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AN OVERVIEW OF THERMAL ENERGY STORAGE SYSTEM

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ABSTRACT

As we known of humanity's massive use of thermal energy, any advances in thermal energy management techniques may have a major positive impact on society. Thermal energy storage is an important part of thermal energy management. This review covers the following features of TES: (1) A broad range of topics in the area of thermal energy storage are addressed. The role of TES in the context of various thermal energy sources is discussed, as well as how TES eliminates the need for fossil fuel combustion. The use of TES in solar power production, building thermal comfort, and other specialized applications is discussed. (2) Provides insight into several types of TES storage materials, including physical characteristics, cost, operating performance, and application appropriateness. (3) A description of the many kinds of TES systems is provided. Different kinds of criteria are used to classify TES systems. Seasonal TES systems, CSP plant TES systems, TES systems for residential solar thermal applications, heat and cold storages in building HVAC systems, and other TES systems are discussed. Thermo cline, packed bed, fluidized bed, moving bed, and other active TES systems are investigated. The use of passive TES systems in buildings, textiles, cars, and other applications is discussed. The following is a list of TES systems that operate in the cold, low, medium, and high temperature ranges. TES system design parameters, operational problems, and cost models are addressed.

KEYWORDS: *Energy, Fossile Fuel, High Temperature, Storage System, Thermal Energy,*

1. INTRODUCTION

The discovery of fire is often considered as the most significant turning point in humanity's development. Cooking food is one of the earliest uses of thermal energy that humans discovered. Even before humans, thermal energy was abundantly accessible in nature. To stay alive, our bodies need a certain minimum ambient temperature. A high need for thermal energy arises as a result of such facts in our lives. The sun's freely accessible solar thermal energy aids in maintaining the favorable ambient temperature conditions required for human survival on our planet. However, solar energy availability varies throughout the globe, resulting in severe cold ambient temperatures in high latitude areas and extreme hot ambient conditions in the equator. The necessity for thermal energy management emerges when people extend their presence throughout the globe into areas with such severe local circumstances. Furthermore, our contemporary lifestyle has given rise to a slew of new thermal energy uses, driving up demand even further. Electricity, heat, and mechanical labor are the three major types of energy consumption at the user end nowadays. The usereend energy consumption data are published as 'Final consumption' by the International Energy Association (IEA)[1].

Energy conversion of various energy sources, including both natural and fuel sources, produces usereend energy forms including electricity, heat, and mechanical work. The energy source data are published by the International Energy Association (IEA) as 'Primary energy supply[2].The International Energy Association (IEA) projected that the world's yearly "total primary energy supply" is 573 EJ (13,699 million tonnes of oil equivalent) and the annual "total final consumption" is 394 EJ (9425 million tonnes of oil equivalent) in its 2014 global energy statistics report. Due to the large quantity of energy required, a significant amount of energy (z31 percent) is wasted throughout the conversion process from "Primary energy source" to "Final consumption[3]." The world currently faces difficulties in fulfilling its energy needs through burning fossil fuels. When fossil fuels are burned quickly, greenhouse gases such as CO2 are released. CO2 levels in the atmosphere are rising, leading to global warming. This has severe implications, such as increasing sea levels owing to polar ice melting. During the energy crisis of the 1970s, the world recognized the significance of renewable energy sources. The supply of fossil fuel reserves is finite, and they are nonrenewable[4]. As a result, energy conservation and the transition to clean and renewable energy sources are critical. Although each thermal energy source has its own specific context, thermal energy storage is a fundamental function that enables energy conservation across all main thermal energy sources[5].

1.1 Heat sourcesc:

- *Thermodynamic energy from the sun:* The nuclear fusion process at the sun's core constantly emits a massive quantity of solar energy towards Earth. According to various estimations, solar energy's yearly potential ranges between 1575 and 49,837 EJ. This is considerably higher than the IEA's estimate of 573 EJ for the world's yearly "total primary energy supply" in 2014. As a result, it is possible to assert that solar energy alone, if completely harnessed, can provide the world's entire energy needs. However, according to the IEA's 2014 global energy statistics report, the current annual "primary energy supply" from alternative sources, such as solar, geothermal, and wind, is just 1.4 percent (z8 EJ)[6]. Solar energy's potential is clearly being underutilized. The sun is expected to continue to supply solar energy for another 4 billion years, making it a sustainable and renewable energy source. Solar energy produced by the sun is accessible on the earth's surface at an estimated intensity of 1000 W m2 under clear sky circumstances. This level of intensity is adequate to meet the thermal energy requirements of low-temperature applications such as hot water delivery[3]. Solar radiation must be focused using appropriate reflectors for high-temperature applications. Photovoltaic (PV) cells or concentrated solar power plants are used to generate electricity from solar radiation (CSP). Solar radiation may also be utilized for space heating, hot water supply, absorption refrigeration, and other purposes with the use of suitable solar thermal equipment. Because of its intermittent nature and lack of availability during peak usage hours, energy storage systems such as the TES system or battery-based electricity storage systems are required. As seen below, TES may be compared to battery-based energy storage technologies[7].

1. When the source energy to be stored is low-grade thermal energy, TES has a round-trip efficiency of 50 to 100 percent. For thermal energy generating facilities such as concentrated solar power plants (CSP) or nuclear reactors, TES is the best storage technique .
2. When the source energy to be stored is high-quality electrical energy, battery storage has a round-trip efficiency of 80 to 100 percent. TES is not well suited to storing electricity from renewable sources such as wind or solar panels on a single grid [2]. Even though TES can store grid energy, the round trip efficiency of this operation would be considerably below 50%.
3. TES, unlike battery technology, does not usually suffer from cycling-induced deterioration, and it has a longer cycle life and calendar life.
4. TES usually employs a large number of compounds with low toxicity.

The TES technology is utilized in CSP plants in areas with high quantities of direct normal irradiance to store solar thermal energy during the day and utilise it for power generation at night. The TES integration possibility for different kinds of CSP facilities operating throughout the globe is shown in Table 1. About half of the world's CSP plants (47%) are connected to the TES system [3]. The usage of TES systems has increased noticeably.It is 72 percent for facilities under development and 77 percent for planned future plants [3]. Various kinds of TES systems that may be used in CSP facilities are shown in Fig. 1. TES systems also have a role in dispersed applications such as space heating and hot water delivery. Thermal energy may be stored as both hot and cold energy, depending on the situation[8].

- *The use of geothermal energy:*Earth is a massive TES system in and of itself. The planetary accretion process and radioactive decay produced a huge amount of heat, which is still retained in layers under the thin crust, such as the mantle, outer core, and inner core. Both the present rate of natural heat escape into space and the world's yearly energy consumption are insignificant when compared to the enormous quantity of thermal energy stored inside the planet[9]. As a result, even if geothermal energy is collected to meet the world's energy need, this energy source will continue to exist and is therefore called renewable. The subterranean water columns within the earth's crust are heated by the heat from the earth's hot mantle.

These geothermal fluids may be extracted from subsurface hot briny water sources. O'Sullivan et al. [4] found in a study of the Wairakei geothermal system in New Zealand that for every 100 years of power production, the geothermal field requires another 400 years for extracted thermal energy to be restored naturally via deep recharge.Long-term, geothermal energy resources are renewable because, after a prolonged period of shut-down, they would completely return to their pre-exploitation condition. Geothermal energy plants are usually located near the earth's plate tectonics, where geothermal fluid is accessible at lower depths and at greater temperatures up to 180 C [5], due to the difficulty of drilling at such depths. Geothermal fluid with a temperature greater than 150 degrees Celsius may be used to generate power using steam.Isopentane, isobutane, propane, butane, and fluorocarbon family refrigerants are ideal for electricity production utilizing the Organic Rankine cycle (ORC) using working fluids such as isopentane, isobutane, propane, butane, and fluorocarbon family refrigerants [6]. Geothermal fluid at a temperature less than 100 degrees Celsius is acceptable for direct usage, such as drying agricultural products. Because a geothermal reservoir is a TES system, thermal energy is accessible 24 hours a day. As a result, unlike solar thermal energy, geothermal energy may be used at any time of day based on need. When ideas like coegeneration, triegeneration, or multiegeneration are utilized, there is still room for a manufactured TES system. In a single-generation plant, only thermal energy is used to produce electricity[10]. The loss of thermal energy remaining accessible in the working fluid at the turbine output, which is lost at the condenser, reduces the overall efficiency of a single generating plant. More functions such as district heating, drying, heat storage TES system, absorption chiller and cold storage TES system (example: ice production from the cooling effect produced by absorption chiller) are integrated to the plant in coegeneration, triegeneration, or multiegeneration thermal power plants to improve efficiencyprovided one example of a cascading triegeneration model.

- *Power plants that use uranium as a fuel:* These power plants create electricity by converting the heat produced by the combustion of fossil fuels such as coal, natural gas, or petroleum products into electricity.Burning fossil fuels is thought to be responsible for approximately 40% of the world's CO2 emissions. In a Rankine cycle, the turbines are powered by steam, whereas in a Brayton cycle, the turbines are powered by air. Coal-fired power stations, for example, are load-following power plants. They are adaptable, allowing them to burn more fuel and produce more power during peak hours to meet energy demand. However, the total efficiency of such power plants is about 35%, implying that a significant amount of heat is lost to the environment. As with geothermal energy, fossil-fuel power plant efficiency may be increased by using heat that is lost to the environment via coegeneration, triegeneration, or multiegeneration, where TES systems also play a part.Similarly, in combined cycle plants such as concentrated solar power plants (CSP) or district heating systems using solar energy as the main energy source, fossil fuels may be used as secondary fuels. As illustrated in Fig. 3, B. provided a case study of a combined cycle district heating system powered by solar-natural gas combined heat sources and a TES system.

1.2 Sensible heat storage materials:

- *Water:* Water is readily circulated and therefore may be utilized as a heat transfer fluid (HTF) and a thermal energy storage (TES) material in active systems. It has a high specific heat (4.184 kJ kg1.K1), is nontoxic, is inexpensive, and is readily available. Water comes in three forms: ice, liquid, and steam. In cold storage, ice is utilized. Liquid phase is utilized to store low-temperature heat energy below 100 degrees Celsius. It is totally safe to humans since it is readily accessible and is a nontoxic, nonflammable substance. As a result, water is the ideal thermal energy storage medium for applications such as residential space heating, cold storage of food items, and hot water delivery. The steam phase is utilized to store high-temperature heat energy. Steam accumulators are utilized as a TES system in CSP facilities employing the direct steam generation (DSG) method, where saturated steam is stored in high pressure insulated steel tanks [15]. Thermocline heat storage is possible with liquid water. Because of the density difference produced by the heating of the liquid, buoyancy aids in the creation of a desired temperature gradient throughout the storage . Water is utilized in chilled water or ice form in cold storage. Water, on the other hand, has a few disadvantages, including as high vapor pressure and corrosiveness.
- *Thermal oils:* Thermal oils are organic fluids that have excellent heat transmission properties. Table 4 shows which thermal oil products are presently in use in various CSP facilities. Thermal properties of non-edible vegetable oils have also been investigated . Thermal oils are typically transparent, colorless liquids. Thermal oils have the advantage over water in that they stay liquid at greater temperatures than water, up to 250 C at atmospheric pressure. Thermal oils have a temperature range of 12 to 400 degrees Celsius, implying a greater DT and increased heat storage. Thermal oils have a low vapor pressure when compared to water. DOWTHERM thermal oil has a vapor pressure of 7.6 bar at 374 degrees Celsius, while water has a vapor pressure of 221 degrees Celsius. This indicates that the container and pipe walls are under minimal pressure. As a result, the thickness of the container and pipe is reduced, as well as the cost of the container and

pipe. Low viscosity and excellent flow characteristics characterize thermal oil. It's simple to circulate, and pumping expenses are cheap. It is utilized as a heat transfer fluid (HTF) and a thermal energy storage (TES) material in active systems. Thermal oils perform poorly in terms of heat transfer. TherminoleVP has a poor thermal conductivity (z0.1 W/m.K) and a heat transfer coefficient estimated to be between 1000 W m2.K1 and 3500 W m2. [20] K1. In the liquid state, thermal oils may create a thermocline. A packed bed of fillers such as rocks, sand, encapsulated PCM, and thermal oil serving as HTF is typical of a thermocline TES system. Thermal oils have an advantage over molten salts in that they do not freeze in pipes due to their low melting point (below 12 degrees Celsius) and the lack of an antifreeze mechanism. The disadvantage of thermal oils over water is that they have a lower specific heat (z2 kJ kg1.K1) and are thus more costly, as seen in Table 4. Thermal oils with aromatic organic components may exhibit low order toxicity and bioeconcentrate in live organisms. Thermal oils deteriorate at temperatures beyond their working range owing to processes such as oxidation by air, which may generate acids such as carbolic acid, peroxide compounds, and other chemicals [19], which can increase corrosion of containers and pipelines. After many hours of high temperature exposure and repeated thermal cycles, thermal oil slowly degrades with age. When thermal oil vapor is combined with ambient air, it poses a fire danger.During system operation, extreme caution should be used to avoid any thermal oil leakage, both financially and environmentally. Nanoeadditives such as graphene, graphite, and metal oxides, among others, may improve the heat transfer characteristics of thermal oils.

- *Molten salts:* Molten salts are the ideal heat transfer fluid and heat storage medium when the system temperature exceeds the thermal oil temperature limit (z400 C). The temperature of solar power tower (SPT) and parabolic dish collector (PDC) CSP plants will be greater than thermal oil limitations, as shown in Table 1. In CSP facilities, molten salts are already the most common thermal energy storage (TES) medium. They are also becoming a preferred option in future generation III and III nuclear reactors due to their excellent thermophysical characteristics. They have a high thermal stability, a high boiling point, and a high volumetric heat capacity. Their vapor pressure is low and close to zero. Molten salts serve as a heat storage medium as well as a heat transmission fluid. The current maximum working temperature for molten salts is approximately 565 C. They can maintain extremely high working temperatures because of their higher boiling point and thermal stability at high temperatures, which increases the thermodynamic efficiency of the Rankine cycle of steam. Higher DT and greater heat storage are additional implications. They're inexpensive, easy to find, nontoxic, and nonflammable. Molten salts, on the other hand, provide a few challenges. Salts have a high melting point, typically over 200 degrees Celsius, which causes them to freeze in pipes when there is no heat source available, such as solar radiation at night. To allow the HTF to function at its full range, it must have a melting point near to ambient temperature and a very high boiling point. Pure salts or salt eutectics having a melting point of less than 250 C are often considered for sensible heat storage in the molten salt form. Eutectic salt combinations of two or more salts assist to lower the melting point while keeping the boiling point high.Table 5 includes a few salts and associated eutectic combinations that are frequently encountered. HITEC Currently, a ternary salt combination (53 percent KNO_3, 7% $NaNO_3$, and 40% $NaNO_2$) with a melting temperature around 142 C is quite common [18]. The melting point of pure KNO_3 is 334 degrees Celsius, whereas that of pure $NaNO_3$ is 307 degrees Celsius. The melting point of their binary salt combination, dubbed "Solar salt" (60 percent $NaNO_3$ and 40 percent KNO_3), is 220 degrees Celsius. When compared to thermal oils and water, they have a high viscosity. As a result, they have poor flow characteristics, raising pumping costs.Heat transmission properties of molten salts are poor.

2. DISCUSSION

In many engineering applications, thermal energy storage (TES) devices are chosen because they can bridge the gap between energy supply and demand. TES systems may efficiently meet energy redistribution needs for cooling or heating. By using stored thermal energy from TES units, peak load demand may be moved to off-peak hours. In comparison to sensible and thermochemical energy stores, latent functional phase change materials have excellent phase transition properties in terms of heat storage and release. As a result, latent TES systems (in active or passive modes of operation) are widely used in a wide range of heat transfer applications. The integration of value-added renewable energy with TES systems has a great potential for executing low-energy design and opens the door to a more sustainable future.

3. CONCLUSION

TES holds the key to breaking our reliance on fossil fuels. The failure to harvest and store energy from clean renewable sources has resulted in the use of fossil fuels. If thermal energy is not stored, it dissipates into the environment, requiring fossil fuel combustion. The economic impact of the TES field is felt across a wide range of industries, including thermal power generation, buildings, textiles, automobiles, health care, agriculture, and food processing. For thermal electricity generation plants, TES is the best energy storage technique. It is important at both the utility and building end of the energy supply chain. Seasonal TES systems, CSP plant TES systems, distributed TES systems for domestic solar thermal applications, passive TES in buildings, heat and cold storages in building HVAC systems, and other TES systems are the most commonly seen today.

Textiles, automobiles, pharmacy, agriculture, and other industries have niche applications for TES. TES materials are divided into three categories. Sensible heat storage materials are the primary TES materials in large-scale and high-temperature TES systems. Phase change materials are the most common TES materials used in low-temperature human thermal comfort applications. Thermo-chemical heat storage materials are still in the lab and have just a few uses in the real world. Sensible heat storage materials such as water, inorganic salts, thermal oils, sand, and gravel, as well as organic latent heat storage materials such as paraffin, are the most frequently utilized TES materials. Water, salts, sand, and other TES materials are inexpensive, while organic TES compounds are expensive. Seasonal thermal energy storage systems have a lot of capacity and need a lot of TES materials. These systems work at low temperatures and have a lengthy storage life.

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