Thermal Performance Improvement of Domestic Refrigerator with Latent Thermal Energy Storage System

Mr. Rajendra P. Patil[1] Nilesh Bajirao Kamble[2] Akshay Vishnu Jori[3] Somesh Sureshrao Patil[4] Sourabh Dhansing Gaikwad[5]
[1]Professor [2,3,4,5]Student
[1,2,3,4,5]Department of Mechanical Engineering
[1,2,3,4,5]Tssm's Padmabhooshan Vasantdada Patil Institute of Technology, Bavdhan, Pune-411021, Maharashtra, India

Abstract— The report presents theoretical studies and experimental investigation was carried out to improve the thermal performance of a domestic refrigerator with latent thermal storage system, highlighting the advantages of use of phase change material (PCM) associated with the evaporator. Phase change materials (PCM) 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 desired working model of domestic refrigerator using (PCM) phase change material is successfully designed and fabricated. It is also successfully tested for working. With PCM, the air temperature is kept constant at 10°C for 12 hours, compared to without PCM where the air temperature rises continuously and rises above 10°C in just 1 hour. As the PCM melts, it absorbs the thermal load that enters the cold storage space, thus limiting the rise in the temperature and maintains a constant temperature inside the cabin during loss of electricity, which may occur due to an accidental power loss or done purposely to achieve electrical load shifting. The analysis of the experiment exemplifies the improvement of a conventional refrigeration system's COP (Coefficient of performance) considerably.

Keywords: Domestic Refrigerator, Latent Thermal Energy Storage, Phase Change Materials, COP

I. Introduction

A refrigerator is a common household appliance that consists of a thermally insulated compartment and a heat pump (mechanical, electronic, or chemical) that transfers heat from the inside of the fridge to its external environment so that the inside of the fridge is cooled to a temperature below the ambient temperature of the room. For the past several decades, the functionality and efficiency of household refrigerators have increased dramatically due to the ubiquitous need of clean and fresh food. With increase in affordability and pursuit of better living standards, the demand for refrigerators has risen, in turn leading to increased power consumption and emissions. It is therefore critically important to make the household refrigerator more energy efficient and eco-friendly.

Thermal Energy Storage: One study explored cooling a cargo space experimentally utilizing a large onboard passive TES tank that is charged while the vehicle is at rest. While novel, it would be possible to reduce the size of this unit by including the refrigeration system onboard powered by the main engine to actively manage the state of charge. Additionally, there is very little mention of modelling in this or any refrigerated transport work. In order to better aid the design of both standalone TES units and hybridized VCC systems,

A. Problem Statement:

Worldwide power consumption is increasing day by day. In world near about every home has a refrigerator for preserving food and other purposes. Refrigerator has also used widely in industry also. Hence there is need to reduce power consumption of refrigerator. Compressor required large power for its working and it frequently gets cut off and cut on it result in more power consumption. Hence our aim should be to increase compressor cut off time. Today's refrigerator are frequently gets cut off and cut on. This problem lead to more power consumption. After retracting heat from the load refrigerator maintain at certain temperature level and send signal to compressor and it gets cut off. After some time when refrigerator temperature is increases again signal is send to compressor and its starts again. This problem leads to less COP of refrigerator. Large amount of CFC and HCFC gases released from refrigerator it leads to global warming which result into increase in world temperature and melting of polar regions.

B. Objective of project

The objectives of the performance improvement of the domestic refrigerator by using the PCM

1) To fabricate the experimental set up by modifying the domestic refrigerator with PCM based refrigerator.
2) To observe the effects of PCM on vapour compression cycle.
3) To observe the difference on the Coefficient of performance (COP) of the refrigerator cycle with PCM and without PCM.
4) To observe the effect of PCM on Compressor.
5) To observe cooling retention time in cabin after PCM get solidify till it convert in to liquid phase for various product load conditions.
6) To observe temperature informality in cabin as compared with normal vapour compression refrigeration system.

II. Literature review

1) Azzouz K et al. carried out experimental investigation 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 °C) 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 with a 10 – 30% increase in COP depending on thermal load and type of PCM used.

2) Marques et al. used Computational fluid dynamics (CFD) 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, temperature and compartment designs. The results suggested that a horizontal PCM configuration produces lower compartment temperatures than a vertical configuration. The temperature distribution with a horizontal PCM was tested experimentally and the results were in agreement with the CFD predictions. Both the simulation and the experimental results suggest that a eutectic with a phase change temperature below 0 °C must be employed to maintain the compartment temperature within acceptable limits. 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.
3) S. Bakhshipour et al. studied that In the present study, numerical simulation of refrigeration cycle incorporated with a PCM heat exchanger is carried out. To this end, the refrigeration cycle without PCM has been simulated and then, the performance coefficients of the refrigerator in either with and without PCM are evaluated. The PCM heat exchanger is located in the refrigeration cycle, at a location after the condenser and before the expansion valve. The utilised PCM is N-Octadecane with fusion temperature of 27.5 °C. The simulation of heat exchanger is based on computational fluid dynamics (CFD) in which the flow inside the pipe is considered one dimensional in the axial extension and PCM surrounding it, is considered two dimensional. Numerical simulation is carried out using MATLAB software. Simulation results show that utilizing PCM in refrigeration cycle of a refrigerator causes an improvement in the convection procedure and results a 9.58% increase in performance coefficient of refrigerator
4) Y. Yusufoglu et al. studied that Efforts to increase energy efficiency of refrigerators shall directly reduce energy consumption in residential buildings. Incorporating phase change materials (PCM) is a new approach to improve the performance of refrigerators. In this study, we have tested four different PCMs in two different refrigerator models. Compressor on/off time was optimized and better energy efficiency was achieved. Increasing condenser surface area by 20% enhanced the PCM effect. The use of only 0.95 kg of PCM has resulted in a 9.4% energy saving. Economic analyses show that using PCMs in household refrigerators is clearly a cost effective method that saves energy and reduces harmful emissions.

III. Methodology

The test setup, as shown schematically in Fig. 1.1 consists of Components like Compressor, Condenser, Capillary Tube, Evaporator, Filter and Drier, Flow Control Valves and Data Logger System

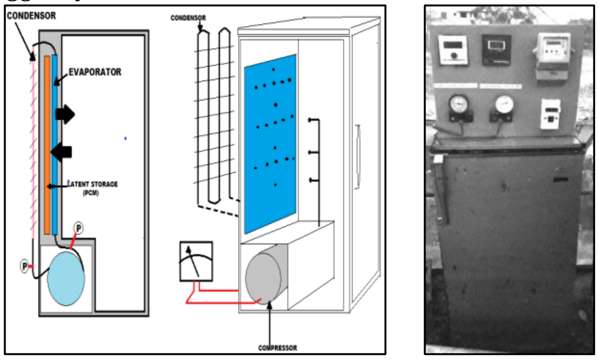

Fig. 1: (a) 3D model of test facility (b) Actual model

A. Data of Test Rig

Compressor Data		
Max. Current	Amp	1.1
Voltage	V	230
Max. Power	W	253
Capillary Data		
Capillary No.	Length(Feet)	Internal Diameter (mm)
1	12	1.40
2	13	1.12
Condenser Data		
Tube Diameter	mm	6.7
Tube Length	mm	420
Pitch	mm	45
Elbow	mm	70.7
No. Of turns		18
No. Of wires		22
Wire Bunch		3
Height	mm	810
Wire diameter	mm	1
Evaporator Data		
Width	Mm	280
Length	Mm	1230
Surface Area	m2	0.3444
Heat Load on Evaporator	W	650
LMTD	°C	10
Heat Transfer Coefficient	w/m2k	188.734

IV. Experimental Results

Experimentation is carried out with load conditions and without load conditions using PCM in the refrigerator.

A. With PCM without Product Load Condition

- T: Time (Minutes),
- CDT1: Compressor Discharge Temperature (˚C),
- CDT2: Condenser Discharge Temperature (˚C),
- EIT: Evaporator Inlet Temperature (˚C),

- EOT: Evaporator Outlet Temp (˚C),
- CT: Cabin Temp. (˚C),
- PCM: PCM Temp. (˚C)

T	CDT1	CDT2	EIT	EOT	CT	PCM
0	67.3	37.4	-14.4	22.4	6.3	-0.1
120	72.2	40.9	-11.9	25.1	4.5	0.6
240	72.3	41.3	-10.7	25	4.7	0.6
360	71.7	40.7	-10.8	24.7	4.7	0.4
480	71.7	40.1	-10.5	24.4	4.1	-3.3
600	71.3	39.3	-10.4	24.1	3.8	-5.6
660	71.3	40.5	-10.7	24.3	4	-9.2
Power Cut Off						
720	30	26.1	10.9	34.5	5.1	-5.7
960	25.1	25.2	16.5	23.5	6.5	1.4
1200	27.6	28.3	16.7	25.3	8.1	1.2
1440	29.8	30.1	19.2	27.8	11.7	2.2
1680	29.4	29.5	19.6	27.5	12.6	2.5
1920	28.8	29	20.7	27.4	14.1	6.4
2160	30	30.3	20.9	28.1	14.9	9.6
2400	30.8	31	21.7	28.7	16.2	12.8
2640	31.6	31.5	24	29.5	20	17.6
2880	31.3	31.2	25.7	29.4	23.2	21.8
3120	30.7	30.6	26	29	25	24.2
3300	30.1	30.4	26.2	28.5	25.8	25.6

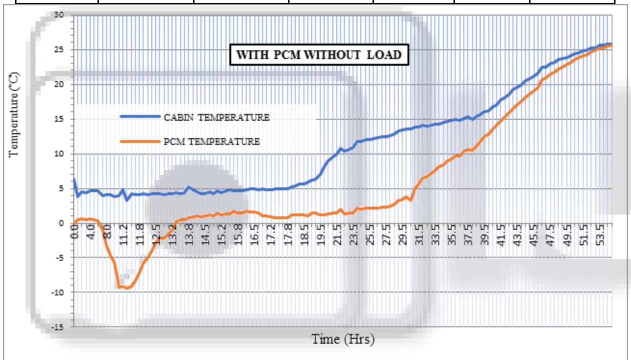

Fig. 2: Temperature v/s Time (With PCM without Load Condition)

B. With PCM with Product Load Condition

T	CDT1	CDT2	EIT	EOT	CT	PCM
0	34.9	27.3	25.4	26.2	24.9	24.7
45	60	37.2	-14.9	20	16	5.7
85	53.4	22.5	-15.7	21	7.5	-2.4
125	67.8	41.3	-16.3	21.1	1.9	-7.9
165	70.3	38.3	-16.8	21	-1.5	-9.8
205	74	41.7	-15.1	21.3	-3.7	-11.4
Load Added						
240	65	26.3	-12.8	22	3.4	-14.9
260	56.9	28.3	-13.5	21.9	4.6	-14.8
280	70.6	31	-10.5	24.7	4.4	-14.3
Power Cut off						
320	57.8	30.5	-10.9	24.7	4	-13.5
350	62.2	31.1	-11.6	24.2	3.7	-13.2
380	63.9	28.7	-11.7	24.3	3.8	-12.1
Door Opening						
440	60.6	30.3	-11.7	25	4.8	-11.9
480	61.4	18.3	14.2	27	3.6	-11.2
520	62.3	20.8	14.6	27.5	2.2	-10
560	21.9	19.8	15.2	27.5	0.8	-8.8
Door Opening						
600	21.7	20.1	15.6	27.4	3.1	-8.6
720	21.3	24.8	19.3	28.3	3	-6.7
840	25.4	26	20.7	28	4.8	-5.1
960	25.4	24.6	20.8	25.5	7.6	-3.6
1080	25	29.1	20.8	28.2	10.5	0.7
1200	27.6	29.7	22.5	29.8	10	4.9
1320	29.3	29.5	20.9	31.1	12.7	7.5
1440	29	30.5	21.7	30.2	13.6	8.9
1560	30	31.8	24.4	30.7	15.6	10.3
Door Opening						
1680	31.2	31.1	25.9	28.4	16.2	13.5
1800	31.3	30.4	26.3	26.9	15.8	15.2

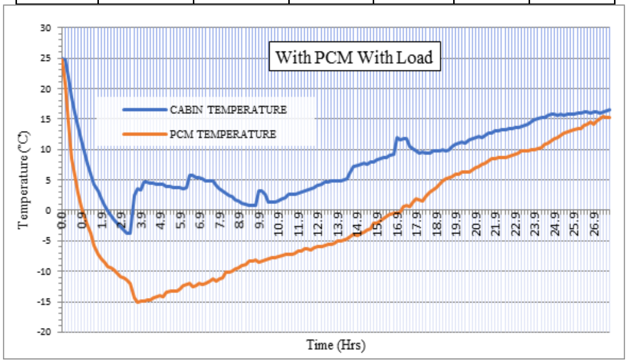

Fig. 3: Temperature v/s Time (With PCM with Load Condition)

V. CONCLUSION

As it is seen though experiments PCM (phase change material) can be useful to maintain the cabin temperature below 100 C for 16 hrs as compared to conventional refrigerator which maintains temperature for 4 hrs. This will improve the life of compressor as frequency of tripping is reducing by 1/6. Another advantage of PCM is maintaining the temperature variation inside cabin within 2°C to 3°C which will help to increase the life span of perishable food products as compared to conventional one where the temperature variation is 6°C to 8°C. With PCM, the air temperature is kept constant at 10°C for 12 hours, compared to without PCM where the air temperature rises continuously and rises above 10°C in just 1 hour. The PCM temperature rises slowly as the PCM melts over this 12 hour period. Once the PCM has finished melting, the air and PCM temperatures rise steeply.

The following conclusions were drawn based on the experimental results.

1) By using phase change material (PCM) at the bottom of refrigerator, sudden rise in temperature due to power failure can be retarded and can maintain constant temperature of 10 ºC for 12 hrs.
2) Depending on the thermal load with phase change material the average compressor running time per cycle is reduced significantly and COP is found to be increased to about 17% to 30% as compared to without phase change material.
3) As the PCM melts, it absorbs the thermal load that enters the cold storage space, thus limiting the rise in the temperature and maintains a constant temperature inside

the cabin during loss of electricity, which may occur due to an accidental power loss or done purposely to achieve electrical load shifting.

VI. Future Scope

1) This experimental work can be extended to investigate the effects of temperature and coefficient of performance by increasing the surface area, and positioning of phase change materials (PCM) panels in different way. It is also observed that when power supply is off this technique is cheapest when compared to other alternate power sources.
2) Investigation of the use of other heat transfer fluids having thermal conductivity higher than that of water.
3) Investigation of thermal losses after thermal storage for a period of time in case of thermal energy storage using phase change materials and compare it with energy storage using without PCM.
4) Detailed analysis of effect of change in mass flow rate of refrigerant on COP and time for which the temperature is maintained below 10˚C can be done.

References

[1] Azzouz K, Leducq D, GobinD. “Enhancing the performance of household refrigerators with latent heat storage: An experimental investigation.” International Journal of Refrigeration 2009;32:1634-44
[2] S. Bakhshipour, M.S. Valipour , Y. Pahamli “Parametric analysis of domestic refrigerators using PCM heat exchanger” international journal of refrigeration 83 (2017) 1–13
[3] Cheng,W.L., Mei, B.J., Liu, Y.N., Huang, Y.H., Yuan, X.D., 2011. “A novel household refrigerator with shape-stabilized PCM (Phase Change Material) heat storage condensers” An experimental investigation. Energy 36, 5797–5804.
[4] Bansal P K. “Developing new test procedures for household refrigerators: harmonization issues and future R&D needs - a review.” International Journal of Refrigeration 2003;26:735-48.
[5] Gin B, Farid MM, Bansal P K. “Effect of door opening and defrost cycle on a freezer with phase change panels.” Energy Conversion and Management 2010;51: 2698-706.
[6] EN 153:2006 Methods of measuring the energy consumption of electric mains operated household refrigerators, frozen food storage cabinets, food freezers and their combinations, together with associated characteristics. European Committee for Standardization. 2006.
[7] Laguerre O, Derens E, Palagos B. “Study of household refrigerator temperature and analysis of factors affecting temperature” A French survey. International Journal of Refrigeration 2002; 25: 653-9.
[8] Verma, P., Varum and Singal, S.K. (2008). “Review of mathematical modeling on latent heat thermal energy storage systems using phase-change material” Renewable and Sustainable Energy Reviews, 12: 999-1031
[9] C. Marques, J.A. Evans, G. Davies, G. Maidment, I. Wood, 2013. “Theoretical modelling and experimental investigation of a thermal energy storage refrigerator”, Energy, Volume 55, Pages 457–465.
[10] James S J, Evans J, James C. “A review of the performance of household refrigerators.” Journal of Food Engineering 2008; 87: 2-10