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EFFECT OF FOUNTAIN CONFINER ON KAOLIN ENTRAINMENT IN A CONICAL SPOUTED BED DRYER

Sukunza Pérez, Xabier [(1)]; Pablos Castro, Aitor [(1)]; Aguado Zarraga, Roberto [(1)]; Vicente Peñalosa, Jorge [(2)]; Olazar Aurrecoechea, Martin [(1)]

[(1)] UPV/EHU, [(2)] NOVATTIA

Spouted bed is a high efficient technology for drying of solids that can process a wide range of particle sizes when including internal devices. Draft-tube (DT) provides bed stability and fountain confiner (FC) reduces particle entrainment. In early studies it has been proven that drying of kaolin can be carried out in a conical spouted bed using fine sand as inert bed, since kaolin easily agglomerates causing bed instability. 60% aperture DT and 600 mm length/200 mm diameter FC have been selected for maximizing drying efficiency. Entrained kaolin (expected product in drying of wet kaolin) is collected in a bag filter, recording recovered mass weight evolution with time.

Reducing the distance between bed surface and confiner turns into a faster entrainment. For distances below 3 cm remarkable pressure drop fluctuations have been appreciated, caused by overpressure into the confiner. As expected, increasing air velocity gives faster entrainment and higher pressure drop. Additionally, low air velocities do not ensure kaolin recovering, establishing a limit of u/ums>2.5 for optimal operation.

Keywords: *kaolin; entrainment; conical spouted bed; fountain confinement device*

EFECTO DEL CONFINADOR DE FUENTE EN EL ARRASTRE DE CAOLÍN EN SECADERO SPOUTED BED CÓNICO

El spouted bed provisto de dispositivos internos ha demostrado ser eficiente para el secado de sólidos, ya que admite un amplio rango de tamaño de partículas. El draft-tube (DT) estabiliza el lecho y el confinador de fuente (FC) reduce el arrastre de las partículas. Anteriores estudios han demostrado que el spouted bed es eficaz para el secado de caolín con el uso de arena fina como lecho inerte, debido a que el caolín forma aglomeraciones. El DT de 60% de apertura y el FC de longitud/diámetro de 600/200 mm son los que presentan mayores eficiencias de secado. El caolín arrastrado (producto esperado en secado) es colectado en filtros de mangas, midiendo la evolución de la cantidad colectada con el tiempo.

La reducción de la distancia entre el confinador y la superficie del lecho aumenta la velocidad de arrastre. Para distancias por debajo de 3 cm se dan fluctuaciones significativas en la pérdida de carga causadas por sobrepresiones en el confinador. Un incremento en la velocidad del aire aumenta el arrastre y la pérdida de carga. Además, velocidades bajas de aire no garantizan la recuperación completa del caolín, estableciéndose un límite de u/ums>2.5 para una operación óptima.

Palabras clave: *caolín; arrastre; lecho en surtidor cónico; confinador de fuente*

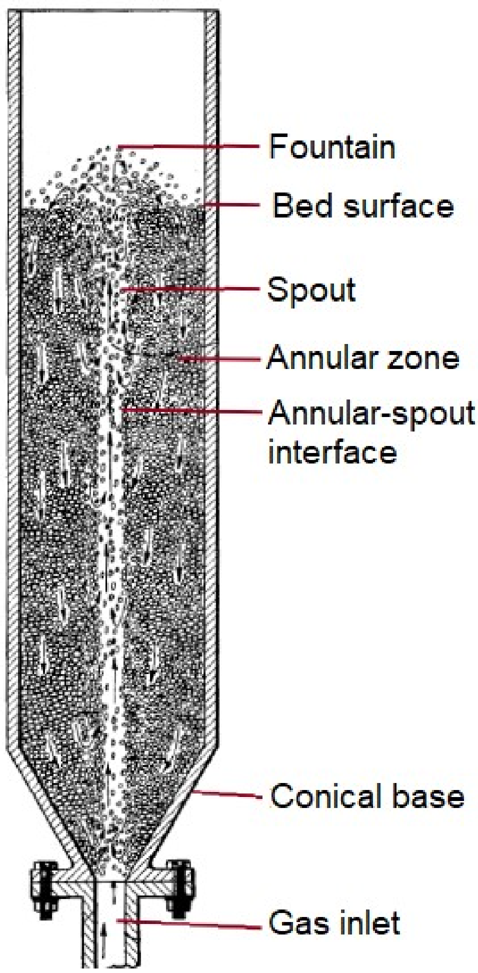
Correspondencia: Xabier Sukunza x.sukunza.perez@gmail.com

1. Introduction

Drying of solids is the final process in many industries such as chemical, mining, pharmaceutical, which can significantly affect the quality of the final product. Among others, thermal drying is preferred since it can accomplish complete moisture content by evaporation of water content. About 85% of industrial dryers supply heat by convection. Energy consumption of theses dryers is very high due to poor mass and energy transfer rates, although several advances have been obtained by the use of fluidised beds.

Spouted bed was first used for drying of granulate solids, Geldart D type solids, as an alternative to fluidised beds, since the latter could not fluidise too coarse particles (Mathur & Gishler 1954). Spouted bed original configuration, Figure 1, consists of a cylinder with a conical base that allows solid recirculation and avoids dead zones. Air is introduced from a nozzle located at the bottom of the conical section, which creates a central channel, called spout. Separation of air and particles occurs at the top of the bed, where the particles return to the bed by gravitation force. This particular bed movement and solid recirculation increases mass and energy transfer rates, which yields higher efficiencies over other technologies.

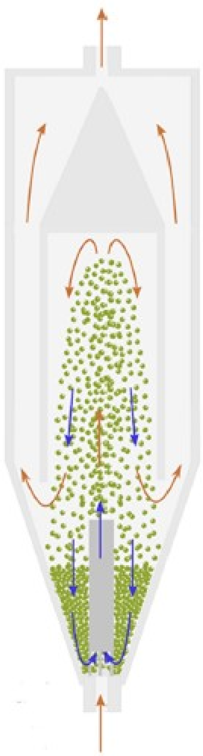
Figure 1. Spouted bed original configuration scheme. Modified from Mathur & Gishler (1954).



However, several drawbacks have been reported, including handling of sticky and cohesive particles, bed stability at certain conditions and spouted bed scaling up (Nagashima et al. 2015). Conical spouted bed, contactor with fully conical geometry, was successfully used for fluidization of sticky but coarse catalysts for benzyl alcohol polymerization. In addition, conical geometry increases bed homogeneity and reduces particle residence time (Markowski & Kaminski 1983). However, conical geometry still shows some limitations for handling of Geldart A and B particles (Olazar et al. 1997). The use of internal devices is a suitable option to overcome these limitations. Draft tube increases spouted bed operability allowing handling of Geldart A and B type particles (Konduri, Altwicker & Morgan III 1999). Moreover, draft tube eases the apparition of central channel, hence bed pressure drop is considerably reduced (Altzibar et al. 2013). However, air velocity at the fountain is remarkably higher, thus fine particle entrainment is observed, emptying the bed and hence hindering spouted bed solid treatment capacity. In order to overcome excessive entrainment, the Research group proposed a modification of the conventional spouted bed. This modification consist of a cylinder that is located above bed surface, called fountain confinement device (Pablos et al. 2018). This device confines the bed, considerably reducing particle entrainment. Air trajectory is also modified, since air goes up until upper zone of the confiner and goes back to bed surface through confiner wall. Therefore, a counter current between particles and gas occurs in the confiner and, since contact time between air and particles is also increased, improving spouted bed efficiency over other technologies (Cortazar et al. 2018).

This configuration, conical spouted bed equipped with draft tube and fountain confinement device, Figure 2, has successfully used for drying of fine and ultrafine sands, allowing very wide operation conditions, including gas velocity, particle size distribution, inlet air temperature, reaching efficiency values up to 90%.

Figure 2. Air and particle movement in a conical spouted bed with draft tube and fountain confinement device (Altzibar et al. 2017).



In fact, due to vigorous particle movement in bed, spouted beds are used for drying of sticky and cohesive particles such and suspensions (Arsenijević, Grbavcić & Garić-Grulović 2004). Since moisture content of the suspensions is high, inert beds are used, which provides continuously renewed surface and intensive contact between inert particles and wet material, increasing mass and energy transfer rates. Size of bed particles must be larger than expected dried product in order to assure bed stability.

In early studies of the Research group, it has been observed that drying of kaolin, Geldart A type solid, can be carried out in conical spouted beds. Since kaolin is a sticky solid and forms agglomerates, an inert bed was formed by glass beads (d_p = 1 mm). However, due to high bed weight, high blower consumption was monitored. As a result, inert bed formed by fine sand has been proposed in this research for drying of kaolin, which reduces bed pressure drop and increases contact area between inert and kaolin.

2. Objectives

This research is framed in the joint project between Catalytic Process & Waste Valorisation Research group (University of the Basque Country, UPV/EHU) and a technology development company, Novattia Desarrollos Ltd, with the aim of designing and commercialising spouted bed based pilot plants. Actually, the consortium owns a spouted bed pilot plant for drying of fine and ultrafine sand, which will be used for drying kaolin.

Due to differences in particle size between inert sand and kaolin, air will force dried kaolin to be entrained from drying chamber. Moreover, kaolin must leave the chamber once totally dried. Therefore, kaolin entrainment and cycle times before leaving the contactor must be studied in order to optimise drying chamber design. However, since any study of kaolin entrainment in conical spouted beds has been found in literature, the aim of this research is to analyse the effect of air velocity and distance between bed surface and fountain confinement device in kaolin entrainment. In addition, the evolution of kaolin entrainment with time was measured.

3. Methodology

Fine sand was used as inert bed with a wide particle size range in between 150 and 1000 µm. Kaolin, with smaller and wider particle size in between 1 and 100 µm, was used in order to study particle entrainment. Inert sand and kaolin particle size distributions are shown in Figure 3.

A conical contactor (4) has been used for the runs, Figure 4a. 600 mm length and 200 mm diameter fountain confiner and 60% aperture draft tube have been selected as internal devices for maximising drying efficiency. Air was introduced by a blower (1), which generates the sufficient air pressure in order to overcome pilot plant pressure drop. Air volumetric flow rate was measured by *Powirl 77* flowmeter (2), which is controlled by a PID system (7). Since kaolin will be entrained from the contactor, a bag filter (5) was used in order to recover kaolin particles, which works with a fan (6) in order to facilitate air exhaust. Contactor pressure drop is also monitored between the inlet and outlet of the contactor (3) in order to determine bed stability. A 3D view of the pilot plant is shown in Figure 4b.

Different experiments have been carried out in order to measure kaolin entrainment. Distances of 7, 5, 3 and 2 cm between bed surface and fountain confiner (FC) were used in order to determine fountain confiner effect on kaolin entrainment. In addition, experiments without fountain confiner were also carried out. Different air velocities at the inlet of the contactor were also studied for all the confiner configurations: u/u_{ms} = 2, 2.5 and 3 m/s, where u_{ms} = 10 m/s.

Before getting started, 19 kg of sand and 2 kg of kaolin were premixed and fed into the chamber, giving stagnant 450 mm of bed height. Afterwards, air was introduced to desired velocity, which was calculated by measuring air volumetric flow rate. Kaolin entrained weight was monitored at the filter over time. The runs were concluded either, once recovered kaolin weight was stabilised, or once kaolin total entrainment was achieved. Furthermore, average pressure drop between air inlet and outlet was also monitored, including bed and internal devices pressure drop.

Figure 3. Particle size distribution for inert sand and kaolin.

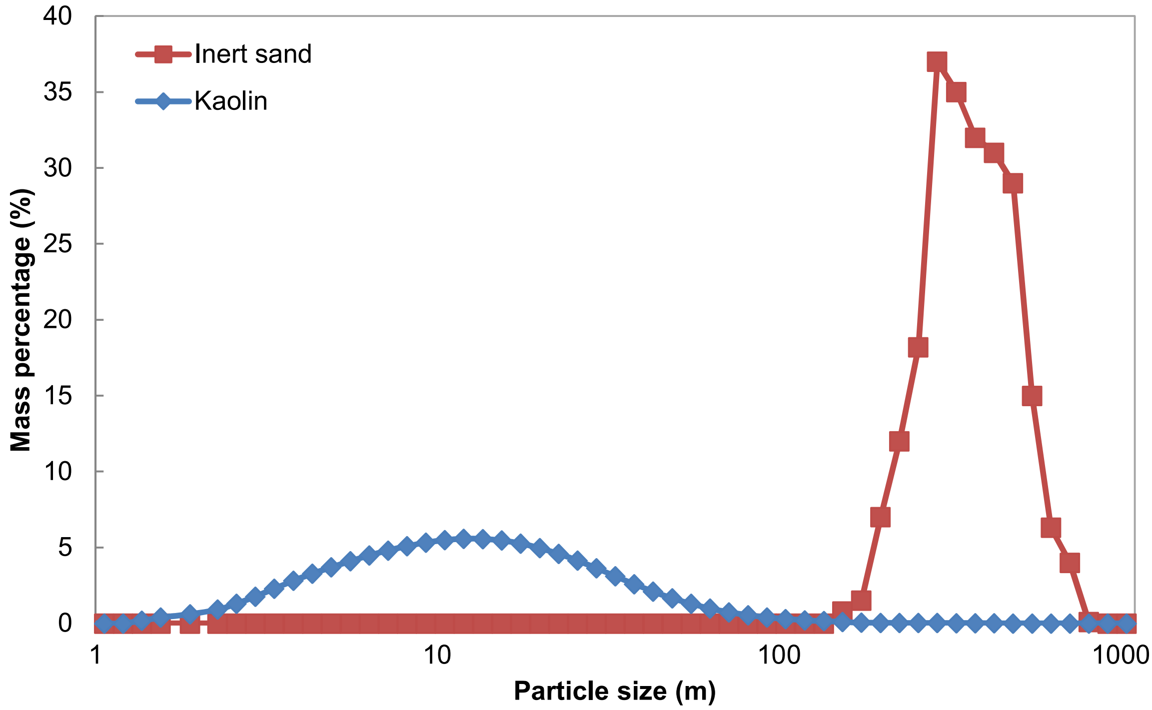
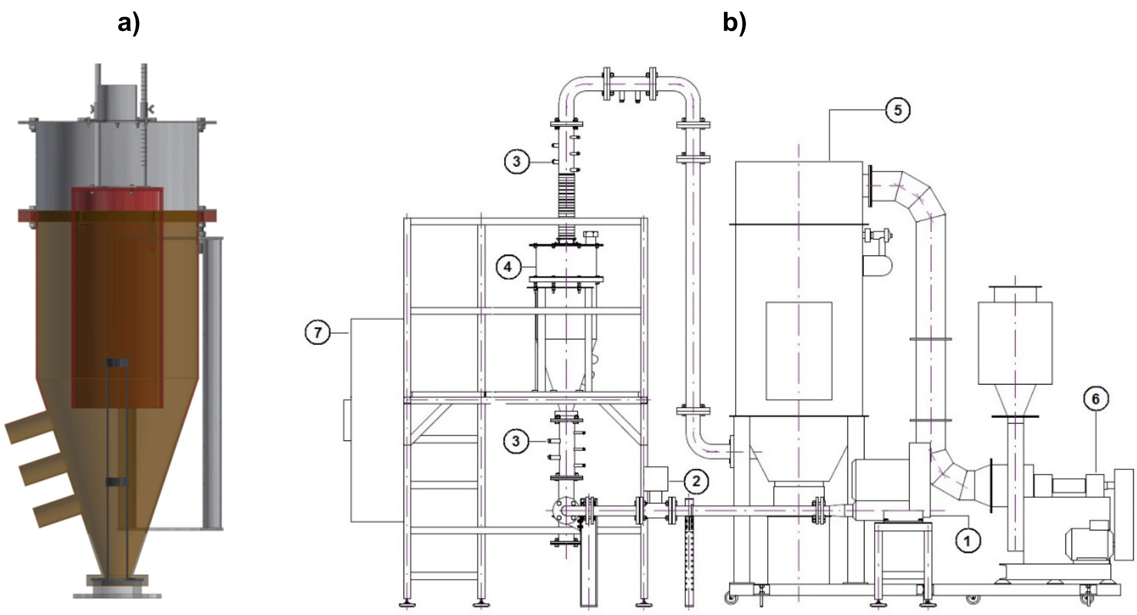


Figure 4. Schematic representation of a) conical contactor and b) pilot plant.



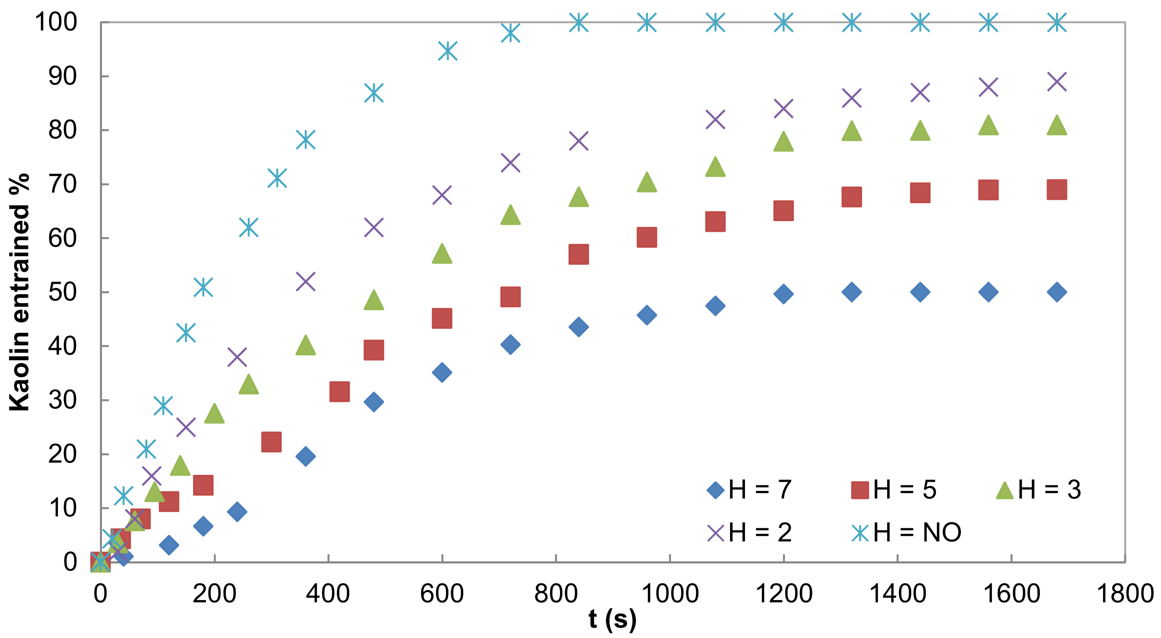
4. Results

Figure 5 shows kaolin entrainment over time for u/u_{ms} = 2 and Figure 6 for u/u_{ms} = 2.5. Entrainment kinetics for u/u_{ms} = 3 will not be shown, since same entrainment behaviour has been observed. Nevertheless, in the latter air velocity, at H_C = 7 cm a 90% of recovery was monitored and 100% kaolin entrainment has been achieved in other configurations.

Reducing the distance between bed surface and fountain confiner turns into higher entrainment kinetics and larger total kaolin is entrained at both air velocities. Moreover, total kaolin entrainment has not been achieved for any distance at low air velocities. However, not using the fountain confiner ensures total entrainment, although kaolin residence time it is considerably reduced. At air high velocities total kaolin entrainment has not been achieved at the H_C = 7 cm.

Figure 7 shows steady state average pressure drop in the contactor. At low air velocities reducing H_{CF} turns into higher pressure drop. In fact, once the fountain is confined, and air and particles return to the bed, the reduction of H_{CF} hinders air exhaust to the annular region of the contactor. However, at a distance of 2 cm, a reduction of pressure drop has been found due to overpressure into de confiner, since there is hardly any slot between bed surface and confiner. In this case, pressure increases in the confiner and air does not open the spout, hence it flows along the annular zone of the bed. Moreover, not using the fountain confiner gives the lowest pressure drop value, since the air does not find any obstacle at the spout.

Figure 5. Effect of distance between bed surface and fountain confiner on evolution of kaolin entrainment over time. u/u_{ms} = 2 m/s



At distances of 7 and 5 cm, pressure drop increases with larger air velocities, which indicates that stable operation has been achieved at both velocities. In fact, two internal devices were installed, hence increasing air velocity must turn into higher pressure drop in the chamber. However, at H_{CF} = 3 pressure drop increases at u/u_{ms} = 2.5, but it suddenly decreases for larger velocities caused by bed instability as well as at u/u_{ms} = 2 and H_{CF} = 2 cm. Moreover, at H_{CF} = 2 cm instable operation was monitored in all studied velocities. As expected, approximately constant pressure drop has also been monitored when fountain confiner was not installed at both velocities, although stable condition was achieved (Altzibar et al. 2013).

Figure 6. Effect of distance between bed surface and fountain confiner on evolution of kaolin entrainment over time. u/u_{ms} = 2.5 m/s

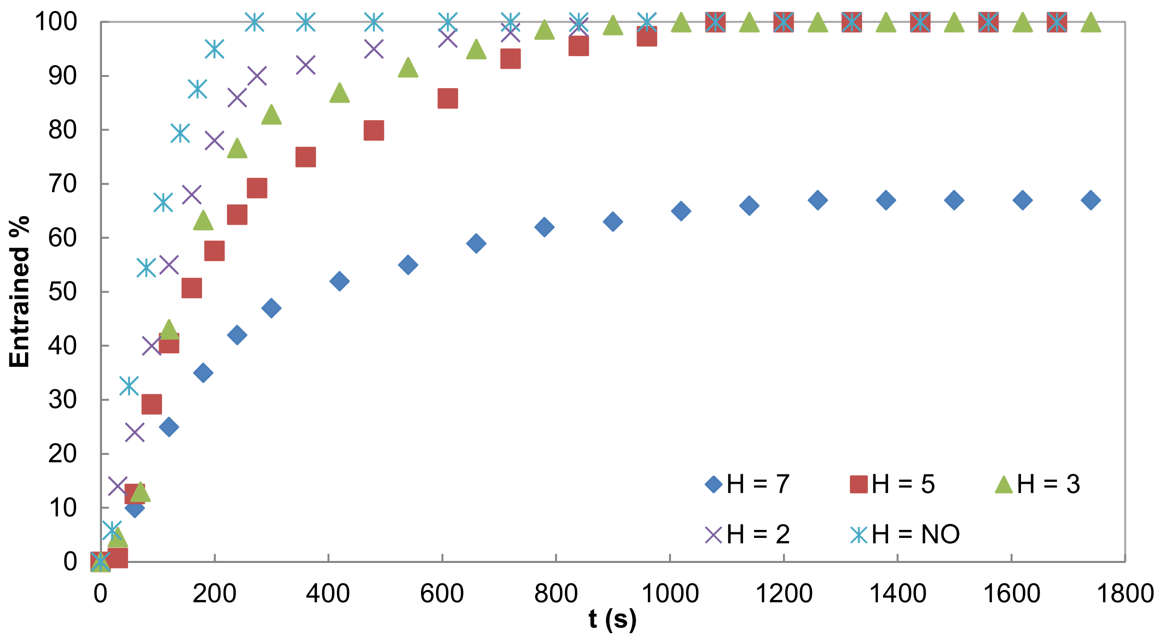
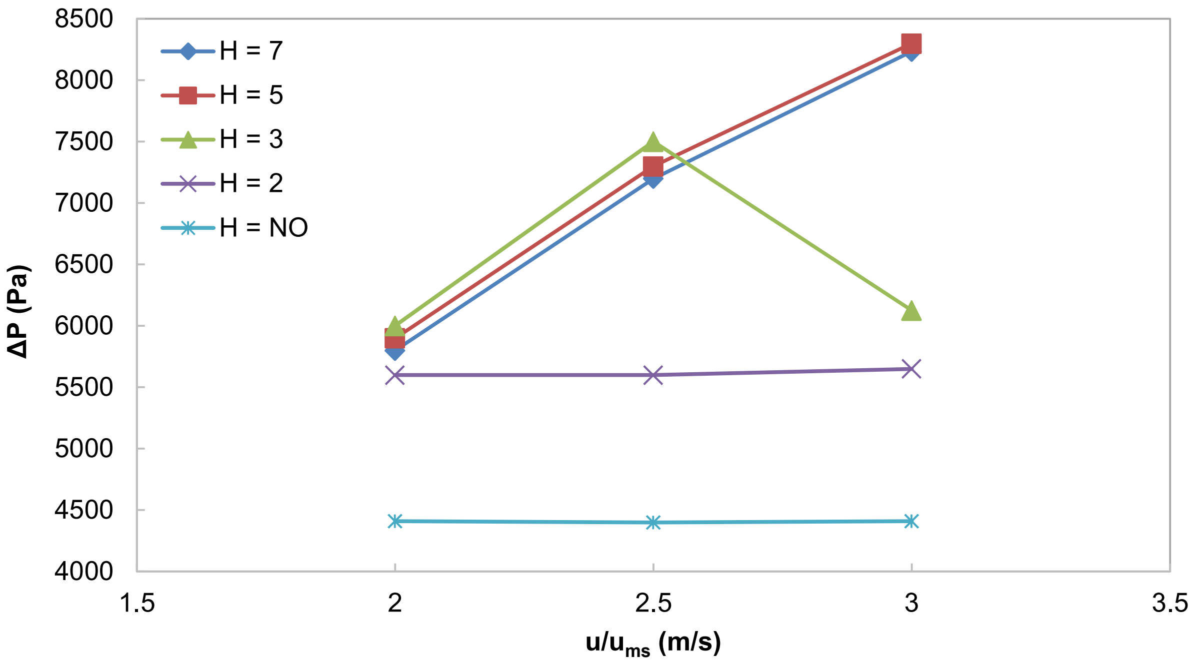


Figure 7. Steady state average pressure drop of all the configurations.



5. Conclusions

Effect of distance between bed surface and fountain confiner (H_{CF}) and air velocity on kaolin entrainment has been monitored in this research. For the experiments, the following conclusions have been drawn:

- Reducing H_{CF} gives higher entrainment kinetics at any air velocity, although at H_{CF} = 2 cm remarkable pressure drop fluctuations have been monitored caused by overpressure in the confiner. Therefore, as Estiati et al. (2019) stated, H_{CF} = 3 cm is the minimum distance required for stable operation and H_{CF} = 5 cm is the maximum distance in order to achieve total kaolin entrainment.
- Increasing air velocity also turns into higher kaolin entrainment kinetics, although at low air velocities total kaolin entrainment has only been observed when the confiner was not installed and at u/u_{ms} = 2.5 total kaolin entrainment was not achieved only at H_{CF} = 7 cm. In addition, almost total kaolin entrainment was achieved at any configurations at high air velocities. Therefore, a limit of u/u_{ms} = 2.5 has been established for optimal operation.
- Although total kaolin entrainment has been achieved in several configurations, a study of kaolin residence time has to be done in order to determine optimal configuration for drying.

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