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Use of Phase Change Materials to Improve the Performance in Direct Cool Refrigerators

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ABSTRACT-- **Going greener growing better, refrigeration and air conditioning are necessary for life and will continue to expand worldwide. Its impact on environment is huge and also can be used to mitigate environmental issues. One of the crucial and constant research now-a-days is how to improve refrigeration effect at the same time reduce the co_2 and associated emissions. The main reason of using phase change materials (PCM) is to enhance the coefficient of performance of the system. These phase change materials when installed around the freezer section (evaporator) would help to reduce the overall electrical consumption.**

Keywords: *Domestic refrigerator, COP, Phase Change Material (PCM)*

I. Introduction

There has been reasonable demand now-a-days for the development of greener refrigeration technologies. Rising and fluctuating prices of fuel ultimately give a higher electricity cost .A growing global environmental awareness and the rising costs of energy are driving the demand for the development of sustainable cooling technologies. In INDIA itself cold appliances are responsible for 17% of average domestic electricity use.Worldwide it has been estimated that there are approximately 1 billion domestic refrigerators in use, although the emissions out from the refrigerators have been greatly reduced by using various environmental friendly refrigerants the real grave problem is the emissions let out during generation of electricity. Various eco-friendly refrigerants like R134a have been already replaced but still developing a sustainable refrigeration system is the rising need for hour.

The compressor among the components is the largest electricity consuming device. Approximations suggest that nearly 40% of energy is being consumed by the compressor. Various researches are especially oriented with a view to reduce the electrical consumption of the compressor and at the same time also get the desired refrigeration effect.

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 use of PCM in domestic refrigerators would be an ideal solution to save energy up to 60%. However the technology of PCM is in the primitive. stages as it is uneconomical and requires a lot of analysis .Most of the household refrigerators that have been used are made to load and run above the recommended usage.The market review past 25years have proven that most of refrigerators have been operated at temperatures above 5 degree Celsius. Usually there are two types of refrigerators in the market namely direct cool refrigerators using the natural convection system of cooling and forced convection systems. Temperature stability is achieved far better in the forced convention system which is frost free.

II. Literature Reviews

Refrigeration systems form to be one of the essential subjects in the field of mechanical engineering. Conserving energy and at the same time obtain the desired refrigeration effect is the challenging part and need of the hour. These materials have great potential to reduce the work load acting upon the compressors and save a considerable amount of energy.

Pradip Subramaniam and Chetan Tulapurkar [2,3,4] have conducted experiment upon the actual designing of novel dual based refrigeration systems. The experiment was performed upon a domestic refrigerator by installing the phase change materials. The PCMs were used as thermal storage units. By using these PCMs as thermal storage units a new sub cooling routine system was introduced. The ultimate aim of this experiment was to improve the coefficient of performance and reduce the running time of compressor. With unique designing methods. Pradip Subramaniam and Chetan Tulapurkar designed a new refrigeration cycle with phase change materials as thermal storage units and the overall food quality used in refrigerators was improved. The results obtained by them were promising Pradeep Subramaniam and Chetan Tulapurkar found out that the refrigeration cycle balance was achieved for both during charging and discharging and also the total gas quantity was properly balanced. One good aspect of the test results was that the food temperatures were more stable for fresh food and especially for the freezer section during the on / off cycling. The PCM based refrigerator in comparison to the conventional refrigerator was effective. This means that PCM is effective in bringing down the fluctuations in the fresh food temperature, which is invariably seen in either single or dual evaporator systems without PCM.

Md. Imran Hossen Khan and Hasan M.M. Afroz [5,7] found out that the main problem encountered in domestic refrigerator was of the food quality & weight. The food quality was significantly changed with temp fluctuations due to on-off cycle of compressor.To eliminate the above problem Imran Hossen Khan and Hasan M.M Afrozperformed the experiments on domestic refrigerator at different thermal loads to reduce the fluctuations in evaporator cabinet by using two different PCM materials(Water and Eutectic solution (90% H_2O + 10% NaCl). As per Md Imran et-all phase change material (PCM) is a latent heat thermal energy storage system which melts and solidifies at a certain temperatures. During the phase change process the material is capable of storing and releasing large amounts of heat energy and that’s why it is called as a heat storage system (LHS).The PCM was placed around the five sides of the evaporator cabinet in which the evaporator coil was immersed. The experimental results with PCM confirm the notable reduction of the fluctuation of the cabin temperature at lower load but at higher load this effect is not so encouraging. Between two PCMs, the Eutectic solution was better than water. This reduction of temperature fluctuation ultimately improves the food preservation quality of the refrigerator. They used PCM material as distilled water and also various Eutectic Solutions. Results obtained were that the use of PCM in a household refrigerator decreases the fluctuations of the cabinet temperatures. By comparing the two PCMs in terms of temperature fluctuations they found out the Eutectic solution is better than water. At higher thermal load this effect is not so encouraging.

Boussinesq [3,4] et-all performed experiments on how to reduce the electrical consumption of a refrigerator system using the phase changing materials. This experiment was conducted on a domestic refrigerator using some ice slabs which were kept in contact with the evaporator section. The results and calculations have proven that the refrigerator couldbe operated without power supply for a period of 9 to 10 hours. Also in order to compare the isentropic efficiencies the compressor performance for different displacements was also carried out. Further the refrigerator efficiency was calculated.Boussinesq et-all also found out by using the computational fluid dynamics the actual simulations of the airflow inside the refrigerator were determined for both of horizontal and vertical placement of the PCM.The results obtained by them were very conclusive. The CFD model predicted the airflow and temperature distribution within the thermal storage refrigerator. Also a horizontal PCM configuration was found to be more effective than a vertically placed PCM. For the horizontally placed PCM, the CFD predicted temperatures were compared with experimentally measured value and were found to be in close agreement. Both the simulation and the experiments results suggested that a eutectic with a phase change temperature below 0°C would be ideal.

Mahmood Mastani Joybari and Fariborz Haghigh[1] conducted the work of showing numerous of applications of Phase Change Materials especially in the domestic refrigerators. Various advantages and disadvantages were discussed by them. The work conducted by them have concluded that when these phase change materials are kept in direct contact with the naturally cooled evaporator are more effective. However if such a evaporator is being immersed in the phase change material compartment a higher resistance will be created around the evaporator which directly will increase the on off cycle time of the compressor. The phase change material used was water eutectic paraffin having a melting point of 37 degree Celsius. The results were promising but still some modifications are required in the research of PCM refrigeration .The PCM materials were not efficient in condenser because it doesn’t give any promising results. By comparing advantages and disadvantages of PCM material installation in evaporator and condenser section has some mutual relation between them.

Rezaur Rahman and Adnan Hasan[5] conducted an experiment for improving the coefficient of performance by installing the phase change materials. In the experiment performed, around 20-28% COP improvement of the refrigeration cycle was been observed with installing PCM with respect to without PCM. Here the phase change materials were used in chamber built manually and which surrounds the evaporator chamber of refrigerator. So the heat transfer rates in evaporator section increases the performance of refrigerator. The experimental results with PCM confirm that depending upon the thermal load and the type of PCM used, it will show a significant reduction in the compressor running time as compared to the evaporator section without PCM. The material used was distilled water having the known value of latent heat of fusion. The results imposed by them showed that use of water as PCM imposes a great improvement in COP at certain thermal load. For a particular time phase until the PCM melts completely the desired temperature of the product can be maintain during the off cycle of the compressor which ultimately increase the off period of the so it will decrease the energy consumption by refrigerator.

Hence by various such reviews and analysis of the researchers we can conclude that the use of phase changing materials although is challenging yet they are worth useful. Use of such materials is a rising need of the hour. One cannot always depend and believe that energy is available in plenty. There always has to be an alternative for sustaining life and sustaining energy.

III. The Different Types Of Phase Change Materials

TABLE I
SALT HYDRATE PCM

Sr no.	Phase changing material	Melting point (0^0c)	Heat of fusion (KJ/Kg)
1.	$Zn(NO_3)_2.6H_2O$ (Zinc nitrate hexahydrate)	36.2	246.5
2.	Mn $(NO_3)_2.6H_2O$ (Manganese nitrate hexahydrate)	25.8	125.9
3.	$Cacl_2.6H_20$ (Calcium chloride hexahydrate)	29.0	190.8
4.	$CaBr_2.6H_2O$ (Calcium bromide hexahydrate)	30.2	115.5
5.	$LiNo_3.6H_2O$ (Lithium nitrate hexahydrate)	30.0	296
6.	$Na_2SO_4.10H_2O$ (Sodium sulphatedecahydrate)	32.4	254
7.	$Na_2CO_3.10H_2O$ (Sodium carbonate decahydrate)	34.2	146.9
8.	$Na_2HPO_4.12H_2O$ (sodium orthophosphate dodecahydrate)	35.5	265
9.	$KF.4H_20$ (Potassium fluoride tetra hydrate)	18.5	231

TABLE II
ORGANIC PCM'S

Sr.no	Phase change material	Melting point (0^0c)	Heat of fusion (KJ/Kgk)
1.	$CH_3(CH_2)16COO(CH_2)_3CH_3$ (Butyl stearate)	19	140
2.	CH_3 $(CH_2)12COOC_3H_7$	19	126
3.	CH_3 $(CH_2)12OH$ 1-tetradecanol	38	205
4.	CH_3 $(CH_2)(CH_3$ (Paraffin)	20-60	200

IV. Method of selection of PCM materials

4.1According to thermo- physical properties,

The melting point of a PCM must be lying in a practical range of operation.

The latent heat should be as high as possible to minimize the physical size of the heat storage.

According to the physical properties, it must have limited changes in density to avoid problems with storage tank, low vapour pressure, favorable phase equilibrium.

4.2According to chemical properties,

A suitable material should be non-toxic, on flammable, non-corrosive.

V. Experimental Set Up

Experimental setup is shown in fig. 1 having specifications as follows:
Refrigerator is of Whirlpool Company.

- Compressor Model – THK1340
- Refrigerator Gross Capacity – 175lts.
- Power Input – 94w
- Current – 0.8A
- Refrigerant Charge with AMT – 85
- Refrigerant Type – R134a
- Voltage Limit

NORMAL	MINIMUM	MAXIMUM
230V	160V	260V
50HZ		

Refrigerant R-134a

- It is haloalkane refrigerant with thermodynamic properties similar to R-12 but with less ozone depletion potential.
- Its Chemical formula is CFH2CF3.-Tetraflurethane
- No chlorine

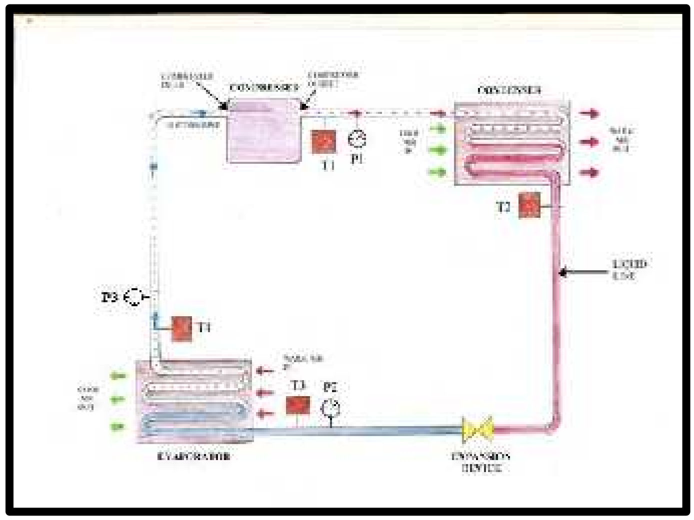

Fig. 1Experimental set up

A The Main Working Area

The main working area is evaporator section which is shown in the fig 2.

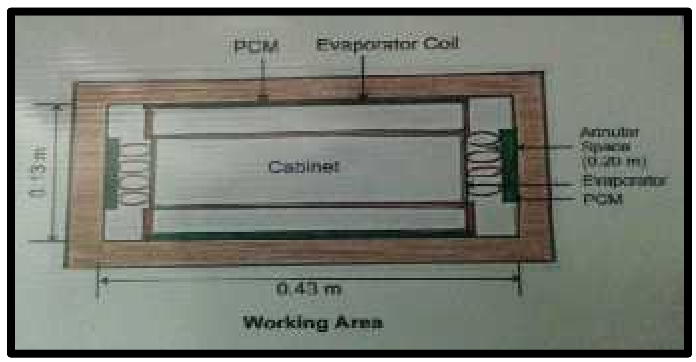

Fig. 2 Main working Area

VI. Procedure

Experiment was performed for one hour. Following is the procedure of the experiment -

- Switch on the main switch.
- Let the stable conditions of the refrigerator be achieved
- Then after one hour take the temperature and pressure readings.
- Then calculate the COP of the system and note down the energy meter

reading and do the power consumption calculations without PCM materials.

Total we were having 500ml of PCM material. So we have divided it in to 4 four parts.

Then carry out the same procedure for all four sets with PCM.

VII. Methodology

Methodology 1 represents calculating the COP which is shown in fig 3.

And Methodology 2 represents energy consumption & it's cost which is shown in fig 4.

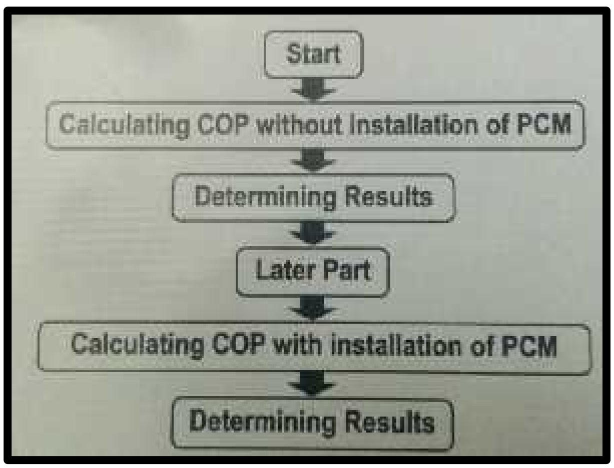

Fig.3 Methodology 1

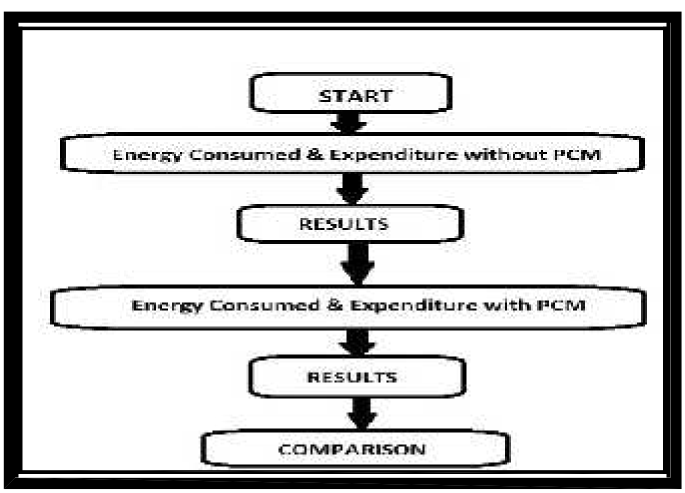

Fig. 4 Methodology 2

Calculation of actual COP without PCM

Step 1:

Power input= m x work input

m = Power input / work input

m = 0.1 / (425-386)

m = 2.56 x 10-3 Kg/sec

Step 2:

Refrigerating capacity = m x Refrigeration effect

R.E.= (h1 - h4)

R.E.= 130 KJ/Kg

Refrigeration capacity = 2.56 x 10-3x130

R.C. = 0.333kw

Q = 0.0946 TR

Step 3:

Actual COP = 3.5 x Q / m x cpx (Tmax-Tmin)

Actual COP = 2.40

Power Consumption & its cost per month without PCM

Power consumed in one hour = 0.1kw

Power consumed in one day = 0.1 * 24

= 2.4 kwh/day

Power consumed per month = 2.4 * 30

= 72 kwh/month

Now,

If we consider Rs3 cost for 1kw-hr (kwh)

Electricity cost per day = 2.4 * 3

Electricity cost per day = 7.2 Rs

Electricity Cost per month = 7.2 * 30

Electricity Cost per month = Rs 216

Calculation of actual COP for 125ml phase change material

Observation table for compressor ON-OFF period

SR.NO.	TIME	COMPRESSOR ON (MIN)	COMPRESSOR OFF (MIN)
1.	12:48 PM – 01:11 PM	23:00	–
2.	01:11 PM - 01:41 PM	–	30:00

Experiment was carried for 1 hour [60min]

Calculations:

Pc= 145 psi ,Tc=50oc

Pe= 1.22 bar, Te= -4.1oc

Step 1:

Power input= m x work input

m = Power input / work input

where,

WI =(h2 - h1) = (425-386) = 39 KJ/kg

m=0.075/39

m=1.9234 x 10-3 kg/sec

Step 2:

Refrigerating capacity = m x Refrigeration effect

R.E.= (h1 - h4)

R.E.= 130 KJ/Kg

Refrigeration capacity = 1.92 x 10-3x130

R.C. = 0.25 kw

Q = 0.071075 TR

Step3:

Actual COP = 3.5 x Q / m x cpx (Tmax-Tmin)

Actual COP = 2.40

Power Consumption & its cost per month with PCM

Power consumed in one hour = 0.075kw

Power consumed in one day = 0.075 * 24

= 1.8 kwh/day

Power consumed per month = 1.8 * 30 = 54 kwh/month

Now,

If we consider Rs3 cost for 1kw-hr (kwh)

Electricity cost per day = 1.8 * 3

Electricity cost per day = 5.4Rs

Electricity Cost per month = 5.4* 30

Electricity Cost per month = Rs162

VIII. COP (Coefficient Of Performance)

- Calculation of COP and calculation of efficiency depends upon the required output.
- If the required output is in the form of heat then we need to calculate COP
- In case of Refrigerators and AC systems the output is always in the form of heat and hence COP.
- Higher the value of COP lower is its operating cost.

$$COP = \frac{\text{Refrigeration effect}}{\text{Work input}}$$

IX. Results

- Ideal COP without PCM is 4.99
- Theoretical COP without PCM is 3.33
- Actual COP without PCM is 2.40.
- Actual COP with PCM (125ml) is 2.40

X. Conclusion

Use of phase changing materials is indeed useful and will significantly contribute to society in saving energy. Due to its appreciable thermo physical properties it has various uses. Use of phase change materials will indeed save electricity and also improve the quality of food in terms of hygiene by reducing the fluctuations of temperatures in the evaporator section. It was observed that there is no significant change in COP value but the performance has improved in terms of saving in electricity by using 125 ml PCM material for the refrigerator we have used in our experiment. Bottom-line we can conclude that phase changing materials are indeed useful serving elements in the refrigeration industry.

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