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The internally circulating reactor (ICR) concept applied to pressurized chemical looping processes

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Abstract

The internally circulating reactor (ICR) has significant potential to reduce costs and simplify scale-up of pressurized chemical looping process concepts. An ICR consists of a single reactor body divided into two or three sections where different reactions are carried out. Simple ports connect the reactor sections to ensure circulation of the oxygen carrier. The cost of this simplicity is a certain amount of gas leakage between reactor sections. Quantification of this leakage revealed good CO_2 purity and capture (>96%) for combustion, reforming and oxygen production chemical looping applications, but poorer CO_2 separation performance for water splitting.

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Keywords: Internally circulating reactor; Chemical looping combustion; Chemical looping reforming; Chemical looping oxygen production; Chemical looping water splitting; Dense discrete phase model; CO_2 capture

1. Introduction

Chemical looping has arisen as a promising technology with great potential to reduce the costs associated with clean utilization of fossil fuels. It was first applied to combustion through the CLC process [1, 2], where inherent separation of CO_2 and N_2 is ensured, using an oxygen carrier circulating between two reactors, namely air and fuel reactors, transferring oxygen from air to fuel. The low energy penalty of CLC relative to other CO_2 capture technologies has led to extensions of the chemical looping principle to other CO_2 and energy intensive processes such as reforming [3], air separation [4] and hydrogen generation through the steam-iron process [5].

High-pressure operation of these chemical looping concepts is necessary for maximizing energy efficiency and competitiveness with other CO_2 capture technologies, but upscaling of pressurized chemical looping processes has been slow. This is due to the challenges linked to the use of the interconnected reactor configuration involving external solids separation; to the authors' knowledge, only one study on pressurized CLC in interconnected fluidized

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beds has been completed to date [6]. This limitation has prompted research into novel reactor concepts to improve the scalability of pressurized chemical looping technology.

Several reactor concepts have been proposed to avoid external solids circulation to remove scale-up issues under pressurized operation. This includes Gas Switching concepts based on packed and fluidized beds [7, 8], and the internally circulating reactor (ICR) which is the subject of this paper [9]. The ICR concept (Figure 1) uses a single reactor divided into two chambers with two connecting ports, one in the top and the other in the bottom. The two chambers are fluidized at different gas flow rates and the solids in the chamber with the larger flow rate are transported to the freeboard to fall and circulate into the second chamber through the port in the top. Accumulation of solids in the second chamber creates a pressure difference between the two sides of the port at the bottom, which provides a driving force for solids circulation back to the first chamber.

The simplicity of the ICR comes at the expenses of gas leakage, which takes place between the two chambers through the connecting ports. A cold flow model of the ICR reactor was therefore designed and constructed in order to investigate the gas leakage [9]. It was shown that gas leakage could be maintained at acceptable levels over a relatively wide range of operating conditions and it was concluded that the ICR is well suited for chemical looping processes. This work will further build on this initial study by simulating a large-scale ICR and assessing CO_2 separation performance for four different chemical looping technologies.

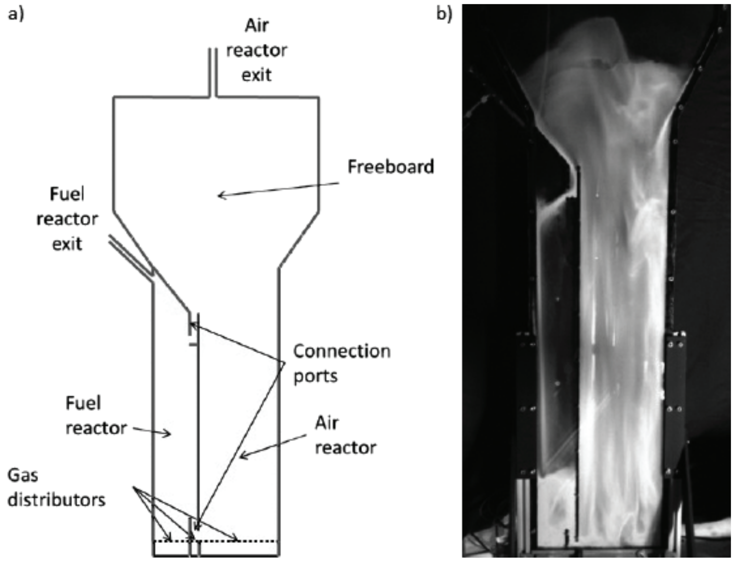

Figure 1: a) Simplified scheme of the pseudo-2D cold-flow ICR design and b) pseudo-2D cold-flow ICR unit under operation.

Nomenclature

α	Volume fraction
ϕ_{pq}	Energy dissipation through drag (W/m^3)
γ_Θ	Energy dissipation through collisions (W/m^3)
λ_p	Bulk viscosity (Pa.s)
μ	Viscosity (Pa.s)
Θ	Granular temperature (m^2/s^2)
ρ	Density (kg/m^3)
$\vec{\upsilon}$	Velocity vector (m/s)