Renewable Energy Resources and Applications of Phase Change Materials –A Review

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Abstract

The consumption of electricity will comprise an increasing share of global energy demand during the next two decades. At present, India is a larger consumer of fossil fuels due to increased population & industrial growth. This rapid increase in use of energy has created problems of demand & supply. It has now been widely recognized that the fossil fuels and other conventional resources, presently being used for generation of electrical energy, may not be either sufficient or suitable to keep pace with ever increasing demand of the electrical energy of the world. Because of which, the future of Non renewable energies is becoming uncertain. In recent years, the severe power crisis and increasing cost of fossil fuels coupled with the emergence of environmental issues of greenhouse gas emissions have renewed the interest in the development of alternative energy resources. The present paper entails about the different alternative energy sources their limitations and the use of different phase change materials.

Keywords: *Renewable energy; phase change materials; conventional resources*

INTRODUCTION

Energy is the indispensable part of universe. It is the basic requirement of each and every human being. The unprecedented growth of industry and population in India has put a great pressure on energy resources. If proper measures are not taken then the gap between available energy and demand will widen with time. In India, the energy demands are generally met from conventional sources including coal, petroleum, natural gas etc.

Abolhosseiniet al. (2004) has discussed the Renewable Energy Supply and Energy Efficiency Technologies. He stressed on the fact that if the nonrenewable resources will not be supplemented with the renewable sources then there will be severe problem in the coming time. However, the increasing future demand will not be fulfilled from these resources as these are non renewable. These will get exhausted very fast with current rate of consumption which is much higher than their natural generation. Literature survey has revealed that the facilities that use renewable energy sources for power generation has been installed in many countries.

It has been estimated that reserves of coal are 301.05 billion tons (Fig. 1).Coal is the most abundant fossil fuel and India's electricity needs are largely dependent on it. Coal deposits are mainly confined to eastern and south-central parts of the country. The states of Jharkhand, Odisha, Chhattisgarh, West Bengal, Madhya Pradesh, Andhra Pradesh and Maharashtra account for more than 99% of the total coal reserves in the country.

The State of Jharkhand had the maximum reserves (26.81%) in the overall reserves of coal in the country followed by the State of Odisha (24.94%). Coal is non renewable source of energy and it has been estimated that at current rate of consumption, its reserves will last for next 80 years only.

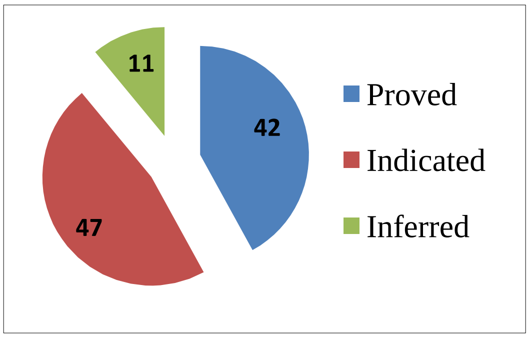


Fig. 1: Estimated reserves of coal as on 31.03.2014

(Source: Energy Statistics 2015)

The other widely used source of energy in india is oil/petroleum. As estimated India has a total reserve of 763.476 MMT of crude oil as on 01.04.2015. Crude Oil production during 2014-15 was 37.461 MMT which is 0.87% lower than 37.788 MMT produced during 2013-14. Furthermore, the consumption of petroleum products in India was 164.987 MMT in 2014-15 with a growth of 4.15% as compared to consumption of 158.407 MMT in 2013-14. Increase in number of automobiles, thrust on road infrastructure, price of oil and many other factors has lead to the increase in demand and consumption of petrol/diesel. However, the reserves in India are not sufficient enough to meet the growing needs. So, to bridge the gap between supply and demand India imports crude oil and it costs the exchequer a hefty bill. Import of Crude Oil in India increased from 16.51 ton million in November to 17.97 ton million in December 2015. The Import of crude oil as reported by Ministry of Commerce & Industry, India is shown in Fig 2.

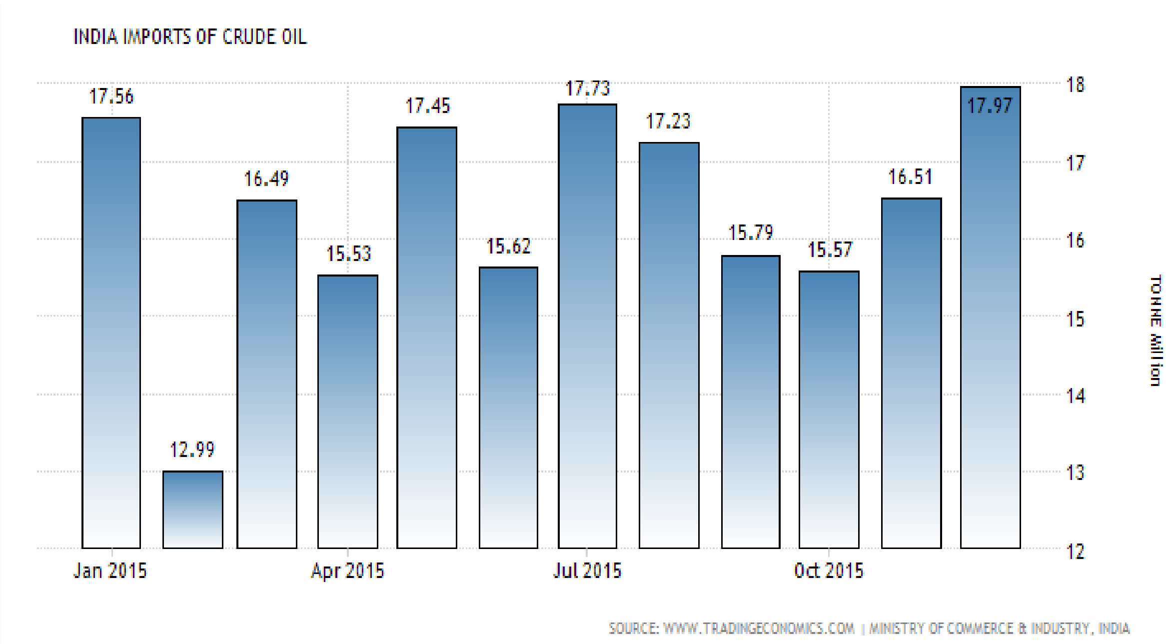


Fig. 2: Import of crude oil as reported by Ministry of Commerce & Industry, India.

The other important source of energy is Nuclear power plants that accounts for 2% of the total electrical power produced in the country. Nuclear power plants have high initial cost but the running costs are comparatively low. One of the biggest challenges with nuclear power is the radioactive waste disposal that is produced during fission reaction. Some of the radioactive waste materials like fuel rods remain radioactive for hundreds or thousands of years and there is no conventional method for disposal of this radioactive waste generated. Slow progress in this sector is because of lack of indigenous uranium, fundamental incompatibility between India's civil liability law and international conventions. India is not the part of Nuclear Non-Proliferation Treaty(NPT)due to which it has been excluded from trade in nuclear materials. Furthermore, there is large local resistance because of the danger associated with nuclear power plants heightened with the recent damage to nuclear installations in Japan caused by an earthquake and subsequent tsunami. AS per the reports, India lies within the zone of seismic activity and a very small area is located in zone 1 that is seismically least active.

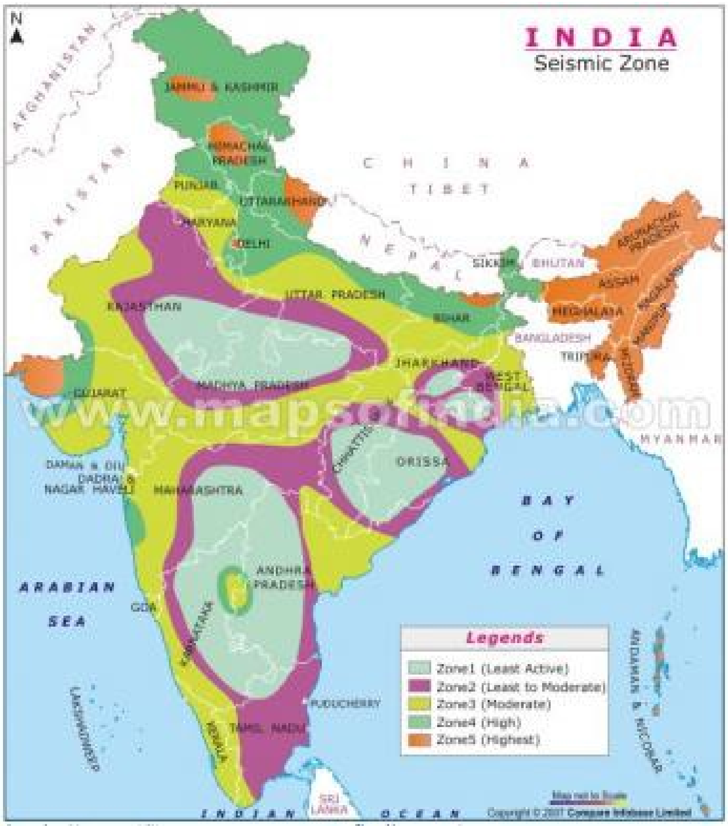


Fig. 3: Map of India with Seismic Zone

(Source: http://www.mapsofindia.com/maps/india/seismiczone.htm)(accessed April 6, 2011).

An overview of available nonrenewable energy resources and their ever increasing demand compel us to either increase the supply or decrease the demand of the consumer. Although, these steps can shorten the gap between demand and supply to some extent but relying completely on the conventional energy resources, will create problem for future generations as these resources are not going to sustain for a longer period of time. In light of all these problems, the best and safest option available with us is to use the renewable energy resources also to generate electricity. It will give us the flexibility for the usage in different terrain and climate and also ensures the availability of energy for a longer period of time. Keeping in mind the above scenario, an effort has been made in the present paper to review briefly the status of renewable energy resources as well as the methods to reduce their demand. Furthermore, an attempt has also been made to discuss the different types of phase change materials

Renewable Energy Resources: These resources are generated and replenished naturally over a short-time period. Renewable energy resources do not include energy generated from fossil fuels, waste products of inorganic sources, or waste products of fossil sources"[treia]. These are solar , wind , biomass, fuel cell , tidal, small hydrothermal, photochemical, and photoelectric etc. India has a great potential for renewable energy as it is the only country in the world to have an exclusive ministry for renewable energy development. In the last 5years, 20% growth has been shown in the net production through renewable energy sources. In the year 2015, renewable energy sources contributed around 13 % of the total production. It is the most viable solution for the electrification of rural population in India. These sources are eco-friendly and don't emit any greenhouse gases. When talking about clean technologies renewable energy sources have a huge contribution to make in creating a sustainable energy system. They help to mitigate climate change, increase the security of our global energy supply system and give developing countries access to affordable energy in support of the UN Millennium Development Goals.

Wind Energy

This form of energy is generated from the conversion of kinetic energy of the wind to the electric energy with the help of turbines. India is the fifth largest producer of wind energy in the world. In 2015, 25,088 MW of energy has been generated through it which accounted for 64% of renewable energy;during the year against a target of 2400 MW. 1,645 MW wind power projects were commissioned [MNRE]. It can be implemented with the flexibility of onshore and off shore model. According to the current estimates, the potential of wind energy in India is 102.8 GW [make in India website].

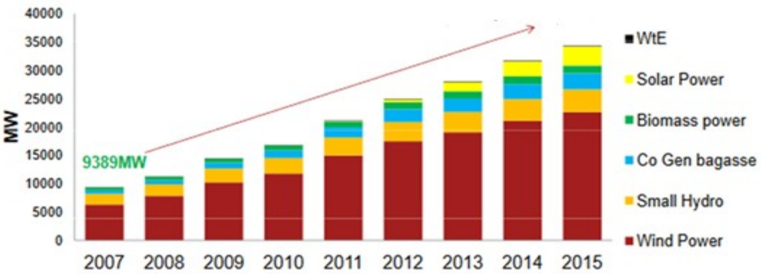


Fig. 4: Source (MNRE)

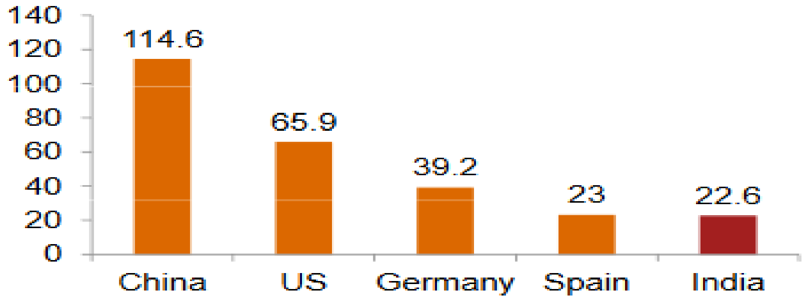


Fig. 5: Source (MNRE 2014)

Solar Energy

Solar energy is the primary form of energy. All forms of energy can be derived from solar energy. It can be used in many ways, Solar PV for the generation of electricity, solar heaters to heat water, solar cookers to cook food. 4,879 MW was generated through solar energy in 2015.During this year, 1119.76 MW solar power projects were commissioned. India has a potential of around 16GW for solar energy due long sunny days.

Bio-mass

When organic matter is decomposed in the presence or absence of air, it leads to the formation of gas of high calorific value (e.g. methane) and some amount of high quality manure. This gas can be used in residential as well as in commercial areas for various purposes. The manure formed can be used for agricultural purpose. In 2015, 4,677MW energy was generated through bio mass. India has a potential of around 22.5GW for bio power due to large cattle population.

Small Hydro Power

In recent years, mini hydro project has gained great importance for generation of power These projects have many benefits over conventional hydro projects. These plants reduce the size of the reservoir and t can be localized in a particular area. Conventional power plants have large reservoir to increase the flow of the water but these plants can be made with high head and reduced flow of water. With the increase in the head, the velocity of water increases. India generated 4,177 MW of power through these plants in 2015. India has a hydro energy potential of around 19.7GW due to high water availability.

There are certain limitations associated with the use of renewable energy in India. Scientists and researchers are working to overcome these limitations to make the best possible use of the energy resources available.

1. Capital cost of setting up the plant is high. Therefore, shifting from conventional to renewable energy resources require huge land, time and money.

2. Aggregate Transmission and distribution losses in India are quite significant. Therefore, setting up a grid connected renewable plant will have a reduced efficiency and consequently energy supplied at the consumer end will be very low.

3. Extensive site selection is required in some cases e.g. Wind, hydro to increase the efficiency to greatest extent possible.

4. Sometimes, it may be difficult to interconnect different renewable-plants with the grid, as they may have variable frequency. One of the solutions to this is the use of back to back converter station but the cost of this type of station is very high.

5. Supply is dependent on the external factors e.g. sunshine, water flow, and airflow; hence the reliability is low .To increase the reliability we have to use storage devices.

6. Skilled labor is required in some of the plants e.g. bio – gas for commissioning and operation of the plant. India has low availability of skilled labor.

7. High technical skills are required for its implementation.

In light of the shortage of fossil fuels and limitations of the renewable resources, the only viable option available with us is to reduce the demand at the consumer end or to use the phase change material. There are many ways to reduce the demand e.g. use of passive elements whereever possible, use of higher star rating equipments, using LEDs instead of CFL. Although, the efforts can be done to reduce the use at consumer level but it is difficult. Therefore, the possible way that is getting great acceptance as well impetus in the recent years is the use of phase change material.

Future Demand of Potential Energy Growth in India

Among the several developing countries, India is ranked as most populous and hottest in the world. As a result of increase in the per capita income, the airconditioners are also likely to go up, which in turn could lead to an unprecedented increase in energy demand. According to an estimate, in metropolitan like Mumbai alone, the demand for cooling is about a quarter of the current demand of the entire United States. With a population of nearly 20 million and average daytime temperature of 30 °C even in winter, Mumbai already spends about 40 percent of its electricity on cooling. Air conditioning sale in India is growing by about 20 percent per year [American Scientist the magazine of Sigma Xi, The Scientific Research Society].The emission of greenhouse gases will also increase which in turn will increase the temperature. Same is the case in heating equipments.'' About 30–40% of the world primary energy is consumed by the building sector and is responsible for one-third of greenhouse gas emissions. In buildings, a major portion of the energy is used for heating and cooling.(See Figure:6) In total energy consumption of India, cooling and heating load forms a major portion. Reducing this load can really cut down the total consumption. Phase change materials are used for cooling and heating a closed space. It can be used alone or in combination with the conventional heating and cooling system.(See Figure:7)

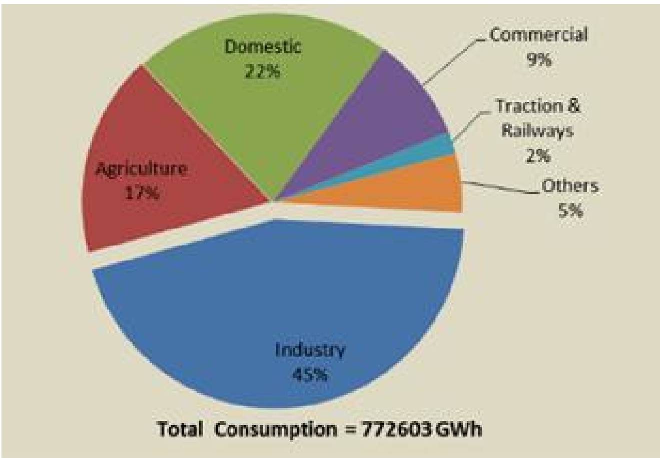


Fig. 6: Source (energy statistics 2013 MOSPI)

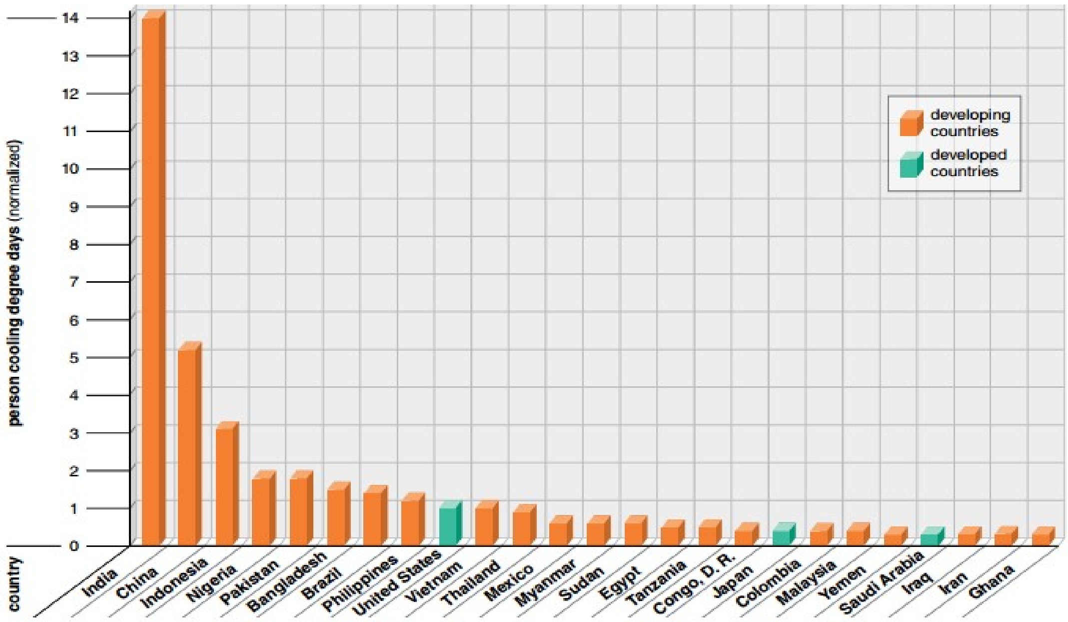


Fig. 7: Potential future use of AC Source:

Phase Change Materials (PCM)

Phase change materials absorb or release a relatively high amount of heat during the change of phase but with almost no change in the temperature of the material. This heat absorbed or released is called latent heat. Among the various heat storage techniques of interest, latent heat storage is particularly attractive due to its ability to provide a high storage density at nearly isothermal conditions. This change of phase can be from solid to liquid, solid to gas, liquid to gas, etc. Each material has its own phase change temperature. For solid to liquid is known as melting point whereas for liquid to gas is known as boiling point. Water is generally used for cooling or heating the substance as well as for heat storage.

This has a specific heat of 4.18 j/ gram per/ Celsius. If one puts a hot object into relatively cool water, the surface of hot object will cool down giving its thermal energy to the water and as a result water will become warm. Therefore, if one wants to heat 1 gram (approximately 1 cc or 1 ml) of water up 1 degree C, for that we need to put in 4.18 joules of energy into the water. Similarly, if one wants to cool 1 gram of water down to 1 degree C, one has to take out 4.18 joules of energy. However, if one wants to freeze water by going from 1°C to 0°C, one has to take out more than the normal 4.18 J/(g•°C) of specific heat. When water undergo phase change from liquid to solid (freezes), the amount of energy required in this process of phase change will no longer 4.18 J/(g•°C), but 333 J/g. Therefore relatively large amount of energy is required for changing the phase from solid to liquid and is referred to as the "latent heat of fusion." Not only, this much energy is needed to freeze water, but this much energy is also required being absorbed for melting 1 gram of ice. That is why ice is to lower the temperature of objects around 0°C.The amount of latent heat required to boil water is 2260 J/g. The energy required to change the phase from liquid to gas is called "latent heat of vaporization."[William R. Sutterlin, Ph.D.]. At different temperatures there is variety of different PCM material available but selection of material has to be made by considering various other parameters like Latent heat absorption capability, operating temperature and heat exchange capability. Sharma et al (2009) has reported that phase change materials are effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. Chen et al (2014) has reviewed that metal foam with high thermal conductivity, porosity, surface-area to volume ratio and strong mixing capability is considered as one of the most promising heat transfer enhancement materials. Sharma et al (2004) has mentioned Phase Change Materials for Low Temperature Solar Thermal Applications. Kuta and Wójcik (2015) reported that the PCMs are interesting for the energy sector because their use enables thermal stabilization and storage of large amount of heat. It is major issue for safety of electronic devices, thermal control of buildings and vehicles, solar power and many others energy domains.

Classification of PCM: For any required temperature range, a large number of Phase Change Materials are available.(See Figure:8)

Paraffin Organic Compounds: Paraffin wax consists of a mixture of mostly straight chain n alkanes CH3–(CH2)–CH3. The crystallization of the (CH3) - chain releases a large amount of latent heat. With an increase in chain length both melting point and latent heat of fusion can be increased. In latent heat storage systems only technical grade paraffins are used as PCMs due to cost considerations. Paraffin acts as safe, reliable, predictable, less expensive and non-corrosive. They are chemically inert and stable below 500 C, that show little volume changes on melting and have low vapor pressure in the melted form. Because of these properties of the paraffins, system-using them usually have very long freezing –melting cycle. Paraffin wax is mainly used commercial organic heat storage PCM (Lane, 1983; Abhat et al., 1983)

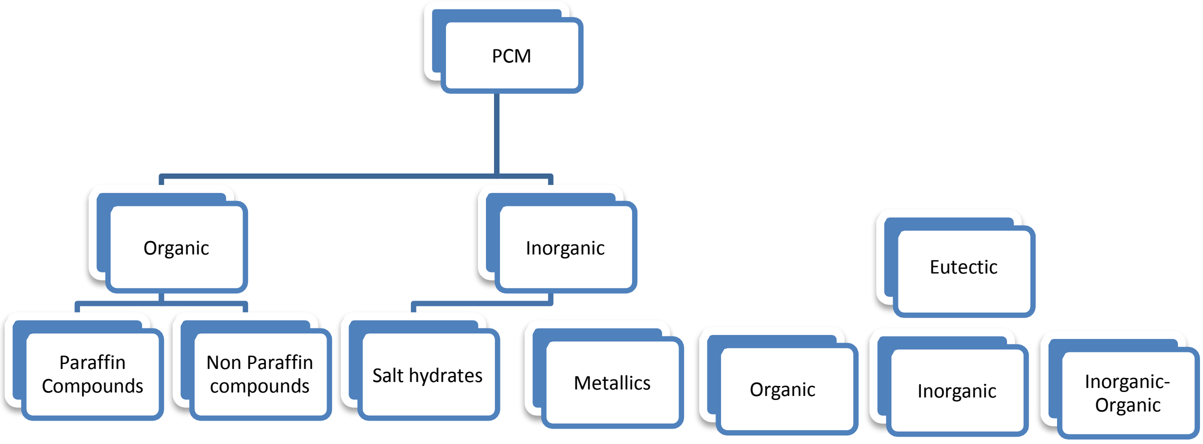


Fig. 8:

Non Paraffins Organic Compounds: The non-paraffin organic compounds are among the most common phase change materials with highly varied properties. Each of the non paraffins have their own properties unlike the paraffins having very similar properties. These organic materials have high heat of fusion and are inflammable. Moreover, low thermal conductivity, low flash points, varying level of toxicity and instability at high temperatures are some of the key features of these materials. Abhat et al., (1981) and Sawhney (1994) identified a number of esters, fatty acids, alcohol's and glycol's suitable for energy storage.

Inorganic Phase Change Materials: They are further classified into salt hydrates and metallics.

Salt Hydrates: Salt hydrates as PCMs are the most-researched latent heat storage materials. Numerous trials and subscale tests have been carried out on these compounds. Salt hydrates are regarded as alloys of inorganic salts and water forming a typical crystalline solid. They have general formula AB-nH2O. The solid–liquid transformation of salt hydrates is actually a dehydration of hydration of the salt, although this process resembles melting or freezing thermodynamically. A salt hydrates usually melt to either salt hydrate with fewer moles of water or its anhydrous form. Salt hydrates have a number of problems associated with them. They have poor nucleating properties that result into super cooling of the liquid salt hydrate prior to freezing. This problem is generally overcome by the addition of suitable nucleating agent that has a crystal structure similar to parent substance. Another significant problem observed by Abhat (1983) was that most of these materials melted incongruently, i.e. they melted to a saturated aqueous phase and a solid phase that is generally a lower hydrate of the same salt. Due to density differences, the salt phase settled out and collected at the bottom of the container, a phenomenon called decomposition. It was further noted that unless specific measures are taken, the irreversible phenomenon, i.e. during freezing, the solid phase did not combine with the saturated solution to form the original salt hydrate'. In addition, volume change, corrosive nature and toxicity of the salt hydrate were some of the additional problems encountered while using these materials.

Metallics: These materials have low heat of fusion per unit weight and high heat of fusion per unit volume. High thermal conductivity, low specific heat and relatively low vapor pressure are important features of these materials. The use of metallics as PCM material poses a number of unusual problems. A major difference between the metallics and other PCMs is their high thermal conductivity. Moreover, metallics have not yet been seriously considered for PCM technology because of weight related issues.

Heat and Temperature: Heat and temperature are not always in proportion if we put an ice cube in a glass of water and compare it with an ice cube in a big pan full of water. Water will be colder in case of glass rather than in big pan. Temperature is related to average kinetic energy of the molecules. Heat is actually a form of energy, present in a substance. If we add heat (form of energy) to a substance, substance could either face rise in temperature, which implies that the average kinetic energy of the substance has increased or the substance can encounter change of phase, which implies that the average kinetic energy is same but the energy in the form of heat is used to beak the bonds between the molecules present in the substance. As in the second case, the average kinetic energy is same, therefore there is no change in the temperature. The second case happens at a unique temperature for a particular substance. *PCM at a certain temperature absorbs heat from the surrounding to change the bonding structure and not the temperature*. This intake of heat is in a relatively large quantity.

Solid-Liquid PCM: When the temperature of the PCM is below melting point, it will be in the solid form. As we increase the temperature, there will be approximately linear increase in the temperature of the material up to the melting point or phase change point as shown in figure1. At this point, the material will absorb a relatively high amount of heat due to phase change. There will be no rise in temperature till the specified amount of heat is supplied. When the heat requirement is fulfilled the solid material will completely change into liquid. Now, the material is in liquid form, if we decrease the temperature, initially the temperature will decrease till the melting point or phase change point is reached. After this point, there will be no fall in temperature till the specified amount of heat is rejected from the material. Now, the material will change the phase from liquid to solid. Again, the process can be repeated many times.

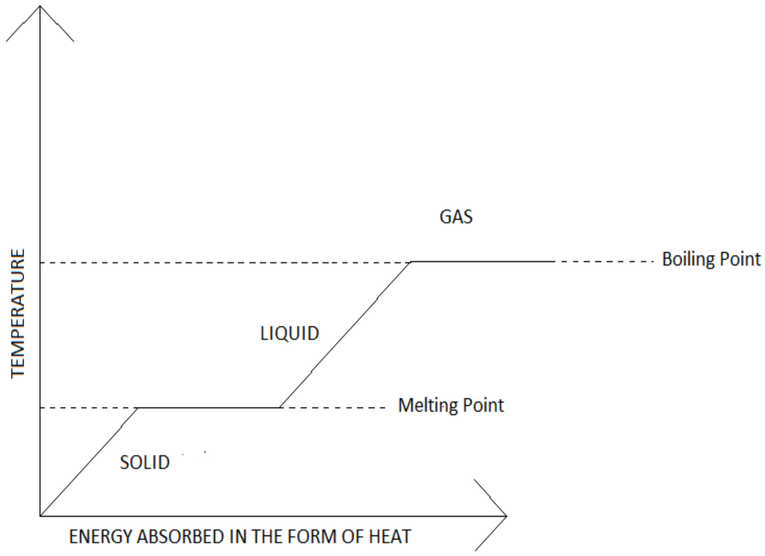
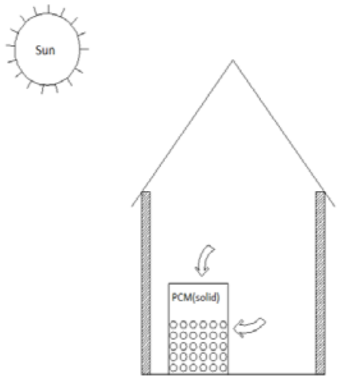
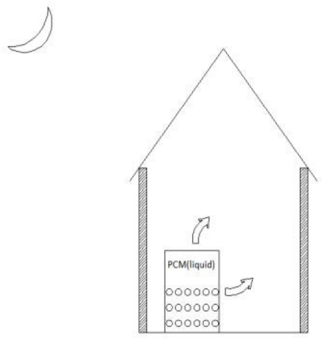


Fig.9: Effect of temperature on the state of change of phase material.

Implementation of Phase Change Material



Change of state from solid to liquid (morning)



Change of state from liquid to solid(night)

Fig. 10: Shows the imlementaton of phase change material

Assuming PCM to have a melting point of 24 degree c. in morning when the temperature starts rising. There will be an increase in temperature of the air inside the house. When the temperature inside the house reaches 24 degree c ,the PCM will start melting and absorb the heat energy from the surrounding atmosphere as shown in figure 2. This heat absorption will help to maintain the surrounding temperature. when it has gained the sufficient amount of energy it will be completely melted.

This process is called discharging. *This situation is analoguos to the putting of ice in a glass containing water. In a similar way as the water cools down and the ice melts ,the room will also cool down but now instead of ice PCM will melt.* During night the temperature drops, but when it will reach the melting point of 24 degree c the PCM will release relatively high amount of heat to the surrounding air. This heat helps to keep the place warm.

When it has released sufficient amount of heat to the surrounding, it will be in complete solid state. This process is known as charging. This situation is analogous to the putting of ice tray containing water in the freezer. In a similar way as the water solidfy, but now instead of water PCM will solidfy. Charging and discharging can be used as per the requirement. During summers, when in the morning room temperature is high PCM can be used for cooling. In the night, it can be charged inside or outside the house as per the requirement, charging it outside will make the temperature inside more colder than charging it outside.

During winters, when the room temperature is bit high in the morning which is generally preferable, the PCM could be discharged in the sunlight or inside the room. In the night, when it is cold inside the house PCM could be charged to release some amount of heat and hence, will help in maintaining the room temperature.

PCM is selected as per the requirement to reduce the temperature fluctuation between the day and night, to reduce the power consumption and to maintain the temperature suitable as per the human comfort.(See Figure:11)

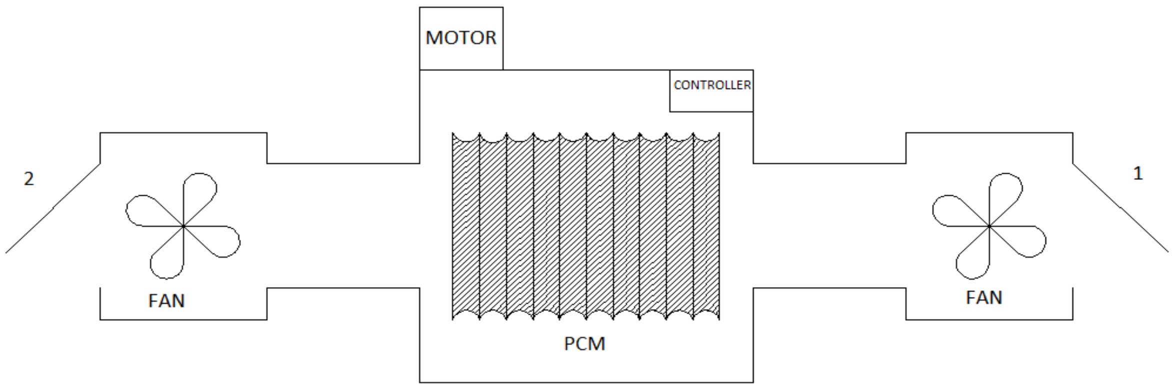


Fig. 11: Phase change controller mode

This research paper purposes a PCM controller model as shown in the figure 3.This can be a possible way for the implementation of PCM. There are four main components, motor, controller, PCM, fan. Motor is used to control the flow of air through movable gates. Controller is used to control the movement of the motor. Fan is used to increase the intake of the air and hence, enhances the circulation of the air. PCM is used for cooling and heating purpose. In this model, PCM is closed in a container having fins to increase the area for the exchange of heat. This model can be used either actively or passively. Initially, both the gates 1 and 2 will be open, and both the fans will be rotating. After some time, the gates will be closed and fans will be stopped to reduce the energy consumption and provide some more time for the exchange of heat. After a specified time depending on the heat exchange ability of the material, the gates will be re-opened and the fans will again start rotating. Opening and closing signal is given by the controller to the motor, which operates the gates. On/off signal is also given by the controller to the fans. This can also be used passively by not using the motor, controller, and fans. Passive system has an advantage of no operating cost.

Advantages and utilities of PCM: Across the globe, Phase change materials (PCM) are being used for energy storage and temperature control applications.

Temperature controlled packaging: Around the world, medicines, proteins, biological samples, food items etc. are regularly shipped in containers and are subjected to a wide range of temperatures. Though, they are shipped in insulated containers or climate controlled environments, the temperature stability of the shipping containers can be significantly improved by using suitable phase change materials. These materials offer a number of advantages like size of shipping containers and the transportation cost can be reduced. Moreover, they are reusable.

Defense Applications: Indian forces face a number of heat related problems. They are working in very harsh environmental conditions like hot deserts at western border and cold regions at high altitudes. Performance of man, equipment, and weapon system gets adversely affected in such harsh environment. In order to overcome this problem, PCM panels can be applied as an internal lining in buildings, structures and vehicles that can help to moderate the extreme temperatures without the use of any external power for cooling. Cooling vest has also been developed with chargeable PCM packs to provide comfortable microenvironment to a soldier on field duty (below 30 °C) for 2-3 hrs. Other products, PCM-based cool vests and caps, having removable PCMs packs in multiple pockets have been developed at DLJ for soldiers on field duties. The weight of the vest been developed is 1.5 kg to 2.0 kg and PCM packs need to be charged in a refrigerator or deep fridge before each application. In a field evaluation, inside engine cabin of APC (Russian model BMP) the vest provided less than 30 °C temperature around human torso for more than 2 h (Kumar et al….).Further, soldiers wearing nuclear biological and chemical individual protective gear (NBC-IPG) suits feel highly suffocated and dehydrated due to heat. PCM cool vest underneath NBC-IPG, can be used which can reduce heat stress to significantly low levels.

Aerospace: Since, the first application of PCM by NASA in aerospace field, the scope of use of PCM in this field has been very fascinating. This concept can be used to a larger scale for space missions which will present varying spacecraft thermal environments. For example, a satellite orbiting the earth encounters different thermal environments as it passes in and out of the earth's atmosphere. During such a mission, solar energy can be stored and released by a PCM to dampen the large temperature changes that would be experienced during the orbit cycle. A specific example might be a crew compartment or refrigeration compartment. In this case, it is required to remain nearly isothermal conditions throughout the orbit. So, in order to provide isothermal conditions, the compartment could be enveloped by a layer of PCM to absorb and release solar energy during the orbit at the melting temperature of the PCM (Haleet al 1971).

Energy efficient buildings: The building sector is the dominant energy consumer with a total 30% share of the overall energy consumption and accounts for one-third of the greenhouse gas emissions around the world. Moreover, in recent years the energy demands for buildings have increased very rapidly due to increase in the growth rate of population and improvement in living standards of people. Memon (2015) has reported that the combination of construction materials and PCM is an efficient way to increase the thermal energy storage capacity of construction elements.

The application of PCMs in building can be used for two different purposes. First include the use of natural heat like solar energy for heating or cold nights for cooling. Second, using manmade heat or cold sources. Basically, PCMs can be used for heating and cooling the buildings in three possible ways like in building walls, building components other than walls, and in heat and cold storage units. A space heating system that incorporates a PCM located in the ceiling void was developed by Gutherz and Schiler (1991). Sun reflectors were used to directly tap the solar energy entering the windows on to the PCMs. It allowed a large area to be dedicated to heat storage without the need of large volumes of storage medium that would be required with sensible heat storage. It was shown that with the use of such a system, 17–36% of heat lost over the initial gains could be recovered. Ceiling boards are the important part of the roof and are utilized for heating and cooling in the buildings.

Bruno developed a system, which stored coolness in phase change material in off-peak time and released this energy in peak time. The effects of the peak-cut control of air-conditioning systems using PCM for ceiling board in the building were also tried byFrank (2002). Kodo and lbamoto in 2002 examined the effect of peak shaving control of air conditioning systems using PCM for ceiling boards in an office building. Peak shaving which is similar to load leveling, but may be used for the purpose of reducing peak demand rather than for economy of operation.

Rock wool PCM ceiling board (PCM ceiling board) was enhanced by adding micro-capsulate PCM, with a melting point of about 25 8C, close to room temperature. In this system, a PCM ceiling board is used instead of a rock wool ceiling board. During overnight thermal storage, the cool air from the AHU flows into the ceiling chamber space and chills the PCM ceiling board, thus storing cooling thermal energy.

The cooling thermal energy was stored using cut-rate electricity. During normal cooling time, the cool air from the AHU flows directly into the room. During peak shaving time, when the thermal load increase, the air from the room returns to the AHU via the ceiling chamber space. As a result of passing through the cooled-down PCM ceiling board, the warm air returning from the room is pre-cooled on its way back to the AHU (Kodo and Ibamoto, 2002).

Solar Water Heating Systems:

Solar water heating systems and solar cookers: Solar energy can also be used for heating the water but its use is limited as it cannot be used in evening. Prakesh et al.(1985) analyzed a built in storage type water heater containing a layer of PCM fitted at the bottom of water heater During the time of sunshine, the water gets heated up which in turn transfer the heat to PCM below it. The PCM collects energy in the form of latent heat and melts.

During no sunshine that is in evening, the cold water gains energy from the PCM and gets heated. The energy is released by the PCM on changing its phase from liquid to solid. A solar pilot plant at the University of Lleida was constructed by Cabeza et al., (2006) to test the PCM behavior in real conditions, which could have the capability to work continuously with the solar system, or could also work with an electrical heater. The PCM module geometry adopted was to use several cylinders at the top of the water tank. Several experiments with two, four and six PCM modules were carried out in the real installation.

A granular PCM–graphite compound of about 90 vol.% of sodium acetate trihydrate and 10 vol.% graphite was chosen as the PCM for the experiments. It was concluded that the inclusion of a PCM module in water tanks for domestic hot-water supply is a very promising technology. It would allow to have hot water for longer periods of time even without exterior energy supply, or to use smaller tanks for the same purpose. Another use of solar energy is cooking using various solar cookers. However, they also cannot be used during no sunshine hours. By using PCMs the utility and reliability of solar cookers can be increased. Domanski et al. (1995) have studied the use of a PCM as a storage medium for a box type solar cooker. They used magnesium nitrate hexahydrate (Mg(NO3)2.6H2O) as a PCM for the heat storage. Sharma et al. (1997) also developed a PCM storage unit for a box type solar cooker to cook the food in the late evening with acetamide. They recommended that the melting temperature of a PCM should be between 105 and 110 8C for cooking in the evening hours.

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