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# Impact of size and temperature on the hydrodynamics of chemical looping combustion

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## HIGHLIGHTS

- Impact of temperature and size on different sections of a typical CLC unit is studied.
- Minimum fluidization velocity decreases as temperature increases.
- Onset of turbulent fluidization increases as temperature increases.
- Impact of temperature and size on the pneumatic valves is investigated.

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## ABSTRACT

Chemical Looping Combustion (CLC) is conventionally carried out in circulating fluidized bed systems involving various kinds of fluidized beds and solid handling devices. Scale-up of these systems is a research and development challenge associated with various risks and uncertainties. Gas bypassing, poor gas–solid contact and poor performance of solid circulation control devices are among the major considerations in this regard.

This paper presents impacts of temperature on the fluidization properties in CLC application. Impacts of temperature on the minimum fluidization velocity and the onset of turbulent regime are studied in various temperatures up to 900 °C. Increase of temperature decreases the minimum fluidization velocity and increases the onset of transition to turbulent regime.

Impact of size and temperature on the performance of pneumatic valves (L-valve and loop-seal) are investigated using valves in a range of 2–24 cm in a temperature range of 25–750 °C. Geldart group B particles of 100–300 μm and density of 2600–4750 kg/m$^3$ are used in these experimental tests.



## 1. Introduction

Scale-up of fluidized bed processes is particularly difficult and associated with various risks related to the change of behavior with unit or particle size and operating conditions such as temperature. Possible difficulties in this domain are mostly related to the hydrodynamics of fluidized bed regarding good solid – gas contact rather than reaction limitation. Geldart [1] has classified particles according to their size and density into four distinct classes (A, B, C, and D) each with different fluidization behaviors. Group B particles with a typical particle size of 50–500 μm, are mostly used in chemical looping combustion application. Examples of the extrapolation difficulties related to unit scale are numerous. In case of group B particles, bubble sizes can grow very large and results in poor performance due to bed bypassing by bubbles [2]. Moreover, high temperature and large scale may cause difficulties in operation of the solid flow control devices [3]. Fluid bed scale-up is still not an exact science but remains the province of that mix of mathematics, witchcraft, history and common sense, called engineering [4].

Chemical Looping Combustion (CLC) uses mostly interconnected circulating fluidized bed (CFB) reactors at high temperatures. Therefore, the hydrodynamics of fluidized bed reactors and solid circulation technology plays an essential role in scale-up of a CLC process. A typical CFB uses various kinds of fluidized beds including bubbling fluidized bed in return chamber of loop-seals, turbulent fluidized bed for combustion of solid fuels in the Fuel Reactor (FR) and fast or dilute fluidized bed for particle transportation and fast reactions such as oxidation in the Air Reactor (AR). However, detailed studies on the impact of temperature and size on the hydrodynamics of these fluidized beds are relatively rare

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**Nomenclature**

| | |
|---|---|
| $A$ | surface area, $m^2$ |
| $Ar$ | Arrhenius number |
| $D$ | diameter, m |
| $d_p$ | particule size, m |
| $Gs$ | solid flux, $kg/(m^2\ s)$ |
| $H$ | height, m |
| $L$ | length, m |
| $Q$ | gas flow rate, $m^3/h$ |
| $R$ | gas constant, J/(K mol) |
| $Re$ | Reynolds number |
| $T$ | temperature, C |
| TGA | Thermo Gravimetric Analysis |
| $U_c$ | maximum pressure fluctuation velocity, m/s |
| $U_{mf}$ | minimum fluidization velocity, m/s |
| $V_{sg}$ | superficial gas velocity, m/s |
| $W_s$ | solid flow rate, kg/h |
| $\Delta P$ | pressure drop, Pa |
| $\varepsilon$ | gas holdup |
| $\varepsilon_s$ | solid hold-up |
| $\mu$ | gas viscosity, Pa s |
| $\rho$ | density, $kg/m^3$ |

*Subscripts*

| | |
|---|---|
| $b$ | bulk |
| $exp$ | experimental |
| $g$ | gas |
| HP | horizontal pipe |
| $ls$ | loop seal |
| $lv$ | L-valve |
| $mf$ | minimum fluidization |
| $p$ | particle |
| $s$ | solid |

for group B particle (used in CLC) compared to group A particles [5,6].

Control of solid circulation flow rate is another critical aspect in CLC process. Solid circulation rate controls the quantity of oxygen transferred into the Fuel Reactor necessary for combustion. In addition, it controls the heat transfer between reactors to maintain thermal balance of the system. However, solid circulation may cause undesired gas leakage into or out of the Fuel Reactor. This can cause reduction of the $CO_2$ capture efficiency or dilute the produced $CO_2$ stream. These critical points together with high temperature of circulating particles in CLC, makes non-mechanical pneumatic valves the best technology for solid flow control. L-vale and loop-seal are the most comment devices of this kind which are widely used in CFB applications thanks to their simple construction, ease of operation, reliability, and low cost. Despite of their wide use, experimental studies on the impact of temperature on the operation of these devices are very rare in literature [7].

Total and IFPEN are conducting a joint program on the research and development of chemical looping combustion. This paper presents research activities carried out on the dense phase fluidized bed transition velocities. Impact of temperature on the minimum fluidization velocity ($U_{mf}$) is first investigated. $U_{mf}$ is an important fluidization property which depends on the particle characteristics and operating conditions. Impact of temperature on the turbulent fluidized bed is then presented. Finally, impact of size and temperature on the performance of non-mechanical pneumatic valves are studied in this paper.

## 2. Materials and methods

Various group B particle of Geldart classification are used in this study as listed in Table 1. The apparent sphericity in this table is measured experimentally by measuring pressure drop across a fixed bed of particles with different packing ratios. The Ergun [8] equation is then used to calculate the particle sphericity.

### 2.1. High temperature testing unit

The impact of temperature on fluidization properties was carried out in an electrically heated fluidized bed of 0.13 m i.d. and 1 m height with a perforated plate gas distributor. This reactor is a part of a high temperature pilot plant presented in Fig. 1. The bed pressure drop and bed level were measured with two pressure probes, one measuring the average bed density and the other one measuring the entire bed pressure drop. An important parameter in this test is the pressure measurement frequency. The principal signal attenuating elements are the pressure transmitting lines between the reactor and the pressure transmitter. Aerations were applied in these lines to avoid this possible interference. The respond time of the pressure transfer lines was selected in a manner to ensure a respond time superior to the response time of the pressure transmitter. This was experimentally verified by measuring artificially created known pressure fluctuations to ensure sensitivity of measurement response time.

This pilot plant was also used to study the impact of temperature on the solid flow rate control in L-valve. An identical cold flow model was also used for investigation of the pneumatic valves in ambient conditions for different solids mentioned above. These devices are described in detail elsewhere [7].

### 2.2. 1 $MW_{th}$ equivalent cold flow prototype

A circulating fluidized bed (CFB) cold flow prototype equivalent to 1 $MW_{th}$ is used in this study. This system, as illustrated in Fig. 2, is composed of a fuel reactor with a dense bottom section connected to a riser above the dense bed leading into a cyclone. Separated particles leave the cyclone into a loop-seal connected to a second fluidized bed. An L-valve is connected into the bottom of this fluidized bed to control solid flow back into the fuel reactor. This system allows studying various scaling fluidization aspects of CLC including reactor hydrodynamics and solid circulation control devices (loop-seal and L-valve). It should be mentioned that the loop-seals in this unit have a rectangular cross section, and the mentioned diameters are equivalent diameters.

## 3. Results and discussions

Chemical Looping Combustion (CLC) process is mostly carried out in Circulating fluidized bed (CFB) reactor systems. Fluidized bed reactors and solid circulation devices are among the most critical sections in a CFB system. In this study, impacts of temperature on bubbling and turbulent fluidized beds are first studied. Impacts

**Table 1**
Properties of particles used in this study.

| Particle | Density ($kg/m^3$) | $d_p$ (μm) | $\phi$ |
|---|---|---|---|
| Ilmenite (ilm) | 4750 | 107 | 0.64 |
| Sand (SP1) | 2650 | 300 | 0.83 |
| Sand (SP2) | 3250 | 180 | 0.85 |