"A Review on the Thermal Energy Storage Unit for Solar Energy Application"

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Abstract:- With the current high energy demand, relying solely on fossil fuels would undoubtedly lead to crises in the future, particularly for emerging nations. Even while the use of renewable energy sources, such as solar energy, is widespread these days, the issue lies in the economy and law, or social and acceptance. The primary causes of these kinds of problems are the low density of solar radiation on Earth's surface and, when present, its erratic nature according to the season and time of day. Solar energy storage units must be implemented in solar thermal energy applications in order to overcome these kinds of challenges. Unlike other solar energy conversion technologies, solar thermal energy (STE) gives the possibility of storing excess energy produced for later use. This is an assured way to extend operating hours and, consequently, power production capacity.

Keywords: *Solar thermal energy, Concentrated Solar Power (CSP) System, Impregnation, Hybrid Heat Storage.*

1. Introduction

World Energy Outlook (2016) states that sixteen percent of the world's population resides in places without access to electrical power grids. 55% of people live without power in Africa, the continent with the lowest rate of electrification. These areas remain undeveloped and are usually found in low-income nations in mid-latitudes with strong sun radiation. Whichever the cause of the absence of an electric grid, residences in these areas might profit from an inexpensive appliance that can produce electricity on-site using a renewable energy source, such solar power. Electricity could be produced in even the most remote regions with a small-scale equipment like this.

The problem with small-scale concentrated solar power systems is that they only produce electricity when the sun is shining, depriving those who depend on them of electricity at night. Parabolic trough and dish engine systems are two examples of the many types of these systems currently on the market, and almost all of them convert solar radiation directly to an engine. Batteries have the capacity to store energy for later use, but they are expensive both monetarily and ecologically. Thus, in areas without an electric grid, having a low-cost, ecologically responsible way to store energy is crucial.

Additionally, the heat storage material needs to be widely available and environmentally friendly. The way the system operates is as follows. An array of spherical mirrors reflects incident solar energy to a focal point, where it generates an extremely high heat flux. This heat is taken up by the heat storage, which is situated at the focal point, and held there until it is conductionally transferred as input energy to a Stirling engine. An electricity-producing generator is powered by this engine. A summary of the system's parts and energy transformations is shown in Figure 1. Thus, electrical power is ultimately produced from solar radiation.

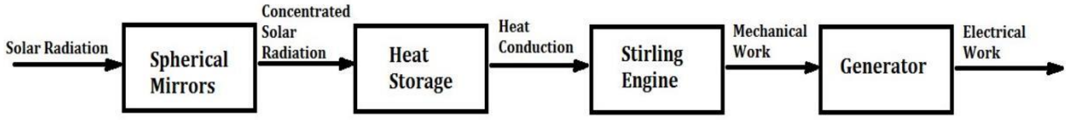

Figure 1: Concentrated Solar Power (CSP) System

This review paper study focuses on the energy input and output of the heat storage component. As an illustration, heat is stored as sensible heat in a graphite block. Graphite is inexpensive, has a large heat capacity, and excellent thermal conductivity. All that is stored is a graphite block that has been insulated and has a heat exchanger receptacle for the engine. The concentrated radiation that the sun emits is absorbed by graphite, which raises its temperature. The engine's heat exchanger then takes heat out of the graphite, bringing its temperature down after the sun has set. If the storage temperature drops below 300º C, the engine would stall; optical models indicate that 700º C is the highest temperature that may be reached. Therefore, the operating temperature range for the storage is from 300º C to 700º C.

2.0 Literature Survey of Thermal Energy Storage

This Review paper aims to provide an overview of current knowledge on heat storage systems in order to uncover undiscovered research directions and prevent redundant efforts. The direction that further study should be focused on becomes evident after reading other researchers' papers, journals, articles, and books on related subjects. It is necessary to address the unresolved inquiries.

Heat storage, sometimes referred to as thermal energy storage (TES), is a vast topic with a wealth of literature on the subject; nevertheless, there are numerous uses for heat storage, and each one has unique challenges. There appear to be two primary applications for various heat storage methods, each with a different goal (Kalaiselvam, 2014). Utilizing the stored heat for process or area heating is one of these uses. Put another way, the goal is the heat itself. In order to recover waste heat generated by industrial operations, Anastasovski suggests using integrated TES (Anastasovski, 2017). Later, when another process requiring heat input calls for it, the stored heat is used. The use of phase change materials (PCM) in wallboards is another instance of TES for heating reasons (Scalat, 1996). Here, heat is trapped and released while a building material goes through a phase transition. This helps to lessen heating load bottlenecks and moderate temperature fluctuations within a structure.

The other application involves using a heat engine of some kind to convert heat into electricity. In this way, achieving the desired temperature is the end aim rather than the primary objective. In this paper, the latter of these two applications will be the main focus. More precisely, research will be done on heat storage for the production of electricity, which will be utilized in addition to concentrated solar power (CSP) as the main energy source. Nonetheless, the former will also be taken into consideration because some of the techniques utilized for space heating can be beneficial for producing power.

The present technologies fall into one of three categories for heat storage: sensible heat, latent heat, or thermochemical heat (Kalaiselvam, 2014), in addition to the two primary uses of heat storage. Every one of these approaches has benefits and drawbacks. As such, they will be carefully analyzed, along with the devices that use them, to determine which is best suited for a given purpose and environment. The methods and technologies that employ them will be defined and evaluated in the ensuing sections.

2.1 Sensible Heat Storage

Thermal energy that causes a change in temperature when it transfers to or from a substance is referred to as sensible heat. It is also known as the part of a system's internal energy related to the kinetic energies of its constituent molecules (Cengel & Boles, 2004). Sensible heat is linked to a change in temperature since the kinetic energy of molecules and atoms is connected to temperature (Schroeder, 2000). For instance, a material has absorbed a certain amount of heat if a specific quantity of that material sees an increase in temperature. As a result, the material's constituent molecules have an enhanced average kinetic energy. The most crucial characteristic of the storage material for this kind of storage is its specific heat capacity, or c. This is the energy needed to raise a unit mass by a unit temperature, and it is not a constant. Temperature affects it. The two distinct heat capacities of gases are represented by the letters cp and cv, which stand for the heat capacities at constant pressure and volume, respectively. Water is a great option for space heating since it is inexpensive and abundant, and it has a very high specific heat capacity of 4.18 kJ/kg/K at ambient temperature. In summer, when sun irradiation is high, large subterranean water tanks are heated. When solar irradiance is low in the winter, the heat is then released for space heating (IEAETSAP and IRENA, 2013). There are limits to sensible heat storage with water. At 100º C, water will evaporate at atmospheric pressure. Therefore, the water's temperature cannot rise above 100º C unless it is kept at exceptionally high pressures. This is a reasonable temperature limit for room heating, although greater temperatures are preferable if using a heat engine to generate electricity is the aim. Regardless of the kind of heat engine used to convert heat into work, one consequence of the second law of thermodynamics is that thermal efficiency rises with an increase in the temperature differential between the heat sources and sink (Cengel & Boles, 2004). Therefore, using sensible heat from water to generate power is not at all optimal. Tiskatine et al. suggest air-based CSP plants use natural rock as a high-temperature heat storage device. They came to the conclusion that minerals including granodiorite, dolerite, gabbro, hornfels, and quartzitic sandstone are appropriate for this use (Tiskatine et al., 2017). A variety of materials have been explored for sensible heat storage, as Table 1 illustrates.

Table 1: Sensible heat storage materials (Kalaiselvam, 2014)

Material	Type	Temperature Range (ºC)	Density (kg/m3)	Specific Heat Capacity (kJ/kgK)	Thermal Conductivity (W/mK)
Thermalite					
Board	Solid	-	753	0.837	0.19
Fiberboard	Solid	-	300	1	0.06
Siporex Board Polyurethane	Solid	-	550	1.004	0.12
Board	Solid	-	30	0.837	0.03
Light Plaster	Solid	-	600	1	0.16
Dense Plaster	Solid	-	1300	1	0.5
Aluminum Aluminum	Solid	up to 160	2707	0.896	204
Oxide Aluminum	Solid	up to 160	3900	0.84	30
Sulfate	Solid	up to 160	2710	0.75	
Cast Iron	Solid	up to 160	7900	0.837	29.3
Pure Iron Calcium	Solid	up to 160	7897	0.452	73
Chloride	Solid	up to 160	2510	0.67	
Copper	Solid	up to 160	8954	0.383	385
Granite	Solid	up to 160	2640	0.82	1.7
Sandstone	Solid	up to 160	2200	0.71	1.83

Once more, these materials have not been evaluated for use in powering a heat engine, merely for space heating. A storage material that can tolerate greater temperatures is needed to maximize the heat engine's efficiency. For temperatures about 400 0C, Science Applications International Canada has suggested using concrete, molten salts, synthetic oils, and ceramics as sensible heat storage materials (Renewable Energy and Climate Change Program, SAIC Canada, 2013). The thermal conductivity of these materials is insufficient to allow heat to be transferred to the engine at a fast enough rate, even when the temperature is appropriate for operating a heat engine.

A TES that uses molten salt as the storage medium is present in the majority of large-scale CSP facilities. The California Mojave desert is home to nine massive CSP facilities created by Luz International Limited, with a total generating capacity of 354 MW (Herrmann et al., 2004). Since the salt is liquid, it also functions as a heat-transfer medium. These plants need three separate fluids to function: water, which is the working fluid of a Rankine power cycle, molten salt for storage, and the HTF, which is often a synthetic oil that circulates through the solar concentrator. Depending on the time of day, heat from the sun heats the oil in the solar field, which then passes through a heat exchanger to heat the water or the cold salt storage tank. Before being transferred to the hot salt storage tank, the cold salt is heated from 300º C to 385º C (Herrmann et al., 2004). This sort of storage is naturally a sensible heat storage because of the temperature increase and lack of phase shift. The hot salt store releases heat while transferring it to the water, converting it to superheated steam in the event of insufficient solar radiation. The turbine is powered by this highly pressurized, superheated steam. The CSP plants are schematically depicted in figure 2.

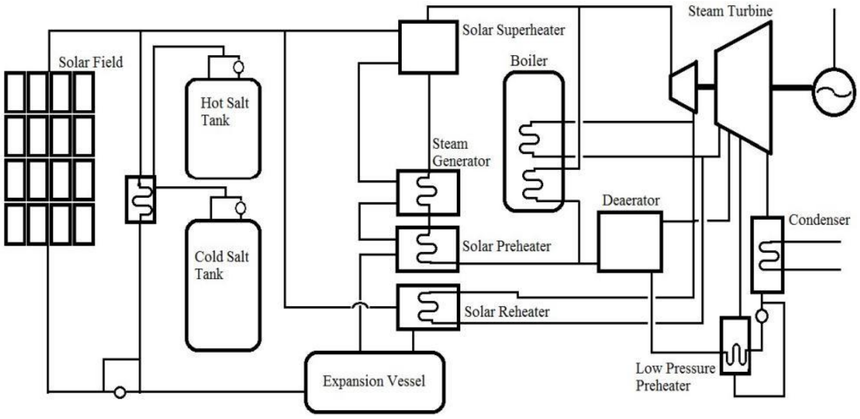

Figure 2: Schematic flow diagram of a parabolic trough power plant with 2-tank molten salt storage (Herrmann et al., 2004)

Typically, the salts employed in the TES are combinations of inorganic nitrate salts, such as $NaNO_2$, $NaNO_3$, KNO_3, and $Ca(NO_3)_2$. These salt blends were selected due to their excellent heat capacity, density, chemical reactivity, and affordability. According to Herrmann et al. (2004), their freezing points range from 130 to 220 degrees Celsius. It seems that in order to permit flow, the salt's temperature needs to be maintained above freezing. As a result, to maintain a high temperature and reduce losses, the storage tanks need to be extremely well insulated. The techno-economic benefits of employing porous concrete as a filler material in shell-and-tube (ST), dual media thermocline (DMT), and single medium thermocline (SMT) systems have been examined by Mostafavi et al. When the SMT, DMT, and ST systems were compared to the standard two-tank molten salt system, the electrical energy generated over a one-year period decreased by 7%, 9%, and 20%, respectively, for the same theoretical storage capacity. The DMT and ST systems had a normalized cost per unit of power generated that was 55% and 46% lower, respectively, than the two-tank molten salt system, while being determined to be less performant (Mostafavi et al., 2017). Although a DMT tank is less expensive, it has a drawback in that ratcheting strains on the tank walls may cause the tank to break mechanically (Mira-Hernandez & Garimella, 2014). An annular gap forms between the filler material and the tank walls as a result of their differential expansion during heating. The filler material then settles to fill the gap; it usually consists of natural rocks. The boulders cause mechanical stress in the tank walls and prevent contraction when the tank cools.

While large-scale business applications have found this kind of technology ideal, small-scale, off-grid residential applications may not find it to be so. A smaller storage tank sized for a single home's energy needs may need more insulation than necessary to maintain an acceptable heat loss when operating within the same temperature range.

For instance, the smaller storage will need significantly thicker insulation if it is permitted for 5% of the total heat stored in both the large and small storage to be lost.

2.3 Latent Heat Storage

As the name suggests, latent heat is linked to a modification in a substance's lattice structure, or the geometric arrangement of its atoms or molecules. For instance, liquid water turns into a gas when heated to its boiling point. The molecules are released from one another and the intermolecular Van der Waals bonds are broken during the vaporization. It takes some heat to break these ties. The heat of vaporization is the name given to this heat at a specific temperature and pressure. It is possible to reverse the phase transition, in which case the change is exothermic rather than endothermic and the vapor condenses to liquid. Water exists as both a gas and a liquid at the same temperature, but the gas has greater heat. This is an illustration of a phase shift. In a similar vein, the heat of solidification can also be either endothermic or exothermic, contingent upon whether the transition is from a solid to a liquid or vice versa. For the same reason that heat is needed to break bonds, a liquid has more heat than a solid at the same temperature. When the bonds are repaired, the same quantity of heat is released. Any material that has the ability to change phases is considered to have latent heat. This idea has been applied by some companies as a heat storage technique. A few typical phase change materials (PCM) are listed in Table 2.2.

Table 2: Phase Change Materials (IEA-ETSAP and IRENA, 2013)

PCM	Melting Temperature (0C)	Melting Enthalpy (kJ/kg)	Density (kg/m3)
Ice	0	333	920
Na-acetateTrihydrate	58	250	1300
Paraffin	0 to 120	150 - 240	770
Erytritol	118	340	1300

Table 2 shows that because the equilibrium temperatures of these materials are too low, none of them would be appropriate for using in a heat engine to produce electricity. These are limited to direct space heating and/or cooling applications. It is necessary to use a PCM with a higher equilibrium temperature. These PCMs not only have a low equilibrium temperature but also poor thermal conductivity, which makes it difficult for them to transfer heat. It has been suggested that one way to increase heat transfer is to employ tiny copper-water heat pipes embedded within the paraffin PCM (Khalifa et al., 2016). As PCMs, a variety of salt combinations with melting temperatures ranging from 300 to 600 degrees Celsius are frequently employed (Kalaiselvam, 2014). Examples of these PCMs include mixtures of different concentrations of $MgCl_2$, KCl, and NaCl as well as different concentrations of Na_2CO_3, K_2CO_3, and Li_2CO_3 (Kalaiselvam, 2014). These salts have relatively low thermal conductivities, ranging from 0.5 W/mK to 1.2 W/mK, while their melting enthalpies normally vary from 177 kJ/kg to 858 kJ/kg (Kalaiselvam, 2014). Although their very low thermal conductivities require an additional layer of complexity in any system that uses them, their melting enthalpies are suitably high. Due to the low thermal conductivity, convection must be used to promote heat transmission when in the liquid phase, necessitating the installation of pumps and a piping system. To further improve the heat transfer, some researchers have analyzed the possibility of nanoparticle additives in the molten salts and have found a 30% reduction in charging times (Miliozzi et al., 2015). As previously indicated, a heat engine's thermal efficiency rises with temperature. Higher temperatures, nevertheless, necessitate materials that can endure them, which raises the price overall. Thus, higher temperatures aren't always preferred. In addition to being expensive, reaching a temperature high enough to melt the PCM could not be achievable, depending on the heat source and the system's mechanical parts. A temperature range of 400–600º C is excellent for a solar concentrator's heat storage needs. With a shell and tube configuration, Zauner et al. have developed a latent-sensible heat storage system with HDPE as a PCM. But according to Zahner et al. (2017), their maximum temperature was only 154 °C, which is too cold to operate a heat engine effectively.

Phase change materials are most frequently utilized for space heating rather than as an input for a heat engine, much like sensible heat storage. The fact that latent heat storage has a far higher energy density than sensible heat storage is its benefit. According to Johansen et al. (2016), they are therefore more appropriate for long-term, seasonal heat storage. A brief description of the commonly used techniques with PCMs follows.

2.3.1 Direct Impregnation

The simplest method for incorporating a PCM into a building is this one. The liquid PCM is absorbed by porous building materials as plaster, concrete, gypsum, and wood (Hawes, 1991). Therefore, the PCM is saturated throughout the building envelope. Hawes suggests impregnation ingredients for concrete to include fatty esters, fatty alcohols, and paraffins. Additionally, the PCM fills the building material's pores and raises its thermal conductivity. The PCM will melt during the day and absorb heat, keeping the building cold. As the heat hardens over the night, release it to keep the building warm. In the end, there is less of a temperature difference between the day and night. By using this technique, the electric utility's peak-hour power consumption would be reduced in addition to stabilizing indoor temperature and heating load variance throughout the day (Karim Lee, 2014).

There have been reports of certain PCMs leaking out of construction materials or reacting chemically with them, which slows down material breakdown and lessens heat storage efficiency.

2.3.2 Microencapsulation

This method involves encasing powdered PCM in a micron-sized polymeric capsule (Kalaiselvam, 2014). These capsules are then combined to make a composite building material. They immediately become a part of the matrix material. By using this method, any chemical reaction between the PCM and the building material is eliminated, provided that the polymeric capsule remains intact and chemically inert. The PCM most commonly used in both techniques is paraffin. Cenospheres—hollow flash ash from coal-burning power plants—are covered with silica to create cenoPCM microcapsules, according to Liu et al. (Liu et al., 2017).

2.4 Thermochemical Heat Storage

Thermochemical heat, also referred to as thermochemical enthalpy, is the energy used in a chemical reaction. Every chemical reaction has products and reagents. A primary bond, which can be covalent or ionic, is created when a mixture of two or more reagents results in a third substance known as the product. Before bonds are formed, the reactants are in a high energy state. During the bond-forming process, their energy state is decreased and energy is released as heat. However, chemical processes are reversible. If the product is heated to a high enough temperature, it will dissociate into its reagents and break the primary bonds. The amount of heat emitted during product formation is exactly equal to the amount absorbed during product dissociation. This heat and temperature are referred to, respectively, as the "equilibrium temperature" and the "enthalpy of reaction". Thermochemical heat storage is reversible, arises from the forming and breaking of bonds, has an equilibrium temperature, and modifies the properties of the materials, much like latent heat storage. Conversely, latent heat storage materials experience a phase transition without changing as a material. Thermochemical heat storage materials undergo a chemical reaction that modifies their substance when two different substances are mixed together. The terms "equilibrium temperature" and "enthalpy of reaction" relate to this heat and temperature, respectively. Similar to latent heat storage, thermochemical heat storage is reversible, results from the formation and breaking of bonds, has an equilibrium temperature, and alters the properties of the materials. On the other hand, latent heat storage materials go through a phase change without altering physically. When two different substances are combined, thermochemical heat storage materials go through a chemical reaction that changes their composition.

Table 3: Potential thermochemical TES materials (Renewable Energy and Climate Change Program, SAIC Canada, 2013.

Material	Dissociation Reaction	Storage Density (kWh/m3)	Equilibrium Temperature (0C)
Calcium Sulfate	CaSO4.2H2O ↔ CaSO4 + H2O	400	90
Iron Hydroxide	Fe(OH)2 ↔ FeO + H2O	630	150
Magnesium Sulfate	MgSO4.7H2O ↔ MgSO4 + 7H2O	633	122
Iron Carbonate	FeCO3 ↔ FeO + H2O	743	180
Ammonia	2NH3 ↔ N2 + 3H2	800	450
Magnesium Hydroxide	Mg(OH)2 ↔ MgO + H2O	943	250 - 400
Calcium Hydroxide	Ca(OH)2 ↔ CaO + H2O	1260	550
Zinc Oxide	ZnO + C ↔ Zn(g) + CO	4571	1400

Table 3 lists some thermochemical heat storage materials that have been considered viable by various researchers and industries. The equilibrium temperature needs to be higher than 400º C in order to be eligible for the suggested design. Zinc oxide, calcium hydroxide, and ammonia would all be eligible based on table 2.3. It is also preferable to have the highest storage density, or enthalpy of reaction. The highest is found in zinc oxide, however its equilibrium temperature is very high. Reaching the necessary temperature by focused solar radiation would be challenging. Calcium hydroxide is a better option than ammonia because of its far higher storage density, abundance, and affordability. In addition, ammonia poses a poisonous, corrosive, and environmental threat as per the worldwide harmonized classification of hazardous materials. This means that the top option on the list is calcium hydroxide.

Within the crust of the Earth is a naturally occurring chemical called limestone. Moreover, because lime is used in chalk and building mortar, it is already a very big industry. Although calcium hydroxide may not have the largest storage density of the suggested thermochemical storage materials, it is unquestionably one of the least expensive, non-toxic, and has an equilibrium temperature that is perfect for combining with a heat engine. The most common type of reactor used in gas-solid thermochemical heat storages is the packed bed reactor, which is also the most common type. Other reactor types include continuous and direct (Pan & Zhao, 2017). The solid powdered reactant is placed between the heat exchanger fins, where heat transfer fluid is circulated, to form the packed bed reactor. There is no contact between the solid reactant and the HTF. A continuous-type reactor simply a series of packed bed reactors. The direct-type reactor has no heat exchanger. Rather, the HTF passes straight through the solid reactant after being combined with the reacting gas. The direct interaction of the HTF with the solid particles increases heat transmission. In contrast to packed bed reactors, however, the high friction in the powder's movement results in a significant pressure drop and greater pumping power requirements (Pan & Zhao, 2017). Tescari et al. propose using a rotary kiln reactor as a solution to these issues. There is no heat transfer fluid (HTF) in this reactor; instead, concentrated solar radiation heats the powdered reactant directly while the reactor rotates (Tescari et al., 2014To improve heat transfer and avoid particle agglomeration, the rotation agitates the powder. Magnesium's absorption-desorption of hydrogen has superior cycling properties compared to CaO hydration. Paskevicius et al.'s tests on MgH2 show that the material's performance and microstructure little deteriorate after 20 cycles (Paskevicius et al., 2015).

Y.A. Criado presented a calcium hydroxide-based TES that uses the packed bed reactor concept (Criado et al., 2014). The reactor is made up of storage tanks for CaO, Ca(OH)2, and liquid water. Steam and powdered CaO are introduced into the bed where the chemical reaction is permitted to happen during the discharging phase. During the process, thermochemical heat is released and used as output heat. As they exchange heat in a heat exchanger, the $Ca(OH)_2$ that leaves the bed has sufficient sensible heat to evaporate the liquid water that is moving in the direction of the bed. They may then store the Ca(OH)2. Concentrated solar radiation heats the $Ca(OH)_2$ in the fixed bed during the charging phase, resulting in the production of steam and CaO. After that, the CaO is kept in reserve while the heat exchanger's steam condenses to warm the Ca(OH)2 that is flowing in the direction of the bed. As a result, the water is kept liquid. Figures 3, 4, and 5 depict the whole idea.

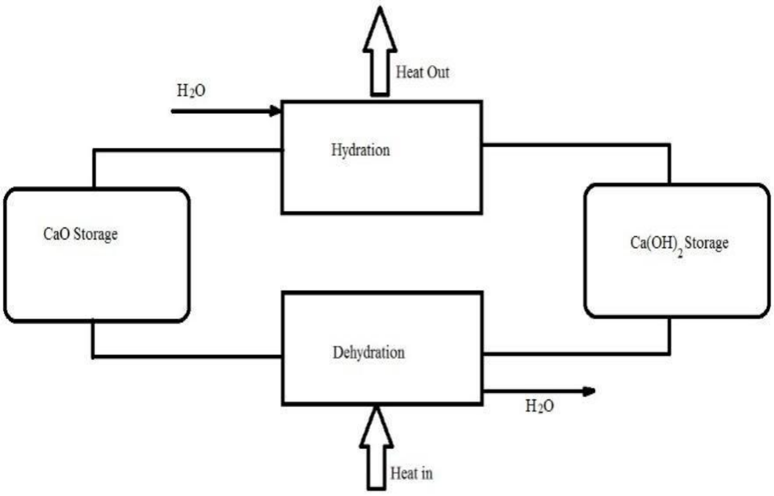

Figure 3: General Concept of thermochemical CaO/$Ca(OH)_2$ TES (Criado et al., 2014)

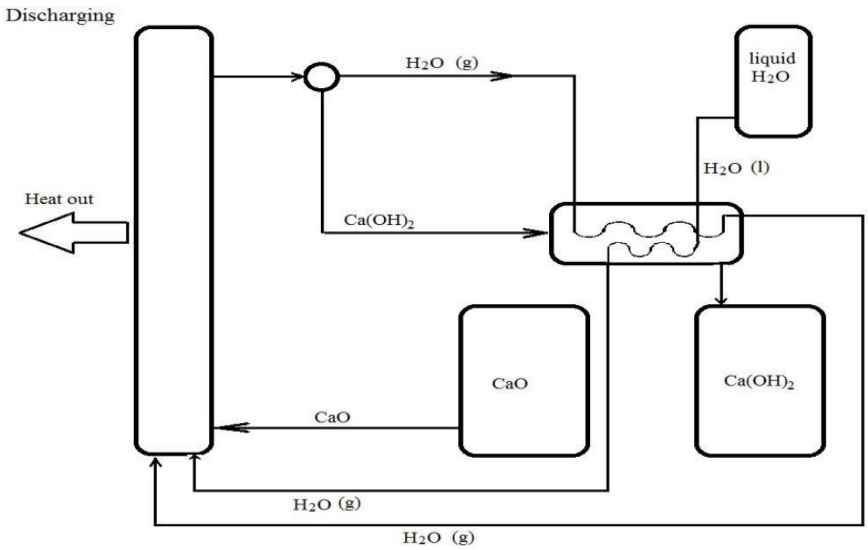

Figure 4: Discharging Process Scheme of CaO/$Ca(OH)_2$ TES (Criado et al., 2014)

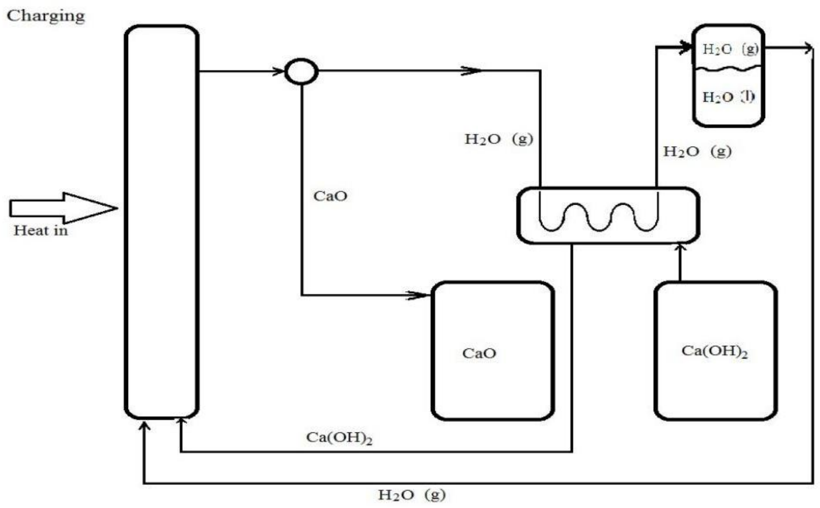

Figure 5: Charging Process Scheme of $CaO/Ca(OH)_2$ TES (Criado et al., 2014)

Since calcium oxide and carbon dioxide react, as previously discussed, it is crucial to keep air out of the system to avoid calcium carbonate from forming. Similar to the hydration of calcium oxide, this reaction is reversible and has an even higher enthalpy of reaction; however, the equilibrium temperature of this reaction is roughly 850ºC (Halikia et al., 2001), which may be too high. It's also crucial that the water evaporates before it reacts with the calcium oxide. If not, a significant amount of the heat generated by the reaction will be consumed in vaporizing that water, which will prevent it from being used for the purpose for which it was intended. Schmidt et al. have found the discharge power of the $CaO/Ca(OH)_2$ system with a packed bed reactor to be 325 kW/t-$Ca(OH)_2$ (Schmidt et al., 2015). They noted, however, that after several cycles, the solid particles agglomerated, resulting in reduced heat transfer. SiO_2 nano-particles were introduced to reduce this effect. Sakellariou et al. have introduced aluminum particles with the calcium oxide as another means of enhancing the particle integrity and crystallinity, ultimately to reduce cycling degradation (Sakellariou et al., 2015).

The large-scale TES is the intended use for this suggested plan. Considering the number of components needed, it might not be economically justified to scale it down to a household level. This still needs to be ascertained. On the other hand, a hybrid reactor that permits both CaO hydration and carbonation might be useful. In this instance, the powdered CaO would be passed by ambient air. The moisture in the air that has already evaporated would form $Ca(OH)_2$, and the CO_2 would produce $CaCO_3$. The cost would be decreased because a heat exchanger and water storage tank would not be required. As long as the solar concentration factor is high enough such that the fluidized bed reaches temperatures above 850ºC during charging, no immediate complications are evident.

The potential for carbonation of calcium oxide to facilitate thermochemical heat storage. They discovered that after a few cycles, the high reaction temperature caused the powdered CaO to sinter. Al_2O_3 composites and intermediate hydration of the CaO were added to solve this issue (Obermeier et al., 2017). Their study demonstrated that the CaO powder degraded less when carbonation and hydration were alternated, but it left open the question of whether simultaneous hydration and carbonation is practical. However, Yan et al.'s investigation into the impact of CO_2 on the hydration reaction of CaO revealed that the creation of $CaCO_3$ at even 1% molar CO_2 significantly decreased the system's cyclic storage capacity (Yan et al., 2017).

However, the highest test temperature was 500ºC, which is not high enough to reverse the carbonation. No research paper could be found that addressed the simultaneous hydration and carbonation of CaO as a potential heat storage method.

2.4.1 Hydrogen Energy Storage

Hydrogen has a thermochemical storage capacity for heat generated by concentrated solar radiation. This process can produce fuel from concentrated solar radiation even if it isn't based on a reversible chemical reaction. This technology would heat the HTF directly without the need for intermediate heat storage, in contrast to the traditional CSP plant structure where solar radiation heats the storage, which in turn heats the HTF that drives a turbine to ultimately drive a generator. The generator's electrical output would power the process of electrolyzing water to create flammable H2 gas. As a result, the energy is saved as fuel (Dincer & Rosen, 2011).

3.0 Hybrid Heat Storage

The goal of hybrid heat storage devices is to minimize the negative aspects of various storage techniques, such as sensible, latent, or thermochemical, while maintaining the positive aspects. A device like the one suggested by Ströhle et al., which combines sensible heat storage and thermochemical heat storage into one unit, combines two or more of the primary categories. The sensible heat part, which uses natural rocks as the storage material, is where most of the heat is held. The thermochemical part serves as a throttling component to address the issue of unstable temperature and heat flow during discharging that affects all reasonable storage devices. The reaction can take place at any temperature by using a compressor to regulate the pressure inside the reactor. Therefore, the reaction temperature can be decreased so that the reactor can still draw low temperature heat to drive the reaction and charge when the sensible section is almost depleted and relatively cool. In order to achieve greater thermal efficiency for the heat engine, the pressure and reaction temperature are raised once the thermochemical section is charged. The study team found energy and exergy efficiency of 95.6% and 94%, respectively, in a transient simulation of this notion (Strohle et al., 2017).

The effectiveness of a sensible-latent hybrid heat storage system for home space heating applications has been studied by Frazzica et al. In essence, the apparatus is a hot water tank with PCMs that have been microencapsulated dissolved in the water. Two distinct PCMs—paraffin and a salt hydrate—were examined. In comparison to pure water, tests conducted on such a device using 2.7% salt hydrate by volume produced a 10% improvement in storage density (Frazzica et al., 2016). However, because of the low temperature, this approach is not practical for CSP applications.

Agrafiotis et al. recommend the utilization of porous ceramic structures coated with a Co3O4/CoO redox system if air is utilized as the HTF between the heat engine and the storage (Agrafiotis et al., 2015). The porous ceramic serves as the framework, increases surface area, and stores some sensible heat while the air provides the oxygen needed for the reversible redox reaction. Thus, the system is a hybrid heat storage that is both thermochemically and sensibly sensitive.

Because of their high heat capacity and cyclical stability, molten salts are used as heat storage in the majority of large CSP facilities. In order to ascertain the enthalpy of fusion of nitrate salts as possible sensible-latent hybrid heat storage materials, Beltran et al. have carried out computer simulations and experiments. According to Beltran et al. (2017), the enthalpy of fusion in the instance of NaNO3 accounted for 3% of the total energy accumulated during the temperature range.

3.1 Classification of phase change materials (PCMs)

High latent heat and thermal conductivity values are required of the materials used in thermal energy storage units. They should be chemically stable, melt congruently with the least amount of subcooling, and have a melting temperature that falls within the realistic operating range. It should be inexpensive, non-corrosive, and non-toxic. Over the past forty years, hydrated salts, paraffin waxes, fatty acids, and eutectics of both organic and non-organic molecules have all been researched materials. The first consideration when choosing phase change materials should be their melting temperature and intended use. Materials with a melting point of less than 15 °C should be chosen for air conditioning, whereas materials with a melting point of more than 90 °C are utilized for absorbent refrigeration systems. Any additional materials that melt between these two points can be used for heat load balancing and sun heating. These materials are representative of the most researched material class [17].

1. Organic phase change materials: Paraffins and nonparaffins are further terms used to characterize organic PCMs. The primary attraction of organic materials is their long-term cyclic thermal and chemical stability, which occurs without phase segregation. As a result, they crystallize with little to no supercooling. Lastly, as previously

said, they are non-corrosive, which is a significant attribute. Paraffin and non-paraffin organic materials are subgroups of organic materials. A significant portion of the energy absorption in paraffin is caused by the crystallization of the (CH_3)-chain, which is one of a combination of n-alkanes CH_3-(CH_2)-CH_3. Paraffin's latent heat of fusion ranges from around 170 kJ/kg to 270 kJ/kg between 5 and 80 °C, making it ideal for solar and construction applications. Non-paraffin organic compounds are the most common type of PCMs and come in a variety of forms. Among PCMs, non-paraffin organic compounds are the most prevalent and have a range of characteristics. [19] Have carried out a thorough investigation on the esters, fatty acids, alcohols, and glycols that are appropriate for energy storage. These substances typically fuse at a high temperature, but they also have low thermal conductivity, are flammable, poisonous, and unstable at high temperatures. Fatty acids cost much more than paraffins, although being somewhat superior to other non-paraffin organics [20].Three key topics must be understood in order to create a latent heat thermal energy storage system: phase transition materials, container materials, and heat exchangers [5].

2. Inorganic phase change materialsMetals, alloys, salts, and salt hydrates are examples of inorganic compounds. The first were looked into as they were inexpensive, which is important for most projects. Furthermore, owing of their high conductivity—which may be twice as high as that of organic materials—and high volumetric latent heat storage capacity, inorganic PCMs enable high density storage. When using salt hydrates, the authors [21] encountered phase segregation, supercooling, and a lack of thermal stability. Additionally, some are said to be caustic. In certain situations, it may be possible to prevent supercooling and phase segregation [22], but the economics might then suffer. Low melting point metals like galium and metal eutectics are examples of metallic PCMs. Due of their weight, these have not yet been properly examined. However, because of their high latent heat of fusion and extremely high conductivities in comparison to other PCMs, they could be taken into consideration when volume is a significant concern.

3. Eutectics: A eutectic is a composite of two or more components that melts and freezes at least as slowly as possible, resulting in a mixing of the component crystals during solidification [23]. Numerous inorganic and organic substances' eutectics have been documented [24, 25]. In terms of segregation, eutectics typically outperform pure inorganic PCMs [20].

4. Composite phase change materials: The top nine PCMs for thermal energy storage devices are shown in [26]. They carefully examined roughly sixty PCMs and chose the best ones based on characteristics including density, melting point, heat of fusion, and thermal conductivity. Regarding the improvement of storage capacity and various phase-change material properties for the appropriateness of thermal energy storage devices. As a novel energy storage technology,[27] introduce the composite PCMs, epoxy resin paraffin wax with a melting point of 27°C. In order to create stable phase transition materials for thermal energy storage, [28] assess the thermal properties of blends of polyvinyl alcohol (PVA)-stearic acid (SA) and polyvinyl chloride (PVC)-stearic acid (SA). The purpose of SA in the blend is to store latent heat of fusion during the solid-liquid phase transition, while the structural strength of the polymer (PVC or PVA) serves as a supporting material to stop melted SA leaking. There are numerous polymer matrices with a wide range of mechanical and chemical characteristics. [29]

4.0 Conclusion

A thermal energy storage unit is integrated with a solar thermal power plant to provide power continuously, even throughout the night or during cloud cover. While many storage unit types are discussed in this study, the thermal energy storage unit using phase change material is the main focus.This study has detailed several PCM types and their attributes; nevertheless, it has also described a unique and relatively new sort of PCMs termed composite PCMs. When compared to single PCMs like paraffin wax, etc., composite PCMs have improved features including thermal conductivity, heat of fusion, density, and melting point. Therefore, the best and most efficient thermal energy storage unit can be constructed if composite phase change materials receive significant attention. Compared to sensible heat thermal energy storage materials, latent heat thermal energy storage systems store five to fourteen times as much heat. Taking everything into account, we conclude that latent heat thermal energy storage is more cost-effective and that their sturdy construction may enable them to store enough energy to constantly supply the parabolic trough concentrator's helical coil solar cavity reception system. Although there are many phase materials available, not all of them are used for the intended purposes. Materials with a melting point of less than 15°C should be chosen for air conditioning, whereas materials with a melting point of more than 90°C are utilized for absorption refrigeration systems. Any additional materials that melt between these two points can be used for heat load balancing and sun heating. To design the most efficient thermal energy storage unit, the primary concern is the phase change material selection and compatibility with the containment where PCM is encased.

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