Performance Analysis of VCRS with Modified Evaporator using PCMC and Measure the COP

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Abstract - *One of the most common types of machines which are used in a domestic life, medicine, agriculture, dairy and all other cooling purpose is a refrigerator. Domestic refrigerator is a common household appliance which works on Vapor compression refrigeration system using refrigerant liquid flowing through all parts of system with phase change due to heat absorption or heat release. Studies show that the performance of refrigerator depends on various factors like frequency of door opening, type of refrigerant used, surrounding conditions, design and specifications of various system parts. If performance reduces then more energy will be required to drive compressor and it will increase running cost of refrigerator. Generally, the energy consumption of a refrigerator device depends upon various factors like efficiency of components, surrounding temperature, thermal load, frequency of door openings, set- point cooling temperature in its compartment(s), and type of refrigerant. [1] Hence improving the efficiency of a refrigerator should be given prime consideration. Using PCM in a domestic refrigerator can enhance the performance effectively.*

Key Words: **Coefficient of Performance (COP), PCM, TES, PCMC**

1. INTRODUCTION

Now-a-days in a world, the most crucial problem is energy crisis. Non-conventional energy systems are developing to meet the need of energy generation. Although energy is produced in large extent but due to various losses the energy losses take place which reduce the performance of systems and various devices. Refrigerator is one of the widely used cooling devices in all fields of engineering applications. The COP and energy consumption of refrigerator depends on various factors. Many methods and refrigeration systems are available to increase the coefficient of performance of refrigerator like adding flash chamber, reducing compressor work, using accumulator, sub-cooling of liquid refrigerant, cooling of condenser by some constructive arrangements but there are some drawbacks in such methods. One of the latest methods is to use energy storage system in refrigerator. The Thermal Energy Storage (TES) is one of the most effective technology for cooling applications. If a latent heat thermal energy storage system is to be used for application, the selection of the phase change material (PCM) and heat transfer mechanisms in the PCM will be the main governing factors of performance of system [1]. TES can be possible for both heating and cooling applications using different methodologies. The use of PCM in refrigeration and cold storage systems will result in higher heat storage capacity and more isothermal behavior during melting and freezing of refrigerant compared to sensible heat storage. The substances used for phase change material can be organic such as paraffin and fatty acids, or inorganic such as aqueous salts solution.

In the current article, PCM is used in domestic refrigerator to investigate the effect on COP.

1.1 Energy Storage System

Energy storage has become an important part of renewable energies such as solar radiation, ocean waves, wind, and biogas power plants. Thermal energy storage (TES) is a technology which stores thermal energy of a working fluid so that the stored energy can be used for heating and cooling applications. TES found its place in thermodynamic systems. Thermal energy storage can be implemented either by using sensible heat storage or latent heat storage for a specific application. [2] The complete cycle of a storage system consists of 3 stages: charging, storing and discharging. For sensible heat storage system the materials suitable are liquid (water, oil) and solid (rocks, concrete, and metal). The most common sensible energy storage systems are tank, pit, and bore hole and aquifer thermal energy storage. Heating a substance until a change in phase is experienced is known as latent heating. Typical latent heat storage materials consist of paraffin, salt hydrates ($NaNO_3$, KNO_3, $NaNO_2$, etc.) and others salts. In case of latent heat storage system the capacity of storing heat is at almost similar temperature range. [4]

1.2 Phase Change Materials

Thermal Energy Storage by using Phase Change material in the field of air conditioning and refrigeration is widely used at Industrial scale. [6] A *phase-change material (PCM)* is a substance having high heat of fusion which, stores and releases large amounts of energy by melting and solidifying at a certain temperature. [7] Latent heat storage of PCM in any application can be done through solid to solid, solid to liquid, solid to gas and liquid to gas phase change. The phase change of PCMs is from solid to liquid phase.

PCMs offer a higher heat storage capacity which is associated with the latent heat of the phase change. [3]

1.3 Properties of Phase Change Materials

PCMs have

Thermo-physical properties (It should have high latent heat of transition and thermal conductivity, and density and volume variations of PCM during phase-transition should be, respectively, high and low in order to minimize storage volume) [5-7]

Kinetic and chemical properties (super-cooling of PCM should be limited to a few degrees, and construction materials should have long-term chemical stability, compatibility, no toxicity, and no fire hazard) [5-7]

Considering real applications in thermal energy storage system, the most common materials are paraffin's (organics), hydrated salts (inorganic), and fatty acids (organics). In cold storage, ice water is often used as PCM for better performance. [8]

PCM	Melting Temp (∘ c)	Melting Enthalpy (KJ/Kg)	Density (g/cm^3)
Ice	0	333	0.92
Na-acetate trihidrate	58	250	1.30
Paraffin	-5-120	150-240	0.77
Erytritol	118	340	1.30

Table -1: PCM Properties

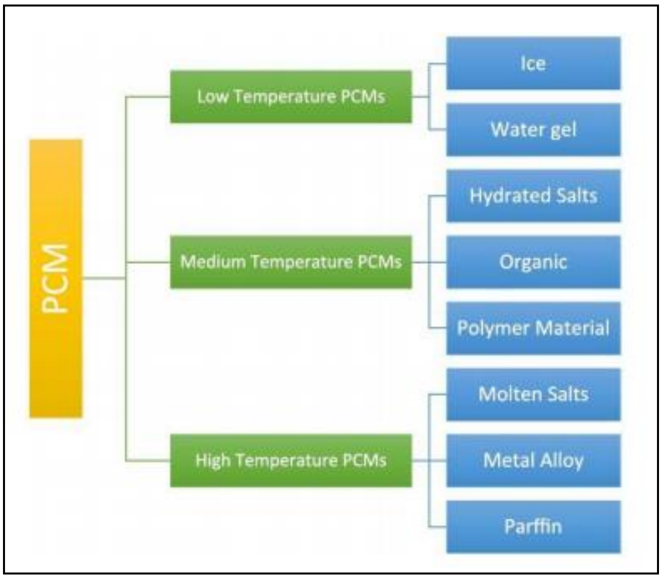

Fig -1. Types of PCM based on melting point

2. REFRIGERATOR WITHOUT PCM

The vapor-compression refrigeration system uses refrigerant liquid which absorbs and removes heat from the space to be cooled and further rejects that heat to surroundings. VCRS systems have four components: a compressor, a condenser, a Thermal expansion valve and an evaporator. Refrigerant enters the compressor at suction valve as a saturated vapor and is compressed to a higher pressure, resulting in a higher temperature as well. [9-10]

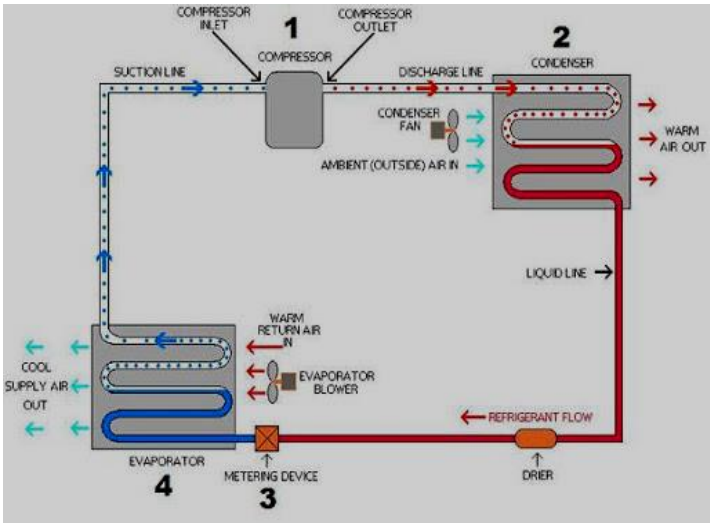

Fig -2: Working Principle of Household Refrigerator. [9]

3. REFRIGERATOR WITH PCM

The domestic refrigerator set up is constructed as per VCRS system and PCM is used in it across evaporator section to investigate the effect of PCM on COP.The refrigerant of the evaporator coil takes cabinet heat during compressor ON mode. If PCM is used around the evaporator section then it will take most of the heat by changing its phase from solid to liquid. The temperature remained constant until the melting process of PCM is finished. If the PCM is making contact with the evaporator coil the stored heat energy of PCM will be absorbed by the refrigerant through conduction method during compressor running. The conduction transfer of refrigerant flowing through system is faster than the natural convection heat transfer. In the conventional refrigerator the evaporator heat is absorbed by the refrigerant through natural convection. [8]

So the PCM will improve the heat transfer performance of the Evaporator also. [11]

4. EXPERIMENTAL SET UP

VCRS System: Refrigerator with R134a having mass of 140g. Compressor power was 1/8HP, Fan cooled condenser of length 10 m and capillary tube of 0.034 inch as expansion device.

Thermocouple: The temperature at various points like evaporator, condenser, and compressor of the system is measured using thermocouples. The thermocouples used for this experimental setup are Chromel-Alumel (known as K type thermocouples).

Pressure Gauge: The pressure gauges used in this experimental setup are of Bourdon tube type pressure gauges. Using copper tubes, the gauges are fixed on the board.

Digital Energy meter: In this VCRS experimental setup single phase digital energy meter is used for measuring the power input to the compressor which is fitted at the top of temperature, pressure display unit.

Display Unit: All the readings of temperature, pressure at various components are measured at the display unit.

Fig -3: Test Rig of Vapour Compression Refrigeration System with PCM

Fig -4: PCM used at Evaporator section

4.1. EXPERIMENTAL PROCEDURE

The liquid PCM is kept surrounding the evaporator compartment.

The evaporator chamber is designed in such way that it has storage space for PCM. When the VCRS system is started, compressor starts operating at the same time the liquid PCM releases the heat and become solid and the refrigerant takes the heat.

Modified Evaporator with PCM (to cover the evaporator and food cabinet) is shown in the figure 4. Temperature rises in the evaporator or food cabinet by placing new foods.

When this heat rises in thermostat temperature the compressor starts again and consumes electricity. In this condition the surrounded PCM takes the extra heat by convection heat transfer from the evaporator and keep it below the thermostat temperature. [8]This certainly increases the off-state of the compressor thus reduces power consumption and increase compressor and condenser life. [7]

5. DATA COLLECTION AND RESULT

The following data have been collected for each test run at the steady state condition of the system.

- P_1= Compressor suction/Evaporator

  Outlet pressure (bar)

- P_3=Evaporator Inlet Pressure (bar)
- T_1= Compressor suction Temperature (˚C)
- T_2=Compressor discharge/condenser Inlet

  Temperature (˚C)

- T_3=Condenser Outlet Temperature (˚C)
- T_4=Evaporator Inlet Temperature (˚C)
- t=Time

Time	Eva inlet Pr. P_1 bar	Cond out Pr. P_3 bar	Comp inlet Temp T_1 ˚C	Comp outlet Temp T_2 ˚C	Cond inlet Temp T_3 ˚C	Cond outlet Temp T_4 ˚C
10.10 am	0.29	9	27	50	33	17
10.25 am	0.42	8.6	29	53	36	17

10.40 am	0.41	9.1	28	58	37	19
10.55 am	0.48	9.7	27	61	37	18
11.10 am	0.53	10.2	27	65	39	21

Table -2: Experimental Data without Phase Change Material (PCM)

Time	Eva inlet Pr. P_1 bar	Cond out Pr. P_3 bar	Comp inlet Temp T_1 °C	Comp outlet Temp T_2 °C	Cond inlet Temp T_3 °C	Cond outlet Temp T_4 °C
10.10 am	0.46	11	30	56	48	22
10.25 am	0.62	11.5	31	59	49	23
10.40 am	0.69	12.4	33	63	53	25
10.55 am	0.77	12.8	34	65	58	27
11.10 am	0.97	14	35	68	59	30

Table -3: Experimental Data with Phase Change Material (PCM)

5.1 Effect on Coefficient of Performance (COP):

One of the parameters that used to compare performances of refrigerators is the Coefficient of Performance or COP.

COP of the refrigeration system is calculated using the formula

Coefficient of performance, COP = Q / W

Where,

Heat removed by evaporator, $Q_e = (h_1 - h_4)$ kJ/kg

Work done by the compressor, $W = (h_2 - h_1)$ kJ/kg

In order to find out enthalpy values we have pressures and temperatures of every points required.

So, the corresponding to pressure and temperature at various points of VCRS system the enthalpy values are obtained from the p-h chart.

The COP values obtained in VCRS system with PCM are higher as compared to COP values obtained in VCRS without PCM.

Number of observation	COP found in Vapor compression Refrigerator Without PCM	COP found in Vapor compression Refrigerator With PCM
1	6.11	9.74
2	5.52	9.38
3	6.08	9.41
4	5.48	9.02
5	5.63	8.85

Table -4: COP found in each test run without and with Phase Change Material (PCM)

5.2 Electrical energy consumption:

By use of PCM in VCRS system, the electric energy consumption is recorded on energy meter and the compressor running time also recorded. After several readings it is found that cut-OFF time is increased by 18 %, which resulted in a clear saving in the electrical energy consumption up to 25%.

In order to find this out, we have attached a digital wattmeter in the system setup.

Some amount of extra energy consumption is due to the fact that additional energy will be required for freezing the PCM. But, this slight increase in energy consumption is understandable because the compressor cut-OFF time period is increased by 18 % large enough to compensate for the small rise in electrical consumption during the compressor-ON period. [8]

6. CONCLUSIONS

1. Experiments were carried out on VCRS system under certain thermal loads with water as PCM. The pressure and temperature readings at various components are measured by using Bourdon tube pressure gauges and thermocouples fitted on setup.

2. Use of water as PCM in VCRS system resulted in a great impact on COP improvement at certain thermal loads. Using water as PCM and certain thermal load it is found that the 45-50%COP improvement is achieved by the PCM as compared to system without PCM in conventional refrigerator.

3. In case of VCRS system working without PCM, during the compressor running time the refrigerant takes the chamber heat by free convection, which is slower heat transfer process as compared to conduction process. But if VCRS refrigerator system is developed with PCM, most of the heat in the cabinet is stored in the PCM during compressor running time. Since the conduction heat transfer process is faster than the free convection process the cooling coil temperature does not require dropping very low to maintain desired cabinet temperature.

4. As per the obtained readings the evaporator works at high temperature and pressure with PCM. Due to higher pressure and temperature of refrigerant at the evaporator section the density of the refrigerant vapor increases, this resulted in higher heat removal rate from the evaporator than without PCM.

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