iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** VII **Month of publication:** July 2018

DOI: http://doi.org/10.22214/ijraset.2018.7033

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue VII, July 2018- Available at www.ijraset.com

Performance Investigation of Cascade System with Latent Heat Storage

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Abstract: In this paper 50-50% concentration of ethylene glycol – water solution is used as PCM having freezing point 239K. This PCM solution is used in evaporator cabin of cascade refrigeration system to increase the overall thermal performance of the system. COP of 5 different cases are compared relative to the COP of normal cascade refrigeration system. Out of five cases increment of COP is 44.08% in case of cascade system with Al chamber compared to normal system's COP.
Keywords: COP, PCM, Al, cascade refrigeration system

I. INTRODUCTION

Cascade refrigeration system generally works in the range of 233K to 193K , especially used in supermarket refrigeration or any other industrial applications. It is not possible to attain these temperatures with single-stage cooling system A cascade refrigeration system is a multistage application in which two separate refrigerant systems are connected in such a manner that one provides the means of heat rejection (condenser) for the other. The lower system may, therefore operate at a much lower temperature. Cascade system has the additional feature, over compound systems of permitting the use of different refrigerants in each cycle of the cascade. Phase change materials (PCM) are substances with high latent heat storage that melts and freezes at constant temperature, releases large amount of energy during freezing (discharging) and absorbs large amount of energy of energy during melting (charging).

Generally PCM makes contact with the outside surface of the refrigerator's evaporator. But to avoid modification of the system. I have used simple method of introducing the PCM material inside the low side evaporator in a rectangular box of G.I sheet and Al sheet. PCM box makes contact with evaporator tubes from inside of the evaporator cabin and in one case rectangular Al chamber is introduced into the cabin which makes gap between the inner surface of evaporator and outer surface of Al chamber. So this gap or void is filled with PCM which ensures complete and direct contact of PCM with evaporator tubes.

II. LITERATURE REVIEW

K.Azzouz et al. [1] has presented a first step in the design of an improved refrigeration system using phase change material. In this paper a 5mm thick slab of water is used as PCM on one side of the evaporator of a household refrigerator. There is a significant increase of efficiency due to enhanced heat transfer. K.Azzouz et al. [2] this paper presents a simplified dynamic model based on differential equations and is developed for predicting the energy impact due to addition of the PCM. This model predicts a 5-15% increase in coefficient of performance, a significant decrease in the number of starts and stops of the compressor and consequently of the temperature fluctuations inside the refrigerator cell. K.Azzouz et al. [3] Results indicate that response of the refrigerator to the addition of PCM and its efficiency are strongly dependent on the thermal load. The integration of latent heat storage allows 5-9h of continuous operation without electrical supply to be compared to 1-3h without PCM and a 10-30% increase of COP, depending on thermal load. The system has been tested with water and with a eutectic mixture(freezing point 270K).

E.Oro et al. [4]A commercial PCM was selected (Climsel-18) with a melting temperature of 255K, which is contained in 10mm thick stainless steel panels placed at different locations in the freezer. During 3h of electrical power failure , the use of PCM maintained the freezer temperature 4-6 degree Celsius lower and that of the frozen products remains acceptable levels for much longer time. This fact demonstrates that PCM could maintain interior freezer temperature almost constant for much longer than 3h of power loss. Rezaur Rahman et al. [5]water is used as PCM in domestic refrigerator, it is found that the 18-26% COP improvement has been achieved by the PCM in respect without PCM in a domestic refrigerator. A.C.Marques [6] Intergration of 5mm PCM slab into the refrigerator allowed for 3-5h 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.

R. Elarem [7]in this work, a novel design of a PCM heat exchanger was made. Based on this design, an experimental studies in order to minimize the energy consumption of the household refrigerator. The experimental results show that under the standard test conditions, the power consumption of the household refrigerator with PCM heat exchanger is reduced by 12% and the COP is increased by 8% compared to the refrigerator without PCM.

III. EXPERIMENTAL

A. Apparatus

The experimental set up is as shown in the following figure. It consists of a two systems interconnected one is low side and another one is high side. Second figure shows the picture of low side's evaporator cabin with PCM.

Fig.1 Cascade refrigeration system experimental setup

Fig.2 Low side evaporator cabin with PCM

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TABLE 1
DIMENSIONS OF PCM CONTAINER

Material	Box No.	Breadth (cm)	Height(cm)	Thickness(cm)
Galvanised iron	1	15	21	2
	2	15	21	2
	3	15	21	2
	4	15	21	2
	5	33	21	2
Galvanised iron	1	15	21	3
	2	15	21	3
	3	15	21	3
	4	15	21	3
	5	33	21	3
Aluminium	1	15	21	2
	2	15	21	2
	3	15	21	2
	4	15	21	2
	5	33	21	2
Aluminium(with fins)	1	15	21	2
	2	15	21	2
	3	15	21	2
	4	15	21	2
	5	33	21	2
Aluminium	1	53	23	21

B. Experimental procedure

High side system is started for 20 minutes and after that low side system is started and just before stopping the system we have to take the pressure and temperature readings from both high and low side, from these values we calculate COP of the system. Two K-type thermocouples are inserted in each PCM box to take down the temperature readings of the PCM.

COP values are calculated using p-h chart. R-23 p-h chart for low side readings and R-404a p-h chart for high side readings.

C. Data reduction

Formula for COP-

$$COP = \frac{Refrigerating\ effect}{Work\ done} = \frac{h1-h4}{h2-h1}$$

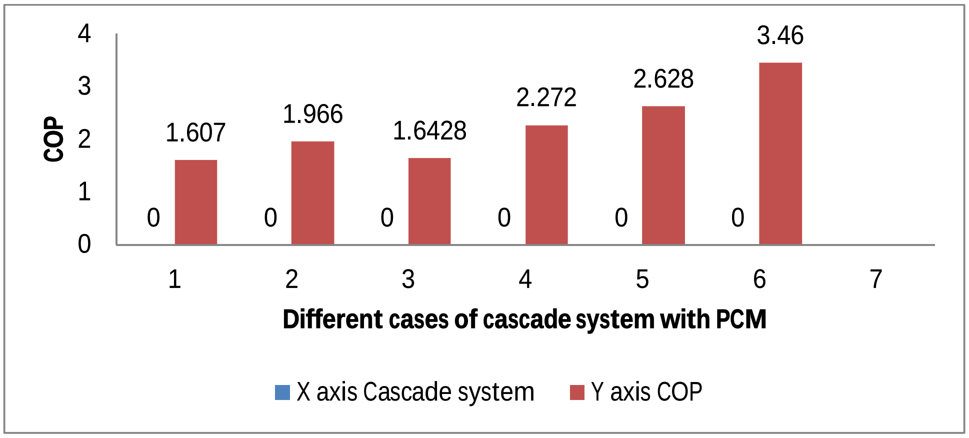
Where h1, h2, h4 are enthalpy at inlet of compressor, inlet of evaporator and outlet of compressor

IV. RESULTS AND DISCUSSIONS

A. Comparison of COP for different cases of cascade system with PCM:-

TABLE 2
COP for different cases

Sr. No	Different cases of cascade system with PCM	COP
1	Without PCM	1.60
2	2 cm G.I sheet box with PCM	1.96
3	3 cm G.I sheet box with PCM	1.64
4	2 cm Al sheet box with PCM	2.27
5	2 cm Al sheet box of fins with PCM	2.62
6	Al chamber with PCM	3.46



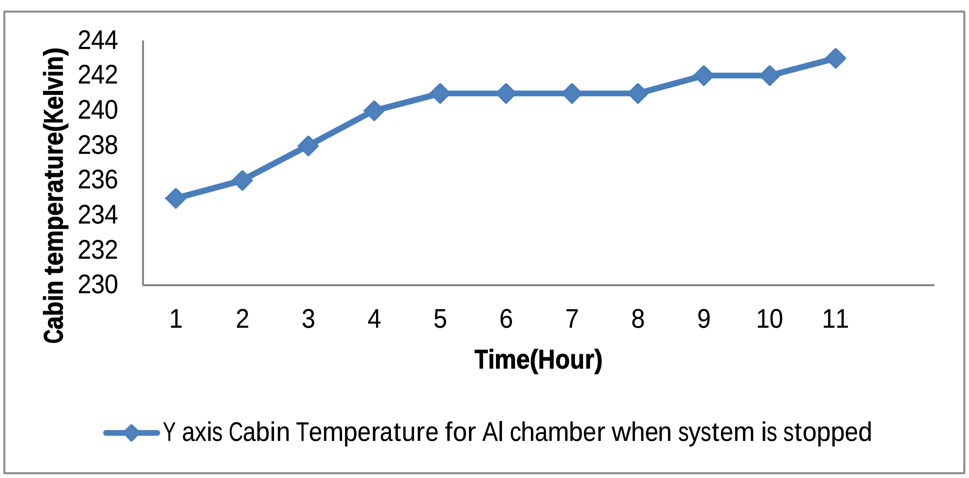
COP in each case increases compared to the COP of normal cascade system, for the case of Al chamber COP increment is highest i.e, 44.08%.

B. Cabin temperature vs Time when system is stopped for the case Al chamber as a PCM container:-

TABLE 2

Cabin temperature vs Time

Time (Hours)	Cabin Temperature for Al chamber when system is stopped(Kelvin)
1	235
2	236
3	238
4	240
5	241
6	241
7	241
8	241
9	242
10	242
11	243



From the results we can see that temperature of evaporator cabin is constant at 241K for 4 hours due to PCM which ultimately reduces compressor on-off cycle.

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V. CONCLUSIONS

System with Al chamber maintains temperature range from 233K to 243K over a period of 11 hours compared to 35 minutes for normal cascade system. COP of the system with Al chamber is 3.46 which 44.08% more compared to normal system's COP.

Hence in my research PCM is useful maintaining low cabin temperature for longer period of time without electrical supply. Compressor life increases and overall COP of the cascade system increases for all the five cases.

VI. ACKNOWLEDGMENT

The authors wish to acknowledge the funding support received from TEQIP PHASE -3 by GCE karad.

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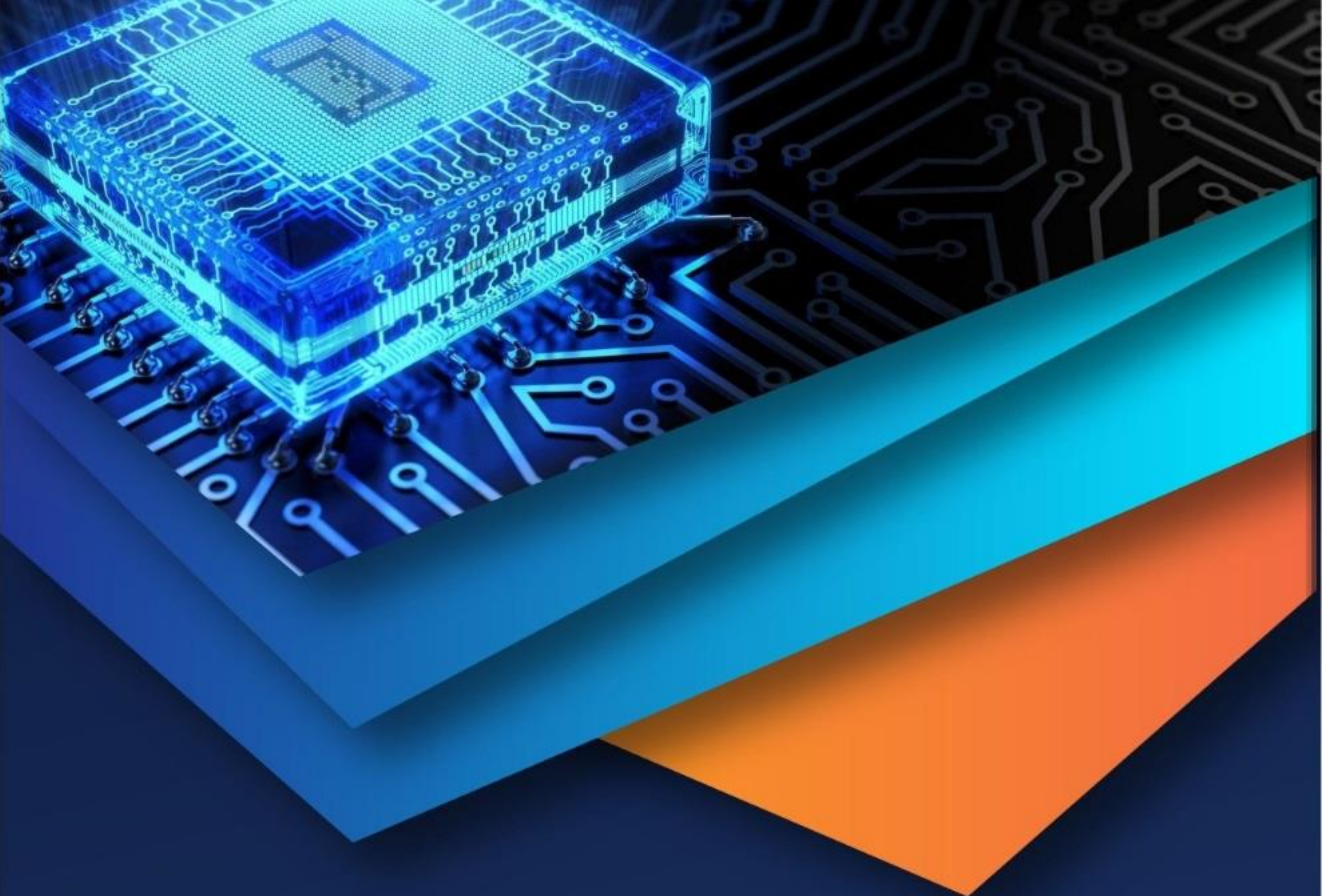

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