CSP Crushed-Rock Heat Storage with Oil or Nitrate-Salt Heat Transfer

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1. Introduction

The large-scale use of wind or solar results in collapse of electricity prices at times of large wind or solar production. Addition of heat storage in Concentrated Solar Power (CSP) plants enables (1) storing heat at times of high solar input to produce (1) electricity at times of high prices and (2) little or no electricity at times of low prices and excess production capacity. The capital cost of heat storage per kilowatt-hour (KWh) determines how long one can economically store heat to match market demand. Solar output has a daily cycle and often in the mid-latitudes a three day cycle associated with the weather. Electricity demand varies on hourly basis over the day, a three day cycle in the mid-latitudes associated with the weather (heating and cooling) and a weekday/weekend cycle associated with the workweek. Very low-cost heat storage enables storing heat for a week (including the weekend/weekday cycle) to maximize revenue. We describe herein (1) the Crushed Rock Ultra-large Stored Heat (CRUSH) system with capital cost goals of $2-4/kWh to enable heat storage from hours to a week and (2) tradeoffs associated with moving heat to and from the crushed rock using heat transfer oils versus nitrate salts. The system can be built in sizes to 100 GWhs.

2. CRUSH System Design

The existing commercial CSP heat-storage systems use tanks of hot and cold nitrate salts with capital costs of $20-30/KWh of heat. More than 85% of the costs are associated with the tanks and the nitrate salt. The CRUSH system [1,2] shown in Figure 1 reduces these costs by (1) storing heat in crushed rock, (2) transferring heat to and from the crushed rock using nitrate salts or heat transfer oils but not using these fluids for heat storage and (3) replacing the expensive tanks with a low-cost building similar in construction to an aircraft hangar with internal insulation.

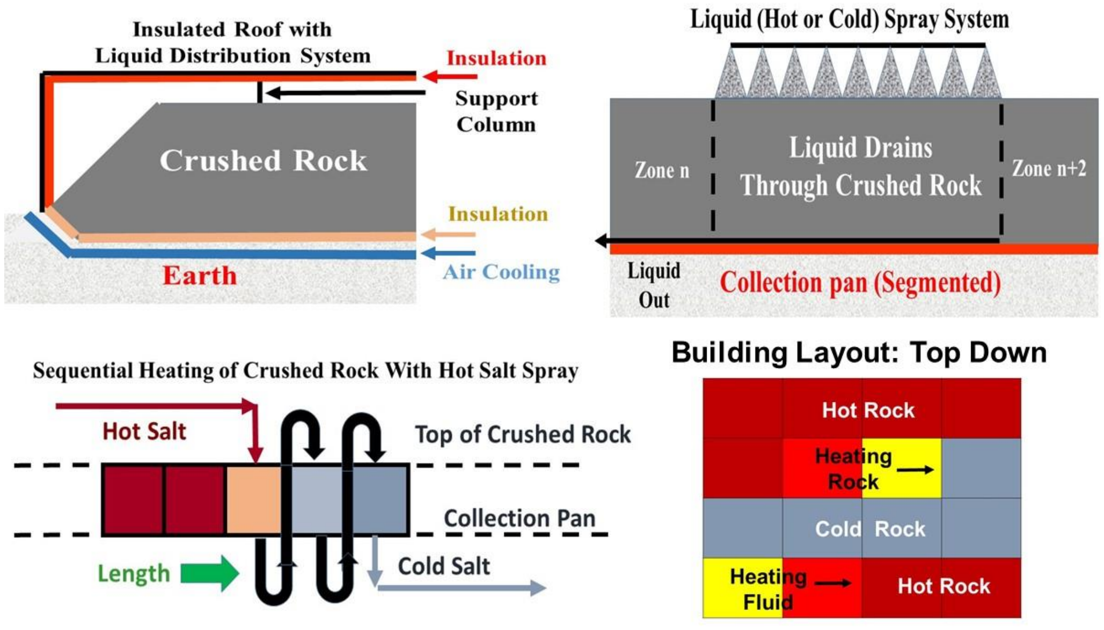

Figure 1. CRUSH System Design

In the CRUSH system, crushed rock fill replaces the fluid (oil or nitrate salts) as the heat storage material. The crushed rock pile may be 15 to 30 meters high inside an insulated building similar to an aircraft hangar. The use of an insulated building avoids the high costs associated with storage tanks. These features are shown in the upper left of Figure 1. The hot fluid from CSP is sprayed onto the top of the rock, flows by gravity to the drain pans below while transferring heat from liquid to crushed rock. If the liquid is not fully cooled when it reaches the drain pans, it is sprayed onto the next section of the rock and then returned to be reheated. (lower left). Rock is heated section by section (lower right). To recover heat from storage, cold fluid is sprayed on top of the hot crushed rock, flows through the rock by gravity to be heated and sent to the power cycle. The fluid is used only for heat transfer, not to store heat as is done in traditional nitrate-salt heat storage systems.

The other design feature to reduce cost is replacing expensive tanks with a low-cost insulated building. The tanks are expensive because they are constructed out of high-temperature steels to withstand the hydrostatic pressures of hot liquid nitrate salt. The crushed rock pile has a flat top and slopped sides—there are no horizontal forces on the buildng walls. This enables the use of a low-cost aircraft-hanger-type building with a low-cost steel structural at atmospheric temperatures with the high-temperature insulation on the inside of the building. Only the surface of the insulation facing the rock sees high temperatures. The heat losses are very low—partly because of the small surface to volume ratio of this system relative to any other storage technology.

3. Choice of Heat-Transfer Oils or Nitrate Salts

Lower-temperature CSP systems use heat transfer oils to ~400°C while higher temperature CSP systems use nitrate salts at temperatures that approach 600°C. Either heat-transfer fluid can be used with the CRUSH system but there are major engineering tradeoffs.

Heat-transfer oils are the simplest option. Oils do not chemically react with most rocks. The oil industry has developed filters to remove small particles from oils—required to avoid the abrasive behavior of a fluid with small particles from crushed rock flowing through heat exchangers. However, heat-transfer oils are expensive. Our assessment of the residual oil on rock surfaces when not transferring heat is less than 1% of the void volume in the crushed rock. Small rock sizes (< 1 cm) with high surface areas are to be avoided. The building and residual oil inventory determine the incremental capital cost of an added gigawatt-hour of heat storage. Those costs are sufficiently low to enable economic heat storage for a week with oil-based CSP systems.

Nitrate salts have two major advantages compared to heat transfer oils: (1) higher peak operating temperatures and (2) significantly lower capital costs per unit volume. However, only some rocks are chemically compatible with nitrate salts. The requirements for salt cleanup beyond filtering out particles may depend upon the type of CSP collector. Traditional solar power tower heat exchangers operate at high heat fluxes that impose more requirements on salt properties. Advanced direct-adsorption nitrate-salt CSP systems [3] avoid these challenges because the concentrated light is volumetrically adsorbed in the nitrate salt—the salt does not flow through tubes in the collector. These open systems pick up impurities from the atmosphere and can operate with higher and more variable levels of impurities in the salt.

References

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