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Effect of Fins spacing on the Performance Evaluation of a Refrigeration System using LPG as Refrigerant

S.O. Banjo[1,3], O.S.I. Fayomi[1], A.A.A. Atayero[2], B.O. Bolaji[3], J.O. Dirisu[1], J. Okeniyi[1], M.E. Emetere[4], B. J Olorunfemi[3], T. Owoeye[5]

[1]Department of Mechanical Engineering, Covenant University, P.M.B. 1023, Ota, Nigeria
[2]Department of Electrical and Information Engineering, Covenant University, P.M.B. 1023, Ota, Nigeria
[3]Department of Mechanical Engineering, Federal University, Oye-Ekiti, Nigeria
[4]Department of Physics, Covenant University, P.M.B. 1023, Ota, Nigeria
[5]Department of Chemistry, Covenant University, P.M.B. 1023, Ota, Nigeria
Corresponding author. solomon.banjo@covenantuniversity.edu.ng +234-08034892109

Abstract
In this paper, experimental analysis was carried out on a vapour compression system by varying the parallel tube condenser fins spacing under the same atmospheric condition in a selected Refrigeration and Air-conditioning laboratory to examine the performance characteristics of the refrigeration system. The fins spacing were 2, 4 and 6 mm using Liquefied petroleum gas (LPG) as working fluid with a mixture proportion of 17.2% isobutene, 56.4% butane, 24.4% propane. The result shows that the coefficient of performance of the system when working with condenser fins spacing of 2 mm was 28.8 and 35.9% higher compared to when the system worked with the fins spacing of 4 and 6 mm respectively. Energy consumed by the single hermetic compressor when the system worked with condenser fins spacing of 2 mm reduced by 16.4 and 18.7% compared to when the refrigerator worked with fins spacing of 4 and 6 mm respectively. The pull down time of the cooling system was attained in 2 hours 45 minute with minimum evaporator temperature of -13 °C while working with 30 g mass charge of LPG.

Keywords: *COP, fins spacing, LPG refrigerant, vapour compression system*

1. Introduction
In refrigeration system the flow of refrigerant across the refrigeration cycle require four essential components, which are compressor, condenser, evaporator and expansion valve. Every domestic refrigerator has condenser and evaporator that serves as heat exchanger in which the working fluid undergoes phase change, while compressor and expansion valve are the pressure related devices. The compressor increases the pressure due to the compression force and capillary tube reduces the pressure of the refrigerant within the refrigeration system respectively. The process of refrigeration demands that evaporator absorbs latent heat from materials to be cooled and the refrigerating space to enable the refrigerant phase change into vapour. This vapoured refrigerant flows through the compressor where it compresses isentropically and transfer through condenser to allow heat gained by the refrigerant to be rejected to the surroundings [1]. The refrigerant at the condenser exit is in its sub cool state due to heat rejection, which is caused by natural air that flows across the total surface area of the condenser and the refrigerant throttled through the expansion valve, where pressure and temperature reduce drastically and the refrigerant returns back to the evaporator for the purpose of continuity of the fluid transport. The role of condenser became imperative in refrigeration system because it brings refrigerant to sub-cool point by rejecting heat out of the system and this phenomenon is significant to have a complete process of refrigeration cycle and likewise, the heat rejected at the condenser enhances coefficient of performance (COP). There are

various types of condenser, which include air-cooled, water-cooled and combination of air and water condensers (evaporative): these could be used in heat, ventilation and air conditioning (HVAC) units depending on the manufacturer specification and application. The condenser could be made from steel or copper materials [2]. Several parameters contribute to the rate of heat transfer within the refrigeration system apart from the condenser, among is the working fluid used in achieving cooling effect. There are various classes of working fluid depending on their thermo-physical properties, this includes boiling point, critical point temperature, and freezing point among others [3-5]. Refrigerant could either be conventional or natural type. The convention refrigerants are known as the synthetic refrigerants and there are different classes of these heat transferring fluids, which include, chlorofluorocarbon (CFC-12), hydro-chlorofluorocarbon (HCFC-22), hydrofluorocarbon (HFC-134a). These refrigerants are highly efficient and have a very large market prospect due to their thermodynamic and thermo-physical properties. The first group of synthetic refrigerant is chlorofluorocarbon, which became useful in most domestic refrigeration [6]. However, it was phased out due to high global warming potential and was replaced by R-134a, which has a very promising future with positive influence on the refrigeration systems and furthermore, it is non-flammability, stability, safe and zero ozone depletion potential (ODP). But due to excessive energy consumption and high global warming potential (GWP), that causes negative effect on the climate and its immediate environment. The international agreement has signed in Montreal protocol to control ozone depletion substances and R-134a has been considered to be phased out by alternative refrigerants that would be appropriate for application in the refrigeration system [7].

Natural refrigerant such as butane, propane, isobutene, propylene and their mixture have been considered as drop-in replacement for the existing hydrofluorocarbon refrigerant and this was done to enable a safe environment and prevent climate change [8-9]. Furthermore, the discovery of newest type of natural gas as refrigerant in a household refrigeration system is of greater advantage. The Liquefied petroleum gas (LPG) known as a domestic cooking gas is a byproduct in petroleum refineries, stored in cylinder at high pressure and it is a mixture of butane, propane and isobutene [10-12]. This refrigerant mixture was used to experiment and analyze this work, since refrigerant type is a primary measuring tool to determine the performance characteristics of any refrigeration system. Therefore, the choice of refrigerant is not negotiable as HVAC system is concern. Liquefied petroleum gas is numbered among the natural refrigerants, which is easily accessible, zero ozone depletion potential (ODP=0), chemically stable at the refrigeration temperature, low operating cost, global warming potential less than nine (GWP < 9), prevent climate change, no formation of acid which often result in the blockage of capillary tube, unlike R-134a [13]. More so, there are series of tests carried out using liquefied petroleum gas as working fluid in the vapour compression refrigeration system as analyzed by Nikan and Dargude [14] that did experiment on refrigeration system, which was designed to preserve meat, food and medicine. Considering the rate of energy consumed by refrigerator, liquefied petroleum (LPG) was employed as refrigerant because of its zero ozone depletion potential (ODP) and negligible global warming potential (GWP) with other thermodynamic properties such as high pressure and low boiling point, which enhances its performance as a refrigerant in countries like India, where there is little or no access to electricity supply. Likewise, Oyedepo et al., [15], performed a comparative analysis on a household refrigerator using liquefied petroleum gas (LPG) and isobutane (R-600a) as refrigerant with variation of capillary tube length (CTL) and refrigerant mass charge. The coefficient of performance (COP) achieved using LPG was higher than that of R-600a and the energy consumption rate of liquefied petroleum gas was higher than R-600a. The performance of the cooling system was better in terms of cooling capacity and COP using LPG while, R-600a has a better energy reduction. Furthermore, Austine and Senthil [16], carried out an experiment on refrigeration system that works on hydrofluorocarbon (R-134a). There were comparison of energy consumed by single hermetic compressor when working with refrigerant mixture and R-134a. The refrigerator attained lowest energy consumption using mixture of butane, propane and isobutene with lower evaporator temperature compared to hydrofluorocarbon refrigerant (R-134a). Also, Satwik et al. [17] studied the performance of a domestic refrigeration system using liquefied petroleum gas with a mixture proportion that contains butane, isobutene and propane. The experiment was carried out on existing refrigeration system and the evaporator temperature of 35 ℃ dropped 5 ℃ without varying condenser fins spacing. Vali and Kumar [18] conducted an experiment by varying condenser fins spacing in a domestic refrigerator using refrigerant-134a as the heat transfer fluid, which has a high global warming potential that makes the refrigerant a threat to the climate. Shah and Gupta [19], conducted an investigation on the performance of a designed refrigerator that uses liquefied petroleum gas as working fluid. This fluid is secured in cylinder at high pressure, the purpose of the LPG refrigerant was to use the cylinder that has energy of high pressure to enhance the refrigerating effect (RE) and the coefficient of performance was higher than the COP of domestic refrigerator that worked using hydrofluorocarbon refrigerant. This work, focuses on the effect of fins spacing using LPG as refrigerant to compute the performance characteristics of the domestic refrigeration system that is the rate of heat transfer, coefficient of performance and rate of energy consumption.

2. Materials and methods

A household refrigerator was used as test rig, which has the following essential components, evaporator, compressor, throttling valve and condenser as shown in figure 1. The heat that transfers through refrigerant flows into the components of refrigeration cycle which was used to evaluate the performance of the refrigeration system. The parallel tube condenser was used as heat rejection device with several numbers of wire known as fins to enhance the rate of heat transfer within the cooling system. Several condensers with different fins spacing were used to carry out the experiment and the extended surface area dimensions were 2, 4 and 6 mm respectively. The numerical data of the domestic refrigerator were captured at an interval of 15 minutes to be able to examine the significant change in the temperatures along the components and the resultant effect on the performance of the refrigeration system as different mechanical devices were used to measure the required data during the performance test. Detachable digital temperature sensors (DDTS) were used to measure the temperatures at various points of the refrigeration system. Energy measuring meter (EMM) was used to measure the energy consumed by the refrigerator and digital weigh balance was employed to determine the gram of refrigerant required to charge into the compressor. Furthermore, pressure gauge that has it valves in series was used to measure the refrigerant pressure at the low and high side of the single reciprocating compressor. The experiment was carried out under an average surrounding temperature of 29 ℃ in a refrigeration and air conditioning laboratory. Every form of safety measure was put in place to enhance the smooth operation of the experiment.

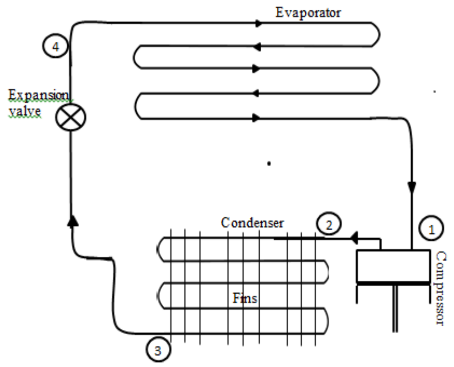

Figure 1: Process flow diagram of a vapour compression system

3. Results and Discussion

The efficiency of a refrigeration system is measured by the coefficient of performance and this is the ratio of the latent heat absorbed in the evaporator to the work done by the compressor. Fig.1 showed the variation of coefficient of performance (COP) with time taken for the experiment of a refrigeration system. The COP of the cooling system for fin spacing of 2 mm was 28.8% and 35.9% higher than when the condenser fins spacing of the refrigeration system were 4 and 6 mm respectively. It was examined that the system performed more efficiently when the condenser fins spacing was 2 mm. Fig. 2 displayed the trend of power input to the compressor of the vapour compressor refrigeration system when working with different fins spacing of 2, 4 and 6 mm. Refrigeration system being one of the household appliances that consumed a lot of energy, the condenser fins spacing enhance the rate of energy consumption in the cooling system. The energy was best conserved with condenser fins spacing of 2 mm with 16.4% and 18.7% reduction compared to when the refrigeration system worked using fins spacing of 4 and 6 mm respectively. Fig. 3-5 showed the rate of heat transfer within the evaporator and condenser of a vapour compression system and this determines the refrigerating effect and performance of the refrigeration system. The amount of latent heat absorbed at the evaporator of the refrigerator when working with condenser fins spacing of 2 mm was 11.3% and 19.1% higher compared to when the refrigeration system worked with fins spacing of 4 and 6 mm respectively. Moreover, the heat rejected from the parallel tube condenser when the refrigeration system operated with the condenser fins spacing of 2 mm was 8.4% and 18.4% higher compared to when the system worked with fins spacing of 4 and 6 mm respectively. Fig. 6 revealed the variation of the Pull down time (PDT) of the domestic refrigerator when working with the fins spacing of 2, 4 and 6 mm respectively. The PDT is the period that the system attained its minimum evaporator temperature (MET) and the fins spacing of 2 mm have minimum evaporator temperature of -13 °C in 2 hours 45 minutes. Furthermore, the domestic refrigeration system when working with fins spacing of 4 and 6 mm attained their MET of -12 °C and -10 °C in 2 hours 45 minutes respectively. Moreover, the PDT of the refrigeration system when working with a condenser fins spacing of 2 mm was 7.7 and 23.1% higher than when the system worked with fins spacing of 4 and 6 mm respectively. Thermodynamic analysis was performed using REFPROP (NIST-23) software to evaluate parameters such as enthalpies of the refrigeration cycle, which was used to determine the performance characteristics of the vapour compression system (VCS).

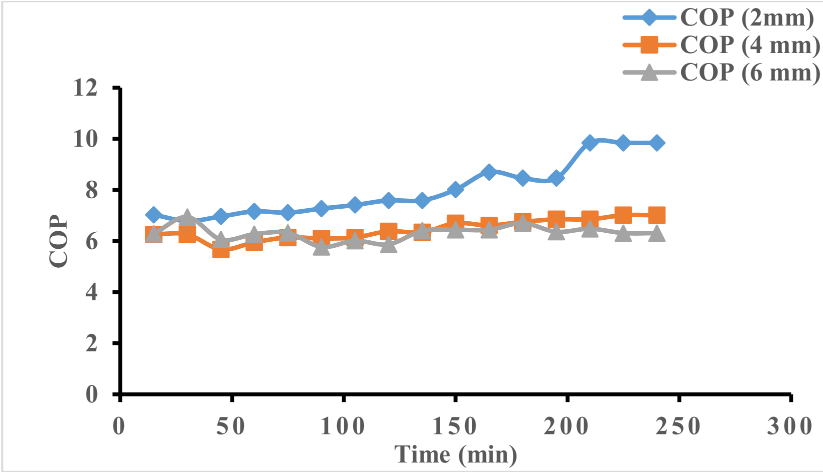

Figure 2: Variation of COP with time for fins spacing of 2, 4 and 6 mm

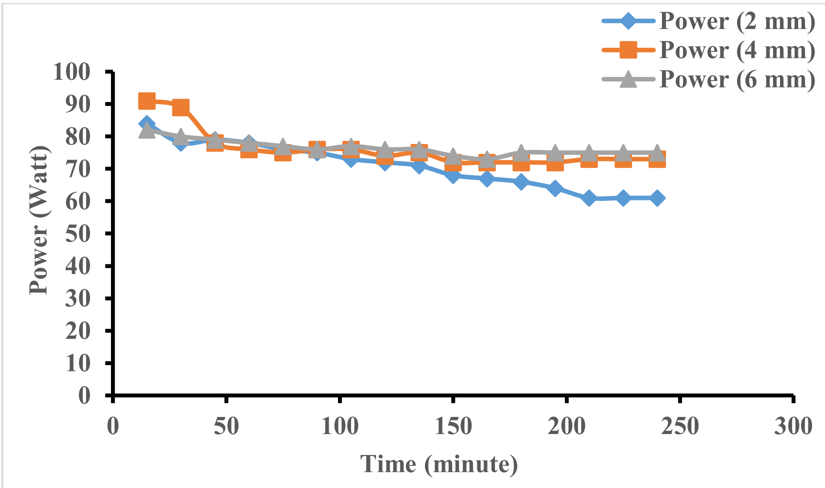

Figure 3: Variation of power with time for fins spacing of 2, 4 and 6 mm

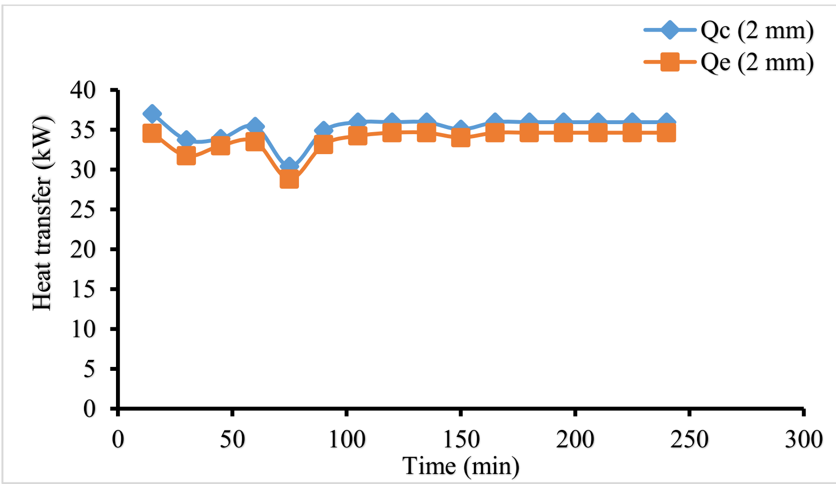

Figure 4: Variation of heat transfer in the condenser and evaporator with time for fins spacing of 2 mm

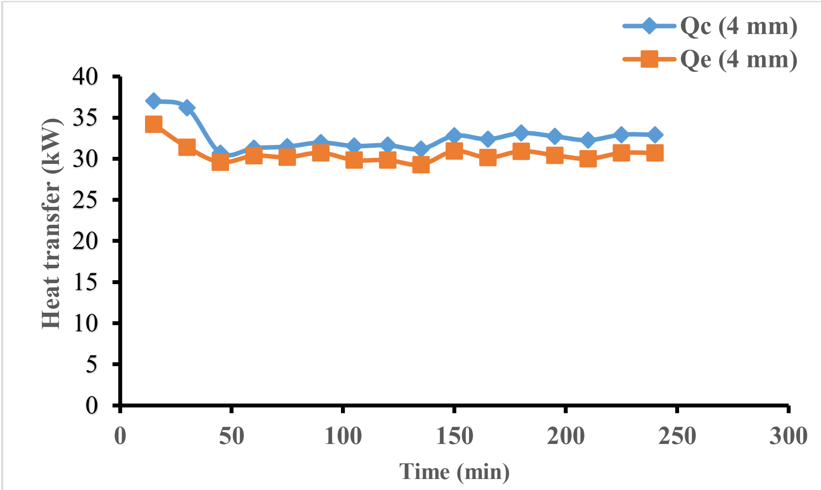

Figure 5: Variation of heat transfer in the condenser and evaporator with time for fins spacing of 4 mm

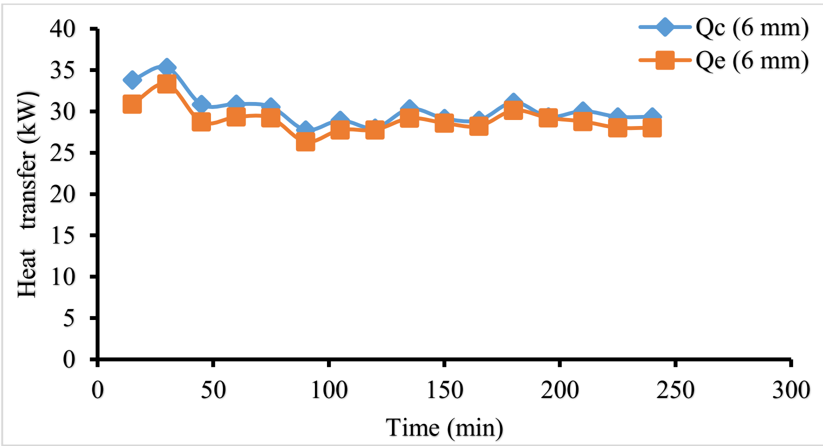

Figure 6: Variation of heat transfer in the condenser and evaporator with time for fins spacing of 6 mm

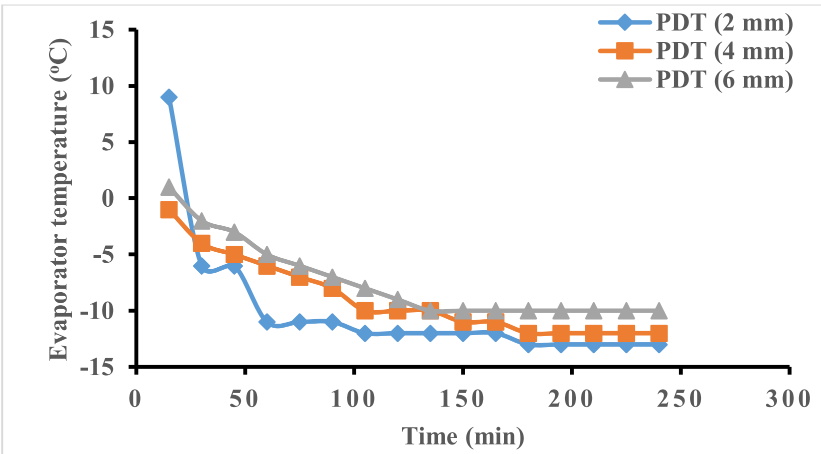

Figure 7: Variation of pull-down time for the fins spacing of 2, 4 and 6 mm

Conclusion

The refrigeration system thrives on the rate of heat transfer within the system and the effect of condenser fins spacing cannot be overemphasized as it enhances heat transfer of a vapour compression system and predicts the performance characteristics of the cooling system. The result shows the significant effect of the condenser fins spacing on the performance of the refrigeration system. The reduction in the surface area decrease the quantity of heat that are rejected in the condenser which result in the increase of the temperature at the sub cool region which less the performance of the domestic refrigerator. The lower the temperature at the sub cool region of refrigeration system, the better the performance as this regulates the thermodynamic refrigeration cycle processes. Liquefied petroleum gas (LPG) was employed as the working fluid to analyze the performance characteristics of the refrigeration system using a refrigerant mass charge of 30 g with variation of the fins spacing. For further study, to improve the performance of the refrigeration system, heat transfer enhancers such as nanofluid and high thermal conductivity materials could be used together with the fins spacing.

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