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A comprehensive Thermal properties of Energy Storage and Quantify Performance System

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ABSTRACT: In This Paper presents the feasibility of a residential scale, low cost, high temperature, and graphite based sensible thermal energy storage (TES) device and proposes a design for such a device. The intended use for the proposed design is as a component of a larger concentrated solar power (CSP) generation system. A scaled down model of the prototype was tested for performance and durability. Measurements of thermal properties, discharge power, charging and discharging efficiencies and resistance to degradation by oxidation and vibration were taken to quantify the performance and durability. Oxidation rates were measured at 700°C with SiC and Al_2O_3 based protective coatings as well as with inert gas blanketing using argon, CO_2 and evacuation. The graphite was also subjected to vibration at 1000 rpm to evaluate any damage caused by contact with a reciprocating heat engine. To quantify the performance, the relationship between temperature and thermal conductivity was determined as well as the variation of specific heat capacity with temperature. These were measured in the range of 5°C to 400°C. Solar irradiance heat flux on the heat storage was simulated on the test samples to determine the temperature variation throughout the charging period of one day. All tests were done on two grades of graphite that vary in density, porosity and microstructure. Obtained from testing the device indicate an effective lifespan of 31 years before needing to be replaced and yields a charging efficiency of 40.2%. Based on these results, a detailed design is presented. Finally, based on the results, a more detailed design of the device is proposed.

Keywords: Phase change material (PCM), Thermal Energy Storage, Renewable Energy,

I. INTRODUCTION

There exist several TES technologies and applications. The selection of a TES technology for a specific application depends on many criteria, including the storage duration, cost, supply and utilization temperature requirements, and storage capacity. For many years, TES devices and systems have been utilized in building designs and integrated into solar power-generation, but the application of TES in the automobile industry did not start until the late 1970s There are various potential applications of TES (Thermal Energy Storage) in the automotive industry. First, a TES device could be charged from an engine's waste heat during normal operation. In addition, TES devices could be utilized to provide heat during warm-up to reduce fuel consumption and emission. The drivers can avoid waiting for preheating and warming the engine. Moreover, TES devices have potential applications in hybrid and electric vehicles powered by batteries. Since the batteries operate poorly at low temperatures, the use of a TES device for rapid heating of the batteries could Alleviate the degradation of battery performance in cold weather. Finally, a TES device could be used to enhance passenger comfort and aid in defrosting of windshields. In cold weather, it could take several minutes to provide significant warming in the passenger cabin before the internal combustion engine could spare enough heat. For electric vehicles, the situation would be even worse due to the lack of a high-temperature heat source. Since TES devices could produce heat directly without sharing with other compartments, they would be able to provide the thermal energy more efficiently and thereby greatly enhance the operation of vehicles during winter. Thermal Energy Storage (TES) devices have attracted profound interest from researchers for their use in eliminating environmental problems and increasing the efficiency of energy consumption in general. TES devices store thermal energy (heat) in hot or cold materials for later use. It is an important technology in bridging the gap between the supply and demand of energy. Thus, TES devices allow the reutilization of stored energy to drive energy systems and prove to be extremely beneficial for renewable energy applications. They can also be used to mitigate the cold engine startup problem. As there are various potential applications of TES in the automotive industry.

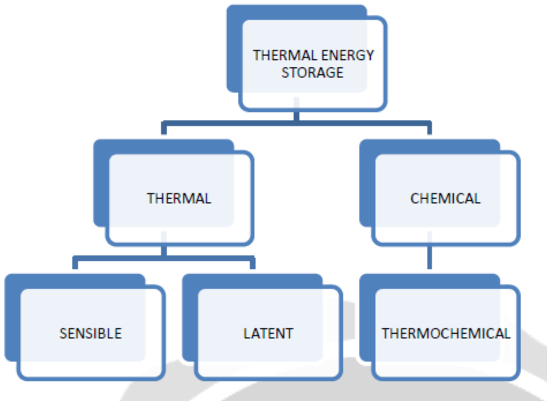

Fig. 1. Different types of thermal energy storage device.

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A. Sensible Heat Thermal Energy Storage

Sensible heat storage devices store thermal energy by heating or cooling the temperature of the storage material through heat transfer. Sensible heat TES devices take advantage of the heat capacity and the change in temperature of the material during the charging and discharging processes. The amount of energy stored in a sensible TES device depends on the mass and specific heat of the storage medium, and the temperature difference of the storage medium between its initial and final states. The total amount of heat stored Among all potential media for sensible heat storage, water has been the most promising candidate. Due to its high heat capacity (~4.2 kJ/kg · K) and low cost, it is often used in storage devices over the temperature range of 20-70°C. Also, as a liquid storage medium with high convective heat transfer, water allows the storage device to have higher heat injection and extraction rates compared to other solid heat storage media.

Due to their simplicity and low cost, sensible heat TES devices have been used in the automotive industry. Generally, they reserve a hot coolant in the storage phase and release the hot coolant into the engine circuit during the cold start.

However, sensible heat storage devices are not great candidates for long-term or automobile applications because of the following drawbacks

- Low energy storage density (~100 kJ/kg),

-Heavy insulation required to minimize heat loss to the ambient,

-Non-isothermal behavior during charging and releasing processes.

B. Thermochemical Energy Storage

Thermochemical energy storage devices use a reversible chemical reaction to store and release energy. It stores heat in the process of dissociation reaction and releases the energy in the exothermic step of a reversible chemical reaction.

Thermochemical storage has not been developed commercially, but its advantages have drawn significant attention

High energy storage density (~2MJ/kg)

-No or low heat losses.

-Long-term storage period.

- Long distance transport possibility.

-Small storage volume.

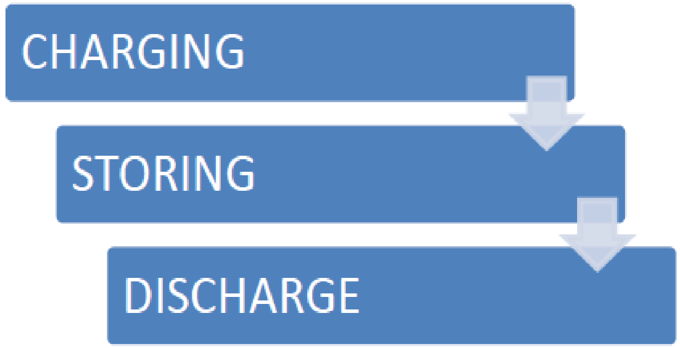

Fig. 2. Process of Thermochemical TES Cycle.

C. Latent Heat Storage

In general, the latent heat storage is the most promising amongst different methods of thermal energy storage. In latent heat TES, energy is stored in the phase change materials (PCMs) through the change of a substance from one phase to another. As the temperature increases, the material transforms from solid to liquid phase and absorbs heat in the endothermic process. When temperature is reduced, the material undergoes phase change from liquid to solid and releases heat. Since PCM's store energy in the form of latent heat of fusion, there is no significant temperature drop in the heat release process.

The energy storage has to go through several phase transitions: solid-solid, solid–liquid, solid–gas and liquid–gas. In solid-solid transition, energy is stored by the crystalline transformation of the material. This transition contains much smaller latent heat and minor volume changes. As a result, solid-solid PCMs have the advantage of less strict container requirements that allow greater design flexibility. On the other hand, solid-liquid transformation plays an important role in the latent heat TES since it provides a high energy storage density and has much higher latent heat of fusion. In contrast to solid-solid and solid-liquid phase transitions, solid-gas and liquid-gas transitions have the advantage of higher latent heat of fusion, but their large volume change during the phase change process increases the difficulty and complexity of the storage system. The expedition for new technologies is essential to prevent the raising environmental pollution and energy deficiency issues. Development of new alternatives for the energy at low cost is the biggest challenge to the modern scientific world. On the other words, effective utilization of available energy resources is also the challenging task. Recovering the energy which is losing through different process and systems is also as good as developing new energy source. Specifically, effective utilization of thermal energy is difficult due to the various operational and material parameters. From thermal power plants and other processing industries, a significant amount of waste thermal energy is released to atmosphere in the form of hot flue gases. This waste heat may be recovered by thermal energy storage methods in sensible and latent heat forms. Latent heat storage method provides high storage density compared to the sensible heat storage method for same volume of the material [1]. Fig. 1 shows growth in renewable energy consumption for heat, 2013-2024. The renewable energy consumption by various sectors such as building, industries and agriculture are considerably increasing. Thermal energy can be considered as the largest form of heat source available naturally but capturing it and utilizing for various purposes is a tedious task. Several technologies have been developed for harnessing and utilizing the thermal energy.

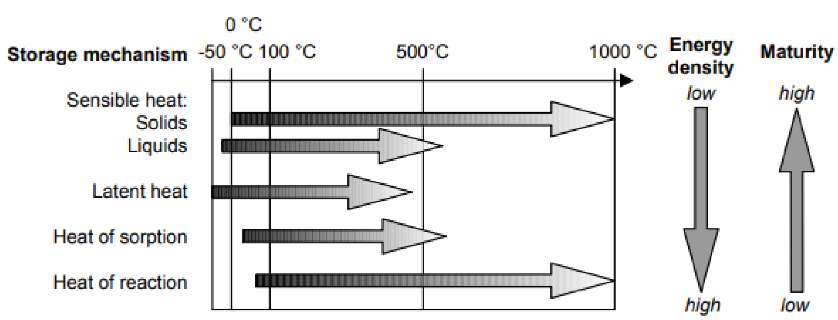

Fig. 3. Thermal energy storage mechanism, their working temperature and correlation to energy density and status of technical maturity.

Energy. TES technology offers large amount of thermal energy and electricity generation with relatively lower cost. However, the irregular and uneven nature of solar energy is prompting engineers to develop specialized technologies to store thermal energy with minimum cost to use thermal energy effectively at low light conditions as well [2]. Generally, thermal energy may be stored in two forms, such as latent heat and sensible heat form. Latent heat storage provides better storage capacity with minimum volume requirement due to usage of phase change materials (PCM's) [3], as compared to sensible heat form. The PCM's are operates at constant temperature and changes its phase by absorbing and releasing large amount of heat [4]. Fig. 3 shows cumulative capacity of thermal energy storage. The TES in all the forms is rapidly increasing and it is projected to increase further in upcoming years. Thermal energy can be stored in well-insulated materials as a change in internal energy of the material such as sensible heat, latent heat and thermochemical and combination of all three heats. Thermal energy storage deals with the storage of energy by cooling, heating, melting, solidifying a material; the thermal energy becomes available when the process is reversed [5].

Thermal energy storage using phase change materials have been a main topic in research since 2000, but although the data is quantitatively enormous. Research area in TES is an international interest and it mainly focusing energy saving by effectively using available resources and efficient use of renewable energies [6]. TES can provide possible solutions to some specific needs like time delay between available power and power production such as solar energy and cogeneration, it can provide security of power supply for healthcare centers, computer server rooms, telecom networks, etc. and finally thermal inertia and thermal protection. The scientific communities around the globe, are putting their efforts to get a stable, firm, effective and continuous energy supply from the renewable sources [7] Recent energy.

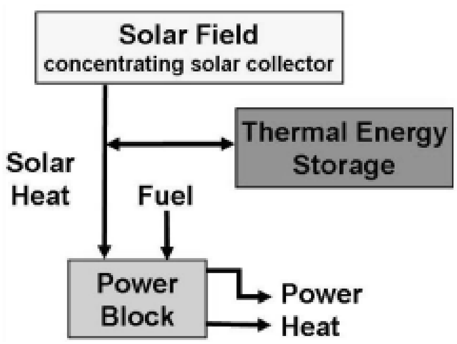

Fig. 4. Basic layout of a solar thermal power plant with integrated storage.

Consumption survey data shows that energy consumption by building sectors is considerably increasing, which consists of residential and commercial buildings. Moreover, it is observed that majority of the energy consumption in buildings is for providing thermal comfort such as heating, ventilating, and air-conditioning (HVAC) systems. The combination of thermal energy storage technologies for building applications reduces the peak loads, separation of energy requirement from its availability, it also allows to combine the renewable energy sources, for efficient utilization of thermal energy. Currently thermal energy storage and utilization is focused only on few areas such as building applications, and some industrial applications. But TES technology can be adopted for wide range of applications. In the present review work an attempt is made to provide an overview on various applications of TES technology including medical and agricultural sector.

D. Thermal energy storage applications

Environmental preservation and protection concerns motivating the investigators to discover new renewable energy sources (RES). However, availability of RES such as solar thermal energy varies from season to season, time to time and area to area [8]. TES technologies helpful to fill the gap between available energy source and requirement; thus, the intermittency of renewable sources may be utilized effectively as per requirement [9]. Fig. 5 shows various applications of thermal energy storage technology which focused for current study.

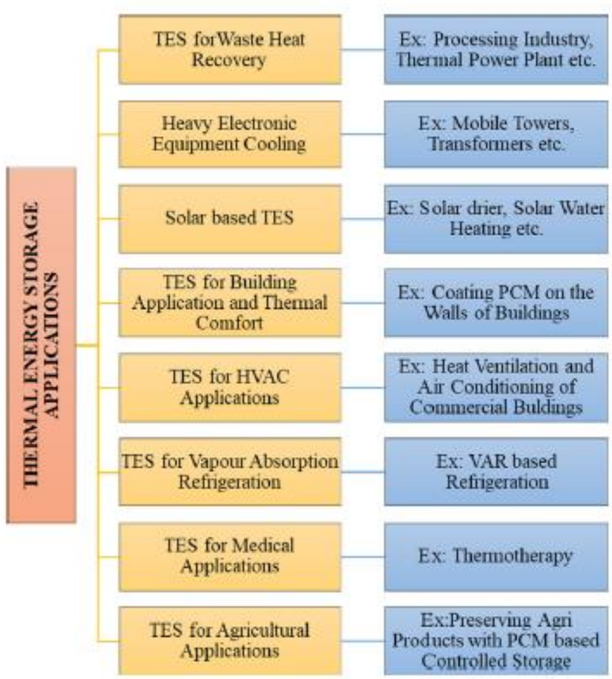

Fig. 5. Various Applications of Thermal Energy Storage Technology.

Thermal energy storage application for waste heat recovery (WHR) Industrial processes are found to be vast potential for waste heat recovery (WHR), because of majority industrial waste heat is unutilized and directly released to sink. The main reason behind is the technical and economic complications in recovering the waste heat. Fig. 4 shows waste heat energy available from various sources [10]. Thermal energy needs to be collected and store from the various industry is important to enhance the efficiency of industries are processes. Highly energy-based industries, such as glass, steel, cement, oil and gas, and food processing industries which are in main focus due to higher levels of energy consumption and significant amount of waste heat is directly released to the atmosphere. Consequently, WHR technologies require more attention in enhancing energy efficiency and by reducing the environmental impact. Accurate and precise estimation of waste heat recovery can be estimated by coupling a latent heat thermal energy storage system (LHTES) to waste heat releasing system. The amount of waste heat recovered can be achieved 45% to 85% depending on the thermal energy storage material properties, size of processing industry, environmental conditions, etc., [11]. TES is an innovative technology which can used in a flexibility manner to utilize the waste heat energy coupled with the other systems by storing and utilizing later [12]. Additionally, this WHR helps in reducing the environmental pollution by controlling CO_2 emissions. The stored waste heat can be utilized for different secondary heating applications such as, water preheating in thermal power plants, preheating the pigments in textile industries. If the distance between the waste heat source and the electronic equipment control room is less, it can be used for cooling with help of vapour absorption refrigeration system. Depending on the distance between the waste heat source and the heat requirement, TES systems can be divided into two types one is onsite TES systems, and an off-site heat storage system [13]. To effectively utilize waste heat from various industrial production techniques, dynamic thermal management using PCM thermal storage technique is adopted for waste heat recovery. In this technique, energy transfer mechanism is designed in two sections such as, sensible, and latent heat zones, and a heat transfer fluid is circulated.

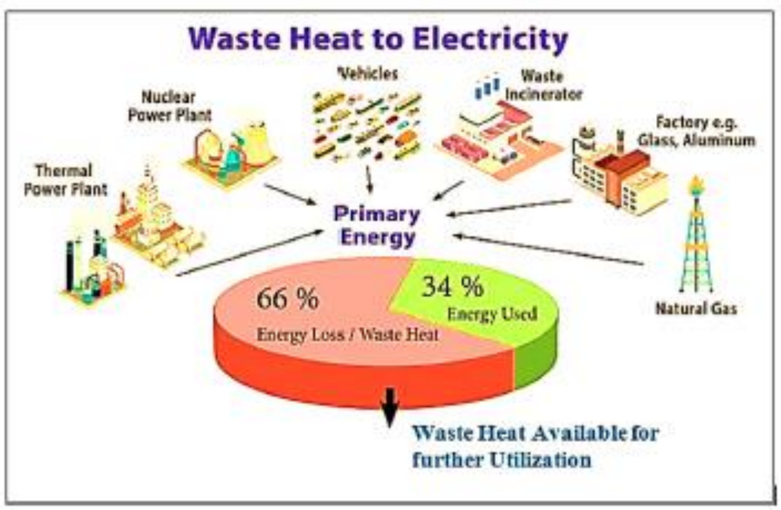

Fig. 6. Waste Heat Energy Available from various Sources.

E. Exchange the heat

Dynamic waste heat capturing model considerably reduced the waste flue gases and recovered it effectively. Similarly, a large amount of heat can be recovered from the exhaust gases evolved in the electric arc furnace of a steelmaking plant. A thermal energy storage system based on a dual-media packed bed TES system is adopted for recovering and reutilizing the waste heat to achieve a continuous heat supply from the steel furnace. This operation approach provides excessive advantages and shows the better waste recovery potential Along with the various advantages waste heat recovery have its own problems. Addressing these problems may further improve the WHR system efficiency. The installation area required, initial investment and operating cost per unit capacity of WHR system reduces with the system capacity. The incongruities between the waste heat source and requirement and energy grade has to be improved by integrating TES systems.

II. CONCLUSION

Present work conducts a comprehensive review of TES for various applications such as waste heat recovery, heavy electronic equipment's cooling, solar based TES, TES for building application and thermal comfort, TES for HVAC applications, TES for vapour absorption refrigeration, TES for medical applications TES for agricultural applications. PCM application is found to be much effective upon combining with TES, and these can also be extended to further heights such as, conservation and transportation of temperature sensitive materials. Concluding remarks for future research in effective utilization of PCM selection based on the application and approach strategy

in heating cooling applications. The primary application of the latent heat TES devices is to store waste heat from an automobile engine during its operation and to provide the stored energy to warm up the engine components in cold weather and at start.

III. FUTURE SCOPE

Material durability tests should be carried out to assure the long-term thermal cycling performance of the TES device. Before commercialization of the product, the latent heat TES has to show reliability and durability closely matching the average lifespan of a vehicle. And to further improve the performance of the latent heat TES device. Compared to increasing the cooling water flow rate which would require a larger pump and greater power, this method could be more cost-effective.

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