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Review on Phase Change Materials and their Applications

S.Panneerselvam

Sri Krishna College of Engineering and Technology, Coimbatore-641008, spanneerselvam91@gmail.com

***Abstract* - Latent heat storage is one of the possible ways of storing thermal energy with use of Phase Change Materials (PCMs). PCMs have the tendency of stores large amount of energy with minimum space availability and the amount of energy stored in PCMs are depends upon the charging time and temperature. Now a days three forms of PCMs are used for cooling and heating applications such as organic, inorganic and eutectic forms. PCMs have been extensively used in latent heat storage system for Heating Ventilation and Air Conditioning (HVAC) applications, textile applications, helmets, heat pumps, space craft's, electronic chips and building applications. The usage of stored heat in PCMs will helps to improve the Coefficient of Performance (COP) of refrigeration cycle by introducing a new sub cooling routines. The theoretical result shows that improvement of COP for different operating condensing temperature in the range of 4-25%.Other than refrigeration and air conditioning applications, PCMs can be used in many applications such as a temperature damper in electronic chips by preventing it from overheating and it can be employed for cooling of buildings by maintaining the constant temperature during the day. This paper reviews the various methods of thermal energy storage and PCM applications in various fields**

Keywords- Phase change materials; applications; refrigeration system; COP.

1 INTRODUCTION

The continuous increase in level of greenhouse effect and rises in fuel price are the major factor in day to day life, at present various types of renewable energy sources are available. In the renewable energy storage, there is a need of large sized energy storage device. Now a day the idea to use phase change materials is new option for storing thermal energy as in the form of latent heat. A phase-change material is a substance with a high heat of fusion which is melting and solidifying at a certain temperature and is capable of storing and releasing large amounts of thermal energy. Heat is absorbed or released when the material changes its phase; thus, PCMs are classified as latent heat storage (LHS) units. Latent heat is the energy released or absorbed by a body or a thermodynamic system during a constant-temperature process. Because of phase change there may be a large energy generated with small change in temperature. This paper reviews various types of phase change materials and their applications in various fields such as refrigeration and air conditioning, cooling of buildings, etc. Also reviews the influence of nano particles in the properties of phase change materials and performance improvement of system by mixing it with them. Then theoretical and experimental results are compared and verified by flow analysis with aid of software.

A. Energy storage methods

Different forms of energies are mechanical energy; electrical energy [1]. Then the thermal energy is stored in two ways as shown in fig 1. Compressed air storage, hydro power storage and fly wheels are generally used mechanical energy storage. In this type of storage system, power is stored when inexpensive off-peak power is available, and it is utilized when insufficient supply of power. Generally batteries are the main electrical storage system; most commonly used batteries are lead acid battery, Ni-Cr battery. Thermal energy storage is carried out in various ways like change in internal energy, sensible heat, latent heat etc. By raising the temperature of solid or liquid, thermal energy is stored. Sensible heat is defined as amount of heat released or absorbed by substance during change in temperature. Sensible heat storage system utilizes the heat capacity of material and change in temperature of material for charging and discharging. The amount of heat stored depends on specific heat of material and change in temperature of material.

$$Q= mC_p(T_2– T_1)$$

When phase change from solid to liquid or liquid to gas or vice versa. Then there is a heat absorption or release in latent heat storage material. The storage capacity of various LHS with PCM [2] is given by

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

Solid – gas and liquid – gas transition have higher latent heat of transition, but it requires large size of container, so it makes system complex and large. Comparatively solid – liquid transition having small latent heat storage, it proves that economically for thermal energy storage system.

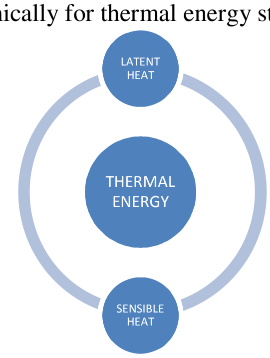

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Figure 1: Thermal energy storage methods

I. PHASE CHANGE MATERIALS

Phase change materials are also known as latent heat storage materials. Thermal energy transfer occurs, when there is change in phase that is solid to liquid or liquid to solid at constant temperature. At initial condition PCM's works as a conventional storage materials. PCM's can absorb and release heat at constant temperature. PCM's can store 5-14 times more heat per unit volume than sensible storage material like water and rock [4]. PCM's are used in refrigerator for improving the coefficient of performance (COP). PCM's are used in building construction applications, electronic device manufacturing, food processing and storage industries and transportation of food and dairy items etc. PCM's used should have following properties like thermal properties, kinetics and chemical properties [5].

A. Classification of Phase change materials

Phase change materials are classified as organic, inorganic, and eutectic. As shown in fig 2. Normally inorganic compounds have almost double volumetric latent heat storage capacity than organic compound. Organic compounds have the capacity of (128 – 200 kg/dm^3), but inorganic compounds have more capacity than organic (250 - 400 kg/dm^3). Organic phase change materials are again classified into paraffin compound and non – paraffin compounds. Paraffin is economic, reliable, less expensive, noncorrosive and chemically inert. It is stable below 500^{0}C. Due to these properties paraffin having long freeze melt cycle [6]. But paraffin having some drawbacks such as it is having low thermal conductivity, somewhat inflammable. Because of these drawbacks we can go for non-paraffin. Non paraffin compound having highly varied properties. Each material has its own properties.

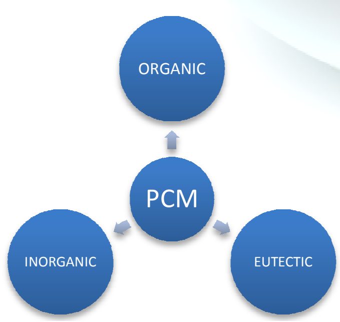

Figure 2: Classification of phase change materials [4]

References [4][7] Have conducted a survey of organic materials and identified number of fatty acids, alcohols suitable for storage. Fatty acids have higher heat of fusion, when compared to other paraffin. It is having the capabilities of reproducibility and freezing behavior also freeze without super cooing [8][9]. But main drawback is it is mild corrosive and cost. So we can go for next preference inorganic phase change materials. It is again subdivided into two groups; they are salt hydrates and metallic. Salt hydrate is the most important type of PCM. This salt hydrates having more attractive properties like, high latent heat of fusion/unit volume. High thermal conductivity nearly doubles the paraffin. They are not corrosive in nature and compatible with plastics, slightly toxic [10]. But it is having some drawbacks such as super cooling and it is suitable for thermal storage, melt incongruently. To overcome the super cooling and segregation of salt hydrates [11] conducted an experiment with rolling cylinder heat storage system. Metallic are the combination of low melting metals and metal eutectics. It is not widely used in PCM technology because of weight penalties but it is having high latent heat of fusion per unit volume and thermal conductivity. Less specific heat and vapor pressure Eutectic is a minimum melting composition of two or more components. Each component will melts and freeze at the same time forming of mixture of the component crystals during crystallization [12]. Some of the important properties required for PCM are,

• Latent heat of fusion per unit mass is high for PCMs, so it can store large amount of energy with lesser amount of materials.

• High specific heat provided by PCMs will lead to additional sensible heat storage effect and also avoid sub cooling.

• It should have high thermal conductivity so that the temperature gradient required for charging the storage material will be small.

• High density, so that a smaller container volume holds the material

• The phase change material should not (poisonous, inflammable and explosive).

• No chemical decomposition, so that the (LHTS) system life is assured.

• No corrosiveness to working materials

• PCM should not have super cooling during freezing.

III. VARIOUS APPLICATIONS OF PHASE CHANGE MATERIALS

For improving energy efficiency and energy savings thermal energy storage is one of the most effective storage method. Thermal energy can be stored in different forms such as sensible heat, latent heat and thermo chemical heat or combination of all three. Among the heat storage methods latent heat storage by PCM is one of the preferable method because of its high storage capacity and storing heat at constant temperature. One of the latent heat thermal energy storage application is in the use of PCM's in building application for improving thermal comfort of inside environment where the persons work or live [13,14]. In building applications there are two methods used for incorporation of PCM's within the concrete structure [15]. First one is incorporation of PCM's in the building materials during manufacturing process. Another one is impregnation

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of building materials in PCM's. In building application among the various PCM's Fatty acids are used due to their great latent heat capacity, non-toxicity, low vapor pressure [16-20]. They can be directly incorporated into conventional building materials. Recent years PCM impregnated walls in interior surface of building walls has gained impacts in maintenance of thermal comfort inside the room. There was a comparative study has been made walls with PCM and without PCM [21]. Fatty acids based mixture capric acid of 82% and lauric acid of 18% and having melting temperature of 20.394oC and freezing temperature of 19.138oC used as PCM in his study. That implementation shows good thermal comfort and warm during winter season. Later that new kind of PCM based tiles used for maintaining indoor air temperature in winter season [22].Temperature control of electronic device is very important one for improving their life and reliability.

Temperature is the main factor to cause failure of electronic components. 1% increase in temperature will reduce its reliability by 4% [23]. Many statistics shows that 55% of electronic components failure occurs due certain relation with temperature [24]. For this purpose we provide thermal control for electronic components. PCM can effectively use for phase change thermal control in electronic devices. PCM's can absorb or release the heat when electronic device working in high temperature or below the working temperature. It will prevent the electronic device from overheating as well as it maintains proper temperature fluctuation. [3] proposed a principle in which another NN yield input control law was created for an under incited quad rotor UAV which uses the regular limitations of the under incited framework to create virtual control contributions to ensure the UAV tracks a craved direction. Utilizing the versatile back venturing method, every one of the six DOF are effectively followed utilizing just four control inputs while within the sight of un demonstrated flow and limited unsettling influences.

PCM can also been used in solar power plants to store thermal energy during day time and release it during the latter part of the day. Microencapsulated PCM's can be used in textile fibers. It will provide great enhanced thermal protection in cold as well as hot environments [25]. PCM's can be used in motor vehicles. In this application there is a latent heat storage module is included for store energy during engine stop condition and it can be used to preheat the engine at new start. Engine can reach the optimum temperature within a shorter time [36]. Compare without heat storage device.

Another application is food processing and transportation. For improving food quality, food taste and nutrition value during transportation and storage the freezer is used, because food transportation at lower temperature plays an important role. Temperature control of low temperature storage chambers like refrigerator and freezers the period and amplitude of cooling cycle influence food quality and energy consumption. If there is any temperature fluctuation inside the chamber or freezer then the food quality will be affected during storage and transportation [27]. So the temperature control is important factor in food storage and transportation. Another factor is frequent compressor activation that leads to mechanical wear of components [28]. Many researchers studied these problem and give solutions by modifying compression cycle [29]. The most efficient control system with variable speed compressor can control the on/ off cycle of refrigerator. In this review mainly focused on refrigeration and air conditioning application, these two are main household appliances in all houses. Because of continuous operation it consumes more power than any other appliances. For reducing the power consumption of these equipment's there are various methods are incorporated by various researchers.

TABLE-1Some commercially available PCM's for cooling and heating applications

PCM name	Type of product	Melting Temp (^{0}C)	Heat of fusion (kJ/kg)	Reference
RT 20	Paraffin	22	172	[36]
RT 25	Paraffin	26	232	[36]
RT 26	Paraffin	25	131	[36]
RT 27	Paraffin	28	179	[36]
RT 32	Paraffin	31	130	[36]
Climsel c23	Salt hydrates	23	148	[37]
Climsel c24	Salt hydrates	24	216	[37]
Climsel c32	Salt hydrates	32	212	[37]
STL 27	Salt hydrates	27	213	[37]
S 27	Salt hydrates	27	207	[37]

IV. METHODS TO IMPROVE COP OF REFRIGERATOR

Losses due to on/off cycles are due to displacement of refrigerant at the time of compressor start and stop. Energy loss due to this phenomenon is about 5-30%. At the time of compressor start most of the refrigerants are accumulated in evaporator. So the evaporator is in positive temperature nearly a cabinet temperature. Since accumulation of refrigerant in evaporator cause more mass flow from the evaporator. Finally refrigerant vapor enters the capillary tube. Then there is a result in accumulation of refrigerant in condenser, and refrigerant entering the capillary tube as in liquid state. By increasing the thermal inertia of refrigerator, the reduction of startup and stop

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period should restrict the above mentioned losses and identified 11% increase in cooling capacity [13].

For improving COP of refrigerator they introduce additional insulation for door and cabinet since additional insulation will reduce the heat loss. Author uses Vacuum Insulation Panels integrated with cabinet. 25% of average energy is obtained. But the main drawback of his experiment was manufacturing still expensive. COP of refrigerator varies with change in thermal load. The results shows effect of PCM on COP at different thermal load[14].Then developed a high efficiency compressor for improving COP. In ordinary refrigerator hermetic compressors are used, these are usually operate at partial load resulting in reduced performance and increased cycle time. Alternatively Variable Speed Compressor (VSC) and Variable Capacity Compressor (VCC) are used to control the refrigerating capacity [23]. The author found that 45% of energy saving is obtained by replacing ordinary compressor by VCC compressor. Using latent heat storage is another option for improving COP [14] [15]. In general heat transfer occurs by natural convection and radiation with low heat transfer coefficient [16]. Addition of PCM slab in one side of evaporator results in enhancement of performance due to conduction inside the PCM also simulated a refrigerator with less quantity of PCM in the evaporator so the COP improvement was 12% [16].

In recent days [17-19] had done experiment with adding thickness of PCM slab on the back side of evaporator. It increases the 25% of COP and significant decrease in compressor start and stop. PCM can absorb large amount of heat during melting at constant temperature [20-22]. And PCM is used to reduce the temperature fluctuation in many applications like in domestic refrigerator and freezer [23] [24]. The use of PCM can reduce product and air temperature fluctuations inside refrigerator freezer [27]. The researcher Incorporated PCM into a domestic freezer and his work was based on using easily available PCM (Sodium chloride with Water). This PCM suffers more corrosion and sub cooling [25]. Another researcher developed a prototype of refrigerator with PCM and he placed PCM in heat exchanger at various locations. His experiment result shows 6-8% increase in COP [26]. Recently [24] shows incorporation of PCM panels in internal walls of domestic refrigerator. His result shows that 8% of decreases in energy consumption during defrost cycle.

V. INFLUENCE OF NANO PARTICLES IN PCM

With the development of nanotechnology an innovative fluid called nano fluid arises. It is formed by metal or metal oxide nanoparticles in a base fluid. While considering PCM's there are various lag of properties such as poor thermal and electrical conductivity [28-31] super cooling nature etc. basically nano is used to get constant thermal conductivity and high heat transfer coefficient. Inorganic compounds like salt hydrates are used as PCM they are chemically stable and non-ignitable but the main problem behind this are super cooling and poor thermal conductivity. For improve their properties nano particles are embedded into PCM [32]. In some fields especially in latent heat microencapsulated PCM's had not well done under repeated cycling because of large particle size. Microencapsulated PCM not only increase the viscosity also crushed during pumping. Because of these reasons nano encapsulated PCM's with smaller size is developed.

VI CONCLUSION

This review paper is focused on the available thermal energy storage technology with PCMs in different applications. Now a days those PCM based application is very beneficial for the humans and as well as for the energy conservation. Also this paper presents the current research in this particular refrigeration field, with the main focus being on the assessment of the thermal properties of various PCMs. and also focused on various applications like building usage for cooling and heating, heat pump, and electronics etc. In all applications PCM acts as a temperature damper. Influence of nano technology with PCMs for enhancing thermal conductivity is also reviewed in this paper.

NOMENCLATURE

m mass of heat storage medium (kg)
Q quantity of heat stored (kJ)
D_{hm} heat of fusion per unit mass (kJ/kg)
C_{ip} average specific heat between Tm and T_f (kJ/kg K)
C_p specific heat (kJ/kg K)
Csp average specific heat between Ti and T_m (kJ/kg K)
a_m fraction melted
T_f final temperature (^{0}C)
T_i initial temperature (^{0}C)
T_m melting temperature (^{0}C)
T_1 initial temperature (^{0}C)
T_2 final temperature (^{0}C)

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