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Thermal Energy Storage: Way of Sustainable Development

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Abstract— This paper aims to present a review on the role of thermal energy storage as a key link which can make renewable reliable & compatible with fossil fuels so as to form the basis of sustainable development. Actually no other means of energy storage is so diverse in terms of providing both high grade energy as well as low grade energy at the end utility as what the thermal energy does. Thermal energy storage actually covers a wide range of temperature and hence not only serves the purpose of low grade energy applications like water heating and air heating but is also equally viable for power generation using molten salt. Various types of thermal energy storage systems along with their applications and advancements like microencapsulation, molten salt and use of heat pipes have been discussed in this paper.

Keywords— Thermal energy storage; sustainable development; microencapsulation.

I. Introduction

Fossil fuel had played a significant role in the development of modern world since 18th century and is continued to be an essential part of our daily lives. The relentless use of fossil fuel over a period of time had cause sufficient emission of greenhouse gases to cause serious consequences like global warming and climate change. Another problem which is directly linked with the continuous use of fossil fuel is its limited preserve which is now getting depleted at a much faster rate. All this had lead the whole world to think and act in the direction of extensive use of renewable sources of energy. In this regard European Commission had set a target of achieving 20% of the total energy budget from the renewable sources by the year 2020 [1], which will stabilize the CO_2 emission, thus reducing the contribution to global warming. The main problem associated with renewable is their intermittent nature, thus comes the role of storage to provide reliable supply at the end utilities (heating, cooling or power generation). Batteries are doing significant job as far as decentralized renewable power generation is concerned but the problem with batteries is the environment issue which is due to the use of toxic and harmful chemicals so the motto of sustainability is not impact fully addressed while using batteries. Pumped hydro a another means of energy storage is site specific and involves huge investment for transmission to long distances, while compressed air energy storage has their own limitations of requirement of large volumes like underground caverns problems like additional heat addition during expansion are also associated with compressed air energy storage. Thermal energy storage is not only well suited both for low & medium range temperature $50 - 150^0C$end utilities but also for high range temperature above 200^0C applications. The integration of thermal energy storage with various solar collectors (flat plate collectors, evacuated tube collectors, parabolic trough, parabolic dish, heliostats) can pave the way of sustainable development in true sense.

II. Types Of Thermal Energy Storage And Application

Increasing demand of energy is the major region for the need of energy as there is a huge gap between energy demand and supply during peak hours and in some of the countries the rate of energy during peak hour is high enough. The idea of energy storage is started in 19th century due to increasing demand and decreasing fossil fuels. This demand of storage is increased after the development and switching over to non-conventional energy sources as there availability is limited during few hours of the day especially sun. The energy storage is one of the major requirements of today's world. Energy can be stored in different form as shown in fig. 1.

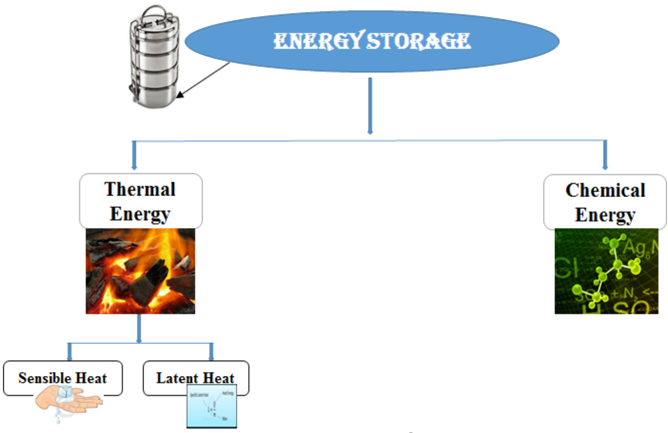

Fig. 1. Energy storage techniques.

A major portion of thermal energy is stored in the form of latent heat for various use. The latent heat can be stored in the form of solid, liquid and gas form (fig. 2). The energy stored in the form of latent heat is calculated by $Q = mL$ in addition with sensible heat, where L is latent heat.

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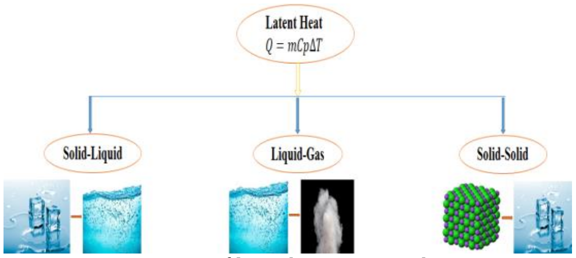

Fig. 2. Types of latent heat storage technique

Latent heat is absorbed and released when change in phase occurs and this amount of latent heat is much significant in comparison with sensible heat.This is explained through figure given below (fig. 3).

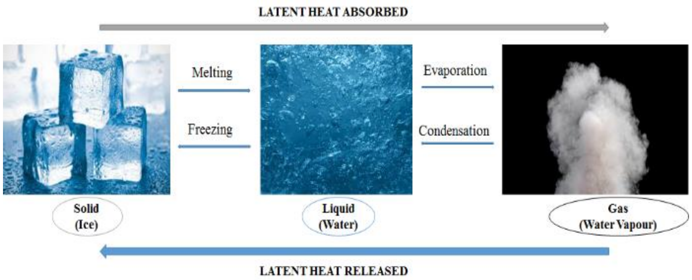

Fig. 3. Latent heat storage mechanism.

The energy stored in materials in the form latent heat is known as phase change material (PCM). There is an availability of large number of PCM for different application working at different temperature ranges these materials are organics, inorganics and eutectics. A PCM classification is presented in figure. There are new developments in the area of phase change material from the melting temperature and latent heat of fusion point of view, the developments also includes the sizing of phase change material. As the inorganic materials are required in larger quantity as compared to organic materials its ratio is almost double. The major properties which are taken in consideration are latent heat of fusion, thermal conductivity, super cooling, nucleating, range of operations *etc.* The use of different phase change material depends on the requirement of desired range of applications. The one single material cannot fulfill all the required condition's hence as per requirement one can chose the required range and type of material. The different types of PCM is explained through fig. 4 [2].

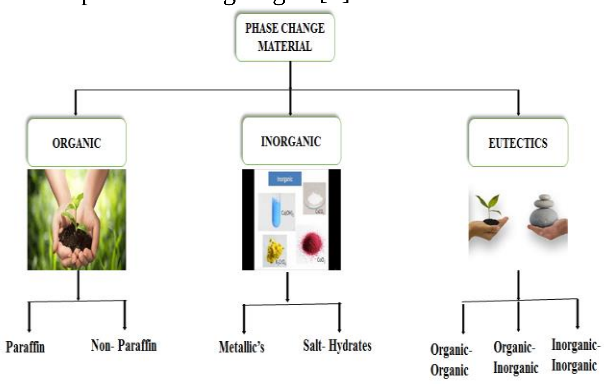

Fig. 4. Types of phase change materials.

A. *Organic Phase Change Materials*

Organic phase change material is the one which are made up of organic compounds. The organic materials are included with consistent melting and freezing in an instantaneous segregation with consequent squalor of latent heat of fusion. Their advantage is there nucleation without supercooling and they are mainly non corrosive in nature. The organic phase change materials are further classified in two more types as paraffin and non-paraffin's material. The type of organic PCM is given in table I.

TABLE I. Types of organic materials

S. No.	Compound
1.	Capric Acid
2.	Vinyl stearate
3.	Paraffin
4.	Butyl stearate
5.	Poly glycol E600

B. *Inorganic Organic PCM's*

The inorganic compounds are most suitable for the use of thermal energy storage as they are non-flammable, lower in cost and latent heat of fusion is high enough to be used in different application. The disadvantage of using the inorganic material is decomposition and supercooling. The inorganic material are also further classified in two parts metallic and salt hydrates. The different inorganic material use in different applications is tabulated in table II.

TABLE II. Types of inorganic materials

S. No.	Compounds
1.	$CaCl_2.6H_2O$
2.	$MgSO_4.\ 6H_2O$
3.	$LiNO_3.\ 3H_2O$
4.	$Na_2SO_4.\ 10H_2O$
5.	$KF.\ 4H_2O$

C. *Eutectics PCM*

Eutectic is a mixture made up of organic and inorganic composition in different ratios. These compounds are a mixture of two or more components due to which its melting point is minimum as it's melting and freezing is followed by each other.. The eutectics are formed in a combination of organic-organic, inorganic-organic, inorganic –inorganic.

The storage with the help of storage material is a costly issue but when commercial grade PCMs are utilized this can be overcome. The use of this material is proving to be the sustainable future of the 20th century [3].

III. Applications of Thermal Energy Storage

Since, the development of thermal energy storage there has been a wide range of applications. The applications of thermal energy storage is in demand now a days due to increasing demand of use of renewable energy and sustainable development. The application of thermal energy storage is wide and discussed below.

A. *Building Applications*

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There is a huge application of thermal energy storage in building for different purposes. The building heat is stored in the form of active and passive form. The thermal energy storage is utilized for building cooling and heating both by storing night heat for cooling in daytime and heat during daytime to be used at night in winter days or cooler places. The PCM materials can be integrated with wall boards, bricks, trombe wall, ceiling etc.

B. Solar Applications

PCMs are now days are utilized in different solar application to increase the efficiency of the system. and, output rate of the system. It has been integrated with flat plate collector, solar evacuated, solar parabolic, solar photo-catalysis and solar desalination.

C. Other Application

PCMs are also integrated with different heating or cooling application like telephones tower, boilers heat are stored and used for other heating applications.

IV. ADVANCEMENTS IN THERMAL ENERGY STORAGE

The advancements in thermal energy storage can be grouped into following three categories (fig. 5).

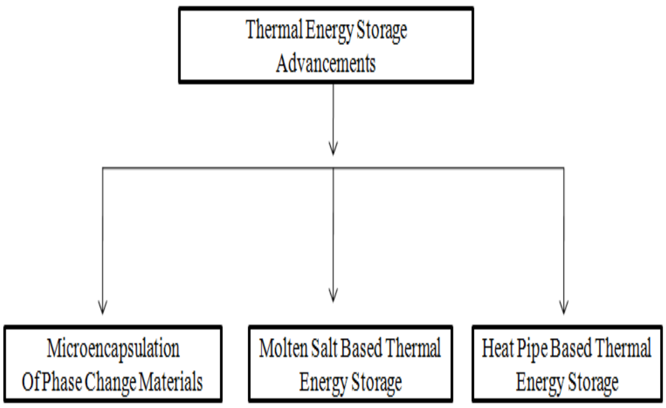

Fig. 5. Showing advancements in thermal energy storage.

A. Microencapsulated Phase Change Materials (MEPCMs)

The encapsulation process was discovered and developed by Barrett K Green of the National Cash Register Corporation (NRC) in the 1940s and 1950s [4]. The outer wall material of the capsule is usually fabricated by using materials like natural and synthetic polymers. The advantages of microencapsulated paraffin wax are (1) reduction of the reactivity of the paraffin wax with the outside environment, (2) it increases the heat-transfer area, and (3) permits the core material, due to coating, to withstand frequent changes in volume of the storage material, as the phase change occurs [5].Microencapsulation is defined as a process in which tiny particles encapsulated in a homogeneous or heterogeneous matrix, to give small capsules with many useful properties [6].Depending on the physico-chemical properties of the core, the wall composition, and the used microencapsulation techniques, different types of particles can be obtained (Fig. 6–A&B [7]): simple sphere surrounded by a coating of uniform thickness; particle containing an irregular shape core; several core particles embedded in a continuous matrix of wall material; several distinct cores within the same capsule and multi-walled microcapsules [6].

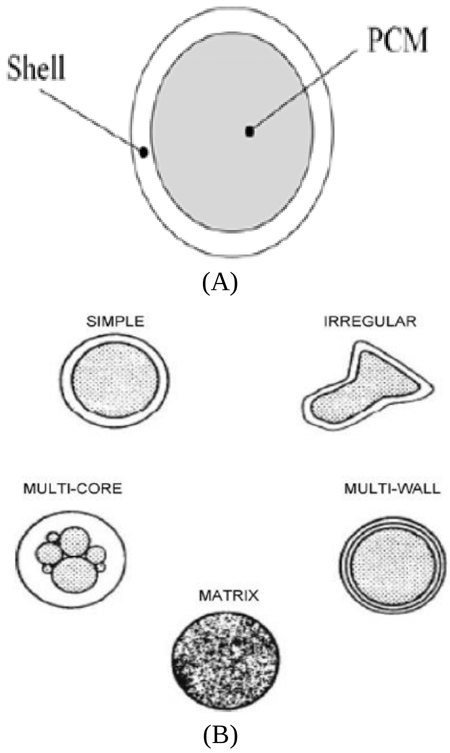

Fig. 6. (A) Microcapsule of PCM [8], (B) Types of microcapsules [7].

Microencapsulated Phase Change Materials (MPCMs) can be combined with many materials that are commonly used in construction of building. The MPCM incorporated with concrete, mortar, plaster, cement and other materials have a significant potential to increase the thermal capacity of the semi-solid mixture. The ultimate aim for PCM microencapsulation is not only to make PCMs easier and safer to handle, but also to reduce reactivity and to improve thermal properties by increasing the heat transfer area. The advantage of this way of containment is that the PCM filled microcapsules can be mixed with other materials (e.g. concrete or gypsum plaster) [8].

B. Molten Salt Based Thermal Energy Storage

There is an extensive literature available on molten salt. This is another form of phase change material, is most commonly used for different medium to high temperature solar energy application [9-11]. Nitrate molten salt is also called as solar salt and is composed of $NaNO_2$ and KNO_3 in proper ratio *i.e.* 54:46 or 6:4. In this regard Rogers and Janz [12] used DSC and presented the phase diagram of latent heat and specific heat of fusion for $NaN0_3$ / $KN0_3$ composite. Thermal physical properties of $NaN0_2$, $NaN0_3$, $KN0_3$ and Na-K-Li-Ca nitrate salts (solar salts) are measured by Inversion *et al.*, [13] and found that Young's modulus, specific heat and thermal conductivity varies with temperature shell and tube

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type latent thermal energy storage is studied by Zhan *et at.*, [14] with eutectic molten salt for better utilization of solar energy at medium temperature (200 ºC) composite PCM by Nickel foam contraction is pure PCM (molten salt) increases the thermal conductivity of LHTES system performance (fig. 7).

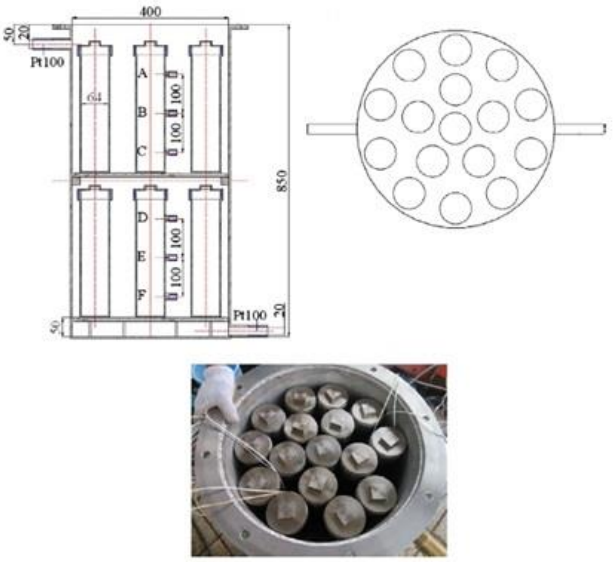

Fig. 7. Molten salt based thermal energy storage technique [14].

Molten salts for power recovery are usually stored at $(500^0 C \ to \ 600^0 C)$ until electricity is needed at day or night, as electricity is needed, molten salt is allowed to flow from the hot tank through a heat exchanger to create super-heated steam which then powers a conventional steam turbine (fig. 8).

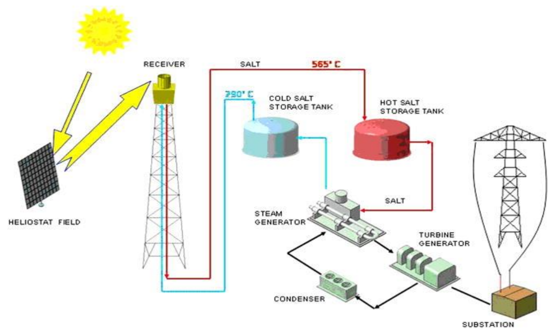

Fig. 8. Molten salt storage based power plant [15].

C. *Heat Pipe Based Thermal Energy Storage Systems*

Heat pipes is the device which can be utilized for heat transfer efficiently. This device is simple and reliable with no moving parts [16]. Mahdavi *et al.*, [17] studied the heat pipe for latent heat thermal energy storage (fig. 9). The excess heat is used to charge the phase change material via the secondary concentric heat pipe. The vapor flow leaving the adiabatic part of the primary heat pipe to the main condenser is similar to the confined jet impingement. As the flow impinges on the surface and spreads out radially, several recirculation zones have formed, resulting in non-uniform condensation on the condenser surface.

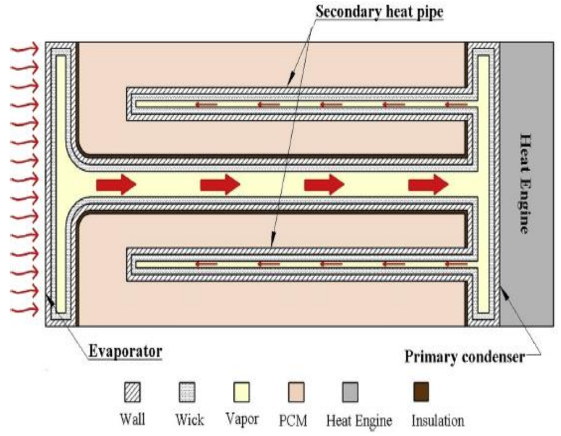

Fig. 9. Heat pipe based thermal energy storage [16].

V. Role in Sustainable Development

The association between energy and economics was firstly recognized in 1970s. Both energy and environment did not receive much attention at this time. High demand side of energy has created environmental concerns, such as acid rain, ozone depletion, climate change and become major cacophonic issues. Since, there has been increasing attention on connection between energy and environment simultaneously on both facets and primarily motto is to bridge the gap between demand and supply of energy [17]. Energy and environment have interdisciplinary mechanism to agglomerate realistic world (fig. 10).

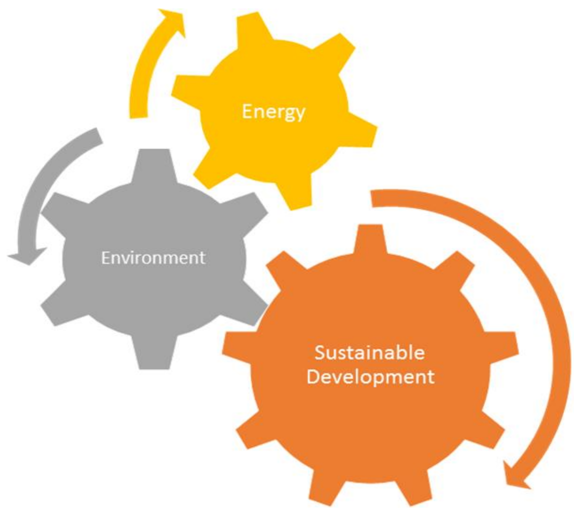

Fig. 10. The interdisclinary mechanism among energy, environment and sustainable development.

In this regarding, thermal energy storage (TES) incorporation to be perform is one of the best option for making balance between supply and demand mode of energy. During the peak load demand, stored TES can be utilized as profitable option without compromising higher cost energy efficiency portfolio. The hybrid system of TES and conventional cooling/heating are most promising option in present time, especially in building applications. Theses

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hybrid systems are reliable route to reduce the carbon foot print of buildings to achieve better future [18] (fig. 11).

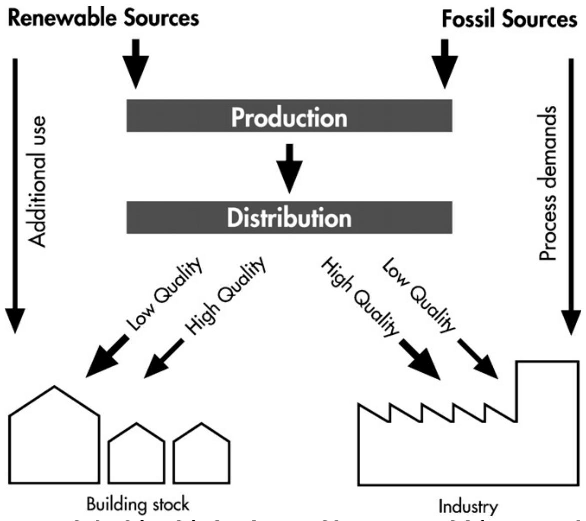

Fig. 11. A hybrid fossil fuel and renewable energy model for sustainable building energy supply [19].

A. Low Energy Thermal Storage

The concept of low energy is mean minimal and energy-efficient utilization in applications. Low energy equipment give better performance in long term building operation such as passive building storage heating are perform efficiently by utilizing the available energy with minimum exergy losses. Studies on energy consumption sector reveals that one-quarter to one-third of overall produced energy is consumed in building applications [20]. Many energy saving schemes are practiced throughout the world in building needs.

B. Low Carbon Thermal Storage

The term low carbon foot print generally refers to the minimum output of greenhouse gas (GHG) emission into the environment. GHG emission controlling is the one of tedious task to do in modern world because most of emission generated by energy industries such petroleum, coal based energy entities. So major concerns about the GHG control is based on replacement of these conventional technologies by renewable technologies. These renewable technologies are low carbon emission because most of the produced carbon sequestrate by their life-time. TES concept is considering low carbon pathway for achieving lower concentration of GHG emission (mainly CO_2) in to environment. Many low carbon emission technologies have been flourishing to contemporary living standard in various countries (Table III).

TABLE III. Summary of potential of various low carbon technologies (Modified table from 21)

Low carbon technology	Potential Savings of CO_2	Local/Location factors	Cost Consideration
Solar thermal energy based systems	֍֍	֍	֍֍
Solar photovoltaics (PV)	֍֍֍	֍֍֍֍֍	֍֍֍
Wind power	֍֍֍֍	֍	֍
Ground couple (source) heat pumps	֍	֍	֍֍֍
Biomass-based heat and light	֍֍֍֍֍	֍֍֍֍֍	֍֍֍
District cooling and heating facility	֍֍	֍	֍֍֍֍

Note: High- ֍֍֍֍֍, High to medium-֍֍֍֍, Medium-֍֍֍, Low- ֍

C. Low Cost Thermal Storage

It seems to be a sustainable design, thermal storage technologies can be considered viable tool to green building grading. The integration of TES with cooling/heating systems in industrial and residential applications can minimize the conventional energy load of about 20%. TES and renewable technologies can enhance the operational performance and cost effectiveness of conventional systems. These renewable based hybrid systems can reduce the cost maintenance in term of long term applications. Different types of financial assistances and incentives are being provided in developing nations (India, China *etc.*).The energy efficiency and cost saving energy services of TES systems can collectively contribute towards the sustainable future.

VI. CONCLUSION

Thermal energy storage covers a wide range of temperature for a diversified class of applications without any kind of environmental concerns as it happens to be with batteries, the problem of large volume requirement in case of compressed air energy storage is also not there with thermal energy storage. Advancements like microencapsulation of PCM, molten salt and heat pipe based thermal energy storage are now slowly becoming part of commercial world. TES systems are economical viable, low cost tool for future energy security in buildings and other applications. The addition of renewable energy with TES has reduce global energy consumption making the bridge between energy demand and energy gap, and geared up to reliable, development of energy efficient and sustainable energy technologies.

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