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LPG based refrigeration system and parameter effect analysis

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Abstract

Energy is needed to run every machine whether it is mechanical, electrical or of any other kind and so is the refrigerator. But continuous supply of electricity is still not found in some regions of country and the world that is remote and hilly areas. This work will be beneficial for obtaining the refrigeration effect for food medicine etc. in such areas. This paper gives the result of an experimental study that shows the effect of parameters on the LPG based refrigeration system that uses liquefied Petroleum gas as a refrigerant which is available in form of domestic cylinders in almost every part of country that mainly comprises of propane and butane. Also the LPG is low cost and of environment friendly nature and has zero ozone depletion potential and no global warming potential. This kind of refrigeration system is basically operates with zero cost as LPG is used for cooking purpose and the LPG refrigerator is so designed that it fits between the cylinder and the burner. Usually LPG is used as a fuel for cooking food in restaurant, hotel, mess and houses etc. This paper incorporates design and analysis of LPG refrigerator. The LPG is available at high pressure inside the domestic cylinder so eliminating the use of compressor and when LPG is allowed to pass through the capillary tube, a pressure drop occurs due to expansion and which results in phase change of LPG. Due to this phase change from liquid to gas, the liquid refrigerant gains latent heat and the temperature drops. This results in refrigeration effect. Through this experiment we came to know cooling effect considerably varies with the change in parameters like effect of variation of inlet pressure of LPG, effect of length of capillary tube, effect of diameter of capillary tube etc.

Keywords: Refrigeration, evaporator, capillary tube, ozone depletion potential, inlet pressure, cooling effect.

Introduction

We can find extensive use of refrigerators in our daily life as they are extensively used in food and beverage industries, ice plants, cold stores, food processing industries, milk plant chillers and in our homes as domestic refrigerators. Since, they are the vital part of the above said industries and should work effectively and economically. As electricity is the main power source to drive these plants so efficient working of these plants directly reflects the economy of the plant. They should be designed to have high effectiveness and low operating cost. Also, electricity is not available in some remote areas. So, to predict the performance of LPG based refrigeration system variation of pressure and capillary tube length is analyzed[1,2]. The system works on the principal of simple vapour compression cycle in which both compressor and condenser are being eliminated and thus the system works on zero operating cost and without electricity. Its behavior under variation of different working parameters should be analyzed in order to predict the effective and efficient performance of the system for the requirements of their use in future. A LPG based refrigerator was designed and fabricated in order to evaluate its performance and to calculate its cooling performance under varying conditions of pressure and capillary tube length[3]. This model can be used to get an instant refrigerating effect from the LPG as a refrigerant[4]. Since, the system is operating without electricity so it can have wide applications in remote areas where electricity is not available and also in restaurants, hotels, big kitchens, oil refineries where continuous use of LPG can be utilized to provide refrigerating effect to the cold stores and deep freezers[5,6].

Construction of LPG Refrigeration System

The LPG refrigerator is shown in the Figure-1. We made a wooden box of 10mm thick ply and have size of 22´´×18´´×12´´. The thermo-coal sheet size is 15mm used for insulation purpose pasted to the inside walls of wooden box with the help of glue so that cold air from the evaporator cannot transfer outside of the refrigerator. The size of the evaporator is 345×242×158mm³. And the evaporator is wrapped totally with aluminium foil.

The fundamental of LPG refrigeration is to use LPG as a refrigerant to absorb the heat[7]. The working mechanism of the LPG Refrigeration system is given in Figure-2[8]. i. LPG stored under high pressure inside the cylinder. After opening the inlet valve the high pressure LPG passes through the high pressure pipes enters the capillary tube. ii. Pressure drop occurs inside the capillary while enthalpy remains constant. iii. Afterwards the LPG passes through the evaporator where it is converted to low pressure and temperature vapour that absorbs the heat from the chamber[9]. Thus a cooling effect takes place. iv. After passing the evaporator the LPG is directed towards burner through pipes for further usage.

Figure-1: LPG Refrigerator.

It works on the simple Vapour Compression Refrigeration cycle shown as follows[10]:

Process 2-3: compression: no need of compressor due pre-pressurized gas inside cylinder.
Process 3-4: condensation: Condenser is eliminated in this process.
Process 4-1: expansion: Pressure drop occurs inside the capillary while enthalpy remains constant.
Process 1-2: cooling: refrigerant passes through the evaporator coil where it absorb its latent heat from the chamber.
The actual setup of LPG refrigeration system is shown in Figure-3 below[11].

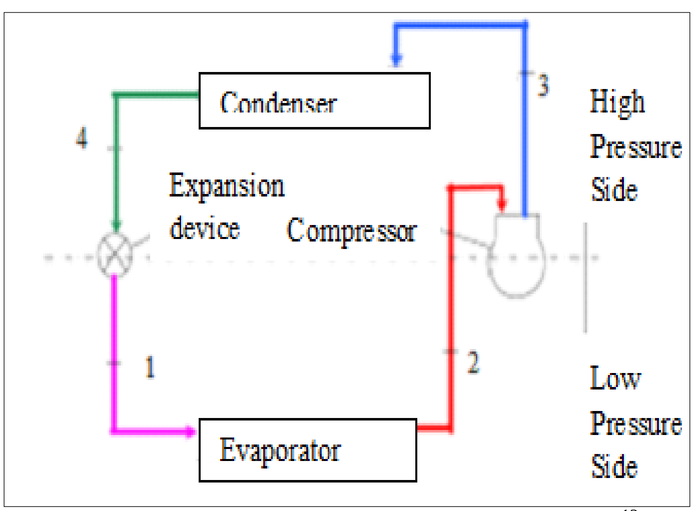

Figure-2: Vapour Compression Refrigeration System[12].

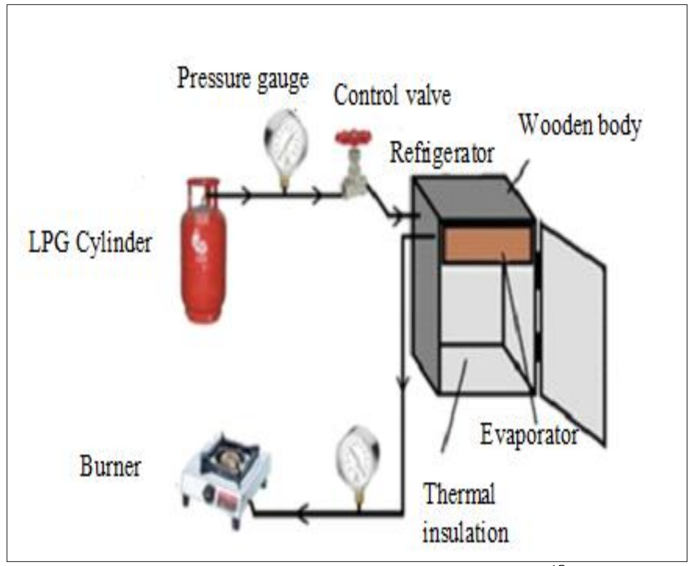

Figure-3: Diagram of LPG Refrigerator[13].

Material Specifications and Procedure

The experiment was conducted on the basis of effect of parameter on the cooling effect of system (In terms of temperature drop (^{0}C)).

Specifications: 1. LPG cylinder (domestic type) = 14.2Kg, 2. Evaporator size =342mm×242mm×158mm (Aluminium Based), 3. Temperature sensor (digital type) with probe.

Experimental Procedure: i. First install the setup with all suitable connections. Make sure all the connections are leak proof. ii. Reverse the LPG cylinder so that liquid LPG refrigerant can be extracted through high pressure pipes. iii. Now gradually open the three way regulating valve and adjust pressure at required (say 70 Psi) initially and maintain constant pressure in the pressure gauge. iv. The liquid LPG refrigerant starts flowing through the capillary tube and at the other end of capillary tube or at the inlet of the evaporator it expands and vaporizes and gains the latent heat of the space which is to be cooled. v. Adjust and maintain constant pressures in the inlet and outlet pressure gauge. vi. The gas at the outlet of the system passes to the burner where it can be burn for use. vii. Once the pressure is being set and get constant in both the pressure gauges, than, starting from time 0 minute in the stopwatch take consecutive readings for the time interval of the 2 (say) minutes[14].

Results and discussion

Observations: Effect of inlet pressure variation: The experiment was conducted on the basis of effect of inlet pressure variation on system. In the first experiment as given in Table-1, we take inlet pressure 70 Psi and outlet pressure of 18 Psi and corresponding to the specifications as mentioned below.

In the second experiment as given in Table-2, we increased the inlet pressure to 80 Psi and outlet pressure to 20 Psi with same specifications.

Specifications: Length of the capillary tube = 6 meters, Inside diameter of the capillary tube = 0.75mm.

Table-1: Observation for first experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (^oC)	Evaporator Temperature (^oC)
0	70	18	30.0	32.0
5	70	18	27.3	15.5
10	70	18	23.4	9.1
15	70	18	18.3	4.8
20	70	18	13.2	2.4
25	70	18	8.6	0.0

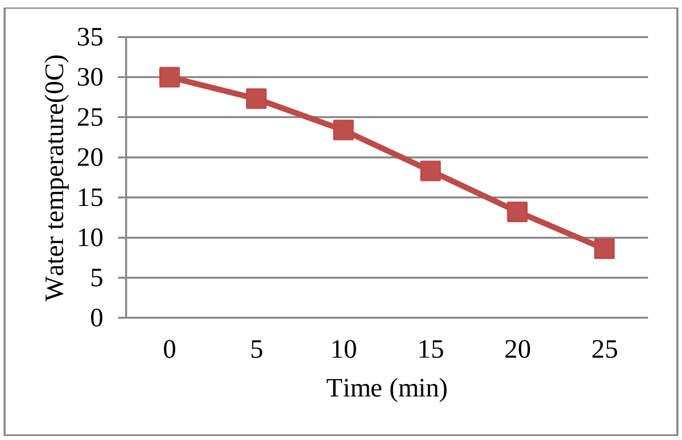

Figure-4: Water temperature V/S Time graph.

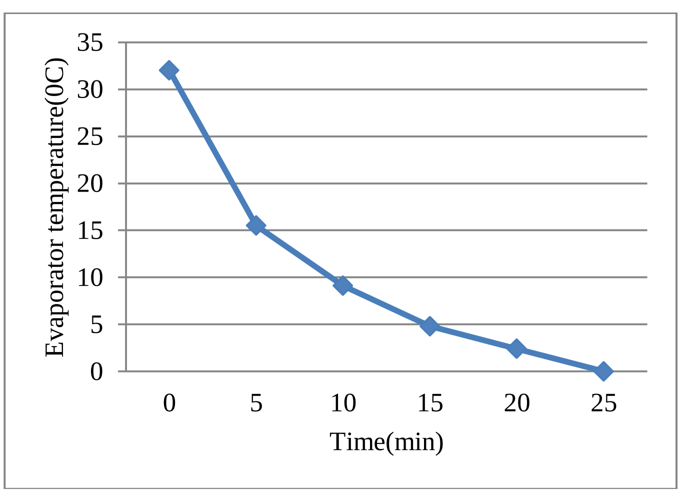

Figure-5: Evaporator temperature V/S Time graph.

Calculation of refrigerating effect (R.E.): The properties of LPG at 70 Psi pressure are: Enthalpy, h_1 = 408 KJ/Kg.
The properties of LPG at 18 Psi pressure are: Enthalpy, h_f = 112 KJ/Kg and, h_{fg} = 372 KJ/Kg.
$h_2 = h_f + x_{LPG}.h_{fg} = 112 + 0.46\times372 = 283.12$ KJ/Kg
$h_g = h_f + h_{fg} = 112 + 372 = 484$ KJ/Kg
$h_3 = h_g + (C_p)_{LPG}.\Delta T = 484 + 1.67\times(32\text{-}0) = 537.44$ KJ/Kg
so, the refrigerating effect (R.E.) is
R.E. = $h_3 - h_2$ = 537.44 – 283.12 = 254.32 KJ/Kg

Table-2: Observation for second experiment.

Time (mins)	Inlet pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (^0C)	Evaporator Temperature (^0C)
0	80	20	30.0	32.0
5	80	20	21.6	8.6
10	80	20	17.2	3.0
15	80	20	11.6	-3.8
20	80	20	8.3	-7.5
25	80	20	5.2	-9.7

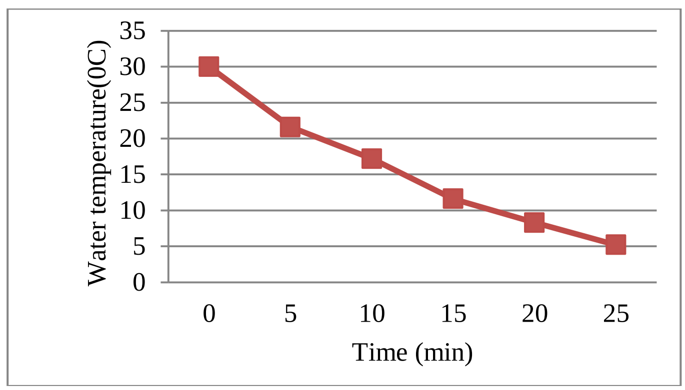

Figure-6: Water temperature V/S Time graph.

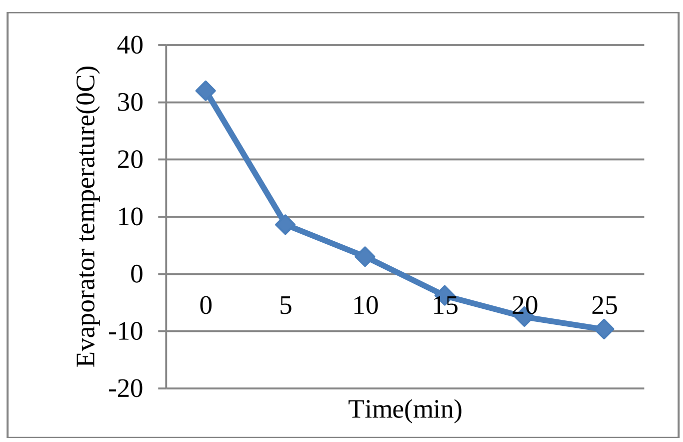

Figure-7: Evaporator temperature V/S Time graph.

Calculation for R.E.: Properties of LPG at 80 Psi pressure are- Enthalpy, h_1 = 435.3 KJ/Kg. Properties of LPG at 20 Psi pressure are: Enthalpy, h_f = 110.6 KJ/kg. h_{fg} = 378 KJ/Kg
Dryness fraction from p-h chart, x_{LPG} = 0.5.
$h_2 = h_f + x_{LPG}.hfg = 110.6 + 0.5\times378 = 299.6$ KJ/Kg
$h_g = h_f + h_{fg} = 110.6 + 378 = 488.6$ KJ/Kg
$h_3 = h_g + (C_p)_{LPG}.\Delta T = 488.6 + 1.67\times(35-(-9.7)) = 563.24$ KJ/Kg
So, the refrigerating effect (R.E.) is given by
R.E. = $h_3 - h_2$ = 563.24 – 299.6 = 263.64 KJ/Kg.

Effect of capillary tube inner diameter: The experiment was conducted on the basis of effect of capillary inner diameter on the cooling of the system. In the experiment we take inlet pressure 60 Psi and outlet pressure of 14 Psi corresponding to the specifications as mentioned below.

Specifications: For first experiment as given in Table-3. Length of the capillary tube = 6 meters. Inside diameter of the capillary tube = 0.78mm (0.031 inch).
For second experiment as given in Table-4. Length of the capillary tube = 6 meters. Inside diameter of the capillary tube = 1.11mm (0.044 inch).
For third experiment as given in Table-5. Length of the capillary tube = 6 meters. Inside diameter of the capillary tube = 1.39mm (0.055 inch).

Table-3: Observation for first experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	24.4	22.0
2	60	14	24.2	10.7
4	60	14	24.0	6.4
6	60	14	22.5	3.8
8	60	14	20.5	1.4
10	60	14	18.2	-1.1
12	60	14	15.6	-1.8
14	60	14	14.0	-3.3
16	60	14	12.6	-6.0
18	60	14	11.3	-7.6

Table-4: Observation for second experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	23.4	28.0
2	60	14	22.6	26.0
4	60	14	18.5	16.1
6	60	14	16.6	-1.3
8	60	14	15.9	-10.0
10	60	14	15.5	-13.6
12	60	14	14.3	-15.4
14	60	14	12.4	-16.1
16	60	14	10.9	-16.1
18	60	14	9.6	-16.1

Table -5: Observation for third experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	21.6	22.0
2	60	14	20.9	15.6
4	60	14	18.7	-0.9
6	60	14	16.5	-9.0
8	60	14	14.5	-11.3
10	60	14	12.8	-12.4
12	60	14	11.3	-12.5
14	60	14	9.9	-12.5
16	60	14	8.8	-12.5
18	60	14	8.5	-12.5

We observed that: the cooling of the system varies considerably with the inner diameter of capillary tube. To illustrate these effects, results with different capillary tube have been plotted as shown in Figure-8.

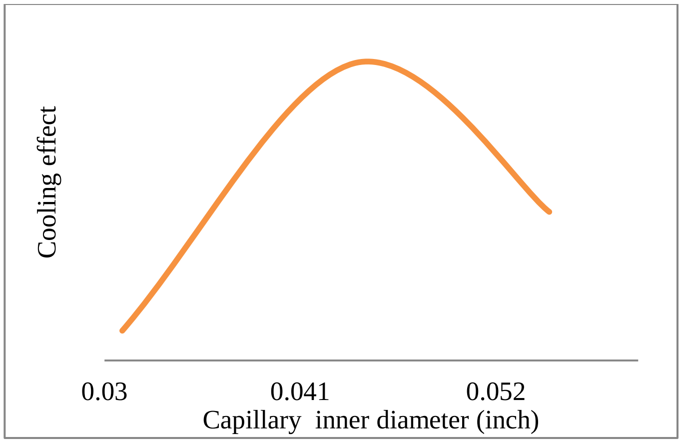

Figure-8: Cooling effect V/S Capillary inner diameter curve.

Effect of capillary length: The experiment was conducted on the basis of effect of capillary length on the cooling of the system. In the experiment we take inlet pressure 60 Psi and outlet pressure of 14 Psi corresponding to the specifications as mentioned below.

Specifications: For first experiment as given in Table-6. Length of the capillary tube = 6 meters. Inside diameter of the capillary tube = 1.11mm (0.044 inch).
For second experiment as given in Table-7. Length of the capillary tube = 4.5 meters. Inside diameter of the capillary tube = 1.11mm (0.044 inch).
For third experiment as given in Table-8. Length of the capillary tube = 3 meters. Inside diameter of the capillary tube = 1.11mm (0.044 inch).

Table-6: Observation for first experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	23.4	28.0
2	60	14	22.6	26.0
4	60	14	18.5	16.1
6	60	14	16.6	-1.3
8	60	14	15.9	-10.0
10	60	14	15.5	-13.6
12	60	14	14.3	-15.4
14	60	14	12.4	-16.1
16	60	14	10.9	-16.1
18	60	14	9.6	-16.1

Table-7: Observation for second experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	25.6	26.2
2	60	14	25.2	20.2
4	60	14	23.4	3.2
6	60	14	20.5	-8.0
8	60	14	17.8	-12.0
10	60	14	15.5	-13.4
12	60	14	13.6	-13.8
14	60	14	11.9	-13.8
16	60	14	11.2	-13.8
18	60	14	10.9	-13.8

Table-8: Observation for third experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	25.8	26.3
2	60	14	25.2	21.7
4	60	14	21.2	2.6
6	60	14	16.4	-8.5
8	60	14	12.9	-12.8
10	60	14	10.2	-14.0
12	60	14	7.8	-14.3
14	60	14	7.0	-14.3
16	60	14	6.5	-14.3
18	60	14	6.4	-14.3

We observed that: the cooling of the system varies considerably with the length of capillary tube. To illustrate these effects, results with different capillary tube have been plotted as shown in Figure-9.

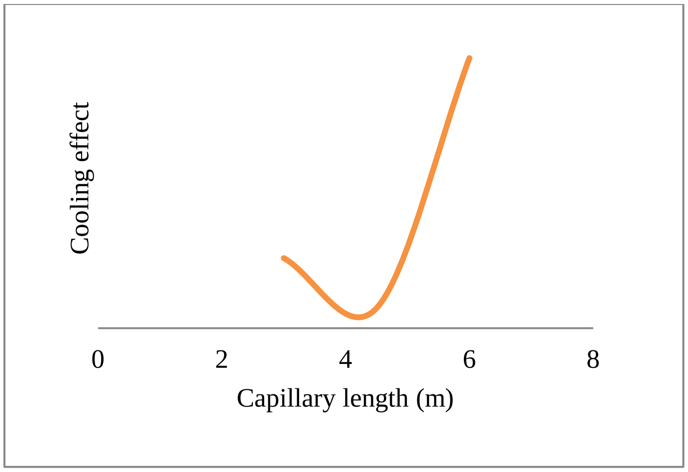

Figure-9: Cooling effect V/S Capillary length curve.

Effect of number of capillaries: The experiment was conducted on the basis of effect of numbers of capillary tubes on the cooling of the system. In the experiment we take inlet pressure 60 Psi and outlet pressure of 14 Psi corresponding to the specifications as mentioned below.

Specifications: For first experiment **as** given in Table-9. No. of capillary tubes = 3. Inside diameter of the capillary tubes = 1.11mm (0.044inch), 0.78mm (0.031inch), 1.39mm (0.055 inch).
For second experiment as given in Table-10. No. of capillary used =1. Length of the capillary tube = 6 meters. Inside diameter of the capillary tube = 0.78 mm (0.031 inch).

Table-9: Observation for first experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	22.0	28.0
2	60	14	20.9	12.7
4	60	14	17.3	-5.2
6	60	14	14.5	-11.4
8	60	14	12.6	-14.0
10	60	14	11.0	-14.5
12	60	14	9.7	-15.1
14	60	14	8.7	-15.1
16	60	14	7.9	-15.1
18	60	14	7.5	-15.1

Table-10: Observation for second experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	24.4	22.0
2	60	14	24.2	10.7
4	60	14	24.0	6.4
6	60	14	22.5	3.8
8	60	14	20.5	1.4
10	60	14	18.2	-1.1
12	60	14	15.6	-1.8
14	60	14	14.0	-3.3
16	60	14	12.6	-6.0
18	60	14	11.3	-7.6

We observed that: the cooling of the system varies considerably with the number of capillary tube used.

As number of capillary is 3 the cooling was high whereas when number of capillary is 1 the cooling effect was less. In first case -15.1^{0}C is reached in 12 minutes whereas in second case only -7.6^{0}C is reached even after 18 minutes.

Effect of ambient temperature: The experiment was conducted on the basis of effect of ambient temperature on the cooling of the system.

In the first experiment as given in Table-11, ambient temperature is 17^{0}C and in second as given in Table-12, it is 26^{0}C. We take inlet pressure 60 Psi and outlet pressure of 14 Psi and corresponding to the specifications as mentioned below.

Specifications: Length of the capillary tube = 6 meters, Inside diameter of the capillary tube = 0.78 mm (0.031 inch).

We observed that: effect of ambient temperature $\alpha \ \frac{1}{\text{Cooling effect}}$

As ambient temperature is low the cooling will be higher and if ambient temperature is high, cooling effect will be less. In first case -16^{0}C is reached in 18 minutes whereas in second case -7.6^{0}C is reached in 18 minutes.

Table-11: Observation for first experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	23.0	16.0
2	60	14	22.4	4.2
4	60	14	20.9	0.8
6	60	14	18.7	-3.8
8	60	14	17.0	-9.1
10	60	14	14.9	-13.3
12	60	14	13.4	-14.8
14	60	14	12.0	-15.6
16	60	14	11.4	-16.0
18	60	14	11.0	-16.0

Table-12: Observation for first experiment.

Time (mins)	Inlet Pressure (Psi)	Outlet Pressure (Psi)	Water Temperature (°C)	Evaporator Temperature (°C)
0	60	14	24.4	22.0
2	60	14	24.2	10.7
4	60	14	24.0	6.4
6	60	14	22.5	3.8
8	60	14	20.5	1.4
10	60	14	18.2	-1.1
12	60	14	15.6	-1.8
14	60	14	14.0	-3.3
16	60	14	12.6	-6.0
18	60	14	11.3	-7.6

Conclusion

The main reason of using LPG refrigerator was to utilize the energy of high pressure LPG stored in the cylinder for producing the refrigerating effect and LPG is eco-friendly refrigerant[15]. LPG in 14.2kg domestic cylinder is stored at high pressure, which is reduced before and after the evaporator with the help of gauge and refrigerating effect is calculated with help of changes in the parameter (i.e. pressure, length of capillary etc.). The system is cheaper at initial as well as running cost. The external energy sources (i.e. compressor) is eliminated there are no moving part in the system therefore this leads to very low maintains cost this kind of system is very suitable for mess, hotel, refineries and industries where the consumption of LPG is high. i. LPG is an attractive and eco-friendly refrigerant having zero ODP[16]. ii. The cooling effect was maximum at specific length of capillary tube. iii. Refrigerating effect is directly affected by inlet pressure. The refrigerating effect increase with the significant pressure rise. iv. As number of capillary is increased the cooling was high whereas when number of capillary was one the cooling effect was less. v. High cooling was obtained and no problem faced during operation therefore use of LPG as refrigerant contribute to the solution of ozone depletion problem caused by CFCs[17]. vi. The cooling of the system was maximum at a particular inner diameter of capillary tube.

Future Scope: There is a scope of further improvement so as to implement in air conditioning of vehicles where LPG is continuously used a fuel[18]. The project can be implemented in food restaurant, mess and community program hall, canteens, mid-day meal of school so to preserve food products like vegetables, milk etc.

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