Solar rotary kiln for continuous treatment of particle material: Chemical experiments from micro to milli meter particles size

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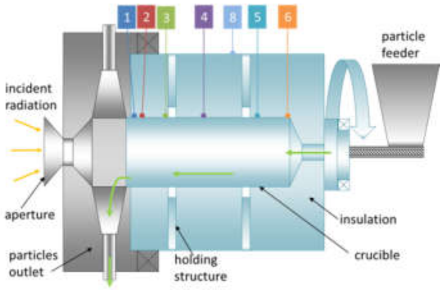
1. Introduction

Concentrated solar energy can provide high temperature renewable heat. This allows its application to high temperature processes such as cement or phosphate production. In these processes a high amount of energy is required to heat the material in the form of particles to temperatures close to 1000 °C. When the treated material has a wide particle size distribution, some reactors such as fluidized bed or vortex reactors are not suitable. At the opposite rotary kiln can operate with a wide range of particle size. Past studies have demonstrated rotary kiln driven by concentrated solar energy on a kg-scale [1,2], but with a narrow range of particle sizes. In the present study, two different materials were successfully treated to demonstrate the versatility of such a reactor with different particle sizes: micrometric particles of $CaCO_3$ were calcined to produce lime (as the main ingredient of cement) and mm-size redox granules were thermally reduced for storing thermochemical energy in solar power plants.

2. The reactor

The reactor, shown in Fig. 1, consists of an inconel cylindrical crucible surrounded by high temperature insulation and an external housing. The particles are fed into the reactor through a screw feeder. Depending on the characteristics of the particles, a suitable screw geometry was chosen. A rotation of 2-4 rpm and an inclination of about 1° allow the particles to flow through the crucible where they are heated and react. A non-rotating front part allows the extraction of the particles and the entry of the incident radiation. The system operates in closed and open configuration. In the closed configuration, a quartz window closes the aperture and a suction unit is applied to the back of the reactor. In the open configuration, the window is removed and two suction units are applied to the top of the front part and of the aperture, to prevent particles from escaping. Sensors are placed to measure the temperature along the reactor and the off-gas composition.



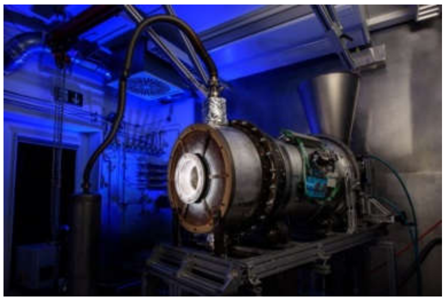


Fig. 1: a) Rotary kiln scheme, with rotating (blue) and stationary (grey) parts. From the right: screw feeder, rotating insulated crucible, fixed front. Green arrows show particles flow. b) Picture during operation

3. Applications

3.1. Cement calcination

The first experiments with the rotary kiln concerned the cement production process. The objective is to calcine cement raw meal (CRM) particles which would in a real plant be fed to a conventional clinkering kiln, for the production of cement. CRM is a mixture of $CaCO_3$ (80-85% of the total mass) and other aggregates such as silica and alumina. During calcination, $CaCO_3$ undergoes the reaction:

$CaCO_3 \rightarrow CaO + CO_2$ (1)

The particle size, ranging between 1-176 µm, must be small enough to ensure a solid-solid reaction between CaO and the aggregates in the subsequent clinkering process.

The first tests were carried out in the closed configuration, using a quartz window at the aperture. 30 minutes after the start of the feeding, dust was deposited on the window, hindering the entrance of the solar radiation. In order to operate for several hours without interruptions, the experiments were continued in the open configuration [4]. Fig. 2a shows an example of the results. The reactor is gradually heated for 1.5 hours, after which the particle flow started. The temperature at the back decreases abruptly to adapt to the temperature of the input material, before it stabilizes. After about 15 minutes the temperature in the entire crucible stabilizes, reaching a maximum of about 980 °C a few cm from the front. Particles leaving the kiln have a conversion rate of 88% which was measured afterwards in a TGA. The system was able to operate for several hours and for several tests without showing any problems [3].

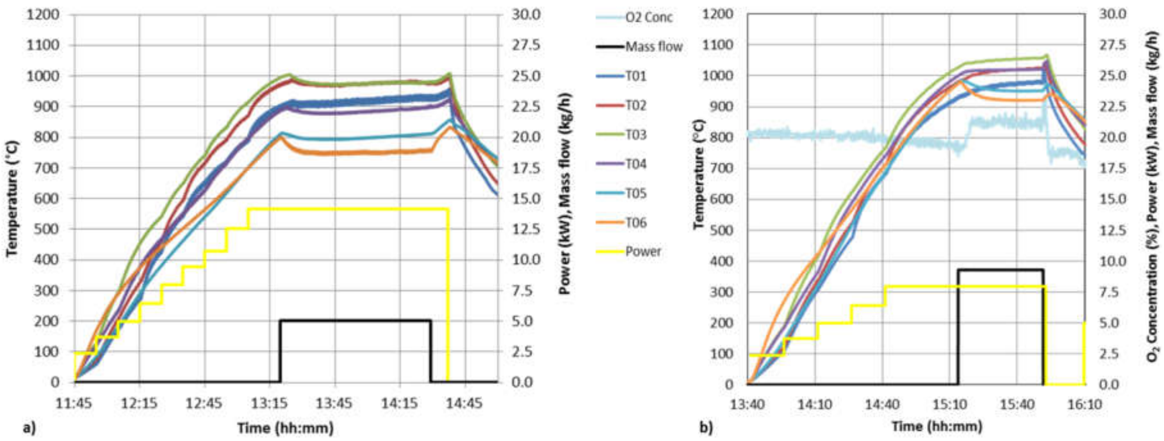


Fig. 2: Temperature evolution following the colors code in of Fig. 1a. On right axis: incident power, particle flow and oxygen concentration. a) Calcination of CRM. b) Reduction of metal-oxide granules.

3.2. Thermochemical storage

The second application is thermochemical storage for solar power plants. The storage material is heated to about 1050 °C and an endothermic reaction occurs during the hours of sunshine. The reversible (exothermic) reaction occurs when the sun is not available, and the energy is released by the particles to a heat transfer fluid. In this study, the storage material is a mixture of manganese and iron oxide $(0.7 \cdot Mn_2O_3)(0.3 \cdot Fe_2O_3)$. The composition has proved suitable for this application from previous studies [4], due to cyclability, operating temperature and reaction enthalpy. The endothermic reaction is the reduction of the metal oxide:

$3(Mn,Fe)_2O_3 \rightarrow 2(Mn,Fe)_3O_4 + 1/2\ O_2$ (2)

The diameter of the granules is 1-2 mm to facilitate the operation of the off-sun reactor. In this case the reactor operates in closed configuration. A seal has been added between the rotating and stationary part and a window has been placed at the aperture. An oxygen sensor was connected to the suction unit. An example of the results is shown in Fig. 2b. After 1.5 h heating, the particle flow was started. The temperature at the back decreases and then stabilizes. In steady operation, the reactor front reaches 1060 °C. When the particle flow starts, the oxygen concentration increases significantly, clearly indicating the reduction reaction.

References

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