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CLEANKER – Clean clinker by Calcium Looping process for low CO_2 cement production

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Abstract

The EU Horizon 2020 CLEANKER project (www.cleanker.eu) aims at demonstrating in operational environment at pre-commercial scale the Calcium Looping (CaL) technology in a configuration highly integrated with the cement production process, making use of entrained flow reactors. To this aim, a demonstration CaL plant will be erected and operated in industrial environment, capturing CO_2 from a slip stream of flue gas of an industrial cement kiln. In CLEANKER, knowledge on the properties of raw meals as CO_2 sorbent, on reactors fluid-dynamics, on techno-economic performance, on life cycle assessment and on CO_2 stabilization by mineral carbonation will be developed, contributing to advance the integrated CaL technology to TRL7.

Keywords: clinker; cement; CO_2 capture; Calcium Looping; Horizon2020

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1. Introduction

Cement production is responsible for about 8% of global anthropogenic CO_2 emissions [1] and for about 27% of global anthropogenic CO_2 emissions from industrial sources worldwide [2]. The cement industry is thus a key-sector for the reduction of CO_2 emissions. Around 60% of the direct CO_2 emissions from the clinker burning process are due to the calcination of limestone (i.e. dissociation of $CaCO_3$ into CaO and CO_2). The balance is associated to the emissions from combustion of heavy fuels, mostly needed to drive the endothermic calcination reaction. In addition, indirect emissions are also associated to the consumption of electric power required by the process (e.g. grinding).

According to IEA and ZEP studies [2, 3], the cement industry is key to the achievement of the 2°C target for the global temperature increase (IEA 2DS scenario), since it should contribute to the largest CO2 emission reduction through CCS in Europe.

In this framework, the CLEANKER (CLEAN clinKER production by calcium looping process) project (www.cleanker.eu) got EC support from October 2017 to September 2021 under the Horizon 2020 call "Enabling decarbonisation of the fossil fuel-based power sector and energy intensive industry through CCS" (LCE 29 – 2017) to advance the integrated Calcium looping process for CO_2 capture in cement plants.

Nomenclature

CaL	Calcium Looping
CCS	Carbon Capture and Storage
EC	European Commission
EU	European Union
IEA	International Energy Agency
LCA	Life Cycle Assessment
LCE	Low-Carbon Energy
SME	Small and Medium-sized Enterprises
TRL	Technology Readiness Level
ZEP	Zero Emissions Platform

2. CLEANKER technology – Calcium Looping and its challenges

In addition to oxyfuel combustion and post-combustion solvent-based capture technologies, which have attracted most of the research efforts up to now, Calcium Looping (or carbonate looping) is recognized as another very promising emerging technology for CO_2 capture in cement plants [4]. Calcium looping is a regenerative process, which takes advantage of the capacity of calcium oxide-based sorbents to capture CO_2 at high temperatures. The process is divided in two basic steps:

(1) the capture of CO_2 by "carbonation" of CaO to form $CaCO_3$ in a reactor operating at around 650°C; and
(2) oxyfuel calcination in a reactor operating above 900-920°C, which makes the CaO available again and releases a gas stream of nearly pure CO_2.

CaL appears particularly promising for application in cement plants because:

- CaO sorbent originates from the same raw material used for clinker production. Therefore, no additional chemical substances are needed with respect to the materials already used in the cement plant;
- The rotary kiln and the clinker cooler, two key units of the clinker production process, can be operated as in conventional plants and retrofittability of existing kilns may therefore be simpler;
- The adoption of entrained flow gas-solid reactors, commonly used in cement plants, is particularly suitable for this Calcium Looping configuration, because in such reactors the same finely grounded raw material

prepared for clinker production (CaO) can also be used for CO_2 sorption without additional milling requirements.

Two fundamental options have been proposed in literature for integrating the CaL in cement kilns [5, 6, 7]. The first and most straightforward one is the tail-end CaL process configuration, where the CaL reactors are placed downstream of the clinker burning line as a relatively independent unit and the carbonator treats the flue gas exiting the cement kiln preheater or the raw meal [8]. The second option is the highly integrated CaL process configuration (Fig. 1), where the carbonator of the CaL process is integrated in the preheating tower of the clinker burning line [9]. The carbonator treats the flue gas from the rotary kiln after proper cooling and the calciner of the CaL process coincides with the cement kiln precalciner, which is operated in oxyfuel combustion mode.

Compared to the tail-end CaL configuration, which is based on the conventional fluidized bed CaL reactors and has been demonstrated up to TRL6 [10, 11] in the framework of the Cemcap project [12], the integrated CaL process with entrained flow reactors is less advanced. Fundamental knowledge needs to be built on the performance of raw meal as CO_2 sorbent, which appears highly influenced by the level of aggregation between Ca and Si compounds in the raw meal and by the calcination conditions [13, 14]. Fluid-dynamics of the carbonator under high solid to gas ratio also needs to be better understood to validate reactor models currently developed with basic gas-solid contact relations [9].

The fundamental knowledge generated by CLEANKER, together with the experience that will be gained in designing and operating the pilot plant will ultimately allow to define more reliable reactor models and to perform techno-economic analyses of full-scale CaL cement plants.

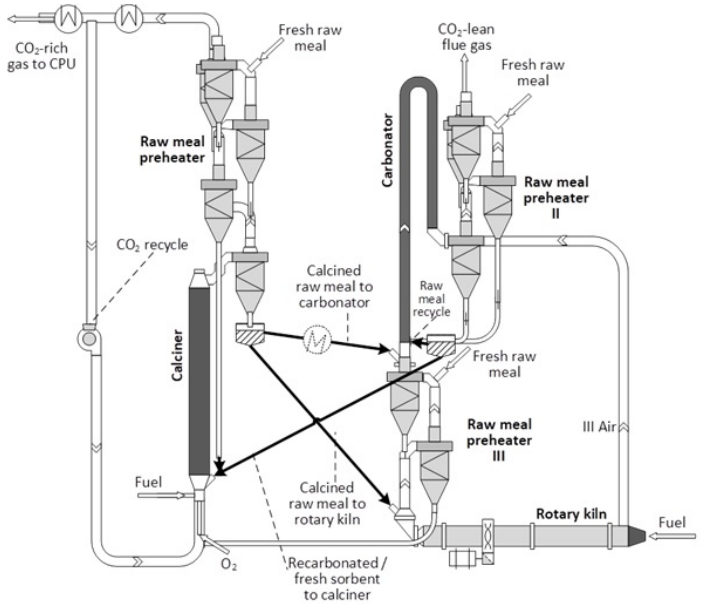

Fig. 1: Highly integrated CaL configuration in a cement plant

3. CLEANKER project

3.1. Objectives and approach

The core activity of the project is the design, construction and operation of a CaL demonstration system including the entrained-flow carbonator (the CO_2 absorber) and the entrained-flow oxyfuel calciner (the sorbent regenerator). This demonstration system will be connected to the Buzzi Unicem kiln of the Vernasca cement plant (Italy) and will capture the CO_2 from a slip stream of the flue gases from the kiln, using the same raw meal that is used for clinker production as CO_2 sorbent.

Other activities will include: (i) screening of different raw meals to assess their properties as CO_2 sorbent, (ii) reactors and process modelling, (iii) scale-up study, (iv) economic analysis, (v) life cycle assessment, (vi) CO_2 transport, storage and utilization study, (vii) demonstration of the complete value chain, including mineral carbonation of waste ash with the CO_2 captured in the pilot system, (viii) exploitation study for the demonstration of the technology in operational environment at pre commercial scale (TRL>7) and for its first commercial exploitation based on CO_2 transport and storage opportunities.

3.2. Toward the demonstrator

CLEANKER will develop the integrated CaL process configuration, by building a demonstration plant that will be connected to the 1.3 Mt/year cement plant in Vernasca. The demonstrator aims at demonstrating the complete CaL loop composed by the entrained flow carbonator and the entrained flow oxyfuel calciner(Fig. 2). Several test campaigns are foreseen in different operating conditions and using different types of raw meals, which will be brought to the plant from other quarries.

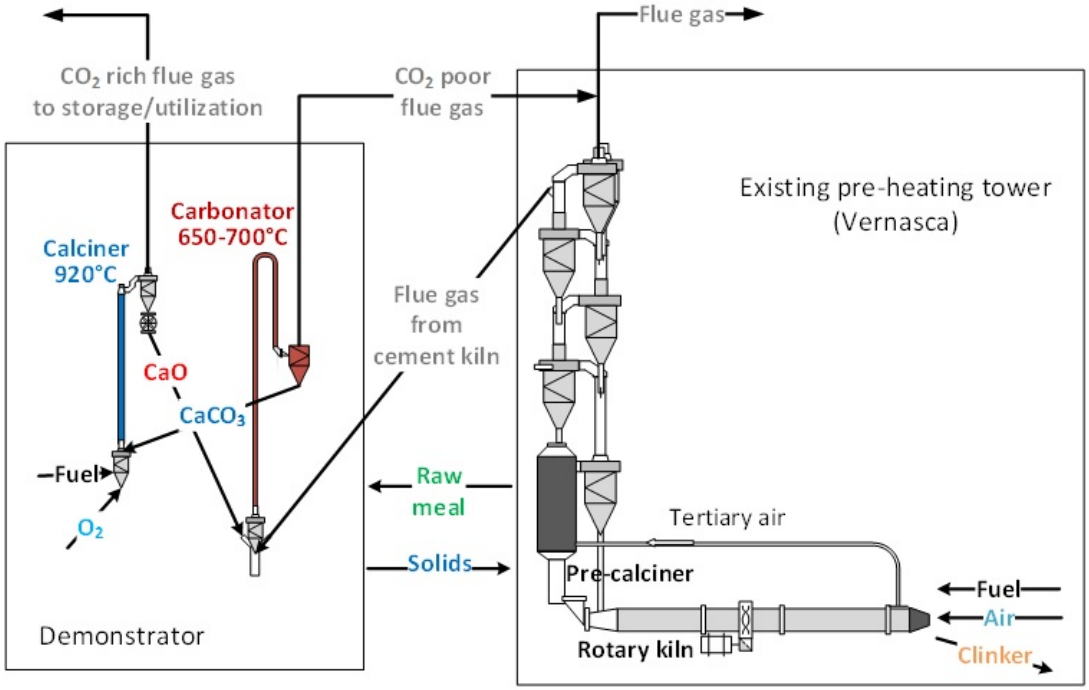

Fig. 2: Integration of CLEANKER demonstrator with the existing cement plant (Vernasca, Italy)

3.3. Implementation schedule

The implementation plan spans four years from October 2017 to September 2021. The first year will be devoted to the detailed design of the CaL demonstration system and extensive characterization of raw meals. The second year will be focused on the erection of the demonstrator. The last two years will see experimental campaigns, results analysis, evaluation of technology scale-up, economic analysis and LCA of the integrated system.

3.4. Partnership

CLEANKER consortium is an international partnership that integrates the research of 13 organizations:

- Representatives from the academia: Politecnico di Milano (Italy), Tallinn University of Technology (Estonia), Lappeenranta University of Technology (Finland); University of Stuttgart (Germany) and Tsinghua University (China);
- Research centres: LEAP (Italy), CSIC (Spain) and VDZ (Germany);
- SME: Quantis (Switzerland);
- Technology provider: IKN (Germany);
- End users: Buzzi Unicem -and Italcementi – Heidelberg Group (Italy);
- Environmental organization: Amici della Terra (Italy).

Thus including all the necessary expertise and access to the industrial facilities to reach the ambitious aim of the project.

The project is coordinated by LEAP, a non-profit research company participated by Politecnico di Milano which pursues effective Academia-Industry interaction in the field of Energy and the Environment.

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