Characterization of a Pilot Fluidized Bed Reactor for Solar Calcination Processes

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1. Introduction

Calcination of minerals at high temperature (> 700°C) is widely used in various industrial sectors to produce chemical commodities (lime, cement clinker, phosphates, mineral oxides, etc.). The minerals are usually crushed into powder and treated at high temperature in rotary kilns or fluidized beds. Nowadays, the heat necessary to drive the endothermic calcination is provided by gas or coal combustion. As a consequence, this process is the second source of carbon dioxide emission worldwide, behind power generation by combustion. Therefore, the use of renewable sources of heat would allow reducing significantly the carbon balance of the concerned industries: cement and glass factories, metal industry, etc. First researches on solar calcination dated from the early eighties [1]; this study targets the pilot-scale solar process based on the fluidization technology.

2. Experimental setup

The H2020 European project SOLPART [2] aims at developing a solar reactor prototype for the calcination of mineral particles such as calcium carbonate, dolomite and natural phosphate. The prototype was designed and tested at the 1-MW solar furnace of Odeillo, France. The solar reactor is a cavity-type solar receiver composed of a refractory cavity in which the absorber/reactor is located (Fig. 1). It consists of 4 compartments in series in which the particles are fluidized with air (Fig. 2) [3]. The front wall of the reactor is heated up by concentrated solar power. With a nominal power around 50 kW_{th}, the absorbed flux leads to wall temperatures around 1000°C and drives the endothermic calcination reaction at about 900°C by providing the sensible heat and the reaction enthalpy to the particles. The process is continuous and enables to treat a particle mass flux of several tens of kg/h depending on the solar flux and the expected conversion rate. The reactor characteristics correspond to an extension beyond the state of the art [4] by at least a factor 5. In order to monitor the process, the setup is equipped with around 50 thermocouples, several pressure sensors and flowmeters, and a gas analyzer (to measure the concentration of CO_2 produced by the reaction).

3. Results analysis and numerical modelling

The first step of the experimental campaign consisted in the calibration of the heliostat field of the solar furnace to determine the aiming strategy that leads to a mean incident flux density on the absorber wall in the range 150-250 kW/m^2. Then the solar calcination of calcite for producing lime has been tested ($CaCO_3 \rightarrow CaO + CO_2$) for various particle mass flow rate (10-60 kg/h). The experimental results obtained at steady state enable to validate a numerical model that assumes each compartment to be an ideal continuous stirred-tank reactor. The model is based on the energy and the mass balances. It takes the solar flux, the reaction kinetics and the properties of the reactor into account to compute the temperature and the conversion rate in each compartment. The model enables to predict the response of the system when the process parameters are varied. This model is the base of a more complete one aiming to scale up the system.

Fig. 1: Picture of the solar pilot reactor.

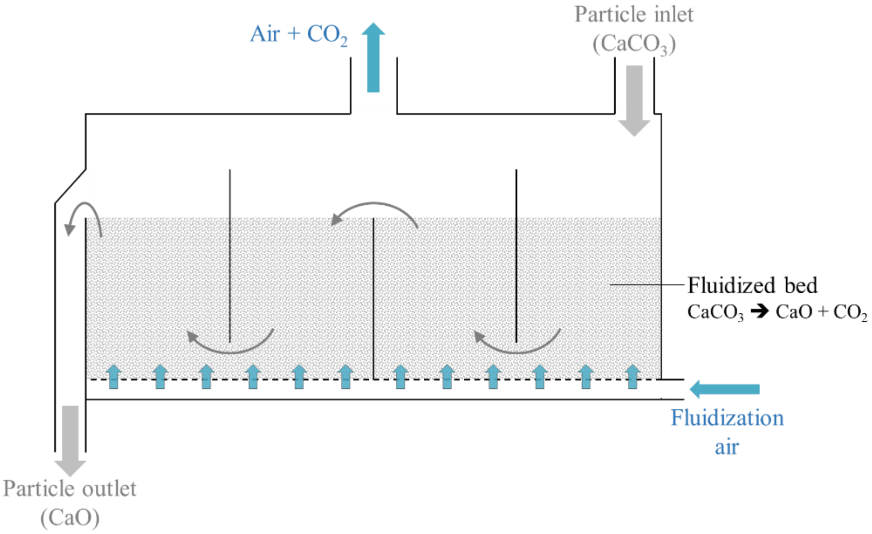

Fig. 2: Principle of particle and gas flows in the reactor.

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References

[1] Flamant G., Hernandez D., Bonet C., Traverse J.P. *Experimental aspect of the thermochemical conversion of solar energy; Decarbonation of CaCO3*, Solar Energy, (1980), Vol 24, 385-395.

[2] www.solpart-project.eu

[3] Levenspiel, O., *Chemical reaction engineering, 3rd Edition*, John Wiley and Sons, 1999.

[4] Meier A., Bonaldi E., Cella G.M., Lipinski W., Wuillemin D., Palumbo R. *Design and experimental investigation of a horizontal rotary reactor for solar thermal production of lime*, Energy (2004), 29, 811-821.