Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2016, 3(4):350-357

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Design and Construction of a Vapour Compression Refrigeration System as Test Rig to Investigate the Performance of Liquefied Petroleum Gas (LPG) as Refrigerant.

Oyelami S[1], Bolaji BO[2]

[1]Mechanical Engineering Department, Osun State University P.M.B4494,Osogbo, Nigeria.
[2]Mechatronics Department, Federal University Oye-Ekiti, Ekiti State, Nigeria.

Abstract The design and construction of a refrigerator as a test rig, in investigating the performance of Liquefied Petroleum Gas (LPG), which has zero ozone depleting potential and very low global warming potential, as working fluid in vapour compression refrigerating system as a possible alternative. The design was made with these assumptions:(a) steady state operation; (b) no pressure loss through pipelines,; (c) heat losses or heat gains from or to the system are neglected and of 75% isentropic efficiency. The following heat sources are considered: transmission load,q_t= (A)(U)(ΔT), infiltration load, q_a= $m_a(h_o – h_i)$, product load, q_{pa}= (m)(c)(ΔT), specific heat given off by the product in freezing, $q_f = mL_f$,, quantity of heat given off by the product in cooling from its freezing temperature to the final storage temperature, q_{pb}= (m)(c)(ΔT), light Load, q_L= Light rating(W) x Time(S). The total cooling load capacity of the refrigerator was obtained summing the various sources of heat into the refrigerated space, $q_{TCL}= q_t+ q_a+ q_{pa}+ q_f+ q_{pb}+ q_L$. The total cooling load (Q_{TCL}) in watt is obtained to be 0.27302 kW. Considering 10% of safety factor, = 0.027302 kW approximately =0.300322 kW. This average load is referred to as Required Equipment Capacity (REC), which is used as a basis for component selection. The required equipment capacity obtained was 0.451 kW. The desired running time is 16 hours/day. The joints were properly welded. The major bought out components are: the evaporator, the compressor, the condenser and the expansion device.

Keywords Refrigerant, Design, Construction

Introduction

Refrigeration is defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool an item or space to the required temperature [1]. Refrigeration has many applications including but not limited to: household refrigerators, industrial freezers, cryogenics, air conditioning, and heat pumps. In satisfying the Second Law of Thermodynamics, some form of work must be performed to accomplish this [2]. A design that does this is called refrigerator. The designed refrigerator in the work was a mobile one. Mobile refrigerator is a particular type which can move from one place to another through the help of roller and allow a lower temperature achieved by refrigeration to be maintained for long hours.

The purpose of refrigeration systems for cold storage is to maintain or extend product life. Refrigeration systems for cold storage are applied to processing, manufacturing, and warehousing food, biomedical materials, ice manufacture, and other uses, but the largest application is for the refrigeration and freezing of foods [3].

In vapour compression refrigerating system, the work is supplied by the compressor.

The component of the modern day refrigeration system where cooling is produced by this method is called evaporator [4]. The condensation process requires heat rejection to the surroundings. It can be condensed at atmospheric temperature by increasing its pressure. The process of condensation was learned in the second half of eighteenth century. U.F. Clouet and G. Monge liquefied SO_2 in 1780 while van Marum and Van Troostwijk liquefied NH_3 in 1787 [4].

Materials and Methods

In this work, a design and construction of an experimental refrigerator as a test rig was involved, in investigating the performance of Liquefied Petroleum Gas (LPG), which has zero ozone depleting potential and very low global warming potential, as working fluid in the designed and constructed vapour compression refrigerating system as a possible alternative. The experimental refrigerator that was developed with the joints specially welded to avoid leakages as test rig (the experimental vapour compression refrigerator) was designed taking into consideration, the following assumptions:(a) steady state operation; (b) no pressure loss through pipelines, that is, pressure changes only through the compressor and the capillary tube; (c) heat losses or heat gains from or to the system are neglected and of 75% isentropic efficiency. Some important performance characteristics like operating pressure, refrigeration capacity, coefficient of performance (COP) and compressor discharge temperature were considered in using LPG as refrigerant in the system.

In the design, the cooling load capacity of the refrigerator is obtained through the summation of various sources of heat into the refrigerated space. The following are the various sources considered.

(i) Transmission load

Since there is no perfect insulation, there is always heat loss, thus the measure of the flow-rate of heat by conduction through walls of the refrigerated space from the outside to the inside in unit time is called the transmission load. Equation below gives the determination of the transmission gain load.

$$q_t = (A)(U)(\Delta T)$$

Where: q_t = the rate of heat transfer (kJ)
A = the outside surface area of the wall (m^2)
U = the overall coefficient of heat transmission (kJ/m^2K) and
(ΔT) = the temperature different cross the wall (K).

(ii) Infiltration load

This is the air change load arising from the heat flow into the refrigerating space when the lid is opened and the outside air enters the refrigerator. The air change load is given by the equation below:

$$q_a = m_a(h_o - h_i)$$

Where: q_a = Air change load (kJ)
m_a = mass of air entering space (kg).
h_o = enthalpy of outside air (kJ/kg)
h_i = enthalpy of inside air (kJ/kg)

(iii) Product load

The quantity of heat to be removed from a product placed in the refrigerator can be calculated from some parameters obtained from the product, such parameters as initial and its final state, mass of the product, its specific heat capacity above and below freezing temperature, also its latent heat.

The quantity of heat of the product to be stored above it freezing point temperature is given as equation below:

$$q_{pa} = (m)(c)(\Delta T)$$

Where: q_{pa}= the quantity of heat of the product above freezing point temperature (kJ)
m = mass of product (kg)
c = the specific heat capacity at that state (kJ/kg.K)
ΔT = the change in the product temperature (K)

The specific heat given off by the product in freezing is given as:

$$q_f = mL_f$$

Where: q_f= the quantity of heat in freezing (kJ)
L_f= latent heat of fusion (kJ/kg)

The quantity of heat given off by the product in cooling from its freezing temperature to the final storage temperature is obtained using

$$q_{pb}= (m)(c)(\Delta T)$$

Where: q_{pb}= the quantity of heat of the product below freezing point temperature (kJ)

(iv) Light Load

This is the heat given off by lights installed in the refrigerated space. It is calculated by the equation below:

$$q_L= (\text{Light rating in watt}) \times (\text{Time in seconds})$$

Where: q_L = light load (kJ)

(v) Total Cooling Load

Total cooling load is the summation of the entire heat load, therefore,

$$q_{TCL}= q_t+ q_a+ q_{pa}+ q_f+ q_{pb}+ q_L$$

Where: q_{TCL}= total cooling load (kJ)

The total cooling load (Q_{TCL}) in watt is obtained as:

$$Q_{TCL} = \frac{q_{TCL}\,(kJ)}{Time\ taking\ (s)}$$

The total cooling load was estimated to be 0.27302 kW

(vi) Factor of Safety

A safety factor of 10% was used during the design of the refrigerator. This was found and added to the total cooling load.

Factor of safety= 10% of (0.27302 kW)
= 0.027302 kW

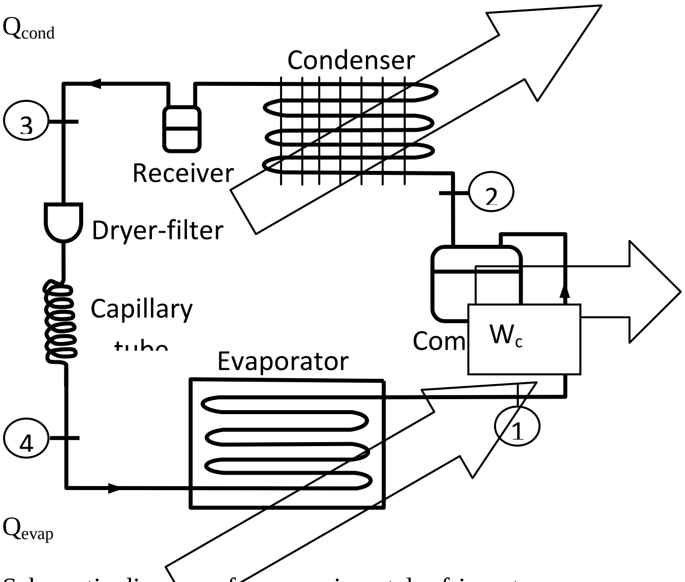
Therefore, total cooling load is obtained as 0.300322 kW

(vii) Required equipment capacity (REC)

Multiplying the cooling load by 24 hours and dividing the outcome by the desired running time in hours to determine the average load alongside putting into consideration the factor of safety, gives the required equipment capacity. This average load is referred to as Required Equipment Capacity (REC), which is used as a basis for equipment selection.

$$REC = \frac{(\text{Total cooling load})(24\ \text{hour})}{(\text{Desired running time in hour})}$$

The required equipment capacity obtained was 0.451 kW. Has the desired running time is 16hours/day.



Schematic diagram of an experimental refrigerator

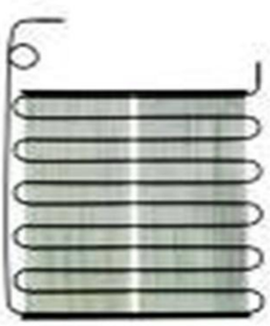
The compressor

The required refrigerant capacity is usually taken as the load determined by the cooling load calculations. However, if an evaporator selection is made prior to the compressor selection; the compressor should be selected to match the evaporator capacity rather than the calculated load. Also, the condensing unit capacity depends upon the capacity of the compressor. The compressor capacity are based on the saturated suction and discharge temperatures, condensing unit capacities are based on the saturated suction temperature and on the quantity and temperature of the condensing medium. The compressor is located at the bottom of the refrigerator and accessed at the back. This shows the type of compressor used in the refrigerator. It is a reciprocating type with power of 0.746 kW.

The hermetic Compressor
Source[5].

The condenser

This is the wire-and-tube type condenser used in the refrigerator. The purpose of the condenser is to remove the amount of heat that is equal to the sum of the heat absorbed in the evaporator and the heat produced by compression. There are many different kinds of condenser.



Wire-and-tube type condenser
Source: [5].

The evaporator

A refrigerant in liquid form will absorb heat when it evaporates and it is this conditional change that produces cooling in a refrigerating process. If a refrigerant at the same temperature as ambient is allowed to expand through a hose with an outlet

to atmospheric pressure, heat will be taken up from the surrounding air and evaporation will occur at a temperature corresponding to atmospheric pressure. If in a certain situation pressure on the outlet side (atmospheric pressure) is changed, a different temperature will be obtained since this is analogous to the original temperature - it is pressure dependent. The component where this occurs is the evaporator, whose job it is to remove heat from the surroundings, i.e. to produce refrigeration.

Plate with inner coil tube evaporator
Source:[5].

Evaporator of the refrigerator is a bare plate with inner coil tube for refrigerant flow. The tube inner diameter is 6.8 mm and tube length is 6600 mm. The dimension of the evaporator is 630 x 839 mm (Fig. 3.5). It formed the inner surface of the evaporating chamber. The evaporator is connected at one end to the capillary tube and at other end to the compressor.

Expansion device of refrigeration system

Various expansion devices are used in refrigeration systems, these includes: hand (manual) expansion valves, capillary tubes, constant pressure or automatic expansion valve (AEV), thermostatic expansion valve (TEV), float type expansion valve, and electronic expansion valve (EEV). Of the above types of expansion devices, Capillary tube which is used in this construction, is the most commonly used in small refrigeration and air-conditioning systems [6].

A capillary tube is a long, narrow tube of constant diameter. It is a metering device that controls the refrigerant flow by pressure drop. The principle of operation of the capillary tube is the flow resistance caused by a long, narrow tube, throttling the refrigerant pressure. Pressure falls gradually as the liquid flows through the tube, until it starts to evaporate in the tube. The amount of refrigerant flow through the device is determined by the bore of the tube and the length of the tube. Capillary tube is a simple drawn copper tube with a very small internal diameter. It normally has a very long length and it is coiled to several turns so to occupy less space. It has an inner diameter ranging from 0.5 to 2.0 mm and the length ranging from 400 to 5000 mm. It has advantages of simplicity, inexpensiveness, and the requirement of low starting torque of compressor over other types of expansion devices. Below is the type of coiled capillary tube used in the refrigerator.

Coiled capillary tube
Source:[5]

The filter-dryer

Filter-dryers are placed at the outlet of the condenser in household refrigerators and contain mesh screens to trap contaminants and chemicals to absorb moisture. This provides protection to the capillary tube which can become clogged and block the flow of liquid refrigerant to the evaporator. A completely blocked capillary tube will stop all refrigerant from reaching the evaporator and no cooling takes place. A clogged capillary tube is difficult to diagnose since it seems the unit is low on refrigerant (the evaporator doesn’t receive refrigerant, but not because it has leaked out). This is one situation where piercing-valves and manifold gauges are necessary to be certain.

Filter-dryer comes in two different types: throw away and refillable type. The former is thrown away if it is not functioning appropriately and it is replaced with a new one. In case of refillable type, the desiccant granules are replaced by a fresh charge after removing the flange, thereafter the same is filled in the line. The desiccant for common use is aluminium sulphate, silica gel, zeolite etc. Below is the type of refillable filter-dryer used in the refrigerator.

Filter-dryer
Source: [5]

Isolation relay, overload protection and thermostat

Isolation relay is a device that is used to prevent stray/unwanted electrical feedback that can cause erratic operation. Overload Protection is a device that will shut down a system if an excessive current condition exists. And thermostat is a device that sense temperature change and changes dimension or condition within to control the operation of the system.

Assembly of Parts

The assembly of parts takes place after the construction of various parts of the refrigerator. The following are the assembly processes involved in this work; cutting, welding, brazing and soldering of the various parts together. A complete structure called a vapour compression refrigerator is formed when all the parts and components have been coupled and fixed in the right positions. The frame of the experimental refrigerator was constructed with rectangular steel pipes. The pipes are permanently joined together using arc-welding.

The frame housed all other components in the system. Refrigerant pipe lines were brazed together using oxy-acetylene welding. A brazing flux is used when the two metals to be joined are of different materials .e.g. iron upon copper. When the compressor is mounted on the system, a similar joining operation is carried out for the suction to compressor connection. Also, brazing operations were used for the connection of discharge line to the outlet of compressor and inlet of condenser.

The liquid line is extended from condenser outlet to the evaporator inlet and it comprises of such components as the filter drier, and the capillary tube. The method employed in joining these components to the liquid line is the same with those of the suction and discharge lines connections. Finally, trolleys were welded to the four base corners of the frame. This will aid the mobility of the refrigerator from one place to another. After making the connections, the system was cleaned off unwanted substances in the line and this was done by carrying out a flushing operation.

The general view of the constructed experimental refrigerator is shown below

The experimental refrigerator

Results and Discussion

The results of the designed and constructed experimental refrigerator:

1. Eliminate the possibility of leakage, as the joints were properly welded. This is one of the major reasons of the design and construction, as the refrigerant under investigation is known to be highly flammable, thus the possibility of leakage needs to be tackled to the bear rest minimal if not totally controlled..
2. Enables mobility of the refrigerator, which allows the movement of the refrigerator, and gives room for performance considerations at various ambient temperatures.
3. Enables both refrigerants to work perfectly in the refrigerator, which shows that the designed and constructed refrigerator conforms well to the principle of refrigeration.
4. Enables basis for comparison as some performance parameters were able to be obtained at various ambient temperatures, as shown in Figures (1 - 3).

Figure 1 shows the variation of the refrigeration capacity with ambient temperature for LPG and the current alternative refrigerant (R134a) in vapour compression refrigeration system. It was observed that for the two investigated refrigerants, refrigeration capacity decreases with increase in ambient temperature. At the same ambient temperature, the refrigeration capacity obtained from LPG is higher than that obtained from R134a by 4.2%. Average refrigeration capacities of 23.236 kW and 22.295 kW were obtained during the tests using LPG and R134a, respectively.

Figure 2 shows the variation of the compressor power with ambient temperature for LPG and R134a. It was observed that the compressor power input increases with increase in ambient temperature and compressor power inputs for both LPG and R134a were almost the same within the range of ambient temperature considered. At the same ambient temperature, the compressor power input of LPG is lower than that obtained for R134a by 12.5%. Average compressor power input of 5.390kW and 6.065kW were obtained using LPG and R134a, respectively.

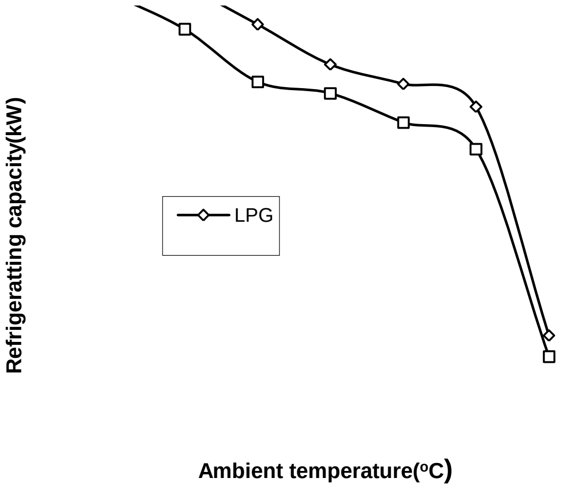


Figure 1: Variation of refrigeration capacity (Q_{evap}) with ambient temperature

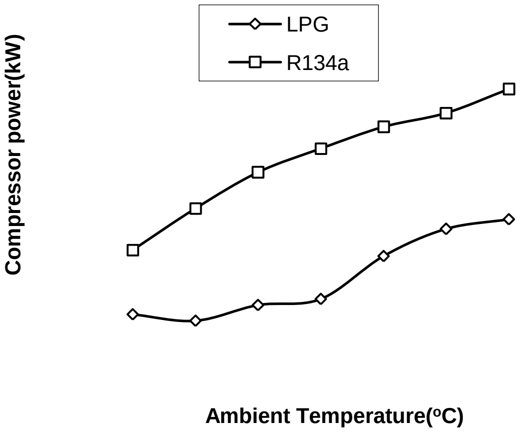


Figure 2: Variation of compressor power (W_c) with ambient temperature

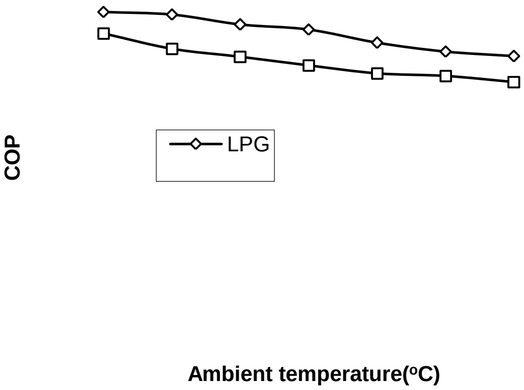


Figure 3: Variation of coefficient of performance (COP) with ambienttemperature

The variation of the coefficient of performance (COP) with ambient temperature for LPG and R134a is shown in Figure 3. It was observed that the coefficient of performance decreases with increase in ambient temperature. At the same ambient temperature, The COP of LPG is higher than that obtained for R134a by 11.16%. Average COP of 3.725 and 3.351 were obtained during the tests using LPG and R134a, respectively.

Conclusion

The designed and constructed refrigerator gives room for proper justification and evaluation of the performances of LPG refrigerant in terms of refrigeration capacity, compressor power input, and coefficient of performance (COP) also the performances were able to be compared with those of R134a, the current alternative Refrigerant. After the successful investigation of this refrigerant, the following conclusions were drawn based on the results obtained:

- The average coefficient of performance of LPG is higher than that of R134a by 11.16% at COP of 3.725 and 3.351 respectively.
- The compressor power of the system using LPG is about the same with that of R134a with average value slightly lower by 12.5% in favour of LPG.
- The experimental refrigerator was charged with 0.05kg of LPG as against 0.15kg in case of R134a. This is an indication of better performance of LPG as refrigerants.
- The refrigeration capacity was 4.3% higher using LPG when compared to R134a.

LPG was allowed to use as refrigerant if small amount of refrigerant is required [2]. This has been justified, in this work, by the high performance of a very low amount of LPG refrigerant charged into the system. LPG refrigerant can be successfully adopted as R134a substitute in vapour compression refrigerating system.

It is recommended that in designs and constructions using LPG refrigerant, the allowable refrigerant charge, flammability properties, safety standard and codes must be taken into consideration [7]. The limiting factors associated with the use of hydrocarbon refrigerants are the refrigerant charge size, the occupancy category and the room size. It is also recommended that workshops and seminars should be organised for the technicians on the need to embrace proper design and construction when considering the use of LPG refrigerant.

References

[1]. David L. (2010) Fundamentals of refrigeration. Free education on the internet, http:/www.free-ed.net.

[2]. ACRIB (2001) Guildlines for the use of Hydrocarbon Refrigerants in Static Refrigeration and Air Conditioning Systems. Vol 1.http:/www.acrib.org.uk

[3]. Kuijpers, L. J. M., de Wit, J. A., Janssen, M. J. P., (1988) Possibilities for the Replacement of CFC12 in Domestic Equipment, *International Journal of Refrigeration, Vol. 11, pp. 284.291.*

[4]. ASHRAE (1993) ASHRAE Handbook Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta (GA), *ISBN 1-883413-54-0.*

[5]. Kiran, (2009) LPG as refrigerant in *Engiblogger Science, Engineering and Technology publication, Indian.*

[6]. MacKenzie, D., (1994) Fridge maker freezes out CFC substitute, *New Scientist, 5thFebruary, p. 4. Germany.*

[7]. UNEP, (1991) Possibility for the conversion of domestic and small commercial refrigeration appliances with refrigerants based on hydrocarbons United Nations Environmental Program.