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Experimental Study on the Performance Analysis of Vapour Compression Refrigeration Test Rig with and without Phase Change Materials

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Abstract

The performance of heat transfer is the essential area of research in the field of thermal engineering. For the process of heat transfer, there are numbers of refrigerants which used in domestic refrigeration to transfer the heat from low-temperature reservoir to high-temperature reservoir. The vapour compression refrigeration technology has made a great improvement over a few decades in the form of the efficiency of cycle through significant efforts of thermal engineers and manufacturers. The modification of the cycle should be investigated to enhance the efficiency of the system.

In this paper, the experimental study is conducted to predict the comparison between the Simple VCR with and without Phase change materials such as potassium chloride solution, Ethylene Glycol. Hence the proposed system could be a new option for performance improvement of a VCR system by enhancing heat transfer of the evaporator with the help of Phase Change Materials.

Keywords: Vapour Compression refrigeration, coefficient of performance, phase change materials.

Introduction

Phase Change Material (PCM) is a material which absorbs or releases the maximum heat during its state change due to change in temperature. It uses chemical bonds to store and releases the heat. The energy transfer takes place when a material changes from a solid to a liquid or from a liquid to a solid which is called a change in state or phase. Ice is an excellent phase change material.

Phase Change Materials (PCMs) are able to change its state at constant temperature and therefore store large quantities of energy. The most commonly used PCM for are paraffin’s (organic), salt hydrates (inorganic) and fatty acids (organic) for technical applications. For cooling applications, it is also possible to use ice storage.

A substance with a high heat of fusion which melts and solidifies at certain temperatures and is capable of storing or releasing large amounts of energy are called as Phase change materials. Within the comfort range of 20° to 30°C, latent thermal storage materials are very effective as they store 5 to 14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock.

In mechanical industry lot of equipments require the heat energy in the form of input/output. In case of condenser, it is necessary to remove the heat from the fluid which is to be cooled or condensed. In case of Internal Combustion Engine, the problem of cold starting can be avoided by using Phase Change Material. It is possible by providing the PCM in jackets of engine.

In electronics equipments, cooling is necessary for its operational requirement. This can be done by means of phase change material which absorbs the heat during working and releases the heat at atmospheric temperature. Energy required for the cooling process can be saved.

Cooling above atmospheric temperature is possible by using Phase Change Material. Cooling of helmet is possible with the help of PCM pads. Material having higher specific heat at constant temperature (Cp) can reduce the volume of the material to be handled for cooling or heating of the substance. When application demands the higher heat transfer with less available volume PCM with higher Cp is the best option for required heat transfer.

CLASSIFICATION OF PCM:

PCMs can be classified as follows:

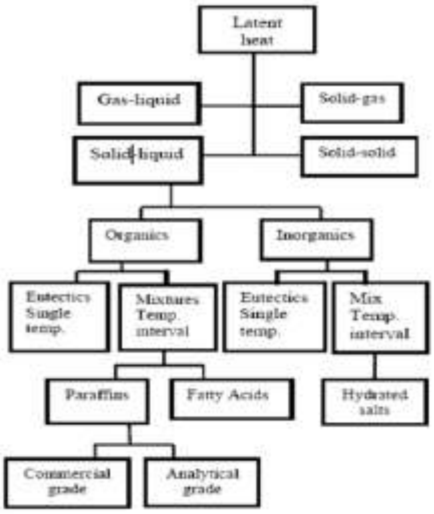

Fig. No.1: CLASSIFICATION OF PHASE CHANGE MATERIAL

Types of PCM

Phase Change Materials are mainly categorized in the four groups, i.e. *Organic, Inorganic, Eutectics, Hygroscopic material.*

Properties of PCM

The phase change materials (PCMs) should involve desirable thermo physical, kinetics, and chemical properties

- Appropriate phase change temperature
- High latent heat of fusion
- High thermal conductivity
- Low viscosity of the fluid phase

- Favorable phase equilibrium
- High density
- Low thermal expansion
- Low vapor pressure (to reduce containment problem)
- Ideally no super cooling
- Long life product, with stable performance through the phase change cycles
- Ecologically harmless
- Non-toxic
- Chemically inert.
- Melting temperature range between approx. –4 °C and 100 °C

Applications

PCMs have the wide area of applications; some of applications are as follows:

- Energy saving in Telecommunication shelters – while using natural energy
- Increasing life of Telecom equipments
- Reduce air-conditioning cost in building industry
- Increase hot water efficiency in solar water heaters
- Capture waste heat in boiler industry
- Cold storage/cold chain applications for horticulture
- Bio-Pharmaceuticals and vaccine transport
- Food / Poultry / Meat transport at specific temperatures
- Thermal wears for adverse climatic conditions
- Can be used as a room heater, same device / trolley can also be used as a cooler in summer
- Backup for room warmers / fireplace

Advantages

- Conserves energy
- Reduce HVAC equipment size & maintenance
- Stabilize grid load for peak and off peak demand
- Promote an environmentally friendly community
- Reduce carbon emissions
- Reduce machine noise
- Provide portable thermal protection & comfort
- Maximize utilization of renewable energy
- Reduce use of fossil fuels

S.No	Water Wt %	Freezing point (^{0}C)	Boiling point (^{0}C)
1	0	0	100
2	10	-4	102
3	20	-7	102

4	30	-15	104
5	40	-23	104
6	50	-34	107
7	60	-48	110
8	70	-51	116
9	80	-45	124
10	90	-29	140
11	100	-12	197

Table No 1: Freezing Point, Boiling Point Of Ethylene Glycol *Vs* Concentration In Water

Boiling Point at 101.3 kPa	197.60 ^{0}C
Freezing point	-13.00 ^{0}C
Density at 20^{0}C	1.1135g/cm^3
Refractive index	1.4318
Heat of vaporization at 101.3 kPa	52.24 kj/mol
Heat of combustion	19.07 MJ/kg
Critical temperature	372 ^{0}C
Critical Pressure	6515.73 kPa
Critical Volume	0.186 L/mol
Flash point	111 ^{0}C
Ignition Temperature	410 ^{0}C
Lower explosive limit	3.20 vol%
Upper explosive limit	53 vol%
Viscosity at 20 ^{0}C	19.83 MPa.s

Table No 2: Physical Properties Of Ethylene Glycol

Properties of Potassium chloride Solution Formula and structure: The chemical formula of potassium chloride is KCl, and its molar mass is 74.55 g/mol. It has a similar crystal structure as sodium chloride (NaCl). Its chemical structure is shown below, in which each KCl molecule consists of one potassium cation (K^+) and one chloride anion (Cl^-).

Occurrence: It occurs naturally as the mineral sylvite. It is also found naturally as a mixture with sodium chloride in a mineral called sylvinite. It is also present in seawater.

Preparation: KCl is commonly obtained by mining its minerals, followed by extraction. It is also extracted from brine (salt water). It can also be prepared in the laboratory in small scales by reacting potassium hydroxide (KOH) with hydrochloric acid (HCl).

$$KOH + HCl \rightarrow KCl + H_2O \quad \text{------------} \quad (1)$$

Physical properties: KCl is an odorless, white crystalline solid, with a density of 1.98 g/mL, a melting point of 770 °C, and a boiling point of 1420 °C.

Chemical properties: KCl is highly soluble in water and a variety of polar solvents, and insoluble in many organic solvents. KCl dissolves in water and gets fully ionized into solvated K^+ and Cl^- ions. Thus, aqueous solutions of KCL show electrical conductivity, making KCl an important electrolyte in many applications. Another important reaction of KCl is used to produce metallic potassium, by reducing KCL with metallic sodium at 850 °C.

$$KCl + Na \rightarrow NaCl + K \quad \text{--------} \quad (2)$$

Uses: The main uses of KCL are in electrolytes, pH buffers, and preparation of fertilizers, explosives, potassium metal and potassium hydroxide. Potassium is essential for various functions of the body, and KCL is a key source of this nutrient. It is also used in medicine, food processing, and as a substitute for table salt (sodium chloride). It has several other similar applications as sodium chloride including de-icing roads and homes, in petroleum and natural gas industry, and in water softening.

Health effects/safety hazards: At low concentrations, KCL solution is non-toxic and essential for the body. However, at high concentrations, potassium chloride is toxic and even lethal. High amounts of KCL can affect the cardiac muscles causing heart attacks and even death.

S.No	Physical Properties	R134a
1	Boiling Point	-26.1^o C
2	Auto-Ignition Temperature	770^o C
3	Ozone Depletion Level	0
4	Solubility In Water	0.11% by weight at 77^oF or25^oC
5	Critical Temperature	122^oC
6	Cylinder Color Code	Light Blue
7	Global Warming Potential (GWP)	1200

Table No 3: Properties of R-134a

EXPERIMENTATION

To explain the working of vapor compression refrigeration system, calculate its capacity and COP. VCR test rig consists of Refrigerant (R-134A), compressor, condenser, cooling fan, throttle valve, capillary tube, evaporator, analogue pressure indicator, digital temperature indicator with selector switch, analogue energy meter.

$$COP = \frac{Among\ \ of\ heat\ extracted\ \ in\ the\ refrigerator}{Net\ \ work\ \ done}$$

$$= \frac{H_{1-H_4}}{H_{2-H_1}} \text{ -- (3)}$$

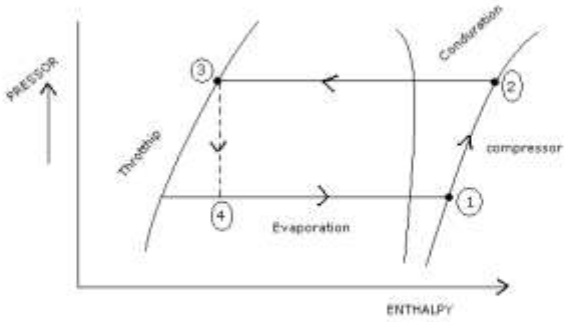

Fig.2 h-s diagram of R-134A

Operational Procedure

1. Switch on the mains and the console.
2. Keep either the throttle valve or the capillary tube open. When the capillary tube is open, the throttle valve should be closed and vice-versa both devices have the same expansion effect.
3. Switch on the motor which drives the compressor and the fan (which cools the condenser)
4. The refrigerant passes through the vapor compression cycle, resulting in cooling in the evaporator chamber or freezer.
5. Wait for about 5 minutes and notes the temperature T_1 to T_4 .
   T_1 = Temperature at inlet of the compressor ($^{\circ}$C)
   T_2 = Temperature at outlet of the compressor ($^{\circ}$C)
   T_3 = Temperature at outlet of the condenser ($^{\circ}$C)
   T_4 = Temperature at inlet of the Evaporator ($^{\circ}$C)
6. Note the input to the compressor
7. Using the measured temperatures, pressures and input power to the compressor, COP and the capacity of the refrigerator can be determined.

RESULTS AND ANALYSIS

Readings taken using the experimental setup of VCR twice by a time gap of 30minutes for each of the following readings started at 11.00AM and second reading at 2.00PM.

AT 11:00 AM:

Temperatures	Without ***PCM***	with ***KCL*** Solution	with ***Ethylene Glycol***
T_1	-13.31 °C	-16.5 °C	-13.9 °C
T_2	50.21 °C	44 °C	48 °C
T_3	31.51 °C	33 °C	32 °C
current(AMPs)	1.8	0.7	0.9
voltage(VOLTS)	190	190	190

Table No 4: Temperatures with & without PCMs

Sample calculation of coefficient of performance (cop):

WITHOUT PCM:

From R134a tables

at T_1 = -13.31 °C, h_1 = 238kJ/kg K

at T_2 = 50.21 °C, h_2 = 272 kJ/kg K

at T_3 = 31.51 °C, h_3 = 91 kJ/kg K

$$COP = \frac{h1-h4}{h2-h1} = \frac{238-94}{272-238} = \frac{144}{34} =$$

4.2

AT 2:00 PM:

Temperatures	Without ***PCM***	with ***KCL*** Solution	with ***Ethylene Glycol***
T_1	-14 °C	-17.2 °C	-15.2 °C
T_2	50 °C	42 °C	48 °C
T_3	32 °C	34 °C	33 °C
CURRENT(amps)	1.56	0.8	1.0
VOLTAGE(volts)	190	190	190

Table No 5: Temperatures with & without PCMs

	without *PCM*	with *KCL solution*	with *ETHYLENE GLYCOL*
COP (*at 11.00A.M.*)	4.2	4.29	4.42
COP (*at 2.00P.M.)*	4.28	4.36	4.309
Avg. COP	***4.24***	***4.325***	***4.364***

Table No 6: Average of COP of VCR system with & without PCMs

CONCLUSION:

Experimental study has been carried out to investigate the performance of a Domestic Refrigerator with and without PCM panels (Ethylene Glycol & KCL solution). The following conclusions were drawn based on the experimental results.

1) By using PCM panels in the refrigerator to regulate the raise of evaporator temperature and to maintain constant temperature for long time
2) Temperature reduction in refrigerator by using ethylene glycol panels is observed to be 1ºC and by using KCL solution, it is observed to be 3ºC for every one hour.
3) Table no. 6 results shows that the coefficient of performance of the VCR with PCM panels is considerably higher than that of without PCM panels.
   - COP Without PCM and without load is 4.24
   - COP With PCM (Ethylene Glycol) and without load is 4.364
   - COP With PCM (KCL solution) and without load is 4.325
4) As the use of Phase Change Material, limiting the rise in the temperature and maintains a constant temperature inside the evaporator for long time results in reduction of electrical power consumption.

This work has great significance for developing new technologies relates to heat recovery from a domestic refrigerator, in order to get cooling at low energy cost, no harmful effect to the environment and also having a low initial cost. So more attention is required in this area and a lot of work has to be done.

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