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Aspen Plus[®] Process Simulation of Calcium Looping with Different Indirect Calciner Heat Transfer Concepts

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Abstract

CO₂ reduction has become an urgent need due to the greenhouse effect. Scientists working on the topic agree that the major cause of global warming is greenhouse gases emitted due to human activities. Burning of fossil fuels is one of the main reasons. Using a solid sorbent to capture CO₂ at high temperature is a concept which is now being widely considered to reduce CO₂ emissions. Capture from flue gas by calcium looping (CaL) may be an attractive alternative due to cheap and readily available sorbent (limestone). CaL may reduce considerably the energy penalty represented by the capture system. A significant transfer of thermal energy is required for the endothermic calcination process. In first generation CaL, the heat is transferred directly by oxy-combustion in the calciner; pure oxygen is then required as the oxidizer to avoid mixing CO₂ with N₂, and the energy required to produce oxygen gives an unwanted energy penalty. CaL technology would be an even more attractive alternative for the thermal power industry if the heat could be transferred indirectly to the calciner. By high-temperature integration between the CO₂ capture plant and the power plant, the energy penalty associated with oxy-combustion would be avoided. In this work, Aspen Plus[®] is used to simulate the CaL process with indirect heat transfer applying different indirect heat transfer concepts. Six different cases are studied and the results are discussed. It has confirmed such a scheme could give an energy penalty lower than for example amine scrubbing or oxy-combustion.

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1. Introduction

Greenhouse gases (GHG) affect significantly the earth's temperature, and carbon dioxide is the most harmful one due to the vast generation of this gas from human activities. Since the 18th century the atmospheric carbon dioxide (CO₂) concentration has risen by some 40% [1]. The main reason for the increase of global CO₂ emission is increased burning of fossil fuels and deforestation after the industrial revolution. As reported in 2007, the total industrial CO₂ production, primarily from burning coal, oil and natural gas and the production of cement, is about 8 Gt carbon per year [2]. During the last 100 years, the average surface temperature of the earth has increased about 0.8 °C and is continuously increasing [3]. During the last decade the scientific research and knowledge on climate change have progressed considerably. As results of that, technological and political goals were set to reduce the CO₂ emissions. A worldwide agreement was made through the Kyoto agreement, and has led to a focus on reduction and prevention of GHG emissions in most of the countries which ratified the agreement [4]. As results of that, capture technologies are being developed and could be applied on thermal power plants, such as coal fired power plants.

CO₂ capturing is not a new concept as removal of CO₂ from gas streams has been a crucial unit operation for many decades to avoid corrosion and also to improve the calorific value of gas streams. Even though the post combustion CO₂ capture technology using amine-based CO₂ solvents to absorb CO₂ from the exhaust gas is scientifically well-established, there are other methods that could be more attractive due to lower energy penalties. Carbon capture based on a solid sorbent operating at higher temperature is one of them. CO₂ capture from flue gas by calcium looping (CaL) may be an attractive alternative as limestone as a readily available and relatively inexpensive material.

CaL was first reported as a potential carbon capture technology in 1999 [5], and is also called carbonate looping as calcium carbonate (CaCO₃) is generated in the process [6]. In CaL, calcium oxide (CaO) reacts with CO₂ to form calcium carbonate (CaCO₃) in a fluidized bed reactor (carbonator) at a temperature around 650°C, in an exothermic reaction[7], (see Eq. 1)



The CaCO₃ is separated from the cleaned exhaust gas by a gas/solid separator and the cleaned flue gas exiting from the carbonator can be released to the atmosphere. In a second reactor, the calciner, the reverse reaction happens, i.e. CaCO₃ decomposes into CaO and CO₂ at a temperature close to 900 °C. This is an endothermic process, so a significant flow of thermal energy must be supplied to the calciner for the reaction to occur. The regenerated CaO is separated from the CO₂ in a gas/solid separator and recycled back to the carbonator.

Most of the CaL processes described in the literature consist of fluidized bed (FB) reactors and the calcination heat is transferred directly by an internal oxy-fuel combustor placed inside the calciner [8-15]. This is known as first generation CaL technology. Even though in CaL most of the heat supplied for the calcination can be recovered at the carbonator, there is an unwanted energy penalty associated with the oxy-fuel combustion process, especially, from the air separation unit (ASU) which provides oxygen for the oxy-fuel combustion.

In the second generation CaL technology, the heat is transferred indirectly from the external combustor to the calciner, and this could reduce the efficiency loss considerably compared with the direct heat supply method by avoiding the oxy-fuel combustion in the calciner [16]. The basic idea is illustrated in Fig.1. The fact that the heat transfer takes place at a temperature higher than the typical operational temperature of a coal fired power plant means that the energy penalty usually associated with CO₂ capture processes can be significantly reduced. Different indirect heat transfer methods may be applied. Strelow et al. [16] applied steam as the heat transfer medium, but use of heat pipes is also being considered [17-19].

In this work, CaL with indirect heat transfer applied to an 1890MW_{th} coal fired power plant is simulated using Aspen Plus V8.6[®] software. Six different indirect heat transfer concepts are studied, and the impact on the energy balance of the system for each case is evaluated. This work is a continuation of previously published work [20], in which three different indirect heat transfer cases were simulated and analyzed. As the concept involves a complete integration between the power plant and the capture plant, it may call Fully Integrated Calcium Looping (FICaL).

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