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Improving the performance of the cooling system using fin-reinforced phase change material

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Abstract

Domestic refrigerators have become an essential part of modern life. Since these devices are connected to the power grid and operate continuously throughout year, they consume a lot of energy. Experimental studies show that adding phase change materials (PCMs) in refrigerators in different places improves the energy efficiency. In this study, the effect of adding a PCM box on thermal performance and power consumption of an ordinary single-door refrigerator/freezer is studied. The PCM box is connected to the bottom surface of the evaporator with different materials including copper, aluminum and steel. Water with a melting temperature of 0˚C has been used as a PCM. Fins of the same material as box placed in the PCM domain to compare its impact on temperature distribution and energy consumption. The results show that the presence of the PCM box in contact with the bottom surface of the evaporator helps to reduce the cabin temperature due to the potential of water in absorbing and releasing cooling energy. Also, the results show that copper is more suitable material and this system has a potential to 1-4% reduce the energy consumption as well as limiting the temperature range of the cabin.

Keywords: Domestic Refrigerator, Phase change material, fin-reinforced, Performance enhancement, Temperature distribution.

1. Introduction

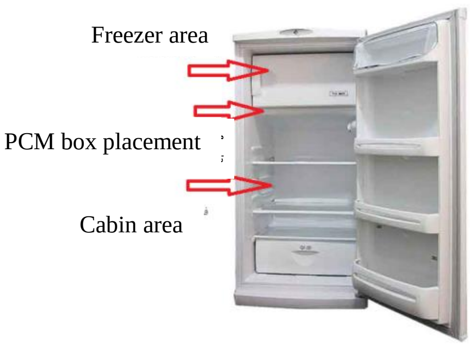
Nowadays, researchers are looking for ways to minimize the energy consumption of household appliances in order to reduce the amount of toxic fumes emitted by power plants, preserve the earth's natural resources, protect the ecosystem from destruction, and also reduce energy costs. Household refrigerators and freezers are among the most widely used electrical appliances in different countries. Considering their widespread use in every home and their continuous operation during 24 hours, a slight improvement in the performance of these appliances leads to a reduction in overall energy consumption. For this purpose, extensive research has been done to improve the performance of refrigerators using various methods, including increasing compressor efficiency, improving thermal insulation, improving heat transfer from heat exchangers placed in refrigerators such as condensers and evaporators and also using phase change materials.

Wang et al [1,2] in a comprehensive numerical and laboratory work investigated the location of the phase change material in the refrigerator cooling system. For this purpose, they used the desired heat exchanger between the condenser and the compressor (PCMA), between the condenser and the exhaust valve (PCMB) and between the evaporator and the compressor (PCMC). Their experimental results showed that the use of heat exchanger with phase change material in positions A and B leads to improvement of system performance coefficient between 6-8%. In position C, thermal stability and superheat are less evident in the compressor. Although the pressure drop caused by placing the heat exchanger in part C affects the performance coefficient.

Regardless of the improvements achieved in the use of PCMs in the condenser, the studies conducted in this field are few due to the low percentage of performance improvement. On the other hand, the use of phase change materials in the refrigerator cabin and also in the freezer compartment has been more researched due to the ease of implementation. For this purpose, Onyejekwe [3] investigated the use of PCM in the freezer of the home refrigerator system. He investigated the thermal properties of the freezer, the appropriate volume of the phase change material and the effects of thermal layering and showed the use of eutectic salt-water mixture for thermal energy storage in the temperature range between -15°C and -15°C. With these studies, it can be seen that the use of PCM in contact with the evaporator, which has an interface with the freezer wall in single-door refrigerators, is an effective method to control the temperature of the system. Also, any improvement in the heat transfer of PCM that have a low thermal conductivity coefficient (use of fins) can improve the performance of the system. Therefore, the simultaneous effect of these two factors, i.e. placing the PCM box in contact with the evaporator and improving heat transfer with the help of fins in the box, is effective. Considering the examined cases, it can be concluded that a comprehensive study on improving the heat transfer of the phase change material with an easy and fast method such as using a fin in the box, structural parameters and its response on thermal performance and energy consumption should be done. By examining these cases, it can be seen that there is space to improve the performance of the refrigerator system by improving the heat transfer properties of these materials. Therefore, in the present study, in order to improve the thermal performance and energy consumption of domestic refrigerator-freezers, phase change materials reinforced with fins of different types have been studied by using them in contact with the evaporator.

2. Elements of the Extended Abstract

The refrigerator-freezer used in the present study is a one-door type (model ARJ, 6448, Iran), which has a freezer (low-temperature unit) in its upper part and evaporator tubes are installed in it, Fig. 1-a. Also, the food storage compartment (high-temperature compartment) is located in the lower part. Table 1 shows the general characteristics of the refrigerator. Water as a phase change material is placed in a box with different materials. with This compartment has the task to keep the water and also make contact with the evaporator, absorbing cold from the freezer and transferring it to the food storage space, Figure 1-b.



(a)

(b)

Figure 1. (a) Ordinary refrigerator-freezer (b) Placement of PCM slab

Table 1. General characteristics of refrigerator-freezer

Compartment	Properties
Cabin	Internal volume of 140 liter
Condenser	Free convection, steel and wire tube, tree shaped
Compressor	Free convection, hot wall condenser
Refrigerant	145 gr of R-134a

The main drawback of phase change materials is their poor thermal conductivity. In this study, in order to improve this defect, fins with different characteristics are used as a factor to improve thermal conductivity to transfer cooling from the cold surface to the water. 4 fins are placed in the width of the box, Figure 2. In this regard, various parameters of the fin, including its material, height and type of arrangement, are investigated on the thermal performance and energy consumption of the refrigerator/freezer. Table 2 shows all the tests performed in the present study.

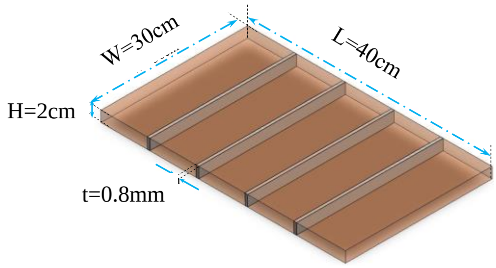


Figure 2. General dimensions of PCM box and fin

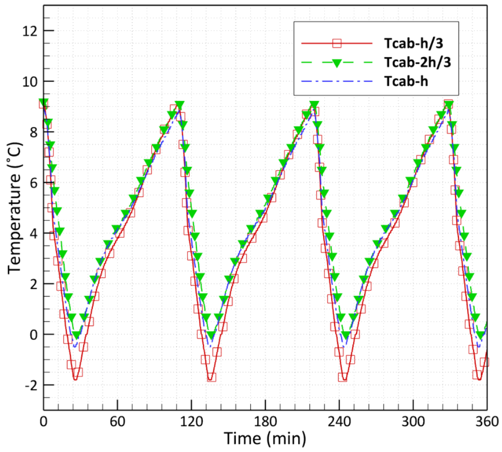
Table 2. Experimental tests

Case A: Ordinary refrigerator/freezer
Case B-1: Refrigerator/freezer with copper PCM box
Case B-2: Refrigerator/freezer with aluminum PCM box
Case B-3: Refrigerator/freezer with steel PCM box
Case C-1: Refrigerator/freezer with copper PCM box and longitudinal fins
Case C-2: Refrigerator/freezer with steel PCM box and longitudinal fins
Case C-3: Refrigerator/freezer with aluminum PCM box and longitudinal fins

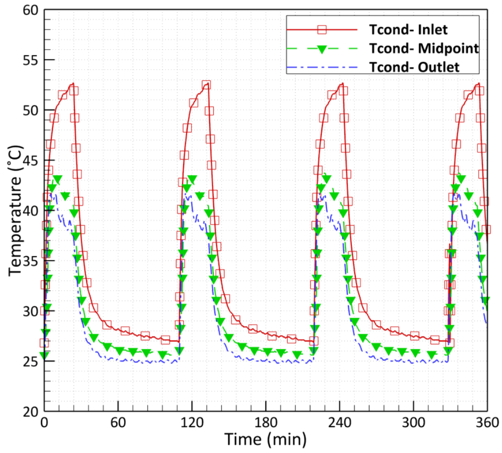
In order to check the performance of the refrigerator/freezer, all the tests are performed inside the test room, in the refrigerator-freezer production company Clever in Neishabur, Razavi Khorasan province. Standard test conditions of 13700 have been set on all tests. The test room is well insulated from the outside environment and its temperature is set at 25˚C with a relative humidity of 70%.

3. Results and discussion

Figure 3-a shows the temperature inside the ordinary refrigerator cabin at different heights. As it is clear in the figure, the increase and decrease of cabin temperature is related to turning on and off the refrigerator compressor. The highest value in each diagram shows the start time of the compressor. On the other hand, the lowest value in each graph is related to compressor shutdown. As it is clear from this figure, in a normal refrigerator/freezer, the average compressor on and off time is about 27 minutes and 85 minutes, respectively, and this cycle is repeated if no external load is applied to the system. Also, in Figure 3-b, the temperature of the condenser at the inlet, middle and outlet points is shown. As can be seen, the temperature is maximum at the inlet point of the condenser due to the exit of the refrigerant from the compressor, and by moving in the direction of the condenser and exchanging heat with the environment, the temperature will be lower at the intermediate and outlet points.



(a)



(b)

Figure 3- (a) Cabin temperature (b) Condenser temperature of a typical refrigerator at different points

As seen in Figure 3, due to the temperature fluctuations inside the cabin and the condenser, the successive turning on and off of the compressor leads to an increase in energy consumption. In the next step, by using PCM box with different materials as a cooling energy absorber in contact with the evaporator, the temperature response of the system to this factor is investigated and the results are compared with a normal refrigerator.

Figure 4 shows the average temperature of the cabin for an ordinary refrigerator and a refrigerator with a PCM box made of copper, aluminum, and steel. The results were taken in a 360-minute period to investigate the effect of different parameters at a specific time. As shown in the figure, in the normal refrigerator/freezer, Case A, the average compressor on and off time for this mode is about 27 minutes and 85 minutes, respectively. The highest and lowest values of average cabin temperature for this mode are 1.9˚C and 0˚C. As it is known, when the compressor is turned on, the refrigerant flows through the pipes and absorbs the thermal load from the freezer and refrigerator cabin, and as a result, the temperature inside the refrigerator decreases to the minimum value set according to the temperature of the thermostat. When the compressor is turned off, the temperature of the inside air gradually increases to the set value and the cycle repeats.

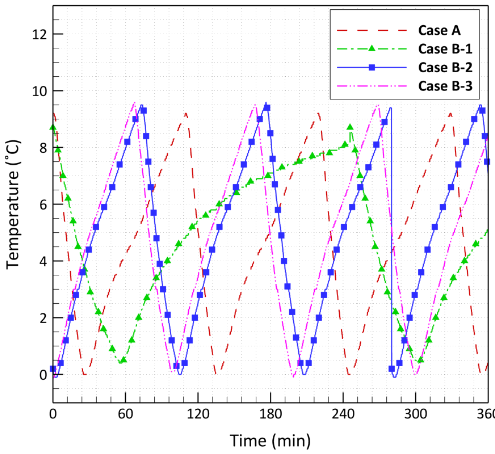


Figure 4- Refrigerator cabin temperature for an ordinary refrigerator and PCM box with different materials

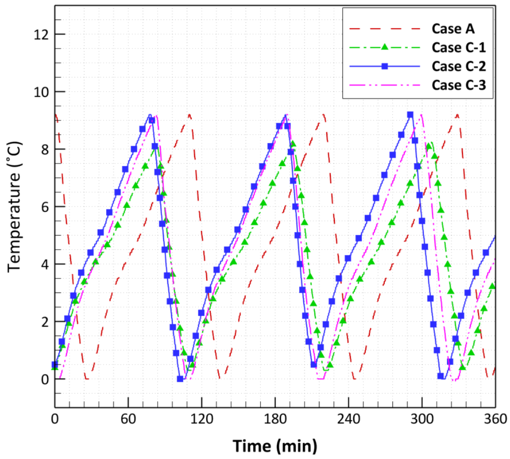


Figure 5- Refrigerator cabin temperature for an ordinary refrigerator and PCM box and fin with different materials

In addition to evaluating the effect of adding a water chamber with three different types, due to the low thermal conductivity of water as a phase change material, 4 fins were added to the water chamber to accelerate the flow of heat/cold through these fins to the fluid. Based on this, Figure 5 shows the average temperature of the cabin for Case A, a normal refrigerator/freezer, and Case C-1, Case C-2, and Case C-3, which respectively have copper water tanks with copper fins, aluminum fins with fins, respectively. It shows that it is aluminum and made of steel with fine steel. As can be seen, compared to a conventional refrigerator/freezer, the addition of a fin of the same material as the water chamber, further reduces the average cabin temperature by increasing the heat conduction from the top wall that is in contact with the evaporator to the fluid domain (PCM). It helps. In particular, Case C-1 with copper materials similar to those discussed in Section 1-3 helps to better control the temperature fluctuations inside the refrigerator due to the higher thermal conductivity of the copper material compared to the other two materials. In addition, the fin with aluminum and steel materials also reduces the temperature range inside the cabin more and has better performance compared to the normal refrigerator and also the compartment without fin. For example, compared to the compartment without fins, the temperature range inside the cabin for copper, aluminum and steel fins is reduced by 0.6, 0.35 and 0.3 degrees Celsius, respectively.

Electricity consumption per month (kW.hr) for all investigated situations, simple refrigerator, refrigerator with water compartment of different types and refrigerator with water compartment and fin of different types are shown in Figure 6. As can be seen, the normal refrigerator/freezer has the highest electricity consumption per month, which is equal to 14.33 kW.hr. By loading the water tank, the amount of energy consumption is reduced so that for the water tank made of copper, aluminum and steel, a decrease in monthly energy consumption is observed by 7.33%, 3.22% and 2.86%, respectively, which shows It improves the performance of the system in energy consumption in addition to improving its temperature performance. In addition, by placing the fin inside the water chamber, a further decrease in energy consumption can be seen. Compared to the usual refrigerator/freezer, the energy consumption for Case C-1, Case C-2 and Case C-3 has a decrease of 11.37%, 5.58% and 3.07%, respectively.

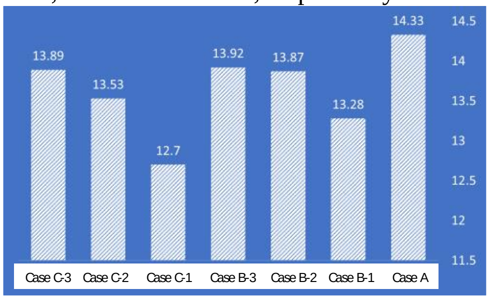


Figure 6- Annual Energy consumption for different cases

4. Conclusion

An experimental study on the effect of increasing the thermal conductivity using fins in a phase change material chamber in a domestic refrigerator/freezer has been investigated. The water tank is placed under the surface of the evaporator of the freezer. The effects of adding fin as an enhancement of thermal conductivity with different materials on the thermal performance and electricity consumption of the refrigerator were evaluated. The results show that by placing the water chamber below the surface of the evaporator, the temperature of the cabin remains within the standard range. In addition, the water chamber with higher thermal conductivity materials shows a better response in both thermal performance and power consumption, where copper is the best choice compared to aluminum or steel (Cu 1.7˚C and 5.1˚C) shows the temperature difference between the lowest and the highest cabin temperature. Also, the total consumption of the refrigerator system while using the water chamber with copper fin shows a reduction of 11.37% compared to a normal refrigerator.

5. References

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