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Evaluation analysis of a developed solar refrigerator using conventional refrigerant for rural and medical applications

S.O. Banjo[1,2], O.O. Ajayi[1], B.O. Bolaji[2] M.E. Emetere[3], O.S.I. Fayomi[1], N.E. Udoye[1], A.O. Olatunde[2], K. Akinlabu[4]

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

Abstract
This paper study the performance evaluation of a refrigeration system that operates on solar energy as alternative source of power to enhance the refrigerating effect, coefficient of performance (COP), preservation of perishable items and short time drug such as vaccine, to remote communities and parts of the urban settlement around the developing nations where there is no access to modern electrical source. The system was made from locally sourced materials using a conventional refrigerant HFC134a as working fluid to improve thermal efficiency and stability of the vapour compression refrigeration system. The COP of the system was enhanced by 8.67% when working with solar and with energy reduction of 2.38% respectively. In case the weather is cloudy or during the night hour when the energy generation is low, the refrigerator can work on battery for an average of 12 hours if fully charge during the day to avoid idle time of the refrigeration system.

Keywords: coefficient of performance, HFC134a, solar energy, refrigerating effect

1. Introduction

Refrigeration system is classified into various types and there are two that are more pronounced both at the domestic and commercial level. The vapour compression refrigeration system (VCRS) and vapour absorption system (VAS). These systems operate using refrigerant as working fluid. The vapour absorption refrigeration system has similar components as the vapour compression refrigeration system, such as evaporator, condenser, compressor and throttling valve but there are main differences between the two systems that is the method of compression, suction and the heat transfer medium [1, 2]. Furthermore, vapour compression refrigeration is preferred for this study because of its thermal efficiency and performance. The four stages required for a vapour compression refrigeration system to function are compression, evaporation, condensation and expansion [2-4]. The system cooling operates as the heat transfer fluid routed into the compressor, where work is done on the refrigerant (HFC134a). The fluid compressed isentropically through the compressor and the superheated vapour exits the condenser outlet as a saturated liquid due to condensation which was due to heat rejection at the condenser [5]. The saturated fluid throttled through the expansion valve and the pressure of the refrigerant reduces drastically and the heat transfer fluid moves to the evaporator at low pressure and low temperature and the cycle continues as the evaporator absorbs latent heat from the refrigerated space and the materials to be cooled.

There are factors that enhances the performance of a domestic refrigerator which called for researchers over decades to engage in rigorous search to improve the performance of refrigeration system using various type of heat transfer fluid such as chlorofluorocarbon (CFC), hydro-chlorofluorocarbon (HCFC), hydrofluorocarbon (HFC) and hydrocarbon (HC) refrigerants [6,7]. The refrigerant is responsible for the heat exchange within the refrigeration system and refrigerant can be classified based on their thermo-physical properties [8-10]. Hydrofluorocarbon refrigerant is the most predominant heat transfer fluid used in both domestic and commercial applications. The domination of halogenated refrigerants for the decades was due to their energy efficiency and thermodynamic properties associated with them, which made them found foot and super acceptable in the developing and parts of the developed communities such as India where more than 80% employed conventional refrigerant (HFC134a) as heat transfer fluid in their refrigeration system [11-13]. The hydrofluorocarbon refrigerant has zero ozone depletion, stable, non-flammable substance and its azeotropes will enhance future prospect to fit into existing vapour compression systems [14, 15].

Moreover, the high demand of refrigeration system in the 21st century and basically to keep and preserve perishable items required a measurable attention. The agriculturist seeking for appropriate means to keep their farm produce, others who are into small-scale businesses desire instant approach for enabling their goods cool and fresh for the purpose of human consumption. Hence, the development of a modern refrigeration system will enhance the cooling rate and saved time and energy, which now served as alternatives to the traditional means of cooling food items, others perishable goods and short time drugs such as vaccine. Thus, the performance of the solar refrigeration system is investigated to ascertain the effectiveness of employment of renewable energy as alternative to conventional sources of energy, which include the fossil fuel and nuclear power, that are always been utilized but with harmful effect to human and environment, most especially fossil fuel which could cause global warming and climate change. However, International arguments have favored the adoption of renewable energy resources for power generation [16, 17]. The global energy demand is on the increase and the fact that small-scale commercial enterprise is largely dependent on the availability of modern electrical sources but due to high demand and inability to access to electricity has been severely challenging in the developing nations. Solar energy was considered as the most potent source of generating electricity for the purpose of rural and medical applications [18]. The choice of energizing the refrigeration system using solar energy is imperative in order to be able to reach out to communities where there is no access to national grid. The solar refrigerator could be used in hot climates to preserve perishable goods and vaccine at their appropriate temperatures. The system is configured such that it accommodates all the refrigeration components in a compacted framework that includes: solar panel, compressor, condenser, evaporator, capillary tube, inverter, solar charge controller with capacity to enhance the performance of the cooling system as the coefficient of performance is reasonably appropriate with energy reduction. This study performs experimental analysis on the effect of conventional refrigerant HFC134a in a developed refrigeration system that operates with renewable energy [19]. The solar energy was used to prevent the system from idle time due to instability in the national grid system for the purpose medical administration and rural communities, where there is less or no electricity supply. More so, this source of energy (solar) is safe, cost effective, little or no maintenance and easily accessible to the end users.

2. Experimental method and procedure

In this study, performance analysis was conducted with a developed test rig, which was a hybrid type of vapour compression refrigeration system that operates on solar and electricity. The refrigeration cycle is shown in Fig. 1.

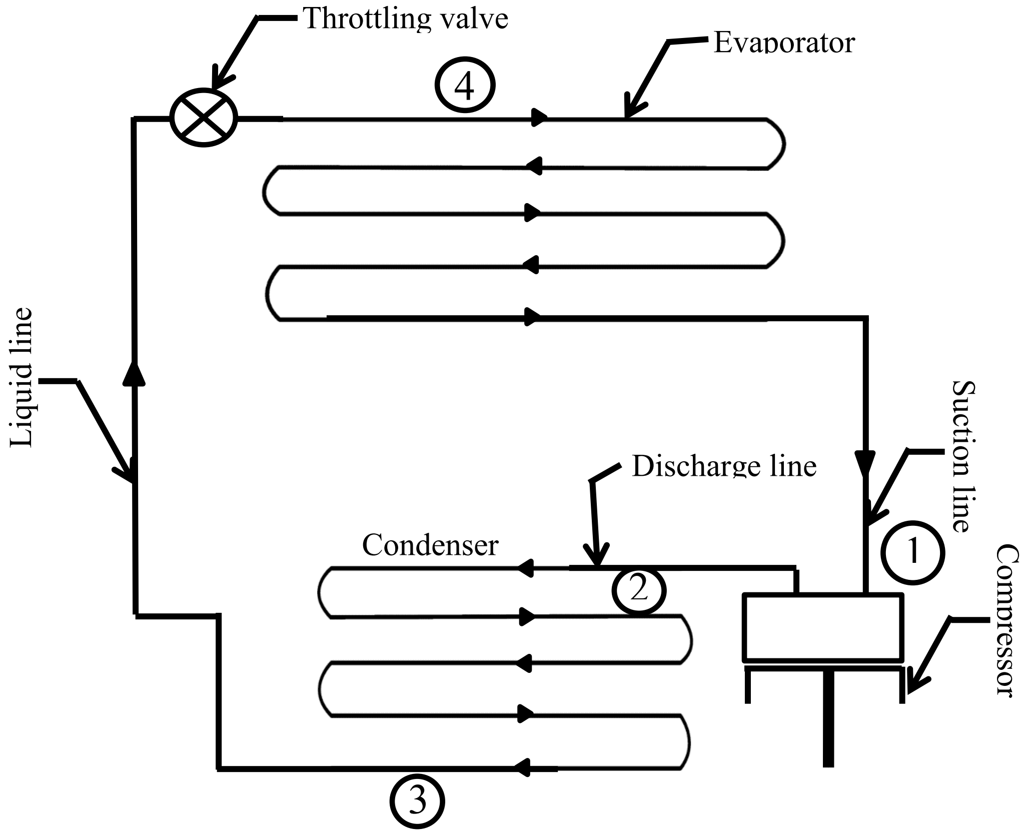

Fig. 1: Process flow diagram of a vapour compression refrigeration system

The system was designed such that it operates between a condenser temperature of 35 ^{o}C and an evaporator temperature of -17 ^{o}C using hydrofluorocarbon refrigerant (HFC134a) as a working fluid, standard sized single hermetic sealed compressor, standard sized tube air-cooled condenser and standard sized plate and tube evaporator. The channels for refrigerant flow are of the same diameter (10 mm) to prevent cavitation along the piping system of the refrigeration cycle, which may lead to turbulence of the fluid, and this will affect the thermodynamics properties of the substance. The temperatures at each of the refrigeration cycle such as compressor, evaporator, condenser and capillary tube were measured using K-Type digital thermocouples and this was achieved by fixing the thermocouples to each point of the refrigeration system. In addition, power-meter was used to read the power input into the compressor and furthermore, pressure gauge was used to capture the pressure at the suction and discharge of the compressor. However, the system was allowed to run for an average of 10 hours 40 minutes per day. The temperatures with other parameters mentioned above were taken at interval of 30 minutes under the surrounding temperature that ranges between 29 ^{o}C and 30 ^{o}C for the periods of the experiment in order to examine the performance of the system for the purpose of rural and medical applications. The solar panel was adjusted to suitable angle of 17 degree (^{o}) to the direction of sun ray, to generate PV voltage and current for powering the system. More so, pulse width modulation charge controller (PWM) was employed to hold the voltage into the battery constant and to prevent the battery from over charge. The list of the materials used for the construction of the solar refrigerator is shown in Table 1.

TABLE 1: List of components of the developed Solar Refrigerator

S/N	DESCRIPTION	MATERIAL
1	Compressor	Single hermetic
2	Capillary Tube	Copper type
3	Evaporator	Plate and Tube
4	Condenser	Wire-on-tube type
5	Solar Panel	Mono-crystalline
6	Battery	Deep cycle
7	Solar Charge Controller	MTTP
8	Power Inverter	Foresolar
9	Refrigeration Compartment	Cooler
10	Frame (Body)	Mild Steel

3. Results and discussion

Fig. 2 showed the variation of temperature of the four main components of a refrigeration system. The average temperatures at the end of the experiment, representing each component's temperature are displayed. The recorded temperatures were used to determine the enthalpies, which were employed to determine the performance characteristics of the refrigeration system. The change in enthalpy during thermodynamics process was taken using REFPROP (NIST-23) software.

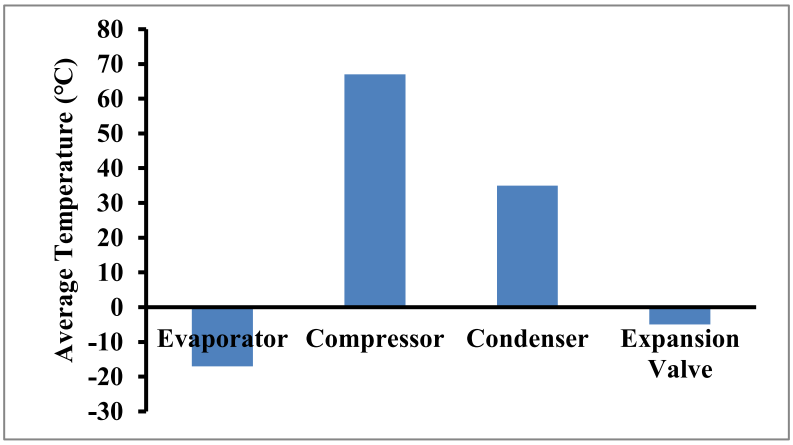

Fig. 2: Average temperature of the components

Fig. 3 showed the power consumed by the refrigeration system when operating with solar and electricity respectively. At the idle state of the system, the compressor requires more energy to takeoff. The power in-flow to system became stabilized and steady after 240 minutes and was maintained at an average of 109 Watt all through the remaining period of running the cooling system. The power input to the compressor when working with solar was reduced by 2.38% compared to when the system operated using electricity as the power source.

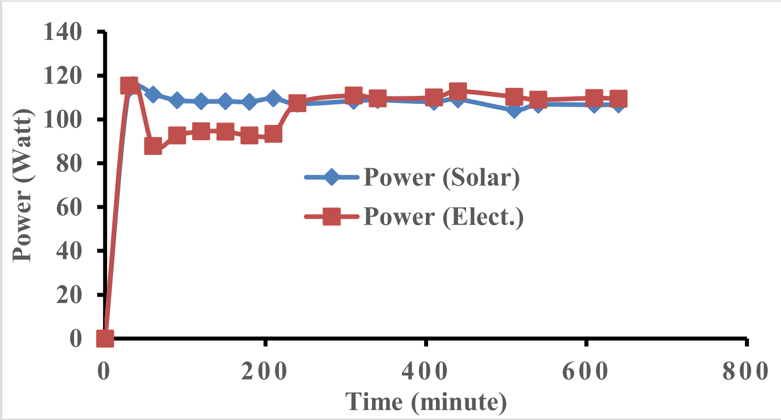

Fig. 3: Variation of power consumption by the refrigeration system with time

Furthermore, Fig. 4 revealed the coefficient of performance (COP) of the vapour compression refrigeration system when working with solar and electricity. The Coefficient of performance is a measure of temperature difference between the evaporator temperature (T_C) and condenser temperature (T_H), which depends on different factors such as power, heat transfer and surrounding air [20]. The COP for the refrigeration system when working under the average evaporator temperature of -17 °C and condenser temperature of 35 °C was determined using equation 1[1]

$$COP = \frac{Q_e}{W_c} \quad (1)$$

Where, Q_e is the latent heat absorbed in evaporator while, Wc is the work done by the single hemertic compressor.The COP of the refrigeration system increased by 8.67% when working with solar energy compared to when the system worked with electricity.This increase in COP was as a result of increase in the evaporator temperature and decrease in the condenser temperature [21-22].

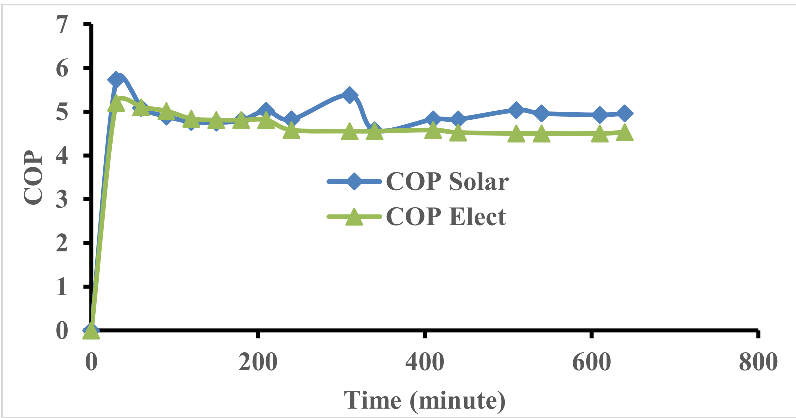

Fig. 4: Variation of COP using different sources of power with time

Fig. 5: showed the comparison of the quantity of heat rejection to the surrounding by convection. The heat exchanger used with the refrigerator was the wire and tube condense. The vapour compression system using solar energy was 4.23% higher compared to when the system worked using electricity as power means. This could be evaluated using equation 2 [1, 23].

$$Qcond = \dot{m}r(hc_2 - hc_3) \quad (2)$$

Where, Qc is the heat rejection in condenser, ṁr is the mass flow rate of the refrigerant that passes through the refrigeration pipes, hc_2 and hc_3 are the enthalpies at the inlet and outlet of the condenser respectively.

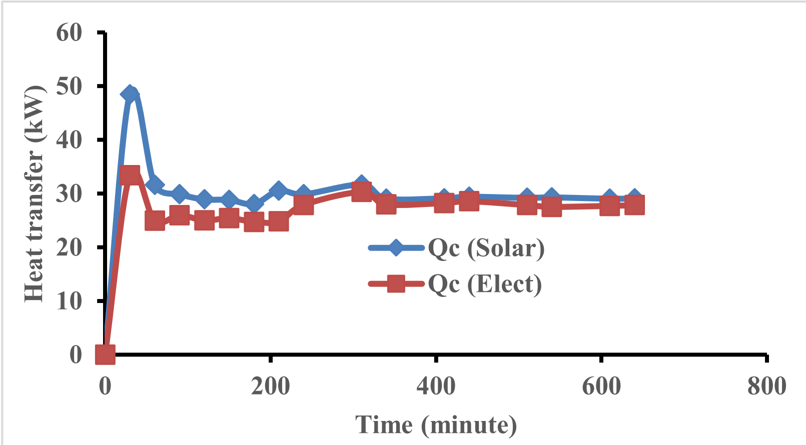

Fig. 5: Variation of heat rejection in condenser with time

In addition, Fig. 6 showed the latent heat absorbed in the evaporator when the refrigerator worked on solar and electricity. The amount of heat gained by the system when operating with solar energy was 6.42% higher compared to when the system used electricity as the source of energy and this was obtained using equation 3 [8, 24]

$$Qevap = \dot{m}r(he_1 - he_4) \qquad (3)$$

Where, Qe is the latent heat absorbed in evaporator, ṁr is the mass flow rate of the refrigerant that moves through the refrigeration system, he_1 and he_4 are the enthalpies at the inlet and outlet of the evaporator respectively.

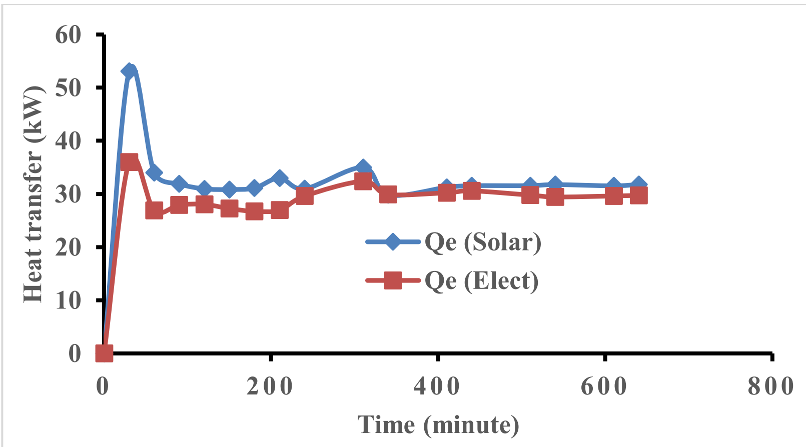

Fig. 6: Variation of latent heat absorbed in evaporator with time

Hence, fig. 7 displayed the energy degradation of the deep cycle battery (DCB) when working at a capacity of 81%. The DCB was employed to enable the solar refrigerator to keep running in case of power outage or cloudy weather during the night when the system could not access solar energy from the sun. Furthermore, the battery used 35% of its capacity to operate for 10 hours 40 minutes.

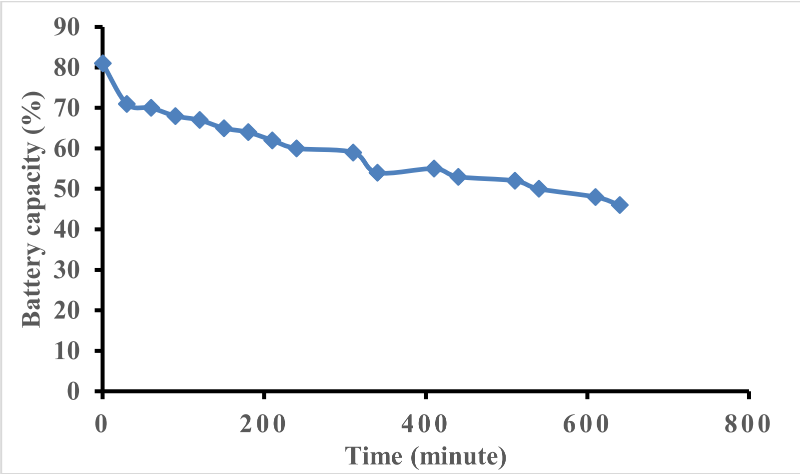

Fig. 7: Battery capacity depreciation with time

Conclusion

This study shows that the average coefficient of performance of the developed solar vapour compression refrigeration system is 4.96 at condenser temperature of 35 ^{o}C and evaporator temperature of -17 ^{o}C under natural convection. The solar refrigeration system is uniquely configured in a single compartment. The condenser was at distance from the main evaporating cooler which is contrary to the normal convectional refrigerators. Hence, the choice of this model is to make it suitable for rural and medical administration purposes; to preserve perishable items and vaccine. However, for further studies, alternative refrigerants, azeotrope mixture of refrigerants can be introduced to improve on the performance characteristics of the system in terms of power consumption, compressor work done and coefficient of performance.

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