A REVIEW ON PARABOLIC TROUGH TYPE SOLAR COLLECTORS: INNOVATION, APPLICATIONS AND THERMAL ENERGY STORAGE

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Abstract
The global demand for energy is growing and conventional energy sources like coal and petroleum are depleting, and renewable resources will play a crucial role in the future. This paper presents an overview about the parabolic trough solar collector which is one of the renewable source. Parabolic trough collector can supply the thermal energy up to 400^0C, mainly in steam power plant for electricity generation. Many applications of Parabolic Trough Collector, it's innovations and thermal energy storage materials has been discussed keeping in mind the environmental benefits. In India, the states of Rajasthan and Gujarat have the potential for widespread application of PTC to harness the solar energy. The launch of The Jawaharlal Nehru National Solar Mission (JNNSM) in 2008 by the Indian Government and its initiatives, complemented by state solar policy passed by the states of Rajasthan and Gujarat, will go a long way based on deployment of both solar PV projects and solar thermal projects in a ratio of 50:50, in MW terms to fulfilling India's upcoming energy needs.

Keywords: Parabolic Trough Collector (PTC), concentrated solar power (CSP), heat transfer fluid (HTF), Thermal energy storage

1. Introduction
The global demand for energy is growing and conventional energy sources like coal and petroleum are depleting, and renewable resources will play a crucial role in the future. A worthy investment option is concentrating solar power (CSP) technology which has the capacity to provide for about 7% of the total electricity needs projected for the world by 2030 and 25% by 2050 (considering a high-energy saving, high-energy-efficiency scenario) [1]. As the world's supply of fossil fuels shrinks, there is a great need for clean and affordable renewable energy sources in order to meet growing energy demands. Achieving sufficient supplies of clean energy for the future is a great societal challenge. Sunlight, the largest available carbon neutral energy source, provides the Earth with more energy in1h than is consumed on the plane tin an entire year. Despite of this, solar electricity currently provides only a fraction of a percent of the world's power consumption. In any country the energy can be obtained mainly two resources i.e.Non-renewable and renewable resources. The renewable energy resources comprise of solar, hydro, wind, tidal, geothermal, ocean thermal. Solar energy can be used both directly and indirectly. Solar radiation is a high-temperature, high-exergy energy source at its origin, the Sun, where its irradiance is about 63 MW/ m2. However, Sun–Earth geometry dramatically decreases the solar energy flow down to around 1 kW/m2 on the Earth's surface [2]. It can be used directly by solar collectors and solar cells. Solar collectors fall into two general categories: non-concentrating and concentrating. Trough type collector is a concentrating type collector. In concentrating type, solar energy firstly falls on concentrator, then concentrated on a receiver, and transferred to the fluid flowing through the receiver. The collector area is different as the absorber area. Though more costly, concentrating collectors have numerous advantages over stationary collectors, and are generally associated with higher operation temperatures and greater efficiencies. The addition of an optical device to the conventional solar collector (receiver) has proved useful in several regards; various concentration schemes can achieve a wide range of concentration ratios, from unity to over 10,000 sun [2]. This increases the operation temperature as well as the amount of heat collected in a given area, and yields higher thermodynamic efficiencies. Radiation focusing allows the usage of receivers with very small relative surface areas, which leads to significant reductions in heat loss by convection. There are many type of concentrating collectors in which PTC is one of type.

2. Parabolic Trough Collector (PTC)
The first practical experience with PTCs goes back to 1870, when a successful engineer, John Ericsson, a Swedish immigrant to the United States, designed and built a 3.25-m2-aperture collector which drove a small 373-W engine. Steam was produced directly inside the solar collector (today called Direct Steam Generation or DSG).

Parabolic trough technology is the most mature concentrated solar power design. It is currently utilized by multiple operational large-scale CSP farms around the world. Solar Electric Generating Systems (SEGS) is a collection of fully operational PTC systems located in the California desert with a total capacity of 354 MW.

SEGS is at present the largest PTC power plant in the world. PTC plant with a 280MW capacity is being built in Arizona and is scheduled to become operational in 2011. PTCs effectively produce heat at temperatures ranging from50 to 400^0 C. These temperatures are generally high enough for most industrial heating processes and applications, the great majority of which run below300^0 C. There is a series of curved mirrors in each parabolic trough which are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough's focal line through which synthetic oil, heated to approximately 400 ◦C by the concentrated sun's rays, is used as a heat transfer medium (**Fig. 1**) [28]. Many parallel rows of these solar collectors usually aligned north to south, span across the solar field. The oil transfers heat from collector pipes to heat exchangers, where water is preheated, evaporated and then superheated. The superheated steam runs a turbine, which drives a generator to produce electricity and the water returns to the heat exchangers after being cooled and condensed [3]. With the sunlight concentrated by about 70–100 times, the operating temperatures achieved are in the range of 350–550 ◦C. The annual solar to electric efficiency is estimated to be 15% [4]. An alternative for the integration of a parabolic trough solar field in a steam turbine power plant is generating steam in the solar field called the direct steam generation technology[5]. Characteristics of the electricity production by stationary parabolic, cylindrical solar concentrator have been discussed in detail by Boji´c et al. [6]. The first parabolic trough systems were installed in 1912 near Cairo (Egypt) [4]. The feasibility analysis of constructing parabolic trough solar thermal power plant in Inner Mongolia of China in carried out in a study by Zhao et al. [7] and the result was that the power plant can indeed be operated with its maximum commercial volume and generate power to grid under the support of the state policy. A more recent study by Yang et al. [8] presents the possibility that Tibet, with enough DNI resources and large amount of wasteland, will be a promising candidate site for the construction of Parabolic Trough Solar Thermal Power Plants in China. Nevada Solar One at Boulder City, NV, USA with a capacity of 64 MW, developed by Acciona and operated by Solar genix Energy is an addition to the parabolic trough plants in the year 2007[9].

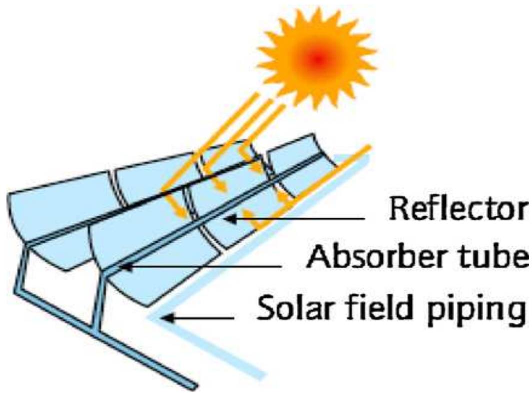

Fig.1 Parabolic trough [3]

The parabolic trough collector design features light structures and relatively high efficiency. A PTC system is composed of a sheet of reflective material, usually silvered acrylic, which is bent into a parabolic shape. Many such sheets are put together in series to form long troughs. These modules are supported from the ground by simple pedestals at both ends. The long, parabolic shaped modules have a linear focus (focal line) along which a receiver is mounted. The receiver is generally a black metal pipe, encased in a glass pipe to limit heat loss by convection. The metal tube's surface is often covered with a selective coating that features high solar absorbance and low thermal emittance. The glass tube itself is typically coated with antireflective coating to enhance transmissivity. A vacuum can be applied in the space between the glass and the metal pipes to further minimize heat loss and thus boost the system's efficiency.

The heat transfer fluid (HTF) flows through the receiver, collecting and transporting thermal energy to electricity generation systems (usually boiler and turbine generator) or to storage facilities. The HTF in PTC systems is usually water or oil, where oil is generally preferred due to its higher boiling point and relatively low volatility. The Jawaharlal Nehru National Solar Mission in Rajasthan(India) is partially solar thermal project which means that it uses sunlight through concentrated solar power technology (based on either line focus or point focus principle) for conversion into heat/steam which can be used for producing electricity.

The DISS (Direct Solar Steam) project PTC plant in Tabernas, Spain, is a leading DSG test facility, where two successful DSG operational modes and control systems were developed and tested[10]. Both methods utilize pressure control in addition to temperature control of circulating water. This approach is done to achieve a constant output of steam at a monitored temperature throughout most hours of the day (9am–6pm). A pressure level of 100bar and temperatures of up to 400^0 C have been demonstrated. The Once Through mode features a preheated water feed into the inlet. As water circulates through the collectors, it is evaporated and converted into superheated steam that is used to power a turbine. In the more water-conservative Recirculation mode, a water–steam separator is placed at the end of the collector loop. More water is fed to the evaporator than can be evaporated in one circulation cycle. Excess water is re-circulated through the intermediate separator to the collector loop inlet, where it is mixed with preheated water. This process guarantees good wetting of absorber tubes and prevents stratification. Steam is separated from water and fed into the inlet of a superheating section. The Recirculation regime is more easily controlled than the Once-through regime, but has an increased parasitic load due to the additional process steps. Usage of water as a HTF inflicts more stress on the absorber tubes than other heat transfer media, due to water's relatively high volatility.

In contrast with the DSG scheme, which employs water as the HTF, recent innovation also promotes the use of ionic liquids (molten salts) for heat transfer media[11], as they are more heat-resilient than oil, and thus corrode the receiver pipes less. Ionic liquids are, however, very costly, and such an investment would have to be weighed against the incurring costs of receiver maintenance and replacement to determine their cost-effectiveness.
PTCs are mounted on a single-axis sun-tracking system that keeps incident light rays parallel to their reflective surface and focused on the receiver throughout the day. Both east–west and north–south tracking orientations have been implemented, with the former collecting more thermal energy annually, and the latter collecting more energy in the summer months when energy consumption is generally the highest[12]. The east–west orientation has been reported to be generally superior [13].

In order to make the PTC structure more resilient to external forces, it is possible to reinforce collector surfaces with a thin fiberglass layer. A smooth, 90^0 rim angle reinforced trough was built by a hand lay-up method [14]. The fiber glass layer is added underneath the reflective coating (on the inner surface) of the parabolic trough. The reflector's total thickness is 7mm, and can with stand a force applied by a 34m/s wind with minimal deviation; deflection at the center of the parabola vertex was only 0.95mm, well within acceptable limits.

3. Applications

PTC applications can be divided into two main groups. The first and most important is Concentrated Solar Power (CSP) plants. Typical aperture widths are about 6 m, total lengths are from 100 to 150 m and geometrical concentrating ratios are between 20 and 30. Temperatures are from 300 to 400^0 C [15]. CSP plants with PTCs are connected to steam power cycles both directly and indirectly. Although the most famous example of CSP plants is the SEGS plants in the United States, a number of projects are currently under development or construction worldwide. The other group of applications requires temperatures between 100 and 250^0 C. These applications are mainly industrial process heat (IPH), low-temperature heat demand with high consumption rates (domestic hot water, DHW, space heating and swimming pool heating) and heat-driven refrigeration and cooling. Typical aperture widths are between 1 and 3 m, total lengths vary between 2 and 10 m and geometrical concentrating ratios are between 15 and 20. Most of the facilities are located in the United States, although some have recently been built in other countries. There are also some projects and facilities for other applications such as pumping irrigation water, desalination and detoxification.

3.1. CSP plants

Appropriate site locations for CSP plants in the world include the North African Desert, the Arabian Peninsula, major portions of India, central and western Australia, the high plateaus of the Andean states, northeastern Brazil, northern Mexico and, of course, the United States Southwest. Promising site locations in Europe are found in southern Spain and several Mediterranean islands [16]. All commercial CSP plants are north–south oriented, because this maximizes the amount of power produced along the year. The higher the latitude, the more necessary this becomes.

There are two ways to integrate a PTC solar field in a steam turbine power plant, directly, that is, generating steam in the solar field (DSG technology), or indirectly, by heating thermal oil in the solar field and using it to generate steam in a heat exchanger (HTF technology). In both cases, solar fields can drive all types of steam turbine power plant cycles. Another interesting option is incorporation of a solar system in a combined cycle (CC), called Integrated Solar Combined-Cycle System (ISCCS), in which two different thermodynamic cycles, a steam-turbine Rankine cycle and gas-turbine Brayton cycle, are combined in a single system through a Heat Recovery Steam Generator (HRSG). The general concept is an oversized steam turbine, using solar heat for steam generation and gas turbine waste heat for preheating and superheating steam [17]. **Fig.2** shows SSPS (small solar power system) based on PTC in spain.

Fig.2. SSPS (small solar power system)/DCS (distributed collector system) plant at the PSA(Spain) [18,19].

3.2 Industrial process heat (IHP)

The key sectors are food and beverages including wine, textile, transport equipment, metal and plastic treatment, and chemicals. And the most suitable processes are cleaning, drying, evaporation and distillation, blanching, pasteurisation, sterilisation, cooking, melting, painting, and surface treatment [20]. Of the total energy used by industry, a major portion, approx.45–65%, is used for direct application of industrial process heat in the preparation and treatment of goods. The thermal energy demand for IPH is below 300 8C, and 37.2% of the total IPH demand is in the range of 92–204 8C [21]. According to the ECOHEATCOOL study done in 32 countries, 3 27% of the thermal energy demand for IPH is between 100–400^0 C [22]. For that reason, one of the most important applications of a small-sized PTC is IPH.

3.3 Domestic hot water and space heating

One of the most widespread applications of solar thermal energy is hot water production. According to an IEA report for 2006, solar thermal collector capacity in operation worldwide was about 127.8 GWth (182.5 million m2), most of it domestic, both for DHW (kitchen, shower, laundry and sanitation facilities) and space heating [23]. The temperatures at which energy is required by these applications are below 100^0 C. Therefore, conventional solar collectors with suitable efficiencies (FPC, CPC or evacuated tube collectors) could be employed. However, when a large amount of hot water is demanded, a large collection area, which sometimes becomes excessive, must be installed. In this case, PTCs might be of interest, because they supply thermal energy at higher temperatures than those required by the load and, therefore, higher demands can be covered by mixing the hot solar fluid with another cooler. Examples of applications with high hot water consumption rates are large swimming-pool heating systems, and DHW and space heating for large buildings, such as industrial buildings, factories, hospitals, educational centres, sport facilities, government buildings, prisons, airports, bus and train stations, etc. In most situations, a minimum hot water consumption of about 1900 l/day would be needed to make a PTC system, which is more effective for large, 7-day-a-week hot water users, to be feasible [24].

The advantages of PTCs over the solar collectors traditionally used in water heating facilities are their lower thermal losses and, therefore, higher efficiency at the higher working temperatures reached, smaller collecting surface for a given power requirement, and no risk of reaching dangerous stagnation temperatures, since in that case, a control system sends the collectors into off-focus position. The disadvantages of PTCs are that its solar-tracking system increases installation and maintenance costs, and the need to clean their components also increases maintenance costs.

3.4 Air-conditioning and refrigeration

PTC facilities connected to high-consumption water-heating systems The Coefficient of Performance (COP) is higher for a LiBr–H_2 O double-effect than for a single-effect absorption chiller, but it requires thermal energy at temperatures of 140–160^0 C [25], at which performance of conventional collectors is not good enough. As PTCs are highly efficient at these temperatures, the combination of these two systems is of great interest. Connection of NH3– H_2 O absorption chillers to a solar system requires solar collectors able to work efficiently at temperatures above 95^0 C, such as the PTCs or high-efficiency stationary collectors. Air-conditioning and refrigeration facilities driven by a PTC solar field are still infrequent. However, several test facilities using this technology have appeared in the literature during the last 50 years.

3.5 Pumping irrigation water

To make use of PTCs for pumping irrigation water, the thermal energy Although pumping irrigation water is not the most frequent application of PTCs, there are several examples of this kind of facility produced by the solar field must be converted into mechanical energy for driving the water pump. This application is of special interest in isolated zones and rural areas, where the grid is far away and fuel transport is economically restrictive.

On an experimental level, a 1-kW water pump was installed and assessed at the UNAM in 1976. The pump was driven by a 12-m2 PTC field with DSG in the absorber tube. Unfortunately, solar system global efficiency was found to be only 2%. This poor result led to a new project, without satisfactory improvement. A feasibility study conducted by the University of Arizona(United States) in 1975–1976 found that lower cost, improved solar devices, improved energy use management and availability of modestly priced capital were the key engineering and economic factors preventing successful marketing and use of solar-powered pumping plants.

3.6 Desalination

The problem of an adequate potable water supply may well become one of the most serious challenges facing the world in this century. Solar desalination is one of the most promising technologies for confronting this problem. The PTC's suitability for solar desalination has been studied in several different types of desalination, such as Reverse Osmosis (RO), Multi-Effect Distillation (MED) and Multi-Stage Flash (MSF). A few commercial or pilot plants were implemented.

3.7 Solar chemistry

The widespread presence of hazardous organic chemical compounds, mainly in water but also in air, has motivated interest in finding alternative environmentally friendly solutions for the treatment and/or removal of these compounds. Concentrated solar energy augments the detoxification process, because more high-energy photons are projected directly into the stream of water or air. Consequently, there are several examples of solar detoxification using a solar concentrating system. When the solar concentrating system selected is a PTC, a transparent tube (usually glass) is placed in the focal line of the reflector instead of the metal absorber tube, as photo-reactor.

4. Innovations

The new receiver design features porous inclusions inside the tube, which increase the total heat transfer area of the receiver, along with its thermal conductivity and the turbulence of the circulating HTF (synthetic oil). Heat transfer for this scheme was enhanced by 17.5% compared with regular (no inclusions) design, but the system suffered a pressure decrease of about 2 kPa.

The integration of a parabolic trough collector field with geothermal sources has been suggested by Lentz and Almanza [25,26]. Hot water and steam from geothermal wells can be directly fed into an absorber pipe going through a PTC field. The combination of both thermal energy sources increases the volume and the quality of (directly) generated steam for power production. Several hybrid designs have been suggested by the authors.
PTCs can also be integrated with solar cells in concentrated photovoltaics (CPV) modules. Heat-resistant, high-efficiency photovoltaic cells can be mounted along the bottom of the receiver tube to absorb the concentrated solar flux. The performance of a CPV parabolic trough system with a 37 sun concentration ratio was characterized by Coventry [27] at Australian National University in 2003. Monocrystalline silicon solar cells were used, along with the thermal PTC apparatus. Measured electrical and thermal efficiencies were 11% and 58%, respectively, producing a total efficiency of 69%. It is important to note that uneven illumination of the solar cell modules causes a direct decrease in the cells' performance, and thus optical considerations must be weighed carefully.

5. Thermal Energy Storage

A significant complication with the utilization of solar thermal power as a primary source of energy is the variable supply of solar flux throughout the day, as well as throughout the year. The cyclical availability of solar energy determines two types of thermal storage are necessary for maintaining a constant supply of solar thermal power driven electricity. The first is short-term storage, where excess energy harvested daily is stored for nighttime usage. The second is long-term storage in which excess energy is stored during spring and summer months in order to complement the smaller energy flux available in winter.

Thermal energy storage can be divided into three main categories: sensible heat storage, latent heat storage and chemical storage. Sensible heat storage involves heating a solid or liquid and insulating it form the environment until the stored thermal energy is ready to be used. Latent heat storage involves the phase change (generally

solid–liquid) of the storage material. The heat- induced phase change stores a great deal of thermal energy while maintaining a constant temperature, and can be easily utilized for nighttime energy storage if kept under proper isolation. Chemical storage is implemented using harvested thermal energy in reversible synthesis/de-synthesis endothermic reactions. The heat 'invested' in producing/dissociating a certain material (ammonia, methane, etc.) can be easily stored indefinitely. The reverse, exothermic reaction will release the heat with minimal losses for electricity generation at a later time. Chemical storage is thus most suitable for long-term or seasonal storage.
Sensible heat storage can employ a large variety of solid and liquid materials. It can be put into practice in a direct or indirect manner. For storage in solids such as reinforced concrete, solid NaCl and silica fire bricks, an indirect storage method must be implemented. This type of system uses a heat transfer fluid to circulate through absorbers, collect heat and transport it to the storage tank. The HTF is then put in thermal contact with the storage solids, allowing them to absorb the heat convectively. Sensible heat storage in liquids can be achieved in a direct fashion, i.e. the heat storage liquids themselves are used as heat transfer fluids, and are transported to an insulating storage tank after circulating through the solar absorbers. Mineral oil, synthetic oil, silicone oil, nitrate, nitrite and carbonate salts, as well as liquid sodium, can all be used for sensible heat storage. Desired characteristics of 'sensible-heat-storage-friendly' molten salts include high density, low vapor pressure, moderate specific heat, low chemical reactivity and low cost. One big disadvantage of molten salts is that they are usually quite pricey. Detailed characteristics of storage materials (**Table5 a-d)** are given by Gil et al.[26].

Table 5 a–d. Various thermal storage materials and their properties. Data compiled from [26].

(a) Sensible heat storage liquid materials and their properties

Storage medium HIETC	HIETC solar salt	Mineral oil	Synthetic oil	Silicone oil	Nitrite salts	Nitrate salts	Carbonate salts	Liquid sodium
Temp. (cold)(1C)	120	200	250	300	250	265	450	270
Temp. (hot)(1C)	133	300	350	400	450	565	850	530
Avg. density(kg/m3)	n/a	770	900	900	1825	1870	2100	850
Avg. thermal conductivity (W/m K)	n/a	0.12	0.11	0.10	0.57	0.52	2.0	71.0
Avg. heat capacity (kJ/kg K)	n/a	2.6	2.3	2.1	1.5	1.6	1.8	1.3
Volume specific heat capacity (kWh/m3)	n/a	55	57	52	152	250	430	80
Cost per kWh (US$/kWh)	n/a	4.2	43.0	80	12.0	3.7	11.0	21.0

(b) Sensible heat storage solid materials and their properties

Storage medium HIETC	Sand-rock Mineral Oil	Reinforced Concrete	NaCl (Solid)	Cast Iron	Cast Steel	Silica Fire Bricks	Magnesia Fire Bricks
Temp. (cold)(1C)	200	200	200	200	200	200	200
Temp. (hot)(1C)	300	400	500	400	700	700	1200
Avg. density(kg/m3)	1700	2200	2160	7200	7800	1820	3000
Avg. thermal conductivity (W/m K)	1.0	1.5	7.0	37.0	40.0	1.5	5.0

Avg. heat capacity (kJ/kg K)	1.30	0.85	0.85	0.56	0.60	1.00	1.15
Volume specific heat capacity (kWh/m3)	60	100	150	160	450	150	600
Cost per kWh (US$/kWh)	4.2	1.0	1.5	60.0	60.0	7.0	6.0

(c)Commercial phase change materials (PCMs) and their properties

Name	Type	Phasechange temp. (C)	Density (kg/m3)	Specific heat (kJ/kg K)	Thermal conductivity (W/m K)	Latent heat (kJ/kg)
RT110	Paraffin	112	n/a	n/a	n/a	213
E117	Inorganic	117	1450	2.61	0.70	169
A164	Organic	164	1500	n/a	n/a	306

(c)Inorganic substances with potential use as phase change materials

Compound	Phasechange temp. (C)	Density (kg/m3)	Specific heat (kJ/kg K)	Thermal conductivity (W/m K)	Latent heat (kJ/kg)
MgCl2-6H2O	115-117	1450(liquid, 120^0 C) 1570(solid,20^0 C)	n/a	0.570(liquid,120^0 C) 0.598(liquid, 140^0 C) 0.694(solid,90^0 C)0.707(solid,110^0 C)	165
Hitec: KNO3–NaNO2–NaNO3	120	n/a	n/a	n/a	n/a
Hitec XL:48%Ca(NO3)2–45%KNO3–7%NaNO3	130	n/a	n/a	n/a	n/a
Mg(NO3)–2H2O	130	n/a	n/a	n/a	n/a
KNO3–NaNO2–NaNO3	132	n/a	n/a	n/a	275
68% KNO3–32% LiNO3	133	n/a	n/a	n/a	n/a
KNO3–NaNO2–NaNO3	141	n/a	n/a	n/a	75
Isomalt	147	n/a	n/a	n/a	275
LiNO3–NaNO3	195	n/a	n/a	n/a	252
40%KNO3–60%NaNO3	220	n/a	n/a	n/a	n/a
54%KNO3–46%NaNO3	220	n/a	n/a	n/a	n/a
NaNO3	307	2260	n/a	0.5	174
KNO3/KCl	320	2100	1.21	0.5	74
KNO3	333-336	2.11	n/a	0.5	266
KOH	380	2.044	n/a	0.5	149.7
MgCl2/KCl/NaCl	380	1800	0.96	n/a	400
AlSi12	576	2700	1.038	160	560
AlSi20	585	n/a	n/a	n/a	460
MgCl2	714	2140	n/a	n/a	452
80.5% LiF–19.5%CaF2 eutetic	767	2100	1.97	1.7	790

NaCl	800-802	2160	n/a	5.0	492
NaCO3–BaCO3/MgO	500-850	2600	n/a	5.0	n/a
LiF	850	n/a	n/a	n/a	1800(MJ/m^3)
Na2CO3	854	2533	n/a	2.0	275.7
KF	857	2370	n/a	n/a	452
K2CO3	897	2290	n/a	2.0	235.8
KNO3/NaNO3 eutetic	n/a	n/a	n/a	0.8	94.25

(d)Organic substances with potential use as phase change materials

Compound	Phasechange temp. (^{0}C)	Latent heat (kJ/kg)	Latent heat (kJ/L)
Isomalt: (($C_{12}H_{24}O_{11}$–2H_2O)+($C_{12}H_{24}O_{11}$))	147	275	n/a
Adipic acid	152	247	n/a
Dimethylol propionic acid	153	275	n/a
Pentaerythritol	187	255	n/a
AMPL ((NH2)(CH3)C(CH2OH)2)	112	28.5	2991.4
TRIS ((NH2)C(CH2OH)3)	172	27.6	3340(KJ/kmol)
NPG ((CH3)2C(CH2OH)2)	126	44.3	4602.4(KJ/kmol)
PE (C(CH2OH)4)	260	36.9	5020(KJ/kmol)

Latent heat storage in the solid–liquid phase transition of materials is considered a good alternative for sensible heat storage. From an energy perspective, storage using phase change materials (PCM) can operate in relatively narrow temperature ranges between charging and discharging thermal energy. Additionally, PCM materials generally feature higher densities than sensible heat storage materials. The interest in PCM latent heat storage systems is increasing, mainly due to potential improvements in energy efficiency and nearly isothermal energy storage and release. In addition to the few commercially available PCMs today, many organic and inorganic compounds are being investigated for latent heat storage purposes. A disadvantage of PCMs is their low thermal conductivity, which results in slow charge–discharge rates. One suggested initiative for all aviating this problem involves the fabrication of PCM composite materials; mixing pure PCMs with graphite, for example, can boost thermal conductivity and promote faster energy storing and releasing. Since sensible and latent thermal energy storage schemes can only retain their energy efficiently for so long, the need for long- term, cross-seasonal storage is made possible by thermo-chemical storage processes. Thermal energy storage in heat intensive endothermic reactions has the possibility to realize higher energy efficient processes the thermal storage regimes. Potentially high energy densities can be stored using chemical storage. Reformation of methane and CO2 , metal–oxide/metal conversions and ammonia synthesis/dissociation are just a few examples of heat-assisted chemical reactions that can store solar thermal energy in their endothermic reaction products and release it at a later time/place by the reverse process. Every storage method mentioned can play an important role in several concentrated solar power designs [27].

6. Conclusion

In light of the necessity to tackle climate change, energy produced from renewable sources is gaining importance. Solar thermal technologies with promising low carbon emissions will play an important role in global energy supply in the future. A number of projects being developed in countries including USA, Spain, India, Egypt, Morocco, and Mexico are expected to total 15 GW. Numerous countries including India have taken up the opportunity to harvest the solar resource. Projects based on PTC have the potential for power generation sources in the near future. World governments are actively announcing incentives for development of solar thermal power plants and establishing policy frameworks. The launch of The JNNSM by MNRE, Government of India is the first step in the promotion and establishment of solar energy as a viable alternative to conventional sources.

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