



IMPROVING THE COEFFICIENT OF PERFORMANCE (COP) IN DIRECT COOL REFRIGERATORS USING PHASE CHANGE MATERIALS (PCM)

Kavita Dhanawade¹, Suprabhat Mohod², Yash Gokhale³,
Akshata Namjoshi⁴, Meghana Patil⁵, Sneha Keluskar⁶, Pratik Hande⁷

^{1,2} Asst. professor, Department of Mechanical Engineering, Lokmanya Tilak College of Engineering,
Koparkhairane, Navi Mumbai, Maharashtra (India)

^{3,4,5,6,7} Department of Mechanical Engineering, Lokmanya Tilak College of Engineering,
Koparkhairane, Navi Mumbai, Maharashtra (India)

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 CO₂ 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

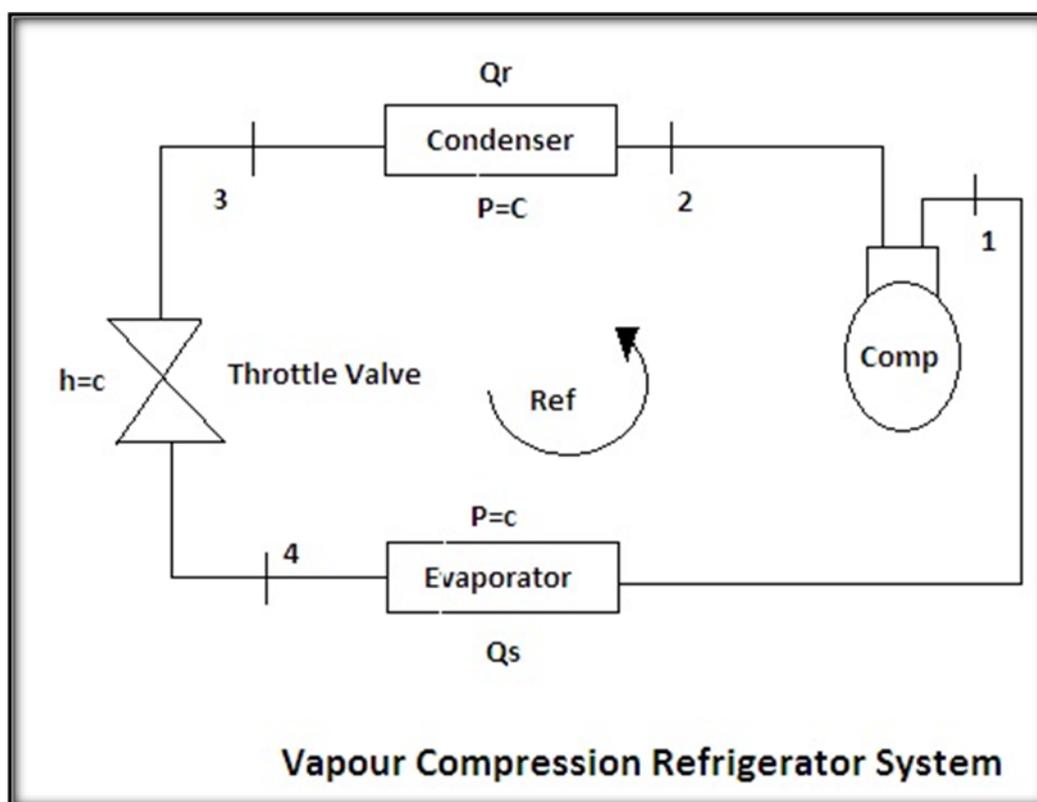
There has been reasonable demand now-a-days for the development of greener refrigeration technologies. Rising and fluctuating prices of fuel ultimately give a higher electricity cost. A growing global environmental awareness and the rising costs of energy are driving the demand for the development of 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 25 years 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 convection system which is frost free.

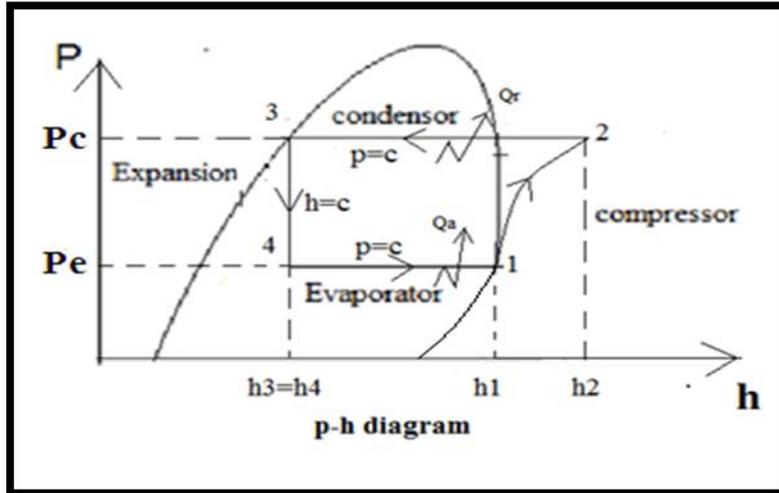
II. COMPONENTS OF REFRIGERATOR AND THE REFRIGERATION CYCLE

2.1 General Block Diagram Representation



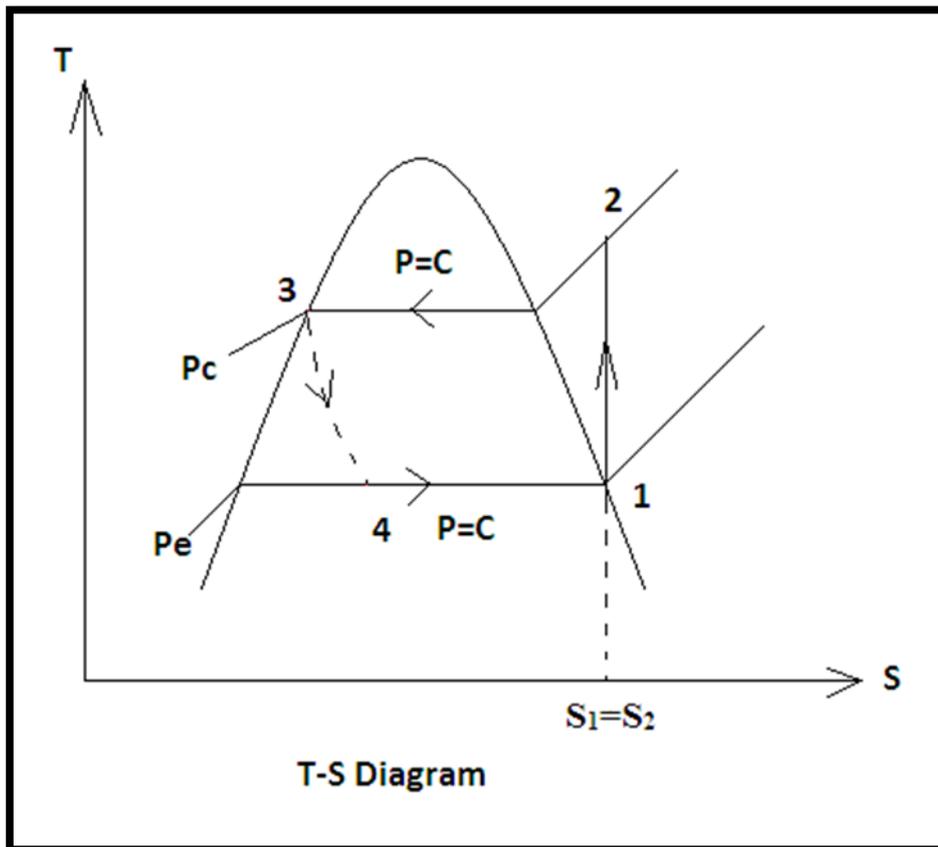
(Fig. 2.1)

2.2 The P-H Diagram of Refrigeration Cycle



(Fig.2.2)

2.3 The T-S Diagram of Refrigeration Cycle



(Fig 2.3)

Where,

$P_c = P_2 = P_3 = P_4 =$ condenser pressure

$P_e = P_1 = P_2 = P_4 =$ evaporator pressure



III. THE DIFFERENT TYPES OF PHASE CHANGE MATERIALS ARE

3.1 Inorganic PCM'S

3.2 Organic PCM'S

3.1 Inorganic pcm's

Salt hydrate PCM (Typical values) [6]

Sr no.	Phase changing material	Melting point (0°c)	Heat of fusion (KJ/Kg)
1.	Zn(NO ₃) ₂ .6H ₂ O (Zinc nitrate hexahydrate)	36.2	246.5
2.	Mn (NO ₃) ₂ .6H ₂ O (Manganese nitrate hexahydrate)	25.8	125.9
3.	Cacl ₂ .6H ₂ 0 (Calcium chloride hexahydrate)	29.0	190.8
4.	CaBr ₂ .6H ₂ O (Calcium bromide hexahydrate)	30.2	115.5
5.	LiNo ₃ .6H ₂ O (Lithium nitrate hexahydrate)	30.0	296
6.	Na ₂ SO ₄ .10H ₂ O (Sodium sulphatedecahydrate)	32.4	254
7.	Na ₂ CO ₃ .10H ₂ O (Sodium carbonate decahydrate)	34.2	146.9
8.	Na ₂ HPO ₄ .12H ₂ O (Sodium orthophosphate dodecahydrate)	35.5	265
9.	KF.4H ₂ 0 (Potassium fluoride tetra hydrate)	18.5	231



3.2 Organic pcm's

Organic PCM'S (Typical values)[6]

Sr.no	Phase change material	Melting point (0 ⁰ c)	Heat of fusion (KJ/Kgk)
1.	CH ₃ (CH ₂) ₁₆ COO(CH ₂) ₃ CH ₃ (Butyl stearate)	19	140
2.	CH ₃ (CH ₂) ₁₂ COOC ₃ H ₇	19	126
3.	CH ₃ (CH ₂) ₁₂ OH 1-tetradecanol	38	205
4.	CH ₃ (CH ₂)(CH ₃) (Paraffin)	20-60	200

IV. METHOD OF SELECTION OF PCM MATERIALS [6]

4.1 According 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.

4.2 According to chemical properties

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

V. 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.



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

VI. 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.

PradipSubramaniam and ChetanTulapurkar [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 methodsPradipSubramaniam and ChetanTulapurkar 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 ChetanTulapurkar 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 Afroz performed 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% H₂O + 10% NaCl)). As per Md Imran et-al 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-al 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 could be 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-al 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 Haghghi [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 an 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.

VII. CONCLUSION

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.

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, improve the coefficient of performance and also improve the quality of food in terms of hygiene by reducing the fluctuations of temperatures in the evaporator section. The over-all purpose of using these phase change materials in the refrigerator is been proved above in various research which include detail analysis and calculations. Bottom- line we can conclude that phase changing materials are indeed useful serving elements in the refrigeration industry.

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