International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 11, Issue 12 [December. 2022] PP: 153-161

Storage of Thermal Energy in Molten Salts

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Abstract—

Thermal storage is widely viewed as the future of the renewable energy movement because it offers a "zero-emissions" technology with firm capacity and dispatchability characteristics, unlike many intermittent renewable resources like wind energy. Molten salt energy storage is an economical and flexible technology that can be integrated in various applications. It stores the heat of renewable energies directly, such as from concentrated solar power (CSP), or indirectly, such as through electric heaters or heat pumps. Due to the high operating temperature and good heat transfer capabilities of molten salt, storage systems based on it are extremely efficient. Using CSP technology, the cost of electricity is also optimized. The salt used is a combination of sodium and potassium nitrite, with a melting temperature of 460 degrees Fahrenheit

Keywords— molten salts, thermal energy, concentrated solar power

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Date of Submission: 10-12-2022 Date of Acceptance: 25-12-2022

I. INTRODUCTION

Thermal storage is widely regarded as the future for the renewable energy campaign because, unlike many intermittent renewable resources such as wind energy, it offers a “zero-emissions” technology with firm capacity and dispatchability characteristics.

Different technologies can be used to store thermal energy. It may be able to store and consume extra thermal energy, depending on the technology. Different technologies are used to accomplish thermal energy storage. Depending on the particular technology, it enables the storage and utilization of surplus thermal energy at various scales, such as individual processes, buildings with numerous users, neighbourhoods, cities, or regions, hours, days, or months afterwards. It is also possible to store solar energy at high temperatures using the heat from molten salt. This is known as molten salt energy storage or molten salt technology. To conserve thermal energy, molten salt can be employed as a thermal energy storage medium. It is a technology that is now employed in the commercial storage of heat obtained from concentrated solar energy (e.g. from a solar tower or solar pan). The heat may then be transformed into superheated steam, which can subsequently be used to drive standard steam turbines and produce electricity. [1]

Utilizing the incredibly effective heat-transfer capabilities of molten salt, this technique ensures that power can be delivered when it's needed while also protecting energy production from changing weather conditions. not utilizing natural gas. The technology is concentrated solar power (CSP) technology, built around a proprietary central receiving tower and a ring of molten salt. [2]

Concentrated solar systems (CSPs) generate solar energy by using mirrors or lenses to focus a large area of sunlight onto a collector. Electricity is generated when concentrated light is converted to heat (solar heat), running a heat engine (usually a steam turbine) connected to a generator, or supplying energy for endothermic chemical reactions. [3]

Evora Molten Salt Platform (EMSP), 2022

(Credit: HeliosCSP)

Using CSP technology, the cost of electricity is also optimized. The salt used is a combination of sodium and potassium nitrite, with a melting temperature of 460°F. The molten salt has the viscosity and the appearance similar to water in liquid state. [4]

II. LITERATURE REVIEW

A. Molten Salt Storage (John Dodaro, Stanford, 2015)

Molten salt can function as a large-scale thermal storage method that would allow other energy sources, such as nuclear and solar, to become more feasible by smoothing out the fluctuations in demand and weather. The lack of widespread use comes down to costs; hydro pumping is less expensive where applicable, and renewable sources don't account for enough of the energy consumption pie to implement thermal storage. Molten salt nuclear reactors may continue to grow, but more developments are needed before large-scale thermal storage for nuclear power becomes competitive. Looking to the future after depleting carbon-based fuel, the successful demonstration of molten salt storage for solar power will provide a price floor for tapping into the desert to meet our power demands.

B. Molten salt storage 33 times cheaper than lithium-ion batteries (Riccardo Battisti, Ambiente Italia)

Cost-effective energy storage is key to transitioning to a low-carbon society. Energy can be stored in the form of heat or electricity. A popular storage method for high-temperature thermal applications is a molten salt tank. Fact sheets created by the German Energy Storage Association, or BVES for short, show that molten salt tanks are around 33 times less expensive than electric batteries when it comes to storing a kilowatt-hour in them.

C. Molten Salts: Thermal Energy Storage and Heat Transfer Media (Ramana G. Reddy, University of Alabama)

In summary, research efforts are improving in identifying novel molten salts for solar energy applications. However, the commercialization of these mixtures as thermal storage media will take some time. Efforts are also necessary towards the fundamental understanding of the phase equilibria and transport properties of novel eutectic molten salt mixtures. The challenge for developing suitable materials such as novel molten salts for tapping renewable energy sources such as solar energy has to be directed in generating thermodynamic and transport properties data of these systems. This will enhance our understanding of the properties of molten salts for their use in other technologies.

D. Thermal Energy Storage In Molten Salts (Nils Breidenbach, Energy Procedia 99, 2016)

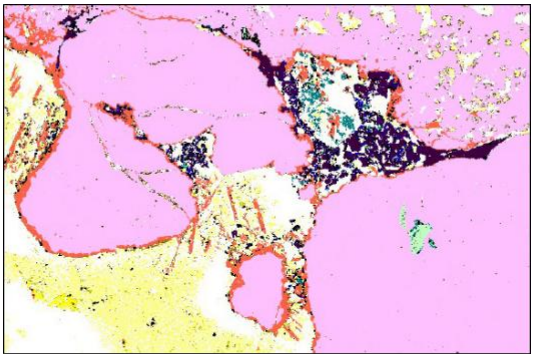
The current development on molten salt storage systems focuses on cost reduction. Within this context three developments of the recent years, are presented in this paper. Due to the need for further operational experience and several open questions on temperatures above 400 °C, DLR focuses its research on the thermocline filler storage (TFS) approach. In order to answer some of the listed questions, DLR is currently setting up a test facility for molten salt storage and component tests. Construction works are in progress and start of operation is scheduled for spring 2017. Additionally, research has been done on a better understanding of the compatibility of potential filler materials for TFS. During 500 h and 1000 h tests quartzite and basalt remained stable but also showed some mineralogical changes. Samples of 5000 h and 10,000 h tests are currently under investigation to retrieve a better understanding of those changes and their consequences. It can be concluded that, according to literature [3,9], TFS offers significant cost reduction potential but still requires further research in the area of material, storage components and system integration for full commercial applicability.

III. MATERIALS & METHODOLOGY

A. Materials

Among the entire class of materials studied for their various properties, molten salts form a very specific group that has great potential as a means of thermal energy storage and heat transfer for energy applications. solar quantity. Molten salt has been proposed as a heat transfer fluid for high temperatures between 250 and 1000°C. Low-melting-point (LMP) molten salts are a group of salts that are liquid over a wide temperature range. Other important properties of LMP salts include:Good thermal and electrical conductivity, high thermal and chemical stability, low viscosity and environmental friendliness.

The liquid range for an individual molten salt can be between 150 and 600°C. Thanks to the combination of different LMP salts and composition optimization, the temperature range of the liquid will increase. significantly. Due to these properties, LMP molten salt can be an excellent heat storage medium and heat transfer fluid in a solar power plant system. Current molten salt heat transfer fluids and heat storage media are mixtures of 60% $NaNO_3$ and 40% KNO_3.



Quantitive analysis of minerals in quartzite after 1000 h exposure to $NaNO_3$-KNO_3 at 560 °C (Credit: Energy Procedia 99)

The liquid temperature range is 220 to 600°C. The main disadvantage of this salt mixture is its high melting point. Salt can freeze and block pipes on winter evenings. To overcome this problem, ancillary equipment must be installed, which can increase investment and operating costs.[5]

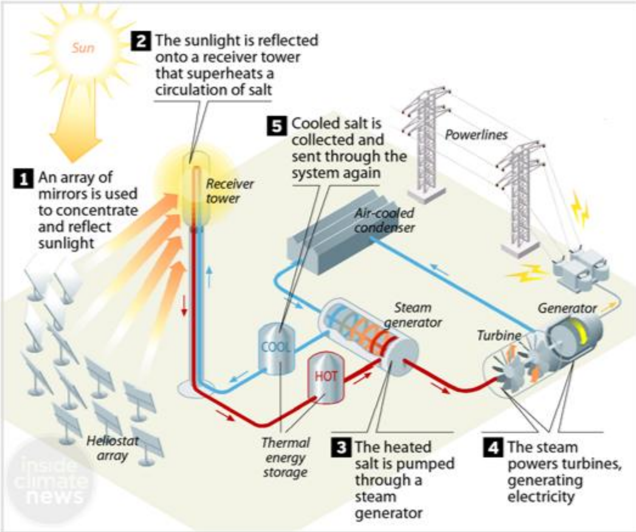
To successfully market a single stock with filling materials, it is imperative to demonstrate the durability of the filling material. Due to its ability to reduce costs, natural stone is considered a promising filling material. In the process of finding the right natural stone, selection based on material properties can be the first step. The aggregate density, specific heat, thermal conductivity, and strength of the material are relevant in this context. Additionally, material availability can be a limiting factor for a commercial storage concept.[6]

For high temperature applications, such as CSP, molten salts are the most widely used material. This is due to their high volumetric heat capacity, a high boiling point, high temperature stability, and their vapour pressure being close to zero. [7]

B. Concentrated Solar Power (Methodology)

CSP technology uses mirrors to reflect sunlight and focus it onto a receiver. The focused sunlight energy heats the hot liquid in the receiver. Centralized solar thermal energy systems are often used for utility-scale projects. These utility-scale CSP plants can be configured in a number of ways.[8]

(Credit: Paul Horn, Inside Climate News)



CSP plants with storage facilities first use solar energy to heat molten salts or synthetic oils and store them in insulated tanks to provide high temperature heat/thermal energy[9][10].

The hot molten salt (or oil) is then used in a steam generator to generate steam and, if required, a steam turbine generator to generate electricity [11].

Thermal storage technology utilises sunlight by focusing energy onto a tower-mounted central heat exchanger or receiver by generating power. This is referred to as a ‘Power Tower’ design.

This solar tower consists of a set of two-axis tracking reflectors (heliostats) that focus sunlight onto a central receiver at the top of the tower; the collector contains the heat transfer fluid, which may include steam or molten salt. Optically, the solar tower is identical to the circular Fresnel reflector. The working fluid in the container is heated to 500–1000 °C (773–1,273 K or 932–1,832 °F) and then used as a heat source for a power generation or energy storage system.[12]

IV. CASE STUDY

The SOLAR Project consists of the **Solar One**, **Solar Two** and **Solar Tres** solar thermal power plants based in the Mojave Desert, United States and Andalucía, Spain. The US Department of Energy (DOE) and a consortium of US utilities built the country's first two large-scale, demonstration solar power towers in the desert near Barstow, California. Solar One/Solar Two have been scrapped since 2009.[2] Solar Tres (later renamed Gemasolar), the first commercial plant of the project, was opened in Spain in 2011. [13]

A. Solar One

East of Barstow, California, in the Mojave Desert, a trial solar-thermal facility named Solar One was built. It was a large-scale thermal solar power tower plant's initial test. The Department of Energy (DOE), Southern California Edison, the Los Angeles Department of Water and Power, and the California Energy Commission collaborated on the design of Solar One under the direction of Sandia National Laboratories in Livermore, California. It was situated in Daggett, California, some 16 kilometers (10 miles) east of Barstow.

MCE Solar One Project, Richmond, California, 2020 (Credit: Michael Layefsky)

Solar One's method of collecting energy was based on concentrating the sun's energy onto a common focal point to produce heat to run a steam turbine generator. It had hundreds of large mirror assemblies, or heliostats, that track the sun, reflecting the solar energy onto a 328 ft (100 m) tall tower[3] where a black receiver absorbed the heat. [14] High-temperature heat transfer fluid was used to carry the energy to a boiler on the ground where the steam was used to spin a series of turbines, much like a traditional power plant.

The project used 1,818 heliostats with a total area of 72,650 m2 (782,000 ft2) and a reflective surface area of 40 m2 (430 ft2) to generate 7 MW of power.

B. Solar Two

By building a second ring of 108 bigger 95 m2 (1,000 ft2) heliostats around the already-existing Solar One in 1995, a total of 1926 heliostats with a total area of 82,750 m2

(891,000 ft2) were created. This gave Solar Two the ability to produce 10 megawatts—enough to power an estimated 7,500 homes. Solar Two used molten salt, a combination of 60% sodium nitrate and 40% potassium nitrate, as an energy storage medium instead of oil or water as with Solar One. This helped in energy storage during brief interruptions in sunlight due to clouds.[15]

The molten salt also made it possible to store the energy for later use, like at night, since Solar Two had enough reserve power to keep operating for up to three hours after the sun had set. Solar Two was shut down in 1999.

Due to the success of Solar Two, a commercial power plant, originally called Solar Tres Power Tower, now known as Gemasolar Thermosolar Plant built in Spain by Torresol Energy using Solar One and Solar Two's technology for commercial electrical production of 15 MW.[16]

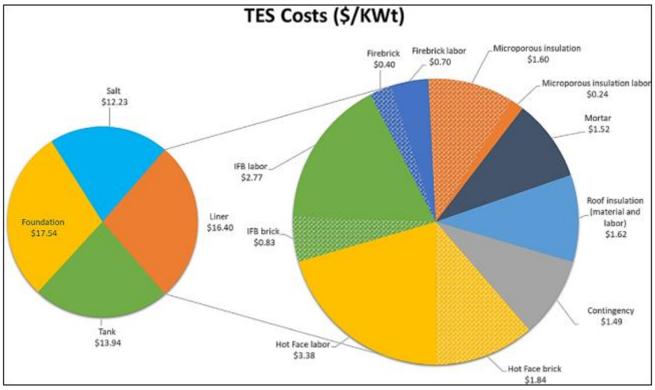
C. Solar Tres

With 2,493 heliostats, each with a 96 m2 reflective surface, Solar Tres is three times bigger than Solar Two. There will be 240,000 m2 (2.6 million ft2) of total reflecting area. To reduce expenses by around 45%, they will be fashioned of a highly reflective glass with a metal back. It will be possible for the plant to store 600 MWh in a larger molten salt storage tank, enabling it to run continuously throughout the summer.

V. ECONOMICS OF APPLICATION

A. Installation Cost

As per the guidelines given by the DOE Gen3 program, TES capacity requires two tank pairs (two hot tanks, two cold tanks) to reduce tank size, provide operational redundancy, and reduce risk of plant shutdown due to a single tank failure. In case of a service or repair , for the plant to operate at atleast ≈50% storage capacity such a design is required. The anticipated tank diameter of a single-pair tank design is larger than that of modern CSP plants, which raises the tank's risk.The estimated hot and cold tank heights and diameters in the two-pair tank scenario are 11 m and 41.8 m and 40.2 m, respectively.



(Credit: S.H. Gage, Science Direct)

This scenario includes a 110 MW power rating, a total of 12 h of storage, and an overall thermal-to-electric plant efficiency of 50% (net). CSP construction consultants have stated that the risk of tank failure significantly increases if the tank diameter is greater than 40 m, so opting for a two-tank scenario would far exceed the 40 m target. Reducing storage hours to 10 would keep the tank diameters below 40 m with minimal impact on levelized cost of energy (LCOE). [17]

While those vegetation function evidence of idea for large-scale molten salt technology, the rarity of industrial sun thermal garage comes right all the way down to value. The envisioned value for a hypothetical two hundred MW molten salt energy tower is $30/kWh and $two hundred/ kWh for an artificial oil parabolic trough plant. [18]

The capital value of a 688 MWh two-tank molten salt garage machine become in addition envisioned to be $31/ kWh. Improvements the usage of a thermocline machine with quartzite rock filler have been envisioned to convey the value right all the way down to $20/kWh. [19]

We can get a completely hard estimate at the charge according to kWh of the AndaSol plant with the aid of using thinking about the potential component: the common energy produced over a 24 hour cycle divided with the aid of using the entire potential output. The potential component development with garage can offer an oblique degree of the fractional value of the garage machine. For sun, the potential component is constrained to 20 - 25% with out garage and as much as 50% (troughs) and 77% (energy tower) with garage. [20]

Assuming a component of 3 development within-side the potential component and a value of $345 million (315 million Euros) for AndaSol, our crude estimate is:

$$\text{Storage Cost} = \frac{\$345{,}000{,}000 \quad 1\ \text{MWh}}{3 \times 1{,}010\ \text{MWh} \quad 1{,}000\ \text{kWh}} = \$114/\text{kWh}$$

This indirect determination overestimates the cost since it doesn't take into account the ability of thermal storage to sell electricity during peak demand hours.[21]

B. Cost Reduction Strategies

To reduce material costs, alternative refractory suppliers have been identified who can provide generic materials with the same properties but at a lower cost. Initial estimates indicate that this could save up to 7% in material costs, with an additional risk associated with material quality. However, even with conventional refractory materials, raw material costs still exceed the target of 3 USD/kWhth.[22]

VI. CONCLUSION

Although, there are many methods for storage of thermal energy , molten salt appears to be one of the best due to its renewable and zero emission properties.Using their property of great heat conductivity, molten salts are used as a heat-transfer medium for generating electricity using Concentrated solar power (CSP) technology .

The CSP technology basically uses multiple mirrors to concentrate onto a receiver tower which superheats the circulation of salts which are pumped through the steam generator. This steam generator drives the turbine generating electricity while the left salt goes through an air condenser which cools it down for further use.

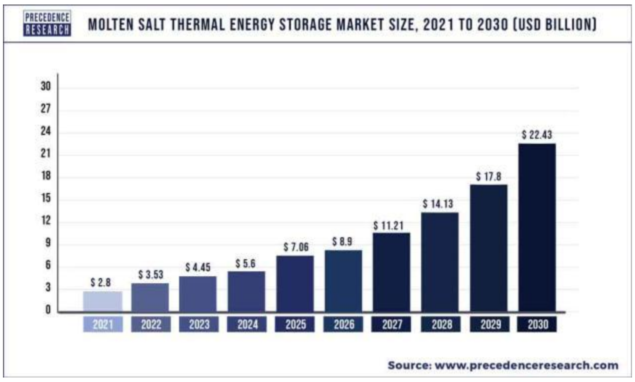
Through the various project developments such as Solar One, Two and Tres , the CSP technology has reached the level of mass use. This, along with the cost reduction in storage of molten salts, has the potential to reduce electricity costs by a significant amount and on a large scale.

Recent research efforts which are improving in identifying novel molten salts for solar energy applications, are also providing, the governments of various developed countries like Spain, with great incentives to invest in this technology.

Thus, Thermal Energy storage in molten salts in conjunction with Concentrated Solar Power (CSP) technology has the potential to become the next big thing.

VII. FUTURE PROSPECTS

The global molten salt **thermal energy storage market** size is expected to exceed $22.43 billion by 2030, from $3.53 billion in 2022, growing at a CAGR of 9.95% in the forecast period from 2022 to 2030.



(Credit : Precedence Research)

Companies in the worldwide molten salt thermal energy storage market are analyzing micro- and macroeconomic factors to maintain company continuity in the face of the current coronavirus outbreak. Molten salts have a significant part in the optimization of energy in industrial operations.

Some of these growth factors include:

- Molten salt has the potential to create reliable power generation or energy storage solutions, allowing customers to reduce energy costs and carbon emissions, while improving the safety of energy supplies.

- The trend of decarbonizing electricity generation and long-term renewable energy storage is driving the growth of the molten salt thermal energy storage market.

- Public funding and high-priority research and development projects, especially thermal energy storage from molten salt, underpin the need for variable renewable energy. The molten salts assist in storing thermal energy for use during periods of little or no sunlight.

Report Coverage	Details
Market Size in 2022	USD 3.53 Billion
Market Size by 2030	USD 22.43 Billion
Growth Rate from 2022 to 2030	CAGR of 9.95%
Base Year	2021
Forecast Period	2022 to 2030

By Technology	•Parabolic Troughs •Fresnel Reflector •Power Tower
Regions Covered	•North America •Europe •Asia-Pacific •Latin America •Middle East & Africa

Some recent developments include :

• A molten salt storage system will be built by MAN Energy Solutions in 2020 at the Jülich solar research site of the German Aerospace Centre. The salt is heated by the system to 565°C.

• Seaborg Technologies said in December 2021 that it had developed a more efficient method for storing molten salt based on sodium hydroxide. This compound uses less salt because it can store more heat per unit of salt and thus store energy more efficiently. In addition, it costs about 90% less than other salts used in the company.[23]

Research shows that concentrated solar could account for up to 25% of global energy demand by 2050. Investment growth will increase from 2 billion euros globally to 92.5 billion euros during this period. [24]

CSPs have other uses besides electricity. Researchers are working on solar thermal reactors to produce solar fuel, making solar energy a fully transportable form of energy of the future. These researchers use solar heat from CSP as a thermochemical catalyst to break down H2O molecules, to generate hydrogen (H2) from solar energy without emitting carbon.[25]

By separating both H2O and CO2, other widely used hydrocarbons – for example, jet fuel used to run commercial aircraft – can also be generated using solar energy instead of fossil fuels. [26]

Spain leads in concentrated solar technology with more than 50 government-approved projects underway. In addition, it exports its technology, further raising the share of energy technology around the world. Because the technology works best in areas with high sun exposure (solar radiation), experts predict the greatest growth in places like Africa, Mexico and the southwestern United States. It turns out that nitrate-based heat storage systems (calcium, potassium, sodium, etc.) will make CSP plants increasingly profitable.

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