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A Review on Properties of Phase Change Material for Solar Thermal Storage System

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ABSTRACT

Thermal energy could have several geneses but storage of solar thermal energy is one of the principal areas of investigation. The various conventional and unconventional materials are investigated for their capability to store thermal energy. These thermal energy storage devices (TESD) are selected on the basis of some essential properties like, thermal, physical, chemical properties and economic aspects. Melting point, heat of fusion, density, heat capacity, thermal conductivity, compatibility with container and cost of production are the chief parameters for selection of phase change material. Phase change materials (PCMs) have the capability of storing heat (latent heat storage units) and phase transition point to the environment of the operating temperature. This research paper focus on assessment of PCMs properties and economic aspect for rural and industrial applications. The design and development of thermal storage system depend on fundamentals of thermodynamic or heat transfer analysis

Keywords: *TSED; Micro/Macro-Encapsulation; Phase Change Slurry*.

1.0 Introduction

The different forms of energy that can be stored include mechanical, electrical, and thermal energy. Mechanical energy storage systems include gravitational energy storage or Pumped Hydro Power Storage, Compressed Air Energy Storage and Flywheels, these technologies can be used for large-scale utility energy storage. Apart from these systems, Thermal energy can be stored as a change in internal energy of a material as sensible heat, latent heat, and thermo-chemical heat. In case of sensible heat storage (SHS) system, energy is stored or extracted by heating or cooling a solid or a liquid which does not change its phase during charging and discharging process.

Water, heat transfer oils, and certain molten salts have been used in liquid type SHS systems where as rocks, pebbles and refractories used in solid type SHS systems.

The latent heat storage system using Phase Change Materials (PCM) is an effective way of storing thermal energy (solar energy, off-peak electricity, and industrial waste heat) and has the advantages of high storage density and the isothermal nature of the storage process. In latent heat storage system, heat is stored in a material when it melts and extracted from the material when it freezes by the phase change of used materials (S.P Shukhatme), 1940s Dr. Telkes found idea about some chemicals based energy storage system, which posses the heat during phase change and define the new area of research as a Latent Heat Storage materials or phase change materials, but did not receive much attention, however until the energy crisis of the late 1970s and early 1980s.

The first PCM application described for heating and cooling in buildings by Telkes in 1975 and by Lane in 1983 (Kaygusuz, 1999; Sari et al. 2000)

Nomenclature

Cp=Specific Heat (J/Kg 0C)
Clp= Specific Heat between Tm and T2 (J/kg K)
Csp= Specific Heat between T1 and Tm (J/kg K)
Δhm = Heat of fusion per unit mass (J.kg)
k= Thermal Conductivity (W/m0C)
m=Mass of heat storage medium (kg)
ρ = Density of PCM medium (kg·m−3)

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Q= Quantity of heat stored (J).
T1= Initial Temperature (0C)
Tm= Melting Temperature (0C)
T2= Final Temperature (0C)
Xm=Fraction Melted
Xτ = Fraction rejected
Δhτ = Endothermic heat of rejection.
VHC = Volumetric heat capacity(·m−3·K−1)
TESD-Thermal Energy storage devices
PCM-Phase change material.
PCS-Phase change slurry.
TES-Thermal Energy storage
LHS-Latent heat storage
CG-Commercial grade
AG-Analytical grade
EGDS-Ethylene glycol distearate
BTU-British-thermal-unit
DSC-Differential scanning calorimeteic
TGA-Thermal gravimetric analysis

1.1 Thermal energy storage (TES)

The need of thermal energy storage may often be linked to the following cases-

- There is a mismatch between thermal energy supply and energy demand,
- When intermittent energy sources are utilized, and
- For compensation of the solar fluctuation in solar heating systems.

1.2 Physical principles of thermal energy storage

When a thermal storage need occurs, there are three main physical principles to provide a thermal energy function:

1) Sensible heat storage (SHS)-

The thermal energy stored by raising the temperature of a solid or liquid material. The amount of heat stored depends on the specific heat of material, change in temperature and amount of storage material (Sharma, S.D et al, 2005).

$$Q = \int_{T1}^{T2} m\,Cp\,dT \quad (1)$$

$$= mCp\,(T_2 - T_1) \quad (2)$$

Water appears to be the best SHS liquid because it is inexpensive and has high specific heat. However above 1000c, oils, molten salts and liquid metals, etc are used. For air heating applications rock bed type storage materials are used. In the application of load levelling, heat is usually stored in a refractory bricks storage heater, these units capable of providing space heating during the day from the stored heat during the night (Prabhu et al, 2012).

2) Latent heat storage (LHS)-

If the material changes its phase at a certain temperature while heating the substance then heat is stored in the phase change. Reversing, heat is dissipated when at the phase change temperature it is cooled back. The heat storage capacity of the phase change materials is equal to the phase change enthalpy at the phase change temperature + sensible heat stored over the whole temperature range of the storage (Sharma, S.D et al, 2005, Buddhi.D.et al, 2007).

There are three main physical ways for thermal energy storage: sensible heat, phase change reactions and thermo chemical reactions. Storage based on chemical reactions has much higher thermal capacity than sensible heat but are not yet widely commercially viable. Large volume sensible heat systems are promising technologies with low heat losses and attractive prices

$$Q = \int_{T1}^{Tm} mCp\,dT + mX_m\Delta h_m + \int_{Tm}^{T2} Cp\,dT \quad (3)$$

$$= m\,[Csp\,(Tm - T_1) + X_m\Delta h_m + Clp\,(T_2 - T_m)] \quad (4)$$

This method of heat energy storage provides much higher energy storage density with a smaller temperature swing.

However, practical difficulties usually arise in applying the latent heat method due to the low thermal conductivity, density change, and stability of properties under extended cycling and sometimes phase segregation and sub cooling of the phase change materials (Prabhu et al 2012)

3) Thermochemical energy storage-

The sorption or thermo chemical reactions provide thermal storage capacity. The basic principle is: AB + heat ⇔A+B; using heat a compound AB is broken into components A and B which can be stored separately bringing A and B together AB is formed and heat is released.

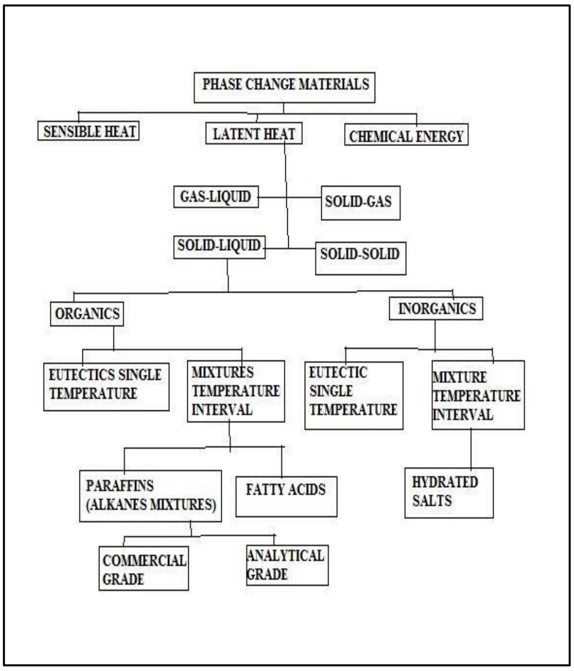
The storage capacity is the heat of reaction or free energy of the reaction (Sharma, S.D et al, 2005) $Q = X\tau m\Delta h\tau$ (5)

2.0 Characteristics and Classification of PCM

Phase change materials (PCMs) have the capability of storing heat (latent heat storage units) and phase transition point to the environment of the operating temperature. The purpose for which they are designed is to prevent heat loss by absorption or release thereof. A PCM classification based on their composition is detailed in fig-1.

PCMs are categorized as Organic, Inorganic and Eutectic materials source

Fig 1. Classification of Phase Change Material (D.Juárez et al, 2013)



2.1 Organic PCMs-(paraffin (C_nH_{2n+2}) and fatty acids ($CH_3(CH_2)_{2n}COOH$))

Organic materials are further described as paraffin and non-paraffins. Organic materials include congruent melting, self-nucleation and usually non-corrosiveness to the container material (A.Sharma et al, 2009). Commonly used organic PCMs for heating and cooling in buildings falling in the range of 20–320C with their melting point and latent heat of fusion are listed in Table 1.

2.1.1 Advantages

1. Freeze without much supercooling.
2. Ability to melt congruently.
3. Self nucleating properties.
4. Compatibility with conventional material of construction.
5. No segregation.
6. Chemically stable.
7. High heat of fusion.
8. Safe and non-reactive.
9. Recyclable

2.1.2 Disadvantages

1. Low thermal conductivity in their solid state. High heat transfer rates are required during the freezing cycle.
2. Volumetric latent heat storage capacity is low.
3. Flammable. This can be easily alleviated by a proper container.
4. To obtain reliable phase change points, most manufacturers use technical grade paraffins which are essentially paraffin mixture(s) and are completely refined of oil, resulting in high costs

2.2 Inorganic PCMs (salt hydrates (MnH_2O))

Inorganic materials are further classified as salt hydrate and metallics. Inorganic compounds have a high latent heat per unit mass and volumes are low in cost in comparison to organic compounds and are non-flammable (Prabhu et al 2012).

However they suffer from decomposition and supercooling which further can affect their phase change properties listed in Table 1.

2.2.1 Advantages

1. High volumetric latent heat storage capacity.
2. Availability and low cost.
3. Sharp melting point.
4. High thermal conductivity.
5. High heat of fusion.
6. Non-flammable

2.2.2 Disadvantages

1. Change of volume is very high.
2. Super cooling is major problem in solid–liquid transition.
3. Nucleating agents are needed and they often become inoperative after repeated cycling.

Table 1: Thermo Physical Properties of Selected Organic/Inorganic PCMs

Material	Organic PCM	Melting point °C	Heat of fusion $kJ \cdot kg^{-1}$	Heat of fusion $MJ \cdot m^{-3}$	c_p solid $kJ \cdot kg^{-1} \cdot K^{-1}$	c_p liquid $kJ \cdot kg^{-1} \cdot K^{-1}$	ρ solid $kg \cdot m^{-3}$	ρ liquid $kg \cdot m^{-3}$	k solid $W \cdot m^{-1} \cdot K^{-1}$	VHC solid $kJ \cdot m^{-3} \cdot K^{-1}$	VHC liquid $kJ \cdot m^{-3} \cdot K^{-1}$	Cost $USD \cdot kg^{-1}$
Water	No	0	333.6	319.8	2.05	4.186	917	1,000	1.6-2.22	1,880	4,186	0.00312
Sodium sulphate ($Na_2SO_4 \cdot 10H_2O$)	No	32.4	252	NA	NA	NA	NA	NA	NA	NA	NA	0.05
$NaCl \cdot Na_2SO_4 \cdot 10H_2O$	No	18	286	NA	NA	NA	NA	NA	NA	NA	NA	0.05
Lauric acid	Yes	44.2	211.6	197.7	1.76	2.27	1,007	862	NA	1,772	1,957	1.6
TME(63% w/w)+ H_2O(37% w/w)	Yes	29.8	218.0	240.9	2.75	3.58	1,120	1,090	NA	3,080	3,902	NA
$Mn(NO_3)_2 \cdot 6H_2O + MnCl_2 \cdot 4H_2O$ (4% w/w)	No	15–25	125.9	221.8	2.34	2.78	1,795	1,728	NA	4,200	4,804	NA
$Na_2SiO_3 \cdot 5H_2O$	No	72.20	267.0	364.5	3.83	4.57	1,450	1,280	0.103–0.128	5,554	5,850	8.0
Aluminium	No	660.32	396.9	1,007.2	0.8969	NA	2,700	2,375	237	2,422	NA	2.04626
Copper	No	1,084.62	208.7	1,769.5	0.3846	NA	8,940	8,020	40	3,438	NA	6.81256
Gold	No	1,064.18	63.72	1,166.3	0.129	NA	19,300	17,310	318	2,491	NA	34,297.8
Iron	No	1,538	247.3	1,836.6	0.4495	NA	7,874	6,980	80.4	3,539	NA	0.3248
Lead	No	327.46	23.02	253.2	0.1286	NA	11,340	10,660	35.3	1,459	NA	2.1151
Lithium	No	180.54	432.2	226.0	3.5816	NA	534	512	84.8	1,913	NA	62.2164
Silver	No	961.78	104.6	1,035.8	0.235	NA	10,490	9,320	429	2,465	NA	492.524
Titanium	No	1,668	295.6	1,273.5	0.5235	NA	4,506	4,110	21.9	2,359	NA	8.0469
Zinc	No	419.53	112.0	767.5	0.3896	NA	7,140	6,570	116	2,782	NA	2.15735
$NaNO_3$	No	310	174	NA	NA	NA	NA	NA	NA	NA	NA	NA
$NaNO_2$	No	282	212	NA	NA	NA	NA	NA	NA	NA	NA	NA
NaOH	No	318	158	NA	NA	NA	NA	NA	NA	NA	NA	NA
KNO_3	No	337	116	NA	NA	NA	NA	NA	NA	NA	NA	NA
KOH	No	360	167	NA	NA	NA	NA	NA	NA	NA	NA	NA
NaOH/ Na_2CO_3 (7.2%)	No	283	340	NA	NA	NA	NA	NA	NA	NA	NA	NA
NaCl(26.8%)/NaOH	No	370	370	NA	NA	NA	NA	NA	NA	NA	NA	NA
NaCl/KCL(32.4%)/LiCl(32.8%)	No	346	281	NA	NA	NA	NA	NA	NA	NA	NA	NA
NaCl(5.7%)/ $NaNO_3$ (85.5%)/ Na_2SO_4	No	287	176	NA	NA	NA	NA	NA	NA	NA	NA	NA
NaCl/ $NaNO_3$ (5.0%)	No	284	171	NA	NA	NA	NA	NA	NA	NA	NA	NA
NaCl(5.0%)/ $NaNO_3$	No	282	212	NA	NA	NA	NA	NA	NA	NA	NA	NA
NaCl(42.5%)/KCl(20.5)/ $MgCl_2$	No	385-393	410	NA	NA	NA	NA	NA	NA	NA	NA	NA
KNO_3(10%)/ $NaNO_3$	No	290	170	NA	NA	NA	NA	NA	NA	NA	NA	NA

2.3 Eutectics (organic-organic, organic-inorganic, inorganic-inorganic compounds)

An eutectic is a minimum-melting composition of two or more components, each of which melts and freeze congruently forming a mixture of the component crystals during crystallization (Sharma, S.D et al,2005). Commonly used Organic–Organic, Organic–Inorganic and Inorganic– Inorganic eutectics PCMs used for building applications are listed in Table-2.

Table 2: Inorganic Eutectics PCM

PCM Compound	Melting temperature (C)	Heat of fusion (kJ/kg)	References
66.6% CaCl2 .6H2O+33.3% Mgcl2 .6H2O	25	127	[9]
48% CaCl2+4.3% NaCl+0.4% KCl+47.3% H2O	26.8	188	[10]
47% Ca(NO3)2 . 4H2O+53% Mg(NO3)2 .6H2O	30	136	[10]
60% Na(CH3COO) .3H2O+40% CO(NH2)2	30	200.8	[11]

2.3.1 Advantages

1. Eutectics have sharp melting point similar to pure substance
2. Volumetric storage density is slightly above organic compounds.

2.3.2 Disadvantages

Only limited data is available on thermo-physical properties as the use of these materials are very new to thermal storage application. For latent heat storage commercial grade (CG) PCMs are preferred due to their large scale availability and low cost. The thermo physical properties/behaviour of CG materials in general was found to be very much different than those quoted in the literature for analytical grade (AG) materials therefore, it becomes important to verify the melting temperature, latent heat of fusion and specific heat of CG latent heat storage materials. (D.Juárez et al, 2013**)** A list of commercial PCMs, which can be used in the buildings for thermal storage (available in the International market), is given in Table-3

Table 3: Commercially Available PCMs in World Wide

PCMs Name	Type of product	Melting temperature (C)	Heat of fusion (kJ/kg)	References
RT20	PARAFFIN	22	172	[12]
RT25	PARAFFIN	26	232	[12]
RT26	PARAFFIN	25	131	[12]
RT27	PARAFFIN	28	179	[12]
RT32	PARAFFIN	31	130	[12]
CLIMSEL C 23	SALT HYDRATE	23	148	[13]
CLIMSEL C 24	SALT HYDRATE	24	216	[13]
CLIMSEL C 32	SALT HYDRATE	32	212	[13]
STL 27	SALT HYDRATE	27	213	[16]
S 27	SALT HYDRATE	27	207	[14]
TH 29	SALT HYDRATE	29	188	[15]

Another category of PCMs based on the size of the capsules (Microtek Laboratories, 2010), may be the following

- Micro PCMs
- Macro PCMs

Microencapsulation defined as the process of surrounding or wrapping one substance to another substance at very limited scale, producing capsules ranging from less than one micron to several hundred microns in size. The microcapsules may be spherical, with a continuous wall surrounding the core, while others are asymmetrical and with varying shapes, with a number of droplets of core material incorporated throughout the microcapsule. Microencapsulations provide a solution to the increasing consumer demand for improved energy efficiency and thermal regulation. The PCM substance is typically a paraffin or fatty ester acid that absorbs and releases heat in order to maintain a defined temperature.

Regardless of the state (liquid or solid) of the PCM, the capsule remains in the solid state, because it is a very stable and inert polymer. It allows the PCMs to be incorporated into construction materials, such as concrete, easily and economically. Micro-encapsulated PCMs also provide a portable heat storage system. By coating a microscopic sized PCM with a protective coating, the particles can be suspended within a continuous phase such as water. This system can be considered a phase change slurry (PCS) (Buddhi.D.et al, 2007).

Typical features are

- Any colour.
- Temperatures available adjustable ranges on request.
- Form Dry or wet filter cake. The filter can be diluted further to suit its application.
- Average particle size microns.
- Stability at elevated temperatures.

Macro PCMs are spherical capsules of a larger size (3-5 mm) containing high concentrations of phase change materials. These materials were originally developed for use in cooling vests and clothing. They regulate body temperature of individuals working in hot environments, such as soldiers in missions in the desert. The macro PCM absorbs heat excess and allows the user for a longer time in a more comfortable temperature. The particles are typically charged into the vests, on the inside, which is in contact with the skin. However, most applications are emerging (Buddhi.D.et al, 2007).

Typical features are

- Any colour.
- Temperatures available adjustable ranges on request.
- Form spherical solid balls.
- Average particle size mm.

Molecular-encapsulation is another technology, developed by Dupont de Nemours that allows a very high concentration of PCM within a polymer compound. It allows storage capacity up to 515 kJ/m2 for a 5 mm board (103 MJ/m3). Molecular-encapsulation allows drilling and cutting through the material without any PCM leakage (Buddhi.D.et al, 2007).

The state of the art is more developed during low and medium temperature than in high temperature. There is ample scope for the R & D in terms of PCM screening (selection), micro/macro encapsulation, the development of new materials and storage systems.

Fallahi and Fang prepared micro PCMs based upon different types of paraffins and analyze their thermal behaviour.

Hadam discusses the transfer of heat during the melting of a phase-change material, determining the spread and inclination of the solid-liquid interface at the time.

Alkan studied the preparation, characterization and thermal properties of a microencapsulated PMC for thermal energy storage.

Alvarado and Bukovec come equally to performance micro PCMs analysis with differential scanning calorimetric (DSC) and thermal gravimetric analysis (TGA) techniques.

Huang studied the improvements made by a 3D model analysis with phase change materials and compare the results with those provided by previous 2D model. Finally, in a longer term, research in nano fluids and nano-PCM can be a significant advance through the application of PCM-based technologies.

3.0 Properties of PCMs

Selection criteria of PCMs for a particular application follow some important points from properties of PCMs (A.Sharma et al, 2009).

- The operating temperature of the heating or cooling should be matched to the transition temperature of the PCM.
- High thermal conductivity would assist the charging and discharging of the energy storage.
- Phase stability during freezing melting would help towards setting heat storage and high density is desirable to allow a smaller size of storage container.
- Small volume changes on phase transformation and small vapour pressure at operating temperature to reduce the containment problem.
- Supercooling has been a troublesome aspect of PCM development, particularly for salt hydrates. Supercooling of more than a few degree will interfere with proper heat extraction from the store, and 5-100C supercooling can prevent it entirely.
- PCM can suffer from degradation by loss of water of hydration, chemical decomposition or incompatibility with materials of construction.
- Low cost and large-scale availability of the phase change material is also very important.

Some crucial PCM properties listed in table-4.

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. PCM storage volume is two times smaller than that of water (Garg et al., 1985; Hasnain, 1998). 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. The PCM to be used in the design of thermal storage systems should accomplish desirable thermophysical, kinetics and chemical properties (Hale et al., 1971; Garg et al., 1985; Buddhi et al., 1994).Thermal stability of fatty acid type novel PCM Ethylene Glycol

Table 4: Desirable Properties of PCM [1, 4, 5, 8]

Thermal properties	Physical properties	Chemical properties	Kinetic properties	Economic factors
Phase change temperature suitable to the desired operating range.	High density	Long-Term Chemical stability	High nucleation rate to avoid supercooling of the liquid phase	Abundant
High latent heat per unit mass. High specific heat. and High thermal conductivity in both solid and liquid phases	Low density variation during phase change	No degradation after a large number of freeze/melt cycle, Complete reversible freeze/melt cycle	High rate of crystal growth, so that the system can meet demands of heat recovery from the storage system	Available in large quantities
Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem	Little or no supercooling during freezing	Compatibility with container materials.		Inexpensi ve
Congruent melting		Non-corrosiveness, non-toxic, non-flammable and non-explosive materials.		

Distearate (EGDS). During heat treatment EGDS kept with calcium oxalate under atmosphere air condition at temperature range of 300C to 8000C for heating rate 100C/min. Heat storage capacity increase with higher density. EGDS has the advantages of higher energy storage capacity over the paraffin's PCMs.

The recorded value of EGDS is 0.9729 kg/m3 where as paraffin's PCMs density lies between 0.7-0.9 kg/m3 (Alkan et al, 2008). Low heat transfer coefficients helps longer solidification time and provide thermal stability for design of thermal energy storage system. Higher Stefan number shows the charging and discharging rate of mass flow, and estimated in size of spherical capsule type PCMs (Felix & Solanki , 2009).

4.0 Working of PCM in Solar Heat Storage

PCM's are chemical substances that undergo a solid-liquid transition at temperatures within the desired range for heating purposes. During the transition process, the material absorbs energy as it goes from a solid to a liquid and releases energy as it goes back to a solid.

As on date, Glauber's salt (sodium sulfate decahydrate) is being sold commercially. Glauber's salt changes phases at 90°F and has a 108-BTU-per-pound "latent heat" (amount of heat absorbed or released during phase change). Because of its high latent heat, Glauber's salt requires less storage volume than either rock or water; that could mean lower storage facility cost and more usable space within the home to offset the material's relatively high cost (Prabhu et al, 2012).

5.0 Major Application area of PCM

The application of PCMs in building can have two different goals. First, using natural heat that is solar energy for heating or night cold for cooling. Second, using manmade heat or cold sources.

In any case, storage of heat or cold is necessary to match availability and demand with respect to time and also with respect to power (D.Buddhi et al 2007). Basically three different ways to use PCMs for heating and cooling of buildings are

1. PCMs in building walls.
2. PCMs in other building components other than walls; and,
3. PCMs in heat and cold storage units.

The first two are passive systems, where the heat or cold stored is automatically released when indoor or outdoor temperature rises or falls beyond the melting point. The third one is active system, where the stored heat or cold is in containment thermally separated from the building by insulation. Therefore, the heat or cold is used only on demand not automatically. Depending on where and how the PCM is integrated, PCMs with different melting points are applied. Currently, there is a lack of commercial PCMs in the lower temperature range that is between 5 and 250C. Especially between 15 and 200C available products show too low enthalpies. Most important PCMs are in the range of 22–250C, as almost everybody agrees that this is the range for building passive heating and cooling (Mehling H et al,2002). Various possible latent heat thermal energy storage (LHTES) devices studied for space heating and cooling are as follows.

1) PCM trombe wall.
2) PCM wallboards.
3) PCM shutter.
4) PCM building blocks.
5) Air based heating system.
6) Floor heating.
7) Ceiling heating.

Other storage systems have been developed by many researchers; **Kaygusuz and Ayhan** investigated the performance of the combined solar heat pump system with energy storage in encapsulated phase change material packing for residential heating. The concept of free cooling was developed for air conditioning applications, where coolness was collected and stored from ambient air during night, and relived to the indoor ambient during the hottest hours of the day. **Vakilatojjar and Saman** worked on the analysis and modeling of phase change storage system for air conditioning applications.

Another application of PCMs in buildings is thermoelectric refrigeration**. Omer et al. and Riffat et al**. integrated a phase change material in the thermal diode to improve effectiveness of the heat sink. **John et al**. designed a novel ventilation night time cooling system (a novel combination of PCM and heat pipes) as an alternative to air conditioning. The system offers substantial benefits in terms of reducing or eliminating the need for air conditioning and thereby significantly reducing CO2 emissions and saving energy in buildings. Apart from storage systems PCM plays important role in medical applications transportation of blood, operating tables, hot-cold therapies (Kenisarin.M et al 2007, Omar A, 2008).Telecom shelters in tropical regions. They protect the high-value equipment in the shelter by keeping the indoor air temperature below the maximum permissible by absorbing heat generated by power-hungry equipment such as a Base Station Subsystem. In case of a power failure to conventional cooling systems, PCMs minimize use of diesel generators, and this can translate into enormous savings across thousands of telecom sites in tropics (Kenisarin.M et al 2007, Omar A, 2008).

6.0 Conclusion

This review paper is focused on assessment of properties of various PCMs. A PCM with an easily adjustable melting point would be a necessity as the melting point is the most important criterion for selecting a PCM for passive solar applications. This paper presents the current research in the particular field of space heating and cooling application for buildings. The use of encapsulated materials with phase change (PCM) is an efficient method for the thermal effects of regulation in heating and cooling systems. The micro PCM can be considered ideal for incorporation as an additive to thermoplastic materials due to its size. The emerging application of Molecular-encapsulation allows drilling and cutting through the material without any PCM leakage.

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