Mr.Ashish.A.Kamble, Mr S. R. Karale / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 2, March -April 2013, pp.1600-1604

A review-thermal energy storage based dual mode air conditioning system

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Abstract:-Electrical energy consumption varies significantly during the day and night according to the demand by industrial, commercial and residential activities, especially in extremely hot and cold climate countries where the major part of the variation is due to domestic space heating and air conditioning. Such variation leads to a differential pricing system for peak and off peak periods of energy use if some of the peak load could be shifted to the off peak load period, which can be achieved by thermal storage of heat or coolness. Phase change materials (PCM) take advantage of latent heat that can be stored or released from a material over a narrow temperature range. PCM possesses the ability to change their state with a certain temperature range. These materials absorb energy during the heating . process as phase change takes place and release energy to the environment in the phase change range during a reverse cooling process

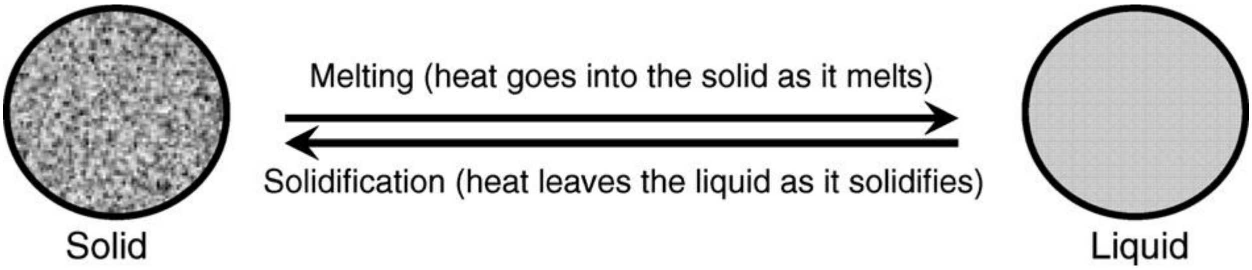
I. Introduction

the peak demand for electricity during hot summer is increasing year by year and the daytime load has become double that of nighttime .also electrical energy consumption varies significantly during the day and night, especially in extremely cold and hot climate countries where the major part of the variation is due to domestic space heating and air conditioning. Such variation leads to an off peak period, usually after midnight until early morning. Accordingly, power stations have to be designed for capacities sufficient to meet the peak load. Otherwise, very efficient power distribution would be required. Better power generation management can be achieved if some of the peak load could be shifted to the off peak load period, which can be achieved by thermal storage of heat or coolness. Hence, the successful application of load shifting and solar energy depends to a large extent on the method of energy storage used. The main reason for this is air conditioning of commercial buildings. Therefore one way to reduce peak demand would be to use electricity supplied at night to reduce daytime air conditioner load. This would not only reduce the cost to consumers by allowing them to use electricity at cheaper night rates but would also avoid the need for capital investment in new electricity generating plants Frank [4] performed a review on using PCM in the walls and in the ducts of the cooling units of the building to provide both heating and cooling effects. Pasupathy et al. [5] performed experimental and simulation analysis of incorporating PCM in the roofs of the buildings. Guo [6] carried out an experimental work on a new kind of PCM and found that the heat storing/releasing ability of it was significantly higher than other PCMs. He also performed a simulation and calculation based on the effective heat capacity method to verify the result. Huang [7] applied a validated model to predict the energy conserving capability of the PCM by fabricating them in walls of the buildings. Experimental study was conducted by Takeda et al. [8] to analyze PCM usage on floor supply air conditioning system to enhance building thermal mass.

This paper summarizes the investigation and analysis of thermal energy storage systems incorporating PCMs for use in building applications the application of PCMs In this paper the selection of materials and the methods used to contain them are discussed

1.Phase change processes

Latent heat storage is one of the most efficient way of storing thermal energy. Unlike the sensible heat storage method, the latent heat storage method provides much higher storage density, with a smaller temperature difference between storing and releasing heat [10]. Every material absorbs heat during a heating process while its temperature is rising constantly. The heat stored in the material is released into the environment through a reverse cooling process. During the cooling process, the material temperature decreases continuously. Comparing the heat absorption during the melting process of a phase change material (PCM) with those in normal materials, much higher amount of heat is absorbed if a PCM melts.



A paraffin PCM, for an example, absorbs approximately 200 kJ/kg of heat if it undergoes a melting process [10]. High amount of heat absorbed by the paraffin in the melting process is released into the surrounding area in a cooling process starts at the PCM's crystallization temperature. After comparing the heat storage capacities of textiles and PCM, it is obvious that by applying paraffin-PCM to textiles their heat storage capacities can substantially enhanced [6].During the complete melting process, the temperature of the PCM as well as its surrounding area remains nearly constant. The same is true for the crystallization process during the entire crystallization process the temperature of the PCM does not change significantly either. Phase change process of PCM from solid to liquid and vice versa is schematically shown in Fig The large heat transfer during the melting process as well as the crystallization process without significant temperature change makes PCM interesting as a source of heat storage material in practical applications. When temperature increases, the PCM microcapsules absorbed heat and storing this energy in the liquefied phase change materials. When the temperature falls, the PCM microcapsules release the this stored heat energy and consequently PCM solidify.

II. Phase change material

Materials to be used for phase change thermal energy storage must have a large latent heat and high thermal conductivity. They should have a melting temperature lying in the practical range of operation, melt congruently with minimum subcooling and be chemically stable, low in cost, nontoxic and non-corrosive According to the literature PCMs can be classified into organic, inorganic, and eutectics. The melting temperature of the PCM to be used as thermal storage energy must match the operation range of the application the PCMs should first be selected based on their melting temperature. Materials that melt below 15 C are used for storing coolness in air conditioning applications, while materials that melt above 90 C are used for absorption refrigeration. All other materials that melt between these two temperatures can be applied in solar heating and for heat load leveling applications

2.1Organic pcm

Organic PCMs have a number of characteristics which render them useful for latent heat storage in certain building elements. They are more chemically stable than inorganic substances, they melt congruently and supercooling does not pose as a significant problem. Moreover, they have been found to be compatible with and suitable for absorption into various building materials, as will be discussed in more detail later. Although the initial cost of organic PCMs is higher than that of the inorganic type, the installed cost is competitive.

Table 1
Hydrated salts and organic PCMs

PCM	Melting point (°C)	Heat of fusion (kJ/kg)
$KF \cdot 4H_2O$ Potassium fluoride tetrahydrate	18.5–19	231
$CaCl_2 \cdot 6H_2O$ Calcium chloride hexahydrate	29.7	171
$CH_3(CH_2)_{16}COO(CH_2)_3CH_3$ Butyl stearate	18–23	140
$CH_3(CH_2)_{11}OH$ Dodecanol	17.5–23.3	188.8
$CH_3(CH_2)_{16}CH_3$ Tech. grade octadecane	22.5–26.2	205.1
$CH_3(CH_2)_{12}COOC_3H_7$ Propyl palmitate	16–19	186
45% $CH_3(CH_2)_8COOH$ 55% $CH_3(CH_2)_{10}COOH$ 45/55 Capric–lauric acid	17-21	143

2.2 Inorganic PCMs

Development of latent heat storage materials used inorganic PCMs. These materials are salt hydrates, including Glauber's salt (sodium sulphate decahydrate), which was studied extensively in the early stages of research into PCMs. The phase change properties of these materials are shown in Table 1. These PCMs have some attractive properties including high latent heat values, they are not flammable and their high water content means that they are inexpensive and readily available. However, their unsuitable characteristics have led to the investigation of organic PCMs for this purpose. These include corrosiveness, instability, improper re-solidification, and a tendency to supercool. As they require containment, they have been deemed unsuitable for impregnation into porous building material

Table 1: *Salt hydrate PCMs (typical values)*

PCM	Melting Point (°C)	Heat of Fusion (kJ/kg)
$KF \cdot 4H_2O$ Potassium flouride tetrahydrate	18.5	231
$CaCl_2 \cdot 6H_2O$ Calcium chloride hexahydrate	29.7	171
$Na_2SO_4 \cdot 10H_2O$ Sodium sulphate decahydrate	32.4	254
$Na_2HPO_4 \cdot 12H_2O$ Sodium orthophosphate dodecahydrate	35.0	281
$Zn(NO_3)_2 \cdot 6H_2O$ Zinc nitrate hexahydrate	36.4	147

Source: Feldman *et al.* 1993

2.3Bio Based PCM

Karthik Muruganantham developed organic-based PCM, here termed "BioPCM" improves safety since it is less flammable than traditional PCMs. Fire retardant materials can also be added to paraffin based PCMs to reduce its flammability, but at the expense of altering the thermophysical properties of the material. The BioPCM can also be manufactured such that the melting point can be made from -22.7 °C to 78.33 °C (−73 °F to +173 °F), and this facilitates its use in various climatic zones.

2.3.1Bio PCM Properties

The properties of the BioPCM used in the experimental setup are described in Table Additionally, commonly available paraffin based PCM, GR27 researched by Huang [7] and water properties are shown for comparison

Table 1: THERMOPHYSICAL PROPERTIES OF BIOPCM, PARAFFIN BASED PCM AND WATER

DESCRIPTION	BIOPCM	GR27	WATER
Melting Point (°C)	29	28	0
Density (kg/m3)	860	710	1000
Specific Heat (kJ kg^{-1} °C^{-1})	1.97	1.125	4.179
Latent Heat (kJ/kg)	219	72	334
Viscosity @ 30 °C (cp)	7	-	0.798
Boiling Point (°C)	418	-	100
Thermal Conductivity (W m^{-1} °C^{-1})	0.2	0.15	0.6

III. Encapsulation of phase change materials

There are many advantages of microencapsulated PCMs, such as increasing heat transfer area,reducing PCMs reactivity towards the outside environment and controlling the changes in the storage material volume as phase change occurs. Lane [47,48] has identified over 200 potential phase change heat storage materials melting from 10 to 90 _C to be used for encapsulation.Microencapsulation of CaCl2 Æ6H2O in polyester resin was particularly successful, and the developments of wall and floor panels were studied. Macroencapsulation of CaCl2 Æ 6H2O in plastic film containers appears promising for heating systems using air as the heat transfer medium. He has assessed the technical and economic feasibility of using encapsulated PCMs for thermal energy storage in solar driven residential heating applications and has developed means of encapsulating a group of promising phase change heat storage materials in metal or plastic containers. After considering a number of heating and cooling schemes employing phase change heat storage, a forced hot air, central storage design using CaCl2 Æ 6H2O encapsulated in plastic pipes was adapted.

The encapsulation of PCMs into the micropores of an ordered polymer film was investigated by Stark [49]. Paraffin wax and high density polyethylene wax were infiltrated successfully into extruded films of the ordered polymer by a solvent exchange technique to yield microcomposites with PCM levels of the order of 40 volume percent. These microcomposite films exhibit excellent mechanical stability under cyclic freeze–thaw conditions.

Royon et al. [50] have developed a new material for low temperature storage. They contained the water as a PCM within a three dimensional network of polyacrylamide during the polymerization process, as shown in Fig. 2. The final material remains well shaped, requiring no support or even coating, so it can be used directly. Nevertheless, the potential use of microencapsulated PCMs in various thermal control applications is limited to some extent by their cost. Recently Hong and Xin-shi [51] have employed a compound phase change material, which consists of paraffin as a dispersed phase change material and a high density polyethylene (HDPE) as a supporting material. This new generation phase change material is very suitable for application in direct contact heat exchangers. The 75% paraffin and 25% HDPE mixture provided a phase change material that has a latent heat of 157 kJ/kg compared to 199 kJ/kg for the paraffin used and with a transition temperature of approximately 57 _C, which is close to that of paraffin.

IV. Application of PCM

4.1 Pcm for Air Conditioning

Thermal energy storage is considered as a proven method to achieve the energyefficiencyof most air conditioning(AC) energy efficiency of most air conditioning(AC) systems. Technologies for cold storage we real so considered and the experience gained in USA and Canada summarized,with a conclusion made that cold storage technologies could be success- fully used for AC in countries with hot climates [6]. Hasnain [50] presented areviewofcoolingthermalstorageforoff-peak air conditioning applications(chilledwaterandicestorage).

He described the three types of cool storag eused during that period, which werechilledwater,iceandeutecticsalt.Inchilled storage system, thewater is stored inside a tank with water at 4–6 1C in stratified layers during the nighttime,thehuge volume needed for storing coldness in this type is the main problem that discourages the use of this type.In ice storage technology,water is also used as a phase change storage medium; ice is produced by using glycol or a brine solution at 3–6 1C below the freezing point of water, which circulates through the icetank or encapsulated plastic ball with deionized water, the advantage softhismethodisthe higher storage capacity due to the latent heat of fusion removed during the charging cycle,which resultsin conversion of water to ice.Unfortunately,it is possible to supply the air into the space with 61C, which would lead to discomfort experienced by the occupants.Ineutecticsalt type,the energy is stored in eutectic salts,which are mixtures of inorganic salts,water and nucleating and stabilizingagents that meltandfreeze at 81C.

Recently, Yauetal. [51] conducted a literature survey of the thermal energy storage system for the space cooling application, which usually stores the energy in the form of ice,PCM,chilled water, or eutectics during the night time,and uses it in the day time to overcome them is match of the energydemand between the peak and off-peakhours.They classified the different types of cool thermal energy storage into chilled water storage,ice thermal storage,and different thermal storage.They recom-mended that the best choice of theTES should be based on the local parameters and situation,such as the electricity demand trend, peak andoff-peak hours,the electricity tariffrate,the system set up costs,and the energy policy.An intensive technical review on sustainable thermal energy storage, which included the latent heat energy and cool thermal energy for building applications,was presented by Paramesh- waran etal.[52]. In this work,they presented through 286 references the performance evaluation of heat storage materials incorporated with building structure sand different HVAC equip-ment. They reported that themicro-andnan encapsulated PCMs would enhance the overall performance of the thermal energy storage, with around 10 15 % for passive building design with LHTES technology,and 45–55% for active technology of condition-ing energy saving potential can be achieved fairly.

Latent heat thermal energy storage could be installed in an AC system, either in a chilled water circuit,ventilation system,or in the thermal power generation of desiccant cooling and absorption systems. Shortly,the benefits for using the thermal energy storage can be summarized as;reducing the loading capacity with respect to the peak load,operating the system at constant load during the partial load,shifting the usage of the electrical energy, reducing the air conditioning size and capacity at the terminal units due to the high difference in temperature. Kurt W. Roth says Overall, the net energy impact of TES depends upon the amount of energy storage shifted to off-peak periods. A simplified study suggests that nighttime operation of a TES-chiller system sized such that the chiller could meet the integrated cooling load of an office building in Atlanta via 24-hour operation at or near full capacity could meet at least 40% of the peak period cooling demand. Using this value, PCM- or water-based TES reduces annual cooling energy consumption by approximately 10% for water-cooled systems3,4 and 20% for air-cooled chillers relative to chillers without TES. Applied to the 0.3 and 0.1 quads of energy consumed by water- and air-cooled chillers5, respectively, TES could reduce cooling energy consumption by about 0.05 quads. In all cases, the ice-based cooling appears to increase energy consumption because the decreased chiller efficiency outweighs other savings.

V. Conclusion

Organic and inorganic compounds are the two most common groups of PCMs. Most organic PCMs are non-corrosive and chemically stable, exhibit little or no subcooling, are compatible with most building materials and have a high latent heat per unit weight and low vapor pressure. Their disadvantages are low thermal conductivity, high changes in volume on phase change and flammability The applications in which PCMs can be applied are vast, ranging from heat and coolness storage in buildings The importance of latent heat thermal energy storage is considerably in contrast to the sensible storage because of the large storage energy densities and various melting temperatures that lead them to be used indifferent air conditioning networks,location of airdistribution,chilled water networks,thermal power, and heat rejection of absorption AC.Different thermal energy storage configurations for airconditioning applications have been studied.Many researchers studied the double pipe,and shell and tube heat exchanger configurations due to their high efficiency, where as other configurations have n ot been studied seriously and need more work as recommended by researchers.

Different heat transfer enhancements have been applied to improve the heat transfer conductivity. The applications of phase change materials in the air-condi-toning networks are focusing on the air distribution, chilled water fluid and slurries ;little work has been found in the thermal power for absorption and desiccant applications. It is expected from this review that PCM s have been recommended as a storage medium for air-conditioning systems and an attractive option to reduce the unit prices and sizes

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