Performance Improvement of Domestic Refrigerator by Using PCM (Phase Change Material) and Refrigerant as a Blend of R290 and R600a

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ABSTRACT

A growing global environmental awareness and the rising demand for energy are driving the demand for the development of sustainable technologies. The modification of domestic cycle should be investigated to enhance the efficiency of the system. The paper investigates the performance improvement by a phase change material associated with the evaporator in a domestic refrigerator. The usage of PCM will help to improve the COP (Coefficient of performance). The use of phase change materials (PCMs) is an effective way of storing energy in the form of thermal energy. PCM materials have large amount of heat energy stored in them in form of latent heat. The heat energy associated with PCM is a natural phenomenon. The latent heat of the PCM can be used for various thermal energy storage applications. It has the advantages of high-energy storage density and the isothermal nature of the storage process. The paper deals with the energy analysis of mixture of propane and iso butane as a refrigerant. The energy consumption of the refrigerator during experiment with mixed refrigerant was measured. The lowest electric energy consumption was achieved using mixed refrigerant with heat level is less than -15oC. This mixture achieved higher volumetric cooling capacity and lower freezer air temperature. The effect of condenser temperature and evaporation temperature on COP, refrigerating effect, condenser duty, work of compression and Heat Rejection Ratio is investigated. The energy consumption and COP of hydrocarbons and there mixture shows that hydrocarbons can be used as refrigerant in the domestic refrigerator.

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1. INTRODUCTION

Vapour compression refrigeration system is a system which is used to transfer heat from low reservoir to the high reservoir by the use of a working fluid as a refrigerant. It is a system which uses high grade energy results in the increase of coefficient of performance. Vapor compression refrigeration system which consists of Compressor, Evaporator, and Condenser and Expansion valve. It has different size for the given capacity of refrigeration. This refrigeration system can be employed over a large range of temperatures and coefficient of performance of this refrigeration system is high. To further increase the coefficient of performance the PCM (Phase change material) can be used in the evaporator and to get the lowest temperature of evaporator the PCM can also be used. It has the main advantage of less running cost. Domestic refrigerators are among the most energy demanding appliances due to their continuous operation. The domestic refrigerator is found in almost all the homes for storing food, vegetables, fruits, beverages, and much more. Materials that can store thermal energy over long time period are often referred to as latent heat storage materials which are termed as PCM. Chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) have suitable properties, for example non flammability, low toxicity and material compatibility that have led to their common use by both consumers and industries around the world, and as refrigerants in air conditioning and refrigerating systems. Results from many researches states that this ozone layer is being depleted. The general consensus for the cause of this is that free chlorine radicals remove

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ozone from the atmosphere and later chlorine atoms continue to convert more ozone to oxygen. The presence of chlorine in the stratosphere results in the migration of chlorine containing chemicals. Propane, butane and isobutene are proposed as an environment benign refrigerant. Hydrocarbons are free from ozone depletion potential and also have negligible global warming potential.

Phase change materials (PCMs) are substances with high latent heat content that freeze and melt at nearly constant temperature, accumulating or releasing large amounts of energy during the process. The application of PCMs in domestic refrigerators is a novel solution with potential to improve the appliance thermal stability and efficiency. The cooling energy stored in the PCM can be used to cool the compartment, increasing the refrigerator energetic autonomy, when the power supply is off. The main objective is to utilize the latent heat of PCM for Thermal Energy Storage applications and also conduct an experimental investigation on the application of Phase Change Materials as Thermal Energy Storage System. These solid–liquid PCMs perform like conventional storage materials and they absorb heat as changing phase from solid to liquid and their temperature rises as they absorb the heat. Unlike the conventional (sensible) materials, PCM absorbs and release heat at a nearly constant temperature.

2. VAPOR COMPRESSION REFRIGERATION CYCLE (WITHOUT PCM)

The vapour-compression uses circulating liquid refrigerants which absorbs and removes heat from the space to be cooled and subsequently rejects the heat. Figure depicts a typical, single-stage vapour compression refrigeration system

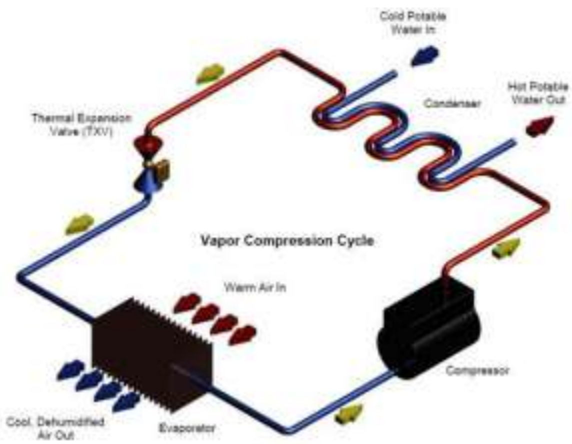

Fig-1: Vapour compression refrigeration system

Vapour compression refrigeration system such systems have four components those are, a compressor, a condenser, Thermal expansion valve (also called a throttle valve and Tx Valve), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state which is known as a saturated vapour and it is compressed to a higher pressure which results in a high temperature as well.

3. PCM MATERIAL

A *phase-change material (PCM)* is substance with a high heat of fusion in which melting and solidifying at a certain temperature is capable of storing and releasing large amounts of energy. Even though the thermal conductivity of phase change materials (PCM) is not high, it is sufficient to enhance the global heat transfer conditions of an evaporator with air as external fluid and natural convection used as heat transfer mechanism.

4. USING PCM AS A LATENT HEAT STORAGE

In the conventional household refrigerator the Compressor works in ON/OFF state. The refrigerant of the evaporator coil takes the cabinet heat during compressor ON state. If PCM is used in the cabinet, it will take most of the heat by changing its phase from solid to liquid. The temperature is constant until the melting process in done. Moreover, if the PCM is placed with the evaporator coil the stored heat energy of PCM will be extracted by the

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refrigerant through conduction method used during compressor on mode. The conduction transfer is faster than that of natural convection heat transfer. In the conventional refrigerator system cabinet heat is extracted by the refrigerant through natural convection. So the PCM will improve the heat transfer performance of the evaporator as well.

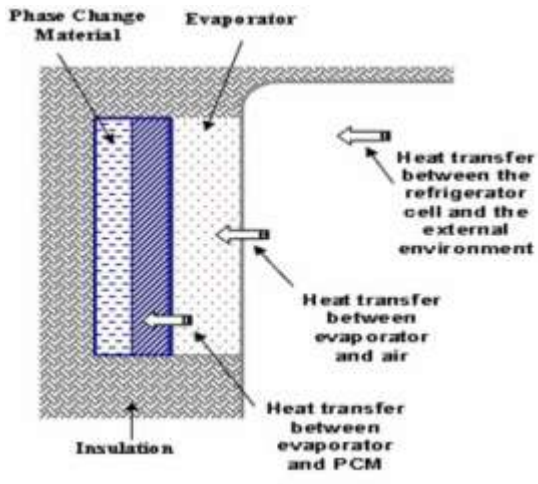

Fig-2: Schematic Model of the refrigerator with PCM

5. PROPERTIES OF ETHYLENE GLYCOL

Ethylene glycol is a clear, colourless, odourless, liquid with a sweet taste. It is hygroscopic and completely miscible with many polar solvents such as water, alcohols, glycol ethers, and acetone. Its solubility is low however, in non polar solvents, such as benzene, and chloroform. Following are some of the physical properties of ethylene glycol.

Boiling point at 101.3 kPa	197.60 °C
Freezing point	-13.00 °C
Density at 20°C	1.1135 g/cm³
Refractive index, n_D^{20}	1.4318
Heat of vaporization at 101.3 kPa	52.24 kJ/mol
Heat of combustion	19.07 MJ/kg
Critical temperature	372 °C
Critical pressure	6515.73 kPa
Critical volume	0.186 L/mol
Flash point	111 °C
Ignition temperature	410 °C
Lower explosive limit	3.20 vol%
Upper explosive limit	53 vol%
Viscosity at 20 °C	19.83 mPa.s
Cubic expansion coefficient at 20 °C	0.62×10^{-3} K^{-1}

Table-1: Name of the table

6. EXPERIMENTAL SETUP

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

Fig-3: Experimental Setup

7. EXPERIMENTATION

SR.NO	Time Interval (hrs)	Ethylene Glycol 90% +10 % water	Cabin Temperature
1.	00	23.90	25.70
2.	1.0	13.20	19.50
3.	2.0	7.30	14.60
4.	3.0	4.70	12.50
5.	4.0	2.40	11.90
6.	5.0	0.40	11.40
7.	6.0	-1.90	10.60
8.	7.0	-4.50	10.10
9.	8.0	-6.25	9.70

Table-2: Experimentation

Experimentation with PCM (Ethylene Glycol 90% & 10% Water) without product load:
During the experimentation power cut after 8 hours at that time PCM temperature was -6.25°C means PCM reach almost at solidify condition and cabin temperature was 9.7 °C. Observe PCM melting effect and cabin temperature increases accordingly till cabin temperature reaches 18.8 °C temperature.
Coefficient of Performance Sample Calculation for 7 hours
Evaporator temperature = -13.2°C
Evaporator outlet temperature = 28.2°C
Compressor outlet temperature = 64.5 °C

$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

$$\mathrm{COP} = \frac{569.5 - 168.72}{682.92 - 569.5} = 3.53$$

Experiment with PCM with load condition:

SR.NO	TIME INTERVAL	PCM TEMP	CABIN TEMP.
1.	00	2.70	6.30
2.	1.0	2.69	3.80
3.	2.0	2.30	4.30

4.	3.0	2.00	4.40
5.	4.0	2.20	4.70
6.	5.0	1.00	4.60
7.	6.0	-1.00	4.70
8.	7.0	-3.50	3.90
9.	8.0	-7.50	4.10

Table-3: Experiment with PCM with load condition

Coefficient of Performance Sample Calculation for 600 min
Evaporator temperature = -10.7°C
Evaporator outlet temperature = 24.8°C
Compressor outlet temperature = 57.9 °C

$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP = \frac{561 - 309.5}{638.43 - 561} = 3.24$$

8. RESULTS

The compressor power cut off at 8hs. After compressor power cut off again cabin temperature goes down by taking heat from ethylene glycol. Up to this graph shows temperature variation inside the cabin is in between 2°C to 5°C. After compressor shut down ethylene glycol maintain temperature inside cabin below 10°C for 15 hours and below 15°C for 20 hrs. Ethylene glycol provides uniform cabin temperature though the all cycle means temperature deviation is minimum which enables to enhance the life of vegetable foods. The temperature deviation in cabin is below 15°C for 20 hours so it will give great advantage over conventional domestic refrigerator for vegetable preservations in case of power failure.

9. CONCLUSION

The energy consumption of the R290 and R600a is about similar to the energy consumption of refrigerator when R134a is used as refrigerant. R290 and R600a offer lowest inlet refrigerant temperature of evaporator up to -22°C. So for the low temperature application R290 and R600a is better than R134a. This is an indication of better performance of R290 and R600a as refrigerants.

By using phase change material (PCM) sudden rise in temperature due to power failure can be retarded and can maintain constant temperature of 10 ºC for 27 hrs after compressor cut off. 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 10.6% as compared to without phase change material. The fluctuation of refrigerated space temperature is maintained with in working temperature range with the help of PCM material, during power failure.

As it is seen through experiment PCM is useful to maintain cabin temperature below 15 ºC for 27 hrs as compared to conventional refrigerator.

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