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Efficiency Improvement of an Iron-based Syngas Fueled Chemical Looping Combustion Plant with Carbon Capture

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Abstract

In this study the performances of two syngas fueled iron-based CLC plants, one using a conventional cold syngas cleaning system and the other one with hot syngas cleaning, were evaluated and compared. In the second configuration, before feeding the chemical looping fuel reactor, the syngas was cleaned at high temperatures using mainly a zinc-based desulfurization unit. The simulation results showed that the plant configured with a hot syngas cleaning system has a net electrical efficiency of 42.6%, which was 1.75% points higher than that of the plant with cold gas cleaning. It was also shown that both CLC plants can achieve more than 99% carbon capture rates.

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Keywords: chemical looping combustion; iron oxide oxygen carrier; cold/hot gas cleaning; coal gasification; CO_2 capture; efficiency

1. Introduction

Fossil fuel combustion releases significant amounts of CO_2 emissions into the atmosphere, the most important greenhouse gas that contributes to global warming [1,2]. Among fossil fuels, coal is the most carbon intensive fuel, being responsible for more than 45% of total CO_2 emissions [2]. Most of these emissions are produced in the energy sector by coal-fired power plants.

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Nomenclature

AGR	Acid gas removal
AR	Air reactor
ASU	Air separation unit
BOP	Balance of plant
CCR	Carbon capture rate (%)
CLC	Chemical looping combustion
DES	Desulfurizer
FR	Fuel reactor
HGD	Hot gas desulfurization
HP/IP/LP	High/intermediate/low pressure
HRSG	Heat recovery steam generator
IGCC	Integrated gasification combined cycle
LHV	Lower heating value (MJ/kg)
OC	Oxygen carrier
PC	Pulverized coal
REG	Regenerator
ST	Steam turbine
WFGD	Wet flue gas desulfurization

There are three main methods for CO_2 capture from coal-fired power plants, namely: post-combustion capture (CO_2 is separated from the flue gas after the combustion of fuel in air); oxy-fuel combustion (CO_2 is separated from a flue gas that is mainly composed of CO_2 and water vapor after the combustion of fuel in nearly pure oxygen); and pre-combustion capture (CO_2 is separated from the fuel before combustion). The first two capture methods can be applied to conventional pulverized coal (PC)-fired power plants [3,4] and, virtually, all the three can be used in coal-fired integrated gasification combined cycle (IGCC) plants [3,5,6]. However, capturing CO_2 either before or after combustion significantly influences the cost and energy performances of the plant [7,8]. For a PC power plant with 90% CO_2 capture using an amine-based post-combustion capture system, the overall plant efficiency can decrease by ~25% compared to the reference plant without CO_2 capture whereas the cost of electricity generation can increase by more than 60%. Somewhat lower energy and cost penalties were estimated for IGCC plants with pre-combustion CO_2 capture, i.e., about 20% reduction in efficiency and 40% increase in cost of electricity.

Chemical looping combustion (CLC) is a promising technology for fuel conversion into power with inherent CO_2 separation [9]. In a CLC process a metal oxide is used as an oxygen carrier (OC) to transfer oxygen from the combustion air to the fuel. Two reactors are used to perform this process, namely, a fuel reactor (FR) and an air reactor (AR). In the FR, the fuel is fully converted to a CO_2/H_2O mixture while the OC is reduced to lower oxidation state. In the AR, the reduced OC is regenerated by air. In this way, the direct contact between fuel and air is avoided. Among different metal oxides, iron-based ones are very attractive for CLC applications due to low raw material cost, high oxygen carrying capacity, favorable thermodynamic properties, high melting points, good mechanical strength, and low environmental and health effects [10]. The CLC can be performed using fixed bed, fluidized bed or moving bed reactors and usually fueled with gaseous fuels (e.g., coal-derived syngas) [10]. The efficiency of syngas fueled iron-based CLC plants is estimated to be around 40% (lower heating value (LHV) basis) using conventional cold syngas cleaning systems, which is 2-3% points higher than that of IGCC plants with CO_2 capture [11].

In order to further increase the efficiency of syngas fueled CLC plants using iron-based OC, in this work we investigated a configuration of the plant using a hot gas cleaning system and compared the performance with that of a reference case using a conventional cold gas cleaning unit.