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Long-term carbonate looping testing in a 1 MW_{th} pilot plant with hard coal and lignite

Martin Helbig[a,]*, Jochen Hilz[a], Martin Haaf[a], Alexander Daikeler[a], Jochen Ströhle[a], Bernd Epple[a]

[a]*Institute for Energy Systems & Technology, Technische Universität Darmstadt, Otto-Berndt-Str. 2, D-64287 Darmstadt, Germany*

Abstract

The carbonate looping process is an efficient carbon capture technology to reduce the amount of carbon dioxide emitted by fossil fueled power and industrial plants. The presented work discusses the results gained in four test campaigns, each four weeks long, performed in a 1 MW_{th} carbonate looping pilot plant at Technische Universität Darmstadt. The flue gas was provided by a coal fired furnace. The calciner was fired in a recirculated oxy-fuel combustion mode, i.e. where coal was burned with oxygen and flue gas was recirculated to moderate the temperature. The objective of these test campaigns with optimized configuration was to improve and to scale up the process into an industrial size. During the campaigns, the type of fuel, sorbent, flue gas composition, reactor design, and operating conditions were varied to investigate long-term effects on the performance. Steady-state conditions were achieved, which means that no parameters were changed during up to 60 hours. The industrial size feasibility of the carbonate looping process was proven by steady state CO_2 absorption over 1219 hours with interconnected fluidized bed reactors and capture rates up to 94 %.

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Keywords: calcium looping; CO_2 capture; pilot plant; dual fluidized bed; oxyfuel regenerator;

* Corresponding author. Tel.: +49-(0)6151-22677; fax: +49-(0)6151-22690.
E-mail address: martin.helbig@est.tu-darmstadt.de

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1. Introduction

It is expected that the energy demand will still increase in the next decades. Fossil fuels as coal and natural gas will remain the major energy source for power production to supply the need [1]. It is available in large quantities in many areas all over the world and ensures a secure power supply as well as it reduces the dependency from other countries. However, in the last decades knowledge on climate change has progressed considerably. It has proven that, the global warming is mainly caused by the antropogenic release of the greenhouse gases like CO_2. Its influence on the greenhouse effect and its contribution to global warming is generally accepted [2]. It is also well known that the combustion of fossil fuels results inevitably in the formation of large amounts of CO_2. Therefore, a lot of organisations e.g. the European Union and the International Energy Agency, have identified Carbon Capture and Storage (CCS) as one important option to mitigate CO_2 emissions from fossil-fueled power plants [2, 3]. Several CO_2 capture processes to reduce the amount of carbon dioxide emitted by fossil fueled power and industrial plants are currently under development. The first generation CO_2 capture processes like *Mono-Ethylene-Emine Scrubbing*, *Integrated Gasification Combined Cycle* and *Oxy-fuel combustion* have a substantial net efficiency loss of 9-14 % points [4, 5]. Therefore, several different CO_2 capture processes with improved efficiency are currently being investigated. The carbonate looping (CaL) process is one of the most promising and efficient post- combustion capture technologies with rather low efficient penalties of 5-7 % points (including CO_2 compression) [6]. CaL was investigated in several mid-scale test facilities the last decade [7-10], and thereby CaL is on the go to enable full-scale realization.

The CaL process is a post combustion CO_2 capture technology using limestone based sorbents. The CO_2 contained in the flue gas is absorbed by solid calcium oxide (burnt lime) in the carbonator and transferred as calcium carbonate to the calciner. There, the calcium carbonate releases CO_2 by increasing the temperature to around 900 °C. The heat for this endothermic calcination reaction is provided by combustion of fuel (e.g. coal) with oxygen. A gas stream of highly concentrated CO_2 leaves the calciner, while the solid CaO is returned to the carbonator. The carbonate looping process is characterized by a low energy penalty of approx. 6 % points efficiency drop including CO_2 compression, low CO_2 capture costs and low environmental impact [6]. The use of limestone for CO_2 capture has also gained increasing interest in the cement industry during the last years since spent sorbent could be utilized as raw material for clinker production .

The feasibility of the carbonate looping process has been proven in various lab scale test rigs. During tests in Spain the first continuous operation of an interconnected circulating fluidized bed carbonator/calciner system was achieved in a lab scale facility of 30 kW_{th} at CSIC [11]. Based on this results, the test rigs were scaled up to a 200 kW_{th} pilot plant at IFK in Stuttgart were they achieved to run the pilot in steady state over more than two days [8]. Furthermore a 1 MW_{th} test rig was erected at EST/Technische Universität Darmstadt (Germany) [12]. Continuous carbonate looping tests in two interconnected circulating bed reactors in pilot scale were achieved for the first time worldwide [13]. Additional test campaigns with natural gas and coal fired calciner were performed [14]. Eventually in a 1.7 MW_{th} test rig in La Pereda (Spain) flue gas originated from a nearby power plant was used in longer tests. Diego et. al achieved to capture CO_2 over more than 8 hours continously [15] and showing promising results. In addition to the standard CaL process with directly heated calciner, an indirectly heated CaL process is currently under development. The feasibility of the indirectly heated CaL process has been confirmed by a 300 kW_{th} pilot plant at Technische Universität Darmstadt [16].

The present paper summarizes the main experimental results from four long-term test campaigns carried out in the 1 MW_{th} pilot plant at Technische Universität Darmstadt. During the campaigns, the type of fuel, sorbent, flue gas composition, reactor design, and operating conditions were varied to investigate long-term effects on the performance. Steady-state conditions were achieved, which means that no parameters were changed during up to 60 hours in one single operating point. Hard coal and lignite were used as fuel in varying particle sizes. Particular focus was on the long-term behavior of the sorbent reactivity under different operating parameters, i.e. reactor temperatures, make-up flow, solids circulation, concentrations of CO_2 and steam in the flue gas. The reactivity of the sorbent, the CO_2 absorption efficiency and the oxygen consumption are the most important parameters to evaluate the carbonate looping process.

The objective of these test campaigns was to optimize the process and to gain reliable data base to scale-up the process into an industrial size. The calciner was fired in a recirculated oxy-fuel combustion mode, i.e. where coal