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GEOSMART- Demonstrating technologies for geothermal to enhance competitiveness in smart and flexible operation

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ABSTRACT

Soaring energy prices, geopolitical issues and securing global net zero to avert the climate crisis presents exciting opportunities for the vast, yet largely untapped geothermal energy. As geothermal installations are foreseen to become significant energy resources with the evolution of the energy market, there is a growing impetus for a strategic move towards improving the flexibility of geothermal facilities. The geothermal power plants are currently engineered as baseload producers due to techno-economic challenges associated with the limitations to regulate geothermal wells without challenging the integrity of the various plant components. The GeoSmart project is developing innovations that combine thermal energy storages (TES) with flexible Organic Rankine Cycle (ORC) solutions to provide highly flexible operational capabilities for geothermal installations. The GeoSmart thermal energy storage system will enable the daily flexibility to provide buffered supply against stochastic and 'duck curve' peaks and ramping needs while the hybrid cooling system for the ORC for continued performance efficiency despite the seasonal variations. The project also addresses the challenges associated with silica scaling and deposition on the reinjection wells - a limiting constraint for geothermal plants to fully utilise the thermal energy of a well- by developing a scaling reduction system that will allow higher utilisation of energy from the fluid streams. These innovations will be demonstrated in working geothermal plants, meeting the different flexibility needs of power plants at Insheim (Germany) and Kizildere 2 (Zorlu, Turkey) combined heat and power provision. This paper presents the ongoing technological developments that will contribute to the enhancing the flexibility and cost-competitiveness of geothermal operations.

INTRODUCTION

Unlike any other sector, the energy market has always been subjected to tremendous upheavals. Rising energy prices, Ukraine war, and global efforts to achieve Net Zero provides the watershed moment for energy transition – phasing out of fossil fuels and massive surge in renewables. This paradigm shift presents investment and geothermal energy deployment opportunities to secure green recovery. However, despite the opportunities, geothermal continues to be a marginal player in the renewable energy mix. The power plant components are exposed to damages, often a combination of corrosion, erosion and scaling mechanisms, the extent of which depends on the inherent geofluid chemistry [1]. The latter also causes geothermal to be engineered as 'baseload' supply due to limited flexibility to throttle the wells without causing issues with scaling and fatigue damages.

The revolution in the energy market requires geothermal energy to exhibit flexibility or dispatchability to adapt to the new incentive structure in the European electricity market [2]. Flexibility is required to meet the differential energy demands to cover fluctuations in the heat and power requirements not only within a day but also for seasonal swings. The more the flexibility we can introduce into the geothermal sector, to cover both diurnal and seasonal fluctuations, the more Renewable Energy Sector (RES) integration it can support, thereby helping achieve the policy objectives towards energy sector decarbonisation, energy security and reduced gas import burden.

The aim of the GeoSmart is therefore to address the strategic flexibility needs of the geothermal installations as they become a significant energy resource to foster clean energy transition. The GeoSmart concept is based on four technology pillars, two of which are aimed to improve system flexibility and other two for improved energy utilisation efficiency, to support the unified objective of establishing geothermal leadership in heat and power balancing capability for the energy market. The project target is to optimise and integrate developments against these four pillars, and to demonstrate them in working geothermal plants – two variants of GeoSmart technology meeting the different flexibility needs in Kizildere 2 (Turkey) and Insheim (Germany) geothermal power plants. These innovations include a) provision of a Thermal Energy Storage (TES) tailored according to the site conditions for flexibility, b) redesign of the Organic Rankine Cycle (ORC) generation system for maximizing energy, c) Increasing ORC efficiency based on adiabatic cooling system and, d) removal of silica scaling constraints to allow higher utilisation of energy from geothermal fluid streams. This paper reports the development of the storage solutions including development of the silica scaling reduction system.

STRATEGIES FOR IMPROVING FLEXBILITY OF GEOTEHRMAL VIA THERMAL ENERGY STORGE

In the field of deep geothermal energy, the aim is to use the energy of the brine, extracted several kilometers underground, to supply heating networks and/or to produce electricity. This source of energy delivers a constant power, hence the need to gain in flexibility to meet variable demand and to integrate into an energy mix with intermittent sources.

Therefore, the GeoSmart project aims to optimize and demonstrate innovations, in thermal storage and heat recovery, to improve the flexibility and efficiency of geothermal heat and power systems.

The objective is the design of the heat storage demonstrators that will be installed on the two geothermal sites, Kizildere 2 in Turkey and Insheim in Germany, as well as the evaluation of their performance in a real situation. For both sites, a TRL of 7 is targeted.

KIZILDERE 2 SITE

The objectives of the TES systems on Kızıldere 2 site are to improve the flexibility of the electricity production in order to increase the economic gain linked to the electricity production.

The specificity of this 80 MWe installed power site is to have a high brine temperature of 165°C and to use this brine directly in the process, without intermediate brine/water exchanger. The major issue is therefore to design thermal storage systems adapted to the particular conditions of the brine, which contains non-condensable gases and high rate of mineral salts with high risk of deposition as soon as the temperature drops.

In order to deal with this issue, the GeoSmart consortium proposed modifications to the industrial site in order to better integrate the storage devices, in particular the addition of a new medium pressure separator. These modifications were validated by the industrial partner, which then allowed the implementation of the two storage demonstrators, one on a steam circuit via a steam accumulator, the other on a liquid brine circuit via a Phase Change Material (PCM) storage module (Figure 1).

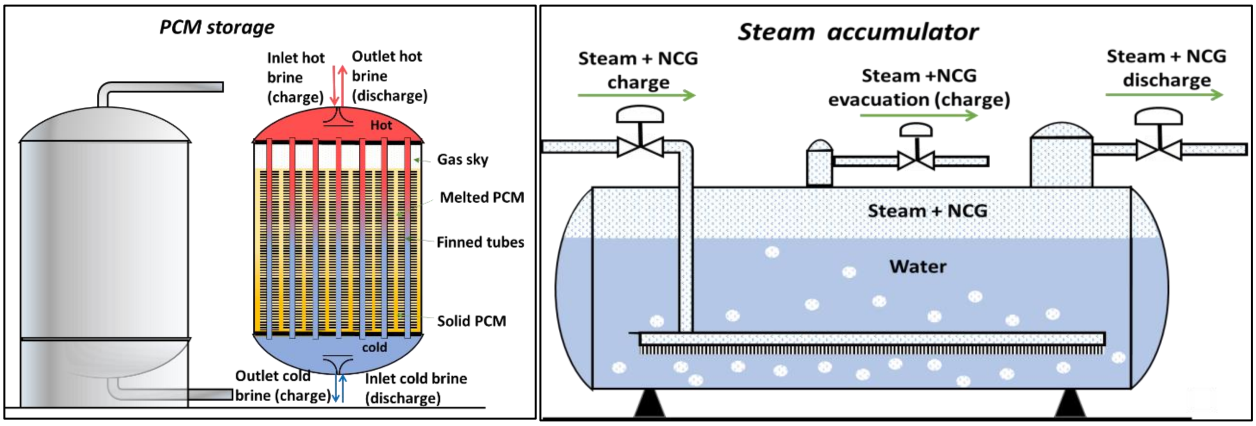

Figure 1. Principle of a PCM storage (left) and a steam accumulator (right)

The targeted capacity of the PCM storage is 2 MWh. The Heat Transfer Fluid (HTF) is the brine in liquid phase, which transfers its heat between 165°C and 107°C to the PCM during the charging phase of the storage and recovers the latent heat of the PCM during the discharge phase. Due to a solid-liquid phase change a large amount of heat is stored in form of latent heat within a small temperature range. Beyond the phase change region the heat is stored in sensible form. A total of nine potentially suitable materials were experimentally investigated with respect to melting temperature, melting enthalpy, cycle stability, supercooling and corrosion. As organic materials Benzanilide, Salicylic acid, Mannitol-Dulcitol 70-30 mixture, Adipic acid as well as Sebacic acid and as salt mixtures KNO3-Ca(NO3)2 67-33, KNO3-NaNO3-NaNO2 53-7-40 (HITEC) or 53-6-41 and LiNO3-NaNO2 62 were considered. Finally, the HITEC salt mixture KNO3-NaNO3-NaNO2 53-7-40 was chosen as PCM. It provides a high cycle stability and a suitable melting temperature of 140 °C and is common as heat transfer fluid. Within the addressed temperature range the material can store 204.5 J/g while no degradation is expected.

One of the issues in this kind of modules is the low thermal conductivity of the PCM (< 1 W/m/K) in solid phase, which limits the exchanged power; the proposed solution is to use commercial finned tubes with aluminum profiles to enhance the heat transfer on the PCM side (Figure 2).

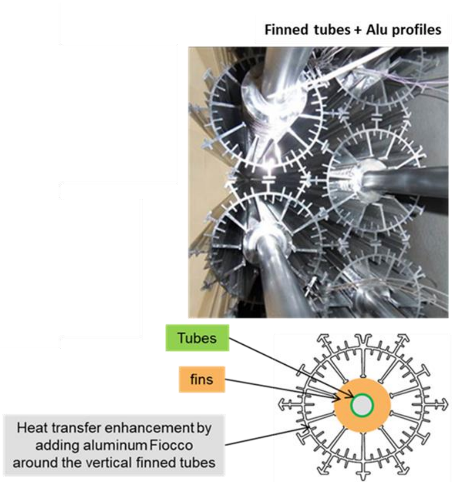

Figure 2. Scheme explaining the design of the tubes in the PCM module

Another difficulty is the high salinity of the brine, which can lead to deposits inside the tubes, that is why the shape of the exchanger is very simple, with straight tubes, to facilitate cleaning. In addition, a cleaning procedure has been investigated to clean the PCM module after every cycle.

For the targeted energy of 2 MWh, the PCM module has a volume of 30 m^3 and contains 241 tubes and 36 tons of PCM. The energy is stored mainly in latent form (70%) but also in sensitive form.

Concerning the steam accumulator, the targeted energy is 5 MWh. It will be connected to the steam outlet of a new Intermediate Pressure (IP) separator during the charge, at a pressure of 5.25 bara and 149°C. The addition of the new IP separator on the process allows decreasing steadily the proportion of non-condensable gases in the steam, the effect on the storage capacity is reduced but still too important. Several operating strategies are then proposed and modeled in order to limit the effect of non-condensable gases in the steam on the storage capacity of the steam accumulator. The basic strategy is to extract steam during charging to remove the non-condensable gases. This allows limiting the partial pressure of non-condensable gases in the sky of the steam accumulator, this pressure being the parameter limiting the energy capacity. To compensate these evacuations, the incoming flow of steam is increased. The extracted gas flow (steam + non-condensable gases) is not lost energetically in geothermal because it can be reinjected and valorized in the process.

For the targeted energy of 5 MWh, the steam accumulator has a volume of 186 m^3 and contains 133 m^3 of liquid water, for a diameter of 3.6 m and a length of 19 m.

INSHEIM SITE

Insheim site has a brine temperature of 160°C, which does not circulate directly in the process. A pressurized intermediate water circuit will be installed, to extract heat from the brine circuit via a series of heat exchangers and supplies an ORC and a District Heating (DH) network. A pressurized water thermocline storage will be installed on this site. In a "thermocline" storage module, the hot HTF is located above the cold HTF in a single tank, the two zones being separated by a thermal gradient or thermocline (Figure 3). The gradient zone must be as thin as possible to increase its capacity for a given size, and this thickness depends in the first order on the distribution of the fluid at the bottom or top of the reservoir.

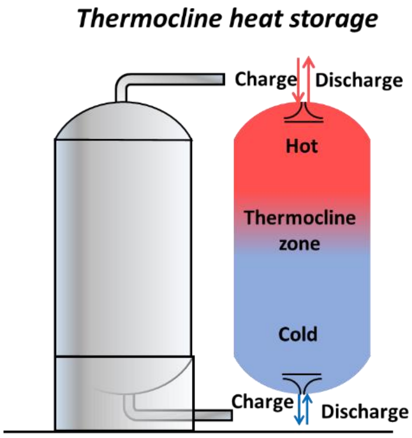

Figure 3. Principle of a "thermocline" storage module

The common objective of this kind of TES systems is to shave the District Heating (DH) demands pics. However, for the Insheim site, the geothermal production (26 MW) is higher than the maximum power of the DH (8MW). Therefore, the possible objectives of the TES system on this site are to cover the geothermal well shutdowns, to add flexibility to the ORC production, and to reduce the variation of the thermal power for the ORC. Those objectives are being studied in the GeoSmart project, in order to calculate the optimum capacity that allows reaching them, taking into account the project budget. The capacity of this storage system will be between 5 MWh and 10 MWh.

STRATEGIES FOR MITIGATING MINERAL PRECIPITATION PROBLEMS USING A SCALING REDUCTION SYSTEM IN KIZILDERE 2 GPP

Mineral precipitation which directly affects production and injection performances , is one of the main challenges in geothermal power production. The operation and maintenance of multi-flash geothermal power plants tend to be more complex than others, such as binary types and single flash geothermal power plants. Various pressure and temperature conditions require chemical treatment applications for each pressure level to control specifc mineral deposition in the system. The scale inhibitor applications provide best solution to control and prevent various deposits if the parameters such as scale type, deposit location, inhibitor type, dosage rate, and dilution rates are well defined. In Kızıldere 2 GPP, organic polymer-based inhibitors prevent calcite scaling in high-temperature production wells and silicate mineral precipitation in surface vessels and injection lines. Variabled dynamic conditions of liquid-dominated geothermal fluids cause multifeed wells to differ over time in terms of water chemistry and production performance. Therefore, the equilibriated water chemistry is significantly affected by the production performance of the any feed zones. Changes in water chemistry have significant effects on mineral solubility. It is essential to monitor the water chemistry of the wells to update the dosing parameters accordingly (Figure 4) .

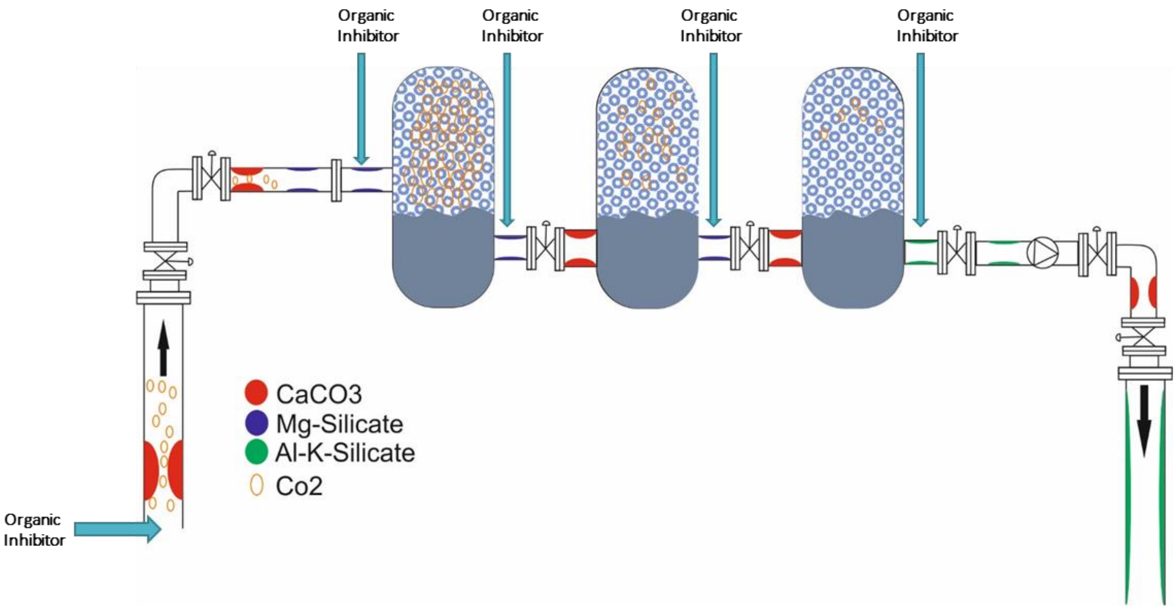

Figure 4. Possible scale and inhibitor application points in Kızıldere 2 GPP.

Silica precipitation has important effects in determining the energy that can be produced from geothermal sources, because the injection temperature is configured by the saturation temperature of silica minerals dissolved in the geothermal fluid. Injection temperature in Kızıldere geothermal field is limited to 104 °C. There is a very intense energy that cannot be used in the field. In a section of GeoSmart project, innovative solutions have been proposed for fully utilize the thermal energy by decreasing injection temperature to 50 °C without additional operation cost and well damages. For this purpose a mathematical model describing silica scale potential and concentration change of SiO_2 with time to optimize the heat exchanger desing and mineral precipitation hazards in injection wells, was carried out by UoI. It's found that the carbonate accompanied silica deposition formed in injection lines and wells causes deplation on injectivity in the injection wells and geologic formation. A scaling reactor which aims preventing the precipitation in injection wells, was added in scale removal system desing as a remedy to work together with the retention tank that provides the silica polymerization (Figure 5).

Sample Number	Location	Sampling P (barg)	Sampling T (°C)	pH	SiO_2 (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{-2} (mg/l)	Na^+ (mg/l)	Mg^{+2} (mg/l)	Ca^{+2} (mg/l)	Scale Type
1	**Shallow Depth Production Well**	8.5	175	6.78	233	1959	109	1107	1133	0.60	15.5	Carbonate
2	**Deep Production Well**	7	170	8.78	478	1503	128	1085	1354	0.07	10.3	Cabonate, Mg Silicate
3	**HP Seperator**	5.6	161	8.11	330	1751	117	1110	1242	0.30	13.7	Carbonate, Mg Silicate
4	**IP Seperator**	2.6	140	9.30	355	608	124	1172	1359	0.52	24.2	Carbonate, Mg Silicate,
5	**LP Seperator**	0.24	105	9.55	352	40	132	1244	1453	0.73	28.5	Carbonate, Mg & Al Silicate,
6	**Brine Inj. Pump Dıscharge**	33	105	9.53	360	54	132	1242	1443	0.51	32.9	Carbonate, K & Al Silicate,
7	**Re-Incetion Well**	27.2	104	9.48	392	143	132	1240	1434	0.28	37.3	Carbonate, K&Al Silicate, Amorph. Silica

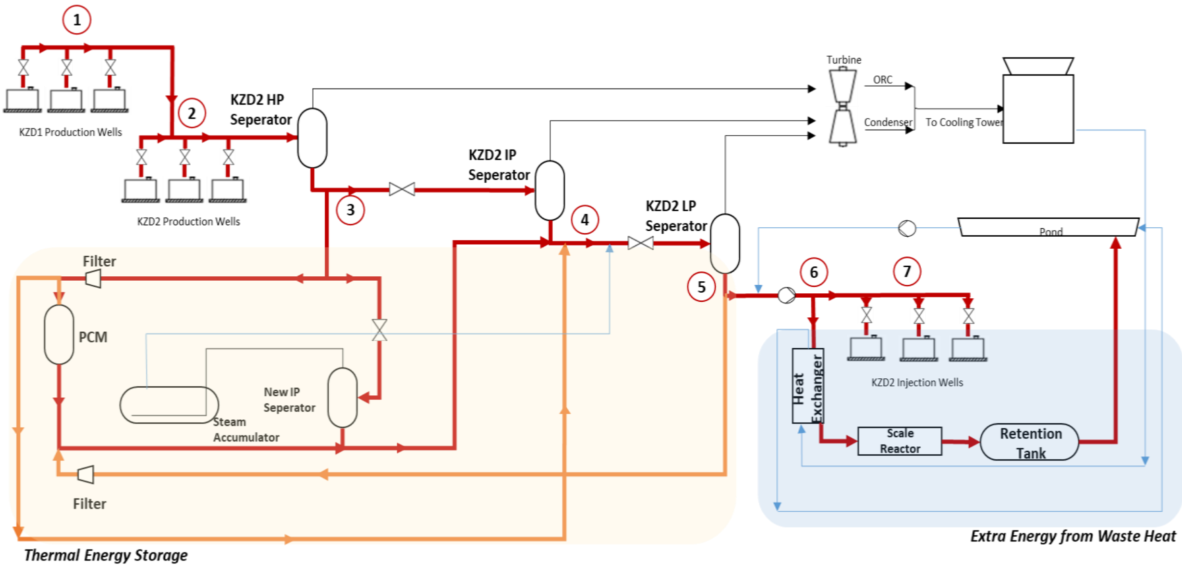

Figure 5. Brine and Scale chemistry and Geosmart integrations shematics of Kızıldere 2 GPP.

CONCLUSIONS

The GeoSmart project has been working on improving the flexibility and efficiency of the geothermal power plants via development of tailored thermal storage solutions including installation of a scaling reduction system. These systems have been designed and will be integrated in the power plants at Kizildere and Insheim for demonstration.

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