International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 25 No. 2 Jul. 2016, pp. 637-645

http://www.ijisr.issr-journals.org/

Design and Fabrication of Liquefied Petroleum Gas Refrigeration System and Comparison with Domestic Refrigerator

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ABSTRACT: Ozone depletion due to Chlorofluorocarbon (CFC) and Hydrochlorofluorocarbon (HSFC) refrigerants is one of the major problem to our natural habitat. Also availability of electricity is still not available in several areas of the world where one need electricity and refrigeration of water, food, and medicine. Such problems can be solved using Liquefied Petroleum Gas (LPG) for refrigeration and generation of electricity since it has no Ozone Depletion Potential (ODP), furthermore LPG is locally available and is easy to transport anywhere. In this paper the performance of LPG based refrigerator has been investigated and is compared with domestic refrigerator. From experimental investigation it has been found that coefficient of performance of the refrigerator which uses LPG is higher than a domestic refrigerator.

KEYWORDS: Liquefied Petroleum Gas, Capillary tube, Evaporator, Coefficient of performance, Environment.

1 INTRODUCTION

The refrigerants chlorofluorocarbon (CFCs) and hydrochlorofluorocarbon (HCFCs) have high ozone depletion potential (ODP) and global warming potential (GWP) thus contributes to ozone layer depletion as well as global warming [1, 2]Results from many researches show that this ozone layer is being depleted. The general consensus for the cause of this event is that free chlorine radicals remove ozone from the atmosphere, and later, chlorine atoms continue to convert more ozone to oxygen. The presence of chlorine in the stratosphere is the result of the migration of chlorine containing chemicals. The chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are a large class of chemicals that behave in this manner[3, 4]. Hydrofluoocarbon (HFC) such as R134a have zero ODP, but it has a relatively high ozone depletion potential. The issues of ozone layer depletion and global warming have led to consideration of hydrocarbon (HC) refrigerants such as liquefied petroleum gas (LPG) as working fluids in refrigeration[5]. The hydrocarbon as refrigerant has several positive characteristics such as very low global warming, non-toxicity, zero ozone depletion potential, good compatibility with the materials usually employed in refrigerating systems. The global warming potential value for HFC 134a is 1300 for CFC 12 is 2125 and for LPG is 11over 100-year[6]. To overcome the problems stated above, this study will evaluate LPG performance characteristic to the existing refrigerant. LPG is the best refrigerant to replace existing ozone depleting and global warming refrigerants like CFC and HFC[7].

The energy crisis persists all across the globe, so the paper discusses recovering the energy which is already spent but not being utilized further, to overcome this crisis with no huge investment. The climatic change and global warming demands accessible and affordable cooling systems in the form of refrigerators. Annually billions of dollars are spent in serving this purpose. Although a continuous supply of a major portion of electricity in most of the urban as well as in rural areas are unavailable, still the people in those regions require refrigeration for a variety of socially relevant purposes such as ice making, cold storage or storing medical supplies and domestic kitchens. In this work designing and fabrication of a refrigerator based on liquefied petroleum gas (LPG) refrigerant has been carried out since LPG is locally available and is easy to transport anywhere.

This work studies replacement of conventional refrigerant (CFC or HCFC) by LPG as a cooling medium in a refrigerator i.e. evaporator and capillary tube according to the properties of LPG. 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 result 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 of refrigerants. In this refrigeration system the high pressure LPG is passing through a capillary tube and expands, after expansion the phase of LPG is changed and converted from liquid to gas and then it passes through the evaporator where it absorbs the latent heat of the stored product and produces the refrigerating effect. After evaporator it passes through the gas burner where it burns and also can be passed through the generator to produce electricity.

2 DESIGN OF BASIC COMPONENTS OF LPG REFRIGERATION SYSTEM

Two main components (capillary tube and evaporator) have been designed in this system.

2.1 DESIGN OF CAPILLARY TUBE

The capillary tube is a fixed restriction-type device. It is a long and narrow tube connecting the condenser directly to the evaporator. The pressure drop through the capillary tube is due to the following two factors:

1. Friction, due to fluid viscosity, resulting in frictional pressure drop.
2. Acceleration, due to the flashing of the liquid refrigerant into vapour, resulting in momentum pressure drop[8].

Design parameters for capillary tube are:

Cylinder size = 14 kg, $D_{cylinder}$ = 295 mm

Cv of LPG = 49.1 Mj / kg , $d_{capillary}$ = 1.05mm

Different calculated parameters for capillary tube are:

$\mathring{m}$ = 9.107×10-4 Kg/sec $A = 2.26\times10^{-8}$ m^2

G = $\mathring{m}$/A = 1190.13 kg/s.m^2 Z = DG = 0.2023 kg/s.m

Y= G / 2D = 3.5 * 10^6 kg/s.m^3

Table 1. Calculations for isenthalpic flow

Section	T °C	x X10²	P bar	v m³/kg	u=Gv m/s	Δh KJ/Kg
k	18	0	5.159	0.00206	0.444	0
1	10	0.086	3.87	0.00646	1.395	0.0008
2	4	0.161	2.56	0.01261	2.721	0.0036
3	0	0.229	1.98	0.02287	4.931	0.0121
4	-4	0.289	1.67	0.03765	8.131	0.0321
5	-14	0.323	1.45	0.05025	10.85	0.0581

Calculations can now be done for actual Fanno-line flow, starting from h_k = 318.49 kj/kg

At 18°C, from table of LPG[9]

h_f = 291.146 kj/kg

h_{fg}= 316.374 kj/kg

v_f = 0.002002 m³/kg

v_g = 0.0541m³/kg

$h_1 = h_k - \Delta h$ = 318.489 kj /kg $x_1 = h_1 - h_f / h_{fg}$ = 0.086 $v_1 = v_f + x_1(v_g - v_f)$ = 0.00648 m³/kg

Similarly finding these values at other sections as given in Table 2.

Table 2. Calculations for fanno line flow

Section	x	(h)Iterated KJ/Kg	(v)Iterated m³/kg	(u)Iterated m/s	(Δh)Iterated KJ/Kg
k	0	318.49	0.002	0.444	0
1	0.086	318.489	0.006	1.399	0.00088
2	0.161	318.486	0.013	2.808	0.00384
3	0.228	318.378	0.022	4.951	0.01215
4	0.289	318.458	0.033	8.141	0.03302
5	0.322	318.432	0.051	10.86	0.05881

Friction factor calculations at point 1:

Viscosity: $u_1 = (1 - x_1)\ u_f + x_1\ u_1\ = 0.0602$ cp

Reynolds: $Re_1 = Z / u_1 = 1435.41$

Friction factor: $f_k = 0.32 / (Re)^{0.25} = 0.05$

Similarly finding these values at other sections

Table 3. Friction factor calculations

Section	T °C	x	µ (cp)	Re	f
k	18	0	0.0546	1582.41	0.0507
1	10	0.086	0.0602	1435.21	0.0519
2	4	0.161	0.0655	1319.08	0.0531
3	0	0.228	0.0725	1191.72	0.0544
4	-4	0.289	0.0797	1084.06	0.055

Length calculations:

Total pressure drop = ${}_k\Delta P_1 = 5.156 - 3.870 = 2.511$ bar

Acceleration pressure drop = $\Delta P_A = G\ \Delta u = 1136.57$ Pa = 1.136 KPa

Friction pressure drop = $\Delta P_f = \Delta P - \Delta PA = 251100 - 1136.57 = 2.49 * 10^5$ Pa

Mean friction factor = f = 0.0415

Mean velocity = u = 0.9215 m/s

Incremental length = ${}_k\Delta L_1 = \Delta P_F / Yfu = 1.86$ m

Similarly finding these values at other sections

Table 4. Capillary tube length calculations

Section	ΔP (bar)	ΔPa (bar)	ΔPf (bar)	ΔL (m)
k----1	2.51	0.01136	2.49	1.86
1----2	2.09	0.01576	2.07	0.68
2----3	1.73	0.02631	1.71	0.29
3----4	1.41	0.03808	1.31	0.12
4----5	0.71	0.03237	0.61	0.03
Total required length = ΣΔL =2.9m				

2.2 DESIGN OF EVAPORATOR

The evaporator is the component of a refrigeration system in which heat is removed from air, water or any other body required to be cooled by the evaporating refrigerant[viii]. In experimental setup plate and tube type evaporator has been used because it provides a gentle type of evaporation with low residence time. It also preserves the food and other products from bacterial attack and requires low installation cost.

The designed dimensions of the evaporator are:

Length = 275 mm, Breadth = 200 mm and Height = 95 mm

The evaporator is made from six plastic sheets of 2.5mm thickness which enclose six thermo coal sheets of 8 mm thickness. The areas for these sheets are as follows:

Area1 = 200×95 = 0.01900 m2 Area2 = 200×275 = 0.05500 m2 Area3 = 200×95 = 0.01900 m2

Area4 = 200×275 = 0.05500 m2 Area5 = 275×95 = 0.02612 m2 Area6 = 275×95 = 0.02612 m2

Thickness of plastic = 2.5 mm Thickness of thermo coal = 8 mm

Temperature of atmosphere = 27˚C = 300 K Temperature of evaporator = -11˚C = 262 K

Thermal conductivity of plastic k_a = 0.12 W/m.k Thermal conductivity of thermo coal k_b = 0.02 W/m.k

Heat flow from area 1 due to conduction

$Q1 = (T_{atm} - T_{evap}) / (Rth_a + Rth_b)$

$= (T_{atm} - T_{evap}) / ((L_a/K_a.A) + (L_b/K_b.A))$

= (300-262)/ (0.698+13.97) = 2.60W

Heat flow from other areas due to conduction is

Q2 = 5.48 W Q3 = 2.30 W Q4 = 5.48 W Q5 = 2.78 W Q6 = 2.78 W

Total heat flow from all areas due to conduction = 21.42 W

Heat flow from evaporator due to convection inside heat transfer coefficient = 30 W/m2.K

Outside heat transfer coefficient = 10 W/m2.K

The overall heat transfer coefficient

$1/U = (1/Uo) + (L_a/k_a) + (L_b/k_b) + (1/Ui) = 0.649$

U = 1.54 W/m2.K

Rate of heat transfer Q[8]

$Q = U.A\,(T_{atm} - T_{evap})$

Q1 = 1.54×0.03578(300-262) = 1.899W

Similarly Q2 = 4.48 W Q3 = 1.91 W Q4 = 4.48 W Q5 = 2.32 W Q6 = 2.32 W

Total heat flow from all areas due to convection = 18.409 W

Heat transfer due to radiation $Q = \sigma T^4 = 5.67\times 10^{-8}(35-(-9.3))^4 = 0.21W$

Total heat flow from evaporator due to conduction, convection and radiation Q_t.

$Q_t = 21.42 + 18.409 + 0.21$

$Q_t = 40.03$ W

3 LPG Refrigeration Cycle Explanation

3.1 Gas Cylinder

From gas cylinder LPG in the start at a pressure of approximately 5.156 flows through the pipe to reach the capillary tube.

3.2 Capillary Tube

While passing through capillary tube the LPG expands and its pressure downs upto or less than 1.2 bar.

3.3 Evaporator

In 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 casing.

3.4 Gas Burner/Generator

After performing the cooling effect, low pressure LPG gas goes into the burner where it burns and through generator to generate electricity.

Figure. 1 Experimental setup for LPG refrigeration system

The experiment of this project was done on 25 March, 2015 at 3:00 p.m. and readings were taken at 10 minute's interval, for 1 hour which is as shown in **Table. 5** below:

Table 5. Eeperimental readings

Time (min)	Inlet Pressure (bar)	Outlet Pressure (bar)	Water Temprature (℃)	Evaporator Temperature (℃)
10	5.156	1.45	25	18
20	5.415	1.43	16	10
30	5.311	1.36	10	4
40	5.209	1.35	5	0
50	5.123	1.31	1	-4
60	5.021	1.29	-2	-14

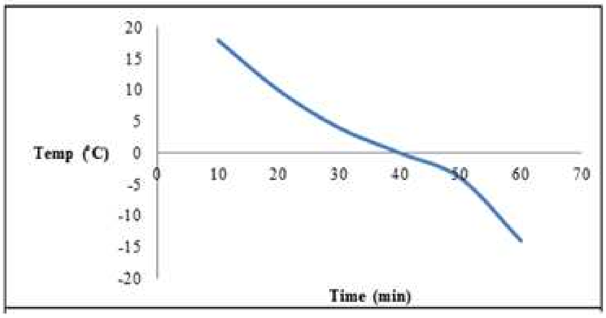

Figure. 2 Evaporator temperature vs time

Again experiment was done on this project on second day on 15 April, 2015 at 1:00 p.m. and readings were taken at 10 minute's interval, with same cylinder for 1 hour which is as shown in **Table. 6** below:

Table 6. Experimental readings

Time (min)	Inlet Pressure (bar)	Outlet Pressure (bar)	Water Temperature (℃)	Evaporator Temperature (℃)
10	5.019	1.31	25	18
20	5	1.28	15	10
30	4.91	1.26	10	5
40	4.82	1.23	4	1
50	4.69	1.2	-1	-3
60	4.52	1.19	-3	-10

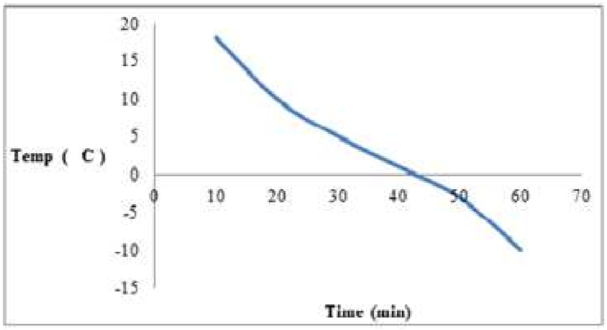

Figure. 3 Evaporator temperature vs time

4 TOTAL CONSUMPTION FOR LPG PUMPS[10]

One pump having 40 kW motor and 96 m head or 150cubic 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 = 3.1354kWh

So 1 kg of LPG is = 3.1354/14.5 =0.2162 kWh

We run the set up for 1 hr = 0.2162×1000/ (9.45/10000) ×3600 = 63.55W

5 COP OF THE LPG REFRIGERATION SYSTEM

COP = (h3-h2)/w = (630.3-307.3)/63.55 = 5.08

After finding out the COP of the LPG refrigerator I found out the heat librated by LPG after burning in the burner with the burner efficiency of 92 %.

Heat liberated by LPG Q_L = m×cv

m = 9.107×10-4 Kg/sec

cv = 49.1 MJ/Kg

Q_L = 9.107×10-4× 49.1×10^3 = 44.41W

6 COMPARISON WITH DOMESTIC REFRIGERATOR[11][8]

COP of the refrigerator using R134a refrigerant of capacity of 165 liters having a compressor pressure of 10 bar and evaporator pressure of 1.4 bars.

Work done on the compressor is -54 Kj/Kg

The heat absorbed by the evaporator is137Kj/Kg and that rejected by the condenser is -191Kj/Kg.

The COP of the refrigerator is COP_R = 2.53.

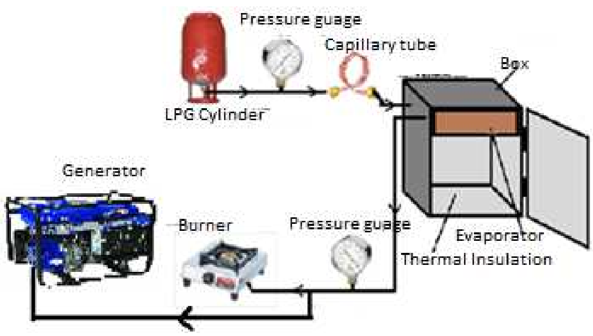

Figure. 4 LPG refrigeration cycle

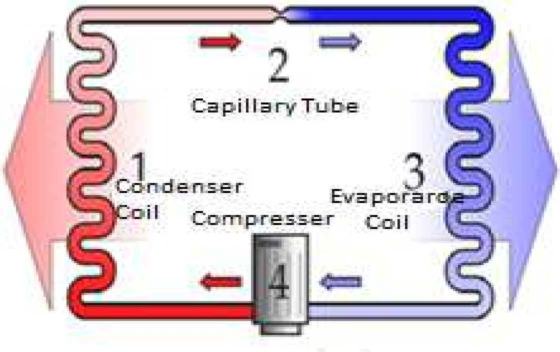

Figure. 5 Domestic refrigerator cycle

7 CONCLUSION

The aim of this paper is to use LPG as a refrigerant and utilizing the energy of the high pressure in the cylinder for producing the refrigerating effect and then for running the generator or burner. This paper concluded that the COP of LPG refrigerator(5.08) is greater than COP of domestic refrigerator(2.53) using conventional refrigerants and is shown diagrammatically in **Fig 6.** This system has low initial as well as running cost. It does not require any external energy sources to run the system and no moving part so maintenance is also very low. This paper also concluded that, one try the burnt to the exhaust LPG, as we daily do but also the refrigeration is obtained which is inherent process takes place daily. In this paper the refrigeration is amplified remarkably and a cheaper and eco-friendly method is developed. This system is most suitable for hotel, industries, refinery, chemical industries where consumption of LPG is very high.

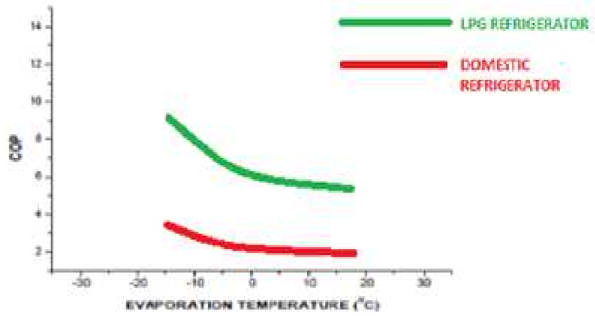

Figure. 6 COP of LPG and Domestic refrigerator at different evaporator temperature

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