CO_2 CAPTURE

Brage Rugstad Knudsen and Kristin Jordal, Sintef Energy Research, and Johannes Ruppertand and Volker Hoenig, VDZ gGmbH, discuss how to reduce CO_2 emissions in cement production.

Introduction

The importance of reducing manmade CO_2 emissions has been recognised by almost all countries worldwide through the signing of the Paris Agreement. Numbers vary between sources, but cement production is estimated to contribute 6 – 7% of global anthropogenic CO_2 emissions. More than 60% of these are process-related CO_2 emissions that result from the calcination of raw materials. This has given rise to the EU Horizon 2020-funded research project CEMCAP,

Sidebar 1. The CEMCAP consortium

Cement producers: HeidelbergCement, Germany; Italcementi, Italy; and Norcem, Norway.

Technology providers: thyssenkrupp, Germany; IKN, Germany; GE Power Sweden, Sweden; and Baker Hughes, a GE company, Germany.

R&D providers: SINTEF ER, Norway (project coordinator); ECRA, Germany; TNO, the Netherlands; ETH Zurich, Switzerland; University of Stuttgart, Germany; Politecnico di Milano, Italy; CSIC, Spain; and VDZ, Germany.

Sidebar 2. CCS technologies

There are several technologies under development or already developed for CO_2 capture from power plants. One post-combustion capture technology, amine absorption, is already implemented at commercial scale at the Boundary Dam coal-fired power plant in Saskatchewan, Canada. With this technology, CO_2 from an exhaust gas is absorbed in a circulating aqueous amine solution, and regenerated with steam. The same type of capture technology, but from a different technology provider, has also been selected by cement producer Norcem in Norway. Norcem is one of three industries that are currently potential candidates for CO_2 capture in the ongoing planning for a full-scale Norwegian CCS project.

where four different options for CO_2 capture from the cement kiln are investigated. In CEMCAP, expert cement producers and technology providers collaborate with researchers from universities and research institutions (Sidebar 1) to generate the knowledge and technology needed for the feasible implementation of CO_2 capture from cement production. In brief terms, capturing CO_2 means to separate concentrated CO_2 (95% purity or more) from a gas mixture, thereby enabling its compression or liquefaction for transport to a geological storage site. This CO_2 management chain is usually denoted with the abbreviation CCS: CO_2 capture and storage.

Governed by the laws of thermodynamics, all technologies for capturing CO_2 from any industrial or power-generating process, require energy. A key element in CEMCAP is therefore to compare and analyse the energy consumption for the investigated capture technologies. The majority of existing or envisaged CO_2 capture technologies have been developed with coal and/or natural gas-fired power plants in mind (Sidebar 2), a field where several of CEMCAP's R&D partners have conducted cutting-edge research. CEMCAP capitalises on this knowledge, facilitating targeted development with a focus on advancing CO_2 capture technologies for retrofit of existing cement kilns.

CEMCAP investigation

CEMCAP investigates four different CO_2 capture technologies. One of the technologies is known as oxyfuel combustion capture. With this technology, combustion takes place in a CO_2/O_2 mixture instead of air, resulting in an exhaust stream with a particularly high CO_2 concentration. The three other capture technologies are different methods for post-combustion capture of CO_2. These end-of-the-pipe capture technologies allow for minimum changes in the traditional clinker production process in cement plants.

For advancing oxyfuel capture of CO_2 from cement kilns, operation of the clinker cooler, calciner, and the rotary kiln burner have been experimentally investigated and demonstrated at pilot scale in CEMCAP. The world's first successful cooling of clinker under oxyfuel conditions has been demonstrated through a prototype oxyfuel cooler designed by IKN and installed at the HeidelbergCement plant in Hannover, Germany. VDZ, as a research partner, leads the testing with hot clinker and laboratory analysis of the clinker product. The oxyfuel pilot-scale clinker cooler is unprecedented in its innovative design, and the successful demonstration may be a game changer for oxyfuel operations in cement production. The tests with the clinker cooler prototype have been documented in a film that can be found on YouTube, or on the CEMCAP website.

A cement burner was tested under oxyfuel conditions in a 500 kW rig at the University of Stuttgart. The burner was designed by thyssenkrupp as a downscaled version of an industrial cement burner. These results were thereafter used for model validation and full-scale simulations of the burning process in the rotary kiln. Furthermore, the oxyfuel calcination was tested under relevant temperatures and residence times at University of Stuttgart, to verify the impact on calcination in an atmosphere with high CO_2 concentration. The CEMCAP experimental and analytical results will provide cement-kiln technology providers and cement-plant operators the necessary basis for a further scale up of the oxyfuel technology and deployment of oxyfuel processes in cement production.

The post-combustion capture technologies explored in CEMCAP are the Chilled Ammonia Process (CAP), Calcium looping (CaL) and Membrane-Assisted CO_2-Liquefaction (MAL). CAP is a proprietary technology of GE Power and close to commercialisation for coal and natural-gas power plants. The principle of CAP is similar to that of aqueous amine (Sidebar 2), but applies an ammonia-water solution for CO_2 capture instead of an aqueous amine solution.

Testing of the IKN oxyfuel clinker cooler prototype at HeidelbergCement in Hannover and corresponding process measurements performed by VDZ.

As for amine capture, the energy consumed by the CAP comes from the steam-supply required for releasing absorbed CO_2. Transferring the CAP technology from power-plant flue-gas capture to cement kilns requires handling higher CO_2 concentrations than earlier implemented by GE.

GE Power in Växjö, Sweden, has accomplished pilot-plant test results with up to 35% CO_2 concentrations in a synthetic cement-kiln flue gas. Further research on operating conditions is conducted by researchers at ETH Zürich to minimise the energy consumption of the CAP.

CaL technology

Calcium looping (CaL) uses calcium oxide (CaO) particles to capture CO_2 from a flue-gas stream in a carbonator, forming limestone ($CaCO_3$). The $CaCO_3$ is thereafter calcined to CaO and ready for a new CO_2 capture loop. There is an obvious potential synergy between CaL and cement production in reusing purged CaO as feedstock in the kiln. Different options for integrating CaL into the kiln are being investigated by University Politecnico di Milano.

The high temperature required to drive fast calcination of $CaCO_3$ requires energy, which is obtained from fuel burnt inside the calciner. Furthermore, to avoid dilution of CO_2 released from the calciner, the fuel must be burnt with oxygen, not air, which means that the calciner operation is similar for the CaL and oxyfuel capture processes.

In addition, electric power is consumed for cryogenic distillation of O_2. The main focus of the CaL technology was originally CO_2 capture from coal-fired power plants. Integrating CaL in cement production requires adapting the carbonator to new operating conditions, including a higher CO_2 load, a more active sorbent, and smaller particle sizes. CEMCAP researchers have tested CaL under kiln-relevant conditions both in a 30 kW facility at CSIC and in one 30 kW and one 200 kW facility at the University of Stuttgart. With the earlier lack of industrial-scale testing of CaL under conditions relevant for cement production, these pilot experiments will provide a decision basis for future systematic process scale-up.

Membrane-assisted CO_2-liquefaction

CO_2 capture by MAL consists of two consecutive steps. The first step is bulk separation of CO_2 from flue gases using CO_2-selective polymeric membranes. This bulk-separation results in a sufficiently high concentration to enable the second step: a separation of liquid CO_2 through compression and cooling from the more volatile gas components.

Commercial and pre-commercial polymeric membranes have been tested in CEMCAP by TNO researchers, with the purpose of finding optimum separation rates for integration with the downstream CO_2 liquefaction. The MAL process requires electric power to drive compressors and vacuum pumps, i.e.

Final preparations are currently ongoing in the low-temperature CO_2 liquefaction rig in Energy Research's laboratories (part of the MAL technology).

there is no requirement for fuel or process heat. Final preparations are currently taking place in the SINTEF laboratories for pilot-scale testing of CO_2 liquefaction in a 10 t CO_2/day research facility. These experiments will provide the basis for optimising the overall MAL process for flue gases with CO_2 concentrations that are of relevance for cement kilns.

Developing a framework for CO_2 capture

Based on the extensive analysis and experimental testing of oxyfuel and post-capture technologies, CEMCAP is now working towards establishing a techno-economic decision-basis to assess the energy requirements and to reduce the CO_2 capture cost in cement industries.

A milestone in this work is a framework document, publically available at the CEMCAP website, providing a common knowledge-basis for cement-plant operations, with input data for experimental and analytical research. This framework enables researchers to undertake consistent comparative techno-economic analyses, and is anticipated to be of relevance for CO_2 capture from cement production well beyond the project lifetime. The framework was established by CEMCAP research partners with Italcementi acting as industrial advisor.

CEMCAP interacts continuously with other research projects and communities that actively work on CO_2 capture related to cement. CEMCAP contributes to the ECRA CCS project through oxyfuel research activities, and also has a dialogue with the Norcem CCS project. This assures that the knowledge and expertise acquired from these different projects are united towards the common goal of low-emission cement production.

CEMCAP focuses efforts on communicating its results to a wide audience of both industries outside the consortium, academic communities, and to the public. Considering the high public focus on curbing CO_2 emission, CEMCAP believes that awareness of the activities and results will lift the cement industry in forefront of industrial CCS deployment.

The targets of CEMCAP are high. For all of the aforementioned capture technologies, an aim is a 90% CO_2 capture rate during tests under industrially-relevant environments for cement production. As cement plants differ significantly in structure, production characteristics, and location, there is no single, optimal one-size-fits-all capture technology. CEMCAP will end its work during the autumn of 2018 upon which pathways and perspectives for the anticipated most cost and resource effective options for CCS in the European cement industry will be concluded. The findings will be presented on 17 October 2018 in a public workshop.

About the authors

Brage Rugstad Knudsen is a Research Scientist at SINTEF Energy Research. He holds a PhD in Engineering Cybernetics from NTNU, the Norwegian University of Science and Technology. His main research interests are the modelling and optimisation of integrated energy systems. He currently works in the field of energy efficiency of industrial processes and CO_2 capture and storage.

Kristin Jordal is a Senior Research Scientist and Research Manager at SINTEF Energy research, where she has worked since 2004. She has work experience from the NTNU, Vattenfall, and Siemens Industrial Turbines. She has a PhD in thermal power engineering from Lund University in Sweden, is a researcher in the field of CO_2 capture, and is the coordinator of the CEMCAP project.

Johannes Ruppert is a Senior Scientist at the VDZ Research Institute of the Cement Industry in Dusseldorf, where he has worked since 2005. He is an expert on climate protection in the cement industry and has professional experience in environmental monitoring, reporting, and related policies. He works as project leader in national and international research projects on CO_2 capture, energy use, and resource efficiency in the cement industry.

Volker Hoenig is Managing Director of the VDZ gGmbH at the Research Institute of the Cement Industry in Düsseldorf. He has more than 25 years experience in cement and lime processing technology. He is expert in thermal processing, energy efficiency, fuel substitution, cooler and preheater optimisation, as well as environmental technologies and climate protection.