PROCEEDINGS, 46th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 15-17, 2021
SGP-TR-218

A Review of Integration of Solar-Geothermal System with the Thermal Energy Storage System

Nilesh Mali, Abhijit NIRANTARE, Kriti YADAV, Anirbid SIRCAR, Namrata BIST, Surbhi SINGH

Research Assistant, Centre of Excellence for Geothermal Energy, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India

Research Assistant, Centre of Excellence for Geothermal Energy, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India

Coordinator, Centre of Excellence for Geothermal Energy, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India

Professor, School of Petroleum technology, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India

Assistant Professor, School of Petroleum technology, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India

Project Assistant, Centre of Excellence for Geothermal Energy, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India

E-mail address, Nilesh.mali@spt.pdpu.ac.in

Keywords: solar thermal, geothermal, hybrid system, Flexible energy use.

ABSTRACT

Thermal energy systems enrich the ongoing modifications that bring to greater integration between various energy systems, intending to achieve a green, more versatile, adaptable, and imperishable use of energy resources. This paper studies the surveys the writing to the advancement and utilization of stored heat of thermal energy systems or thermal energy storage (TES) - based solutions in space heating and cooling, desalination systems, utilization of heat for food processing industries, and electricity generation. These arrangements encourage the combination of the energy framework to accomplish extra adaptability in the administration of energy, take into account additionally adjusting utilization of variable sustainable power sources also called variable renewable energy source (VRES), and offer revamping the framework of the TES system, the improvement of the operating traditions of the grid, including energy shifts, and utilization of feasible network services. This paper gives a perspective of various studies dealing with energy storage technology elements for TES applications. The principal exposure is to understand the properties, criteria, and various representations of TES systems, the formation of TES network with a renewable energy source (RES), grids, and miscellaneous power system, and new tendency for TES implementation.

1. INTRODUCTION

The expansion in energy challenges and the generation of that energy from traditional sources cannot be tackled with the major issues of the present and the future. Higher levels of contaminants, organic compounds, ashes, and greenhouse gases internationally are enormous. Replacement of energy demand from conventional sources of energy that can substitute energy requirements from green energy sources such as solar energy (PV and thermal), geothermal energy, wind energy, tidal, and biofuel. The rise in renewable energy will have fewer environmental consequences for us. There are also several innovations and implementations for TES. The selection of TES technology for a specific utilization depending on a variety of criteria, including storage duration, cost, supply, and efficiency requirements for temperature and storage capacity.TES technologies and systems are being used in building designs and integrated into solar power generation for many years.TES for the most part includes the transitory stockpiling of high and low heat for some time to utilize in the future. Type of integrated TES is the capacity of solar-based/geothermal for night warming, solstice heat for winter use, Snow ice for space cooling in solstice summer and electrically made during off-top hours for use during or later for Zenith periods. Mitigate this mismatch between the accessibility of thermal energy and the demand for electrical energy from thermal energy. Integration of TES systems with other systems can be fulfilled partially or fully by the demand of conventional sources of energy. The analysis Is done by (Dincer and Rose, 2013).The elements through which energy is captured and processed are vital parts of the system for any solar thermal application. The purpose of solar collectors is to convert energy from the sun either instantly into electricity using photovoltaic solar panels or get heat energy into the fluid by CSP, PTC, or solar tower for heat energy (Bai et al, 2019). Likewise, perfect thermal storage includes long-term stability, lower production price, extraordinary storage substance, and the capacity to pass on heat efficiently through instant involvement and liberation (Faiz, 2017). In differentiate to solar oriented energy, which could be an occasionally inconstant energy source, and wind energy it is an irregular energy origin, geothermal heat is ceaselessly accessible. Geothermal plants throughout the globe constantly create power, it is allotted to achieve rising internationally energy needs and merge with the inexpensive cost of power generation, this feature makes geothermal assets engaging for industries that progressively integrate geothermal power plants to their generation blend. (Michaelides, 2016). With certain special cases, major of the best elevated-temperature, enthalpy, geothermal assets have been utilized around the globe in the undetected area of volcanic nations. As the progression of geothermal innovation and the improvement of Organic Rankin Cycles (ORCs) with less temperature gradient assets can presently be utilized for the new era of power generation. ORC generation unit attributes for most of the expansion in geothermal power. Some of the studies are done by (Calise, 2016) and (Bruscoli, 2015). Due to the intermittent nature of solar-based irradiance, TES frameworks are essential for constant power generation. This topic is covered by a much number of Systematical and mathematical studies (Yang et al, 2019). Analytical researches have been published on the impacts of the overheating of ORC vapors utilizing solar-based control to offset regular temperature uncertainties. The study concerns power generation with low-temperature gradient geothermal assets and heating and cooling frameworks, where intermittent temperature changes responsible for a definite elevation in output energy fluctuations (Kutlu et al, 2018).The ORC designed to simulate the input of solar energy and discovered that the saturation temperature sequence significantly enhances the effectiveness of the cycles for all operating solutions. With the design and performance of solar organic energy, storage cycles were examined. This met the electricity consumption and supply employing a TES system. The achievement of sun-powered ORC cycles equipped with TES and is analyzed by (Manfrida et al, 2016). A geothermal-solar plant operating at a low-temperature gradient so geothermal brine is able of providing more output than development or implementation in a sub-critical ORC unit. The extra privilege of the geothermal and solar unit is that it is able of conveying nonstop and non-variable power during the acting hours of the unit. In hybrid units with sun oriented energy, a supercritical ORC can be utilized which supplies the warm rate required to superheat the working liquid. The created extra energy may be utilized amid crest generation hours to reduce the higher request for power caused by space cooling. The combination of the critical series and superheated steam from sun-powered radiations comes about in altogether higher thermal efficiencies with other sorts of geothermal power plants, indeed even though the exergetic performance decreases since the expansion of high-energy radiations. Since sun-powered radiation could be a diffuse source of warm energy, the capturing and handling of the sun-based processing of the heat addition is required to collector area and then the energy is stored in TES storage. This sort of renewable energy power plant would be especially engaging where solar-based thermal plants are to be created developed and integrated with geothermal assets at low temperatures are to be found nearby. (Bokelman et al, 2020).

2. PAST AND PRESENT STUDIES ON TES

There are various studies that have been found in the publications regarding TES. The methods of storing thermal energy into thermal heat storage system are mainly classified into two categories which are thermal and chemical. The categories have been depicted in the figure 1.

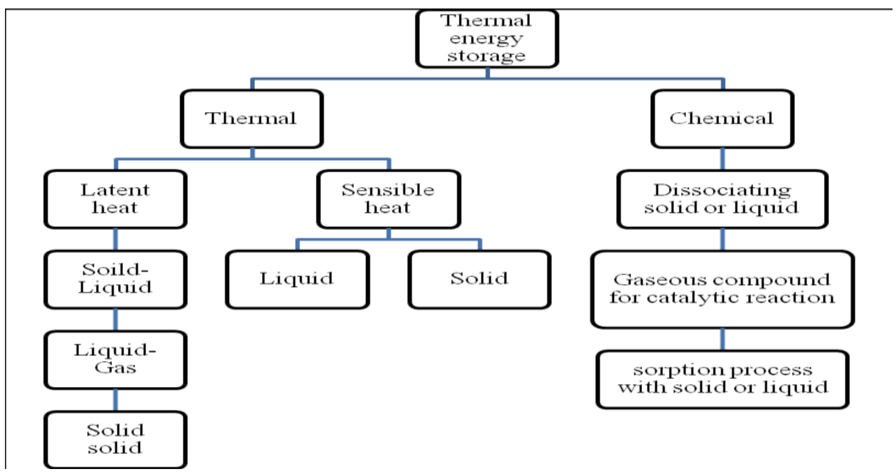

Fig. 1 Classification of TES types

2.1 Sensible storage system

The Sensible Heat Storage (SHS) system is utilized to collect thermal energy resulting from a temperature rise in the solid or liquid phase of the material. Sensible heat TES substances collect heat energy in the specific heat capacity i(Cp). It is possible to express the thermal energy deposited by sensible heat as $Q = im \cdot Cp \cdot \Delta T$. Such a framework utilizes the heat potential and temperature alter of the substance that occurs while the charging and discharging method. The temperature alters, the specific heat of medium and the amount of storage material has a significant effect on the amount of heat stored (Bauer et al, 2012).

2.2 Latent heat storage system

The latent heat storage network is linked to a state conversion of the materials (phase-change materials-PCM), usually reforms physical state from solid to liquid when ever heat is added or contrariwise. The variation in state is constantly united with heat capture or delivers and happens at a uniform temperature. Thus the heat that has been added or discharged unable to sense and looks latent. The collected energy is similar to melting and solidifying with heat. (Avghad et al, 2018).

2.3 Thermo chemical heat storage

The storage of the thermo-chemical heat is based on reversible chemical reactions. The energy is stored in the form of chemical compounds generated from an endothermic reaction and is recovered in an exothermic reaction by recombining the compounds again. The stored and released heat is equivalent to reaction heat (enthalpy) (Argyrou et al, 2018).

2.4 Characteristics of the TES Systems

TES could be an innovation that permits the interim storage of thermal energy at low, medium, or very high temperatures by cooling or heating a stockpile medium (at warm storage/container) at a specified time. The collected energy is afterward utilized, for hours, the whole day, or moth also, in elevation of temperature or cooling purposes or electricity generation. (Demirel, 2012). The heat of the storage medium might be kept up at a temperature high (hotter) or low (icy) than at atmospheric temperature. The benefits of TES are the emission of negligible carbon content and energy request, low toxin emanations, great adaptability in operation predominant storage capacity and power from any thermal or electrical source whenever it is required (Dekka, 2015). The difficulties with TES are the comparatively less productivity of the TES framework and heat backup losses (Boicea, 2014).TES systems difficulties vary significantly at many levels but thermal energy levels, and in terms of heat carrier, or also known as heat transfer fluid (HTF). HTFs are different of a single-phase type (e.g. H2O, air, oil) or a two phase-type with a liquefaction and evaporation process in the system (e.g. H2O/steam). One medium may be the storage material and the heat carrier. In a more simplistic direct storage idea, an extra volume of the hot working liquid is used to store energy. This idea is cost-effective as long as the medium holds a low partial pressure to bypass expensive pressure vessels and the mechanism itself is inexpensive (e.g. H2O) (H Albedin et al, 2012).

2.5 Properties require for TES system material

- Higher density increases energy storage density, which decreases the area required for the TES system.
- Phase change elements (PCM) should produce a very high latent melting temperature. High latent fusion heat advances the system's energy storage density.
- High specific heat increases device capacity for energy storage. State/phase change materials (PCM) have a liquefying point near the necessary operating temperature range of the TES system.
- Super-cooling during the freezing cycle should be minimal for phase shift products. Storage material must be freeze as close towards its freezing point as possible.
- High thermal conductivity enhances the heat charge - discharge rate.
- Low vapor pressure helps to reduce the need of pressure to withstand high temperature containment. It also lowers the cost of insulation.
- Materials should not be disintegrated at elevated temperatures. This results in a more spacious managing temperature range and a more powerful energy storage capability for the substance. Properties of material must be enduring after elongated heat and cooling cycles.
- Strong chemical resistance of storage materials increases the life of the energy storage facility.
- In the case of phase change materials, the volume change during the state change method should minimum. Huge changes in volume raise the size of the vessel required. A large density variation between two phases also causes the problem of phase separation (Ava et al, 2018).
- Abundant and readily usable materials reduce the expense of the process.
- Matters should not have an adverse effect on the fitness of operators and the atmosphere.
- Eroding TES elements significantly reduce the life of the energy storage plant due to the corrosion of vessels.
- Elements are to be non-flammable and non-explosive. More affordable storage material price reduces capital and process costs (Kousksou et al, 2014).

3. TECHNIQUES OF TES FOR HYBRID SYSTEM

There are various techniques for energy storage using TES systems. Figure 2 discusses about the various techniques utilized for the same.

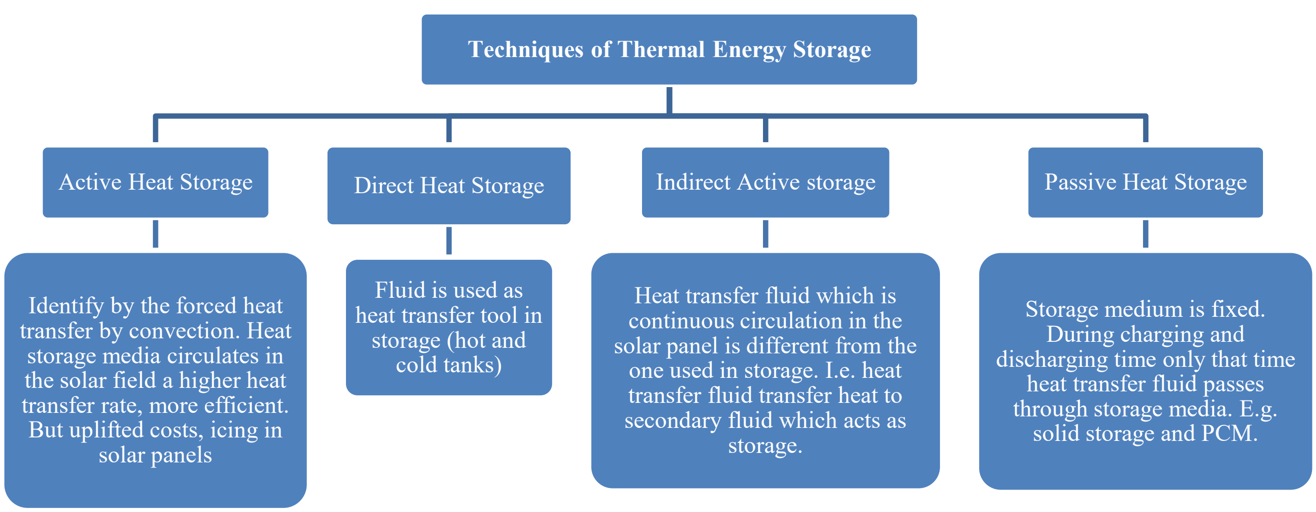

Fig 2: Classification of TES types.

3.1 Materials used in TES system

The classification of different materials used in TES has been found in literature. Many materials has been studied for efficiency and cost effectiveness. Table 1 lists the most effective materials in TES systems. (Kibria et al, 2015), (Michaelides, 2016)

- Water –H_2O
- Oil
- Molten Salts
- Liquid metals organics
- Solid materials
- Salt composites
- Paraffin wax
- Fatty Acids
- Glycols
- Ester
- Metal oxide(Al2O3,CuO,NiO,ZnO, and TiO2)
- Inorganic salt hydrates
- Nano composites
- Metallic
- Eutectic
- Alcohols
- Silver nanowires.

Table 1: Pros and cons of the various TES material.

3.2 Pros and Cons of the TES Materials or Media

It is imperative to understand and compare different TES materials before finalizing the material for a system. Table 2 discusses about the advantages and disadvantages of various materials that are being utilized in the industry for TES systems.

Fluid Group	Pros	Cons
Mineral oil	• Low Viscosity • Low vapor pressure No need of pressure vessel • Low Operating cost • Good Volumetric heat capacities • Low initial cost	• Less temperature range than molten salts or synthetic fluids • Rates of rusting and decay is higher than synthetic fluids • More cost of operations and maintenance
Synthetic fluids	• Higher ranges of operating temperatures • Rates of decomposition or oxidation is lower than mineral oils • The volumetrically heat capacities are as good as mineral oils • O&M cost is less	• More expensive upfront • Procurements price is more than mineral oils • Higher vapor pressures, so it require high-cost and more safe pressure vessels storage, particularly at high temperatures
Silicon oils	• Thermal stability are satisfactory	• In fluid group it is most expensive • Steam pressures and fluidity are high • Overall heat capacities are low
Molten salts	• Pressurization is not needed • Heat capacities are high volumetrically • Widely used in CSP and thermal storage • Competitive cost	• Solidifying point is high so may require additional component for maintain it into liquid • More viscosity increase in pumping costs
Water	• Thermal conductivity and heat capacity are high • Less viscous	• Steam pressures is increasing above 100°C leads to higher costs of storage and pressure-related special

	• Negligible cost • Environmentally friendly and non toxics • Abundant in nature	strategies should required and a limited operating temperature range • Due to Corrosion of Material design is constraints
Glycols	• High thermal conductivities and volumetric heat capacities • Less viscous • This fluid group has lowest cost	• High vapor pressures and limitation in temperature ranges • Thermal oxidation bring down pH and has corrosive products • Frequent maintenance required and has higher rates than other fluids

Table 2: Pros and cons of the various TES materials

3.3 The Irregular Nature of Energy Generation from Renewable.

Renewable energies, such as wind power energy, tidal energy, and solar power are environmentally irregular but provide uncontaminated and spotless electricity generation. The process of RES with storage was analyzed very intensively main because of the climatic changes. VRES are the subject of particular attention. A fluctuating nature of energy is a non-dispatch able RES (such that, it cannot be commanded to meet the varying requirement for power). Because of varying existence, a VRES does not function as a controlled RES such as bio energy, hydro energy or at some extinct, as a source of geothermal power. VRES production networks such as solar power (solar photovoltaic (PV), solar thermal, concentrated solar heat and wind energy (coastal and marine) have not constant output power generation due to their irregular nature. The energy production of these VRES is unknown and totally depends on climate conditions matched to conventional power stations capable of delivering their output in terms of market conditions and energy balances. In the case of photovoltaic (PV) and CSP systems, VRES-based energy production is unsteady, confide in not only on the shadow of cloud covering but also short term shadow of objects. Moreover, the defects of the modules may essential to eliminate and to the storage system to operate external its normal operating range to counterbalance for the loss of energy generation. In worldwide, hybrid energy practices provide better energy security as they can use a variety of different energy origins in a hybridized manner. Hybrid systems are preferred, in particular, for renewable energy sources to defeat the challenges of their fluctuating and intermittent nature. In addition, hybrid renewable energy systems are preferred for peak performance demand, particularly if there are also conventional energy systems that deliver electricity to the grid. Low enthalpy system with integrated Geothermal and Solar Hybrid combination system can efficiently. Increase daily the contribution of the Renewable Energy, Source as the low enthalpy system cannot generate or operate below the minimum temperature range of the turbine so that the integrated systems are currently in exclusive R&D phases of different types (Dipippo, 2015). Fig.2 shows the integration of the variable energy source (solar) is utilize with geothermal well and TES to get continuous and uninterrupted flow of electricity and space heating and cooling.

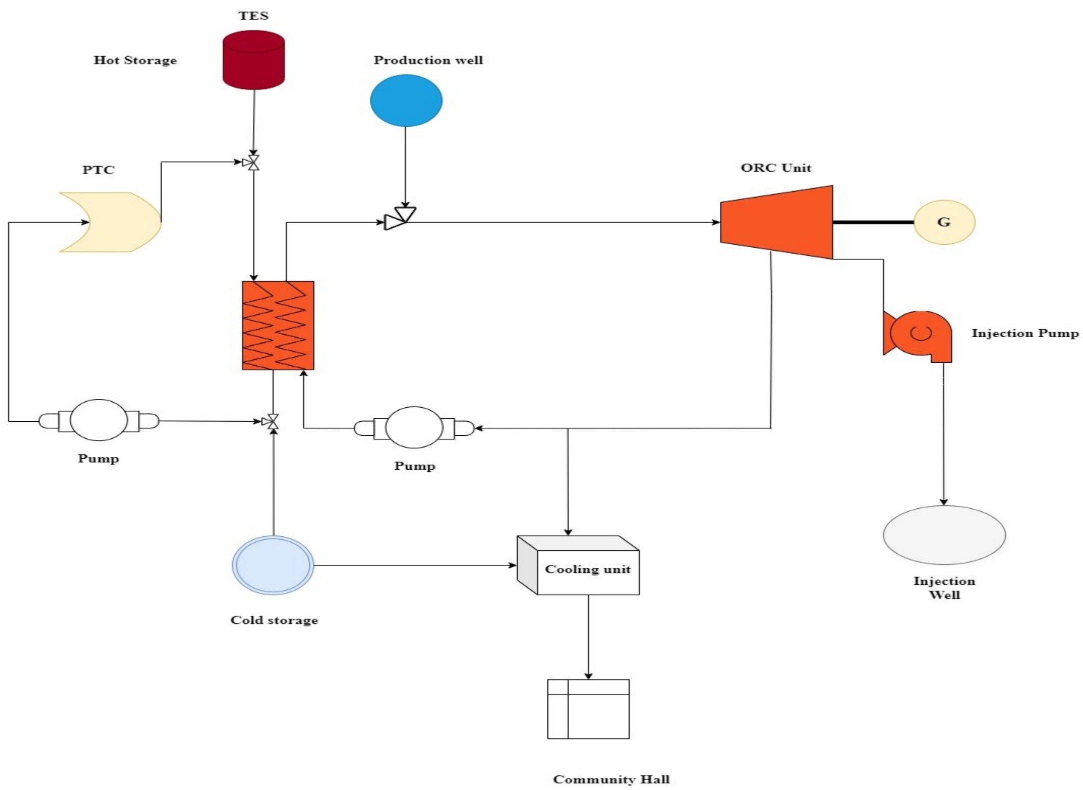

Fig 2: Schematic representation of the hybrid solar/geothermal plant with TES.

5. CONCLUSION

As TES system can store heat for long time and that heat can be beneficial for power and energy demands. The use of TES unit is to coordinate with variable energy sources like solar/geothermal control plants to supply ceaseless control indeed at midnight or within the circumstance when the cloud cover is happening within the sky and the fluctuation of demand at peak moments. At first, the significance and need for the integration of energy system are discussed. It is insisted that conventional approaches got to be changed into greener systems by taking into consideration a few angles such as natural effect, asset utilization, efficiency, and cost-effectiveness, which can offer assistance to achieve way better sustainability for the variable energy sources. Nowadays the solar-geothermal system integration is already in utilization for the low enthalpy power generation and space heating and cooling as there are solar limitations only the solar radiation is only available heating for day time but that thing is also solved at some extinct by the TES systems. As discussed in the paper of different types of TES and is application. Many power storage solutions exist, but they are so distinct in nature of specific requirements and characteristics that make it troublesome to choose a single technology for all energy storage applications. This paper gives the thought and idea for the determination of TES. In this way, whereas creating and actualizing sustainable structure integration, there are diverse approaches criteria such as safe-energy, environment friendly, dependable, fundamental, financially, commercially fruitful, and socially worthy should be meet. Thermal energy systems storage seem to achieve an economical future by handling challenges and issues that happen to generation, processing, and utilization of that energy in all the possible forms directly or indirectly.

REFERENCES

Alva, G., Lin, Y. and Fang, G.: An overview of thermal energy storage systems. Energy, 144, pp.341-378(2018).

Argyrou, M.C., Christodoulides, P. and Kalogirou, S.A.: Energy storage for electricity generation and related processes: Technologies appraisal and grid scale applications. Renewable and Sustainable Energy Reviews, 94, pp.804-821(2018).

Avghad, S.N., Keche, A.J. and Kousal, A.: Thermal energy storage: A review. J. Mech. Civ. Eng, 13, pp.72-77(2018).

Bai, Z., Liu, Q., Gong, L. and Lei, J.: Application of a mid-/low-temperature solar thermochemical technology in the distributed energy system with cooling, heating and power production. Applied Energy, 253, p.113491(2019).

Bauer, T., Steinmann, W.D., Laing, D. and Tamme, R.: Thermal energy storage materials and systems. Annual Review of Heat Transfer, 15(2012).

Boicea, V.A.: Energy storage technologies: The past and the present. Proceedings of the IEEE, 102(11), pp.1777-1794(2014).

Bokelman, B., Michaelides, E.E. and Michaelides, D.N.: A Geothermal-Solar Hybrid Power Plant with Thermal Energy Storage. Energies, 13(5), p.1018(2020).

Bruscoli, L., Fiaschi, D., Manfrida, G. and Tempesti, D.: Improving the environmental sustainability of flash geothermal power plants—a case study. Sustainability, 7(11), pp.15262-15283(2015).

Calise, F., d'Accadia, M.D., Macaluso, A., Vanoli, L. and Piacentino, A.: A novel solar-geothermal trigeneration system integrating water desalination: Design, dynamic simulation and economic assessment. Energy, 115, pp.1533-1547(2016).

Dekka, A., Ghaffari, R., Venkatesh, B. and Wu, B.: October. A survey on energy storage technologies in power systems. In 2015 IEEE Electrical Power and Energy Conference (EPEC) (pp. 105-111). IEEE(2018).

Demirel, Y.: Energy: production, conversion, storage, conservation, and coupling. Springer Science & Business Media(2018).

Diaz, P.M.: Analysis and comparison of different types of thermal energy storage systems: A review. Journal of Advances in Mechanical Engineering and Science, 2(1), pp.33-46(2016).

Dincer, I., and Rosen, M.A.: Exergy analysis of thermal energy storage systems. Exergy, 2nd ed., I. Dincer, and MA Rosen, eds., Elsevier, Oxford, UK, pp.133-166(2013).

DiPippo, R.: Geothermal Power Plants, Principles, Application, Case Study and Environment Impact(2015).

H Abedin, A. and A Rosen, M.: A critical review of thermochemical energy storage systems. The open renewable energy journal, 4(1)2011).

Kibria, M.A., Anisur, M.R., Mahfuz, M.H., Saidur, R. and Metselaar, I.H.S.C.: A review on thermophysical properties of nanoparticle dispersed phase change materials. Energy Conversion and Management, 95, pp.69-89(2015).

Kousksou, T., Bruel, P., Jamil, A., El Rhafiki, T. and Zeraouli, Y.: Energy storage: Applications and challenges. Solar Energy Materials and Solar Cells, 120, pp.59-80(2014).

Kutlu, C., Li, J., Su, Y., Pei, G. and Riffat, S.: Off-design performance modelling of a solar organic Rankine cycle integrated with pressurized hot water storage unit for community level application. Energy Conversion and Management, 166, pp.132-145(2018).

Manfrida, G., Secchi, R. and Stańczyk, K.: Modelling and simulation of phase change material latent heat storages applied to a solar-powered Organic Rankine Cycle. Applied Energy, 179, pp.378-388(2016).

Michaelides, E.E.S.: Future directions and cycles for electricity production from geothermal resources. Energy Conversion and Management, 107, pp.3-9(2016).

Sarbu, I. and Sebarchievici, C.: A comprehensive review of thermal energy storage. Sustainability, 10(1), p.191(2018).

Verma, A., and Pruess, K.: Enhancement of Steam Phase Relative Permeability Due to Phase Transformation Effects in Porous Media, Proceedings, 11th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (1986). <Reference Style>

Wang, C.T., and Horne, R.N.: Boiling Flow in a Horizontal Fracture, Geothermics, 29, (1999), 759-772. <Reference Style>

Yang, J.; Li, J.; Yang, Z.; Duan, Y. Thermodynamic analysis and optimization of a solar organic Rankine cycle operating with stable output. Energy Convers. Manag.: 187, 459–471(2019).