PERFORMANCE ENHANCEMENT OF HERMETIC COMPRESSOR USING PHASE CHANGE MATERIALS

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Abstract

The present study is motivated by the need for the research of simple measures for increasing energy efficiency of hermetic compressor. The measure is the application of phase change materials for performance enhancement. The first experimental study should be guide for choice of PCM. It has been performed to investigate the effects of thermostat setting temperature on the performance of hermetic compressor. The effects of thermostat setting temperature with and without load on power consumption have been analyzed. Performance enhancement using phase change materials (PCMs) has been studied by employing a phase change material Rubitherm-42 (RT-42) on the top surface of compressor. Choice of PCM material is based on basic compressor performance measured in the first part of the present study. Experiments have been carried out for different load values and different quantities of PCM. The quantity and phase change characteristic of PCM are essential parameters that determine the percentage of performance enhancement in term of energy consumption. Reduction of energy consumption of about 10% has been achieved in the present study by using PCM. The present study shows that how to reduce the electrical power consumption to enhance compressor heat dissipation method to improve efficiency.

Keywords: Compressor, efficiency, Enhancement, Phase change material.

1. Introduction

Compressor is defined as component in any system to remove heat from any space. Compressor is using in small application such as refrigerator, large application such as chiller. The hermetic compressor is studied in this paper. Main components of a hermetic reciprocating compressor include a piston, cylinder, intake and discharge lines. The compressor also contains lubricant oil in the bottom. A schematic of such a compressor is shown in figure 1.

Figure 1. Schematic of a hermetic reciprocating compressor [Cavallini et al., 1996]
Using hermetic reciprocating compressor is lead to design to satisfy the maximum load [1]. Variable Speed Compressor (VSC) and Variable Capacity Compressor (VCC) are efficient alternatives to control the refrigerating capacity, which continuously matches the compressor speed to the thermal load [2]. Embraco (2005) developed a VCC for household refrigerator using compressor. This test results show up to 45% energy saving by replacing a conventional on/off compressor by a VCC compressor technology [3].

Compared the performance of different positive displacement compressors, including an open-type reciprocating, a semi-hermetic reciprocating and an open-type rotary vane compressor, for refrigeration applications are discussed. The results indicated that, all compressors showed an energy economy in the range of 12–24% when a speed control was used in comparison to the ones operating at constant speed [4,5]. Developed has been a numerical simulation of a refrigeration system with speed control. Simulations were carried out to verify the possibility of controlling the refrigeration system and the superheating of the refrigerant at the outlet of the evaporator by varying the compressor speed. The results suggested that the proposed model could be used to formulate an algorithm to control refrigeration systems [2].

Studied the capacity control of a refrigeration system by injecting hot gas straight into the compressor suction side and demonstrated that the compressor discharge temperature significantly increases for this set-up [6]. On a later study carried out a comparative study of three different capacity control schemes of a vapor-compression refrigeration system. The comparative study was performed in terms of the system coefficient of performance and the operating temperatures, among other parameters [7].

Bitzer compressors [8,9] are used inventor frequency with reciprocating compressors, hermetic and semi-hermetic. The main study used two frequencies and speed ranges are follows that: i) standard range of 30–60 Hz/850–1750 rpm, and (ii) extended range of 2570 Hz/ 700–2050 rpm.

Leducq et al. [10] mention that, although some commercial systems are already equipped with variable speed-compressors, the lack of knowledge about the dynamic behavior of these systems leads to poor control performance improvement. The industries where such systems have been implemented still have not been able to take full advantage of them.

In the present work temperature profile and power consumption have been measured for the different load of compressor. The effect of load on power consumption, efficiency has been analyzed.

2. Materials and methods

A compressor is used in the present work with the following characteristics:

- Compressor: Hermetic reciprocating.
  - Model: HSL11Y-5, with mineral oil lubricant.
  - Rated volt: 220-240 Volt.
  - Frequency: 50 Hz.
  - Rated current: 0.7 Ampere.
  - Displacement: 4.51 cc/rev.
  - Consumption power: 109 W.
- Cooling Capacity: 93 Watt.
- EER (Energy Efficiency Rate) = 2.91 Btu/Wh.
- Motor type: Resistance Start Induction Run (RSIR).
- Cooling type: Static Cooling (ST).
- Net weight: 7 kg.
- Oil Qty.: 230 cc

Where Test Condition (ASHRAE) LBP (Low Back Pressure) applications:
1- Evaporating temperature : -23 °C (-10 F).
2- Condensing temperature : 54.4 °C (130 F).
3- Ambient temperature : 32.2 °C (90 F).
4- Gas superheated to : 32.2 °C (90 F).
5- Liquid subcooled to : 32.2 °C (90 F).

- Refrigerant: 550 g of Tetrafluoroethane (R134a).
- Lamp power: 15 Watt.
- Control: On/off by thermostat setting and self defrost. The thermostatic control of the original appliance is driven by a bulb placed in contact with the evaporator wall.
- Refrigerant: R134a.

Figure 2 shows the experimental set up. Temperatures at various locations (compressor inlet, compressor outlet and on the compressor surface) are measured with copper-constantan thermocouples type T, 0.5 x 10^{-3} m diameter. Compressor power consumption is measured by recording the instantaneous volt and current data entering to the computer. The measurement circuit includes current and voltage transformer. The uncertainty of measurements is ± 0.02% for temperature and ± 1% for power.
All signals output for thermocouple and power are connected to an NI DAQ system, consisting of a NI cDAQ-9178 chassis, NI 1913 thermocouple module input and an NI 9219 universal analog input module for measuring voltage and current.

All experiments were carried out in a temperature-controlled room (20 ± 0.2 °C). Stability of room temperature was first assured before starting any experiment. The hermetic reciprocating compressor is then allowed to work continuously at a selected thermostat setting temperature for at least 48 hours. Measurements of temperature and power consumption are recorded every 1 second. Data are stored in separate files for analysis.

3. Result and Discussion

In the following sections steady periodic results of the experimental measurements are analyzed for two main cases. Namely, no load and load conditions.

The results are presented thermostat setting temperatures as shown in Table 1. It should be noted that the start and stop compressor are observed to be identical for a given thermostat setting at different load conditions.

| Table 1. Thermostat setting temperature (Setting 4). |
|-----------------------------------------------|
| **Thermostat Setting** | **Setting Temperature (°C)** |
| | **Setting Value** | **Range** |
| Setting 4 | -16.6 | ±8 |

Table 2 shows total cycle time, compressor operation time and idle time in seconds at thermostat setting temperature -16.6 and no load with and without PCM.

| Table 2. Total cycle time, operation time and idle time of compressor for no load at thermostat setting 4. |
|---------------------------------------------------------------|
| **Thermostat Setting** | **Cycle Times (s)** |
| | **Without PCM** | **With PCM (10 g)** |
| | **On** | **Off** | **Total Cycle** | **On** | **Off** | **Total Cycle** |
| Setting 4 | 166 | 445 | 611 | 178 | 430 | 608 |

The compressor temperatures corresponding to these setting are observed to be in the range of 40-46 °C. This range is compatible with the PCM phase change temperatures because the choice of PCMs is applicable. Thermostat settings 4 has been used to study the effect of PCM to match the phase change temperature range of RT42 (38-43 °C).
Table 3 shows the effect of PCM on refrigerator performance, summary of experiments.

Table 3. Effect of PCM on refrigerator performance, summary of experiments.

| Exp. No. | Setting Temperature (°C) | Quantity of PCM (grams) | load condition (Watt) |
|----------|--------------------------|-------------------------|----------------------|
| 1        | - 16.6                   | 0                       | 0                    |
| 2        | - 16.6                   | 10                      | 0                    |
| 3        | - 16.6                   | 0                       | 5                    |
| 4        | - 16.6                   | 5                       | 5                    |
| 5        | - 16.6                   | 10                      | 5                    |
| 6        | - 16.6                   | 15                      | 5                    |

Figure 3 illustrates variation of surface compressor temperature and power consumption for the case of no load at thermostat setting 4. As shown in Figure 3 below the compressor undergoes an initial transient period after which steady state periodic conditions are observed.

Figure 3. Variation of compressor surface temperature and power consumption at no load, setting 4 without PCM (transient state).
Performance comparisons at thermostat setting 4 with no load

Figure 4 illustrates the comparison of variation of temperature and power consumption of compressor at no load with PCM (10 g) and without PCM at thermostat setting 4 for a typical cycle.

It can be observed that the compressor is "on" for longer continuous periods while using 10 grams of PCM and thus resulting in the higher energy consumption as compared to the case without PCM at thermostat setting 4.

It has been observed during the experiment of using 10 grams of PCM that PCM does not undergo a phase change melting/solidification process at thermostat setting 4.

In this case, the PCM layer on the compressor top increases the thermal resistance between the compressor and the ambient and results in an adverse effect of an increase in compressor temperature.
Table 4 shows total cycle time, compressor operation time and idle time in seconds at thermostat setting temperature -16.6 and no load with and without PCM.

**Table 4.** Total cycle time, operation time and idle time of compressor for no load at thermostat setting 4.

| Thermostat Setting | Cycle Times (s)                |
|-------------------|-------------------------------|
|                   | Without PCM                  | With PCM (10 g)               |
|                   | On  | Off | Total Cycle | On  | Off | Total Cycle |
| Setting 4         | 166 | 445 | 611         | 178 | 430 | 608         |

The total cycle time for thermostat settings 4 with and without PCM are 608 and 611 sec, respectively. The cycling time decreases with PCM applied on the compressor. The decrease of cycle time indicates larger daily operation time of the compressor and a consequent increase in overall energy consumption.

Table 6 shows the energy consumption in 1 hr. (kW.hr) and average compressor temperature at thermostat setting temperature -16.5 °C for no load with and without PCM.

**Table 6.** Energy consumption results at thermostat setting 4 for no load.

|                      | Without PCM | With PCM (10 grams) |
|----------------------|-------------|---------------------|
| **Energy Consumption in 1 hr (kW.hr)** | 0.0191      | 0.0209              |
| **Average Compressor Temperature (°C)**    | 40.4        | 41.3                |

The compressor energy consumption for two cases has been calculated for one hour period of steady state operation by integration of the data shown in Figures 4. The results shown in Table 6 shows that an increase in energy consumption of compressor by about 9.44% is observed while using 10 grams of PCM of this thermostat setting.

**Performance comparison at thermostat setting 4 at Different Load Conditions**

Four experiments have been carried out to investigate the refrigerator performance at different load conditions with and without PCM. Namely, experiments with load value (5 Watt), three quantities of PCM (5, 10 and 15 grams) have been considered at thermostat setting 4.

The choice of above values of refrigerator load and thermostat setting have been done based on preliminary experiments. Present experiments parameters have been chosen to satisfy the first basic requirement of compressor temperature compatible with PCM phase change temperature. The second basic requirement related to the correct quantity of PCM is function of the temperature difference between compressor and ambient condition.
Performance comparisons at thermostat setting 4 for 5 watt load

In the following sections performance comparisons at thermostat setting 4 at load value of 5 watt with various quantities of PCM (0, 5, 10, 15 grams) are analyzed. The range of thermostat setting is -16.6 ± 8 °C.

Figure 5 illustrates the case of variation of temperature and power consumption of compressor at 5 watt load with various quantities of PCM (5, 10 and 15 g) and without PCM at thermostat setting 4.

For easy comparison, Figure 5 shows a typical periodic cycle of compressor operation at steady state for different values of PCM quantities. The start point for all the cases are aligned together for quantitative interpretation of results.

It can be observed from Figure 5 that, as compared to the base case without PCM, the compressor temperature using 5 grams of PCM is lower than without PCM. On the other hand, using 10 and 15 grams of PCM increases the compressor temperature. The compressor operation time for 5 grams is lower than no PCM case. However, using 10 and 15 grams of PCM increases the compressor operation time. Also, during the compressor on time the peak and average power consumption of compressor decreases by using 5 grams of PCM and increases by using 10 and 15 grams of PCM.

Figure 5. Variation of temperature and power consumption of compressor at 5 watt load with PCM (5, 10 and 15 g) and without PCM at thermostat setting 4.

Table 7 shows total cycle time, operation time and idle time in second at thermostat setting temperature -16.6 °C for different quantity of PCM with load 5 watt.
Table 7. Total cycle time, operation time and idle time of compressor for load 5 watt with different quantities of PCM at thermostat setting 4.

| Thermostat Setting | Cycle Times (s) | Cycle Times (s) |
|--------------------|----------------|----------------|
|                    | Without PCM    | With PCM (5 g) |
|                    | On  | Off  | Total Cycle | On  | Off  | Total Cycle |
| Setting 4          | 181 | 371  | 552         | 175 | 392  | 567         |
|                    |     |      |             |     |      |             |
|                    | With PCM (10 g) | With PCM (15 g) |
|                    | On  | Off  | Total Cycle | On  | Off  | Total Cycle |
| Setting 4          | 187 | 352  | 539         | 193 | 350  | 543         |

The total cycle time for thermostat settings 4 with and without PCM at different quantities are 567s (at 5g), 539s (at 10g), 543s (at 15g) and 552s (at no PCM) at load value 5 watt. As compared to no PCM, the cycle time decreases and on time increases with PCM applied on the compressor at 10 and 15 g. On the other hand, the cycle time increases and on time decreases with 5 g of PCM applied on the compressor. The increase of on time with decrease of cycle time compressor operation indicates larger daily operation time of the compressor and a consequent increase in overall energy consumption.

Table 8 shows comparison of the energy consumption and average compressor temperature at thermostat setting temperature -16.6 °C for 5 watt load with different PCM quantities. It can be observed that, the energy consumption of compressor decrease by about 9% while using 5 g of PCM as compared to no PCM case.

Table 8. Energy consumption results at thermostat setting 4 for load 5 watt with different quantities of PCM.

|                      | Without PCM | With PCM (5 grams) | With PCM (10 grams) | With PCM (15 grams) |
|----------------------|-------------|-------------------|---------------------|--------------------|
| Energy Consumption   | 0.0218      | 0.0198            | 0.02411             | 0.0274             |
| in 1 hr (kW.hr)      |             |                   |                     |                    |
| Average Compressor   | 44.2        | 42.6              | 45.1                | 45.2               |
| Temperature (°C)     |             |                   |                     |                    |

Table 9 shows the percentage increase of energy consumption at different thermostat setting temperature, quantities of PCM and load value condition.

Table 9. % Energy increase at thermostat setting temperature 4, different quantities of PCM and load value conditions.
| Exp. No. | Thermostat Setting Temperature (°C) | Quantity of PCM (grams) | No/load Condition (Watt) | Energy Consumption | % Increase of Energy Consumption |
|---------|------------------------------------|-------------------------|--------------------------|-------------------|---------------------------------|
| 1       | -16.6                              | 0                       | 0                        | 0.0191            | -                               |
| 2       |                                    | 10                      | 0                        | 0.0209            | + 9.44                          |
| 3       | -16.6                              | 0                       | 5                        | 0.0218            | -                               |
| 4       |                                    | 5                       | 5                        | 0.0198            | -9                              |
| 5       |                                    | 10                      | 5                        | 0.02411           | +10                             |
| 6       |                                    | 15                      | 5                        | 0.0274            | +25                             |

In general, as a guideline for reduction of energy consumption of hermetic compressor, proper choice of thermostat setting is a zero cost method. For high setting levels (low temperatures), the use of right quantity of PCM is lead to performance enhancement of about 10%.

4. Conclusion of the Present Work

The major findings and contributions of the present work are summarized as follows:

1- The performance of hermetic compressor decreases with the increase of load value.
2- Performance enhancement methods should focus on enhanced heat dissipation methods for reduction of compressor temperature with the increase of load values.
3- Judicious selection of phase change temperature and quantity of phase change material applied on the compressor could reduce the compressor energy consumption.
4- The feasibility of using PCM applied on the compressor for performance enhancement of household refrigerators has been approved.
5- Enhancement of refrigerator performance is obtained at low values of thermostat setting temperature and using small quantities (5 g) of PCM. Reduction in energy consumption by about 10% can be achieved.
6- High quantity of PCM may increase the power consumption of the hermetic compressor. This is due to higher compressor temperature.

In general, reduction in energy consumption of the hermetic compressor occurs when the PCM applied on the compressor undergoes a cyclic melting/solidification process. For cases when such processes do not occur the PCM acts as an insulating material for the compressor and worse the performance of refrigerator.
5. References

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