PCM in Solar Applications

Introduction

At the 1992 conference on climate change, the United Nations Inter-governmental panel concluded that a 60% reduction in the use of fossil fuel would have to be made in order to freeze the level of CO_2 emissions by the year 2005. This will have a large impact on the way buildings are operated as currently they account for over 50% of fuel consumption, with heating and lighting residential buildings responsible for 60% of emissions [1].

Solar power has enormous potential for use in residential buildings for approximately 30,000 times as much solar energy reaches the earth than is actually needed to meet human demand. It is also a clean source of energy in that it does not produce any CO_2 and it is totally renewable.

However there are several major problems with harvesting solar energy; its availability is unpredictable, intermittent and is often subject to interruptions due to changes in weather. Due to this and the fact that for approximately for half of the 8760 hours per year any location is in darkness, a form of thermal storage is required to match supply with demand.

An effective solar thermal storage system must form an integral part of a solar heating system for without this maximum utilization of solar energy is not possible. Thermal storage can also address the problem in trying to match supply to demand were maximum solar availability occurs during the day, but maximum demand occurs at times when there is a little if any solar availability.

Phase change materials - A Solution

In many cases, solar thermal energy can be used directly; in other cases heat storage is required. To date, most heat storages are water based and their capacity depends largely on the storage size and operating temperature. In order to expand the solar thermal usage, new storage concepts and technologies must be developed – not only for industrial processes but also in all sectors possible. Where large water tanks are not feasible, either thermo-physical methods (e.g. using phase-changing materials) or thermo-physical processes could store large amounts of energy in the future [11].

Energy storage is the most fundamental requirement of all solar energy systems. Phase change materials offer the best solution to this fundamental requirement thereby resolving the problem met during the time of peak demand.

Principle

The principle on which the Phase change material works; the material absorbs the available heat from the atmosphere when the ambient temperature reaches above the transition temperature. Similarly, it emits the same heat to the atmosphere when the ambient temperature falls below the transition temperature, thereby, maintain the ambient temperature equal ($\pm 1^{o}C$) to the transition temperature.

Advantages

The main advantages during the use of phase change materials are

- These materials occupy less space to store the same amount of energy, which can be accounted due to the high latent provided by these materials. This is illustrated by the fact that the sensible heat capacity of concrete is approximately 1.0 kJ/kg, compared with calcium chlorine, which

during phase transition, can store or release 190 kJ/kg Due to the large volume of material required, sensible heat storage is not suitable for retrofit applications and does not conform to the current trend for lightweight structures [6].

- Another major advantage with latent heat storage is that heat is stored under isothermal conditions, which means they can deliver or store energy at a constant temperature. The use of latent heat storage is especially suited to the storage of solar energy where it can result in high solar collection efficiency, which can mean that solar collector area can be reduced by 30% [2].

Types of PCM

PCMs can be broadly classified as

1. Organic based PCMs:
   These PCMs contains 90-95% or more organic material. Organic PCMs offer several advantages
   - They possess a wide range of melting points,
   - Non toxic,
   - Non corrosive,
   - Chemically stable,
   - Compatible with most building materials,
   - Have a high latent heat per unit weight,
   - Melt congruently and
   - Most importantly exhibit negligible supercooling [2].

   Some disadvantages of organic PCMs are;
   - High cost [3],
   - Low density, and
   - Low thermal conductivity in comparison to inorganic compounds, but this can be addressed by the addition of filler with a high thermal conductivity or the use of aluminium honeycombs or matrixes [4].

2. Hydrated salt based PCMS:
   These are mainly inorganic chemicals, with/without water of crystallization. The advantages that salt hydrates offer are;
   - Low cost in comparison to organic PCMs,
   - High latent heat per unit mass and volume,
   - High thermal conductivity,
   - Offer a wide range of melting points from 7-117° C [9].

   However, they can also suffer from some disadvantages.
   - Loss of water when subjected to long-term thermal cycling.
   - Corrosion,
   - Degrade over time due to decomposition because of which it melts incongruently and produces two separate parts, an aqueous phase and a solid phase, which possesses different densities, consequently the denser solid phase settles at the bottom of the container and this process is irreversible. This process results in low latent heat of fusion.

Solar Appliactions

1. Domestic or industrial **solar water heaters**,

2. **Space heating**,
3. **Drying processes:** Removing moisture from a dissolved solids/liquid mixture, paper, spools of dyed thread, hanks of yarn, fresh cut lumber, and countless other industrial products can be achieved through various thermal methods (cans, ovens, rotary, flash, dehumidification and spray dryers), for which solar thermal energy can be used. One typical drying process is crop drying, which usually occurs between 30 and 80^{o}C. The system can also be used for production of coffee, tea, maize and tobacco drying [11].
4. **Fruits and Vegetable drying**: drying of coconut is one of the applications in which PCMs can be used for drying purpose. It is done for extraction of oil used for domestic purposes. Drying of coconut is done using solar energy. But the process of drying works effectively during the daytime and during night the process stops completely. The process can be made effective during night using thermal energy storage mediums.
5. **Tobacco drying:** Drying of tobacco is a tedious process**,** as it involves the stages of different temperatures. At different phase different range of temperatures are maintained. In first phase 37 degrees Celsius is maintained for 2 days. In 2nd, 3rd and 4th phases, a temperature of 51, 57 and 71 needs to be maintained for 2, 3 and 3 days respectively. Drying process during daytime can be achieved to desired extent but the challenge is to maintain it at night too in order to maintain the quality and quantity to the required demand.
6. **Solar cooking** [13],
7. **Architecture and urbanization:** Solar energy also finds an application in maintaining the temperatures in the building to a comfortable range. But during night the buildings can be made to maintain the same comfort level, by using thermal energy technique.
8. **Concentrated Solar Power (CSP) for generation of electricity**

   The other type of technology that can be used to harness solar energy is Concentrated Solar Power. The basic premise of concentrated solar power involves the conversion of solar radiation to thermal energy which is then used to run a conventional power system from steam. Concentrated solar power plants can be composed of either parabolic trough concentrating collectors, power tower/heliostats, or parabolic dish collectors. The important aspect of concentrated solar power is its thermal storage capabilities. The mirrors focus solar energy onto a receiver which heats the heat transfer fluid. Then to produce electricity immediately, the heated fluid transfers its heat energy to water creating steam. The steam is then used for the conventional turbine and generator to create electricity. However, this heat energy in the fluid can also be stored and used at a later time to generate electricity which makes solar energy more cost-competitive and a realistic option for clean, renewable energy.
9. **Solar air conditioning**:

   Principle of operation: Solar Refrigeration system is based on Heat instead of Electricity, having Thermal Compression technique instead of Mechanical Compressor. TCS (Thermo Cool System) is a Heat-Operated unit that uses special refrigerant which is alternatively absorbed and released. The function of the Compressor in Vapour Compression Refrigeration (VCR) system is replaced by Thermal Compressor made up of an Absorber, a Solution Pump, and the Refrigerant Generator & Rectifier. In an Absorber, the Refrigerant Vapour from the Evaporator is Absorbed in a weak solution. This increases the pressure and the solution is then passed to the Generator via liquid-liquid heat exchanger. Moreover, water is added into a cycle to assist suction & discharge of refrigerant by cooling & heating.

Sub zero temperatures even up to -20 C are possible in the system. Thermo-Cool Absorption machine excels in reliability, that in turn reduces maintenance and repairs requirement to an utter minimum, without requiring highly qualified operating personnel [12].

10. **Washing processes:** Typical applications for solar thermal washing systems are feed water for bottle washing and washing processes in textile industry and transport sector [11].
11. **Distilling and chemical processes:** for the industrial processes where temperatures between 120°C and 250°C are required, concentrating solar collectors, such as parabolic trough collectors have to be used. The heat carriers in these systems are oil, pressurized water or steam [11].

Industrial Sector	Process	Temperature Level [°C]
Food and beverages	Drying	30-90
	Washing	40-80
	Pasteurising	80-110
	Boiling	95-105
	Sterlising	140-150
	Heat treatment	40-60
Textile industry	Washing	40-80
	Bleaching	60-100
	Dyeing	100-160
Chemical industry	Boiling	95-105
	Distilling	110-300
	Various chemical processes	120-180
All sectors	Pre-heating of boiler feed water	30-100
	Heating of production halls	30-80

Table1: Industrial sectors and processes with the greatest potential for solar thermal uses [11]

PCMs with the transition temperature 30 – 400°C can be suitable for these applications.
PCMs with the transition temperature of 120-400°C can be used for generation of electricity.

Sources and range of PCMs involved in the above range known to Pluss: [15]

Establishing Criteria for Energy Saving Opportunities [7]

Two key criteria considered in demand analysis are technical and economic feasibility.

A ***technical*** analysis for energy savings examines the substitution of the dominant existing stock (e.g., device, appliance, equipment, building, and vehicle) with the best available technology on the market, and the subsequent energy savings. The difference between the best available technology and the existing stock is large; savings of 50 per cent or more are common. Economic and behaviour barriers to the uptake of this technology may only be considered to a limited extent. Purely technical studies can provide a very optimistic view of the opportunity.

The ***economic*** analysis considers the cost-effective options. It assumes that consumers make rational, informed purchasing decisions based on a life-cycle cost analysis. It assumes the knowledge and financial means to access the opportunity are in place. However, many consumers do not take the most economic option for a variety of reasons.

But consumers do not respond to the new technology. This leads to a big barrier which may be because of lack of financing and information deficiencies. It also reflects the fact that consumers make choices for non economic reasons. As an example, larger cars offer a perception of greater safety or status. This adds a new behavioral element, i.e., **achievable target**. The achievable targets can be swayed by market intervention such as using subsidies and advertising that would increase the uptake of a new technology. Figure 1 indicates a theoretical level of energy saving based on evaluation criteria (Figure 1).

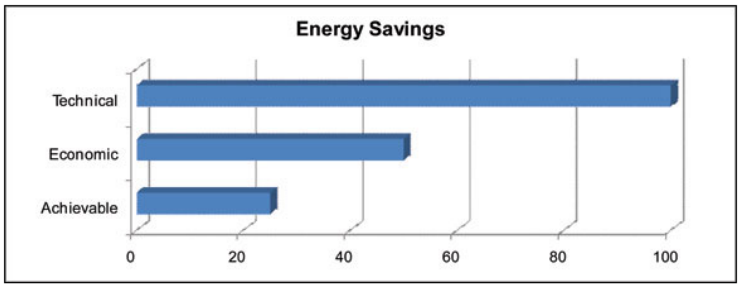


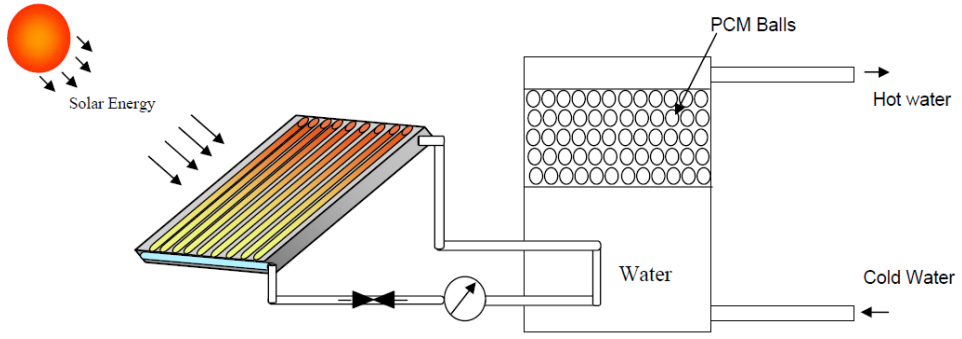
Fig. 1: Levels of energy saving opportunity

A conclusion of the American Council for an Energy Efficient Economy was "programs are often short-changed because programs frequently overemphasize the savings that are attributable to the installation of new technologies but often underemphasize the ways in which behaviour enables technology based savings" [16]. As an example, compact fluorescent light (CFL) bulbs have been promoted for over twenty-five years. It is only in the last few years that the majority of homes can claim more than one installed CFL.

Today the challenge is to encourage residential, industrial, and commercial sector to adopt the new technology coming up. Moreover, motivation is required to utilize the available technology in a more responsible manner. New products offering better service and lower energy use are constantly appearing on market. However, a "good idea", is unlikely to translate into rapid uptake.

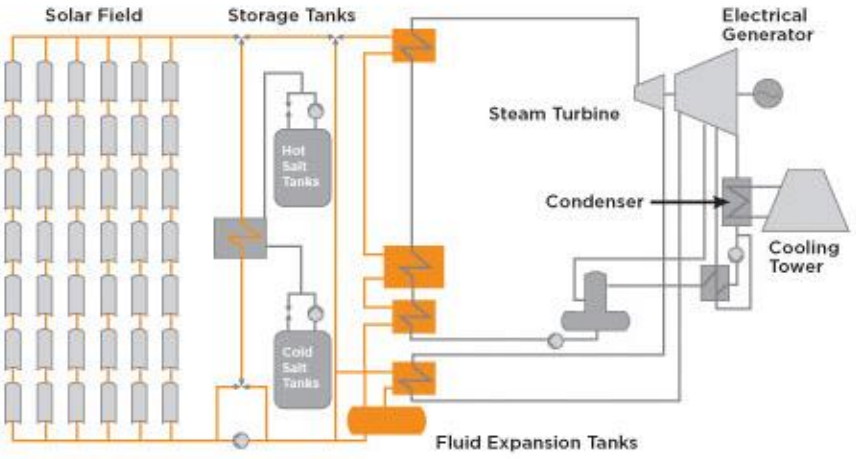
Market survey of PCM in Solar applications

1. **Solar water heaters:** In order to use solar water heater effectively, following design is proposed by Pluss Polymers. The design helps to warm water even during night. The PCM used in the design is taken as savE HS58. The product is yet to come in the market.



2. **Maintaining temperatures during night at high altitude:** The technology though theoretically looks feasible yet the product design is to be commercialized.

3. **Coconut drying:** In order to increase the productivity of coconut oil, a company in south India is using PCM for thermal energy storage. The design for the same application is yet to be proposed.
4. **Tobacco drying:** ITC is looking for a method to dry tobacco leaves even at night temperatures. The desired temperature, according to the stage leaves are going through, can be achieved by using PCMs. The design is yet to be proposed.
5. **Solar cookers:** In a TEDA exhibition January 2011, an idea was put forward about the use of thermal energy storage in cooking. Dr. Someshwar Dutt Sharma has also done some research related to the use of PCM in solar cookers [19]. But today the no solar cookers exist in the market for night and evening cooking.
6. **Architecture and urbanization:** At cooler places, the room temperatures are maintained at a comfortable level by burning wood. Wood consumption can be minimized by constructing buildings which receives the maximum sunlight during the daytime. The walls of such buildings can be incorporated by PCMs, where during daytime the PCMs can get charged. During night this charged PCM can maintain the temperature to optimum level. Such designs still need initiative.
7. **Concentrated Solar Power for generation of electricity:** Abengoa solar is working to effectively use the solar energy for generation of electricity during night also. The challenge is to develop a PCM in a higher degree range.



8. **Solar air conditioning:** The new 100 kw Solar Air-Conditioning System works at 30% higher efficiency than the current available systems and has several unique features. It is based on the new triple effect absorption cooling technology. The system has indigenously built medium temperature high efficiency parabolic troughs for collection of solar energy and effective solar thermal energy storage in the form of Phase Change Materials.

   The present system will cater to air-conditioning needs of 13 rooms of solar Energy Centre. To achieve this, 288 sq mtr of Solar Collector area has been installed which generates nearly 60 kW of 210 °C Pressurized hot water. This heat is used in Vapour Absorption Machine to generate 7 °C Chilled water which in turn circulates through the Fan coil unit installed in the thirteen rooms. The major attraction of this system is that the hottest days have the greatest need for cooling and simultaneously, offer the maximum possible solar energy gain.

   The system has been developed in joint collaboration by Solar Energy Centre with Thermax Limited, Pune and is expected to meet the growing demand for air-conditioning in India in highly efficient and cost effective way through use of direct solar energy [18].

Solar air conditioning system is also developed by Bhaskar solar air conditioning system. But presently the company is involved with the use of PCMs.

Pluss knowledge

Pluss polymers has a wide range of PCMs which can be very useful for the solar applications:

- HS58 can be used for solar water heaters.
- OM48, OM46 and OM53 can be used for coconut drying. Pluss is through with designing of the system required for the application and trials are under process for drying coconut.
- OM67 can be used for tobacco drying. The application has been at the stage of consultation.
- HS08 can be used for solar air conditioning. The product has been under development to cut down the cost involved in the raw materials of PCM.

PCM has a vast application area. Out of which utilizing solar energy can be boon for the world. This area needs awareness and interest of a common man. Saving energy should be a target of every individual. Giving shape to the above technologies needs efforts and investments.

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