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Determination of solids circulation rate through magnetic tracer tests

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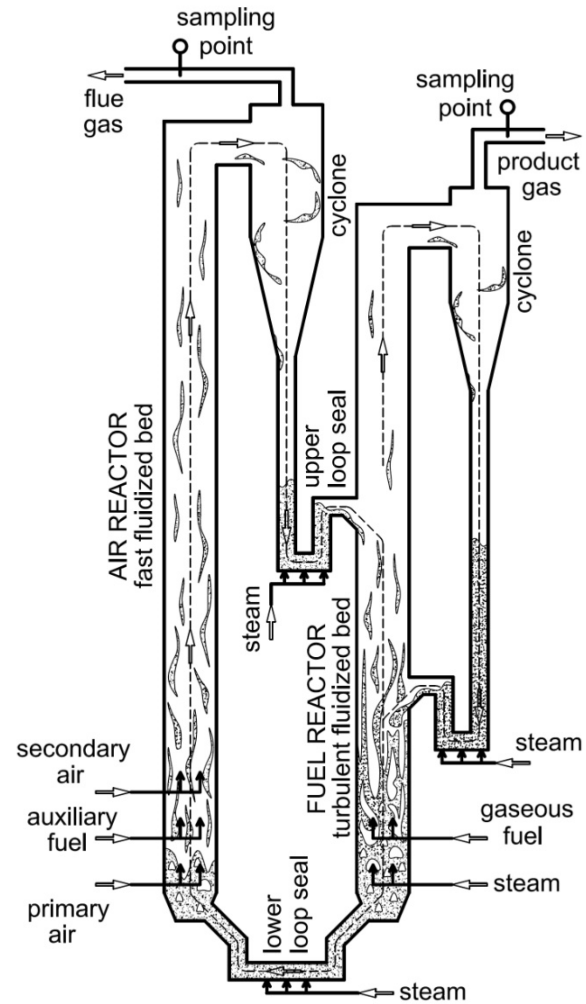
Introduction

- Solids circulation rate is one important parameter in the study of circulating fluidized beds (CFBs)
- The measurement of the circulation rate should ideally:
  - not interfere with the operation of the unit (non-invasive),
  - require no calibration,
  - be implementable on-line,
  - and have an adequate sensitivity.
- Most of the double CFB systems operate with fixed inventory. Circulation rate depends on the total solids inventory, the flow resistances in the system, and the carrying capacity of the fluid



Introduction

Solids circulation rate

Solids velocity

Solids hold up

Residence time

Pressure drop

$$Gs = f(\Delta P, \tau)$$

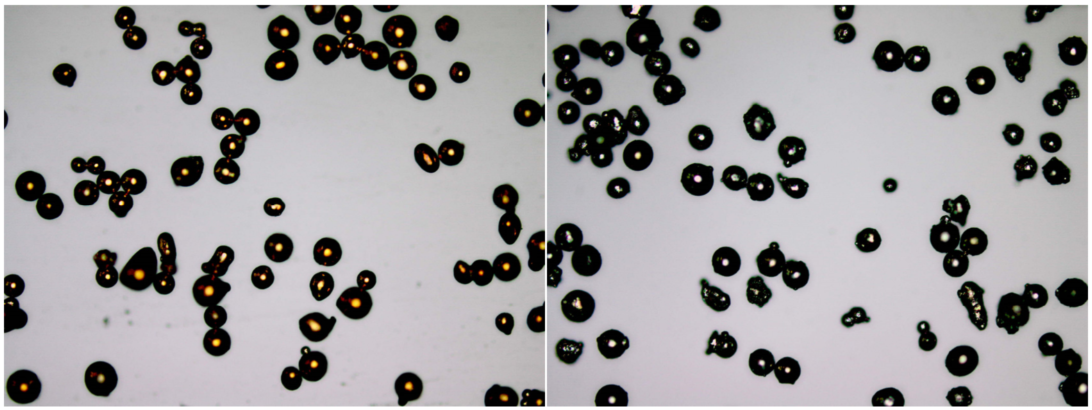
- Cross-sectionally uniform solids velocity
- Plug flow
- Constant bed density

- Minimum fluidization
- Homogeneous particle size
- Spheric

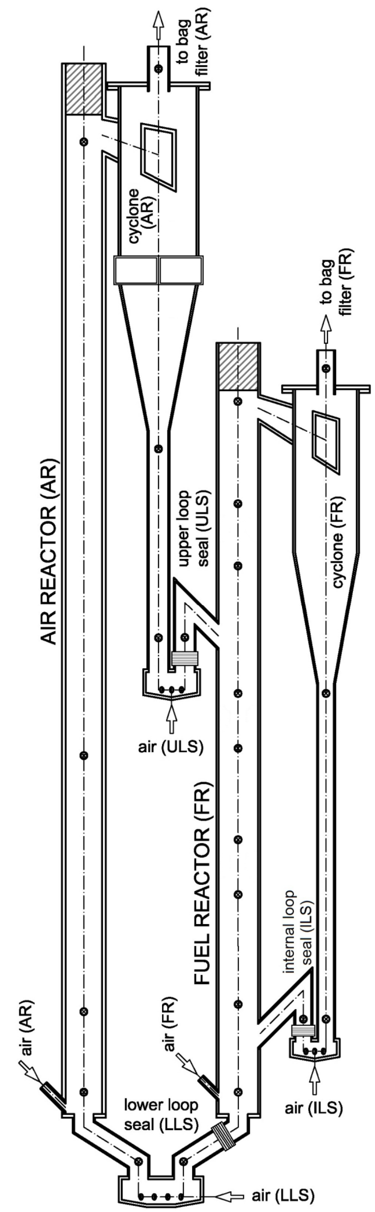
$$\tau = \frac{v}{\dot{v}} = \frac{m}{\dot{m}}$$

$$\frac{\Delta P}{L_{mf}} = (1 - \varepsilon_{mf})(\rho_p - \rho_g)g$$

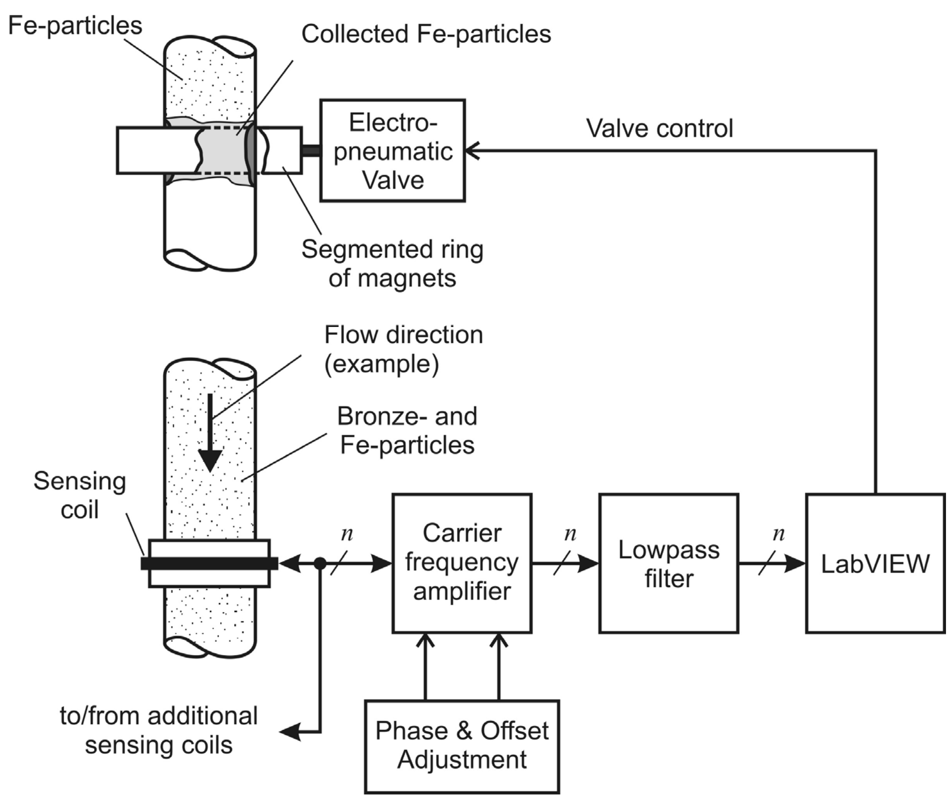
Experimental: Cold flow model

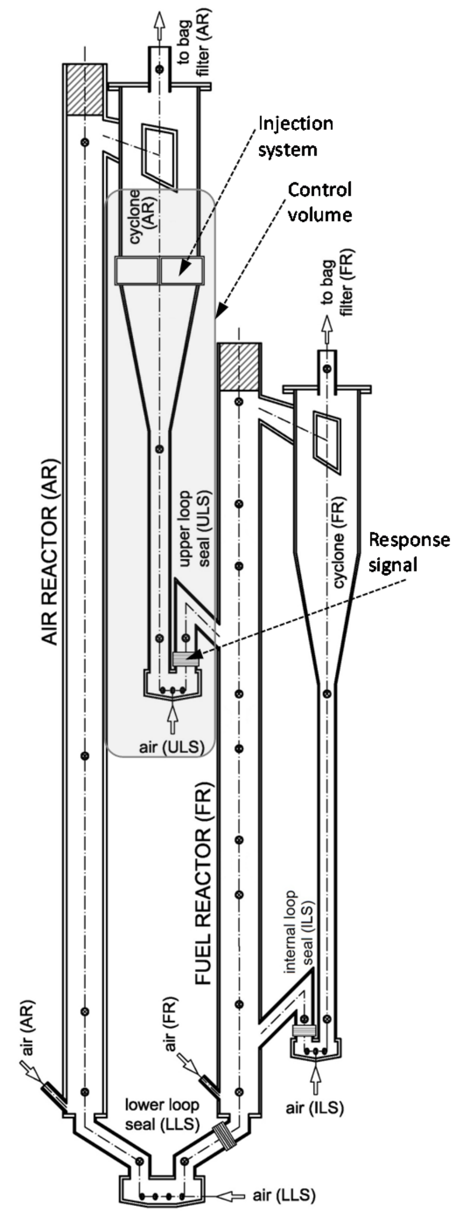


Parameter	Bronze	Steel	Units
Particle density (ρ_P)	8730	7579	$kg{\cdot}m^{-3}$
Sauter mean particle diameter (d_p)	$6.80{\cdot}10^{-5}$	$7.20{\cdot}10^{-5}$	m
Particle sphericity (ϕ)	1	1	--
Archimedes number (Ar)	$1.07{\cdot}10^{2}$	$1.11{\cdot}10^{2}$	--
Reynolds number (min.fluidization, Re_{mf})	$8.03{\cdot}10^{-2}$	$8.28{\cdot}10^{-2}$	--
Minimum fluidization velocity (U_{mf})	$1.69{\cdot}10^{-2}$	$1.65{\cdot}10^{-2}$	$m{\cdot}s^{-1}$
Relative Permeability μr (μ/μo)	< 1.01	>300	[-]



Experimental: Tracer method





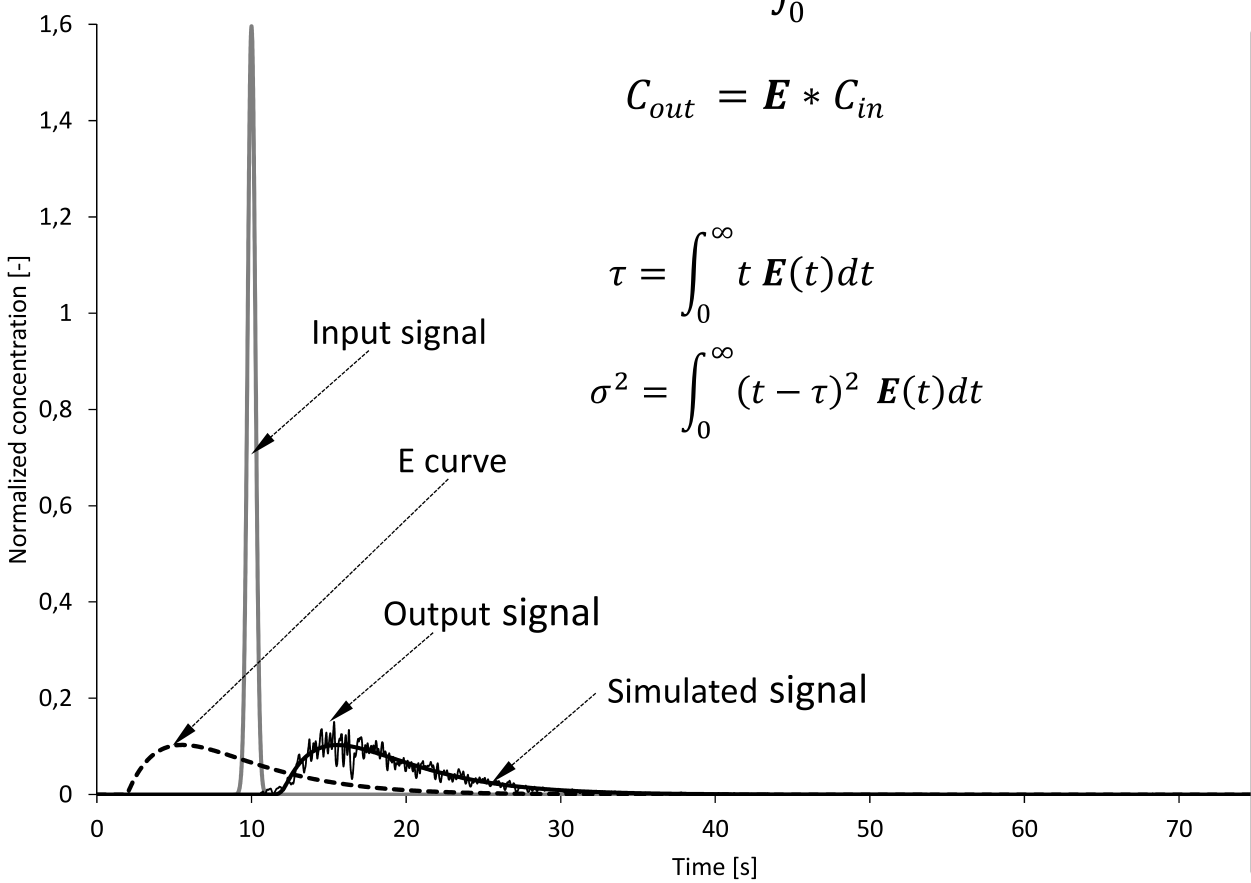
Experimental: Tracer method

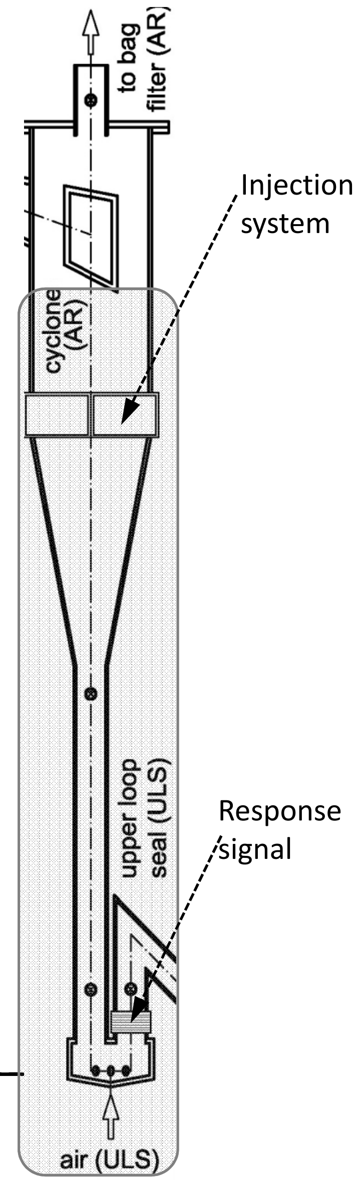
$$C_{out}(t) = \int_0^t C_{in}(t')\boldsymbol{E}(t-t')dt'$$

$$C_{out} = \boldsymbol{E} * C_{in}$$

$$\tau = \int_0^\infty t\,\boldsymbol{E}(t)dt$$

$$\sigma^2 = \int_0^\infty (t-\tau)^2\,\boldsymbol{E}(t)dt$$

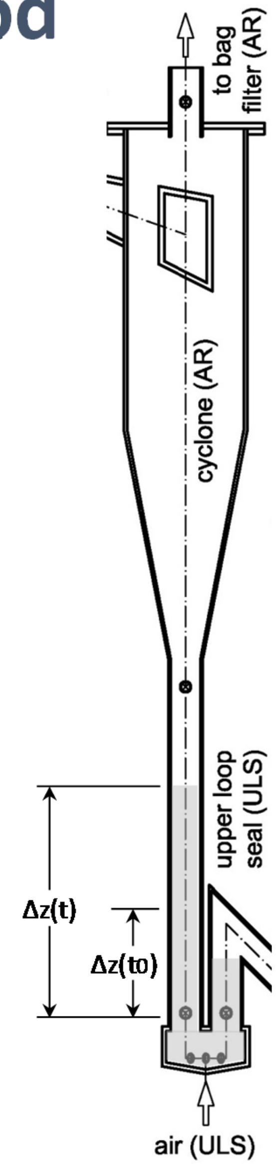




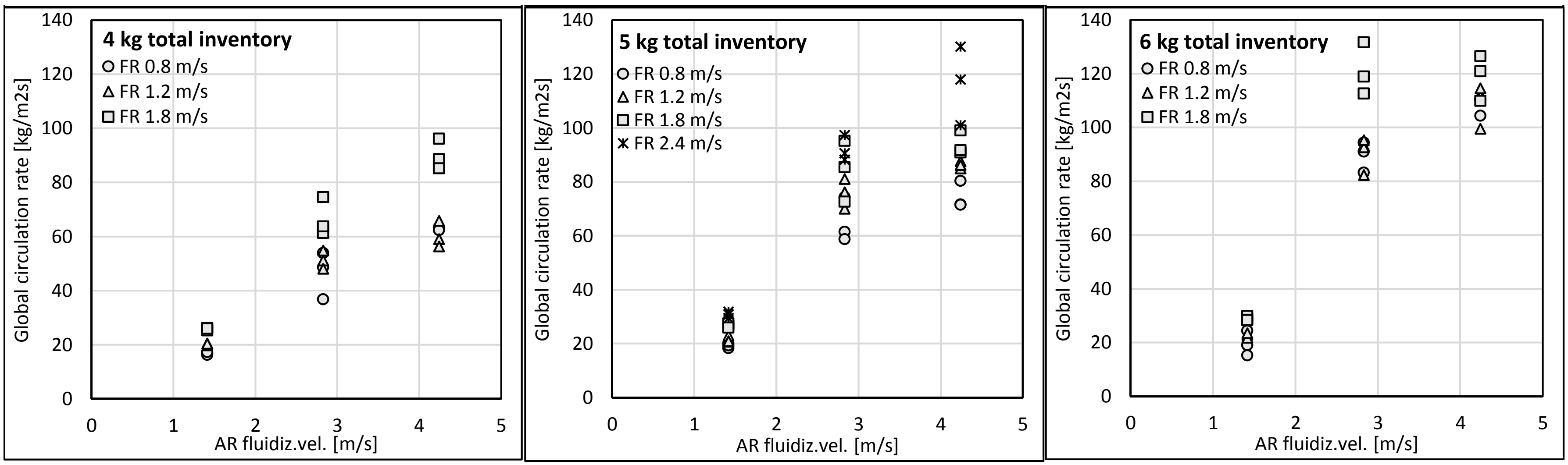
Experimental: Accumulation method

$$G_s = \frac{\dot{m}}{A_{Reactor}}$$

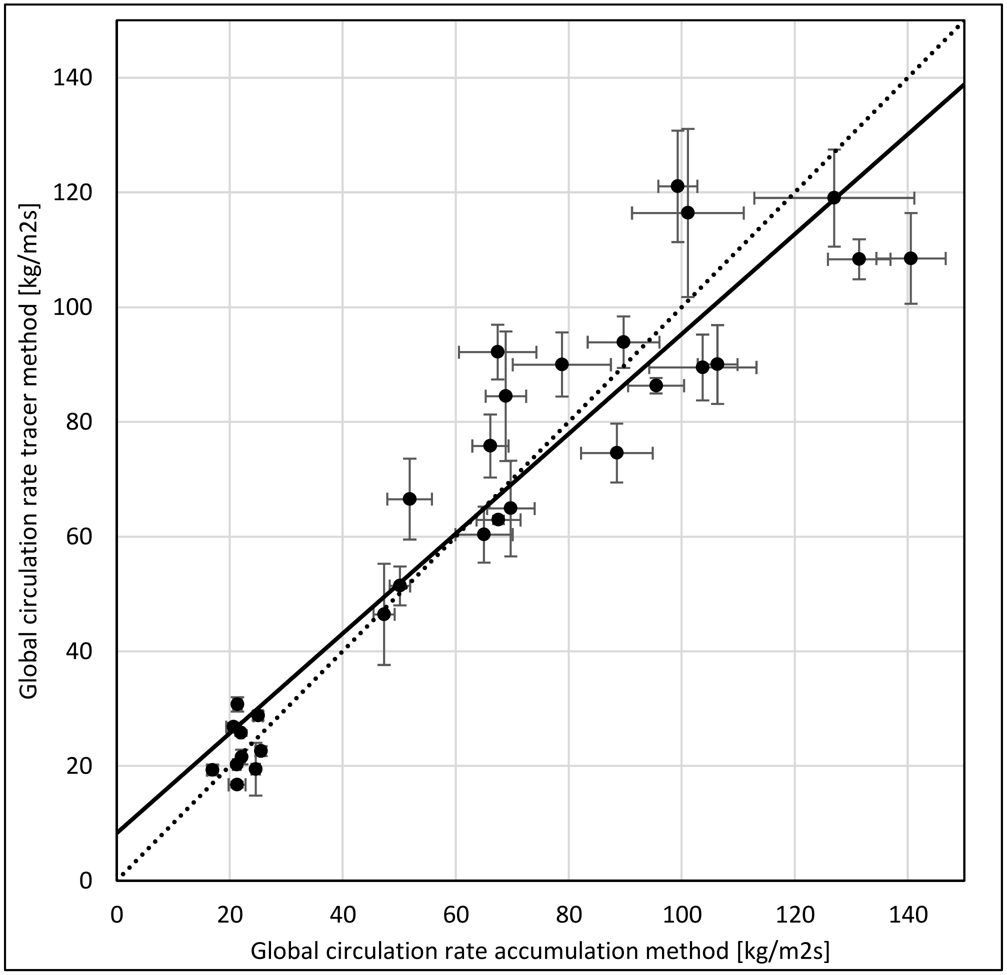
$$= \frac{\frac{\Delta z}{\Delta t} * \rho_B * A_{Downcomer}}{A_{Reactor}}$$



Results

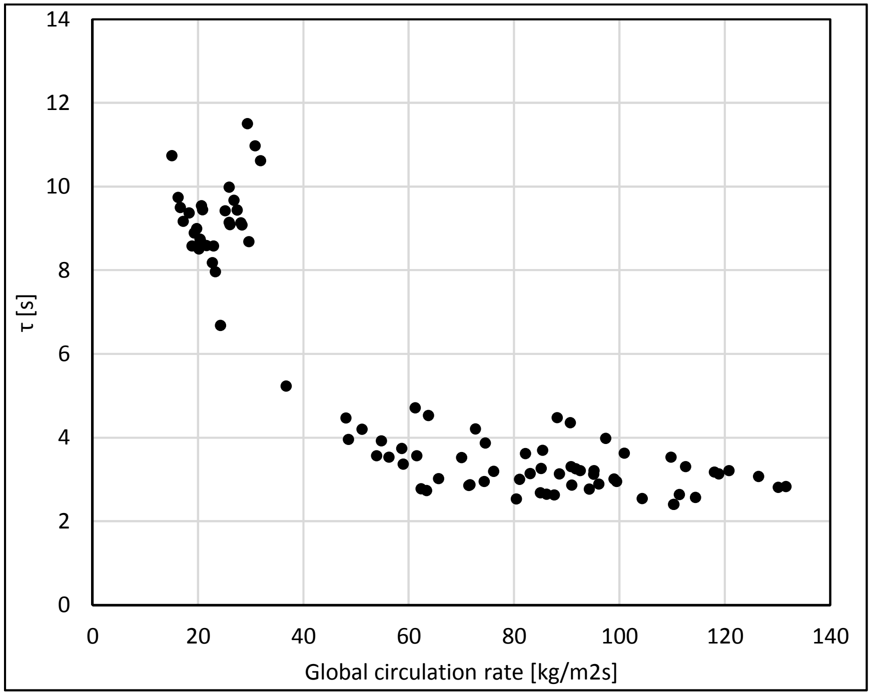

4 kg total inventory
FR 0.8 m/s
FR 1.2 m/s
FR 1.8 m/s
5 kg total inventory
FR 0.8 m/s
FR 1.2 m/s
FR 1.8 m/s
FR 2.4 m/s
6 kg total inventory
FR 0.8 m/s
FR 1.2 m/s
FR 1.8 m/s
Global circulation rate [kg/m2s]
AR fluidiz.vel. [m/s]

Results

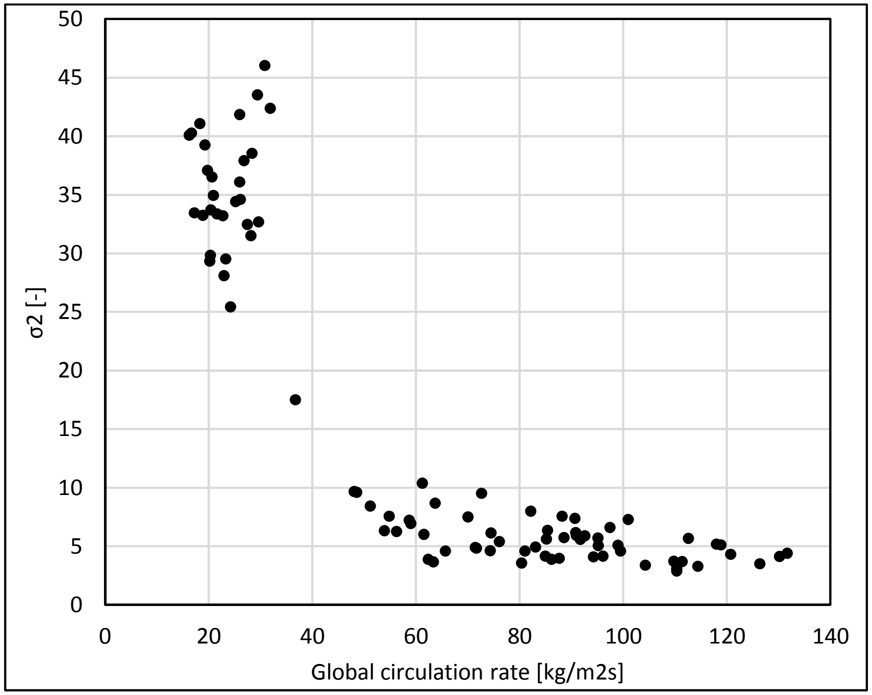


Global circulation rate tracer method [kg/m2s]
0
20
40
60
80
100
120
140
Global circulation rate accumulation method [kg/m2s]

Results



τ [s]
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120
140
Global circulation rate [kg/m2s]



σ2 [-]
0
5
10
15
20
25
30
35
40
45
50
0
20
40
60
80
100
120
140
Global circulation rate [kg/m2s]

Conclusions

- The proposed method uses a magnetic tracer and an impulse-response test to determine the velocity of the particles. The particles volume fraction is determined based on pressure difference measurements. A bed under minimum fluidization conditions and a flow pattern similar to plug flow are assumed.

- The tracer method is suitable for the determination of solids circulation rates, but might introduce some error to the measurement of low circulation rates, since at these conditions backmixing might occur (verification of flow conditions is possible from the analysis of the E curve variance).

- The tracer method constitutes an on-line, sensitive, non-intrusive and cost efficient method for determination of circulation rate, which does not need a calibration. The applicability of the magnetic tracer method is for now limited to low temperature processes.

- The possibility for gathering two tracer concentration signals at two different heights in the downcomer would improve the measurement considerably.

Thanks for your attention!

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