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# Double loop circulating fluidized bed reactor system for two reaction processes, based on pneumatically controlled divided loop-seals and bottom extraction/lift

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ABSTRACT

Many industrial processes are based on two reactions: a primary one related to the achievement of the main process objective and a secondary one which is necessary to continuously run the process. Those reactions can be performed continuously by means of two interconnected fluidized beds.

The proposed design consists of two interconnected circulating fluidized beds (CFB). Both reactors can be operated in fast fluidization regime improving the particles' gas contact and reducing the reactor's system volume. The two CFBs are interconnected by means of pneumatically controlled divided loop-seals and a bottom extraction/lift. The divided loop-seals can re-circulate back to the reactor of origin part of the entrained solids; this implies that the amount of exchanged solids can be controlled and uncoupled from the amount of entrained solids. The bottom extraction/lift compensates the lower entrainment capability of the reactor with less fluidizing gas availability.

An intense hydrodynamic test campaign has been performed with a full scale cold flow model. The design has proven to be reliable offering a stable operational window. Some interesting dependencies of the entrained solids flux have been found: from the cyclone pressure drop and the superficial gas velocity.

The divided loop-seal allowed a stable internal recirculation of the entrained solids, up to 50%, without affecting the reactors' hydrodynamics. Such system could work effectively by controlling the pressures in correspondence of the points where the loop-seals return legs merge with the reactors. In this way gas backflows and particle losses through the cyclones are avoided.

A safe operational procedure of the pneumatically controlled double loop CFB has been defined by means of a combined usage of the two key components: the bottom extraction/lift and the pneumatically controlled divided loop-seals. Design improvements were also identified.



## 1. Introduction to interconnected circulating fluidized bed

The industrial processes based on fluidized beds are continuously growing in number and complexity since the discovery of the fluidization phenomenon in 1922 [1]. Several of those processes require the usage of two interconnected fluidized bed reactors because they have to deal with two reactions: a primary reaction which is accomplishing the process main objective and a secondary reaction necessary to continuously run the process [2].

The fluidized catalytic cracking (FCC) is one of the most important and consolidated circulating fluidized bed (CFB) processes, anyhow it is meeting new challenges related to availability and flexibility as well as to more stringent environmental regulations and feed-stocks more difficult to process [3].

Several are the dual fluidized bed plants worldwide that deal with gasification, mainly biomass [4,5]. Some already utilize two circulating fluidized beds [6]: one acts as gasifier the other as combustor. This process still has room for improvement when it comes to syngas composition optimization, tar removal and fuel flexibility. In addition, the usage of a bed material capable to selectively transport carbon dioxide can be utilized to further develop such processes. This will enhance the reforming reactions taking place in the gasifier; at the same time a $CO_2$ rich/ready to capture flue gas will be produced in the combustor. An interesting overview of those issues, together with their design implications is provided by Pfeifer et al. [7]. A significant presence of solids in both the reactor freeboards is important as well as the reduction of the reactor volume in order to be capable to go higher in scale, i.e. improve limitations which have typically been associated with bubbling fluidized beds.

Interconnected fluidized beds can also be used for $CO_2$ capture processes to reduce the carbon dioxide emissions into the atmosphere. One of those is the carbonation/calcination cycle, proposed by Shimizu et al. [8]; especially relevant for retrofitting existing power plants. This technology is becoming more investigated world-wide and several research groups are testing pilot plants with two interconnected circulating

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fluidized beds operating in fast fluidization regimes [9–11]. This idea of having a solid sorbent transferring the $CO_2$ from the gas to the solid phase can be used also in sorption-enhanced hydrogen production processes in order to overcome the equilibrium restrictions of the steam methane reforming and the water gas shift reactions. In this way the $H_2$ production on the reformer side is improved and a $CO_2$ rich gas is obtained, from the reactor where the sorbent is regenerated. Also this process can be ideally performed by means of two interconnected circulating fluidized beds [12].

This overview of the processes requiring two interconnected fluidized beds is concluded with the chemical looping combustion (CLC). CLC is based on a two-step combustion, where a metallic powder circulates between two reactors carrying oxygen from one reactor to the other. The fuel combustion takes place in the primary reactor, the fuel reactor (FR). The particles carry the heat and oxygen necessary to the fuel combustion to take place; it is slightly exothermic or endothermic depending on the oxygen carriers' materials and fuel. Once deprived of the oxygen, the particles are transported into the secondary reactor, the air reactor (AR), where they get oxidized in a highly exothermic reaction with air. In this way the irreversibility of the process is reduced and a stream of ready to capture $CO_2$ is produced in the FR. Nowadays the CLC technology has been successfully demonstrated for more than 4000 h of operation in several pilots up to a thermal load of 140 kW. Both gaseous and solid fuels have been tested; each of those applications faces different challenges related to reactor system design and oxygen carrier particle properties [13]. In addition, chemical looping reforming (CLR) can be performed by reducing the air to fuel ratio below the stoichiometric value; CLR has already been successfully tested for gaseous fuels [14].

Summarizing, the improvement of interconnected fluidized bed reactor performance is often depending on a higher particle–gas contact since the solids presence is fundamental for the gas phase conversion [15]. In addition, an increase in the volumetric conversion rate is required for up-scaling purposes in order to avoid too excessive reactor volumes. The use of two interconnected circulating fluidized beds is one possible answer to these requirements.

A double loop circulating fluidized bed (DLCFB) design originally meant for chemical looping combustion/reforming purposes, has been proposed [16] and is shown in Fig. 1. The actual design key features can be extrapolated to a wider context.

One feature consists on the usage of pneumatically controlled divided loop-seals. The divided loop-seal is designed in order to control the share of entrained solids which will be exchanged from one reactor to the other in addition to the conventional loop-seal task of avoiding gas leakages. The loop-seal control is exerted re-circulating back to the reactor of origin part of the entrained solids. It is done by means of gas injections in order to avoid the usage of mechanical valves. The bottom extraction/lift represents another core element of this design. It brings solids from that one of the two CFBs entraining fewer solids to the other one. Depending on the process and/or on the operating conditions, it may happen to have one reactor with a smaller availability of fluidizing gas (fuel reactor, in the actual design), thus not capable to entrain back to the other reactor the same amount of solids it receives if no actions are taken on the fluidization gases e.g. adding inert gases or recirculating part of the exhausts. For this reason the lift can easily compensate this unbalance and consequently shift the mass from one reactor to the other reducing the pressure difference among reactors bottom sections. This avoids that the two return legs of each loop-seal will experience a pressure unbalance larger than what the loop-seal design can deal with. The bottom extraction/lift has been designed with the intention to rely mainly on active control by fluidizing gas injections (fast fluidization up to transport regime).

In the presented design, the reactor with more solids entrainment capacity, AR, is setting the upper limit solids entrainment, thus exchange. The divided loop-seal can be used to uncouple the solids exchange from the solids entrainment according to process needs. The reactor with less fluidizing gas availability, FR, can use in a combined way the lift and the divided loop-seal in order to exchange the needed

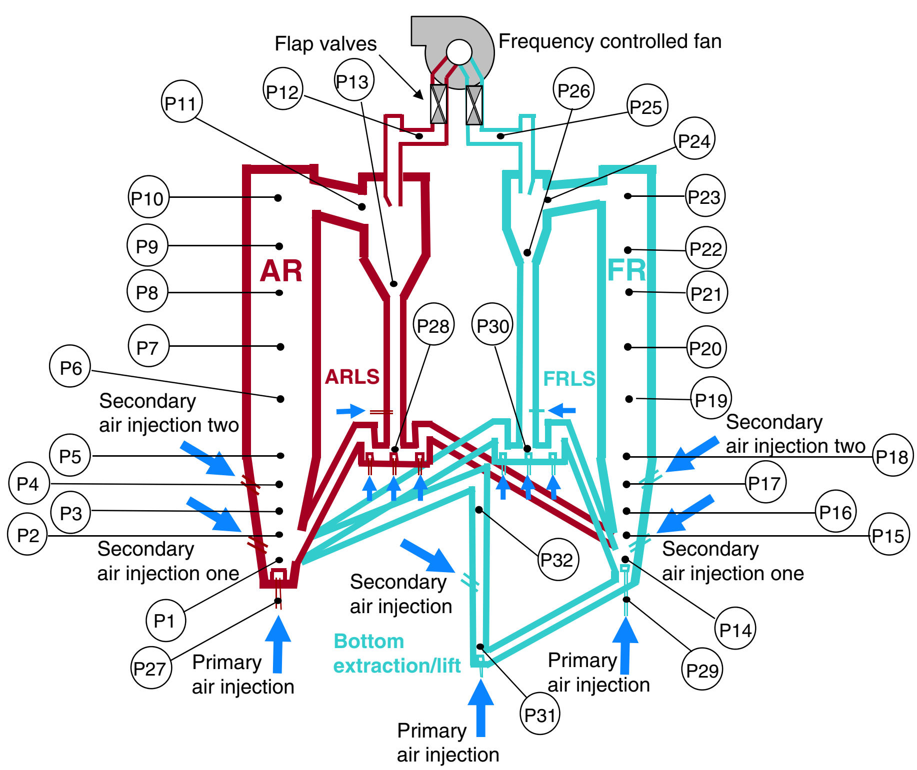


**Fig. 1.** Schema of the cold flow model used to study the hydrodynamics of the proposed double loop circulating fluidized bed (DLCFB) reactor system design.