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ORIGINAL RESEARCH ARTICLE

EXPERIMENTAL INVESTIGATION OF THE PERFORMANCE OF A HOUSEHOLD REFRIGERATOR USING PLYWOOD AS RADIATION SHIELD

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ABSTRACT

This research work investigates the performance of domestic refrigerators. Test were carried out on two configurations of household refrigerators; a conventional refrigerator and a refrigerator that was modified by incorporating a radiation shield. In this work, plywood was used as thermal radiation shield placed between the back of the refrigerator and the condenser and compressor. Pressure gauges were welded to the evaporator inlet and condenser outlet. Thermocouples were attached to the compressor inlet and outlet, condenser outlet and evaporator inlet in order to obtain data from the test. The pressure and temperature data obtained was applied to evaluate the performance of the two systems. With further repeated tests, the coefficient of performance (COP) of the refrigeration systems were determined at normal ambient condition. The highest evaporator temperature obtained for the conventional refrigeration system (CRS) and modified refrigerators system (MRS) were -5°C and 0°C respectively. Interestingly, an efficiency improvement of about 10% was achieved for the MRS. The result shows a remarkable improvement in the COP of the MRS. Therefore, for a better performance, thermal radiation shield can be recommended to be incorporated in vapour compression refrigeration system

1.0 Introduction

Domestic refrigerators are among the most energy demanding appliances in a household due to their continuous operation. The domestic refrigerators are found in almost all homes for storing food, vegetables, fruits, beverages, and much more (Marques et al., 2010). Materials that can store thermal energy reversible over a long time period are often referred to as latent heat storage materials. Refrigerators maintains temperature a few degrees above the freezing point of water. The optimum temperature for most perishable food is stored at temperature just slightly about the freezing (McDonald and Sun, 2000). A refrigerator is a large container which is kept cool inside, usually by electricity, so that the food and drink in it, stays fresh.

Other names of refrigerator include: fridge, chiller, cooler, ice-box etc. Since long time ago, all the components of commercial domestic refrigerators, freezers have been assembled in the same relative position. The four typical equipment of the vapour compression refrigeration system are the evaporator, compressor, expansion valve and condenser. These components are placed in a close position in most of the refrigerators. The compressor is located in a recess, at the bottom of the refrigerator while the natural air-cooled condenser is located in the rear wall of the refrigerator. There are differences in the refrigerators over the years mainly due to some aesthetic and the use of the new zero depletion ozone refrigerants (Riffat et al., 1997). However, most refrigerator types are initially based on the conventional vapour compression refrigeration cycles (Gosney, 1982). The refrigerant after adiabatic expansion in capillary tube flows through the freezer evaporator followed by the refrigerator evaporator (Fearon, 1978). After heat gain in both spaces, the refrigerant is then compressed and releases the accumulated energy in the condenser, usually of a natural air-cooled type, hence a complete refrigeration cycle. In previous experimental work, Afonso (2013) had shown that the outside surface temperature of the rear wall where the condenser is located as well as the walls close to the compressor has a very much higher temperature than the outside air with which all refrigerator surfaces exchange heat. This is due to the heat released from condenser and compressor produces larger heat gains to the refrigerator through those walls, when compared with the others. In order to evaluate the effect of the heat released from the condenser and compressor on the thermal behaviour of this kind of system, tests have been carried out in a new commercially available refrigerator.

Arifulkabir et al. (2018) studied the improvement in COP with heat recovery scheme for solar adsorption cooling system. In order to facilitate the heat transfer area, heat transfer fluid was distributed within two adsorbers that maintain the same mass flow rate between the heated and cold adsorber. The process distributes some heat of the desorption bed to the adsorber preparing it for the next preheating mode where heat transfer between them occur adiabatically. There is a satisfactory increase in the COP of the system. There have been several methods applied in order to investigate the performance of household refrigerators. Cobanoglu et al. (2020) carried out an investigation of the performance improvement of a household freezer using a natural circulation loop. The method employed the application of innovative refrigeration system that works with single-phase natural circulation loop. The loop was considered as heat exchanger suction line between the high and low pressure sides of the CRS of a household chest freezer. Computational Fluid Dynamics (CFD) analysis was carried out to study the heat transfer by the single-phase natural circulation. The performance of the system was presented based on different compressor suctions and discharge pressures, discharge temperatures and compressor speed. The result showed an efficiency improvement of 11.5% for the household freezer with single-phase natural circulation loop at maximum compressor speed and lowest compressor suction and discharge pressures and temperatures.

Similar work conducted by Safa et al. (2015) investigated the performance characteristics of ground source heat pump. Experimental tests were carried out to obtain the performance curves of the system with an efficiency evaluated at different load/source temperatures. The ground source heat pump was modelled using the performance curves obtained from the test and the COP of the system was determined at some external load and source temperature. Raveendran and Sekhar (2020) carried out an experimental study to analyse the performance improvement of a household refrigerator connected to a domestic water supply with a cooled condenser in a tropical region The study involved a pull-down performance testing for two refrigerators; the conventional and modified household refrigeration system. The modified refrigerator type was connected to a water cooled condenser system. The space temperature inside the refrigerators was recorded at different locations. Power consumption was manually recorded at an interval of 30s using a wattmeter. The pressure and temperature of components state points were recorded at an equilibrium condition. The COP of the conventional and modified refrigeration system were computed at normal ambient condition. The result showed MRS could decrease 21-27% daily energy consumption. Afonso and Gabriel (2017) demonstrated experimentally, the improvements achieved in household refrigeration systems if several modifications are implemented. By implementing the modifications tested in the virtual model, the thermal behaviour of the systems was improved. A decrease in electrical energy consumption as well as the associated CO_2 emission reduction were attained. It is evident that the performance of household refrigeration system is affected by the heat emission from condenser and compressor of the refrigeration system. The objective of this work is to investigate the performance of household refrigeration system by incorporating a thermal radiation shield at the condenser and compressor of the system.

2. Typical Refrigeration System

A refrigeration system comprised of four main components in which a fluid called refrigerant flow through the components to complete a refrigeration cycle in order to produce a cooling effect. These components are the compressor, condenser, expansion valve and evaporator. The refrigerant is contained in a loop or piping that connects the four main components together. To achieve a complete refrigeration cycle, the refrigerant which is at different states of liquid and vapour, moves through the components in open or closed system. The CRS operates as either a vapour compression or absorption refrigeration system. Figure 1 shows a schematic diagram of a vapour compression refrigeration system with an enthalpy-pressure relation.

The cycle starts when the refrigerant is pressurized with its volume reduced by process 1-2 at the compressor which acts as the prime mover of the system. The refrigerant turns into a very hot and pressurized gas moves to the condenser for process 2-3. The work of the condenser is to cool the refrigerant and convert it into a hot liquid or condenses. At this point excess heat is rejected by the condenser into the atmosphere (Thakar et al., 2017). The refrigerant flows through the process 3-4 at the expansion device which is responsible to metering and lowering the pressure and temperature of the refrigerant. Because of the rapid drop in the pressure at the expansion device, the refrigerant turns into a mix of cold liquid and gas and moves slowly through the evaporator in process 4-1. The evaporator absorbs the heat and cools the load inside the refrigerator. However, air is blown in the evaporator to maximise heat transfer from the refrigerant to the air that cools the space. This turns the liquid into a vapour which is pushed back into the compressor in order to start a new refrigeration cycle.

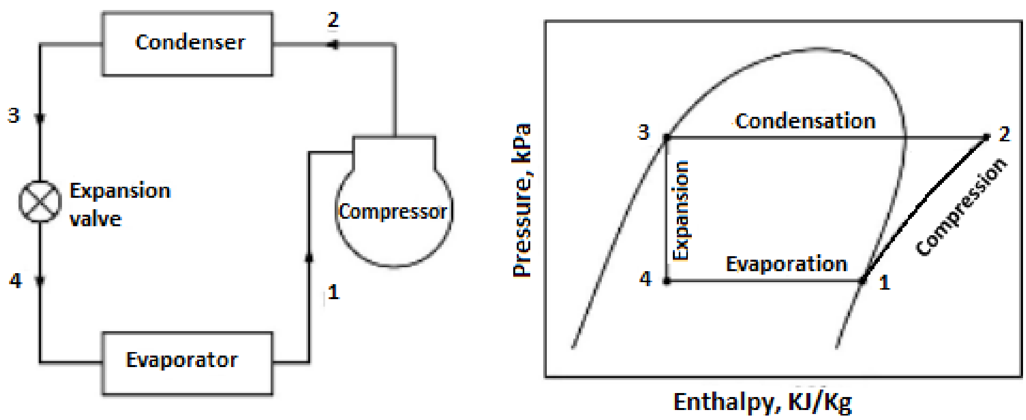

Figure 1: Schematic diagram of refrigeration system with enthalpy-pressure relation (Nasution et al., 2019)

3. Materials and Methods

The method applied in the present work is similar to the work of Afonso and Matos (2006) with some modifications in the rear and recess wall near the condenser and compressor separately, to evaluate the performance of the system. The improvement was achieved by placing a radiation shield composed of aluminium foil over the surfaces close to condenser and compressor to test the performance of the systems. However, in this work, a thermal radiation shield made of a plywood was used to investigate the performance of the conventional household refrigerator in relation to the modified refrigerator system. With reference to a standard vapour compression refrigeration system, the COP was obtained using the expression in Equation 1 defined as the ratio of the heat absorbed in the evaporator to the work input to the compressor (Nasution et al., 2020) where Q_L and W_C are the power input and compressor work respectively.

$$\text{Coefficient of performance (COP)} = \frac{Q_L}{W_C} = \frac{h1-h4}{h2-h1} \quad (1)$$

The materials used in this work is the refrigerator that comprises of the four main components of the refrigeration system. Pressure gauge was applied to determine the pressure at the evaporator and condenser of the refrigerators. Thermocouple was used to obtain condenser and compressor and evaporator temperature at a given period of time. Ply-wood which serve as the thermal radiation shield of size 45 cm x 20 cm and 45 cm x 60 cm were attached to the compressor recess wall and condenser wall respectively. A stop clock, masking-tape and refrigerant R-134a were all used in the test in the vapour compression refrigeration system.

Figure 2 shows how these instruments were attached to the refrigerator. The method employed to achieve the result involved the use of a pressure gauge which was welded to the condenser outlet and evaporator inlet of the refrigerators (Figure 2a). The thermocouple wires were placed at the refrigerators' compressor inlet and outlet, condenser outlet and evaporator inlet (Figure 2b). Experimental tests were carried out with six observations at an ambient temperature of 32 to 35°C. The temperature and pressure data were recorded at an interval of 10 minutes in the tests for the two systems. The experimental tests data recorded were applied to determine the COP of the refrigerators. The refrigeration system performance map of the two systems was evaluated and analysed using the COP values obtained.

(a)

(b)

Figure 2: Pressure gauges (a) and thermocouples (b) fixed to the refrigerator to obtain data

4. Results and Discussion

The experiment was carried out using plywood as the radiation shield in order to investigate the performance enhancement of the household refrigerator. Temperature and pressure are the two main important parameters considered for the analysis. Data were analysed according to the theory of refrigeration system and the results were tabulated (Tables 1 – 2). The data collected for the evaporator inlet and outlet temperature and pressure, condenser inlet and outlet temperature and pressure as well as the compressor inlet and outlet temperature and pressure were applied to determine the COPs of the two refrigeration systems. Tables 1 and 2 show the temperature and pressure data recorded at an interval of 10 minutes from the compressor, condenser and evaporator of the CRS and MRS. The performance of the two refrigerators were analysed in terms of the COP.

The COPs of the CRS and MRS were determined in each test. The COPs of the MRS are considerably higher than that of the CRS. It can be deduced that the use of thermal radiation shield in household refrigerator imposes a considerable impact on the COP improvement. However, this shows that the heat generated by the compressor and rejected with the condenser for MRS has great impact on the evaporative effect than that of the CRS. Figures 3-5 shows the comparative analysis of COP with time, COP with the compressor discharge temperature and condensation temperature as well as compressor discharge temperature and condensation temperature with time. The improvement in the COP ranges in between 5-20% depending upon thermal load, external temperature and material property type. The COP increases with time due to higher evaporation temperature obtained in the MRS.

Table 1: Experimental data obtained for the conventional household refrigeration system

Time (Minutes)	Evaporator inlet pres. P_1 (bar)	Condenser outlet pres. P_2 (bar)	Compressor inlet temp. T_1 (°C)	Compressor outlet temp. T_2 (°C)	Condenser outlet temp. T_3 (°C)
10	1.32	8.15	25	43	33
20	1.34	8.22	28	46	34
30	1.35	8.23	33	51	36
40	1.36	8.31	35	55	37
50	1.38	8.35	37	61	38
60	1.41	8.41	40	66	40

Table 2: Experimental data obtained for the modified household refrigeration system

Time (Minutes)	Evaporator inlet pres. P_1 (bar)	Condenser outlet pres. P_2 (bar)	Compressor inlet temp. T_1(°C)	Compressor outlet temp. T_2 (°C)	Condenser outlet temp. T_3 (°C)
10	1.24	8.28	27	44	35
20	1.27	8.39	30	50	36
30	1.29	8.50	34	55	38
40	1.33	8.71	36	61	39
50	1.36	8.84	38	65	40
60	1.38	8.95	42	70	42

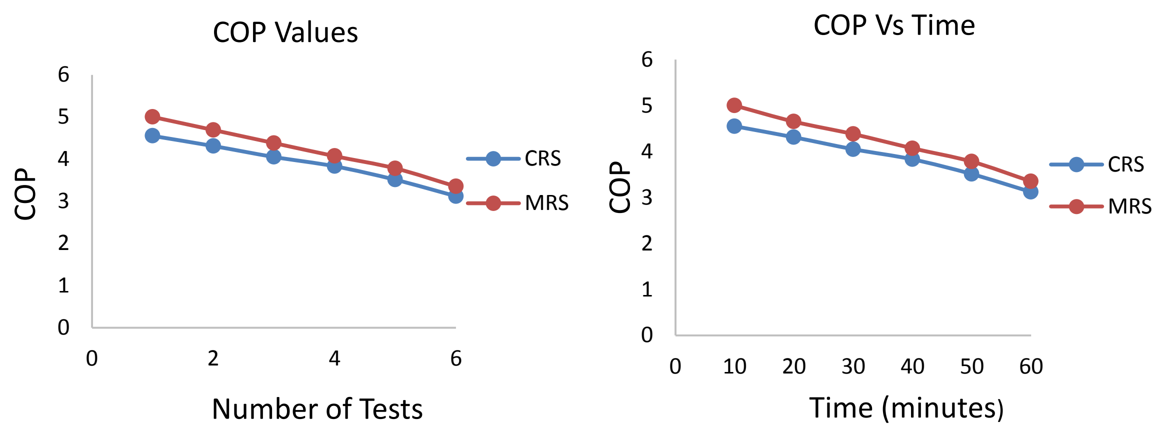

Figure 3: Comparison of COP for the conventional and modified refrigeration systems

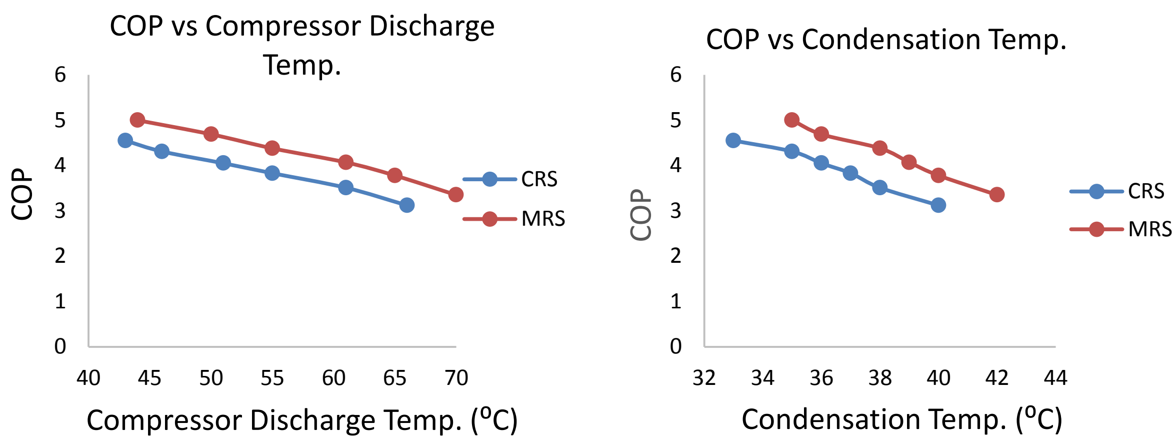

Figure 4: Comparison of COP with compressor discharge and condensation temperature

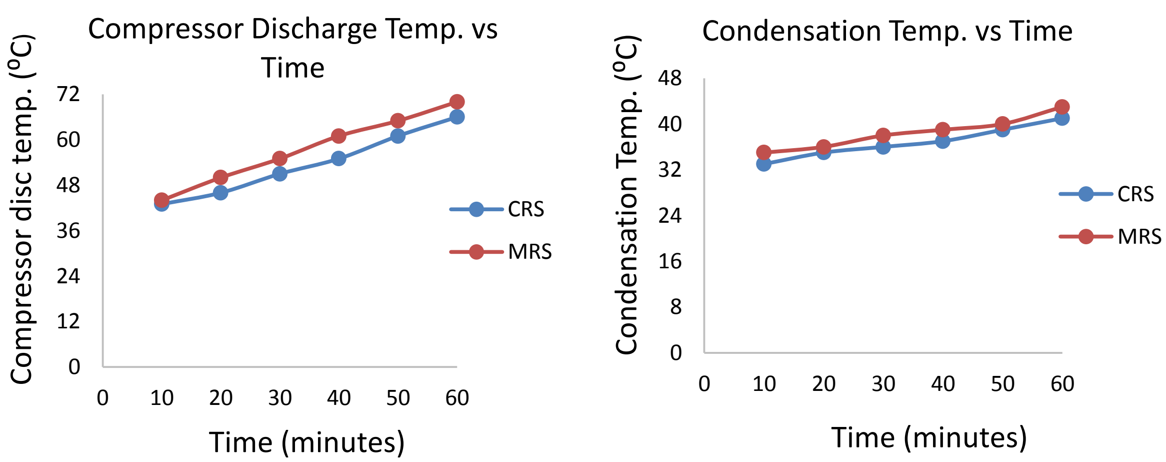

Figure 5: Comparison of compressor discharge and condensation temperature with time

It can be observed from Figure 3 for every number of observations with time, the COP obtained for the MRS are comparably similar with that of the CRS. Similarly, Figures 4 and 5 showcased the existing relationship of the COP for CRS and MRS, with the compressor discharge temperature and condensation temperature and how these temperatures vary with time. The compressor discharge temperature and the condensation temperature increase with increase in time with which the refrigeration systems operate. On the other hand, the COPs of the CRS and MRS decreases when the compressor discharge and condensation temperature increases. However, there is an outstanding difference in their values. In this regard, it can be deduced that the use of thermal radiation shield improves in the COP of refrigeration system. The improvement in this system can be achieved with a single evaporator refrigeration system for a refrigerator or freezer combination.

5. Conclusion

This work involved a study of vapour compression refrigeration system where the performance of two refrigeration systems was investigated. The COP achieved for MRS in each test was higher than that of CRS. However, for both systems, the COP decreases with increase in time, compressor discharge temperature and condensation temperature. It is clear that the use of radiation shield improves the overall performance of the refrigeration system. The heat load was minimized hence the cooling effect of the refrigerators were enhanced.

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