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# Effect of Sub-cooling on Domestic Refrigerator Operated with LPG As Refrigerant

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**Abstract:** Now-a-days R134a is used as a replacement for R12 in Domestic Refrigerators. Because it is a globally accepted refrigerant with Zero Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) of 1300. Recent investigations shows that Liquefied Petroleum Gas (LPG) which is inexpensive, readily available in the market with Zero ODP and Negligible GWP can be used an alternative refrigerant to R134a in Domestic Refrigerators. In the present work performance comparison between R134a and LPG has been carried out. For this purpose the Domestic Refrigerator which is originally manufactured to work with R134a is used. In addition to this, sub-cooling of Vapour Compression Refrigeration System (VCRS) also has been carried out by providing small shell and tube heat exchanger in the suction line of Refrigerator. Here, sub-cooling of liquid refrigerant at the condenser outlet is done with the help of vapour refrigerant coming from the evaporator. The experimental data so obtained has been analysed and results are presented in the project.

**Keywords:** Vapour Compression Refrigeration System(VCRS), Ozone DepletionPotential(ODP), Liquefied Petroleum Gas(LPG).

## I. INTRODUCTION

### A. Introduction to Refrigeration

Refrigeration is defined as "the process of cooling of bodies or fluids to temperatures lower than those available in the surroundings at a particular time and place". It should be kept in mind that refrigeration is not same as "cooling", even though both the terms imply a decrease in temperature. In general, cooling is a heat transfer process down a temperature gradient; it can be a natural, spontaneous process or an artificial process. However, refrigeration is not a spontaneous process, as it requires expenditure of energy (or availability). Thus cooling of a hot cup of coffee is a spontaneous cooling process (not a refrigeration process), while converting a glass of water from room temperature to say, a block of ice, is a refrigeration process (non-spontaneous). "All refrigeration processes involve cooling, but all cooling processes need not involve refrigeration". Refrigeration is a much more difficult process than heating; this is in accordance with the second law of thermodynamics. According to second law of Thermodynamics, Removal of heat from a body at lower temperature is possible only with the help of an external agency. A refrigerator as shown in Fig.1 is a reversed heat engine which either cool or maintain the temperature of a body ($T_1$) lower than the atmospheric temperature ($T_a$).This is done by extracting the heat ($Q_1$) from a cold body and delivering it to a hot body ($Q_2$). In doing so, work $W_R$ is required to be done on the system. According to First Law of Thermodynamics,

$$W_R = Q2 - Q_1 \quad (1)$$

The Performance of a refrigerator is expressed by the ratio of amount of heat taken from the cold body ($Q_1$) to the amount of work required to be done on the system($W_R$).This ratio is called as coefficient of performance. Mathematically, coefficient of performance of a refrigerator,

$$C.O.P = Q_1/ W_R = Q_1 /( Q_2 - Q_1) \quad (2)$$

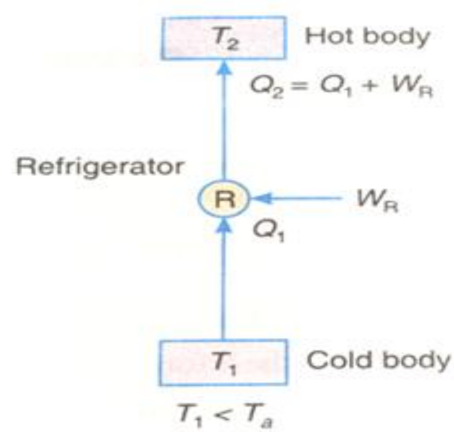


**Fig.1. Refrigerator.**

## II. REFRIGERANTS

R134a is also known as Tetrafluoroethane ($CF_3CH_2F$) from the family of HFC refrigerant. With the discovery of the damaging effect of CFCs and HCFCs refrigerants to the ozone layer, the HFC family of refrigerant has been widely used as their replacement. It is now being used as a replacement for R-12 CFC refrigerant in the area of centrifugal, rotary screw, scroll and reciprocating compressors. It is safe for normal handling as it is non-toxic, non-flammable and non-corrosive. Currently it is also being widely used in the air conditioning system in newer automotive vehicles. The manufacturing industry uses it in plastic foam blowing. Pharmaceuticals industry uses it as a propellant. It exists in gas form when expose to the environment as the boiling temperature is -14.9°F or -26.1°C.

This refrigerant is not 100% compatible with the lubricants and mineral-based refrigerant currently used in R-12. Design changes to the condenser and evaporator need to be done to use this refrigerant. The use of smaller hoses and 30% increase in control pressure regulations also have to be done to the system.

### A. About LPG


**Fig.2. Liquefied petroleum Gas.**

Liquefied Petroleum Gas (LPG) is a flammable mixture of hydrocarbons such as Propane, Butane and Iso-butane is used as a fuel in heating appliances, cooking equipment and vehicles as shown in Fig.2. LPG is used as an aerosol propellant and a refrigerant, replacing Chloro Fluoro Carbons (CFC) in an effort to reduce damage to the ozone layer. The chemical composition of LPG available in the market contains the following hydro carbons:

- PROPANE (R290) --- 30%
- BUTANE (R600) --- 55%
- ISO-BUTANE (R600a) --- 15%

In addition to the above components, Propylene, Butylenes and various other hydrocarbons are also present in small concentrations. LPG is prepared by refining petroleum or wet natural gas, and is almost entirely derived from fossil fuel sources, being manufactured during the refining of crude oil or extracted from petroleum or natural gas streams as they emerge from the grounds. LPG is instrumental in providing off-the-grid refrigeration, usually by means of a gas absorption refrigerator. LPG has zero ODP and negligible GWP and can serve as a functional replacement for R-12, R-22, R134a and other CFC or HFC refrigerants in conventional stationary refrigeration and air conditioning systems.

### B. Secondary Refrigerants

The secondary refrigerant circuit is commonly used in all big commercial and industrial refrigeration plants. Secondary refrigerants are air water and brine. Air, water, sodium chloride brine, calcium chloride brine and propylene glycol are commonly used. An issue of growing concern for the present day environment is the impact of the various refrigerants on the ozone depletion and global warming of the environment. The main culprits in this case are the chlorine containing halogenated hydrocarbons, commonly known as chlorofluorocarbons or CFC which are being used as refrigerants. The Earth's atmosphere is made up of various layers. The layer just above the Earth's surface is known as the troposphere. The troposphere extends up to 10 km from the surface. The ozone layer is just above the troposphere and located in the stratosphere. The stratospheric ozone is Earth's natural protection to harmful ultraviolet (UV) radiation from the sun. UV radiation is harmful to human, plant and animal life. The ozone layer gets depleted by the action of these refrigerants. CFCs, when they are released from the surface of the Earth, rise slowly into the stratosphere. Here they are bombarded by the incoming UV light from the Sun, which releases the chlorine atoms from the parent compound. It is this chlorine atom which reacts with the ozone molecules. The detailed reactions are given below: Chlorofluorocarbon Irradiated with UV light free Cl

$$Cl + O3 \longrightarrow ClO + O2$$
$$ClO + O \longrightarrow Cl + O2$$

The free chlorine atom can again take part in the reaction with another ozone atom as shown in Fig.3. A single chlorine atom, released by the action of UV radiation on CFCs, can catalytically destroy tens of thousands of ozone molecules during its residence in the stratosphere.

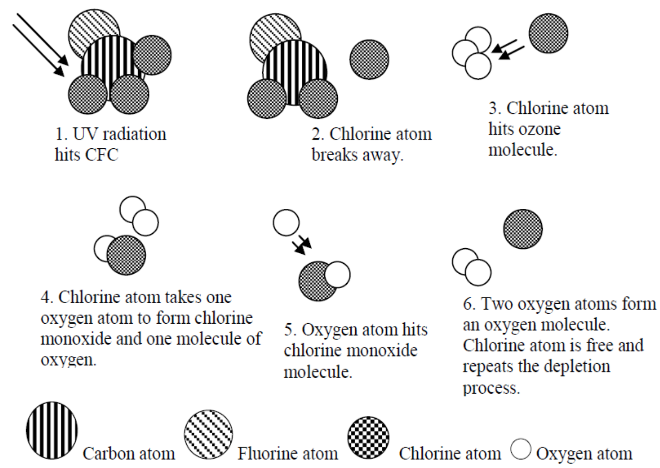


**Fig.3. Graphical Representation of the Reactions Involved in Ozone Depletion.**

Ozone depletion will permit UV rays to reach earth which can result in several harmful effects on living creatures. The UV radiation can cause skin cancer, cataracts and destruction of the body's immune system. Along with ozone depletion, CFC refrigerants also contribute to a large extent in the global warming of the planet. These gases create a greenhouse effect which traps the heat in the lower atmosphere. This makes the Earth warmer because the green house gases do not allow infrared radiation to pass through tem. The earth emits IR rays during its cooling when sun is not there. CO2 is the most important green house gas but one molecule of CFC has warming potential which is more than 1000 times the warming potential of one molecule of CO2. Sun's rays are allowed into the lower atmosphere, but the heat from these rays is not allowed to escape. The "Montreal Protocol on Substances that Deplete the Ozone Layer" signed in 1987 by several countries stipulates the gradual phase-out of CFC refrigerants. Use of HCFC refrigerant is advocated as an interim measure, but even these are to be eventually phased out. This therefore necessitates the need for new refrigerants which can at least perform as well as the refrigerants they replace without harming the atmosphere. Based on this requirement, R134a emerges as the refrigerant of the future.

## III. SUB-COOLING OF VCRS

In actual refrigeration cycles, the temperature of the heat sink will be several degrees lower than the condensing temperature to facilitate heat transfer. Hence it is possible to cool the refrigerant liquid in the condenser to a few degrees lower than the condensing temperature by adding extra area for heat transfer. In such a case, the exit condition of the condenser will be in the sub cooled liquid region. Hence this process is known as subcooling. Similarly, the temperature of heat source will be a few degrees higher than the evaporator temperature; hence the vapour at the exit of the evaporator can be superheated by a few degrees. If the superheating of refrigerant takes place due to heat transfer with the refrigerated space (low temperature heat source) then it is called as useful superheating as it increases the refrigeration effect. On the other hand, it is possible for the refrigerant vapour to become superheated by exchanging heat with the surroundings as it flows through the connecting pipelines. Such a superheating is called as useless superheating as it does not increase refrigeration effect. Sub cooling is beneficial as it increases the refrigeration effect by reducing the throttling loss at no additional specific work input. Also subcooling ensures that only liquid enters into the throttling device leading to its efficient operation. The following are the methods of Sub-Cooling the liquid refrigerant in Vapour Compression Refrigeration System:

- Sub-Cooling of Liquid Refrigerant by using Vapour Refrigerant
- Sub-Cooling of Liquid Refrigerant by using Low Temperature Liquid Refrigerant
- Sub-Cooling of Liquid Refrigerant by External Source.

## IV. EXPERIMENTAL SETUP & PROCEDURE

### A. Pressure Gauges

**Suction Pressure Gauge:** This is joined in the suction line i.e., before the compressor by means of Gas Welding. It is used for measuring the pressure of vapour refrigerant before entering the compressor. Its range is from 0 to 17.5 bars.

**Discharge Pressure Gauge:** This is joined in the discharge line i.e., after the compressor by means of Gas Welding. It is used for measuring the pressure of the vapour refrigerant after leaving the compressor. Its range is from 0 to 35 bar.


**Fig.4. Thermo Couple.**

**Temperature Indicators and Thermocouple:** Temperature Indicators are used for measuring the temperature of the refrigerant. In the present experimental work, One Thermocouple and 6 Temperature indicators are used.


**Fig.5. Temperature Indicators.**

**Fig.6.Suction Pressure Gauge.**

**Fig.7. Discharge Pressure Gauge.**

The schematic line diagram for charging is shown in the figure. It is necessary to remove the air from the refrigeration unit before charging. First the valve $V_2$ is closed and pressure gauges P2, vacuum gauge V are fitted as shown in the figure. The valve $V_5$ is also closed and valves $V_1$ and $V_3$ are opened, the motor is started. Thus the air from the condenser, receiver and evaporator is sucked through the valve V1 and it is discharged in to the atmosphere through the valve V6 after compressing in to the compressor. The vacuum gauge V indicates sufficiently low vacuum when most of the air is removed from the system. The vacuum reading should be 74 to 75 cm of Hg. If the vacuum is retained for above an hour it may be concluded that the system is free from air. After removing the air, the compressor is stopped and the valves V1 and V6 are closed and valves V5, V2 and V7 of the refrigerant cylinder are opened and then the compressor is started. Whenever sufficient quantity of refrigerant is taken in to system which will be noted on the spring balance as shown in the figure, the compressor is stopped. The valves V7 and V5 are closed and valve V1 is opened. The refrigerant cylinder is disconnected from the system. The Pressure gauges fitted are used to note the pressure during charging the system as shown in Fig.8.

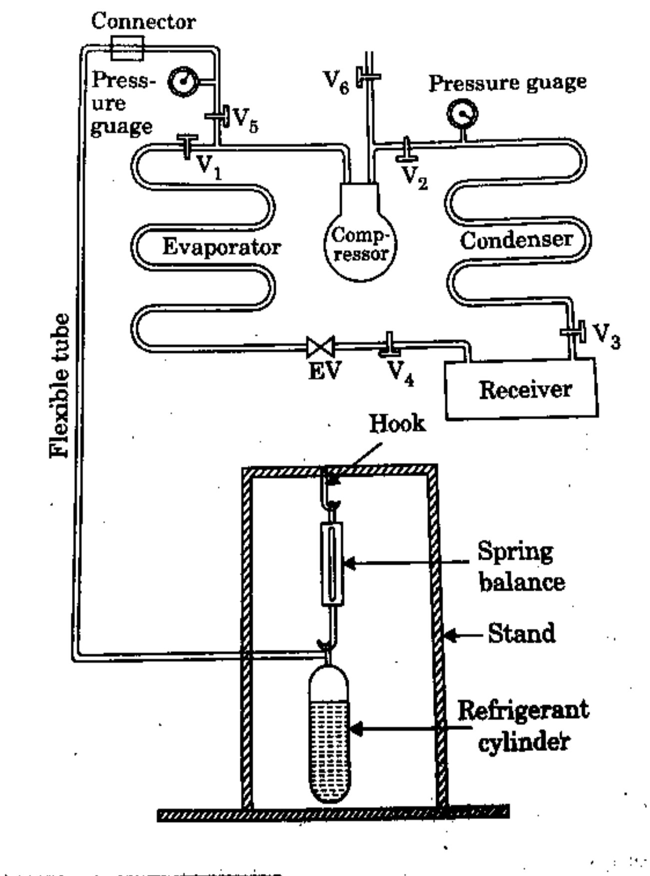


**Fig.8. Charging of Refrigeration System.**

**B. Charging of Liquefied Petroleum Gas (LPG) in to Domestic Refrigerator**

After flushing the system with pressurized nitrogen gas, it is charged with Liquefied Petroleum Gas (LPG) following the same procedure as that of R134a. Here, LPG is first transferred from Cylinder used in houses to small cylinder (empty refrigerant cylinder) as shown in the fig.9.

- With the help of weighing machine it is then transferred from small cylinder in to the refrigerator as shown in the fig.10.
- With the help of Temperature Indicators and Pressure gauges, readings are noted and tabulated.

**Fig.9. Transfer of LPG.**

**Fig.10. Charging of LPG.**

**Preparation of Heat Exchanger:** In Vapour Compression Refrigeration System, Sub Cooling of liquid refrigerant by Vapour Refrigerant has been carried out by providing a small heat exchanger at the condenser outlet. In the present experimental work, a small shell and tube heat exchanger is provided for attaining the sub cooling. A Heat Exchanger is a device used to exchange heat from one fluid to the another fluid. A small shell and tube heat exchanger is prepared with the following dimensions:

Diameter of the shell = 1/2" = 12.7 mm
Length of the shell = 1 ft = 12" = 304.8 mm
Diameter of the tube = 6.5 mm
Length of the tube = 315 mm
Material used for Heat Exchanger = Copper

By using 1/4" Drill bit two holes are provided at the top and bottom of the shell near the ends. These holes are welded with two pipes (tubes of 6.5mm dia and 5mm length) by means of Gas Welding. Tube is inserted in to the shell by means of gas welding process. The actual diagram of the heat exchanger prepared above is shown in the fig.11.

**Fig.11. Shell and Tube Heat Exchanger.**

**Fixation of Heat Exchanger in to the Refrigerator:** The Heat Exchanger prepared above is fitted to the Domestic Refrigerator of capacity 165 liters. By means of gas welding i.e., with the help of Butane Gas, Heat Exchanger is incorporated at the junction of evaporator and condenser outlets as shown in the fig.12.

**Fig.12. Heat Exchanger Fitted to the Refrigerator.**

- After fixation of Heat Exchanger to the Refrigerator, Foam Insulation is provided to the heat exchanger to reduce the heat losses to the environment.
- Again LPG is charged in to the Refrigerator following the same procedure as that of R134a charging.
- With the help of Temperature Indicators and Pressure Gauges readings are noted and tabulated.
- The calculations have been carried out for the values noted from the above experiments under No Load and Load conditions.

## V. RESULTS AND DISCUSSIONS

An Experimental Investigation has been carried out with the experimental setup fabricated for the present project work and the data has been systematically recorded by operating the Vapour Compression Refrigeration System (VCRS) first with R134a and later with Liquefied Petroleum Gas (LPG) without subcooling and with subcooling. The temperature of Refrigerant at 7 different locations and pressures at two points (before and after the compressor) in the system has been recorded.

### A. Graphs

The data shown in the tabular columns has been carefully analyzed and the important calculated parameters are presented in the following graphs:

**Variation of Freezer Temperature with Time:** The Variation of freezer temperature w.r.t Time for VCRS run with R134a, LPG (without sub cooling) and LPG with sub cooling has been presented in the following figure:

- From Fig.13, It can be observed that the lowest temperature of -32$^{O}$C has been obtained when the system is run with LPG with subcooling, where as lowest temperatures of -28$^{O}$C with LPG(without subcooling) and -25$^{O}$C with R134a are obtained.
- It can also be inferred from the figure that Trend in the variation of freezer temperature w.r.t time of LPG with and without sub cooling has been found similar to that of R134a.
- It is interesting to note that the lowest temperature of -25$^{O}$C has been obtained when the system is run with R134a in a time period of 90 minutes, whereas the same temperature has been obtained with in a time period of 45 minutes when the system is operated with LPG. Further its value is reduced to 30 minutes when the system is run with LPG with sub cooling.

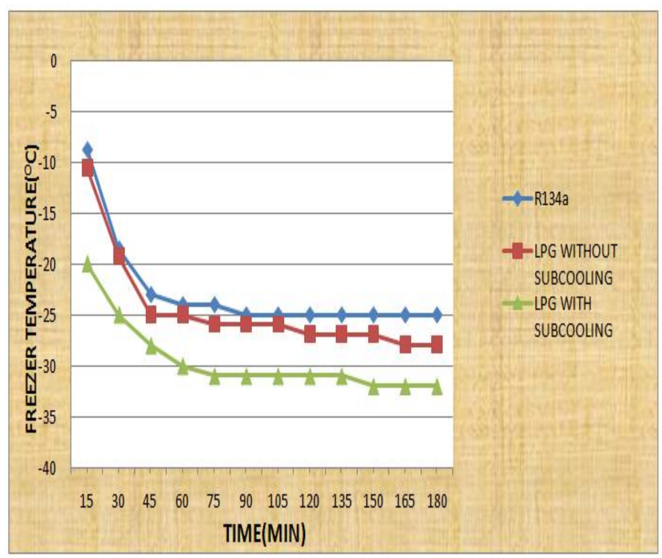


**Fig.13. Variation of Freezer Temperature with Time.**

**Variation of Compressor Discharge Pressure with Refrigerant:** The variation of compressor power with R134a, LPG (without sub-cooling) and LPG with sub-cooling are represented in the following figure:

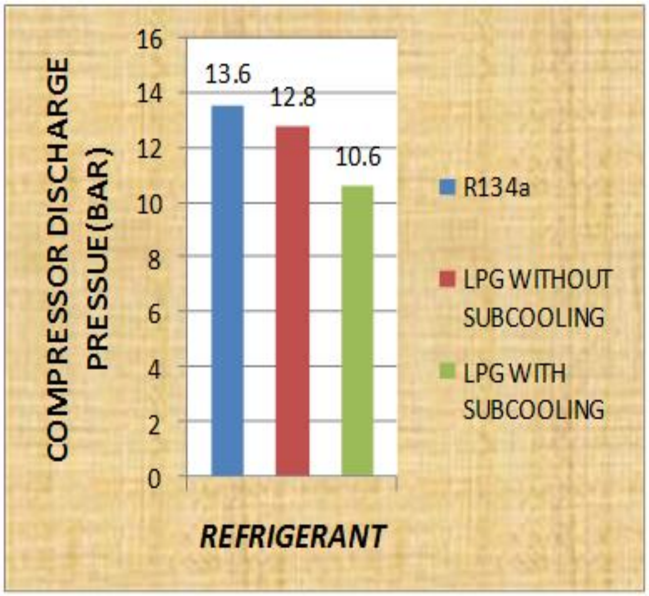


**Fig.14. Variation of Compressor Discharge Pressure with R134a, LPG and LPG with Sub Cooling.**

- From fig.14, it can be found that Compressor Discharge Pressure of the system run with LPG is 5% less than that of with R134a.This is because of more specific volume of LPG as compared to that of R134a.
- It can also be seen that there is 17% drop in Compressor Discharge Pressure of the system operated with LPG with Sub Cooling.

**Variation of COP of the system with Load and No Load Conditions:** The variation of COP of the system run with R134a, LPG and LPG with sub cooling under Load and No Load conditions has been presented in the following figure:

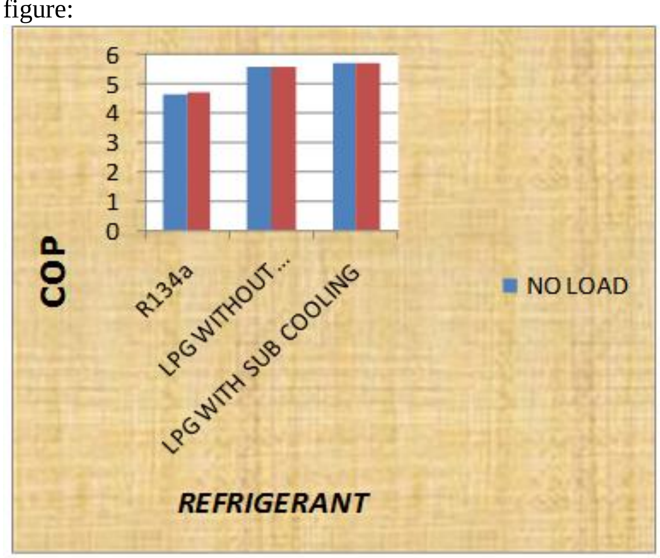


**Fig.15. Variation of COP with Load & No Load conditions.**

- From fig.15, it can be inferred that COP of the system run with LPG is 20% more than that of with R134a.This is because of increase in Refrigerating Effect for LPG as compared to that of R134a.
- It can also be seen that there is 1.6% increase in COP of the system operated with LPG with Sub Cooling.
- It can be also be inferred that there is a slight increase in the value of COP of the system under Load as compared to that with No Load for all the above three cases (R134a, LPG & LPG with Sub Cooling). This increase in COP is due to the increase in Refrigerating Effect with Load.
- It can also be concluded that along with Refrigerating Effect there is increase in Work of Compression, because of increase in discharge pressure. But increase in Refrigerating Effect is slightly more as compared to increase in Work of Compression.

**Comparison of mass flow rates for R134a, LPG and LPG with Sub Cooling:** The comparison of mass flow rates of VCRS operated with R134a, LPG (without sub cooling) and LPG with sub cooling are represented in the following figure:

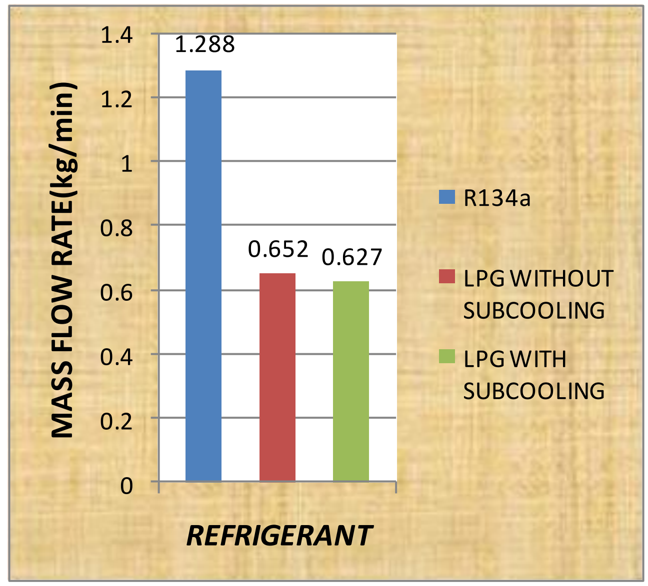


**Fig.16. Comparison of mass flow rates for R134a, LPG and LPG with Sub Cooling.**

- From fig.16, it can be observed that mass flow rate of the refrigerant is reduced to approximately 50% when the system is operated with LPG as compared to that of R134a.This reduction is due to increase in Refrigerating Effect as the latent heat of vaporization of LPG is more than that of R134a.
- It can also be seen from the above graph that mass flow rate of the refrigerant is nearly same when the system is operated with LPG without sub cooling and LPG with sub cooling.

**Variation of Compressor Power with R134a, LPG and LPG with Sub Cooling:** The variation of compressor power with R134a, LPG (without subcooling) and LPG with subcooling are represented in the following figure:

- From fig.17, it can be concluded that Compressor Power is reduced by 17% when the System is operated with LPG as compared to that of R134a. This is because of decrease in mass flow rate of the refrigerant.
- It can also be seen from the above graph that compressor power is still reduced by 1.4% when the system is operated with LPG with subcooling.

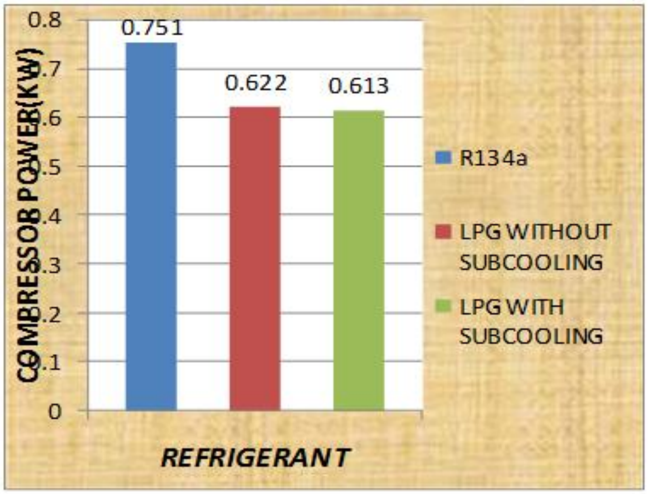


**Fig.17. Variation of Compressor Power with R134a, LPG and LPG with sub cooling.**

**Variation of Pull Down Time with R134a, LPG and LPG with Sub Cooling:** The variation of Pull down Time with R134a, LPG (without subcooling) and LPG with subcooling are represented in the following fig.18:

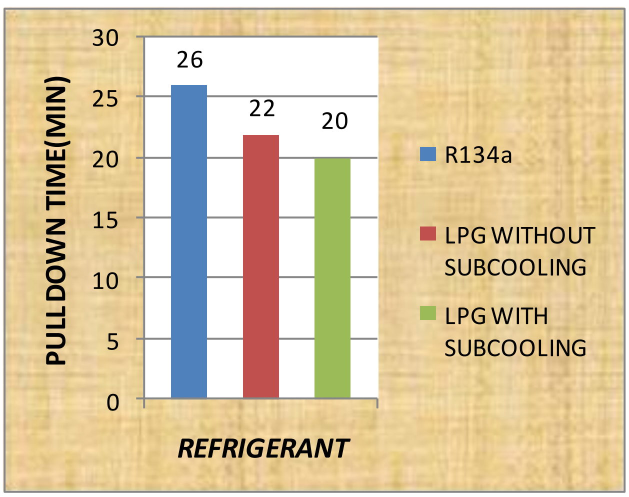


**Fig.18. Variation of Pull Down Time with R134a, LPG and LPG with Sub Cooling.**

The time taken by the Refrigerator Cabinet to reach +7$^0$C from atmospheric temperature.

## VI. CONCLUSION

The following conclusions are obtained from the present experimental work carried out: The Coefficient of Performance (COP) of Vapour Compression Refrigeration System (VCRS) run with Liquefied Petroleum Gas (LPG) is 20% more than that of the system run with R134a. Further an additional improvement in COP of 1.6%, when the system is operated with LPG with Sub Cooling. The present project work has successfully retrofitted in the VCRS (R134a) run with LPG. The lowest freezer temperature has been lowered from -25$^O$C (with R134a) to -32$^O$C by operating the system with LPG with sub-cooling. The time taken for achieving the lowest freezer temperature of -25$^O$C is 90 minutes in case of R134a, whereas with LPG with sub-cooling it has taken only 30min to achieve this temperature.

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