Research Article

A bibliography on recent advancement in thermal energy storage – a Mini Review

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Abstract: *The thermal energy storage (TES) system is one of the most innovative technologies available for meeting long-term energy demands. Energy storage technology has demonstrated its ability to close the energy gap between supply and demand. The storage of thermal energy (TES) building integration is expected to reduce energy demand shortages while also allowing for better energy management in the construction industry. This paper will review about recent advancements in thermal energy storage which is in mini-review. There is some point that is highlighted in the review. There is sensible heat storage, latent heat storage and thermal chemical storage and the advantage of thermal energy storage. In this review paper, recent advancement has been studied and discussed, most commercial thermal energy storage was the sensible heat storage which is most cheap and most ready to use in recent technology. While future research is needed for giving confidence to the audience to use their system, which latent heat storage and thermochemical storage provide high energy capacity and high temperature for storing effect. These technologies were come in to track which has the advantage of their effectiveness.*

Keywords: thermal energy storage; thermal energy; sensible heat storage.

1. INTRODUCTION

The global concern towards the energy crisis has become a major flashpoint in recent years. The worldwide energy demands have increase precipitously in past decades and presumed to be continually rising. The foreseen significance growth of the energy demand is induced by climatic change and economy development is further amplified by the expected increase of the local population. Although the current energy source has proved to meet the demand by far, this fossil-based energy source is anticipated to be depleted (Aziz, 2018). Thermal energy storage is keys for integrating renewable heat sources into an energy system --from domestic applications to district heating and from industrial applications to the power sector. The flexibility storage provides is necessary for the coupling of energy sectors. When higher temperatures, volume restrictions or very long storage periods come into play, new compact thermal storage technologies are needed, but so is more work on their development for the different energy sectors (SHC Solar Update, 2020).

Energy system operators can match supply and demand of energy through forms of flexibility such as energy storage. This helps to make energy systems more stable, flexible, and cheaper to build and operate. TES technologies offer unique benefits compared to other forms of flexibility. There can facilitate flexibility in the delivery of heat and cold, decoupling supply and demand. It is also as variable supply integration which is heat/cold produced at times of peak supply of renewable electricity can be used to meet demand even when the sun is not shining, and the wind is not blowing (International Renewable Energy Agency, 2018). For sector integration, TES enables whole system benefits through increased sector integration, allowing renewable electricity to reliably meet a greater proportion of energy demand. Besides, network management have Increased flexibility arising through the deployment of TES can alleviate the strain on electricity networks and can reduce the need for costly grid reinforcement. Last but not least, TES can enable winter heating demands to be met through thermal energy stored from sunny summer days, and cooling demands in summer to be met through cold stored from winter (International Renewable Energy Agency, 2018).

There are keys actions required to accelerate the deployment of thermal energy storage. There are ensure a technology neutral, whole-systems approach is taken in energy systems policy making and planning, in order to address conflicting rules and regulations that arise from thinking across heat, energy and transport. Furthermore, invest more in research and development activities to help overcome the relative immaturity of some technology. Then increase the number of Thermal Energy Storage, TES demonstration projects in all parts of the energy system to improve stakeholder awareness of the benefits that these technologies can deliver (International Renewable Energy Agency, 2018).

Thermal energy can be stored by three methods which are sensible heat, latent heat and thermochemical energy storage. Sensible heat storage (SHS) is the most common way of energy storage which storage process can be sensed by the change in temperature of the medium. The energy storage density in SHS is determined by the value of its specific heat capacity and the temperature changes based on designed application. Meanwhile, the latent heat storage (LHS) is referred to the heat stored during a phase change process, is then calculated from the enthalpy difference ΔH between the solid and liquid phase (Aziz, 2018).

2.0 THERMAL ENERGY STORAGE (TES)

One of the most important forms of energy, which was the thermal energy, hence the thermal energy storage was very important (Rismanchi, & Yau, 2012). TES is very applicational, it mostly uses from the heating and cooling using the solar energy which is renewable energy to high temperature energy storage for producing the power or other industrial processes (Domański, 1995). Besides, the application of thermal energy storage system can also improve the flexibility within the energy system. In current technology advancement of TES can be categories in several type using the different of the internal material of energy storage system which include three types, the thermal-chemical storage, sensible heat storage and latent heat storage or even combination of these technology of thermal storage (Sharma, 2009).

In the thermodynamic systems, thermal energy storage was taking its theory for function which due to the intermittency in availability in the solar radiation (Sarbu, 2018). The effective TES can reduce the different or waste from supply energy and demand energy through the system by conserving the energy, it is also to improve the thermal reliability and the performance of the system. Hence, there is very important to design and research for improving the efficient and economical TES systems in this sustainable development era. Thermal energy storage can be classified into two class which is the thermal and chemical classes, thermal class Includes sensible heat storage and latent heat storage while chemical class include the thermal- chemical storage. The figure 2.1 present the main types of tes in solar energy system.

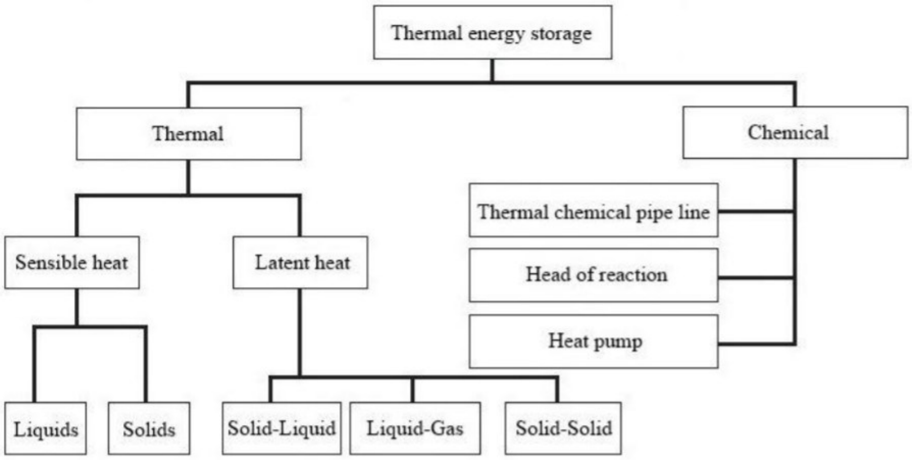

Figure 2.1. Types of solar thermal energy storage (TES) (Sarbu, 2018).

Thermal energy storage system can consider in several characteristics which includes power, capacity, efficiency, storage period, charge and discharge time and the cost (International Renewable Energy Agency, 2013). The definition of the characteristics shown in table 2.1.

Table 2.1. The characteristics definition for thermal energy storage

Characteristics	Definitions
Power	How fast the energy stored in the system can be discharged (and charged)
Capacity	The energy stored in the system and depended on the storage process, the medium, and the size of the system
Efficiency	The ratio of the energy provided to the user to the energy needed to charge the storage system. It accounts for the energy loss during the storage period and the charging/discharging cycle
Storage period	How long the energy is stored and lasts hours to months (i.e., hours, days, weeks, and months for seasonal storage)
Charge and discharge time	How much time is needed to charge/discharge the system
Cost	Refers to either capacity (€/kwh) or power (€/kw) of the storage system And depends on the capital and operation costs of the storage equipment iis lifetime

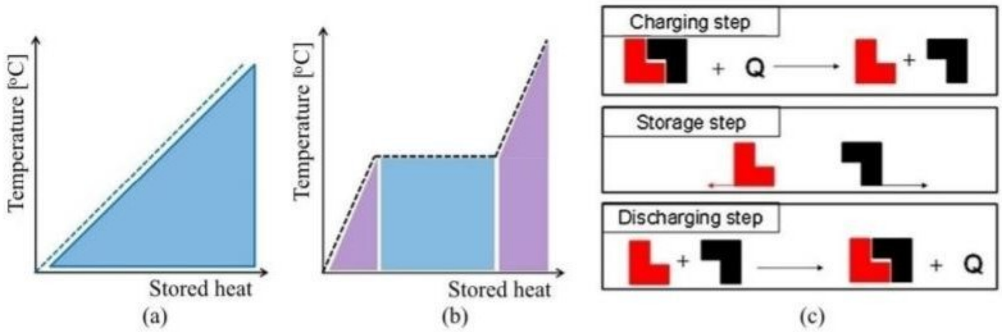

Figure 2.2 show the method of TES used a) sensible heat; b) latent heat; c) thermal-chemical reactions

The storage medium is chosen depends on the nature of the process or system. The method of TES simply shows in graph presented in figure 2.2. Water heating usually using the sensible heat system for energy storage, store the water is logical. If for the air heating process, the suitable storage is sensible and latent heat systems, such as the pebble-bed heat exchanger is using sensible heat system. Sensible heat in building the elements is provided in the storage of passive heating. While the thermochemical storage (TCS) is logically used in the photovoltaic or photochemical processes (Sarbu, 2018).

2.1 SENSIBLE HEAT STORAGE

Sensible heat storage is the most straightforward and matures way in storing heat energy (Becattini, 2017). Sensible heat energy is stored by heating or cooling the liquid or solid medium. Sensible heat required liquid or solid storage medium such as water, sand, molten salts bricks and etc, with water is the cheapest storage medium (Sarbu, 2018). During this process, there is no phase change when the temperature change in the medium [12]. Hence, sensible heat storage has two major advantages which is cheap, and it is without the risk in using toxic materials (Sarbu, 2018).

During the process of charging and discharging, sensible heat storage system is making use of the heat capacity and the vary in temperature of the storage medium. This makes a relationship between the specific heat of the medium, temperature, and storage material (Kumar, 2015).

$$Q_s = mc_p dt$$

Where Qs is the quantity of heat stored, in joules; m is the mass of heat storage medium, in kg, cp is the specific heat, in j/(kg.k); dt is the temperature changes between the initial temperature and final temperature, in °C.

The storage material is playing an important role in the heat energy which mainly depends on physical the thermal properties of the storage materials. Hence, table 2.2 has groups out the desire properties and criteria for the storage materials. The storage materials should have high energy density, high heat capacity, high thermal conductivity, cheap and abundant materials, low carbon dioxide footprint which is more sustainable and non-topic materials.

Table 2.3 Groups of properties and desirable criteria for storage materials (Fernandez, 2015).

Properties	Criteria
Thermophysical	High energy density (per unit mass or volume), high thermal conductivity, high heat capacity, high density, long term thermal cycling stability
Chemical	Long term chemical stability with no chemical decomposition non-toxic, non-explosive, low corrosion potential or reactivity to HTFs, and compatible with materials of construction
Economic	Cheap and abundant materials with low cost of manufacturing into suitable shapes
Mechanical	Good mechanical stability, low coefficient of thermal expansion, high fracture toughness, high compressive strength
Environmental	Low manufacturing energy requirement and CO_2 footprint

2.1.1 *Water tank storage*

For sensible heat storage, water is the most often material used. One of the famous technologies for sensible heat storage are the use of hot water tanks. The purpose of hot water tank storage is to save the energy in the water heating systems through the solar energy and co-generation energy supply systems. One of the frontier projects (International Energy Agency, 2016) have proved that water tank storage gives a more cheaper storage option, and the efficiency can be better if the thermal insulation be more effective and ensure the optimal water stratification in the tank. A model system on how the water tank is used in shown in Figure 2.3.

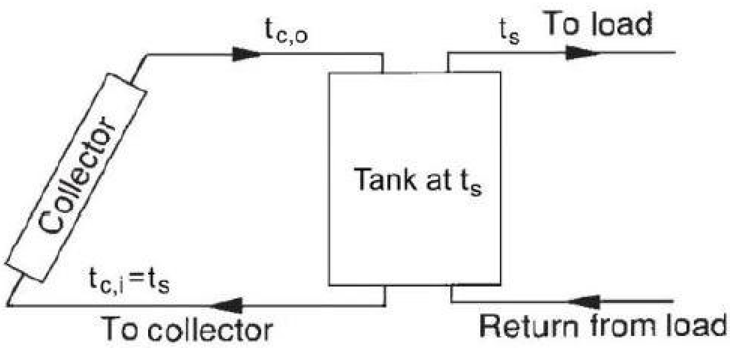

Figure 2.3. A model system using water tank storage (Sarbu, 2016)

Moreover, water tank storage has more complex system which is shown in figure 2.4. This is a solar combi system due to the solar collectors is charged in one of the heating sources and another heating source which commonly contain biofuel or gas boiler is extracting the heat. This combi system is very popular in European country that have the topic of European project combisol. This project is to promote and standardize the solar combi systems in Europe.

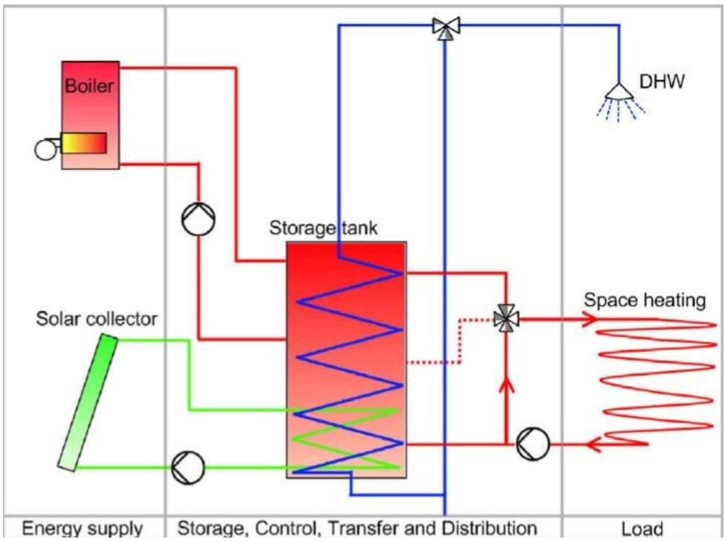

Figure 2.4. A schematic of solar combi system with solar collectors and a boiler charging water storage tank (Heier, 2015).

2.1.2 Underground storage

Another sensible heat storage technology is the underground thermal energy storage. This is a popular storage technology that widely used because of its high efficiency and the cost if cheaper. This type of energy storage is utilizing the ground materials such as soil, sand, and rocks as a medium of heating and cooling storage. There are four main types of underground thermal energy storage systems that shown in figure 2.5.

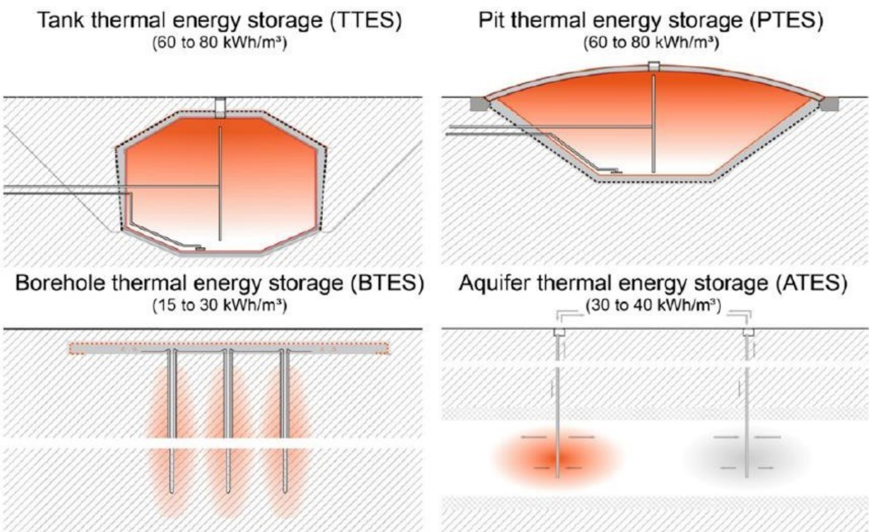

Figure 2.5. Seasonal thermal energy storage methods (International Energy Agency, 2015).

2.1.3 Packed-bed storage

A packed-bed storage also known as pebble bed storage. The energy is store by utilize the heat capacity of the bed of loosely packed material. It involved solid and fluid material. Fluid material normally is air, used to circulate through the bed to add and remove energy. For solid material, rock and pebble are commonly used.

A conceptual pebble-bed storage unit is shown in figure 2.6 (Dincer, 2011). When the pebble-bed storage is operating, there are two types of flow in the pebble-bed storage. During addition of heat, the flow usually will flow downward through the bed in one direction, and it will flow in opposite direction when the heat is removed. These two directions of flow cannot be done at the same time. However, this limitation does not happen in water storage system, where the addition and removal of heat from the storage can be occur simultaneously.

High degree of layer is one of the major advantages of packed-bed storage. For example, when the pebbles are heated close to the entrance, the heat is hard to transmit to the bottom or exit of the pebbles. This causes the temperature of the pebbles will remain near the initial temperature of the bed in the exit. However, as time move on the temperature will pass through each of the layer of the bed. The temperature will finally become uniform when the bed is fully charged.

2.2 LATENT HEAT STORAGE

In cooling and heating system, thermal energy storage is very important as it provide energy stored and always ready for use when needed. Where latent heat storage system makes use of the phase change materials (PCMs) as a heat storage medium due to their very good properties of absorbing and releasing thermal energy (Chidambaram, 2011). These PCMs stored the energy during the phase change process such as melting (solid to liquid) and freezing (liquid to solid). For example, as the temperature rises, the chemical bonds within the materials will start to break up due as the heat absorption occurs at the same time.

After that, the materials will begin to melt from solid to liquid phase when the melting point is reached. The temperature will then remain constant until the melting process is finished. During heat absorption in the melting process, the materials is storing the heat and the heat stored is so called latent heat. Phase change materials are widely used because of their high thermal density. It is much better than waters as a heat storage medium which used in conventional thermal storage systems (sensible heat storage).

In addition, there are two types of measurement techniques that is commonly used to measure latent heat of fusion and the melting temperature of PCMs. The techniques are so called differential thermal analysis (DTA) and differential scanning calorimeter (DSC) (Tian, 2013). Both techniques used similar method to get a DSC curve as the result by heating the sample and reference PCMs at a constant rate. After obtaining the curve, the latent heat of fusion can be calculated using the area under the peak, and the melting temperature can be estimated by using the tangent at the point of greatest slope on the face portion of the peak.

2.2.1 Selection and characteristics of PCMs

Material selection is always the most important things when designing a latent heat storage system. When selecting PCM, the temperature and heat of fusion of the materials must be considered. The parameters necessary to identify the material include the temperature required for the application and heat requirements. Thus, the type of PCM is selected for its physical and chemical properties, considering the drawbacks. Heat flux DSC is one of the most reliable methods of laboratory thermal analysis for testing heat storage capacity of PCM with a constant heating and cooling rate (Höhne, 2003). A visual combination of important thermal properties for some types of PCM was shown in figure 2.6 (Li, 2012).

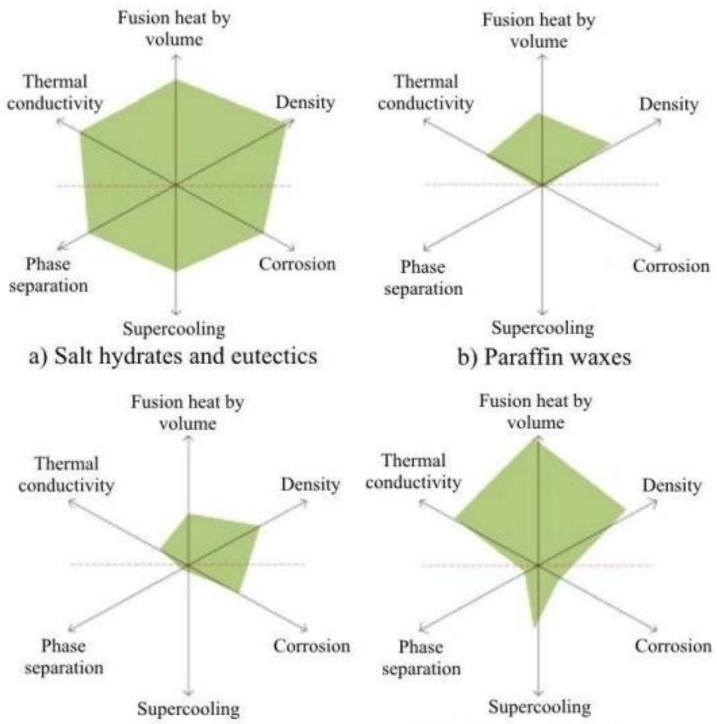

Figure 2.6. Thermal properties of various PCMs (Chidambaram, 2011).

As PCMs are widely used in thermal energy storage from the past decades. Where a good PCM must obtains long-term chemical stability, no fire hazard, no toxicity, compatibility with materials of construction and super-cooling must be limited to a few degrees. When in terms of thermo-physical properties, PCM must have high thermal conductivity and high latent heat of transition, the density and volume of the PCM should be high and low respectively during phase transition so the storage volume can be minimized.

Besides, low cost of PCM is also essentials when looking at the economic advantages. As PCMs have different characteristics, it can be classified based on their physical transformation for heat absorbing and releasing capabilities. The solid-to-liquid PCMs that have different material natures and can be classified into three categories (organic, inorganic and eutectic) as shown in figure 2.7. Furthermore, the most widely used materials for real case in latent heat storage system are paraffin compounds (organic), fatty acids (organic) and hydrated salts (inorganic).

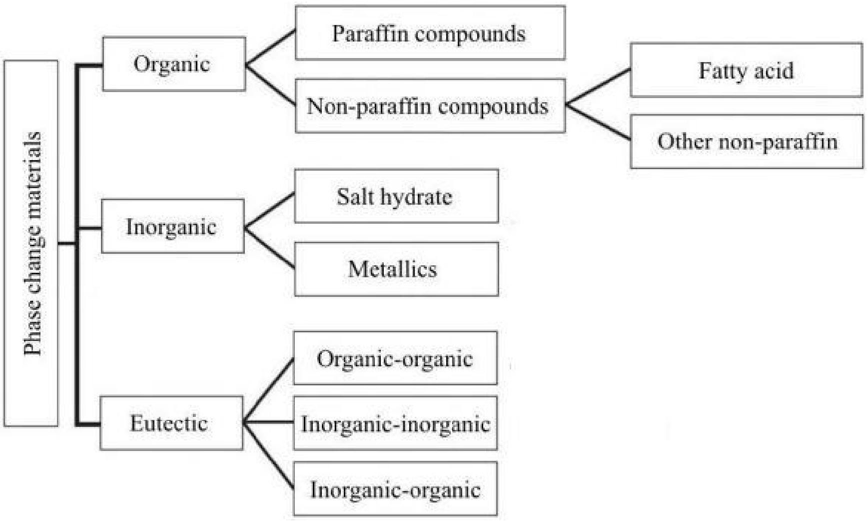

Figure 2.7. Classification of PCMs

2.2.2 *Pcms Used For Heat Energy Storage In Building*

Due to the great latent heat absorption and high thermal conductivity, PCMs have become a potential energy saving materials that can substantially increase the thermal mass of buildings compared to the traditional building materials such as glass wool, wood, plaster, concrete, iron, etc. The result of comparison is shown in figure 2.8 (Hassan, 2016).

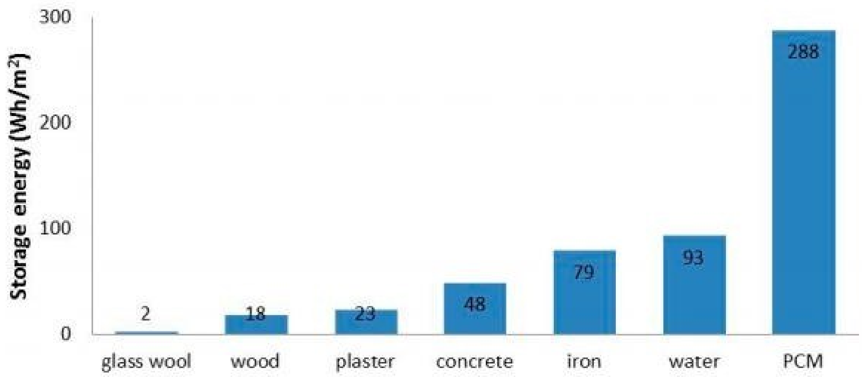

Figure 2.8. The maximum energy storage capacity of different 10-mm-thick building materials (Hassan, 2016).

The PCMs that used in energy storage in the buildings can be classified into passive or active technologies. Passive heat energy storage system is more environmentally friendly as it used the heat energy source that is naturally available from the environment to maintain the temperature comfort in the buildings. Therefore, the used of heating or cooling system can be minimized in order to save energy and cost. Hence, the objective of passive heat energy storage system was usually used in buildings to provide free cooling. On the other hand, active heat energy storage usually used in buildings to shift the thermal load from on-peak period to off- peak period conditions by improves the way of storing heat energy and providing a high degree of control of the indoor conditions. For instance, active heat energy storage system was implemented in some of the cases, such as HVAV systems (Agyenim, 2010) and DHW applications (De Gracia, 2011).

2.3 THERMAL-CHEMICAL STORAGE (TCS)

Thermal-chemical storage (TCS) which using the technique of chemical bond to store the heat energy. With the help of endothermal and exothermal reactions in chemicals which some of the process to broke and form the chemical bond where can absorb and release a huge amount of energy (Chen X, 2018). The efficiency can be measure or describe from the reaction which can be reversible with the least energy lost for example that the cobalt oxide reaction below, efficient thermal storage means the reactions was fully reversible.

$$2Co_3O_4 + \Delta H \leftrightarrow 6CoO + O_2$$

Thermal chemical storage using the thermo-chemical materials (TCM) for storing the energy as state above using endothermic and exothermic reaction is shown as a simple description in figure 2.2a. Charging process which is applying heat to the materials, cause the reaction to separation of 2 molecules where b and c in figure 2.2a. The products from the resulting reaction are chosen that be easily separate and store to store the energy and release through the discharging process when it is needed. The discharging is then mixed the products b and c with some suitable condition such as pressure and temperature, the energy will be release and use.

The thermal losses are restricted to the effect of sensible heat from the storage which stored the products b and c separately, this usually small compared to other heat of reaction (Sarbu, 2018). The energy storage using the thermal decomposition of metal oxide has been study and considered (Kerskes, 2012). This consideration about the advantage of oxygen evolved in the reaction of metal oxide which oxygen can use in other purpose or discarded, moreover the atmospheric oxygen can be used in reverse reactions, this may reduce the cost in storing it. Example of metal in recent research was potassium oxide and lead oxide.

$$4KO_2 \leftrightarrow 2K_2O + 3O_2$$

Potassium oxide reaction occur in a temperature range of 300 to 800 °c with the heat energy for decomposition of 2.1 MJ/kg [8]. Lead oxide reaction occur in a temperature range of 300 to 350 °c with the heat energy for decomposition of 0.26 MJ/kg. However, there are still many problems need to be considered and resolve in the future using these reactions.

$$2PbO_2 \leftrightarrow 2PbO + O_2$$

The thermal decomposition of calcium oxide ($Ca(OH)_2$) already study extensively for energy storage (Fujii, 1985). The reaction was that Ca(OH)2 ↔ CAO + H_2O, its forward decomposition will react at the temperature estimate above 450 °C, and the catalyst to increase the rate of reaction will be the zinc and aluminium. The decompose product CAO can be easily store in the water, and the reverse exothermic reaction can proceed easily when it is needed.

Another recent study of decomposition reaction was photochemical decomposition reaction using nitrosyl chloride, the decomposition reaction as NOCl + Photons → NO + Cl. The decomposition of NOCl, energy is added in the decomposition and the chlorine gas will form through the products of chlorine atom, which the overall rection will be 2NOCl + Photons → 2NO + Cl_2. The reverse reaction carries out where to provide or recover the energy of the photons entering to the reaction this is means when using the energy from the energy storage such as the electrical storage batteries. The electrical energy may store as a potential chemical energy and release energy when it is been use.

Thermochemical reaction can store heat or cold through the adsorption reaction where adhesion of a substances to other solid or liquid substances surface, moreover, can control the humidity as well (Sarbu, 2018). The thermal energy transportation is allowed through the high storage capacity of sorption processes.

3.0 CONCLUSION AND FUTURE TRENDS

Sensible heat storage (SHS) is most common thermal storage which applicable to the domestic systems, industrial systems, and the district heating. The water is the medium which is the most popular and commercial heat storage medium. Both liquid and solid media is used in the underground sensible heat storage which for typically large-scale applications. There has a limitation of SHS for thermal energy storage which the specific heat of the storage medium. Moreover, there is difficulty of designing the SHS systems to ensure the discharge thermal energy at constant temperature.

Latent heat storage technique using the phase change materials (PCM) which can provide higher storage capacity. The higher capacity using the latent heat of the phase changing for materials used. The constant temperature of phase changing can set for target-oriented discharging temperature in PCM. In any application, there are three basic factors which influence the PCM selection. The factors are melting temperature, the PCM thermo-physical issues and the latent heat of fusion. In selection approach, the two primary requirements are high heat of fusion and an accurate melting or solidification temperature.

Higher heat transfer rate can be achieved by the many mechanical and nano-level enhancements in the future development. The recent solution for phase segregation in salt hydrates was the micro- encapsulation which also increase the rate of heat transfer. Since, most of the literature review on the PCM materials, in such the paraffin for commercial used, here some the future recommendation which can study and research focusing on wider temperature range of PCM such as salt hydrates and integrating the specialized PCM which suitable for specific application in the building. The higher storage capacity can be provided by thermal-chemical storage (TCS). The thermo-chemical reaction is used to accumulate and restore the heat or cold energy such as the absorption processes. TCS can also control the humidity using variety of chemical reactants in different of applications.

Recently, thermal energy storage is commercially available using the sensible heat technique. The technique of thermal-chemical storage and latent heat storage using phase change material are currently under demonstration and development. Further recommendation was that support the study and research even demonstration investment for new storage materials. TES helps a lot in sustainable development which decrease of energy loss in storing it and used for variable renewable power generation as well. Further research and development for TCS and PCM technique is needed to become commercially in more cost-effective manner.

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