global warming and have high ozone depletion potential and global warming potential. Therefore these refrigerants should essentially be replaced with eco-friendly refrigerants to protect the environment. R134a is the long-term replacement refrigerant because it has the favourable features such as boiling point, auto ignition temperature, zero ODP, solubility in water, non-flammability and critical temperature stability [1].

Hydrocarbon fluids, such as R290 and R600a refrigerants, provide alternatives to a number of CFC, HCFC and HFC refrigerants. In addition to their zero ODP and very low GWP, they are compatible with common materials found in refrigerating systems and are soluble in conventional mineral oils. Since hydrocarbon refrigerants contain no chlorine or fluorine atoms, they cannot undergo reaction with water and, hence, do not form the corresponding strong acids that can lead to premature system failure. R290 and R600a refrigerants have been proposed and actually used in small refrigeration systems. Their thermodynamic and transport properties are very similar to R134a currently used in refrigeration and air conditioning systems. The most important concern regarding the adoption of hydrocarbons as a refrigerant is their flammability. It should be remembered that millions of tons of hydrocarbons are used safely every year throughout the world for cooking, heating, powering vehicles and as aerosol propellants. In these industries, procedures and standards have been developed and adopted to ensure the safe use of the product. The same approach is also being followed by the refrigeration industry. Various applications have been developed in handling flammability and safety problems such as using enhanced compact heat exchangers, optimizing system designs, reducing the charge of systems and establishing rules and regulations for safety precautions. Therefore, in this study, the performance of R290 and R600a mixtures in a vapor compression refrigeration system is conducted by experimental analysis of performance parameters. Also, the results obtained were compared to the baseline refrigerant R134a [2].

[3, 4] Even though the R134a refrigerant has an ODP of zero level, it has a relatively high (GWP).The ozone layer depletion issues and global warming have led to the scenario of considering hydrocarbon refrigerants and their isomers such as propane, isobutene, *n*-butane or hydrocarbon components as working refrigeration fluids for usage in refrigerators and air-conditioning systems. R134a enters the compressor as a low-pressure vapour. Hydrocarbons are appointed as A3 refrigerants. The hydrocarbons as refrigerants has several positive properties such as zero ODP, low GWP, non-toxicity, miscibility of high versatility with mineral oil and good compatibility with the materials regularly employed in refrigeration systems. The paper is organized into an introduction section followed by a thorough study of the existing methods, an explanation on household refrigerators, working fluids, the construction and working principle of a refrigeration system, experimental setup, results and discussion, conclusion and references.

2. LITERATURE REVIEW

The [5] have analyzed experimentally the effects of water-cooled condenser in a house-hold refrigerator. The research was carried out using HFC134a as the refrigerant and Polyester oil as the lubricant. The functionality from the home refrigerator with air-cooled and water-cooled condenser was examined for many load situations. The solutions display that the refrigerator general functionality got elevated when water-cooled condenser was employed rather than air-cooled condenser on all load situations. Water-cooled condenser reduced the energy use in assessment with the air-cooled condenser meant for different load situations. There was also an improvement in coefficient of performance, when water-cooled condenser was applied rather than air-cooled condenser. The water-cooled heat exchanger was made and the system was revised using retrofitting it, the water-cooled heat exchanger was built and the functional program was modified using retrofitting it, rather than the regular air-cooled condenser by producing a bypass range and therefore the gadget can be employed as a waste heat retrieval. The warm drinking water acquired can be used for home uses like cleaning, dish washing, showering and so on. Experimental result signifies that on the subject of 200 L of warm water at a temperature around 58 Celsius more than a day could possibly be generated and then the system indicates the cost-effective importance from the energy conservation perspective.

The [6] have illustrated the practical feasibility of the heat recovery system to extract heat which is waste from the condenser exit of the refrigerator and use it for heating. The shown work, attempted to retrieve the waste heat out of a 210 L refrigerator, intended for residential requirements. The top chamber of the refrigerator was made as a hot chamber, by extension of the condenser coils, and the connection of the top section, towards top surface of the lower chamber of the refrigerator. Hot chamber and the cold chamber had temperature difference inside hence, was analysed considering the different variables considering the aspects of time, capacity of chamber and load. From the outcomes, it had been founded that the mentioned technique of heat recovery, could be engineered and developed for each and every domestic refrigerator, with the nominal cost. Thus, the reuse of waste heat provided method for optimum energy conservation. This kind of work could be improved by providing better insulation which in turn reduces the heat loss and increases the performance of the system.

The [7] have determined the energy savings concerning better utilization of waste heat from a residential refrigerator. Residential refrigerators potentially perform constantly to maintain appropriate food storage condition. The constant operation of the equipment accounts considerably more electricity consumption. Further, a substantial amount of waste heat is discarded by the condensers of refrigerator. Heat discarded by condenser is of low quality, so this means temperature is low. Therefore, functional applications of waste heat from the residential refrigerators are generally restricted to space heating and water heating system. In order to more efficiently utilize waste heat, the temperature of the waste heat can be raised, to a limited degree, by increasing the condensing pressure of the refrigeration device. Even so, analyses have demonstrated the fact that increasing the condensing pressure to attain high quality waste heat utilizes even more energy than it saves.

3. WORKING PRINCIPLE AND CONSTRUCTION OF A REFRIGERATION SYSTEM

The standard vapour compression is shown on the TS-diagram. The processes constituting the standard vapour-compression cycle are:

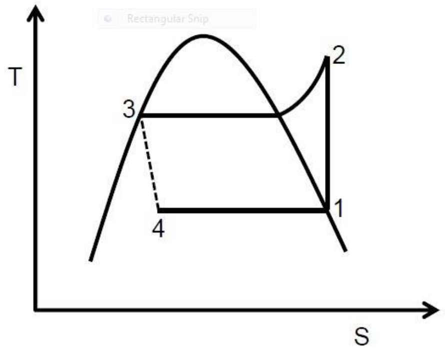

Fig.1: Standard vapour compression system

Where,

1-2: reversible and adiabatic compression from saturated vapor to the condenser pressure.

2-3: reversible rejection of heat at constant pressure, de-superheating and condensation.

3-4: Irreversible expansion at constant enthalpy from saturated liquid to the evaporator pressure.

4-1: reversible addition of heat at constant pressure in evaporation to saturated vapour.

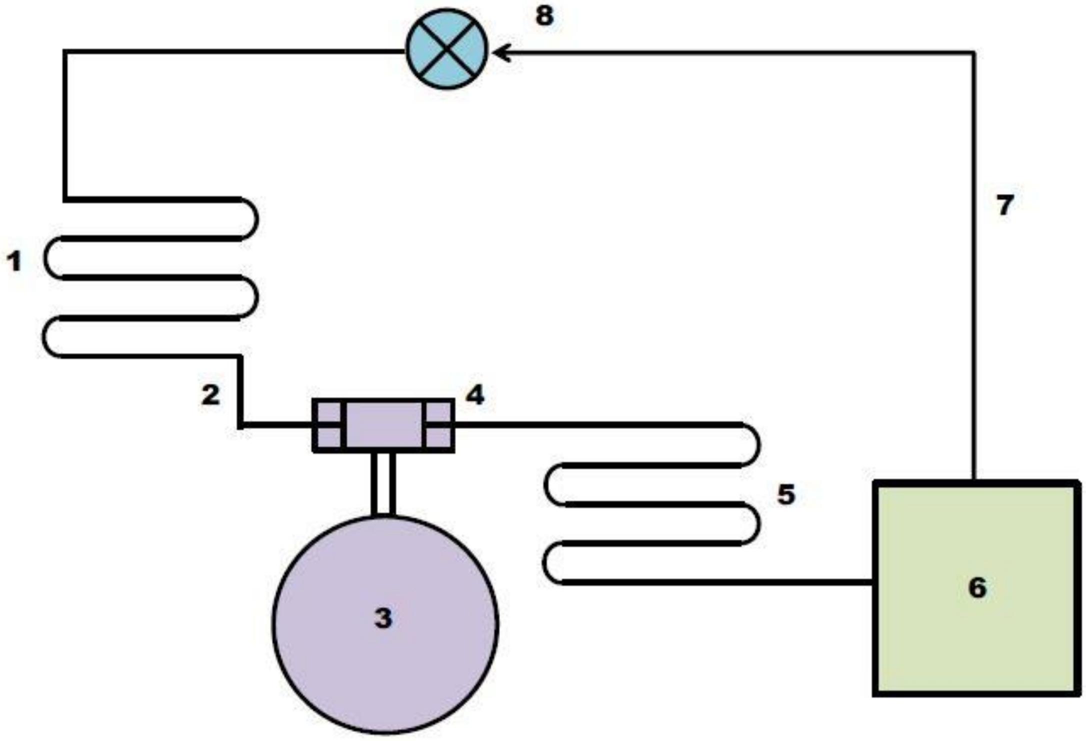

Fig.2: Flow diagram of a simple vapour compression system

1- Evaporator: its function is to produce a heat transfer surface through which heat can pass from the refrigerant space into the vaporizing refrigerant. Since the capacity of a refrigerant to absorb heat energy is greatest when changing state from liquid to vapor, the heat exchanger (Evaporator) within the conditioned space is continuously supplied with liquid refrigerant, which vaporizes in order to absorb heat energy from the conditioned space.

2- Suction Line: it carries the low pressure vapor from the evaporator to the suction inlet of the compressor.

3- Compressor: the function of the compressor is to draw refrigerant vapor from the evaporator and then it rises its temperature and pressure to such a point so that it may be easily condensed with normally available condensing media. If the system is to reject this heat energy to outdoor air during peak summer conditions where the air temperature may be as high as 30 °C, the Saturation Temperature of the refrigerant must be raised from 5 °C to a higher temperature than 30 °C, say 40 °C. This is achieved by raising the pressure of the Saturated Vapor leaving the Evaporator by passing the vapor through a Compressor.

4- Discharge Line or Hot Gas Line: Discharge lines which delivers the high temperature, high pressure vapor from the discharge of the compressor to the condenser.

5- Condenser: the function of the condenser is to provide a heat transfer surface through which heat passes from the hot refrigerant vapor to the condensing medium, which is either air or water. The energy that must be rejected by the Condenser comprises the heat energy removed by each kilogram of refrigerant passing through the Evaporator and the heat energy added to each kilogram of refrigerant passing through the Compressor. The total heat that must be rejected therefore equals and is termed the Total Heat of Rejection (THR). The Condenser coil is therefore normally larger than the Evaporator coil.

6- Receiver Tank: it acts as a reservoir which stores the liquid refrigerant coming from the condenser and supplies it to the evaporator according to the requirement.

7- Liquid Line: it carries the liquid refrigerant from the receiver tank to the refrigerant flow control valve.

8- Refrigerant Flow Control or Expansion Valve: its function is to supply a proper amount of refrigerant to the evaporator after reducing its pressure considerably so that the refrigerant may take sufficient amount of heat from the refrigerant space during evaporation.

4. SYSTEM COMPONENTS USED FOR REFRIGERATION SYSTEM

- Hermetically sealed compressor-1/3 Hp
- Air cooled condenser- 1/83 Hp
- Fan motor with blade-1/83 Hp
- Expansion device- Capillary and Thermostatic expansion valve
- Hand shut off valves- ¼ inch
- Filter drier
- Energy meter
- Solenoid valve
- Thermostat
- Pressure gauges
- Digital voltmeter
- Digital Ammeter- 0 to 5A AC
- Digital temperature indicator- 50 to 150°C
- Thermocouple selector switch
- Thermocouple- K type(Cr/Al)
- LP/HP cut-out
- DP switch for mains

- Refrigerants- R134a and R600a
- Evaporator coil placed in a chiller

5. EXPERIMENTAL SETUP

Experimental set up is designed in such a way that it can be used to find the domestic vapour compression system COP. The vapour compression system will be of the size of a 180 L household refrigerator. Figure 2 shows the line diagram of the experimental setup which is used to find the coefficient of performance of household refrigerators vapour compression system

In this experimental setup, refrigerant R-600a is compared with R-134a. The compressor which is hermit sealed type, the natural convection air cool condenser and the capillary tube used for the set-up is similar to the ones used for domestic refrigerators.

By placing the water in chiller box for a specific duration of time, we need to note down refrigerant pressure at inlet-outlet of compressor and respective temperatures of refrigerant at inlet of compressor, outlet of compressor, exit of condenser. exit of expansion device and water temperature in chiller.

By using following formulas the calculation is carried out

- $Q = M_w C_{pw} (T_i - T_f)$ / Time taken in secs, in KW

  Where,

  M_w = Mass of water, in Kg

  C_{pw} = Specific heat of water = 4.187KJ/Kg K

  T_f = Final water temperature in chiller, in ^oC

  T_i = Initial water temperature in chiller, in ^oC

- $W = \frac{n \text{ X } 3600}{T \text{ X } EMC}$, in KW

  Where,

  n = No of revolutions in energy meter disc

  T = Time taken, in secs

  EMC = Energy meter constant = 3200 imp/KWh

- Actual COP = $\frac{Q}{W} = \frac{\text{Refrigeration effect}}{\text{Compressor input}}$

6. TABULATION AFTER CONDUCTING EXPERIMENT

✓ By using R134a as refrigerant the following tabulations is obtained:

Condition	**Min**	**Normal**	**Max**	**Min**	**Normal**	**Max**
Mass(Kg)	1.5	1.5	1.5	2	2	2
P_1(Kg/cm^2)	1.9	1.9	1.9	1.9	1.9	1.9
P_2(Kg/cm^2)	24.4	24.3	24.4	24.8	25	24.2
Time(Min)	30	30	30	30	30	30
Voltage(V)	245	244	245	239	238	240
Current(A)	0.7	0.7	0.7	0.7	0.7	0.7
T_1(°C)	23.2	22.7	22.2	23	22.6	22.4
T_2(°C)	88.9	90	90.1	89.2	89.4	88.9
T_3(°C)	41.2	41.9	42.3	42	43.2	42.2
T_4(°C)	0.2	0.12	0.03	0.5	0.8	0.3
T_i(°C)	32	33	32.5	33.6	33.1	33.3
T_f(°C)	27	26.5	24.5	28.5	26.4	25.3
EM_{in}(KWH)	1.72	1.81	1.89	1.97	2.06	2.14
EM_{fi}(KWH)	1.8	1.88	1.96	2.05	2.13	2.21
n	8	7	7	8	7	7
Actual COP	3.489	5.183	6.380	4.745	7.124	8.506

Ex: Calculation of Actual COP for first reading:

- $Q = \frac{\text{Mw Cpw (Ti−Tf)}}{\text{Time taken in secs}} = \frac{1.5 \text{ X } 4.187 \text{ X } (32-27)}{30 \text{ X } 60} = 17.4458 \text{ X } 10^{-3}$ KW
- $W = \frac{\text{n X 3600}}{\text{T X EMC}} = \frac{8 \text{ X } 3600}{30 \text{ X } 60 \text{ X } 3200} = 5 \text{ X } 10^{-3}$ KW
- Actual COP $= \frac{Q}{W} = \frac{\text{Refrigeration effect}}{\text{Compressor input}} = \frac{17.4458 \text{ X } 10^{-3}}{5 \text{ X } 10^{-3}} = 3.489$

✓ By using R600a as refrigerant the following tabulations is obtained:

Condition	**Min**	**Normal**	**Max**	**Min**	**Normal**	**Max**
Mass(Kg)	1.5	1.5	1.5	2	2	2
P_1(Kg/cm^2)	1.2	1.2	1.2	1.2	1.2	1.2
P_2(Kg/cm^2)	14	14	14	14	14	14
Time(Min)	30	30	30	30	30	30
Voltage(V)	245	245	245	237	239	244
Current(A)	0.7	0.7	0.7	0.6	0.6	0.7
T_1(°C)	9.8	9.7	9.7	10.5	10.4	10.1
T_2(°C)	78.1	78.2	78.5	76.8	77.6	77.9
T_3(°C)	41.2	41	40.9	40.5	40.8	40.8
T_4(°C)	0.9	0.9	0.8	1.2	0.8	0.9
T_i(°C)	32.3	33	33.2	34.7	34.5	34.4
T_f(°C)	26.3	26.7	26.1	29.8	29.4	28.9
EM_{in}(KWH)	2.64	2.70	2.76	2.45	2.51	2.57
EM_{fi}(KWH)	2.69	2.75	2.81	2.50	2.56	2.63
n	5	5	5	5	5	5
Actual COP	6.699	7.034	7.927	7.294	7.592	8.187

Ex: Calculation of Actual COP for first reading:

- $Q = \frac{\text{Mw Cpw (Ti}-\text{Tf)}}{\text{Time taken in secs}} = \frac{1.5 \text{ X } 4.187 \text{ X } (32.3-26.3)}{30 \text{ X } 60} = 20.935 \text{ X } 10^{-3}$ KW
- $W = \frac{\text{n X 3600}}{\text{T X EMC}} = \frac{5 \text{ X } 3600}{30 \text{ X } 60 \text{ X } 3200} = 3.125 \text{ X } 10^{-3}$ KW
- Actual COP $= \frac{Q}{W} = \frac{\text{Refrigeration effect}}{\text{Compressor input}} = \frac{20.935 \text{ X } 10^{-3}}{3.125 \text{ X } 10^{-3}} = 6.699$

Where,

- EM_{in} = Energy meter reading(Initial) in KWH
- EM_{fi} = Energy meter reading(Final) in KWH
- n = (EM_{fi} – EM_{in}) x 100
- T_1(°C) = Inlet temperature of compressor
- T_2(°C) = Outlet temperature of compressor

- T_3(°C) = Outlet temperature of Condenser
- T_4(°C) = Temperature after expansion through capillary tube
- T_i(°C) = Initial temperature of water in chiller
- T_f(°C) = Final temperature of water in chiller
- P_1(Kg/cm^2) = Entry pressure of refrigerant through compressor
- P_2(Kg/cm^2) = Exit pressure of refrigerant through compressor

7. EXPERIMENT RESULTS

Fig.3: Variation of Refrigeration effect with Evaporating temperature

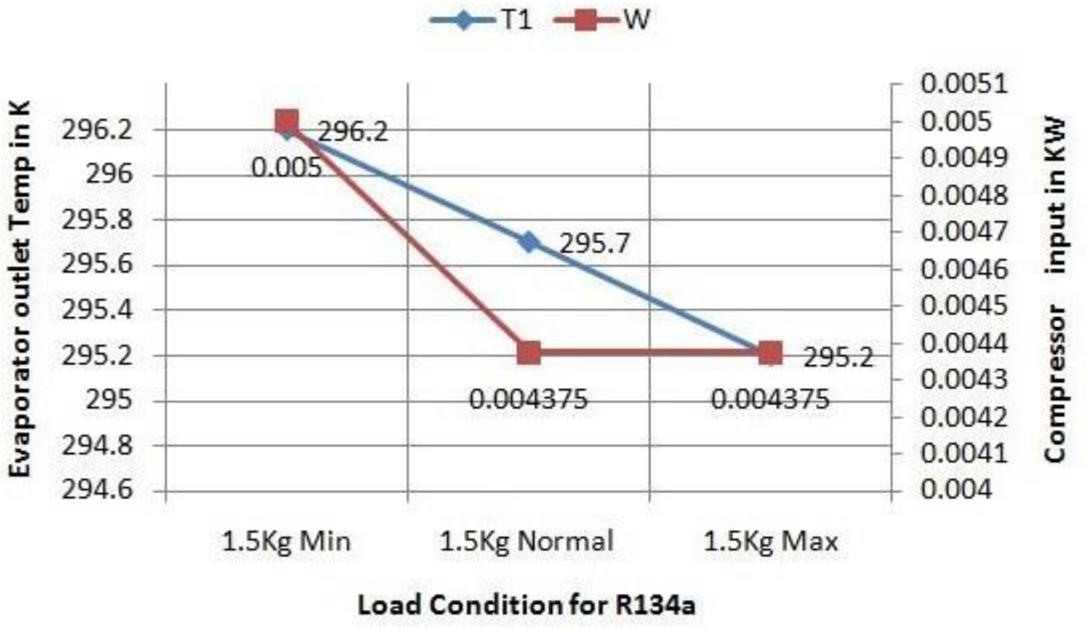

Fig.4: Variation of Evaporating temperature with compressor input

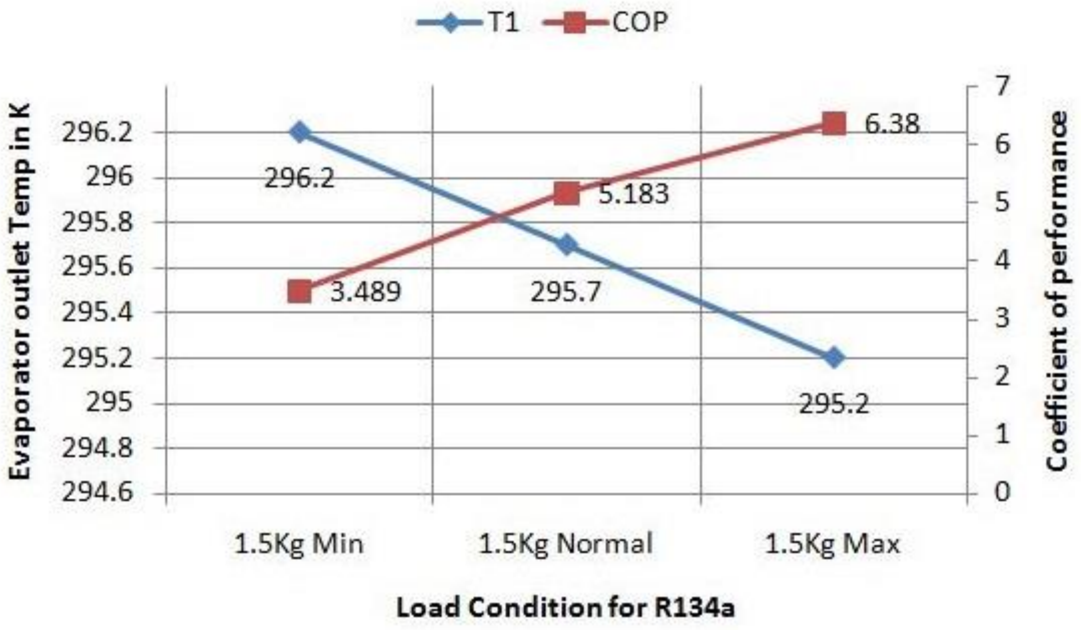

Fig.5: Variation of Evaporating temperature with COP

Fig.6: Variation of Refrigeration effect with Evaporating temperature

Fig.7: Variation of Evaporating temperature with compressor input

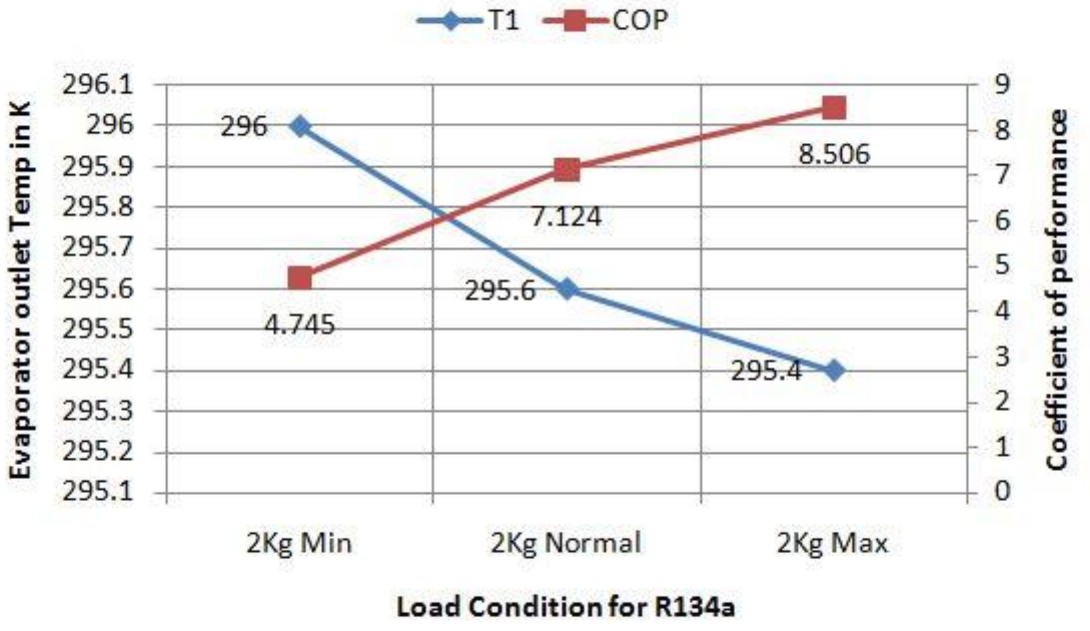

Fig.8: Variation of Evaporating temperature with COP

Fig.9: Variation of Refrigeration effect with Evaporating temperature

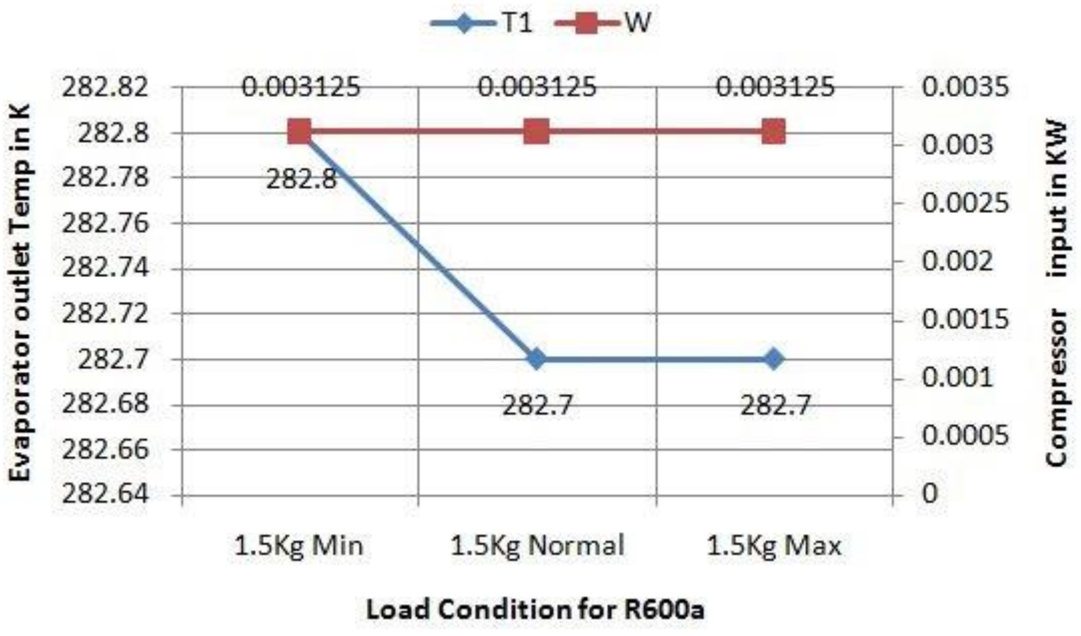

Fig.10: Variation of Evaporating temperature with compressor input

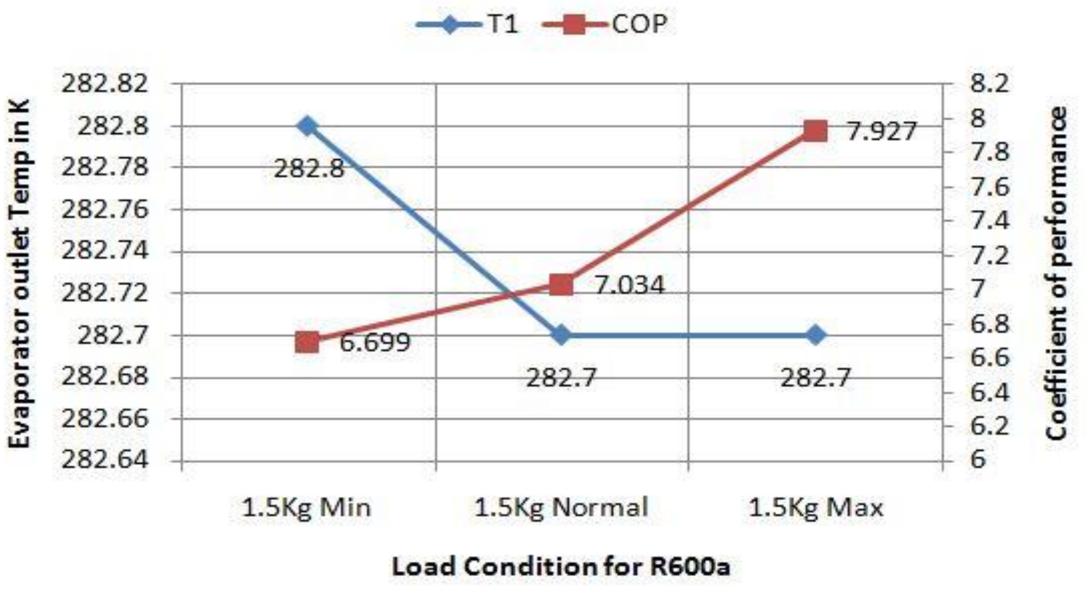

Fig.11: Variation of Evaporating temperature with COP

Fig.12: Variation of Refrigeration effect with Evaporating temperature

Fig.13: Variation of Evaporating temperature with compressor input

Fig.14: Variation of Evaporating temperature with COP

CONCLUSIONS

The results of the experiment are evaluated by comparing the coefficient of performance obtained with the refrigerants R-134a and R-600a.

- R600a coefficient of performance was found to be in the higher range compared to R134a. It was almost 20%-25% better than R134a at a constant load conditions and at a constant evaporating temperature.R-600a provides better cooling effect than R-134a.
- The discharge compressor temperature of R600a refrigerant is appropriately 13% less than R134a.
- The compressor energy consumption of R600a refrigerant is reduced in a step by step manner to 29% when compared to normal R134a refrigerator used in domestic compressor.
- A household refrigerator which used 165g of R134a refrigerant had the highest energy destruction in the compressor followed by the condenser, capillary tube, and evaporator. On the contrary a domestic refrigerator which uses 89g of R600a showed an optimal compressor energy destruction followed by the condenser, capillary tube and evaporator.
- The pressure ratio obtained for compressor using R134a as refrigerant is more than R600a.
- The charge amount required for R600a is approximately 89g which is lower than that of R134 by 46.06%.

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