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REVIEW PAPER ON EXPERIMENTAL PERFORMANCE INVESTIGATION OF HOUSEHOLD REFRIGERATOR WITH LATENT THERMAL ENERGY STORAGE

Ms. Gaikwad P.R*, Ms. Londhe A.G, Prof. Shaikh S.M
ME Heat Power Engineering Student. J. J. M. C. O. E. Jaysingpur Maharashtra, India.
ME Heat Power Engineering Student. J. J. M. C. O. E. Jaysingpur Maharashtra, India.
Professor, J. J. M. C. O. E. Jaysingpur Maharashtra, India.

ABSTRACT

Refrigerators have increasingly been finding way in the Indian homes. Importantly, a large proportion of the Indian population still resides in such areas. A growing global environmental awareness and the rising costs of energy are driving the demand for the development of sustainable cooling technologies. It is estimated that refrigeration and air-conditioning are responsible for 15% of the global electricity consumption. Most governments have implemented minimum energy performance standards for household refrigerators and energy labeling programs to regulate the market and drive the search for innovative solutions, to further improve the efficiency of these appliances. Phase change materials (PCMs) are substances with high latent heat content that freeze and melt at a nearly constant temperature, accumulating or releasing large amounts of energy during the process. The application of PCMs in domestic refrigerators is a novel solution with the potential to improve the appliance efficiency. The cooling energy stored in the PCM can be used to cool the compartment, increasing the refrigerator energetic autonomy, while the power supply is switched off.

KEYWORDS— Household refrigerator, Latent thermal energy storage ,Phase change materials.

INTRODUCTION

Refrigerators have increasingly been finding way in the Indian homes. As per industry reports, the refrigerator market registered and annual growth of 15% for the year 2010-11. The total Indian market was at 8.4 million units in 2010-11, a 15% increase from 7.3 million units in 2009- 10. The contribution of frost-free category of refrigerators has been gradually increasing with approximately 24% share in 2010-11. The Bureau of Energy Efficiency (BEE) introduced mandatory star labeling for Frost free refrigerators in 2010 with a provision of tightening up of energy performance standards periodically i.e. subsequent revisions in the standards every two years. However, while revision of standards eliminates less efficient products from the market, by itself it does not provide an incentive to increase energy efficiency.

On the other hand a technology push through the introduction of super-efficient appliances increases the average efficiency even without the imposition of energy efficiency standards.; The Super-Efficient Appliances Deployment Initiative (SEAD) has 16 member countries working together to "raise the efficiency floor by bolstering national or regional policies like Minimum Efficiency standards and labels and strengthening the foundations of efficiency programs by coordinating technical work to support these activities''.

Refrigerators are among the most common household appliances increasing the energy efficiency of this device is thus an important issue in terms of energy savings. A number of countries have introduced labeling programs and minimum energy efficiency standards In response to these regulations, many investigations have been carried out in the recent years to develop technical options for improving the energy performance of household refrigerators. They may be classified in three categories improving the cabinet and door insulation to reduce heat losses. For instance, a 25% average energy saving is observed by the VIP (Vacuum Insulation Panels) integration in the cabinet The

drawback of this technology is linked to the fact that the manufacturing process is still expensive. Developing high-efficiency compressors. In conventional refrigerators, the usual compressor technology is the hermetic reciprocating compressor, designed to satisfy the maximum load. These compressors usually operate at partial load, resulting in a reduced performance and increased cycling losses.
Variable Speed Compressor (VSC) and Variable Capacity Compressor (VCC) are an efficient alternative to control the refrigerating capacity, which continuously matches the compressor speed to the thermal load**.** Embraco Ltd. developed a VCC for household refrigerator: test results show up to a 45% energy saving by replacing a conventional on/off compressor by a VCC compressor technology**.** It must be noted that an increase of 20% of the cost is also observed. Improving the efficiency of heat exchangers, and particularly of the evaporator which is a key component of refrigerator. Heat transfer through the evaporator requires a temperature difference between the air and the refrigerant the higher the air side convective coefficient, the lower the temperature difference between the evaporation temperature and the air. For a given cabinet air temperature, this results in a higher evaporation temperature, and consequently an enhanced performance of the system.

LITERATURE REVIEW

Cheng *et al.* [1] analyzed the performance of a fridge-freezer with a PCM fitted around the condenser pipes, which lowered the condensing temperature and produced energy savings of 12% compared to the same fridge-freezer without thermal storage.

Gin *et al.* [2] covered 26% of the internal walls of a frost free upright freezer with PCM panels reducing peak air and product temperature by 3°C and 1°C respectively during an electric defrost.

Azzouz *et al.* [3] tested a domestic refrigerator with 5 x 10^{-3} and 10 x 10^{-3} m (i.e. 5 and 10 mm) ice slabs in contact with the evaporator surface. Their results showed that the time for which the refrigerator could be operated without power supply increased by up to 5 and 9 h respectively, depending on the thermal load. It was observed however, that only 60% of the 10 mm slab was frozen when the compressor switched off during the tests, probably due to the low thermal conductivity of the PCM, and/or the low cooling capacity of the 5 x 10^{-6} m^3 (i.e. 5 cm^3) swept volume compressor employed. The impact of compressor selection on conventional refrigerators' energy consumption and running time is also demonstrated. However, high efficiency is only achieved when the compressor is running, and frequent on/off cycling of the compressor will reduce the overall efficiency. An effective way to exploit the higher performance of large compressors is to accumulate their excess cooling capacity in a PCM, thereby extending the length of the on and off cycle periods and minimizing the number of cycles per unit time. The remainder of the paper describes a numerical and experimental investigation of the heat release and storage rate of encapsulated ice, which was used as the thermal energy storage material (i.e. PCM) in the refrigerator.

Wang F.*et al.* [4] *et al.* used mathematical model to predict the heat transfer during the phase change is based on the enthalpy method [4], with the governing equations discretization on a fixed grid using the finite difference method. The influence of PCM thickness (2, 3, 4 and 5 mm slabs) and ambient temperature (20^0C, 25^0C, 30^0C) and evaporating temperature (-15^0C and -10^0C) have been investigated numerically. The numerical model was validated experimentally at two ambient conditions using a test rig specifically designed for that purpose. The test rig consisted on a prototype refrigerator, fitted with a 5 mm PCM slab, which was cooled by an external coolant system.

Cerr[5] has previously simulated a domestic refrigerator including a low quantity of PCM in the evaporator. In this study, the coefficient of performance is improved by 12%. In recent numerical investigations (Azzouz et al., 2005, 2008), we have shown that the addition of a thick slab of PCM on the back side of a refrigerator evaporator may result in a higher evaporating temperature. A 25% increase in the coefficient of performance and a significant decrease in the number of starts/stops of the compressor were observed. In this context, the purpose of this study is to experimentally investigate the effects of the addition of a phase change material to the household refrigerator in terms of performance and heat storage capacity and to compare the results with the classical system.

K. Azzouz *et al.* [6] *et al.* studied the effect of adding a phase change material (PCM) slab on the outside face of a refrigerator evaporator. A dynamic model of the vapour compression cycle including the presence of the phase change

material and its experimental validation is presented. The simulation results of the system with PCM show that the addition of thermal inertia globally enhances heat transfer from the evaporator and allows a higher evaporating temperature, which increases the energy efficiency of the system. The energy stored in the PCM is yielded to the refrigerator cell during the off cycle and allows for several hours of continuous operation without power supply.

K. Azzouz *et al.* [7] carried out experimental tests to investigate the performance Of a household refrigerator using a phase change material (PCM).The PCM is located on the back side of the evaporator in order to improve its efficiency and to provide a storage capacity allowing several hours of refrigeration without power supply. The system has been tested with water and with a eutectic mixture (freezing point -3^0C) and for a range of operating conditions (PCM thickness, ambient temperature, thermal load). The analysis of the results shows a significant improvement of the performance compared to a conventional system.

A.C. Marques *et al.* [8] investigated the design and operation of a thermal storage refrigerator. Firstly, compressor performance at a range of typical refrigerator operating conditions was analyzed. The model results suggest that larger compressors are more efficient when running, with isentropic efficiency increasing by 50% as the displacement increased from 4 to 8 cm^3. The impact of compressor performance on the overall refrigerator efficiency was estimated and the results indicated that an energy reduction of 19.5% can be obtained by replacing a conventionally sized, 4 cm^3 compressor by a larger 8 cm^3 model. However, using a larger compressor will normally lead to more start/stop events, which reduces overall efficiency. A method is proposed for exploiting the superior performance of large compressors by accumulating their high cooling capacity output in a phase change material (PCM), reducing the number of on/off cycles. Numerical modeling and experimental validation were undertaken using a prototype thermal storage refrigerator, incorporating a PCM, to estimate the PCM charge and discharge rate and the corresponding refrigerator on and off cycle durations at different ambient conditions. The results showed that the integration of a 5 mm PCM slab into the refrigerator allowed for 3e5 h of continuous operation without a power supply. The numerical model was found to be in good agreement with the experimental results, with the error between the simulation and tests below 5% for most experiments.

A.C. Marques *et al.* [9] carried out numerical simulations using the computational fluid dynamics (CFD) software ANSYS Fluent were undertaken to characterize the airflow and temperature distribution in a natural convection thermal energy storage refrigerator. The model compared the household refrigerator temperature stability with different phase change materials (PCM) incorporated into the storage compartment. Scenarios investigated included the PCM orientation , PCM temperature and compartment designs .The model indicated that combining horizontal and vertical PCMs in a full height compartment or dividing the same compartment into two drawers with a horizontal PCM configuration for each drawer are feasible design options for the household thermal storage refrigerator.

CONCLUSION

From the outcome of the study, the following conclusions will be drawn:

- The present study is honestly tried elaborate effort to examine the performance of a Most governments have implemented minimum energy performance standards for household refrigerators and energy labeling programs to regulate the market and drive the search for innovative solutions, to further improve the efficiency of these appliances.
- The energy consumption of refrigerators is affected by the efficiency of their components, ambient temperature, product loading, and number of door openings, thermostat setting position and refrigerant migration during the compressor off-cycle.
- Improving the efficiency of heat exchangers, and particularly of the evaporator which is a key component of refrigerator.
- Heat transfer through the evaporator requires a temperature difference between the air and the refrigerant: the higher the air side convective coefficient, the lower the temperature difference between the evaporation temperature and the air.
- For a given cabinet air temperature, this results in a higher evaporation temperature, and consequently an enhanced performance of the system.

- The application of PCMs in domestic refrigerators is a novel solution with the potential to improve the appliance efficiency.
- The cooling energy stored in the PCM can be used to cool the compartment, increasing the refrigerator energetic autonomy, while the power supply is switched off.

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