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Modelling a Calcium-Looping Fluidised Bed Calcination Reactor with Solar-Driven Heat Flux

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A new unidimensional computational model is developed to simulate a calcination reactor in a Calcium-looping process for thermochemical energy storage in concentrating solar power systems. The proposed reactor is an absorber tube exposed to concentrated solar radiation. This tube is also the riser of a circulating fluidised bed where the calcination reaction takes place. The proposed heat transfer process models are based on the core-annulus model and the hydrodynamic model is a modified version of the Kunii-Levenspiel model. The model considers the change in the mass flow rate of species and the density change of the phases in the axial direction of the reactor, usually considered constant in the models found in the literature. A higher calcination efficiency, up to 8 p.p., is obtained for the studied reference case when assuming constant density and mass flow rate. Simulations were performed by imposing a solar-driven non-uniform heat flux distribution on the reactor wall. The results show that a 6 m height reactor allows achieving a calcination efficiency of 66% for the reference conditions used. A sensitivity analysis shows that the solids mass flow rate and the inlet bed temperature are the parameters that most affect the calcination process efficiency.

1. Introduction

Concentrating solar power (CSP) is unique among the renewable energy technologies because it can easily be coupled with thermal energy storage (TES), making it highly dispatchable. Nowadays commercial TES uses molten-salt technology, which accounts for 75 % of the globally installed TES capacity. However, the molten salts that are currently used as heat transfer fluid have several disadvantages: corrosiveness, the maximum working temperature (~560 °C), which limits the system efficiency, and the significant energy consumption required to keep the molten salts at temperatures over 220 °C, to avoid solidification (Ortiz et al., 2019). In contrast, thermochemical energy storage (TCES) is an option that allows higher energy densities (Lovegrove and Stein, 2012). Several reversible reactions have been proposed for TCES, mainly based on carbonates, hydroxides, metal redox, and hydrides. One of the most promising systems relies upon the calcination-carbonation reversible reaction of $CaCO_3$-CaO and is known as the Calcium-looping (CaL) process. In this system, concentrated solar radiation is used to carry out the endothermic calcination reaction:

$$CaCO_3(s) \Leftrightarrow CaO(s) + CO_2(g), \qquad \Delta H_{calc} = 178.4 \times 10^3 \text{ J mol}^{-1} \tag{1}$$

The reaction products CaO and CO_2 may be stored separately and, when needed, they are brought together to carry out the exothermic carbonation reaction, releasing the stored energy (Ortiz et al., 2019). The main advantages of the CaL process are: (i) the low cost, wide availability, and harmlessness of natural CaO precursors, such as limestone and dolomite, (ii) the theoretical energy density of the CaL system, which is one of the largest among TCES systems, and (iii) the high reaction temperature of carbonation, which can overcome the current CSP temperature limitations of 550 to 600 °C for molten salts.

The CaL process for post-combustion CO_2 capture has been successfully demonstrated at lab- and pilot-scale, with carbonation under low CO_2 concentration and calcination under high CO_2 concentration at temperatures

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