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Portland cement clinker production using concentrated solar energy – A proof-of-concept approach

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ABSTRACT

The aim of this work was to demonstrate the feasibility of producing Portland cement clinker upon direct exposure of the raw materials under concentrated solar radiation using the PSA high concentration solar furnace SF40. For this purpose, a short thermal cycle (< 40 min) was devised including 5 min dwell times at temperatures in the range 900–950 °C and 1250–1300 °C, followed by 10–15 min at 1500–1550 °C. The chemical and mineralogical data of the grey clinker produced are encouraging since values of 51.0 ± 6.9% C_3S, 22.7 ± 5.3% C_2S, 8.6 ± 0.4% C_3A and 10.8 ± 0.7% C_4AF are similar to those observed for conventional clinker used for the production of Portland cement in accordance to EN 197-1 standard. White clinker, in turn, could not be produced by direct irradiation in this setup conditions because of its low absorptance of solar energy.

1. Introduction

It is of no surprise that concrete produced from Portland cement is one of the most versatile construction materials used in the world. The global production of Portland cement was estimated to be roughly 4.1 Gt in 2017 (van Oss, 2018).

The European Standard EN 197-1 defines Portland cement clinker as a hydraulic material consisting of at least two-thirds by mass of calcium silicates, the remainder being Al- and Fe-containing phases and other compounds.

Portland cement clinker is typically made by heating, in a rotary kiln, a homogenous mixture of calcaneus (i.e. containing $CaCO_3$ or other insoluble calcium salts) and argillaceous (i.e. clay-like) materials to a calcining temperature above 600 °C and then fired, normally at temperatures around 1500 °C, to produce a fine powder known as clinker (Sorrentino, 2011). When clinker is mixed with typically 6% gypsum ($CaSO_4{\cdot}2H_2O$), one gets Portland cement (Moir, 1997, ASTM C 150-07, 2007).

Breaking the reaction processes into a number of simple zones, one can make some approximations about the clinker formation process, in a rotatory kiln, where the following main reactions take place (Baron and Ollivier, 1996):

Zone 1: 2 min, 800–900 °C

Decomposition of calcium carbonate as follows:

$$CaCO_3 \xrightarrow{\text{heat}} CaO + CO_2 \quad (1)$$

Zone 2: 15 min, 900 – 1300 °C

Formation of secondary silicate phases, mainly $2CaO{\cdot}SiO_2$ (up to 1200 °C) as follows:

$$2CaO + SiO_2 \xrightarrow{\text{heat}} 2CaO{\cdot}SiO_2 \quad (2)$$

Zone 3: 12 min, 1300–1450 °C

Sintering and reaction within the melt to form ternary silicates and tetracalcium aluminoferrates:

$$2CaO{\cdot}SiO_2 + CaO \xrightarrow{\text{heat + time}} 3CaO{\cdot}SiO_2 \quad (3)$$

$$3CaO{\cdot}Al_2O_3 + CaO + Fe_2O_3 \xrightarrow{\text{heat + time}} 4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3 \quad (4)$$

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