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# Improving the Performance of Vapor Compression Refrigeration System by Using Phase Change Materials

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## 1. INTRODUCTION

As a demand for refrigeration and air conditioning increased greatly during the last decade, large demands of electric power and limited reserves of fossil fuels have led to a surge of interest with efficient energy application. Electrical energy consumption varies significantly during the day and night according to the demand by the, industrial, commercial and residential activities. This variation leads to a differential pricing system for peak and off peak periods of energy use. Efficient and economical technology that can be used to store large amounts of heat or cold in a definite volume is the subject of research for a long time.

Sensible heat storage (SHS) and latent heat storage (LHS) are the two main methods of storing cool thermal energy. Cool thermal storage using the latent heat of phase change material has the advantages of high storage density and heat retrieval at almost constant temperature during phase change. Latent heat storage is relatively new area of research. It did not receive much attention until 1970. The first application of phase change material (PCM) was its use for heating and cooling in buildings. The use of phase change materials in solar heating systems leads to effective utilization of solar energy. Until 2005 there is not much development in the use of latent heat storage materials in the refrigeration and air conditioning field. The application of phase change materials in the refrigeration field becomes main area of research in these days.

### 1.1. Energy storage methods:

The different forms of energy that can be stored include mechanical, electrical and thermal energy.

### 1.1.1Mechanical energy storage

Mechanical energy storage systems include gravitational energy storage or pumped hydropower storage (PHPS), compressed air energy storage (CAES) and flywheels. The PHPS and CAES technologies can be used for large-scale utility energy storage while flywheels are more suitable for intermediate storage. Storage is carried out when inexpensive off-peak power is available, e.g., at night or weekends. The storage is discharged when power is needed because of insufficient supply from the base-load plant.

### 1.1.2 Electrical storage

Energy storage through batteries is an option for storing the electrical energy. A battery is charged, by connecting it to a source of direct electric current and when it is discharged, the stored chemical energy is converted into electrical energy. Potential applications of batteries are utilization of off-peak power, load leveling, and storage of electrical energy generated by wind turbine or photovoltaic plants. The most common type of storage batteries is the lead acid and Ni–Cd.

### 1.1.3 Thermal energy storage

Thermal energy storage can be stored as a change in internal energy of a material as sensible heat, latent heat and thermo chemical or combination of these. An overview of major technique of storage of solar thermal energy is shown in sensible heat storage. In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material.

$$Q = \int_{T_i}^{T_f} mC_p \, dT$$

$$= mC_{ap}(T_f - T_i)$$

Water appears to be the best SHS liquid available because it is inexpensive and has a high specific heat. However above 100 0C, oils, molten salts and liquid metals, etc. are used. For air heating applications rock bed type storage materials are used. Latent heat storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa. The storage capacity of the LHS system with a PCM medium is given by

$$Q = \int_{T_i}^{T_m} mC_p \, dT + ma_m \Delta h_m + \int_{T_m}^{T_f} mC_p \, dT$$

$$Q = m[C_{sp}(T_m - T_i) + a_m \Delta h_m + C_{lp}(T_f - T_m)]$$

### 1.2 Refrigerants

Different substances have been tried as refrigerants since the first use of ether as the refrigerant by Perkins in his hand operated vapor compression refrigeration machine in 1834. In the earlier days, ethyl chloride (C2H5Cl) was used as a refrigerant. Ammonia (NH3) found its application as a refrigerant in 1875. Sulphur dioxide (SO2) in 1874, methyl chloride (CH3Cl) in 1878 and carbon dioxide (CO2) in 1881, found application as refrigerants. In the initial decades of 20th century, many new refrigerants were used which mainly include the hydrocarbons.

In 1928 halogenated hydrocarbons were developed by Charles Kettering and Dr. Thomas Mingle. After their development the chlorofluorocarbons (CFCs) such as R11, R12 and hydro chlorofluorocarbons (HCFC) such as R22, became the most prominent refrigerants due to their favorable thermodynamic properties and due to their nonflammable, non-toxic and non corrosive nature. But unfortunately CFCs were found to be the main cause of ozone layer depletion (ODP) in the stratosphere. In 1974 Molina and Rowland found out that CFCs in spite of their stability diffuse slowly to the upper atmosphere where they are attacked by strong ultraviolet radiation and the chlorine atoms would be split off from the molecules, react with ozone.

## 2. PHASE CHANGE MATERIALS

Phases Change Materials (PCM) is also called as latent heat storage materials. Phase change materials (PCMs) have a strong ability to store energy and have an excellent characteristic of constant temperature in the course of absorbing or releasing energy. The phase change is a heat-seeking (endothermic) process and therefore, the PCM absorbs heat. Upon storing heat in the storage material during low load condition, it releases energy in the high load condition.

The temperature then stays constant until the melting process is finished. The comparison between latent and sensible heat storage shows that using latent heat storage, storage densities typically 5 to 10 times higher can be reached. Latent heat storage can be used in a wide temperature range. A large number of PCMs are known to melt with a heat of fusion in any required range.

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### 2.1 Thermo Physical Properties

- Melting temperature in the desired operating temperature range.
- High latent heat of fusion per unit volume so that the required volume of the container to store a given amount of energy is less.
- High specific heat to provide for additional significant sensible heat storage.
- High thermal conductivity of both solid and liquid phases to assist the charging and discharging of energy of the storage systems.
- Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem.
- Congruent melting of the PCM for a constant storage capacity of the material with each freezing/melting cycle.

### 2.2 Kinetic Properties

- High nucleation rate to avoid super cooling of the liquid phase.
- High rate of crystal growth, so that the system can meet demands of heat recovery from the system.

### 2.3 Chemical Properties

- Chemical stability.
- Complete reversible freeze / melt cycle.
- No degradation after a large number of freeze / melt cycles.
- Non-corrosiveness to the construction materials.
- Non-toxic, non-flammable, and non-explosive materials for safety.

### 2.4 Taxonomy of Phase Change Materials

A classification of PCMs is shown in Fig 3.1. There are large number of PCMs (organic, inorganic and eutectic), which can be identified as PCMs from the point of view melting temperature and latent heat of fusion. However, except for the melting point in the operating range, a majority of PCMs do not satisfy the criteria required for an adequate storage media. As no single material can have all the required properties for an ideal thermal storage media, one has to use the available materials and try to make up for the poor physical properties by an adequate system design. For example, metallic fins can be used to increase the thermal conductivity of PCMs, super-cooling may be suppressed by introducing a nucleating agent in the storage material, and incongruent melting can be inhibited by the use of a PCM of suitable thickness.

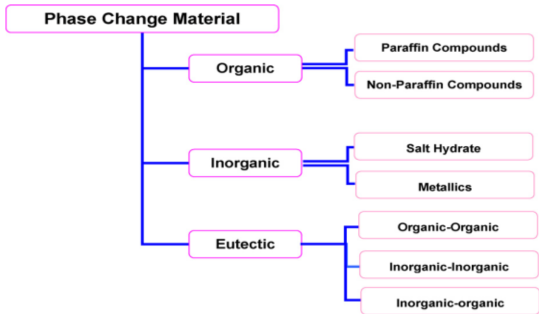


Fig1: Classification of Phase Change materials

## 3. FABRICATION OF DEEP FREEZER

### 3.1Evaporator:

Storage Capacity = 80 lit. ; Sheet Material = G.I.
Gauge = 22
Size of Tank: l = 43.18 cm.
w = 43.18 cm
h= 45.72 cm.

### 3.1.1 Evaporator tank

Evaporator coil: material = Cu ;
Length = 1524cm.
Size = 0.952cm.
Suction Line:
Material = Cu
Size = 0.952 cm.
Discharge Line:

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Material = Cu
Size = 0.635cm.
Capillary Tube: shape = helical; material = Cu ;
Size = 0.036 inch. ;
Length = 396.24cm.

### 3.1.2 Compressor

Compressor: capacity = ¼ h.p
Input power = 230v, 50Hz

### 3.1.3 Condenser:

Al fin, Cu tube air cooled condenser.
Condenser fan – 10/60 w
0.35 A/1300 rpm

### 3.2 PCM integrated evaporator

### 3.3 Compressor & condenser with connections


Energy Meter

### 3.5 Tools Used:

Tube Bender Capillary Bore

Tube Cutter

Gauge to Check

Temperature indicator

Deep freezer with PCM

## 4. EXPERIMENTATION

Selection of Phase Change Material:

Selection of latent heat storage material plays an important role in cool thermal storage systems. It mainly depends on the minimum temperature to be maintained in evaporator section. The temperature limit that should be maintained in deep freezers for maintaining the better food quality is 30C and 200C.Hence the PCM phase transition temperature should not be less than 30C.Two phase change materials are selected for cool thermal energy storage in the above temperature region, and their properties are listed below table.

**Table1 Properties of Phase change materials**

| MATERIALS | Melting Point (0C) | Thermal Conductivity (W/m K) | Melting enthalpy (kJ/kg) |
|---|---|---|---|
| Sulphuric Acid | 10.4 | 0.26 | 100 |
| Polyethylene Glycol | 13 | 0.187 | 99.6 |
| Craplyic Acid | 16 | 0.149 | 148 |

Based on the properties of PCMs mentioned below, eutectic salt solutions are selected for the present investigation.

## 5. RESULTS AND DISCUSSION

In this section the performance of vapor compression machine tested with R12, R134a, and R290/R600a as refrigerants in the presence of latent heat storage material. The phase change materials used are sulphuric acid, acrylic acid, poly ethylene glycol (E600).

### 5.1 Experimental results With R-12

Initially the vapor compression system is retrofitted with 135g of R12, and the performance of the system is investigated in the presence of three latent heat storage materials one by one.

### 5.2 Poly Ethylene Glycol (E600) as Latent Heat Storage Material

The amount of poly ethylene glycol used is 1.575 kg. This material is arranged inside the evaporative container with the help of 1liter capacity vessel. The use of this phase change material is to store cool energy in the “on” Condition of the refrigerating machine and releases this energy in the “off” Condition of the machine to heat transfer fluid (HTF).

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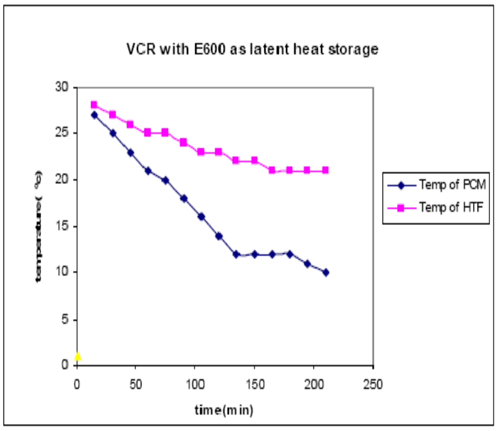
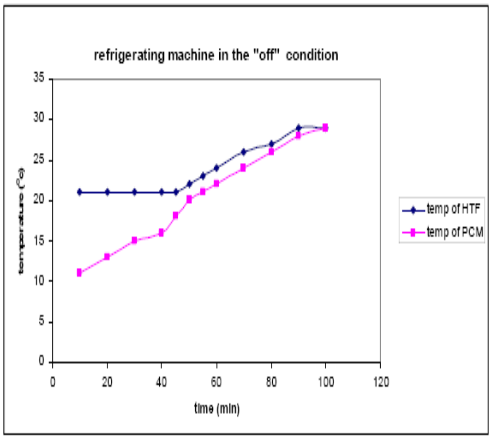


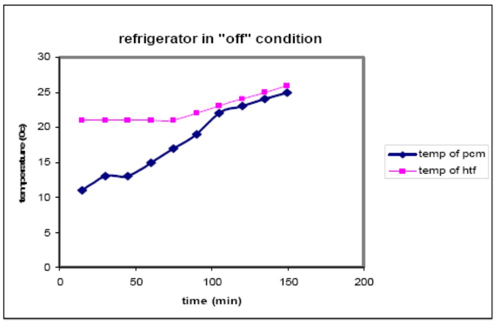

Graph1: Temperature variation of PCM with water in the charging mode




Graph2: Temperature variation of PCM with water in the discharging mode

The variation of temperature of PCM and HTF in the .on and "off" condition of the refrigerating machine is shown in fig 6.1 & 6.2. The minimum temperature attained by the poly ethylene glycol is 9°C, and the temperature attained by the water is 21°C. The phase transition temperature of poly ethylene glycol is 12°C.

The time required for attaining minimum temperature is 220 min. The refrigerating effect is maintained up to 45 minutes in the off condition of refrigerating machine as shown in fig 6.2. So for every 220 min running of the refrigerating machine, it s possible to switch off the machine for 45 minutes without affecting the refrigerating effect.



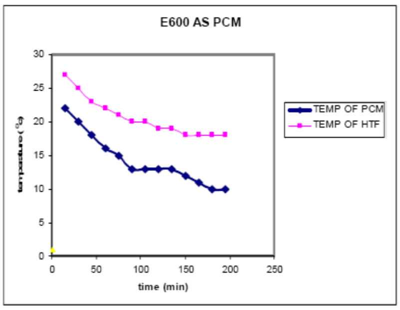

Graph3: Temperature variation of PCM with water in the discharging mode

The variation of temperature of PCM and HTF in the "on" and "off" condition of the refrigerating machine is shown in fig 6.11 & 6.12. The minimum temperature attained by the caprylic acid is 10°C, and the temperature attained by the water is 21°C. The phase transition temperature of caprylic acid is 14°C. The time required for attaining minimum temperature is 200min. The time required for attaining minimum temperature is 220 min.

The refrigerating effect is maintained up to 75 minutes in the off condition of refrigerating machine as shown in fig 6.12 So for every 220 min running of the refrigerating machine, it is possible to switch off the machine for 75 minutes without effecting the refrigerating effect.

### 5.3 Poly Ethylene Glycol (E600) as Latent Heat Storage Material

The amount of poly ethylene glycol used is 1.575 kg. This material is arranged inside the evaporative container with the help of 1liter capacity vessel.




Graph4: Temperature variation of PCM with water in the charging mode

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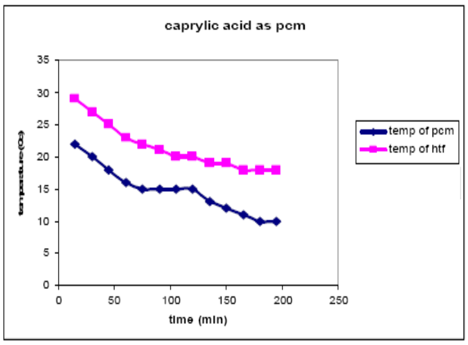
It is possible to switch off the machine for 75 minutes without affecting the refrigerating effect.

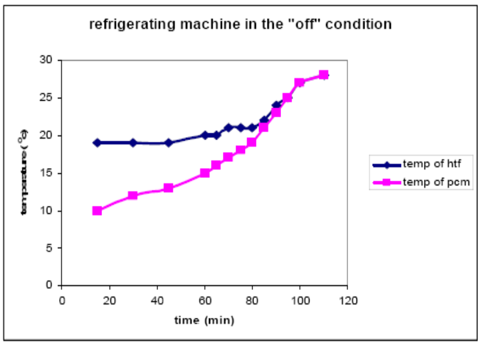
### 5.4 Caprylic acid as phase change material.

The variation of temperature of PCM and HTF in the "on" and "off" condition of the refrigerating machine is shown in fig 6.17 & 6.18. The minimum temperature attained by the caprylic acid is 10°C, and the temperature attained by the water is 18°C. The phase transition temperature of caprylic acid is 14°C. The time required for attaining minimum temperature is 200min. The time required for attaining minimum temperature is 220 min.

The refrigerating effect is maintained up to 85 minutes in the off condition of refrigerating machine as shown in fig 6.18 So for every 200 min running of the refrigerating machine, it is possible to switch off the machine for 85 minutes without effecting the refrigerating effect.




Graph5: Temperature variation of PCM with water in the charging mode

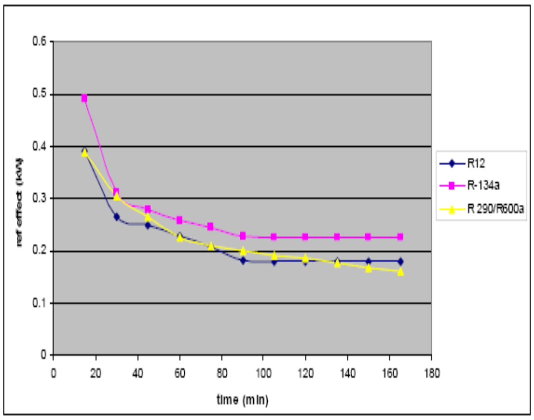



Graph6: Temperature variation of PCM with water in the discharging mode

The minimum temperature of heat transfer fluid attained is 18°C and for latent heat storage material the temperature is 9°C. The volume of the three latent heat storage materials is kept constant. The phase change temperature for poly ethylene glycol is 11°c- 14°C, for caprylic acid it is in between 13°C-14°C, and for sulphuric acid it is 10°C at different mass flow rates. Using poly ethylene glycol as PCM, refrigerating effect is maintained up to 80 minutes in the off condition of the refrigerating machine. Using sulphuric acid as PCM refrigerating effect is maintained up to 85 minutes, and using caprylic acid refrigerating effect is maintained up to 100 minutes at minimum mass flow rate of water. The minimum response time attained is for poly ethylene glycol and for maximum response time attained is for caprylic acid at minimum mass flow rate of water

### Calculations for R134a

H1=158 KJ/kg
H2=284KJ/Kg
H3=48KJ/Kg
Refrigeration Effect (Q) = H1 - H3
=158-48
=110
Work Done (W) =H2-H1
=284-158
=126
Co efficient of Performance (COP) =Q / W
=110/126
=0.87




Graph7: A comparison of refrigerating effect of the vapor compression refrigeration

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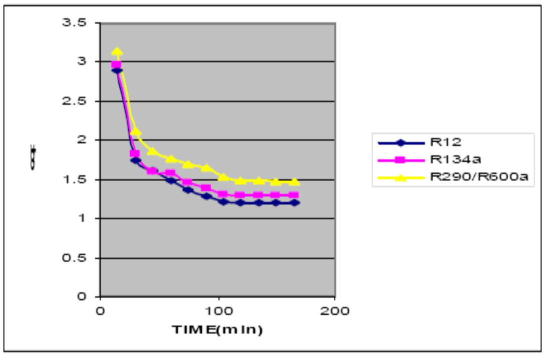
It is clear from the graph that the refrigerating effect of R134a is higher than that of R290/R600a. As the charging amount of R 290a is half of that of R134a, the refrigerating effect of R290/R600a is lower in spite of its high latent heat.

### 5.5 Comparison of Coefficient of Performance




Graph8: Comparison of C.O.P of refrigerants

A comparison of the COP of the vapor compression refrigeration machine with various refrigerants is shown in Fig 6.21. R290/R600a is having higher C.O.P compared to R12, and R134a, due to low compressor power input, and high latent heat of fusion.

### Table2: Annual energy savings with PCM

| Refrigerant | Phase Change Material | Energy Saving per year(Rs) |
|---|---|---|
| R12 | Sulphuric Acid | 3230 |
| | Polyethylene Glycol | 2595 |
| | Caprylic Acid | 3355 |
| R134a | Sulphuric Acid | 4490 |
| | Polyethylene Glycol | 3925 |
| | Caprylic Acid | 4645 |
| R600a / R290 | Sulphuric Acid | 4567 |
| | Polyethylene Glycol | 4002 |
| | Caprylic Acid | 4722 |

## 6. LITERATURE REVIEW

The use of a latent heat storage system using Phase Change Materials (PCM) is an effective way of storing thermal energy and has the advantages of high storage density and the isothermal nature of the storage process. It has been demonstrated that, for the development of a latent heat storage system, choice of the PCM plays an important role.

### 6.1 Latent Heat Storage Systems

Latent Heat Storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa. LHS systems have certain benefits in comparison with SHS systems. The most important is the higher energy density per unit mass and per unit volume.

### 6.2 Phase Change Materials

Phase change materials (PCMs) have a strong ability to store energy and have an excellent characteristic of constant temperature in the course of absorbing or releasing energy S.D. Sharma et al. [1] suggested various types of latent heat storage materials and advantages of a latent heat storage system. This paper is a compilation of much of practical information on various PCMs and latent heat storage systems. This review will help to find the suitable PCM for various purposes, suitable heat exchangers with ways to enhance the heat transfer, and it will also help to provide a variety of designs to store heat using PCMs for different applications, that is space heating & cooling, solar cooking, greenhouses, solar water heating and waste heat recovery systems. Thermo-physical property measurement techniques, thermal cycles testing for stability and enhancement of heat transfer in PCMs are discussed in this paper. This paper contains a list of about 250 PCMs and more than 250 references.

### 6.3 Cool thermal energy storage systems

Cool thermal energy storage (CTES) using the latent heat concept as an alternative to sensible heat storage offers a good option because of its high storage density and the nearly constant temperature heat removal characteristics during the charging and discharging cycle. During the periods of low cooling demand the

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system removes heat from the thermal storage medium (water, phase change material, etc.) to be used latter to meet the air conditioning M. Cheralathan et al. [3] investigated the transient behavior of a phase change material based cool thermal energy storage (CTES) system comprised of a cylindrical storage tank filled with encapsulated phase change materials (PCMs) in spherical container integrated with an ethylene glycol chiller plant. A simulation program was developed to evaluate the temperature histories of the heat transfer fluid (HTF) and the phase change material at any axial location during the charging period. The results of the model were validated by comparison with experimental results of temperature profiles of HTF and PCM. The results showed that increase in porosity contributes to a higher rate of energy storage.

The significance of time wise variation of HTF and PCM temperatures during charging and discharging processes is discussed in detail. J.M. Marin et al. [9] Designed a thermal energy storage system (TES) using air as heat transfer medium. The aim of the work is to study the feasibility of a thermal energy system for storing cold from outside air during the night and using it during the day for cooling air or air conditioning. This technology can be used in places where there is a strong difference of temperature between day and night in summer, of at least 15 0C. An experimental set-up has been constructed to simulate the above application. A.F. Regin et al. [10] studied main requirements of a latent heat storage system.

This paper reviews the development of available latent heat thermal energy storage technologies, and compared the advantages of latent heat storage system over sensible heat storage system. The different aspects of storage such as material, encapsulation, heat transfer, applications and new PCM technology innovation have been investigated. This paper deals with the different stages involved in the design of latent heat thermal energy storage system. The researchers found out different phase change materials suitable for storing thermal energy. They studied the performance of the latent heat storage system combined with solar heating systems, and investigated the melting and solidification characteristics of the phase change materials. They discussed the desirable properties of latent heat storage materials, and developed different designs for thermal energy storage system.

## 7. CONCLUSIONS

- The performance of vapor compression machine was tested with R12, R134a, and R290/R600a in the presence of latent heat storage material.
- Using R12 as a refrigerant for every 220 min running of vapor compression machine maintained refrigerating effect up to 55 min without compressor power input. Using sulphuric acid as PCM, maintained a refrigerating up to 60 min, and caprylic acid as PCM, maintained refrigerating effect up to 70 min.
- Using R134a as a refrigerant for every 220 min running of vapor compression machine maintained refrigerating effect up to 75 min without compressor power input. Using sulphuric acid as PCM, maintained a refrigerating up to 80 min, and caprylic acid as PCM, maintained refrigerating effect up to 90 min.
- Using R290/R600a as a refrigerant, for every 200 min running of vapor compression machine maintained refrigerating effect up to 80 min without compressor power input. Using sulphuric acid as PCM, maintained a refrigerating up to 85 min, and caprylic acid as PCM, maintained refrigerating effect up to 100 min.
- The refrigerating effect of R134a is higher than that of R290/R600a. As the charging amount of R290/600a is half of that of R134a.
- By using R290/R600a as a refrigerant and caprylic acid as PCM in domestic refrigerator, annually an energy saving of 432.22 Kw-h (units) was obtained.

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