Experimental Analysis of the Solids Discharge in a Three-Phase Airlift Loop Reactor

Experimentelle Analyse des Feststoffaustrags in einem dreiphasigen Airlift-Schlaufenreaktor

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Motivation & Objective

Research project for the implementation of a newly developed chemical process in form of a continuously operated, three-phase airlift loop reactor in industrial scale

Aim: help in the scale-up of a loop reactor for three-phase flows

three phases: pressurized air (gas) | deionized water (liquid) | catalyst carrier (solid)

→ efficient retention of an expensive, heterogeneous catalyst

Questions:

- How well does the retention of solids work in dependency of the lamella load?
- Can all particles above a certain diameter be retained?

→ design and commissioning of a pilot-scale plant at the Institute of Multiphase Flows

→ investigation of the retention of the catalyst in the commissioned plant

→ with an integrated sedimentation unit

→ in an external, commercial separator

→ comparison to theoretical considerations of separation

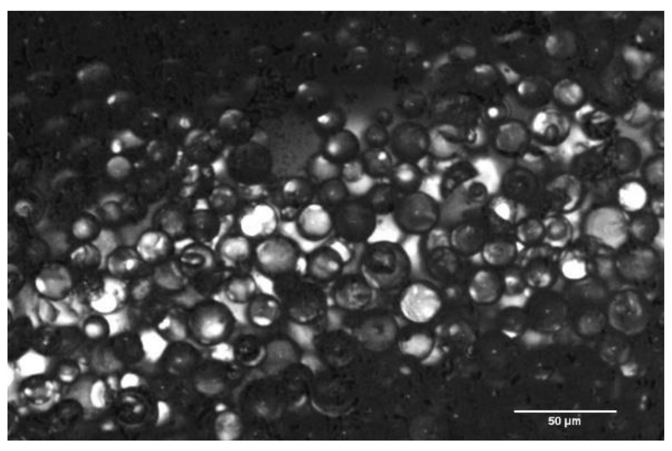


Fig. 1: CLSM image of the spherical catalyst carrier particles

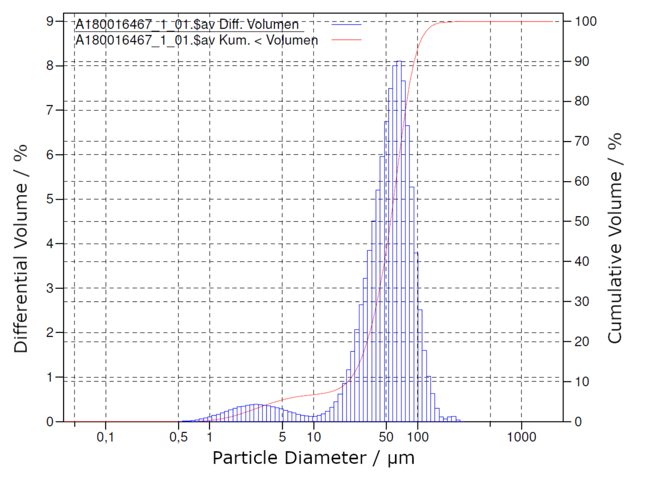


Fig. 2: Bi-modal particle size distribution of the catalyst carrier

Experimental Set-up & Procedure

- reactor is filled with deionized water and catalyst carrier
- gassing used for propulsion of loop and suspension of solid particles
- external feed pump used to apply different volume flow rates $\dot{V}_F$ on investigated separation units
- main design parameter lamella load q, which relates applied volume flow rate $\dot{V}_F$ to projected surface A_P of lamellas
- varied lamella loads and solid fractions
- particle samples at exit of separation unit; analysed using laser diffraction spectrometry
- concentric metal sheets for internal separator
- rectangular external separator with honeycomb structure

Fig. 3: Top-view of the commercial separator

parameters	settings
separator unit	internal, external
solids fraction ε_S	8 wt.-%, 10 wt.-%
aeration rate $\dot{V}_G$	210 L min^{-1}
lamella load q	{0.30, 0.50, 0.75, 1.00} m^3 h^{-1} m^{-2}

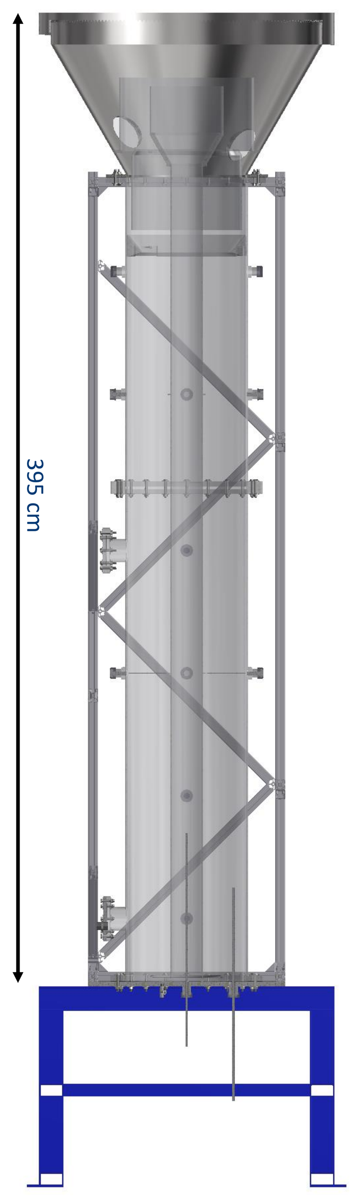


Fig. 4: Airlift loop reactor with conical head

Results

separator	solids content ε_S / wt.-%	lamella load q / m^3 h^{-1} m^{-2}	ideal separation limit d_P / µm	maximum particle diameter $d_{P,max}$ at 1 h / µm
internal	8.45	0.32	11.37	33.01
	8.45	0.53	14.61	33.01
	8.45	0.75	17.50	39.78
	8.45	0.99	20.13	52.62
	10.73	0.53	14.61	36.24
	10.73	0.76	17.64	36.24
	10.73	0.98	20.03	52.62
external	10.73	0.33	11.62	30.07
	10.73	0.66	16.37	39.78

- increase in lamella load leads to larger particles in effluent
- in general, larger particles found than expected from ideal considerations
- no significant difference discernible for different solids contents
- maximum particle diameters in samples taken at t = 1 h comparable for both investigated separation units

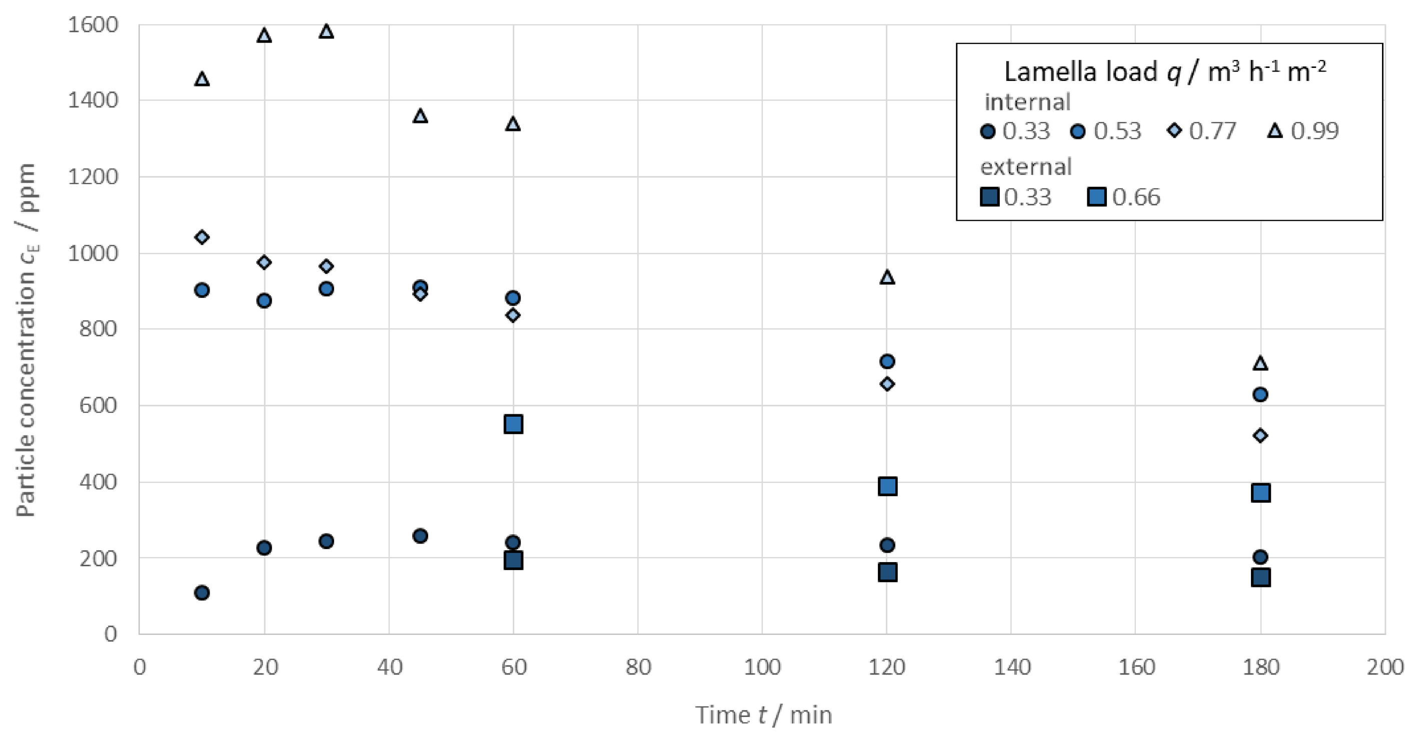


Fig. 5: Measured particle concentrations in the effluent of the separation units; concentration c_R in the reactor initially at ≈ 100,000 ppm

- concentration-wise, the commercial separation unit performs better than the internal unit for a lamella load q above 0.33 m^3 h^{-1} m^{-2}
- significant retention of particles possible

Discussion

- uneven loading of lamellas (measured with ultrasonic probes) results in some pumping downwards and higher velocities in up-pumping ones, and thus larger particles in the effluent
- the increased efficiency of the external separator is thought to be due to the used honey comb structure
- particle concentrations are lower than predicted by calculations based on Fair and Geyer[2]

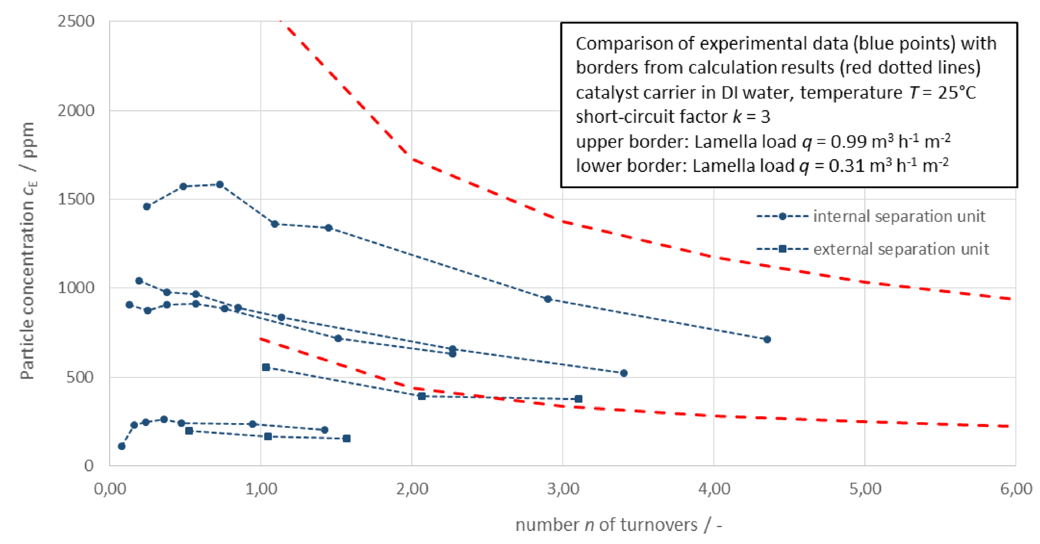
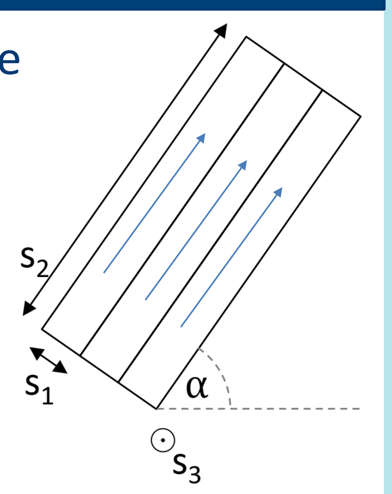


Fig. 6: Comparison of experimental results to predicted particle concentrations in the effluent

Fundamentals

- The relation between the needed sedimentation velocity and the lamella load in an ideal rectangular lamella pack is as follows:

$$v_S = \frac{s_1}{\cos(\alpha)} \cdot t_S^{-1} = \frac{s_1}{\cos(\alpha)} \cdot \frac{\dot{V}_L}{V_L} = \frac{s_1 \cdot \dot{V}_L}{\cos(\alpha) \cdot s_1 \cdot s_2 \cdot s_3 \cdot n} = \frac{\dot{V}_L}{\cos(\alpha) \cdot s_2 \cdot s_3 \cdot n} = q$$



- The sedimentation velocity of single particles is calculated by:[1]

$$v_S = \sqrt{\frac{4}{3} \cdot \frac{\rho_P - \rho_F}{\rho_F} \cdot g \cdot d_P \cdot \frac{1}{\zeta}}$$

- An ideal separation limit with $d_P \approx 14$ µm is expected for an exemplary lamella load q = 0.50 m^3 h^{-1} m^{-2}.

List of Symbols

c_E	particle concentration in effluent	ppm
c_R	particle concentration in reactor	ppm
d_P	particle diameter	m
g	gravitational constant	m s^{-2}
n	number of lamellas, turnovers	-
q	lamella load	m^3 h^{-1} m^{-2}
s_1	distance between lamellas	m
s_2	length of lamellas	m
s_3	depth of lamellas	m
t	time	s
t_S	time needed for sedimentation	s
$\dot{V}_G$	gassing rate	L min^{-1}
$\dot{V}_L$	liquid volume flow rate	m^3 min^{-1}
V_L	volume of lamellas	m^3
v_S	sedimentation velocity	m s
α	inclination of lamellas	°
ε_S	solids fraction	wt.-%
ζ	drag coefficient	-
ρ_P	density of particle	kg m^{-3}
ρ_F	density of fluid	kg m^{-3}

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[1] Kraume, M.: *Disperse Systeme*. In: *Transportvorgänge in der Verfahrenstechnik*, Springer, Berlin, Heidelberg, 2012.

[2] Fair, G.M., Geyer, J.C.: *Water supply and waste-water disposal*. John Wiley & Sons, Inc., New York, 1954.