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Comparison of downer and riser flows in a circulating bed by means of optical fiber probe signals measurements

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Abstract

In this work, the riser (2.42 m high) and downer (0,85 m high) sections with an ID of 82 mm in both, were analyzed to study the temporal fluid dynamics properties of a circulating bed system in terms of electrical signals of particles concentration obtained by an optical fiber probe. Experiments were conducted using ambient air as the fluid phase and FCC (fluid catalytic cracking) particles as the solid phase. The measurements with the optical fiber probe were conducted in the inlet and outlet zones of both riser and downer. Signals were evaluated in the phase space (chaos analysis), by reconstructing the attractors and calculating the Kolmogorov entropy and the correlation dimension. Results show that the downer presents a less chaotic flow, with lower values of Kolmogorov entropy and correlation dimension, compared to the riser. In the entrance of the downer, the flow is less complex and more predictable in the center due to the effect of the solid feeder. The flow develops in direction of the exit zone and at that position there is no much difference in complexity between the central and wall. In the case of the riser, at the entrance effect is caused by a question of configuration, due to a presence of a curve, making the solid concentration increase toward the wall. In the exit zone, the flow suffers the effect of the abrupt exit.

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Keywords: Riser; downer; optical fiber probe; temporal dynamics

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1. Introduction

Circulating fluidized beds (CFBs) are widely used in the petrochemical industry (e.g. Fluidized Catalytic Cracking - FCC units), metallurgical industry (e.g. calcinators) and in the energy sector (e.g. coal combustors). The advantages of CFBs include high efficiency and flexibility in catalyst or heat-carrier regeneration and control of the feeds [1]. In the case of FCC applications, the CFB can be divided into two basic parts, functioning as two separate reactors: the riser and downer. The riser reactor is characterized as a section of vertical transport in which there is a co-current contact between phases, flowing against the gravitational action. On the other hand, in tubular FCC downer reactors the co-current gas and solid phases move downwards.

CFBs in which particulate and gaseous phases have upward flows (riser) are widely used in chemical, metallurgical and petrochemical industries. Risers have many advantages over the conventional bubbling and turbulent fluidized bed, such as high efficiency of gas-solid contact and reduced axial dispersion [2]. However, riser reactors still has some shortcomings such as the downflow of solids in certain positions (typically near the wall) and the formation of clusters and non-uniformity in the radial and axial profiles, thereby reducing the efficiency of gas-solid contact and selectivity. These disadvantages can be reduced in a downer reactor [3], where the flow moves downward.

The local distribution of solids concentration, in particular its changes over time, are very important for any gas-solid operation. The time series of solid concentration contain information about the dynamics of the bed, and its transient behavior has influence on mass and heat transfers in CFBs. In this work, concentration signals are measured with an optical fiber probe in the downer and riser sections of a circulating bed. The time series gotten can be interpreted in the phase space domain (chaos analysis) and they are used to describe the fluid dynamics of the gas-solid flow.

2. Experimental

Experiments were performed in a laboratory-scale circulating bed (Figure 1). The riser section has 2.42 m high and the downer has 0.85 m high, both with an ID of 82 mm. The gas phase is ambient air (25 °C) and the solid phase is FCC catalyst ($d_p = 80\mu\text{m}$, $\rho_p = 902\text{ kg/m}^3$). The gas distributor consists of four nozzles and, in contrast to many CFBs studied previously, e.g. [1,4], the feeding of air is parallel to the feeding of solids at the entrance of the downer section. After passing through the downer, the flow pass through a curve, then it is conduced to the riser. This configuration seems like a J-valve and allows a weak restriction on the riser bottom zone. The exit structure of the riser is an abrupt T-shaped exit (elbow with projected end) which can cause a strong restrictive exit effect.

Local measurements inside the riser were performed by means of a reflective-type optical probe (33 cm in length and 6 mm in ID), composed of 37 fibers to measure local electrical signals of concentrations.

Measurements of electrical signals relating to solids concentration were taken at two axial positions located in both downer ($Z = 0.05$ and 0.80 m) and riser ($Z = 0.25$ and 1.87 m) sections. Five radial measurements ($r/R = 0, 0.25, 0.50, 0.75$ and 0.875) were performed at each axial position. Operating conditions of solids mass flow and gas superficial velocity are presented in Table 1.

2.1. Data Processing Technique

Chaos analysis begins with the reconstruction of attractors in phase space. To quantify these attractors it is necessary to calculate the correlation dimension, D (a measure of the complexity of solids concentration fluctuations) and the Kolmogorov entropy, K (a measure of predictability of solids concentration with time), which are the main parameters for the characterization of chaotic dynamics in the system.

In this study, the attractors were determined by the method of "Singular value decomposition", proposed by Broomhead and King [5]. Invariants of the system, D_{ML} (-) and K_{ML} (bits/s) were calculated by the "Maximum Likelihood Estimation", developed by Schouten et al. [6,7].

Using these parameters, the detection of change in the interaction between the phases present in flow (gas velocity and flow of solids) was studied in several axial and radial positions to map the fluid dynamics of this laboratory-scale circulating bed.

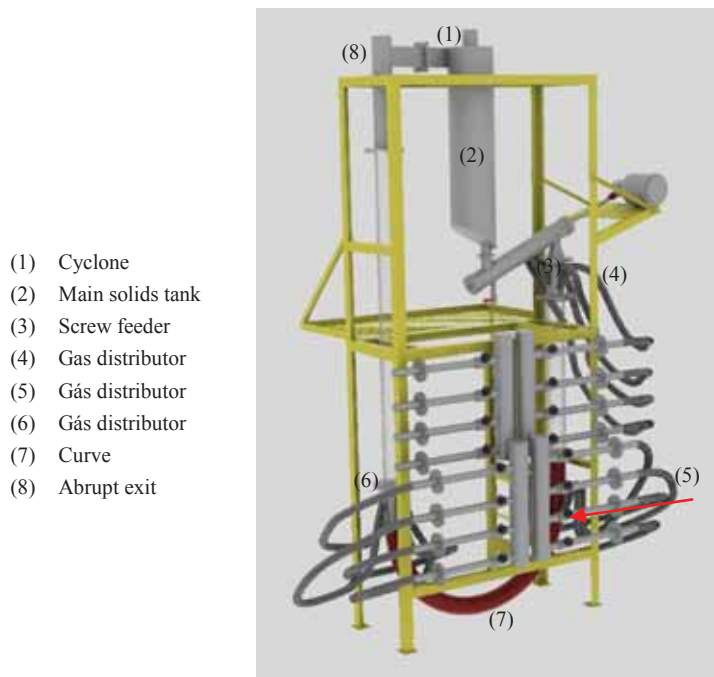


Fig. 1: Schematic of the circulating bed unit

Table 1. Operating conditions

Solids mass flow, G_s (kg/m ² .s)	0.076	0.164	0.164	0.296	0.472	0.648
Superficial gas velocity, u_0 (m/s)	4.21	4.21	5.26	5.26	7.36	8.42

3. Results

Different comparisons between downer and riser were made in terms of correlation dimension (D_{ML}) and Kolmogorov entropy (K_{ML}), as follows:

3.1. Correlation dimension analysis

Lower values of chaotic parameters are generally found for conditions with high solids concentrations. This is due to the fact that the presence of solids in the gas stream reduces the amount of turbulence and complexity of flow [8].

The radial profiles of correlation dimension are shown in Figure 2.

In the downer inlet zone, the profile presents minimum values are in the central position, showing the flow is less complex in this region. As it approaches the wall, the values become higher, with maximum at $r/R = 0.75$, indicating a gas-solid suspension less uniform in this region. The lower values of D_{ML} in the central are due to the high concentration of solids in this radial position, caused by the particles feeding. At the entrance section of the downer, the solids jets are just starting to mix with air, causing a totally irregular radial flow, with higher solids concentration in the central region.

In the exit zone of the downer, there is a more intensive mixing stage. The solids flow in this axial position is directed to the wall due to the exit effect caused by the curve. Thus the central zone is further diluted and complex, and as it approaches the wall, the flow becomes more concentrated and less complex. However, there is a slight increase when it reaches the position $r/R = 1.0$. Some studies [8,9] also reported this behavior in downers. This increase in D_{ML} can be attributed to interactions between solids and wall.

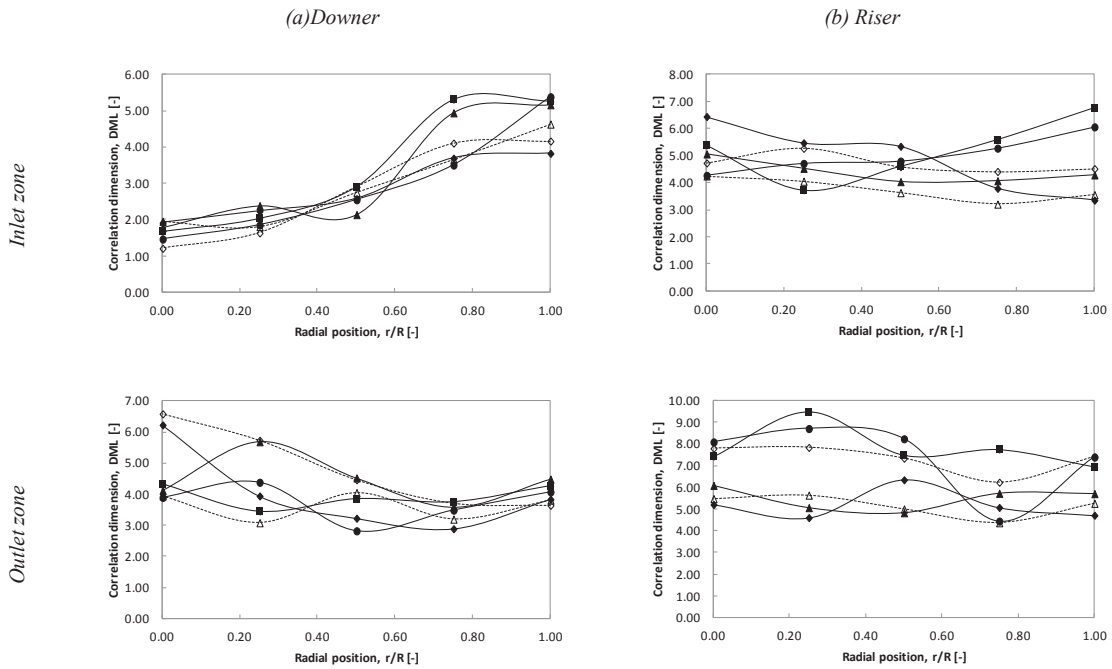
In the case of the riser, the radial profiles are flatter in comparison to the downer, however the values of D are higher. This is due to the fact that the solid and gaseous phases are now better mixed. In the region of the wall, there is an increase of D_{ML} , except for the most dilute condition ($G_s = 0.076 \text{ kg} / (\text{m}^2 \cdot \text{s})$). This fact can be explained by the interaction between the particles and the wall, attenuated by the passage of the flow in the curve before reaching the riser section. Furthermore, for more concentrated conditions, increasing D_{ML} toward the wall occurs due intermittent behavior of large agglomerates of particles in this region. The central region is more diluted, and has higher values of D_{ML} . This is because under diluted conditions, particles have high degrees of freedom, leading to more complex variations in solids concentration.

In the exit zone of the riser, the behavior is similar. The profiles are flat and lower values of D_{ML} are found near the wall. However, when compared to the entrance zone, values of D_{ML} are greater. That occurs because the gas-solid mixture is more intense in this axial position. The wall effect was observed only in the more concentrated conditions ($G_s = 0.472 \text{ kg}/(\text{m}^2 \cdot \text{s})$) and $G_s = 0.648 \text{ kg}/(\text{m}^2 \cdot \text{s})$), where there is a small increase of D_{ML} in $r/R = 1.0$.

3.2. Kolmogorov entropy analysis

The radial profiles of Kolmogorov entropy are shown in Figure 3. In the case of the downer, in the inlet zone K_{ML} values increase towards the wall. In the exit zone, the flow exhibits flatter radial profiles with values slightly higher in the central region, corresponding to the dilute phase. Near the wall, where

there is higher solids flow, and high values of K_{ML} are mainly due to the interaction between solids and the wall. Due to the high solids flow directed towards the central region, K_{ML} values are low and almost independent of operating conditions.



Subtitle:

- ◆— $G_s = 0.076 \text{ kg}/(\text{m}^2.\text{s})$; $u_0 = 4.21 \text{ m/s}$
- $G_s = 0.164 \text{ kg}/(\text{m}^2.\text{s})$; $u_0 = 4.21 \text{ m/s}$
- ▲— $G_s = 0.164 \text{ kg}/(\text{m}^2.\text{s})$; $u_0 = 5.26 \text{ m/s}$
- $G_s = 0.296 \text{ kg}/(\text{m}^2.\text{s})$; $u_0 = 5.26 \text{ m/s}$
- ◇--- $G_s = 0.472 \text{ kg}/(\text{m}^2.\text{s})$; $u_0 = 7.36 \text{ m/s}$
- △--- $G_s = 0.648 \text{ kg}/(\text{m}^2.\text{s})$; $u_0 = 8.42 \text{ m/s}$

Fig. 2. Radial profiles of correlation dimension (DML) in the inlet and outlet zones of (a) downer e (b) riser.

For the riser, it can be seen that the values of K_{ML} are much higher, indicating that the flow in this section is less predictable. At the entrance of the riser, for some operating conditions, the flow tends to be more predictable, with lower K_{ML} near the wall. However, for the condition with $G_s = 0.164 \text{ kg}/(\text{m}^2 \cdot \text{s})$, for example, the opposite happens: the flow is more predictable in the central region, and tends to become more chaotic - or less predictable, as it approaches the region of the wall. This is a very diluted condition with pronounced effect of the interaction between particles and wall.

In the exit zone of the riser, the K_{ML} values are very high, reaching 37.43 bits/s at $r/R = 0,5$ in the operating condition with $G_s = 0.296 \text{ kg}/(\text{m}^2 \cdot \text{s})$. K_{ML} values are relatively low both in the region of the wall, due to the presence of a greater flow of solids in this position, as in the central region, indicating that the flow is also more predictable in the center. This phenomenon can be explained by the exit effect, which directs the particles to the central position, thus reducing the amount of turbulence and complexity of flow.

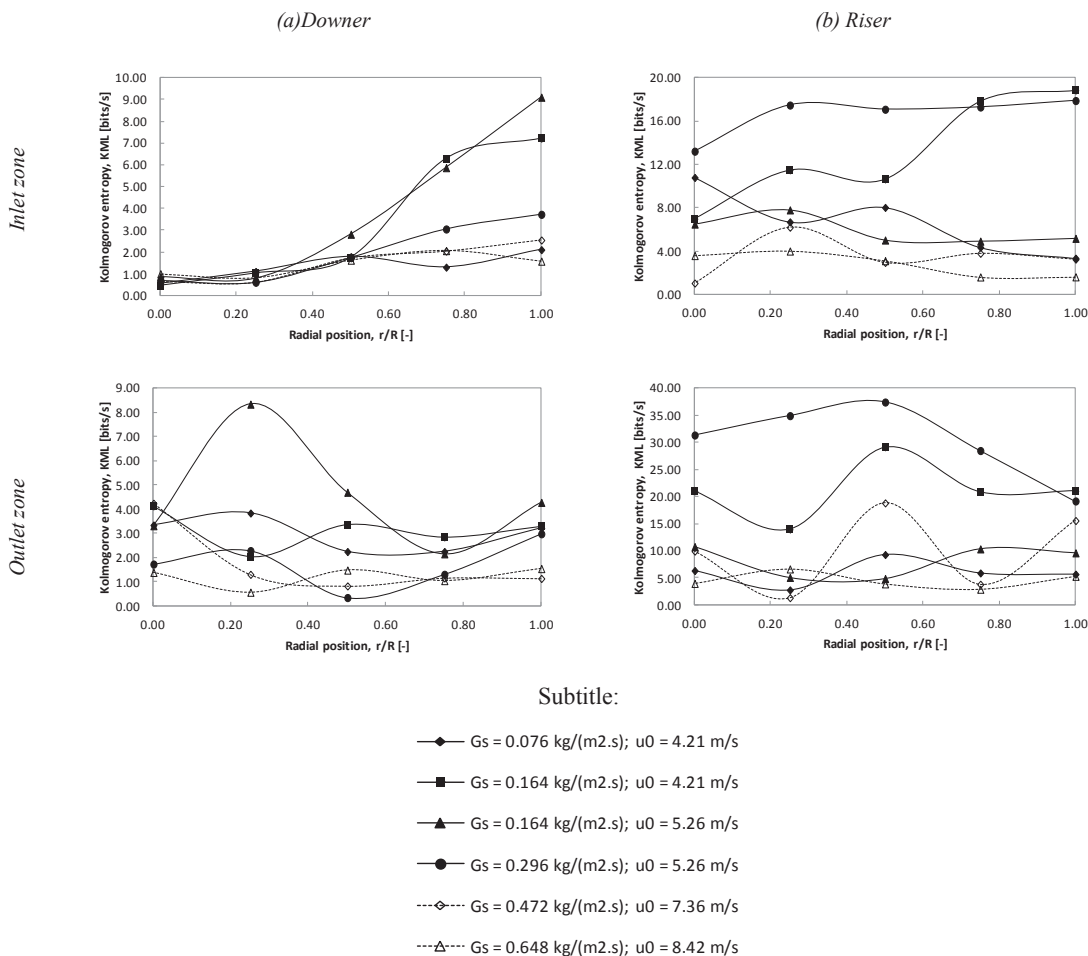


Fig. 3. Radial profiles of Kolmogorov entropy (KML) in the inlet and outlet zones of (a) downer e (b) riser.

4. Conclusions

The downer and riser sections of a circulating exhibit chaotic behavior indicated by positive values of Kolmogorov entropy. Higher values of correlation dimension (D_{ML}) and entropy (K_{ML}) were found in the riser, showing that the flow is more complex and less predictable in this section.

When compared to the riser, the downer shows a less chaotic flow, with much lower values of D_{ML} and K_{ML} . At the entrance of the downer, the flow is less complex and more predictable in the center next to the solids feed. This occurs due to the periodicity offered by the solids feeding. At the exit, there is little difference in complexity between center and wall regions because the particles flow becomes more distributed as the flow develops.

The inlet zone of the riser suffers a great effect of the curve, which provides additional acceleration to particles, so that the solid concentration is higher near the wall and smaller as approaching to the center. Depending on the solids flow used, one can find a less chaotic behavior close to the wall due to the particles concentration effect. However, for more dilute conditions, the turbulence and the interaction between particle and wall prevail, leading to a more chaotic behavior. In the outlet zone, the flow is influenced by the abrupt exit, directing the flow toward the center, making it more concentrated and less chaotic at this position.

Nomenclature

D_{ML}	Correlation dimension, [-]
d_p	particle mean diameter, [μm]
K_{ML}	Kolmogorov entropy, [bits/s]
G_s	solids mass flow, [$\text{kg}/\text{m}^2 \cdot \text{s}$]
r	radial position, [mm]
R	radius of the riser, [mm]
u_0	superficial velocity of the gas, [m/s]
Z	axial position, [m]
ρ_p	Particle density, [kg/m^3]

Acknowledgments

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