# Design and Performance Analysis of a Car Air Conditioner with LPG as a Refrigerant

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***Abstract* - In this work we found out the experimental performance results of LPG as refrigerant in air conditioner of an automobile car. We have used the existing and new developed evaporator coil in the experiment with different combinations of capillary tube diameter and length.**

**The diameter from OD 0.8 mm to OD 1.26 mm and length from 3.96 m to 0.6 m and some tube gave better refrigeration effect. We have found the actual capillary size which is suitable for the experiment, and then calculated system COP and monitor the Engine performance externally.**

***Index Terms - Heat Load, LPG Air Conditioner, LPG, Capillary tube, Evaporator, COP, and Vaporizer.***

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## I. INTRODUCTION

In this work a system is designed and analyzed for a car which runs on LPG. LPG is used as refrigerant as well as fuel in the engine of car, Liquid LPG is coming from the cylinder and passes through the capillary tube of small internal diameter, and the pressure of LPG is dropped due to expansion because it is isenthalpic process. Due to the phase change in evaporator from liquid to gas latent heat is gained by the air which comes in contact with it and its temperature drops. In this way LPG can produce cooling effect for a confined space and remaining low pressure LPG will come out from the evaporator coil to the vaporizer of car and then it goes to engine of car as a fuel. It works on the principle that during the conversion of LPG into gaseous form, expansion of LPG takes place. Due to this expansion there is a pressure drop and increase in volume of LPG that results in the drop of temperature and a refrigerating effect is produced. This refrigerating effect can be used for cooling purposes. So this work provides refrigeration for socially relevant needs as well as replaces global warming creator refrigerant.

The single largest auxiliary load on an automotive engine is caused by the air-conditioner compressor. During peak load it can draw up to 5 to 6 kW power from the vehicle's engine, and this is equivalent to a vehicle being driven down the road at 56 km/hr. The additional fuel consumed due to air conditioner usage is substantial and the air conditioner usage reduces fuel economy by about 20% and increases emissions of nitrogen oxides ($NO_X$) by about 80% and carbon dioxide (CO) by about 70%, although the actual numbers depend on the actual driving conditions[1].

Up to 19.4% of vehicle fuel consumption in India is devoted to air conditioning (A/C). Indian A/C fuel consumption is almost four times the fuel penalty in the United States and close to six times that in the European Union because India's temperature and humidity are higher and because road congestion forces vehicles to operate inefficiently. Car A/C efficiency in India is an issue worthy of national attention considering the rate of increase of A/C penetration into the new car market, India's hot climatic conditions and high fuel costs[2].

Ibrahim H Shah and Mohammad Shoeb Sheikh has done reviewed study on LPG Air Conditioner system, they studied in two parts, in first part they mentioned the possibilities of LPG as refrigerant and in second part the effects of emissions on automobile engine when use Air conditioner. In first part they investigated the use of LPG in domestic refrigerator and their limitations and safety, this study gave the potential how to use the LPG in refrigerator and in the second part they studied the load of Air Conditioner on an automobile engine and their effects on tail pipe emissions and fuel efficiency. So studies shows that LPG can be used in a car air conditioner as a refrigerant and as a fuel for an automobile engine [3].

In this work we have investigated the performance of an air conditioner based on liquefied petroleum gas (LPG) refrigerant. LPG is a byproduct in petroleum refineries and comprises of 40% propane, 60% butane and the proportion is varies with refineries. The use of LPG for air conditioning purpose can be environment friendly since it has no ozone depletion potential (ODP) and low global warming potential (GWP) comparatively to other refrigerants. Usually LPG is used as a fuel for car and cooking food and the combustion products of LPG are $CO_2$ and $H_2O$.

## II. DESIGN OF LPG AIR CONDITIONER SYSTEM

There are five main parts in this system

1. Heat load calculation of car
2. Copper Tubes (For carrying LPG from cylinder to filter before capillary)
3. Capillary tube
4. Solenoid Valves (Operate the system)
5. Evaporator

**Heat Load calculation Procedure**

The net heat gain by the cabin can be classified under different categories. The total load as well as each of these loads may depend on various driving parameters. In the following, each of these load categories are presented and discussed. Some of the correlations used here for general validation of load calculation. The summation of all the load types will be the instantaneous cabin overall heat load gain. The mathematical formulation of the model can thus be summarized as [1, 2].

$$\dot{Q}_{Total} = \dot{Q}_{Metabolic} + \dot{Q}_{Solar} + \dot{Q}_{Equipment} + \dot{Q}_{Fresh\ air}$$

**Metabolic Load**

The Metabolic activities inside human body constantly create heat and humidity (i.e. perspiration). This heat passes through the body tissues and is finally released to the cabin air. This amount is considered as a heat gain by the cabin air and is called the metabolic load. The metabolic load can be calculated by [6].

$$\dot{Q}_{Met} = M * A$$

Where,
M- Metabolic Load, W/m$^2$
A- Area of the body, m$^2$
Which can be calculated by the Dubois Surface Area

$$A_{Du} = 0.202 * W^{0.425} * H^{0.725}$$

Where,
W- Weight of the person, kg
H- Height of the person, m
For the calculation of the Metabolic load consider five persons in the car at a time and each person weight 90 kg and height 6 ft then area of each person same which is

$$A_{Du} = 2.052\ m^2$$

And the complete metabolic load calculation is describe in the table

| Activity | Persons | M, W/m$^2$ | Heat, W | | A, m$^2$ | Q ,W |
|---|---|---|---|---|---|---|
| | | | SL | TL | | |
| Driving | 1 | 115 | 75 | 40 | 2.052 | 235.98 |
| Seated | 4 | 80 | 55 | 25 | 2.052 | 656.64 |
| | | Total Metabolic Load | | | | 892.65 |

**Solar Load**

The heat gain due to solar radiation is a significant part of the cooling loads encountered in vehicles. The radiation which comes is normal solar radiation and it is divided into direct, diffuse and reflected radiation loads [10]

**Normal Solar Radiation**

$$I_n = 1082 * e^{\frac{0.182}{\sin\beta}}$$

Where,
$\beta = altitude\ angle$

$$\sin\beta = cosl * cosh * cosd + sinl * sind$$

l = latitude
h = hour angle
d = sun declination

$$d=23.47\sin\frac{360(284+N)}{365}$$

N is the day of the year counted from 1 January.

$$I_n = 895.20\ \text{W/m}^2$$

**Direct Radiation**

$$I_D = I_n \cos\theta$$

$I_n = normal\ solar\ radiation$
$\theta$ = angle of incidence

$$\cos\theta = \cos\beta * \cos\alpha$$

$\alpha$ = surface solar azimuth angle

$$\alpha = 45 - h$$
$$I_D = 216.16\ W/m^2$$

**Diffuse Radiation**

$$I_d = CI_nF_{ss}$$

Where,
C Dimensionless coefficient for sky radiation of each month.
$F_{ss}$ Factor between the sky and the surface.

$$F_{ss} = 0.5$$

C = 0.121 for May month

$$\boldsymbol{I_d}\textbf{=54.159 W/m}^2$$

Total heat gain of the space

$$\dot{Q}_{solar} = Q_1 + Q_2 + Q_3$$

Where,
$Q_1$ Total transmitted radiation.
$Q_2$ Total absorbed radiation.
$Q_3$ Heat transmission by conduction, convection and radiation.

**1. Total Transmitted Radiation**

$$Q_1 = \text{A}\,(\tau_D I_D + \tau_d I_d)$$

Where,
A Expose area, m$^2$
$\tau_D$ Transmissivity of the direct radiation [4, 11]
$\tau_d$ Transmissivity of the diffuse radiation.
$I_D$ Direct radiation, W/m$^2$
$I_d$ Diffuse radiation, W/m$^2$

**2. Total absorbed radiation**

$$Q_2 = \frac{A * \alpha * I}{1 + \frac{f_o}{f_i}}$$

Where,
A Area of window glass and roof, m$^2$
$\alpha$ Absorptivity of glass and roof, [4, 11]
I total radiation, W/m$^2$
$fo$ Outside heat transfer coefficient, W/m$^2$ k
$f_i$ Inside heat transfer coefficient, W/m$^2$ k

**3. Heat transmission by conduction, convection and radiation.**

$$Q_3 = UA\,(t_o - t_i)$$

$$\frac{1}{U} = \frac{1}{f_i} + \frac{\delta}{k} + \frac{1}{f_o}$$

U Overall heat transfer, W/m$^2$ k
A Area of glass, door, roof, m$^2$
$\delta$ Thickness of the material, m
K thermal conductivity, W/m k

$$\boldsymbol{\dot{Q}_{total,solar} = 1235.96\ W}$$

**Equipment load** - In a car only equipment is the music system.

$$\boldsymbol{\dot{Q}_{equipment} = 80\ W}$$

**Calculation for Fresh air load**
**Fresh air flow [9]**

$$\text{V} = R_p * P_z + R_a * A_z$$

$R_p$ Outdoor airflow rate required per person
$P_z$ Zone population
$R_a$ Outdoor airflow rate required per unit area
$A_z$ Zone area

$$\textbf{V= 0.708 m}^3\textbf{/min}$$

**Mass of fresh air**

$$\boldsymbol{\dot{m}_{fa} = 0.0129\ \textbf{kg/min}}$$

**Sensible load**

$$\text{SH} = m_{fa} C_{pm} (t_o - t_i)$$

$$\textbf{SH = 0.1977 kW}$$

**Total Load**

$$\text{Total Load} = m_{fa}(h_o - h_i)$$

$$\textbf{TL = 0.4347 kW}$$

**Latent Load**

Latent load = Total –Sensible

**LT = 0.2370 kW**

**Total Load Summary**

| S no | Source | Sensible Load, W | Latent Load, W |
|---|---|---|---|
| 1 | Occupant | 605.34 | 287.28 |
| 2 | Solar | 1235.96 | - |
| 3 | Equipment | 80 | - |
| 4 | Fresh Air | 197.7 | 237 |
| 5 | Total | 2119 | 524.28 |
| **Total Load** | | **2643.28 W** | |

$$Cooling\ Load = \mathbf{0.75\ TR}$$

**Mass flow rate of refrigerant**

$$\dot{m}_a = \frac{Cooling\ load}{h_{fg}}$$

At 6 $^0$C of coil ADP,

$h_{fg} = 364.49\ kJ/kg$

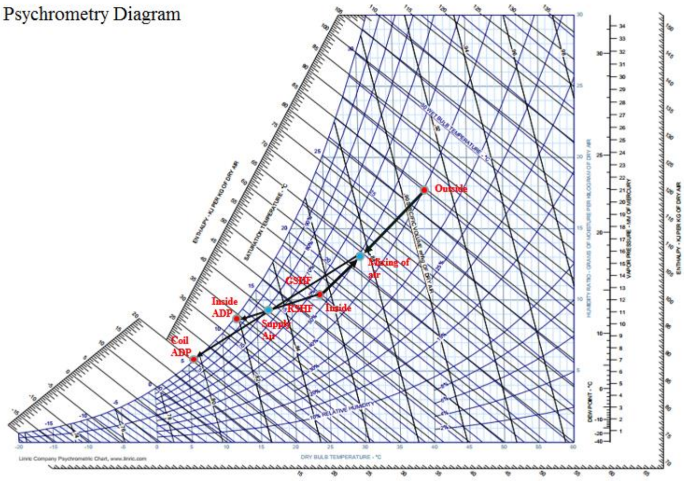
$$\dot{\boldsymbol{m}}_{\boldsymbol{a}} \textbf{= 0.0072 kg/sec}$$

**Volume flow rate of refrigerant**

$$\dot{V} = \dot{m}_a v_f$$

$$\dot{\boldsymbol{V}} \textbf{= 0.00002451 } \boldsymbol{m^3}\textbf{/sec}$$

Psychrometry Diagram




**Copper Tube**

Copper is the preferred material to be used with most refrigeration systems. Because of its good heat transfer capacity as well as corrosion resistance and cheaper in cost. As for all materials, the allowable internal pressure for any copper tube in service is based on the formula used in the American Society of Mechanical Engineers Code for Pressure Piping [16, 17].

$$P = 2S\ (t_{min} - C)/\ D_{max} - 0.8\ (t_{min} - C)$$

Where: P = allowable pressure, bar

S = maximum allowable stress in tension, bar

$t_{min}$ = wall thickness (min.), in mm

$D_{max}$ = outside diameter (max.), in mm

C = a constant for copper tube, because of copper's superior corrosion resistance, the B31.5 code permits the factor C to be zero. Thus the formula becomes:

$$P = 2St_{min}/D_{ma} - 0.8t_{min}$$

According to the pressure 90 psi the tube outside diameter is become = 7 mm and the thickness of the tube is = 1 mm.

**Capillary tube**

The capillary tube serves almost all small systems, and its application extends up to refrigeration capacity of the order of 10 KW. A capillary tube is 1 to 6 m long with an inside diameter generally from 0.5 to 2 mm. The name is misnomer, since the bore is too large to permit capillary action. Liquid refrigerants enters the capillary tube, and as it flows through the tube, the pressure drops because of friction and acceleration of the refrigerants. Some of the liquid flashes into vapor as the refrigerant flows through the tube [10].

**Solenoid Valve** – In this system use three solenoid valves which operate the flow of LPG

**Evaporator** Evaporators are heat exchangers with fairly uniform wall temperature employed in a wide range of HVAC products, spanning from household to industrial applications.

## III. Description of Maruti 800 car

**Brake power** [12]

| S no | Description | Specification |
|---|---|---|
| 1 | Stroke | 72 mm |
| 2 | Bore | 68.5 mm |
| 3 | Rated Power | 5000 rpm |
| 4 | Torque | 57 Nm |
| 5 | No of Cylinder | 3 |
| 6 | AF ratio | 15.7:1 |

$$Bp = \frac{2*\pi*N*T}{60}$$

N Number of revolution, rpm
T Torque, Nm

$$bp = 29.845\ kW$$

**Swept volume**

$$V_s = \frac{\pi}{4}d^2 l$$

d Bore, m
l Stroke length, m

$$V_s = 2.65 * 10^{-3}\ \mathrm{m}^3$$

**Volume of air**

$$\boldsymbol{V_a = n_v * V_s}$$

$n_v$ Volumetric efficiency [17]

$$n_v = 0.73$$

$$\boldsymbol{V_a = 1.936*10^{-4}\ m^3}$$

**Mass of air**

$$\boldsymbol{m_a = \rho_a * V_a}$$

$\rho_a$ Density of air at atmospheric temperature $\boldsymbol{m_a} = 2.287*10^{-4}$ kg

**Mass flow rate of air**

$$\dot{m}_a = 9.53*10^{-3}\ \frac{kg}{min}$$

**Mass of fuel**

$$m_f = \frac{m_a}{AF}$$

$$\mathbf{m_f = 1.456*10^{-5}\ kg}$$

**Mass flow rate of fuel**

$$\dot{m}_f = m_f * \frac{N}{120} * n$$

$$\boldsymbol{\dot{m}_f = 1.82*10^{-3}\ kg/min}$$

## IV. The LPG Air Conditioning System

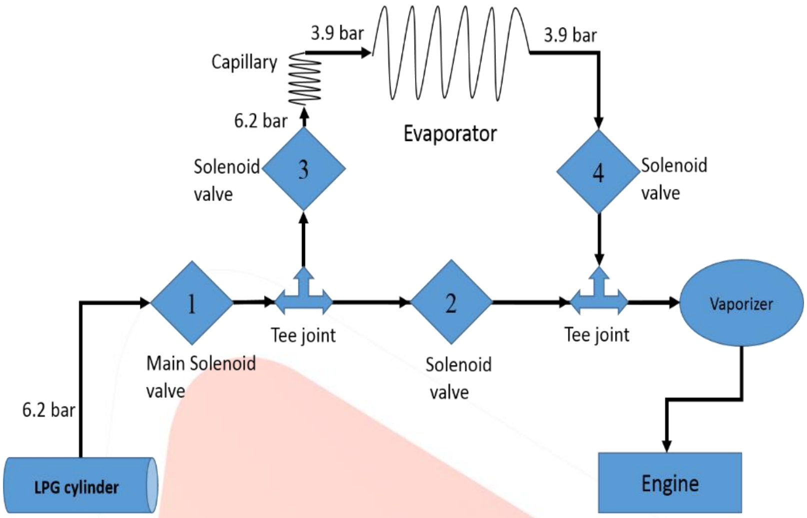
**LPG Cylinder** from the LPG gas cylinder of 28 kg, LPG flows through the pipe and reaches to the capillary tube. LPG gas pressure is approximate 6.2 bars.

**Capillary Tube** As the capillary tube, capillary tube downs the pressure up to 3.9 bars.

**Evaporator** In the evaporator LPG is converted into the vapor form with low pressure. After passing through the evaporator low pressure and temperature LPG vapor absorbs heat from the inside area of car.

**Vaporizer** After performing the cooling effect, low pressure LP Gas goes into the vaporizer where it further decreases in pressure and complete vapor form of LPG goes into the engine for driving the car. As we know whenever the fluid flow through the narrow pipe there is a pressure drop. The amount of pressure drop in our system is calculated.

## V. Basic Experimental Setup of LPG Air Conditioning system




The basic components in this system are shown in line diagram.

This experiment was done with various combination of capillary tube and different evaporator which is mentioned below with their results [13].

In first three experiment used the original coil of 800 car AC which is serpentine type.

**Experiment- I**

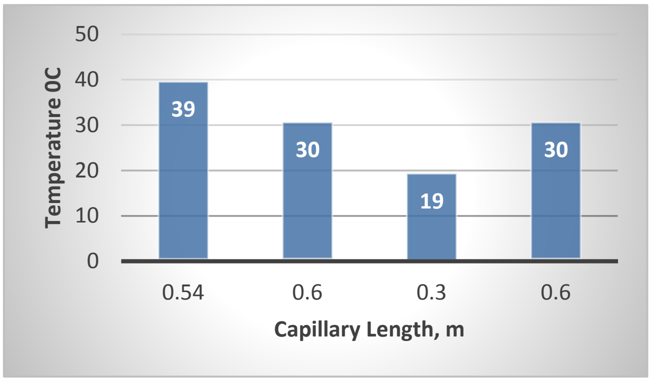
| Sn | Capillary size, mm | Capillary length, m | Temp Drop, $^0$C | Pressure bar | Time |
|---|---|---|---|---|---|
| 1 | OD -1.26 ID -1.16 | 2.13 | 39 | 6.2 bar | 20 min |
| 2 | OD -1.26 ID -1.16 | 1.52 | 39 | 6.2 bar | 15 min |
| 3 | OD -1.26 ID -1.16 | 1.21 | 39 | 6.2 bar | 15 min |
| 4 | OD -1.26 ID -1.16 | 0.91 | 39 | 6.2 bar | 15 min |
| 5 | OD -1.26 ID -1.16 | 0.60 | 39 | 6.2 bar | 15 min |
| 6 | OD -1.26 ID -1.16 | 0.54 | 39 | 6.2 bar | 15 min |

**Results-** In this arrangement no drop in temperature.

**Experimental Setup**

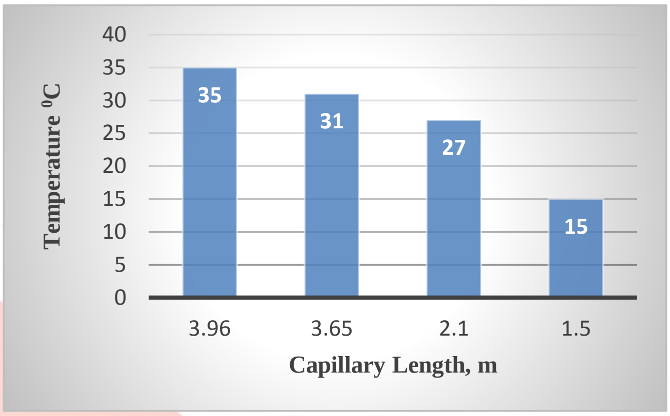
**Experiment- II**

| Sn | Capillary size, mm | Capillary length, m | Temp Drop, $^0$C | Pressure bar | Time |
|---|---|---|---|---|---|
| 1 | OD -1.26 ID -1.16 | 0.54 | 39 | 6.2 | 20 min |
| 2 | OD -1 ID -0.91 | 0.6 | 39-30 | 6.2 | 1 min 55 sec |
| 3 | OD -1 ID -0.91 | 0.3 | 39-19 | 6.2 | 10 min |
| 4 | OD -0.84 ID -0.78 | 0.6 | 39-30 | 6.2 | 1 min 30 sec |




**Experiment-III**
Results and observations are same for second and third experiments and which are mentioned below

| Sn | Capillary size, mm | Capillary length, m | Temp Drop, 0C | Pressure bar | Time |
|---|---|---|---|---|---|
| 1 | OD-0.8 ID 0.71 | 3.96 | 39-35 | 6.2 | 4 min |
| 2 | OD-0.8 ID 0.71 | 3.65 | 39-31 | 6.2 | 5 min |
| 3 | OD-0.8 ID 0.71 | 2.1 | 39-27 | 6.2 | 2min 5 sec |
| 4 | OD-0.8 ID 0.71 | 1.5 | 39-15 | 6.2 | 1min 39 sec |

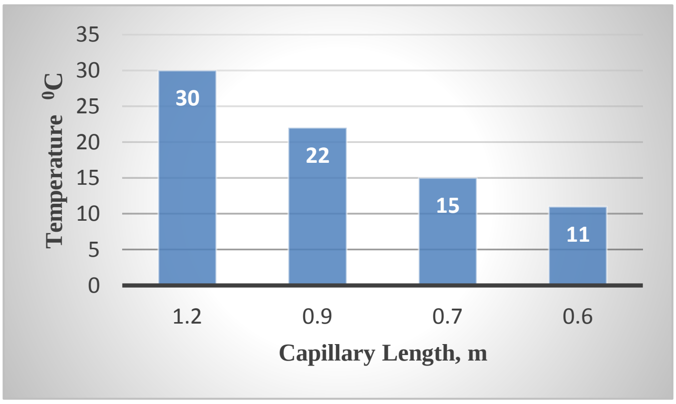



**Results-**
1. Set up were tested in no load condition.
2. After that we drive the vehicle on high way and again tested within driving condition and vehicle was driven 40 km and found that it produces cooling because LPG is continuously flowing from the evaporator coil to engine but when slow down the speed and stop the vehicle the cooling was gone and LPG filled in the cooling coil due to that the cooling is not produced.

**Observation**-In this experiment it is important to have a continues flow of LPG from the cooling coil and does not stay LP Gas in coil once it stay in it then for again cooling it takes lot of time and drive the vehicle for a longer distance and when the engine is utilizes the complete stayed gas from the cooling coil then new gas is coming from the LPG cylinder and it produces cooling. This is due to mismatch between LPG coming from cylinder regulator rate of discharge and experiment rate in capillary and evaporator and then to vaporizer of conventional LPG kit again suction rate and RPM of engine.

**Experiment- IV**
In this experiment changed the standard evaporator coil with simple spiral coil which is handmade and having dimensions of 3/16" (OD- 5 mm, ID- 3mm) coil size and length 5 feet (1.524 m) the length of coil is calculated by the various relations

| Sn | Capillary size, mm | Capillary length, m | Temp Drop, 0C | Pressure bar | Time |
|---|---|---|---|---|---|
| 1 | OD-0.8 ID-0.71 | 1.2 | 39-30 | 6.2 | 2 min 30 sec |
| 2 | OD-0.8 ID-0.71 | 0.9 | 39-22 | 6.2 | 2 min 05 sec |
| 3 | OD-0.8 ID-0.71 | 0.7 | 39-15 | 6.2 | 2 min |
| 4 | OD-0.8 ID-0.71 | 0.6 | 39-11 | 6.2 | 1 min 15 sec |




**Results-**
1. Small amount of frost deposited during no load condition within 1 min and after 1 min half of coil got iced but the remaining coil is without ice and when press the pedal to open the throttle of intake system it will turn off the engine.

2. As compared with above more frost has deposited and when press the accelerate pedal it will turn off the engine.
3. Same as above.
4. In this arrangement during no load and load conditions ice has deposited on whole coil and during slow down the speed it has gone rapidly with respect to the speed. This is due to mismatch between capillary experiment-3 and suction rate of engine through vaporizer.

**Observation-**

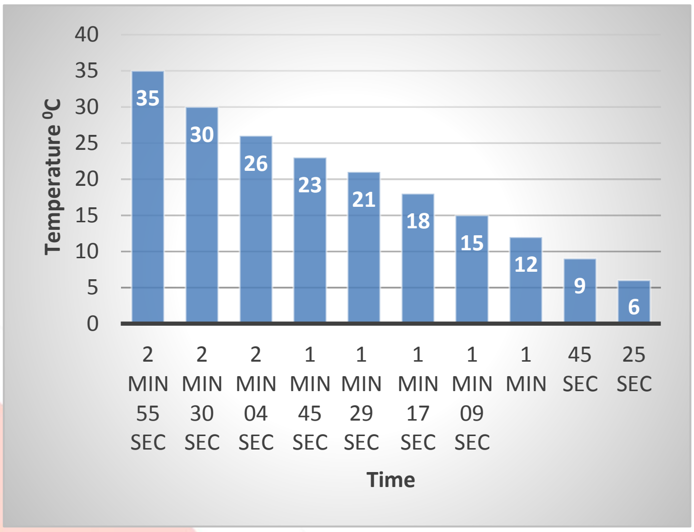
In this arrangement found that the ice not deposited on coil for longer time then we move to new coil have same length with different diameter and its results are mentioned in next experiment.

**Experiment-V**

Hand made spiral coil with 1/4" (OD-7 mm, ID-5mm) coil size and length 5 feet (1.524 m) the coil length is same as previous experiment.

| Sn | Capillary size, mm | Capillary length, m | Temp Drop, $^0$C | Pressure bar | Time |
|---|---|---|---|---|---|
| 1 | OD-0.8 ID-0.71 | 0.6 | 39-6 | 6.2 | 15 min 20 sec |

| Time | Inlet Press, bar | Evaporator Temp, $^O$C |
|---|---|---|
| 2 min 55 sec | 6.2 | 35 |
| 2 min 30 sec | 6.2 | 30 |
| 2 min 04 sec | 6.2 | 26 |
| 1 min 45 sec | 6.2 | 23 |
| 1 min 29 sec | 6.2 | 21 |
| 1 min 17 sec | 6.2 | 18 |
| 1 min 09 sec | 6.2 | 15 |
| 1 min | 6.2 | 12 |
| 45 sec | 6.2 | 9 |
| 25 sec | 6.2 | 6 |




**Result-**

In this arrangement during no load and load conditions ice has deposited on the whole coil and engine is running perfectly.

**VI. Calculate the COP of the system**

For work input we have a LPG cylinder of 14.5 Kg. so the work input is amount of energy required for filling of 1 cylinder. A typical LPG bottling plant has the following major energy consuming [13].

Equipment-
1. LPG pumps
2. LPG compressors
3. Conveyors
4. Blowers
5. Cold repair facilities including painting
6. Air compressors and air drying units
7. Transformer, MCC & DG sets
8. Firefighting facilities
9. Loading and unloading facilities

Some of the LPG bottling plants use a comprehensive monitoring technique for Keeping track of energy / fuel Consumption on per ton basis. PCRA Energy Audit [14].

1. Consumption = 40×4200

=168000kWh

2. For lighting energy consumption= 227340kWh
3. LPG compressor consumption= 153360 kWh

Total consumption for LPG pumps
One pump having 40 kW motor and 96 m head or 150 cubic meter /hour discharge
Annual operating = 4200 hrs
Annual energy 6 hrs /day in 350 days = 168000 + 227340 + 153360

= 548700kWh

Per day consumption = 548700/350 = 1567.71 kWh
500 cylinders are refilled every day, so per cylinder electricity consumption = 1567.71/500

= 3.1354kWh

For filling of 1 LPG cylinder of 14.5 kg the power input is = 3.1354 kWh

So 1 kg of LPG is = 3.1354/14.5

= 0.2162 kWh

We run the set up for 1 hr = 0.2162×1000/ (0.00072×3600)

= 83.41W

COP = Refrigerating effect/ W

COP = 368.89/83.41

**COP = 4.63**

## VII. Conclusion

**1.** The aim of LPG air conditioner is to use LPG as a refrigerant and utilize the energy of pressure in the cylinder for producing the refrigeration effect. LPG at a pressure of 6.2 bar from the car cylinder equipped with LPG at this pressure comes into the capillary tube and after that its pressure is 3.9 bar At this pressure it goes into the evaporator where refrigeration effect will produce and the remaining LPG goes into the vaporizer and then into the engine of a car where use LPG as a fuel. Still we have not explain or stated the condition of Liquefied Petroleum Gas condition at any place of system. But surely we know that liquid is vaporized and goes into intake system of engine with the help of vaporizer as it does so with the pressure difference principle since the diaphragm of vaporizer is operated with the help of vacuum (low pressure) created due to piston suction motion towards BDC.

**2.** We calculate different loads coming on car air conditioner like the occupant, equipment, solar load, fresh air load, and ambient load after that is summarized it and got the cooling load which is 0.75 TR required to cool the inside area of car for human comfort.

**3.** Cost analysis of present and proposed model were done and found extensive difference.

**4.** So we concluded that LPG with some enhanced design and some more precise calculations will better be useful for refrigeration in car air conditioner as well as fuel for combustion inside engine cylinder.

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