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CEMCAP – making CO_2 capture retrofittable to cement plants

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Abstract

CEMCAP (http://www.sintef.no/cemcap/) is an EU Horizon 2020 project that aims at maturing CO_2 capture technologies suitable for retrofitting to existing cement plants by undertaking pilot-scale demonstration under industrially relevant conditions. Four capture technologies are being tested, analyzed and compared on a consistent basis: Oxyfuel capture, Chilled Ammonia Process (CAP), membrane-assisted CO_2 liquefaction and Calcium looping. Beyond CEMCAP, having more options than the already mature amine technology available for retrofittable CO_2 capture from cement plants, the technology options for CCS deployment will be expanded. However, it must be recognized that technology development alone will not contribute to the realization of CCS in the European cement industry or any industrial sector. Investment decisions in the EU will require a long term predictability of the policy for prevention of carbon leakage (re-location of production and emissions).

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Keywords: CO_2 capture; cement; oxyfuel; post combustion; retrofitability; Horizon2020

1. Introduction

CO_2 generation is an inherent part of the cement production process, due to the calcination of the most important raw material, limestone ($CaCO_3$ converted to CaO and CO_2): around 60 % of the CO_2 emissions from the clinker

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burning process are due to this reaction. There are currently no feasible methods to produce clinker and thus cement without releasing CO_2 from $CaCO_3$, and the cement production process emissions contribute to around 5% of global anthropogenic CO_2 emissions. In addition there are the emissions from combustion at the cement plant of fuels, which are to a large extent fossil, as well as the generation of electric power required for e.g. grinding of raw materials and clinker. Replacement of fossil fuels with renewables and waste is increasing but still limited in cement plant combustion, and the necessary electric power can in the future come from renewables or fossil power generation with CO_2 Capture and Storage (CCS). As stated by the IEA, solutions to contributing to reach the 2DS have to go beyond energy efficiency improvements and switching to low-carbon fuels [1]. Basically, this means that the main option to significantly reduce GHG emissions from the cement industry is to apply CCS. Because cement plants typically have a lifetime as long as 30-50 years, technologies must be developed to enable retrofit of CO_2 capture to existing cement plants. Against this background, the Horizon 2020 project CEMCAP (http://www.sintef.no/cemcap/) has been developed. The CEMCAP consortium comprises the following partners:

- Cement manufacturers: Norcem (NO), Italcementi (IT), HeidelbergCement (DE)
- Technology Providers: GE Carbon Capture (DE), GE power Sweden (SE), IKN (DE), ThyssenKrupp Industrial Solutions (DE)
- RD&I providers: SINTEF Energy research (NO), ECRA (DE), TNO (NL), ETH Zürich (CH), IFK/University of Stuttgart (DE), Politecnico di Milano (IT), CSIC (ES), VDZ (DE)

SINTEF Energy Research is project coordinator.

2. CEMCAP technologies – oxyfuel and post combustion capture

CEMCAP will develop and test three components for oxyfuel cement plants (oxyfuel calciner, burner and clinker cooler) and three widely different post combustion capture technologies (Chilled Ammonia Process, Membrane assisted CO_2 Liquefaction and Calcium Looping). Table 1 summarizes the characteristics of these four approaches to capture CO_2 from cement plants as they were anticipated at project startup.

Table 1. Characteristics of CO_2 capture technologies investigated in CEMCAP, as anticipated at project startup.

		Post combustion		
	Oxyfuel	**Chilled ammonia**	**Membrane-assisted CO_2 liquefaction**	**Calcium looping**
CO_2 capture principle	Combustion in oxygen (not air) gives a CO_2-rich exhaust. CO_2 is separated through condensation after compression and cooling.	Exhaust passes through a cold NH_3/water mixture, which absorbs CO_2. CO_2 is released as heat is added to the solution in a subsequent vessel.	A polymeric membrane is used to increase exhaust CO_2 concentration. CO_2 is separated through condensation after compression and cooling.	CaO particles react with CO_2 to from $CaCO_3$. CO_2 is released in a subsequent vessel through the addition of heat.
Required cement plant modifications	Retrofit possible through modification of burner and clinker cooler.	Retrofit appears simple, minor modifications required for heat integration.	No modifications of cement plant necessary. SOx, NOx, H_2O removal required upstream of capture unit.	$CaCO_3$/CaO integration: Waste from capture process (CaO) is cement plant raw material.
Clinker quality	Maintained quality must be confirmed.	Unchanged.	Unchanged.	Clinker quality is very likely to be maintained.
CO_2 purity and capture rate	CO_2 purification unit (CPU) needed. High capture rate and CO_2 purity possible (trade-off against power consumption).	Very high CO_2 purity, can also capture NOx, SOx. High capture rate possible.	High CO_2 purity (minor CO_2 impurities present). Trade-off between power consumption and CO_2 purity and capture rate.	Rather high CO_2 purity (minor/moderate CO_2 impurities present). High capture rate.

3. CEMCAP objectives and approach

3.1. CEMCAP objectives and final deliverable

The overall CEMCAP objective is to prepare the ground for large-scale implementation of CO_2 capture in the European cement industry. More specifically, CEMCAP will undertake pilot-scale demonstration under industrially relevant conditions for three components for the oxyfuel capture technology (oxyfuel burner, calciner and clinker cooler) and three fundamentally different post combustion capture technologies (chilled ammonia, membrane assisted CO_2 liquefaction and calcium looping) through testing at industrially relevant conditions.

Part of the analysis of the CO_2 capture technologies will be to evaluate their retrofitability to cement plants. This study will focus not only on how a capture technology can be retrofitted to a typical cement plant, but also on the environmental compatibility and maintained product (clinker) quality. It is also an objective to describe how the investigated capture technologies must be developed further to reach commercial scale, and the associated necessary/potential innovations. The ultimate deliverable of CEMCAP will be a public document that summarizes the project with the aim to constitute a techno-economic decision base for CO_2 capture implementation in the European cement industry.

3.2. CEMCAP approach

The overall approach of CEMCAP (Fig. 1) is to iterate between on one hand experimental work in pilot-scale test rigs and on the other simulations of capture technology integration and cost analysis, to assess the impact of CO_2 capture on the cement production process. Experimental research will be undertaken in the following fields and by the following partners:

- Oxyfuel combustion burner for cement plants (IFK/University of Stuttgart) [2]
- Oxyfuel calciner (IFK, University of Stuttgart)
- Oxyfuel clinker cooer prototype (on site at a HeidelbergCement plant in Hannover, Germany)
- Chilled Ammonia absorber, direct contact cooler and water wash (GE Power Sweden)
- Membrane assisted CO_2 liquefaction (membrane testing at TNO and CO_2 liquefaction testing at SINTEF Energy Research)
- Circulating Fluidized Bed and Entrained flow Calcium looping (IFK/University of Stuttgart, Germany and CSIC) [3,4]

The first experimental results will feed into the analytical research (process and combustion modelling and simulations, and intermediate analytical results will give feedback to more experimental campaigns (Fig. 1).

3.3. The CEMCAP framework – ensuring research consistency

To ensure consistency in CEMCAP, a framework document has been established to provide a common knowledge basis about cement plants and their operation, and to provide input data for experimental and analytical research [5]. The framework describes a reference cement plant, the four investigated capture technologies and a reference capture technology (MEA). Process unities and utilities are specified, as well as CO_2 capture rates, CO_2 purity, relevant economic parameters and key performance indicators. To the extent that it has been possible, the framework document relies on the EBTF (European Benchmarking Task Force) documents established by the three EU FP7 projects DECARBit, CESAR and CAESAR[6].

The CEMCAP framework document is the tool that enables the project to obtain consistent results for different CO_2 capture technologies. Relying on the document, capture process simulations and cement plant simulations without and with CO_2 capture can be conducted by different project partners and still generate comparable techno-economic results [5,7,8,9]. The framework document is foreseen to be made public in the course of 2017, which will enable researchers around the world to generate results that are comparable with the results provided by CEMCAP.

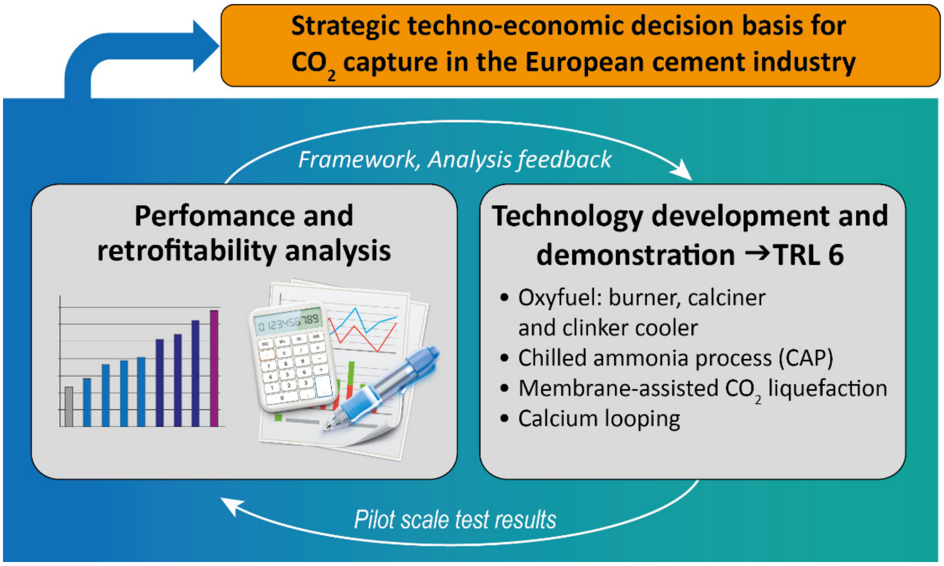

Fig. 1. The CEMCAP approach: iterating between experimental and analytical research.

3.4. Differences between CO_2 capture for cement plants and power plants

The framework document specifies data such as flue gas compositions that are relevant to the experimental work on post-combustion capture, and thus provides a common basis for the three different post-combustion capture technologies to be tested. Unlike fossil-fuel power plants, that were investigated by the EBTF projects, the flue gas CO2 concentration and volume flow varies with operational mode, on a daily basis as well as in annual cycles, even if the cement plant is operated in steady state. In a cement plant, flue gas is produced by burning fuel in the rotary kiln and calciner, and by calcination of the raw meal in the calciner. A cement kiln switches between so-called interconnected and direct mode of operation during the daily operation, and this has an impact on the resulting flue gas characteristics, as described further in [5].

A cement kiln is run in *interconnected mode* typically ~90% of the time during (21-22 h/d). In interconnected mode the flue gas is sent through the mill that grinds the raw material, where it is used for drying. The air leak into the mill is significant, which leads to dilution of the flue gas, resulting in a CO_2 concentration of 20-25% at the stack. The raw mill may be stopped almost every day for visual inspection and control. When the mill is out of operation the kiln is run in *direct mode*. The kiln is run in direct mode typically 10% of the time during a day. The flue gas is then bypassed the raw mill, the air leak in the mill is eliminated, and the CO_2 concentration at the stack is consequently higher (up til 35%), while the flue gas flow rate is lower than in the interconnected mode. Also, the amount of air leak in the system varies over the year. The air leak increases steadily over the year, and is decreased under the (annual) maintenance/revision.

Post combustion capture technologies retrofittable to cement plants must hence be able to operate under these daily and annual variations in flue gas flows. More significant efforts to limit the increase in air leak over the year may be relevant to make in the case of implementation of post-combustion capture. In the case of oxyfuel capture, design for varying gas flowrates can be avoided, since the capture process affects the core of the plant (preheaters, calciner, rotary kiln, clinker cooler) and, in line with oxyfuel technology for coal, the stack is not needed.

4. CEMCAP relation to the ECRA and Norcem CCS projects

The CEMCAP project has been set up to complement and strengthen two already ongoing CCS projects in the cement industry, namely the ECRA CCS project and the Norcem CCS project.

ECRA (the European Cement Research Academy) is a member of the CEMCAP consortium. With its member base of around 50 cement producers and technology suppliers, ECRA constitutes a foundation for efficient sharing of CEMCAP results far beyond the lifetime of the project. The ECRA CCS project (http://www.ecra-online.org/226/) has completed its phase IV, with a pre-study of an oxyfuel cement plant. Through the testing of three oxyfuel components in CEMCAP, knowledge will be provided, that feeds directly into the future plans of the ECRA CCS project for an oxyfuel cement plant demonstrator.

When considered for the cement sector, CO_2 capture technologies were, at the startup of CEMCAP typically at TRL 4-5 or lower, with the exception of the amine technology demonstrated on-site (TRL8) at the Norcem cement plant in the Norcem CCS project. Based on the results from this project, Norcem has undertaken a feasibility study for full-scale CO_2 capture with amine technology, and is one of three candidates for the implementation of a full Norwegian CCS chain by 2022. Norcem also continues to be host for on-site testing of post-combustion capture with amine-impregnated sorbents and fixed-site carrier membranes in a new phase of the Norcem CCS project. Altogether in CEMCAP, Norcem can broaden its post combustion capture knowledge, and also contribute as an advisor and broaden the perspective of post-combustion CO_2 capture from cement plants.

5. The context for CCS implementation in the cement industry

CEMCAP has taken on the necessary task to advance retrofittable CO_2 capture technologies for the cement industry to TRL6 and identifying the most cost- and resource efficient options for CCS in the cement industry. When further developed to commercial scale, this will broaden the portfolio of available capture technologies for this industrial branch, which is necessary, since different capture technologies are likely to be the best choice for different cement plants. This will expand the technology options for CCS deployment in Europe. However, it must be recognized that technology development alone will not make CCS deployment happen in the cement industry. Several roadmaps for CO_2 reduction underline the need for a significant share of cement plants worldwide to be equipped with CO_2 capture as a breakthrough technology. The only way to speed up the potential implementation is to demonstrate CO_2 capture methods at the earliest possible opportunity. However, appropriate funding will be needed for their demonstration at larger scales. Current research results and cost projections of CO_2 capture technologies show, that the technology is related to significant investment costs and operational costs. The industrial application of CO_2 capture technologies will need to rely on related climate and industry policies. E.g. investment decisions in the EU will require a long term predictability of the policy for prevention of carbon leakage (re-location of production and emissions) due to the CO_2 costs. From today's perspective the application of CO_2 capture technologies would significantly impede European cement industry's competitiveness in the world market. In this context it can be mentioned that CEMCAP will deliver a report on the options for handling CO_2 after it has been captured from cement plants (CO_2 storage, use in products such as fuels, use in carbonates [10]) with focus on available and future options for the cement industry.

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