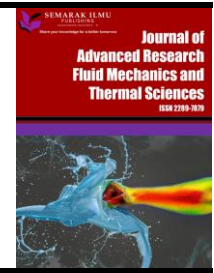




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Ternary Molten Salt as a Phase Change Material: A Review

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ABSTRACT

Phase change materials have gained much attention due to their excellent properties. This research paper delves into the utilization of ternary molten salt as a thermal storage medium for Thermal Energy Storage (TES) within the context of Concentrated Solar Power (CSP) systems. Meanwhile, different types and compositions of molten salts are discussed in detail in this paper. Molten salts are used extensively as heat transfer media and in the production of solar power because of their special qualities and affordable cost. Nitrates are less expensive, less corrosive, and do not break down below 500 °C when compared to other molten salts. For this reason, the primary heat storage component of solar power generation is mixed molten nitrate salts.

1. Introduction

With the increasing energy crisis and environmental pollution, solar thermal technology has attracted widespread attention. However, solar energy has the disadvantages of intermittency and instability, so phase change thermal storage technology is particularly important in solar energy utilization systems. Solar thermal power generation supporting thermal storage technology has also become the focus of research. Thermal storage technology can achieve large-scale heat storage, when needed, the energy will be released smoothly to meet the demand for power generation, to effectively improve the traditional solar energy rain and shine, day, and night intermittent power supply problems, and effectively solve the contradiction between the demand and supply peak. One of the key points in the heat storage technology is the selection of heat transfer and storage materials, traditional heat transfer and storage materials including water/water vapour, liquid metal, heat transfer oil, smoke, etc., they are in other energy fields, heating, cooling applications are used very often. Water / water vapour is cheap and easy to obtain, and can directly drive the turbine rotation power generation, greatly eliminating the intermediate energy consumption, but water as a

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heat transfer medium to adapt to the temperature is not high, at most not more than 300°C, and the need for the system pressure is greater, prone to safety accidents. Liquid metal is used at higher temperatures, heat transfer performance is good, at higher temperatures can also maintain good fluidity, vapour pressure is also lower, but in general, the liquid metal is expensive, and at high temperatures prone to react with other substances, corrosive, and stability is not enough. Heat conduction oil fluidity, the use of temperature range than water, in a period, had been put into use as a heat transfer and storage medium, but its limitations lie in the vapour pressure being too large (400 °C greater than 1MPa), high temperature is easy to decompose and fission, poor stability caused by the limited-service life. Relative to these (especially in terms of safety and production) shortcomings of the more obvious heat storage medium, phase change material molten salt has a wide range of temperatures, low vapour pressure, good thermal stability, low viscosity, heat capacity, cheap and easy to obtain qualities, and therefore has become the majority of scientific research institutes or units of research in the solar photovoltaic power generation of heat transfer and storage of the first choice of the medium [1-8].

Solar thermal energy systems encompass a diverse technical domain dedicated to converting sunlight into thermal energy for the purpose of supplying heat, electricity, or a combination of both. Concentrated Solar Power (CSP) represents a specific subset within solar thermal energy. It is characterized by the concentration of solar radiation flux density to attain elevated temperatures and increased efficiency, primarily with the goal of enhancing the feasibility of electricity generation. Figure 1 provides a visual representation of the essential components and conversions integral to CSP, spanning from the energy source to meeting the demand.

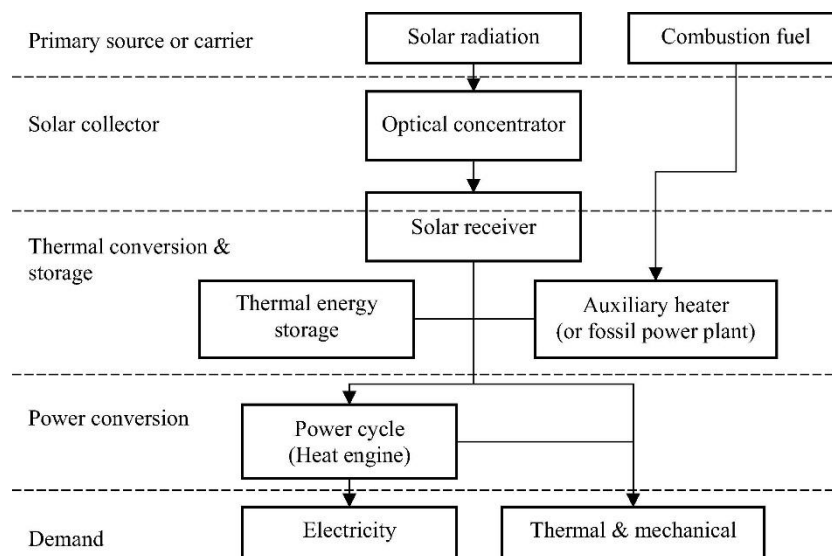


Fig. 1. The fundamental elements and conversions involved in CSP

Concentrated Solar Power (CSP) involves capturing direct solar radiation using mirrors or lenses to intensify sunlight, thereby collecting solar energy and heating a fluid. This versatile method finds applications in various thermal processes, including electricity generation, seawater desalination, district heating and cooling (DHC) systems, industrial process heating, hot water, absorption refrigeration systems, or any combination thereof, incorporating co/tri/multi-generation technology [9-12]. Moreover, seamless integration of solar thermal energy with other renewable sources like wind, tidal, biomass, and geothermal energy is feasible [13-15].

CSP stands out as a highly cost-effective and promising renewable technology capable of producing clean, reliable, safe, and efficient electricity [16,17]. Its significance is emphasized by its

substantial contribution to achieving the Sustainable Development Goals (SDGs), particularly SDG 7: affordable and clean energy, as outlined in the 2015 Paris Agreement. Figure 1 highlights additional key benefits of CSP, emphasizing its crucial role in addressing environmental challenges caused by human activities and meeting the escalating energy demand for a sustainable planet [17-20].

1.1 Principle

Global radiation is the amount of solar radiation that reaches Earth. It is made up of two parts: solar radiation, both diffuse and direct. The most crucial factor in the production of solar-concentrated electricity is direct solar irradiance, or DNI, which is the quantity of solar energy that reaches a plane perpendicular to the sun's beams. Therefore, the most suitable locations on Earth for CSP are those with high levels of DNI, typically regions between approximately 15° to 40° latitude in both the northern and southern hemispheres, as well as elevated areas. Consequently, regions with significant solar thermal power generation potential include parts of the Americas such as Chile, Peru, northern Mexico, and the southwestern United States; Western Australia; South and North Africa; certain Mediterranean regions; the Middle East; and areas in Asia like northwestern India and western China [21,22].

CSP operates on a simple principle: direct solar radiation is focused to produce high-temperature heat, usually between 500 and 1000°C, which is subsequently transformed into electricity [23]. While there are different arrangements, CSP systems fundamentally consist of the same elements [24,25]:

- i. Solar reflectors (or reflector systems) are used to collect and concentrate solar radiation.
- ii. solar receiver that absorbs and concentrates sun radiation.
- iii. System for converting concentrated solar thermal energy into mechanical energy through power conversion.
- iv. Generator that produces electricity from mechanical energy.

1.2 Classifications

There are now four recognized categories of concentrating solar power systems. As seen in Figure 2, they can be identified by the way that solar radiation is focused on the receiver.

Parabolic Trough Collector (PTC): Comprising parabolic mirrors, PTC concentrates solar radiation onto the focal line. The most mature technology among them is the parabolic trough collector, characterized by parabolic mirrors that focus sunlight onto a receiver along the focal line. **Linear Fresnel Reflector (LFR):** Using a linear array of flat mirrors that serve as Fresnel lenses, LFR adopts a similar technique as PTC in order to focus sunlight onto a linear receiver. **The Parabolic Dish Collector (PDC)** is a device that focuses solar heat into a dish-shaped focal point by reflecting it using a set of parabolic mirrors. **Central Receiver System (CRS) or Solar Power Tower (SPT):** These heliostats, when arranged in a field, reflect sunlight onto the central receiver situated at the summit of the tower. These heliostats track the sun on two axes, and they are considered point-focus collectors.

Solar power tower stations, whether in commercial operation or in the research phase, exhibit variations in type based on the characteristics of their individual components. As previously mentioned, solar power towers, also referred to as central receiver systems, comprise a field of heliostats, with a varying number of these heliostats reflecting solar radiation towards the central receiver. Concerning the symmetry of the heliostat field, two primary types of commercial stations emerge: surround field and polar field.

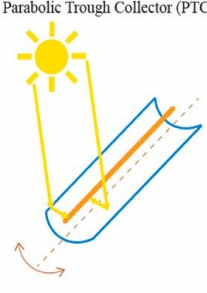
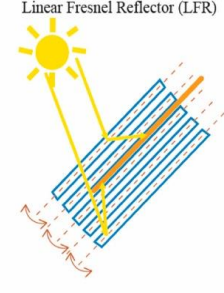
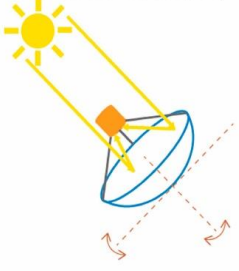
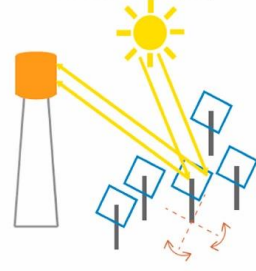
Collector type	Continuous reflector	Discrete reflector
Line focus	Parabolic Trough Collector (PTC) 	Linear Fresnel Reflector (LFR) 
Point focus	Parabolic Dish Collector (PDC) 	Solar Power Tower (SPT) 

Fig. 2. Categorization of the widely used CSP systems according to reflector geometry. Sun radiation is represented by yellow arrows, solar receivers are symbolized by orange structures, solar reflectors are represented by blue structures, and the rotation axis of the reflectors is shown by brown arrows with dashed lines [12,14,16]

In a surround field configuration, heliostats are strategically positioned around the central tower in a shape that approximates a circle, covering or nearly covering the entire 360° circumference. Conversely, a polar field is formed by heliostats arranged within a fan-shaped sector of a circle, resulting in a wedge-shaped field. In regions with low latitudes near the equator, a surrounding field is deemed optimal for minimizing land use and tower height. As latitude increases, a field concentrated on the polar side of the tower proves more effective in enhancing performance. Thus, depending on the hemisphere, a north/south polar field is the favored choice in high-latitude areas. Since the sun faces south all year round on a north field, all the heliostats are located on the north side of the tower [26-28].

At the apex of the tower, the concentrated solar radiation reaches the solar receiver. Presently, the receiver may either be external or possess a cavity aperture, contingent on its geometric shape. External receivers are well-suited for surrounding fields (especially if cylindrical in shape) or polar fields (particularly if composed of flat panels). Conversely, cavity receivers feature a small aperture through which concentrated solar radiation enters. Due to their geometric limitations, these receivers are typically employed in polar fields [26,27]. Consequently, the choice of heliostat field configuration is intertwined with the type of receiver, and vice versa [28].

1.3 Thermal Energy Storage (TES)

It is challenging to meet the need for sustainable energy sources for industrial operations due to the intermittent and inefficient nature of solar energy. Of the several methods available, thermal energy storage (TES) is regarded as one of the most promising and successful ways to solve this issue. A technique known as thermal energy storage (TES) uses heat or cold to store media, allowing the energy to be used for power generation, heating, and cooling in the future. Thermal applications include air conditioning, cooling, waste heat utilization, and space and water heating have recently

seen a rise in interest in TES. TES is superior to mechanical or chemical storage methods in a number of ways, including inexpensive startup costs and excellent operating efficiency. Applications for TES systems are numerous and include power generation, industrial operations, and space heating and cooling. The particular application, the necessary operating temperatures, the length of storage, and efficiency all play a role in the choice of TES system.

CSP systems, passive thermal management of batteries, thermal storage in buildings, solar hot water, cold storage, photovoltaic heat, storage-integrated thermo-poltaics, thermally conditioned textiles, and microelectronics are a few examples of recent TES applications and technologies [29-41]. Utilizing various characteristics, TES units can be categorized into different types, as illustrated in Figure 3. Thermal energy storage (TES) systems play a crucial role in storing heat or cold and are further classified into sensible heat storage, latent heat storage, and thermochemical storage. In the sensible heat storage system, heat is accumulated by elevating the material's temperature, while the latent heat storage system leverages the phase change material's melting or solidification process for thermal energy storage. Conversely, thermochemical storage systems store heat through the either breaking or forming of chemical bonds.

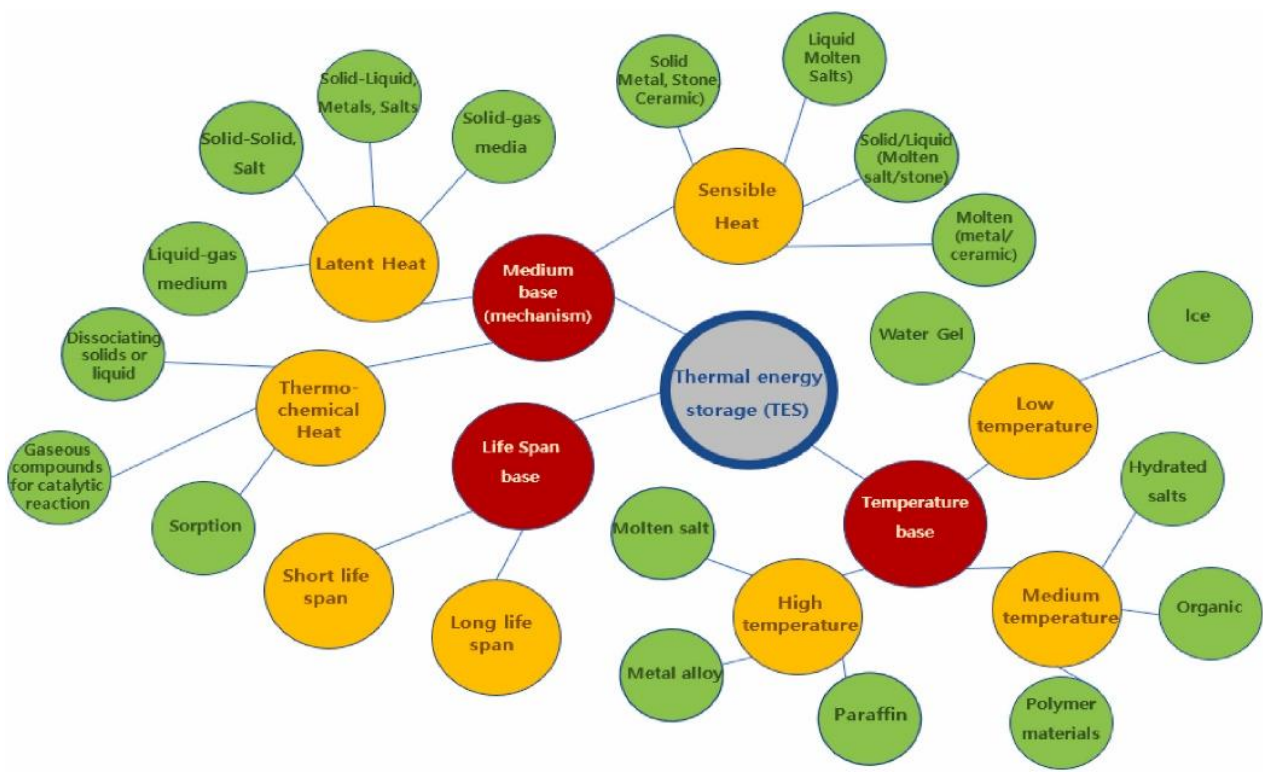


Fig. 3. Utilizing various characteristics

There exist three categories of TES models, with one of them being sensible heat storage (SHS). SHS employs substances such as water, molten salts, and rocks to store thermal energy. These setups are widely used in various applications, including space heating, cooling, industrial processes, and power generation. The efficiency of the system is affected by factors like the storage material, heat source, and heat sink temperature. Enhancements in performance can be attained by utilizing materials with high specific heat capacity and adhering to specific temperature conditions. While SHS systems offer advantages like simple design and economical operation, they demonstrate lower energy density when compared to latent heat storage and are more vulnerable to thermal shock [42].

1.4 Latent Heat Storage

SHS systems can be categorized into two types: liquid and solid. Liquid systems are more cost-effective than their solid counterparts. Current SHS technologies encompass high-temperature systems using molten salts, concrete units featuring embedded pipework, and rock-bed units utilizing boreholes for heat transfer. During off-peak hours, large water systems are employed to store excess heat [43-46]. Advanced control systems leverage predictive algorithms and machine learning to enhance SHS management [47]. Latent Heat Storage (LHS) is a technique used in power generation, heating, and cooling that stores energy by taking advantage of the phase transition of materials like salt and paraffin. Efficiency is governed by variables such as temperature and phase change materials, and its efficacy depends on the heat that these materials absorb and release throughout the phase transition process [48].

Although LHS has a high energy density and efficiency, there are comparatively substantial operational and maintenance costs involved. This includes thermochemical units, composite phase change material systems, and sophisticated encapsulation methods, all of which are designed to maximize heat release and storage efficiency while augmenting the equipment's longevity and scalability [48-50]. According to classical models of latent heat storage units, the following three components are essential [51]:

- i. The heat-storing and heat-releasing working substance (PCM).
- ii. A container holding the PCM.
- iii. A wall that isolates the heat transfer fluid from the PCM to facilitate heat exchange.

1.5 Thermochemical Storage Systems

By using chemical reactions to store and release heat, thermochemical storage transforms stored energy into either heat, cold, or electrical power [52]. This method applies to open units where gaseous fluids release entropy, like desiccant units; in closed systems, entropy is released via heat exchangers. Thermochemical storage may store heat indefinitely and performs better per unit mass or volume than sensible and latent heat storage devices. In order to effectively absorb and store extra thermal energy, recent research developments have included the creation of sophisticated reactive materials and redox reactions as well as integration with renewable energy sources [53-56].

1.6 Comparison Between Sensible, Latent and Thermochemical Storage

Sensible thermal storage systems offer advantages such as availability, non-flammability, non-toxicity, light pollution, and suitability for high-temperature TESs up to 1000°C with a relatively low capital cost [57,58]. However, drawbacks include low thermal storage capacity per unit of stored material. Thermochemical thermal storage systems provide very high energy density and storage capacity, but potentially chemically hazardous, complex and costly [59-61].

Phase transition materials are necessary for the storage of latent heat thermal energy (LHTES). LHTES applications face the same issues as phase change material applications. Potential liquid state leakage, low heat conductivity, high authenticity, and corrosion susceptibility are a few examples. Phase change storage has many advantages, and the size and compactness of storage devices are important design considerations. Sensible heat storage has low thermal capacity, requiring larger thermal storage units [62-64]. Latent heat storage systems offer high energy density, allowing for smaller volumes of the required material, resulting in a more compact system. The selection of

appropriate phase change material (PCM) is particularly crucial for specific applications, with the main selection criteria as follows:

- (a) The melting temperature of PCM should be below the operating temperature range, and preferably close to the operating temperature [65-70].
- (b) PCM materials should have higher melting latent heat, especially important for compact storage devices.
- (c) Higher density is preferable for storing a large amount of PCM within a given volume.
- (d) PCM materials with high latent heat exhibit high specific heat, and those with sensible heat effects are preferred.
- (e) High thermal conductivity is essential to maintain lower temperature gradients during the melting/solidification process.
- (f) The material should undergo minimal volume change during the phase change process. For significant volume changes, special container designs are required.
- (g) Little or no supercooling should occur during the solidification process, especially critical for salt hydrates.

The material should be chemically stable to avoid reactions with the container material, and it should not be corrosive. It should also be non-toxic and non-flammable, easily accessible, and inexpensive. Selecting PCM materials that meet all these criteria is challenging and requires consideration based on the specific working conditions. Salts and salt compounds are interesting materials for high-temperature latent heat storage. These materials have the advantage of high melting heat and high latent heat values at high temperatures, but a drawback is their relatively low thermal conductivity.

2. Type of Single Molten Salt and Characteristic

Molten salts are economical to use, having low vapour pressure and viscosity, great thermal stability, a wide range of service temperatures, and reasonably good thermal conductivity. Alkali metals (Li, Na, K) or alkaline earth metals (Mg, Ca) combined with fluorine, chlorine, carbonic acid, and nitric acid make up the more prevalent molten salts. These individual salts are often divided into the following main categories.

2.1 Carbonates

Carbonates are a promising material for heat storage during phase transitions because they are affordable, have a high specific heat and density, have a modest corrosive property, and have a high heat storage capacity during phase transitions. While Na_2CO_3 is a white powder with a melting point of 854°C , K_2CO_3 is a colorless crystal with a melting point of 891°C . These two carbonate varieties are low-cost and possess a little corrosive property along with a high specific heat and density. These are the most commonly used carbonate materials because they are both affordable and thermally stable. By combining carbonates in varying quantities, mixtures with varying melting points can be created. The usage of certain carbonates is restricted since they break down readily when heated. Carbonates have the following latent calorific values: $\text{MgCO}_3 > \text{Li}_2\text{CO}_3 > \text{K}_2\text{CO}_3 > \text{Na}_2\text{CO}_3$.

2.2 Fluorine Salt

Generally speaking, fluorine salts are the non-aqueous salts of certain metal fluorides. Although their thermal conductivity is not very great, their benefits include small viscosity, huge heat of fusion, good compatibility with metal materials, high-temperature heat storage materials, and some applications in the recovery of industrial high-temperature waste heat. $\text{LiF} > \text{MgF}_2 > \text{NaF} > \text{KF} > \text{CaF}_2$ is the fluorine salt's latent heat value size.

2.3 Nitrates

In general, nitrates are less costly and damaging to materials that transport salt. In general, they are difficult to break down at temperatures below 500°C. They can transport heat more effectively than fluoride salts, though. Its drawbacks also include the low service temperature and the comparatively tiny heat of fusion. The nitrate's latent heat value has the following magnitudes: $\text{LiNO}_3 > \text{NaNO}_3 > \text{Ca}(\text{NO}_3)_2 > \text{KNO}_3$.

2.4 Chlorine Salts

Chlorine salts are generally very inexpensive, come in a variety of forms, and can be made to meet specific needs such as using a wide range of temperatures and different melting points for mixed chlorine salts. However, their strong corrosive nature limits their application. Chlorine salt has the following latent calorific value: $\text{NaCl} > \text{MgCl}_2 > \text{LiCl} > \text{KCl} > \text{CaCl}_2$.

3. Type of Mixed Molten Salt and Characteristic

Single-component molten salts are expensive because they contain lithium, which has a high latent heat value (LHV) and a high melting point. Consequently, at low to medium temperatures, the thermophysical characteristics of single component salts do not satisfy the requirements of heat transfer mediums. Therefore, in order to create novel eutectic molten salt blends by scientific methods, different types of salts must be mixed and recombined. Other thermal properties of the new eutectic molten salt will be improved, but its melting point will be dropped dramatically. The maximum latent heat value of a variety of mixed molten salts, $\text{LiF}:\text{LiOH} = 20:80$ (mol%), with a melting point of 427°C and a latent heat value of 1,163 J/g, both of which contain lithium ions, was counted by Kenisarin [71] using fluorine salts and alkali mixing, which is higher than the latent heat value of their unit salts after mixing. 154.2J/g. The lowest eutectic point of the prepared lithium-containing five-member chloride fused salts was 356.5°C, and the latent heat of the phase transition was 150.9 J/g.

According to research by Lu *et al.*, [72], the latent heat of phase transition and melting point of ternary fluoride salt ($\text{LiF}:\text{MgF}_2:\text{KF}=64:30:6$, wt%) are 782 J/g and 710 °C, respectively, while those of binary fluoride salt ($\text{LiF}:\text{CaF}_2=80.5:19.5$, wt%) are 790 J/g and 767 °C. Ye *et al.*, [73] looked into the melting point and latent heat of phase transition of two binary fluoride salts: $\text{NaF}:\text{MgF}_2=75:25$, wt%, and $\text{LiF}:\text{MgF}_2=67:33$, wt%, which were found to be 746 °C and 947 J/g, as well as 832 °C and 650 J/g, etc. After a thorough investigation into a novel tetrameric mixed nitrate ($\text{KNO}_3\text{-NaNO}_3\text{-LiNO}_3\text{-Ca}(\text{NO}_3)_2$), Ren *et al.*, [74] of the Beijing Institute of Technology obtained a low-melting-point molten salt with a melting point of 96.8°C, a maximum operating temperature of 600°C, and a latent heat of phase transition of more than 100 J/g. It was discovered that the salt was a low-melting-point molten salt with a latent heat of phase transition of more than 100 J/g and a maximum operational

temperature of 600°C. $\text{LiNO}_3:\text{NaCl}=87:13$ (wt%) eutectic salt was prepared by Zou *et al.*, [75] using an indirect mixing method. Its thermal properties were measured using differential scanning calorimetry over a number of cycles.

The results indicated that the eutectic salt's melting temperature is approximately 220°C, and its latent heat of melting value is higher at 290 J/g. According to research by Chen and Zhao [76] from Shanghai Jiao tong University, the latent heat of melting for $\text{Ca}(\text{NO}_3)_2:\text{NaNO}_3:\text{KNO}_3=32:24:44$ (wt%) is just 67J/g, and the melting point is 80°C. It can be used as a phase-change material and heat-transfer fluid for solar energy power plants because it has the benefits of significant heat of fusion, low viscosity, low cost, and good thermal stability. The STA test demonstrates that the thermal cycling stability is good within the range of 50-250°C, and the XRD test indicates that the upper limit of the temperature is 600°C.

This is evident in the nitrate, carbonate, fluoride salt, chlorinated salt, and other mixed molten salts that contain lithium salt. These mixtures will have a higher latent heat value due to the lithium salt's high cost of use, which makes them unsuitable for large-scale commercialization; additionally, the fluoride salt has a very high melting point and is only useful for high-temperature heat transfer and heat storage. despite the low melting point, the remaining combined molten salt Not employed for latent heat storage, the leftover mixed molten salts have a low melting point and a low latent heat value. In general, mixed molten salt latent heat values exhibit the property that the more components blended, the lower the latent heat value.

After years of both theoretical and experimental studies conducted both domestically and internationally, two types of mixed nitrate salts have been identified as the ideal heat transfer and storage media for solar thermal collector power generation. It has been confirmed that the ternary mixed nitrate salt, abbreviated as HTS or Hitec molten salt with a melting point of 142°C and a mass ratio of 53% KNO_3 , 7% NaNO_3 , and 40% NaNO_2 , and the binary mixed nitrate molten salt, abbreviated as Solar Salt with a melting point of 220°C and a mass ratio of 40% KNO_3 and 60% NaNO_3 , have been commercially used. It is important to note that each type of mixed nitrate salt has its own advantages. Solar Salt has a higher thermal stability than HTS, but its melting point is higher, which requires more energy to maintain its molten state. However, HTS salt can be better used in low-temperature heat transfer and storage, but its thermal stability is not as good as Solar Salt.

4. Comparison of Single, Binary and Ternary molten salt

There are several hard parameters to measure the quality of a heat transfer and storage medium, namely, density, specific heat capacity, thermal conductivity, and viscosity. Density and specific heat capacity determine how much energy can be stored per unit volume of the material, which directly affects the efficiency and cost of the heat storage system; thermal conductivity relates to the supply efficiency when heat is stored and released; and viscosity affects the fluidity of the work mass flow in the pipeline. In order to improve the heat transfer and storage performance of molten salts, many researchers have studied many new types of molten salts for different working conditions, but the hotspot of the research on molten salt modification still lies in the strengthening of the thermal properties of existing molten salts.

At present, solar thermal power stations use sodium/potassium binary nitrate molten salt as a heat storage medium, in the existing Solar salt (binary molten salt) and Hitec (ternary molten salt) molten salt systems based on many scholars have begun to study the addition of other nitrates to prepare a high heat storage density, a wide range of temperature range of the heat transfer and storage materials. For example, Hitec XL molten salt (NaNO_3 (7 wt.%) - KNO_3 (45 wt.%) - $\text{Ca}(\text{NO}_3)_2$ (48

wt.%) has been commercially available, and its melting point has been reported to be as low as 120°C [77,78].

The addition of LiNO₃ to the Solar salt system can also reduce the melting point of the system to below 130 °C. Chen *et al.*, [79] added Ca(NO₃)₂ and LiNO₃ to Solar salt to obtain a tetrameric nitrate salt Ca(NO₃)₂-KNO₃-NaNO₃-LiNO₃ with a melting point as low as 85.4°C, and a service temperature of 600°C. Zhang *et al.*, [80] added other nitrates to Solar salt and compared the melting points and service temperatures of Li-Na-K ternary nitrate, Na-K-Cs ternary nitrate, Na-K-Ca ternary nitrate, Li-Na-K-Cs ternary nitrate, and confirmed that the addition of LiNO₃ or CsNO₃ decreased the melting point of Solar salt.

The maximum service temperature is lower than that of Solar salt, its service temperature range is wider than that of Solar salt. Xu *et al.*, [81] added different ratios of magnesium nitrate to sodium nitrate and found that, except for a few ratios that did not melt at the operating temperature, there was only a typical single peak in the DSC results for the Mg(NO₃)₂:NaNO₃ mass ratios of 4:6, 5:5, 6:4, 7:3, 8:2, and 9:1, and the melting point of the molten salts was in the range of 340 °C to 350 °C. Table 1 shows the thermal property parameters of common molten salt. The melting points of these molten salts span a wide range, and their specific heat capacities and thermal conductivities are also given in the table. The specific heat capacity of LiCl is 18.00 KJ/Kg-K, which is significantly higher than the others; the thermal conductivities of BaF₂ and CaCl₂ are significantly higher than the others.

Table 1
 Thermal property parameters of common molten salt

Classification	Melting point (°C)	Density (g/cm ³)	Heat capacity (KJ/Kg · K)	Conductivity (W/m · K)
Li ₂ CO ₃	732.00	2.11	3.58	—
Na ₂ CO ₃	858.00	2.53	1.04	0.41
K ₂ CO ₃	900.00	2.42	1.49	—
Rb ₂ CO ₃	873.00	3.20	—	—
Ca ₂ CO ₃	1330.00	2.70	0.82	2.5
BaCO ₃	155.00	4.43	—	—
LiF	849.00	2.64	1.56	—
NaF	996.00	1.02	—	—
KF	795.00	2.48	—	—
RbF	312.00	3.55	—	—
CaF	1418.00	3.18	0.85	—
BaF ₂	1368.00	4.89	0.70	11.72
Li ₂ NO ₃	253.00	2.38	—	—
Na ₂ NO ₃	307.00	2.26	1.34	0.72
K ₂ NO ₃	335.00	2.11	1.34	—
Rb ₂ NO ₃	312.00	3.11	—	—
K ₂ NO ₃	560.00	2.50	0.35	—
BaNO ₃	594.00	3.24	—	1.17
LiCl	610.00	2.07	18.00	—
NaCl	801.00	2.16	2.03	16.9
KCl	771.00	1.98	7.40	—
MgCl ₂	714.00	2.32	—	0.216
CaCl ₂	772.00	2.15	1.25	12
BaCl ₂	961.00	3.85	—	—
NaNO(60)- KNO ₃ (40)	1.752	221	1.47	0.519
MgCl ₂ (50)- NOCl(50)	2.24	429	0.93	0.96
Li ₂ CO ₃ (28)- K ₂ CO ₃ (72)	2.24	498	1.46-1.8	1.85

LiCO ₃ (35)-	2.26	505	1.34-1.76	1.89
K ₂ CO ₃ (65)	1.835	78.8	1.5	0.55
KNO ₃ (53.4)- CA(NO ₃) ₂ (46.6)				
MgCl ₂ (48)-	2.53	342	0.80-0.92	0.88
KCl(25)- CaCl ₂ (27)				
NaCO ₃ (60)-	2.38	283		
K ₂ CO ₃ (20)- Li ₂ CO ₃ (20)				
NaNO ₃ (7)-	1.99	142	1.34	0.387
NaNO ₂ (40)- KNO ₃ (53)				
NaNO ₃ (7)-	1.992	140	1.44	0.519

5. Application in CSP

From 1984 to 1991, Lutz International built the first commercial CSP power plant in the Mojave Desert of California, USA, and then this technology was gradually valued by various countries, Spain, Cyprus, France, Greece, Italy, Portugal and other countries have established 2 billion kWh level of photovoltaic power plants [82]. According to the data of the International Energy Agency IEA, the total international concentrated solar power generation is rising year by year, reaching 15.6 billion kWh in 2018, and it is expected that the total power generation is expected to exceed 183.8 billion kWh in 2030 under the circumstances of sustainable development [83]. In 2005, the 70kW tower solar thermal power generation system with air as the medium, which is a cooperation between several Chinese and foreign research institutes, was built. Based on the "863" programme, the Chinese Academy of Sciences Institute of Electrical Engineering 2008 on start the 1MW pilot plant finally in 2012 power generation success, becoming Asia's first "MW" level of photovoltaic power station.

In August of the same year, the 10MW class photovoltaic power generation demonstration project in Delingha, China, achieved continuous steam production and smooth operation. In June 2013, the 600MW trough test circuit of Longteng Solar in Inner Mongolia achieved stable operation under typical working conditions. At the end of 2018, the world's largest and most technologically advanced 700MW photovoltaic power generation project in Dubai cooperated with China and the UAE began construction. In 2019, the collection of wind power, photovoltaic, photovoltaic, energy storage and other energy storage projects will be launched, PV, photovoltaic, solar thermal, energy storage and other comprehensive use of energy Luneng Haixi State Multi-Functional Complementary Integration and Optimisation Demonstration Project 50MW photothermal project was completed and put into operation, which provides an innovative demonstration of the rational use of resource scheduling.

The planning of several photothermal power generation bases, such as Gansu Yumen Huahai Mega Kilowatt Scale Photothermal Power Generation Base and Qinghai Province 10 million Kilowatt Scale Renewable Energy Base, has provided a good opportunity for the development of China's photothermal power generation. The Northwest Academy's Hami 50MW tower and Yumen Xinneng 50MW tower projects continued to advance in 2019. As of the first half of 2020, the first seven photothermal power generation demonstration projects, including the CGN Delingha thermal oil tank project and Shouhang Energy Saving Dunhuang molten salt tower project, have been successfully connected to the grid, with a total installed capacity of 4.5×105MW [78].

6. Conclusions

- i. Molten salts have been used as heat storage materials in tank power plants for many years, and energy storage in molten salts has been successfully commercialized in Europe and the USA.
- ii. Molten salts are frequently employed as heat transfer medium and in solar power generation because of their special qualities and inexpensive cost. Nitrates are less expensive, less corrosive, and do not break down below 500 °C when compared to other molten salts. Therefore, the primary heat storage component employed in the production of solar electricity is mixed molten nitrate salts.
- iii. Molten salt solar thermal power generation has the advantages of high energy conversion efficiency, small mass, and windward area, and can be easily scaled up to the megawatt level. Currently, molten salts are used in troughs, towers, and Fresnel plants.

Declaration of Competing Interest

The authors declare that the work reported in this study was not affected by any conflicting financial interests or personal connections.

Data Availability

No data was used for the research described in this article.

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