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Minimum spouting velocity of fine particles in fountain confined conical spouted beds

Presenter: Mikel Tellabide

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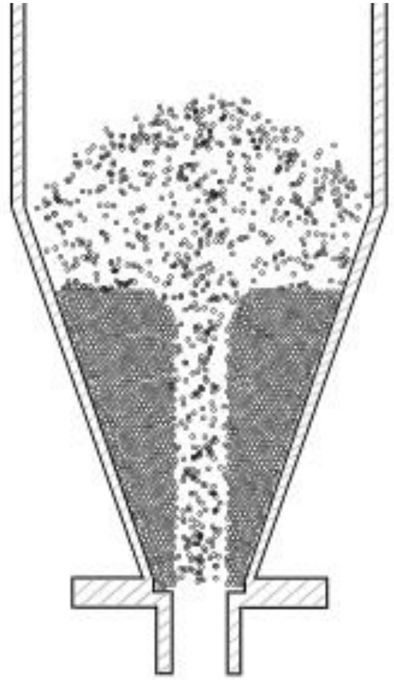
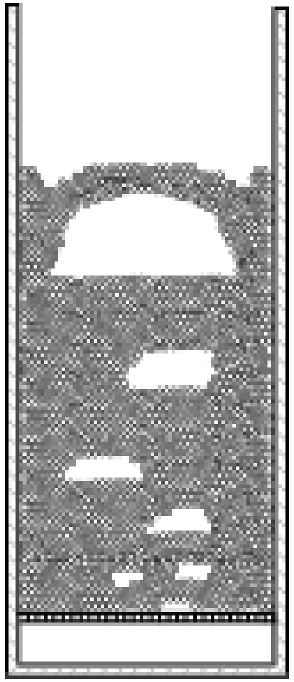
VS.

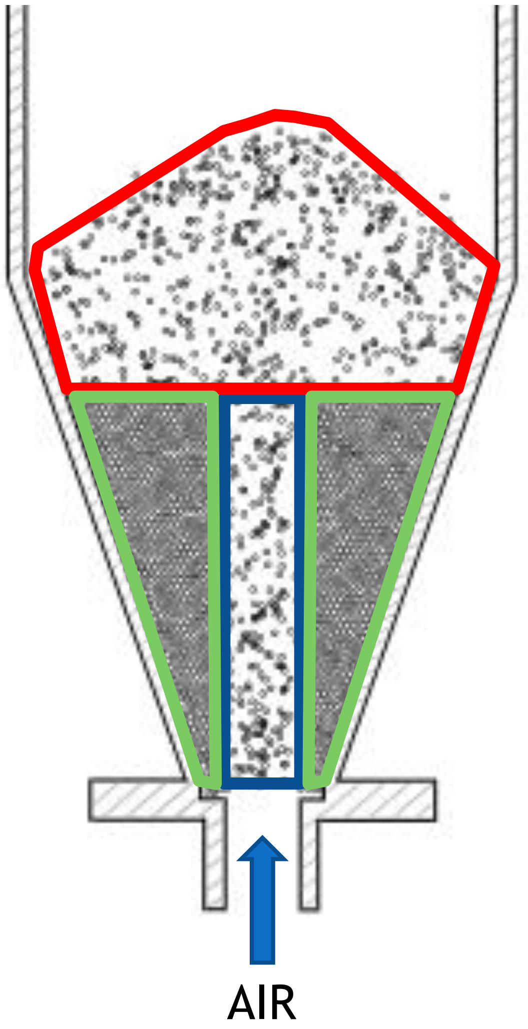
SPOUTED BED



- Suitable for coarse particle treatment.
- Great versatility in the gas flow rate:
  - Particles of irregular texture.
  - Wide size distribution.
  - Sticky solids.

FLUIDIZED BED





SPOUT

FOUNTAIN

ANNULUS

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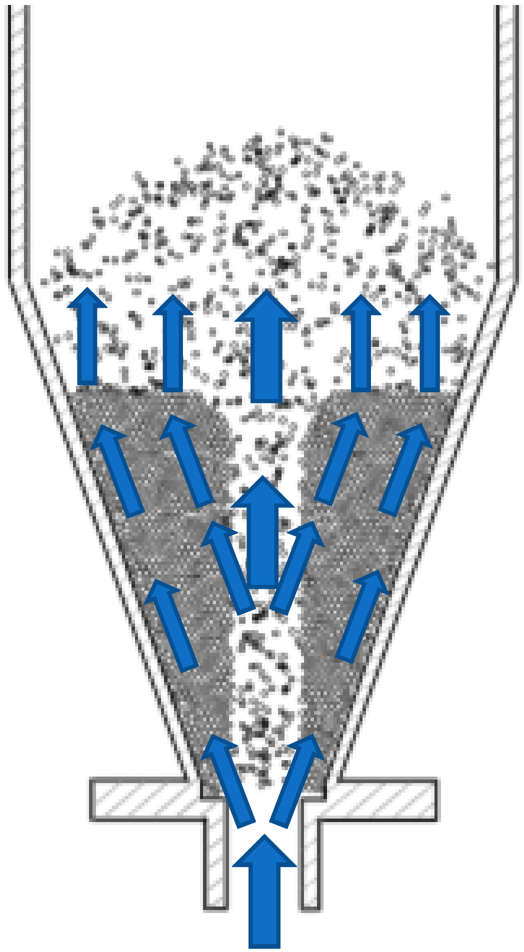
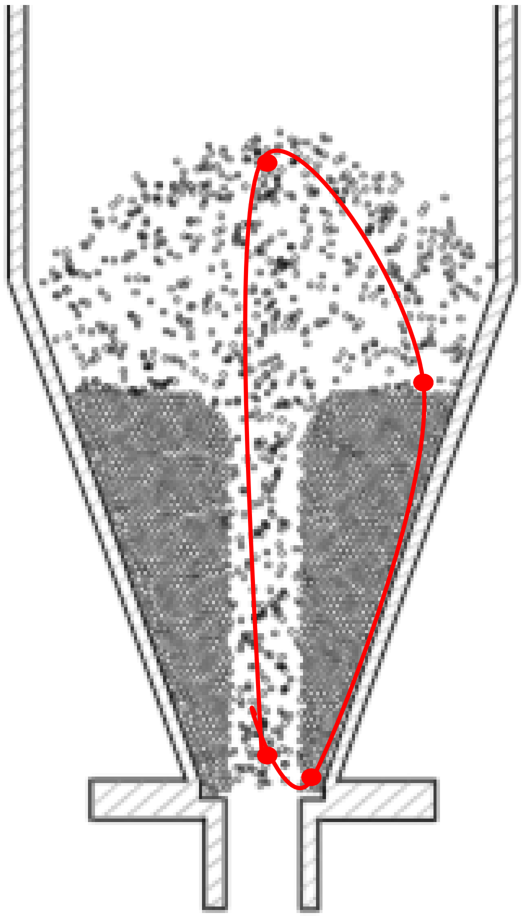


GAS CIRCULATION



SOLID CIRCULATION

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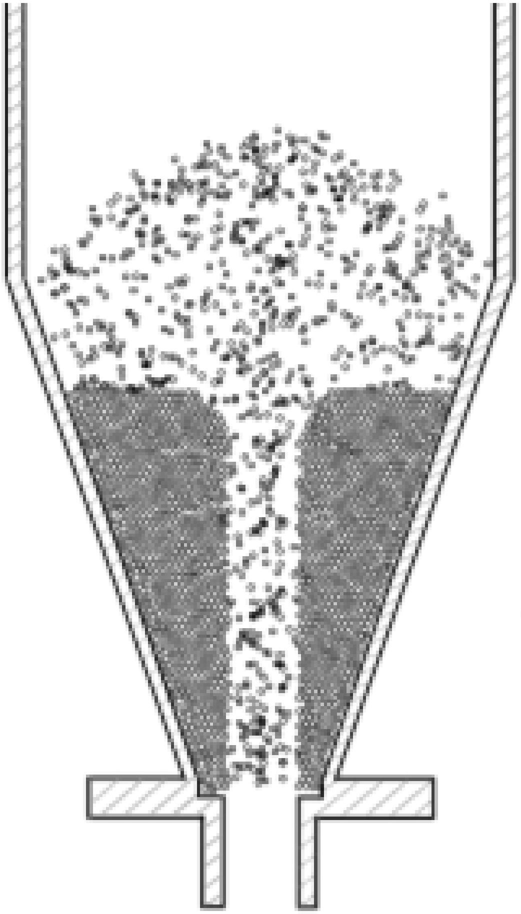


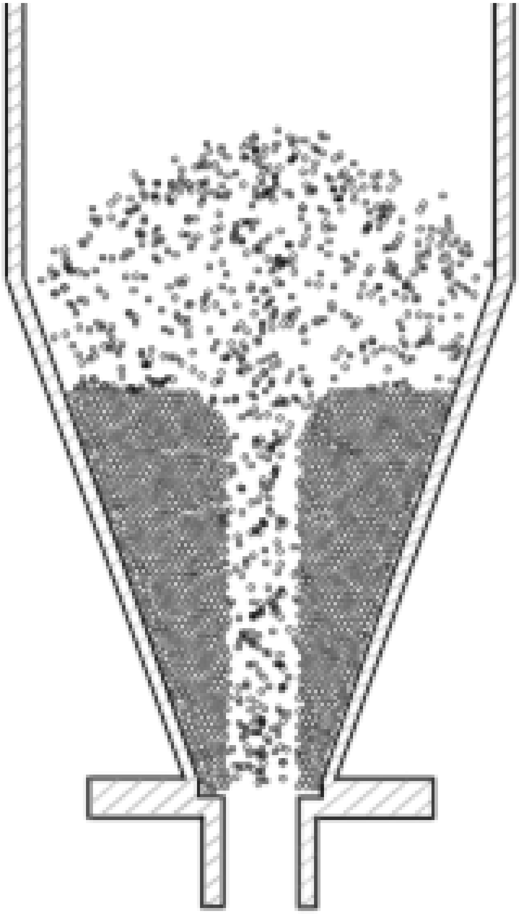
D_0/d_p

^

20-30[1,2]

>Stable regime

<Slugging regime



[1] M. Olazar, M.J. San Jose, A.T. Aguayo, J.M. Arandes, J. Bilbao, Stable operation conditions for gas-solid contact regimes in conical spouted beds, Ind. Eng. Chem. Res. 31 (1992) 1784–1792. doi:10.1021/ie00007a025.

[2] N. Epstein, J. Grace, Spouted and Spout-Fluid Beds Fundamentals and Applications, Cambridge, 2011

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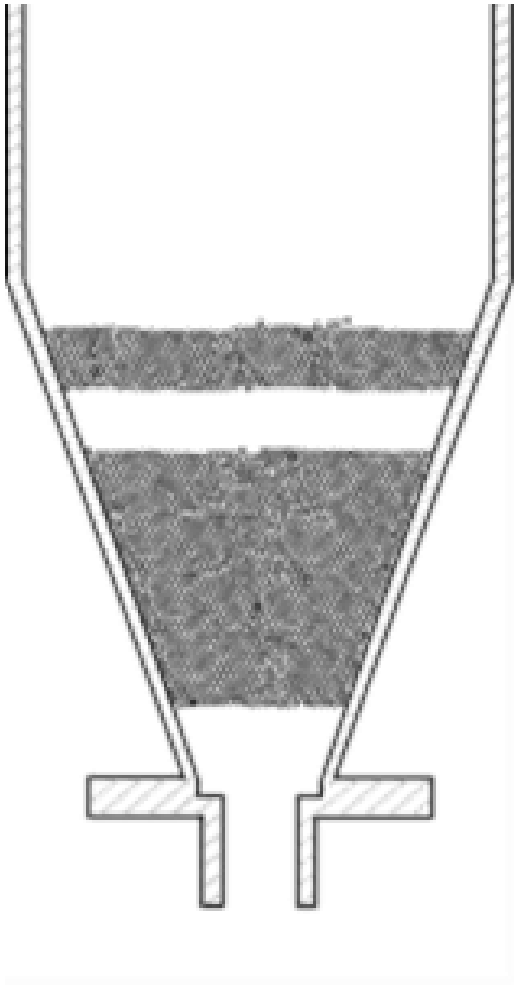
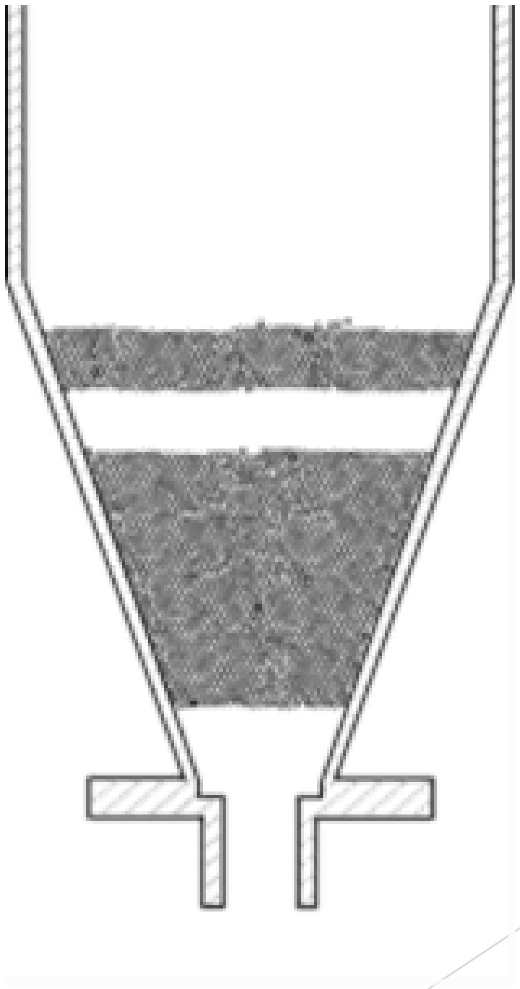


D_0/d_p

20-30[1,2]

>Stable regime

<Slugging regime



[1] M. Olazar, M.J. San Jose, A.T. Aguayo, J.M. Arandes, J. Bilbao, Stable operation conditions for gas-solid contact regimes in conical spouted beds, Ind. Eng. Chem. Res. 31 (1992) 1784–1792. doi:10.1021/ie00007a025.

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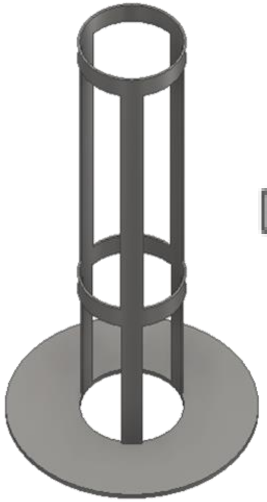
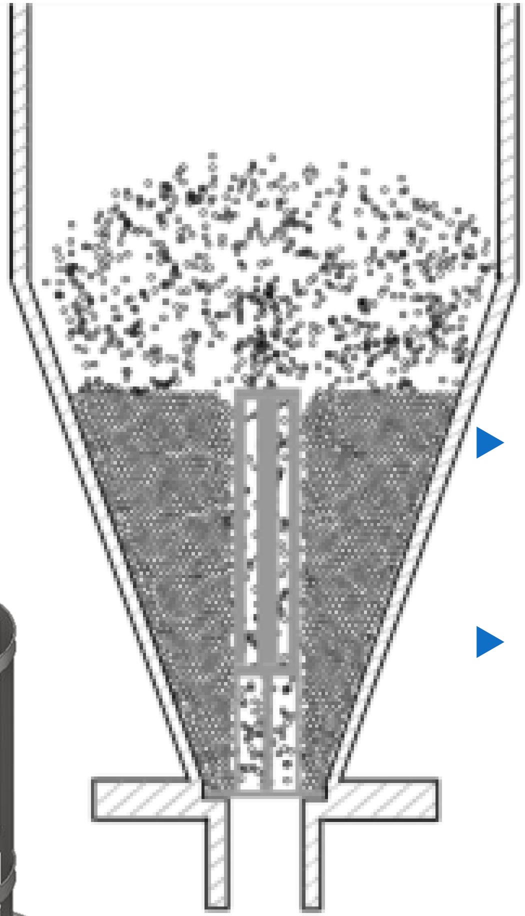
Draft tubes

Open-sided

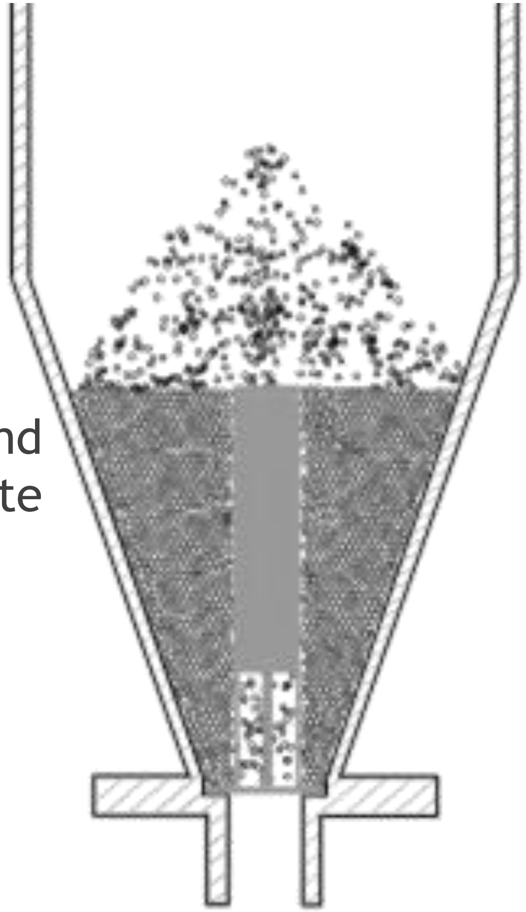
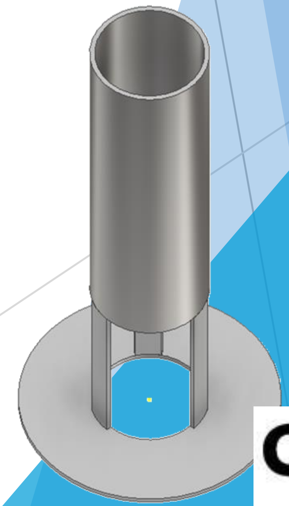
- System hydrodynamics and solid circulation flow rate are changed.
- High fountains.

↓

Particle entrainment

↓

Low gas flow rates must be used

Nonporous

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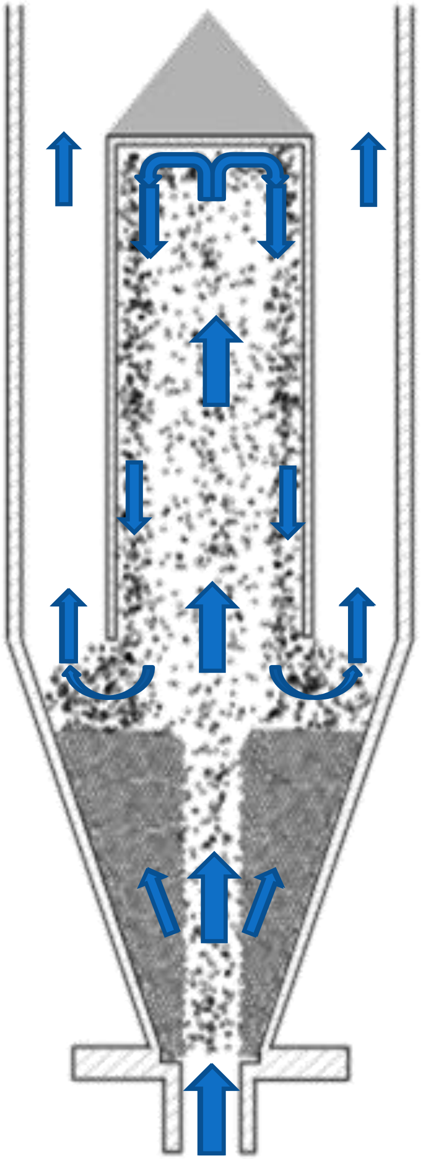
FOUNTAIN CONFINER



Fountain confiner…

- …allows stable operation with fine particles without draft tube.
- …increases the upper limit of the residence time of the gas and improves gas-solid contact.
- …avoids particle entrainment, allowing operation at high gas flow rates with and without draft tubes.

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AIMS

- To ascertain the validity of the correlations in the literature for calculating the minimum spouting velocity in fountain confined conical spouted beds with fine particles.
- In case there is no valid correlation, modifications in those of best fit will be carried out.

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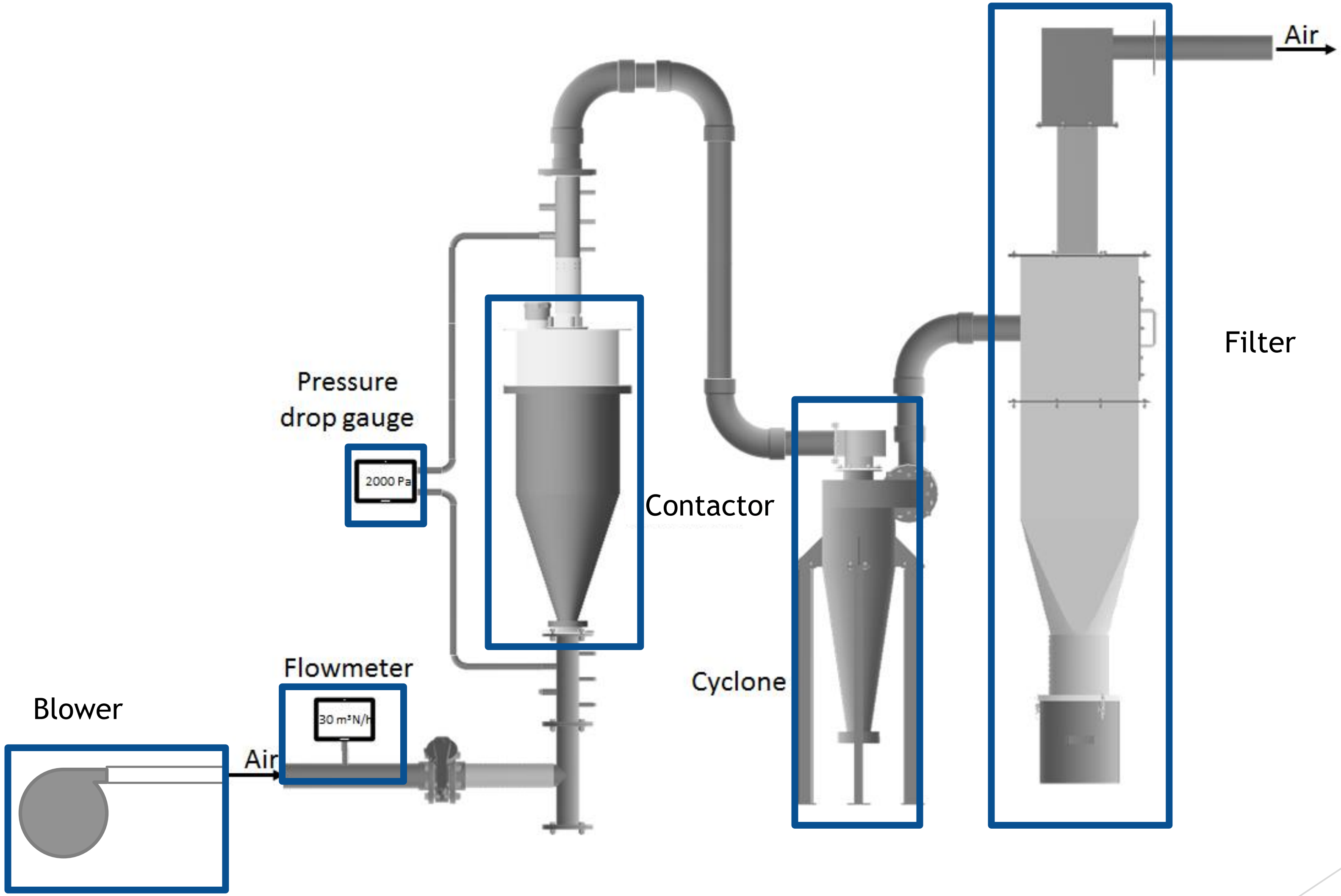
Pilot plant



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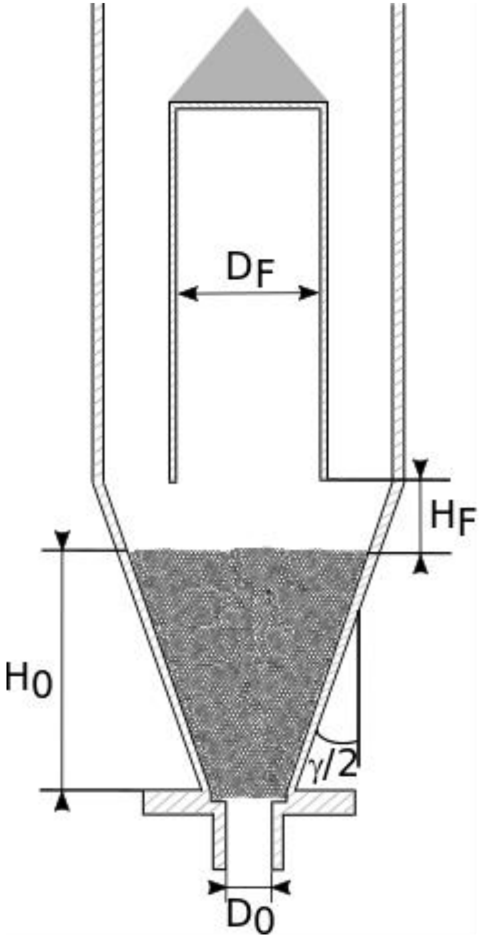
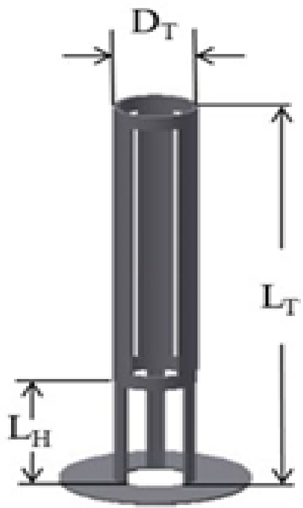
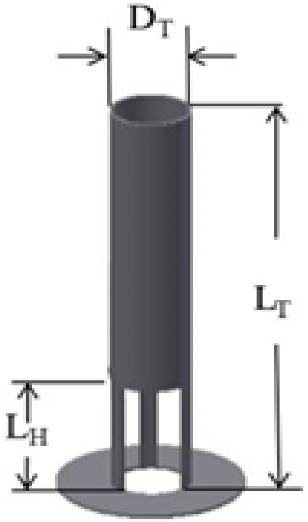
Contactor and internal devices

- ⍰: 28°, 36°, 45°
- D_0: 3, 4, 5 cm
- H_0: 22, 27 cm
- D_F: 15, 20 cm
- H_F: 2, 4, 6, 8, 10 cm





- L_T: 22, 27 cm
- AR (Aperture ratio): 42, 57, 79%
- D_T: 4, 5 cm
- L_H: 7 cm



- L_T: 22, 27 cm
- D_T: 4, 5 cm
- L_H: 7, 15 cm

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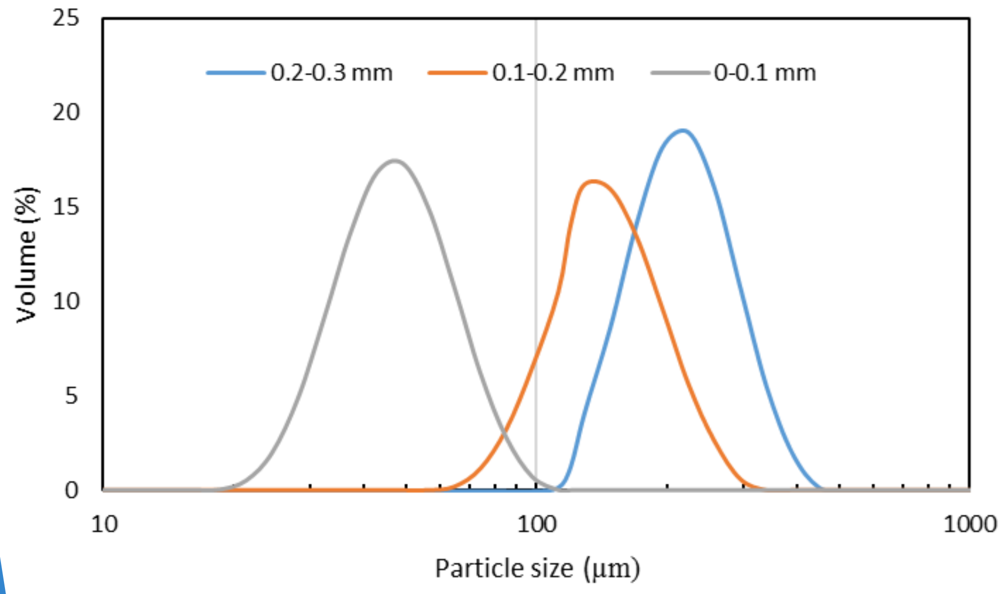
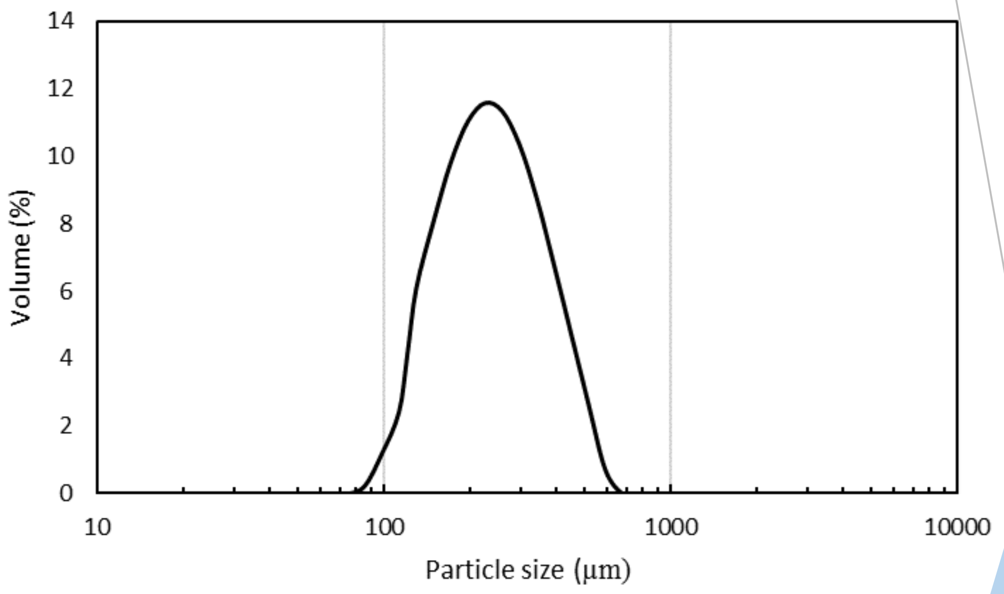
Material

Building sand



- d_p: 0.053, 0.155, 0.246 mm
- Density: 2387 kg/m^3

Sawdust



- d_p: 0.244 mm
- Density: 496 kg/m^3

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Significant factors in the minimum spouting velocity

Analysis of variance

Configuration	Material	Significance order
Without draft tube	Sand	$H_0 >> H_0{}^*D_F > D_F > d_p > D_0$
	Sawdust	$D_0 > H_0 > \gamma > H_0{}^*D_0$
	Both materials	$H_0 > \rho_s > D_F{}^*H_0 > H_0{}^*\rho_s$
Open-sided draft tube	Sand	$H_0 >> d_p > D_0 > D_T > D_0{}^*D_T > D_T{}^*d_p$
	Sawdust	$H_0 > AR > \gamma > D_0 > D_T > D_F{}^*H_0$
	Both materials	$\rho_s >> H_0 > d_p > D_0 > D_0{}^*\rho_s > AR$
Nonporous draft tube	Sand	$H_0 >> d_p > D_0 > \gamma > L_H > D_F$
	Sawdust	$H_0 > D_0 > D_T > \gamma > L_H >> D_F{}^*H_0$
	Both materials	$\rho_s > H_0 >> d_p > L_H > \gamma > D_T{}^*d_p$

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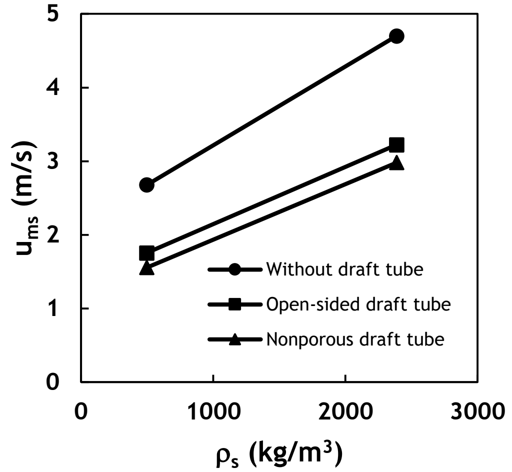
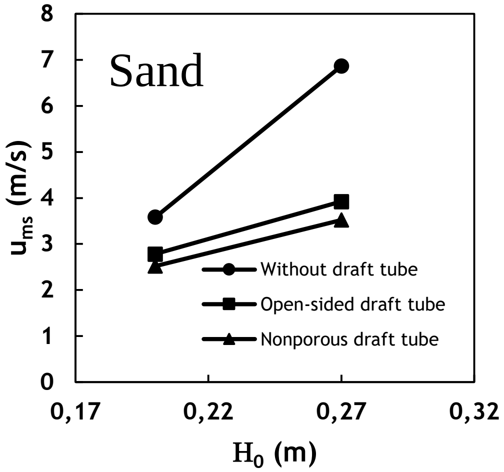
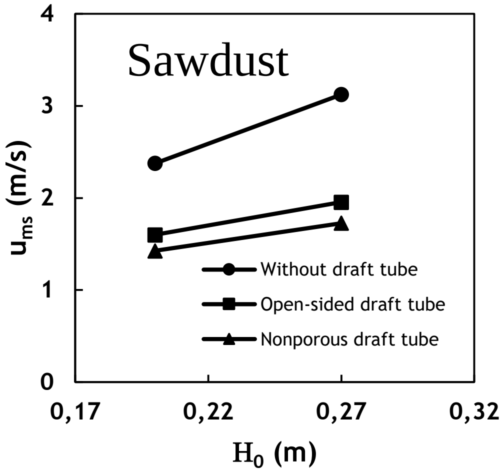
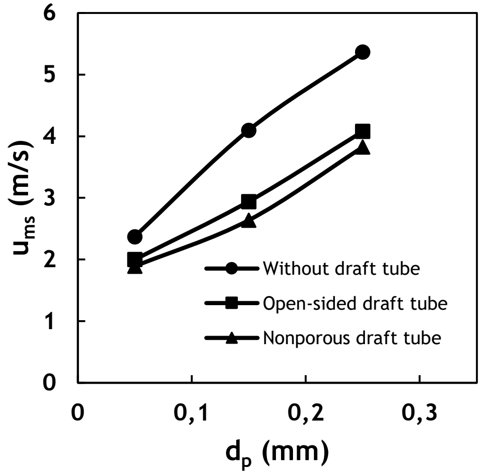
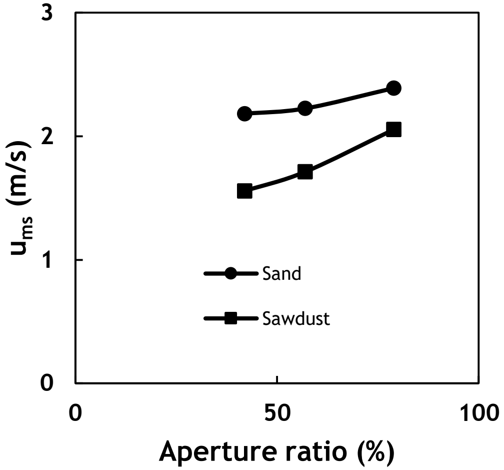
Significant factors in the minimum spouting velocity

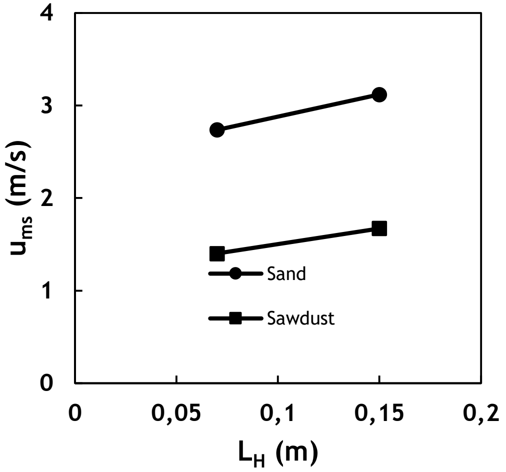












$(\rho_s, H_0, d_p, AR, L_H)\ \Uparrow \quad u_{ms}\ \Uparrow$

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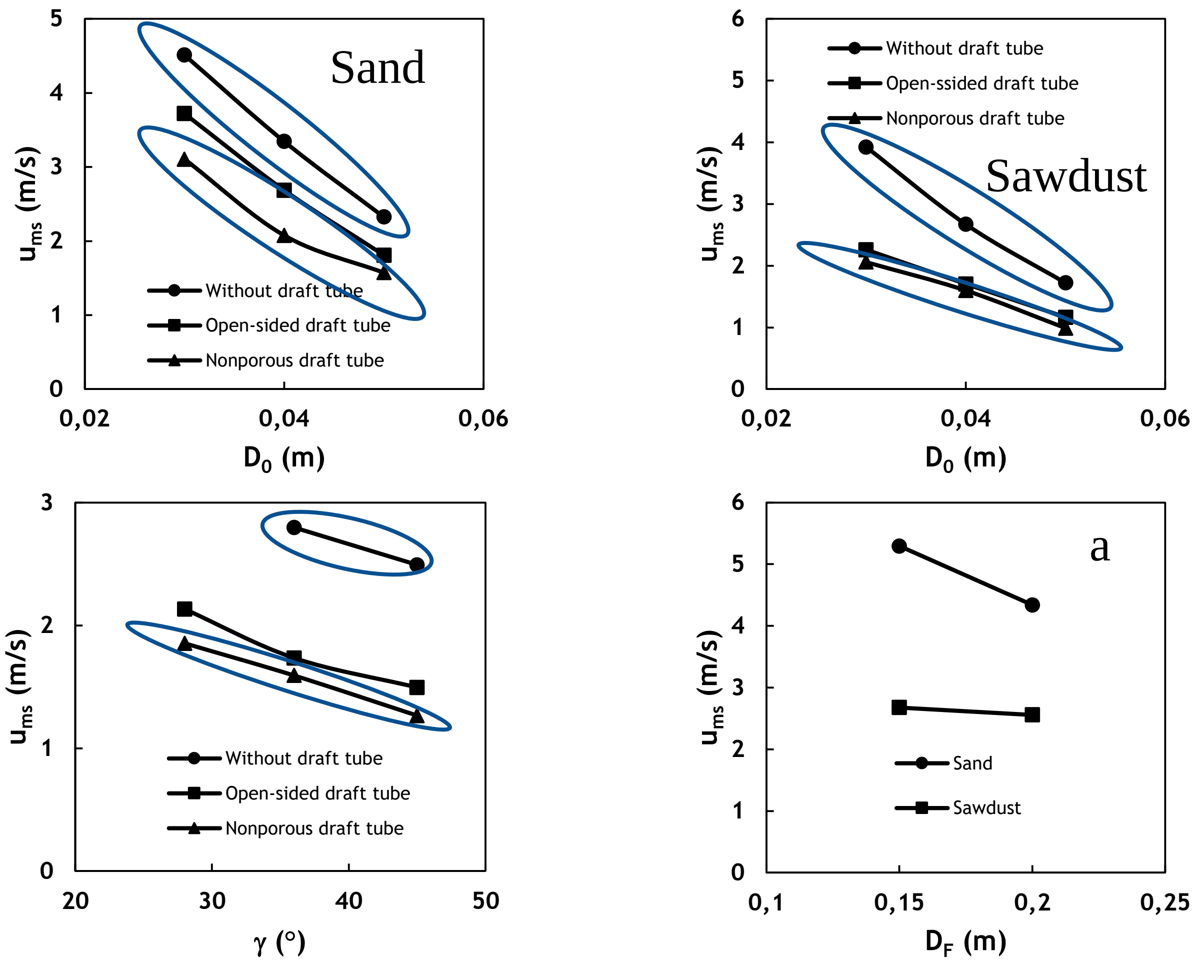
Significant factors in the minimum spouting velocity



(D_0, γ, D_F) ↑ u_{ms} ↓

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Hydrodynamics correlations

Author	Correlation	Eq.	Configuration
Gorshtein and Mukhlenov	$(Re_0)_{ms} = 0.174Ar^{0.5}(D_b/D_0)^{0.25}(\tan(\gamma/2)^{-1.25}$	1	Conical spouted bed
Tsvick et al.	$(Re_0)_{ms} = 0.4Ar^{0.52}(H_0/D_0)^{1.24}(\tan(\gamma/2)^{0.42}$	2	Conical spouted bed
Markowski and Kaminski	$(Re_0)_{ms} = 0.028Ar^{0.57}(H_0/D_0)^{0.48}(D_c/D_0)^{1.27}$	3	Conical spouted bed
Olazar et al.	$(Re_0)_{ms} = 0.126Ar^{0.5}(D_b/D_0)^{1.68}[\tan(\gamma/2)]^{-0.57}$	4	Conical spouted bed
Olazar et al.	$(Re_0)_{ms} = 0.126Ar^{0.39}(D_b/D_0)^{1.68}[\tan(\gamma/2)]^{-0.57}$	5	Conical spouted bed
Saldarriaga et al.	$(Re_0)_{ms} = 0.126Ar^{0.51}(D_b/D_0)^{1.37}(\tan(\gamma/2))^{-0.57}$	6	Conical spouted bed
Golsthan et al.	$(Re_0)_{ms} = 0.0965Ar^{0.67}(H_0/D_0)^{1.32}(\tan(\gamma/2))^{0.76}$	7	Conical spouted bed
Altzibar et al.	$(Re_0)_{ms} = 0.126Ar^{0.5}(D_b/D_0)^{1.68}(\tan(\gamma/2))^{-0.57}(A_0/A_T)^{0.3}$	8	Open-sided draft tube conical spouted bed
Saldarriaga et al.	$(Re_0)_{ms} = 0.272Ar^{0.5}(D_b/D_0)^{1.25}(\tan(\gamma/2))^{-0.57}(A_0/A_T)^{0.3}\emptyset^{0.274}$	9	Open-sided draft tube conical spouted bed

Plain conical spouted beds (CSB)

Open-sided draft tube CSB

Hydrodynamics correlations

Author	Correlation	Eq.	Configuration
San José et al.	$u_{ms} = 0.126 Ar^{0.5} \left(\frac{D_b}{D_0}\right)^{1.68} \left(tan\left(\frac{\gamma}{2}\right)\right)^{-0.57} \left(\frac{H_0 - L_T}{H_0}\right)^{0.45} \left(\frac{D_i}{D_i - D_T}\right)^{0.17}$	10	Nonporous draft tube conical spouted bed
Kmiec et al.	$(Re_0)_{ms} = 0.0137 Ar^{0.71} (D_b/D_0)^{-0.55} (\varphi\, V_r/V_0)^{0.41} \gamma^{0.8}$ $\varphi = \frac{(h_{r0} - H_0)}{L_T}$	11	Nonporous draft tube conical spouted bed
Altzibar et al.	$(Re_0)_{ms} = 0.25 Ar^{0.5} (H_0/D_0)^{1.2} (L_H/D_0)^{0.3}$	12	Nonporous draft tube conical spouted bed
Saldarriaga et al.	$(Re_0)_{ms} = 0.5 Ar^{0.5} (H_0/D_0)^{1.7} (L_H/D_0)^{0.1} \emptyset^{0.54}$	13	Nonporous draft tube conical spouted bed

Nonporous draft tube CSB

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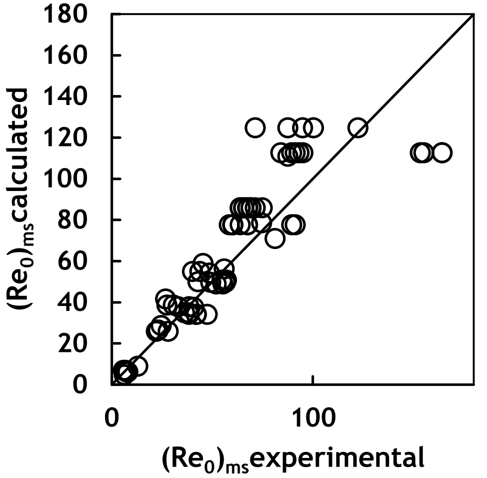
Correlations of best fit in the literature

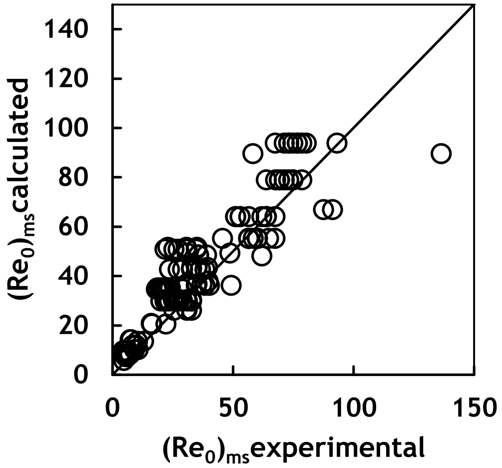
Best fit …

Without draft tube



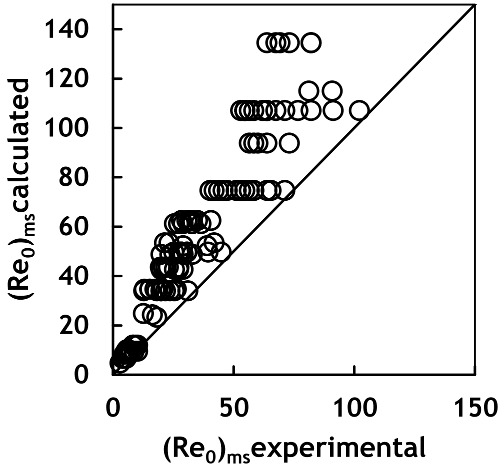
Eq. 2 (Tsvick et al., 1967)
$r^2 = 0.6$
Relative error = 42%

With open-sided draft tube



Eq. 5 (Olazar et al., 1996)
$r^2 = 0.7$
Relative error = 35%

With nonporous draft tube



Eq. 12 (Altzibar et al., 2013)
$r^2 = 0.62$
Relative error = 47%

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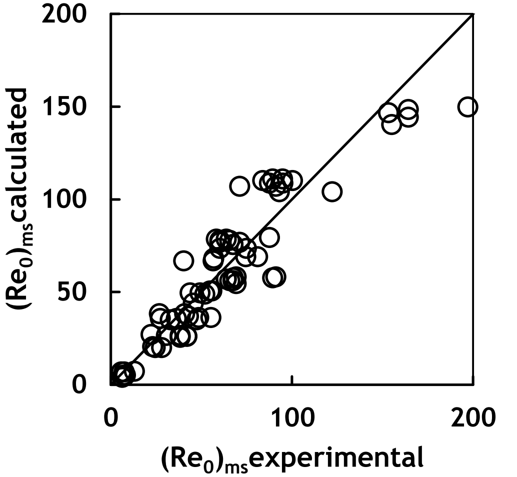
Correlation proposal

Without draft tube

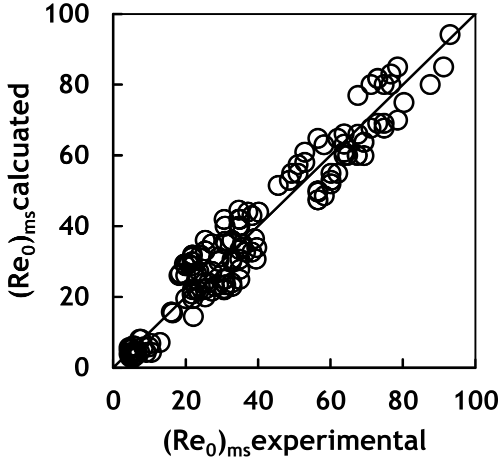


$$(Re_0)_{ms} = 0.25Ar^{0.5}\left(\frac{H_0}{D_0}\right)^{1.15}\left(\frac{H_0}{D_F}\right)\left(\frac{H_F}{D_F}\right)^{0.04}$$

$r^2 = 0.86$

Relative error = 15%

With open-sided draft tube

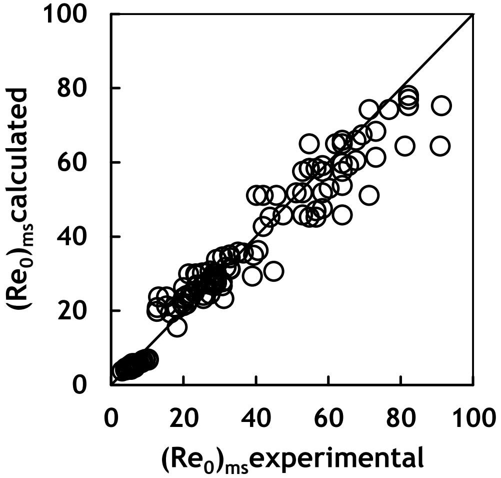


$$(Re_0)_{ms} = 0.43Ar^{0.5}\left(\frac{H_0}{D_0}\right)^{0.9}\left(\frac{H_F}{D_F}\right)^{0.03}\left(\frac{A_0}{A_T}\right)^{0.21}$$

$r^2 = 0.94$

Relative error = 9%

With nonporous draft tube



$$(Re_0)_{ms} = 0.23Ar^{0.5}\left(\frac{H_0}{D_0}\right)^{0.8}\left(\frac{L_H}{D_F}\right)^{0.05}\left(tan\frac{\gamma}{2}\right)^{-0.5}$$

$r^2 = 0.92$

Relative error = 10%

- The novel fountain confiner has proven to stabilize beds made up of fine particles (Geldart groups A and B) without any draft tube. Therefore, it is an essential element for the scaling up of the spouted bed technology to industrial level.
- As solid density, static bed height, particle diameter, aperture ratio and entrainment height are increased the minimum spouting velocity increases. Nevertheless, as the inlet diameter, contactor angle and confiner diameter are increased the minimum spouting velocity decreases.
- There is no a valid correlation in the literature to estimate the minimum spouting velocity for fountain confined conical spouted beds. Therefore, a new one has been developed for each configuration.

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