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Rock bed storage for solar thermal power plants: Rock characteristics, suitability, and availability

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ABSTRACT

It is proposed that air–rock packed beds are suitable for thermal storage in solar power plants at temperatures of approximately 500–600 °C. However, little has been published in the field of thermal energy storage on the suitability of rock for this particular application. Desirable characteristics of rock for this application are presented, and the different rock types are discussed in the light of these requirements. A survey of the literature in other fields on rock characteristics shows which rock is most likely to be suitable. Results from thermal cycling tests (more than 900 cycles at rates of 2 °C/min) on a variety of rock samples are reported. Dolerite withstood this process well; some gneisses did but others did not. Geological maps showing the availability of potentially suitable rock in solar-rich regions of South Africa are presented. There are potentially suitable rock types (for example dolerite, granite, gneiss) in parts of the country which are deemed to have a good solar resource. Dolerite, which is found in copious quantities in insolation-rich regions, should be well-suited to packed bed thermal storage.

1. Introduction

Solar thermal power plants which incorporate thermal storage are desirable because they can supply electricity on demand. However, there is a need for the development and improvement of thermal storage systems, which need to be made more cost effective. At present, most of the thermal storage in use in solar power plants is based on liquid sensible heat storage – molten salt [1]. One alternative to molten salt thermal storage is an air–rock packed bed. Several papers have discussed the use of air–rock beds for thermal storage at temperatures in the region of 500 °C. Curto and Stern [2] proposed a combined cycle solar power plant which makes use of copper smelter slag at temperatures of approximately 540 °C. Fricker [3] wrote that there is “great potential” for using rock beds at temperatures up to 550 °C, and Zanganeh et al. [4] have tested a 21 m^3 rock bed at temperatures up to 650 °C and proposed a design for use at solar thermal power plants.

The *S*tellenbosch *UN*iversity *S*olar *PO*wer *T*hermodynamic (SUNSPOT) cycle (Fig. 1) proposed by Kroger [5] is an example of a solar thermal power plant in which a rock bed is used. The exhaust gas from the turbine is ducted into a rock bed, where the thermal energy is stored. The thermal energy in the rock bed is recovered by reversing the flow direction of the air stream, which is ducted to a boiler to generate steam for a steam turbine. Alternatively, a power plant to meet peak demand could make use of a packed bed, as shown in Fig. 2.

There are few experimental results for packed beds of rock at 500 °C. Zavattoni et al. [6] tested a 25 m^3 bed of steatite, a compact form of talc, a mineral (see also [4]). There is little long-term performance data for rock beds to show the degradation of the rock over time with thermal cycling. There is a need to know which rock types are likely to be suitable for thermal storage at these temperatures, and the localities in which they are found. This paper forms a part of a study on the suitability of rock beds for thermal storage in concentrating solar power plants [7], and focuses on the requirements of a rock bed thermal storage system and presents the characteristics of rocks as they are known from the literature. Experiments were conducted to gauge the suitability of rock for thermal cycling resistance. Maps showing the location of suitable rock in South Africa are given.

2. Rock types, properties and availability

This section gives a brief overview of the different types of rock. The method of formation of the rock is summarised, and

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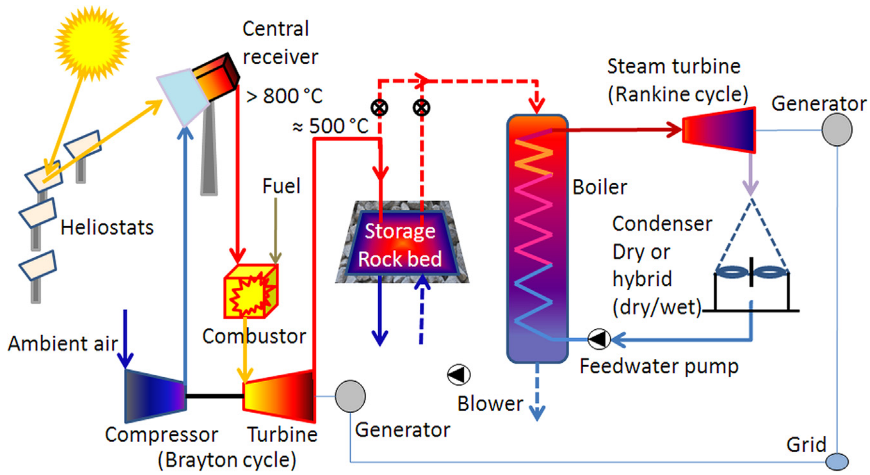

Fig. 1. SUNSPOT cycle schematic for a solar power plant.

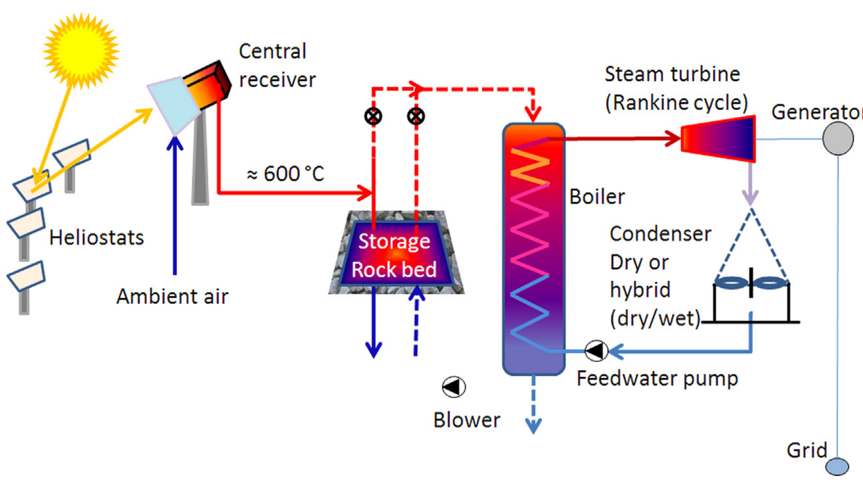

Fig. 2. Solar power plant cycle for peak demand periods.

characteristics most likely to influence suitability for thermal storage are mentioned. Desirable thermal storage material characteristics for a rock bed at temperatures up to 500–600 °C are presented, and the different rock types are discussed in the light of these requirements.

2.1. Rock types: igneous, metamorphic and sedimentary

There are three types of rocks; they are classified as igneous, metamorphic and sedimentary [8]. A brief description of each follows in Sections 2.1.1–2.1.3, with emphasis on those aspects of the rock formation and properties that are most likely to influence the suitability of the rock in a thermal storage application. Sufficient background is given to allow a reader with no knowledge of geology to understand Sections 2.3 and 2.4. A selection of common rock and mineral types is given in Table 1, Section 2.1.4.

2.1.1. Igneous rock

Igneous rocks are formed as a result of the solidification (crystallisation) of magma. As the magma cools, the ions in the melt arrange themselves in orderly patterns, and crystals grow, until all the liquid has solidified into interlocking crystals (crystallisation; [9]). The molten material does not all crystallise at once – different minerals have different crystallisation temperatures.

Two main types of igneous rocks can be distinguished: intrusive or plutonic rock, crystallised and solidified below the surface at higher ambient temperatures and pressures; and extrusive or volcanic rock, solidified on the surface [8]. Plutonic and volcanic rocks may be compositionally similar, but are texturally distinct. Plutonic rock – such as granite – tends to have large, mm- to cm-size mineral grains (visible to the naked eye). These coarser, interlocking textures are the result of the relatively slow cooling of the magmas. Volcanic rocks – such as basaltic lavas – show finer grain sizes that are the result of rapid cooling. Porphyritic textures describe rock with larger minerals in a finer matrix in which the larger grains are inherited from crystallisation of a magma at depth that has subsequently risen to shallower crustal levels. Very rapid cooling may lead to amorphous, non-crystalline textures and volcanic glasses.

Granites are the most widespread plutonic rocks, forming a substantial component of the continental crust. Granites are commonly coarse- and even-grained rocks, consisting of quartz, feldspars and micas. Large plutonic bodies may be surrounded by metamorphic rock. Smaller bodies of igneous rock, for example dolerite, usually have a finer grain; they are found in bodies such as dikes, which are parallel-sided sheet-like bodies [10].

Volcanic rocks result from magmas that have reached the Earth's surface to form lava flows, gas-rich eruptions (tuffs) or