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Full Length Article

Experimental investigations of oxyfuel burner for cement production application

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ABSTRACT

The production of cement is one of the CO_2 intensive processes, due to the inherent formation of CO_2 in the calcination process by decomposition of limestone which is additional to the CO_2 generated from fuel combustion. Carbon capture and storage technologies have been seen as a promising way to comply with CO_2 reduction targets. As part of the objectives of the Horizon 2020 project CEMCAP, the retrofitting of key parts of the equipment of a conventional cement plant to oxyfuel combustion are investigated. The present study reports the results of several combustion tests employing a downscaled commercial kiln burner to determine its adequacy for oxyfuel operation mode. The investigations were carried out in the 500 kW_{th} top-fired combustion facility at University of Stuttgart, which was previously adapted for these tests, including the installation of an electric preheating system to rise secondary gas temperature up to 800 °C. Fuel used is a German pre-dried lignite previously milled to required fineness in a separate location. A variety of in-flame measurements are performed at a dozen of ports located at different distances from burner outlet in order to characterize combustion behavior in each firing mode. It was observed that under oxyfuel mode additional parameters in burner configuration like total oxygen concentration and oxygen distribution in primary and secondary gas are key variables to adjust flame formation and obtain similar results as in conventional air firing.

1. Introduction

Cement is a binding material used globally for construction of buildings and infrastructures. The global annual production of this commodity has increased over 78% in the last thirteen years and rounds now 4,200 Mtpa [1,2]. The demand of this material is expected to increase by 12–23% by 2050 compared to 2014 [3]. In terms of CO_2 production, 0.54 tonnes of carbon dioxide are emitted per tonne of cement [3]. As a result, this sector is considered a CO_2 intensive industry. Over the years the sector has increased efforts to reduce CO_2 emissions, which include the use of alternative fuels and materials, as well as improvements in process efficiency. However, as stated by a recent study of OECD and IEA, if mitigation targets (maximum 2 °C increase from pre-industrial level) want to be achieved, CCS technologies should necessarily be implemented [4].

Oxyfuel combustion for the power sector is a mature CCS technology tested in demonstration facilities and scaled up to 30 MW [5–8]. The concept of oxyfuel can be summarized as the combustion of fuel in a gas mixture composed of pure oxygen and inert recirculated gases to control furnace temperatures. In the oxyfuel carbon capture technology concept for cement kilns, the recirculated exhaust gas predominantly consists of CO_2. By excluding air-borne nitrogen, CO_2 becomes enriched to very high concentrations, which simplifies its capture in a processing unit.

Oxyfuel research for cement production has been so far limited to theoretical analysis of its techno-economic feasibility [9,10] as well as numerical simulations [11–13] and small scale and pilot studies [14,15]. In contrast to the application of oxyfuel technology in power plant boilers, for the application in cement plants, changes in gas temperature and heat transfer to walls and material bed inside the rotary kiln must be considered, as they affect cement clinker formation [11,16]. A key question for retrofitting a cement plant for oxyfuel operation is whether conventional kiln burners can be used in oxyfuel operation and whether process stability and product quality are maintained. Modern cement kiln burners are constructed to be flexible in dosing gaseous, liquid or pulverized fuels. Most of these modern burners are constructed to allow flame adjustments e.g. by modifying axial and swirling flows according to particular operation needs. The present investigations are focused on testing a downscaled cement burner to assess its suitability to operate under oxyfuel conditions and identify

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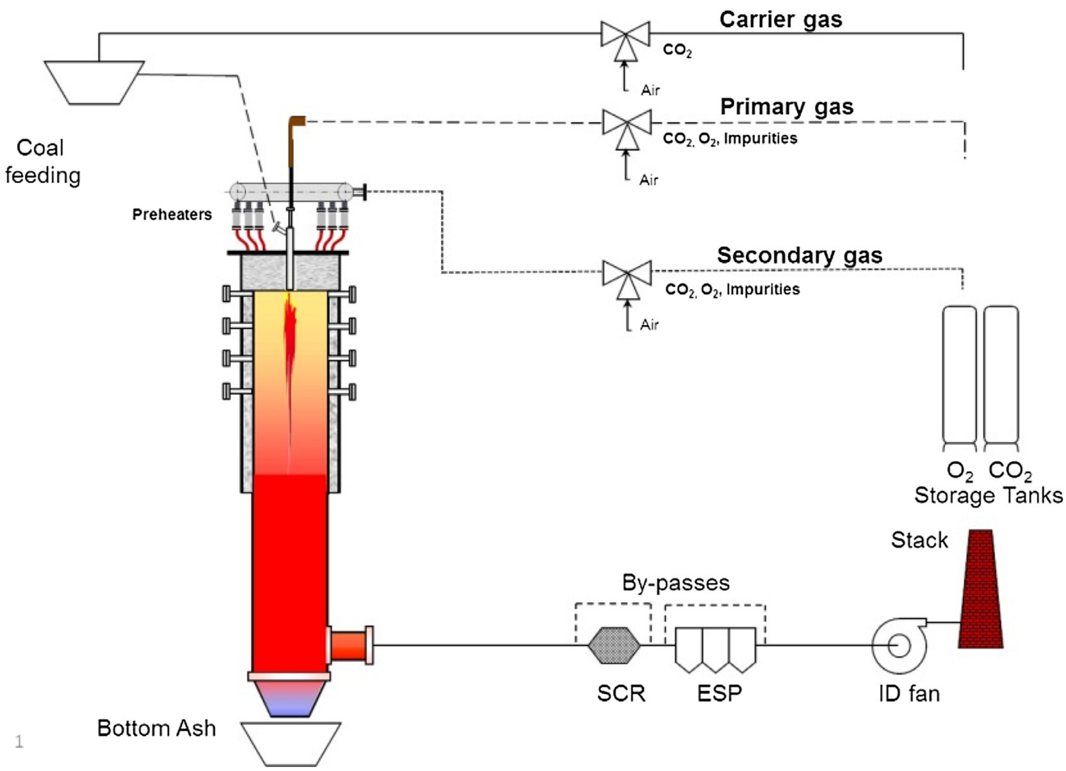

Fig. 1. Schematic of the 500 kW_{th} pilot test facility.

key burner settings in order to obtain similar flame/process characteristics as in conventional operation with air.

2. Experimental setup

2.1. Test rig

The tests were carried out in a 500 kW facility located at University of Stuttgart (see Fig. 1). The test rig was previously modified to account for singularities of cement process conditions regarding the injection of secondary gas. In a rotary kiln for cement production only 10–15% of total air for combustion is supplied through burner channels. The complementary air for combustion is preheated above 800 °C in the clinker cooler and later supplied directly to the furnace as secondary gas flow. This process condition was implemented in the test facility by installing an electrical gas preheater. Secondary gas is supplied directly into the combustion chamber through an annular opening in furnace roof that surrounds burner location. The dimension of this annular slot was designed to reproduce a secondary gas velocity in the range of industrial scale (5 m/s approx.).

The combustion chamber has a total length of 7 m and an inner diameter of 0.8 m. Multiple measurement ports are distributed along the height of the reactor where probes are introduced to perform inflame measurements. Combustion gas is sampled at furnace outlet and analysed continuously for O_2, CO, CO_2, SO_2 and NO_x. With a portable sample device gas inflame measurements are done at various axial and radial locations to create an enhanced overview of gaseous species distribution inside the furnace.

Additional equipment is located along the flue gas cleaning train (SCR, dust electro-filter, bag filter). The recirculation of exhaust gases back to the furnace is possible, however, during the tests reported here a synthetic recirculation, i.e. a controlled mixture of CO_2 and O_2 from storage tanks was used. The justification for this decision lays in the need to avoid a recirculation of water/dust that could suppose an operation risk for the electrical preheater system with the additional advantage that a better control of primary, carrier and secondary gas composition was achieved in this way.

2.2. Description of burner design

The burner used for the present investigations is a downscaled design of a modern cement kiln burner. The downscaling was done focusing on the Specific flame momentum (SFM) or flame impulse, which is calculated according to the next equation:

$$SFM\left[\frac{N}{MW}\right] = \frac{m_{prim} \cdot v_{prim}}{Q_{fuel}}$$

where m_{prim} and v_{prim} are the mass and velocity of primary gas, and Q_{fuel} the thermal fuel input. Modern kiln burners are typically designed for specific momentum in the range of 6–14 N/MW. As shown in Table 1, the burner produced a SFM of 10 N/MW in air mode, while during oxyfuel operation higher momentum was calculated due to primary gas flow and density differences between CO_2 and air.

Fig. 2 presents a sketch of the tested burner. The burner diameter is 75 mm and the design is characterized by an arrangement of eight jet nozzles for primary gas injection. These gas nozzles are designed to produce a high momentum jet flame, which is necessary to promote the

Table 1
Inflow conditions in air and oxyfuel demonstration tests.

		Air	OF29	OF32
Thermal Input	kW	400	400	400
Primary gas composition	Vol.-%, wet	Air	60% O_2 40% CO_2	60% O_2 40% CO_2
Secondary gas composition	Vol.-%, wet	Air	19,5% O_2 80,5% CO_2	23,5% O_2 76,5% CO_2
Fuel carrier gas composition	Vol.-%, wet	Air	100% CO_2	100% CO_2
Amount primary/secondary/carrier gas	Nm^3	80/285/25	90/170/25	90/140/25
λ	–	1,10	1,10	1,10
Flame momentum	N/MW	10,0	17,8	17,7

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