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Lessons learnt during the design, construction and start-up phase of a molten salt testing facility

Margarita-Manuela Rodríguez-García [a,*], Miguel Herrador-Moreno [b,1], Eduardo Zarza Moya [a]

[a] CIEMAT-Plataforma Solar de Almería, Carretera de Senés, km 4, 04200 Tabernas, Almería, Spain
[b] ABENGOA, C/Energía Solar 1, Palmas Altas, 41014 Sevilla, Spain

HIGHLIGHTS

- Description of the experimental molten salt storage system built at CIEMAT.
- Design technical considerations for an experimental molten salt storage plant.
- Hints for piping and heat exchangers design and thermal losses calculation.
- Recommendations for selecting instrumentation and elements with electronic parts.
- Installation remarks for insulation and heating elements.

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ABSTRACT

In 2010, CIEMAT (Centro de investigaciones energéticas medioambientales y tecnológicas) signed a turnkey contract to have an experimental plant for thermal storage using molten salts at its PSA (Plataforma Solar de Almeria) facilities. This plant was designed to evaluate components, instrumentation and operation strategies and to give support to the industry in the qualification and evaluation of components.

During the design, construction and start-up phases of this plant, many different aspects regarding design, construction and commissioning have been learnt and these will contribute to the improvement of other plants.

Among other tips explained in the paper, we recommend the use of venting valves to eliminate the water present in the system after the pressure test or released by the salts during the first melting. The selection of instrumentation with no electronic components near a heat source, thus preventing them from overheating, is also advisable. The heat exchanger design and dimensioning should take into account not only the thermal losses to the atmosphere and through pipes and supports, but any possible reduction in the heat exchange surface that could have detrimental consequences in the thermal performance.

Special attention must be paid when dimensioning and installing the EHT and insulation because both components are decisive in the avoidance of plug formation. Its correct installation in valves and supports and the proper positioning of the temperature control sensors, i.e. where no other heat source can distort the readings, are crucial.

Recommendations and strategies for the operation and shutdown of this experimental plant are being gathered for a future paper.

1. Introduction

The storage of energy is crucial to Solar Thermal Electricity (STE) Plants. It allows the production of electricity from energy derived from the sun, even when there is no solar radiation (cloudy periods or evening hours). This ability to separate the hours of production from the sunlight hours provides STE plants with a high degree of

* Corresponding author. Tel.: +34 950387900.
E-mail addresses: margarita.rodriguez@psa.es, marodriguez@psa.es (M.-M. Rodríguez-García), miguel.herrador@abeinsabd.abengoa.com (M. Herrador-Moreno).
[1] Tel.: +34 618506800.

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Acronyms

CIEMAT	Centro de investigaciones energéticas medioambientales y tecnológicas
EHT	electrical heat tracing
MI	mineral insulated
MNS	molten nitrate salt
PSA	Plataforma Solar de Almería
STE	solar thermal electricity
Symbols	
ΔT	temperature difference between inlet and outlet
ε_r	relative static permittivity

dispatchability, thus adapting the supply of electricity to consumers' demands.

Molten nitrate salt (MNS) (60%w $NaNO_3$, 40%w KNO_3) is widely used as a thermal energy storage medium. Its main advantage is that its operating temperature range is well matched to the Rankine thermodynamic cycle of the power block. The main properties of fluid molten salt in the range from 300 to 600 °C are given in Table 1 [1].

The industry has already implemented molten salt thermal storage systems in central tower receivers and parabolic trough solar plants: the first commercial parabolic trough solar thermal electricity plant in Spain, Andasol I [2], uses tanks of molten salt to store thermal energy and it has a capacity of 1 GWh (enough to keep the 50 MW power block running at full load for 7.5 h). Elsewhere, with a 19 MWe power block and 15 full-load hours of storage [3], Gemasolar is the first commercial-scale STE plant in the world to use a central tower receiver and molten salt heat storage technology. Table 2 shows the operational and under-construction STE plants with molten salt thermal energy storage [2–11].

Many engineering questions related to this type of storage system are still open (e.g. the long-term reliability and durability of the valves, heat tracing systems, heat exchangers, pumps, etc.). Therefore, CIEMAT installed a multi-purpose molten salt test facility at the Plataforma Solar de Almería (PSA) (See Fig. 1). The purpose of this facility is to control and evaluate the heat exchange between molten salts and different fluids (i.e. CO_2, or other pressurized gases, and thermal oil, at present a eutectic mixture of 73.5% diphenyl oxide ($C_{12}H_{10}O$) and 26.5% biphenyl ($C_{12}H_{10}$). The system has been initially filled with MNS, but this can be replaced by any other salt.

2. Facility description

The PSA molten salt facility basically consists of the following components (See Fig. 2 and [12] for more information).

Two molten salt tanks (see Table 3), each of which are provided with a vertical pump, thermal insulation, inner electrical heaters, electrical heat tracing on the outer side of the walls, level measurement and temperature control systems.

The cold salt tank is a horizontal tank which is supported on three legs to minimize heat losses through its base and thus the total thermal loss. This tank is placed in a concrete pit which has the additional function of a retention basin. The tank is placed below ground level and all the piping has a tilt of at least one degree to allow the complete drainage, into this tank and by gravity, of the whole facility.

The hot salt tank is a vertical, cylindrical tank, designed with the same philosophy as a commercial tank. The foundation of this tank is based on expanded clay aggregate contained in a metallic ring made of a carbon steel plate.

In both tanks, the design has followed two criteria: that of minimizing the wall thickness of the tank itself and minimizing the outer surface, thereby minimizing the thermal losses. Both tank designs had to accommodate the standard length salt pump, thereby reducing the residual volume of salt for each of the tanks.

During the start-up phase, the cold salt tank was filled up with 40 tons of salt. During operation, this salt is pumped from one tank to the other via either of the two heat exchangers, depending on the operation mode (see Fig. 2).

An experimental facility that uses CO_2 as heat transfer fluid [13]. This is composed of two 50 m Parabolic Eurotrough Collectors, connected in series to a blower that propels the gas and to an air cooler for heat exhaust into the atmosphere. This facility was modified in 2010 to allow heating of the CO_2 up to 525 °C. The facility is connected to the molten salt test facility via a CO_2-molten salt heat exchanger (See Fig. 2).

CO_2-molten salt heat exchanger (see Table 4). Here, molten salt at 290 °C is heated, using CO_2, up to 505 °C in nominal conditions. The gas currently used is CO_2, but the heat exchanger can work with any other gas to give different rates of heat exchange.

Air cooler for cooling down the hot salt in the range between 290 °C and 505 °C.

Thermal oil loop. This can be used for cooling the molten salt of the hot tank to 290 °C when the salt temperature is below 400 °C, and for heating the salt up to 380 °C, the normal commercial parabolic trough plant solar field outlet temperature, depending on the circuit used (salt coming from the hot tank or from the cold tank respectively, see Fig. 2). It comprises a thermal oil expansion tank, a centrifugal pump, an oil heater, a thermal oil-molten salt heat exchanger and an oil cooler refrigerated by ambient air for cooling down the hot thermal oil. The expansion tank serves as an oil buffer in the oil circuit. The oil heater provides the oil with the necessary heat to simulate a solar parabolic trough collector, and it allows the simulation of cloud transients by changing the set-point temperature.

The design data of the expansion tank and oil heater is given in Table 5 and Table 6 respectively.

The thermal oil-molten salt heat exchanger characteristics are listed in Table 4.

Two flanged pipe sections (4″ and 20″) where different components and equipment can be installed to be tested under real working conditions in the molten salt circuit.

Electrical heat tracing (EHT) is installed in all pipes and equipment where the salt can pass through or stay in place. Its main function is to preheat and maintain the temperature of pipelines and components above the salt freezing point, typically at 290 °C, to prevent plug formation. It is divided into different circuits, each of which can be activated independently. Power runs from 67.3 W/m

Table 1
Fluid molten salt properties in the range of 300–600 °C. (T in °C).

	Fluid nitrate salt properties (T in °C)
Solidification temperature [°C]	221
Crystallization temperature [°C]	238
Heat of fusion (based on the average of heat of fusion of each component) [kJ/kg]	$h_{sl} = 161$
Change in density upon melting	$\Delta V/V_{solid} = 4.6\%$
Density [kg/m^3]	$\rho = 2090 - 0.636 \times T$
Specific heat capacity [J/kg °C]	$c_p = 1443 + 0.172 \times T$
Thermal conductivity [W/m °C]	$k = 0.443 + 1.9{*}10^{-4}T$
Absolute viscosity [mPa s]	$\mu = 22.714 - 0.120T + 2.281{*}10^{-4}T^2 - 1.474{*}10^{-7}T^3$