Scale-Up Strategies of Jet Loop Reactors for the Intensification of Mass Transfer Limited Reactions

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MOTIVATION & OBJECTIVE

Within the scope of an **industrial research project** in cooperation between the *Institute of Multiphase Flows* (IMS) and *Ehrfeld Mikrotechnik GmbH*, an **existing industrial-scale gas-liquid process** is to be implemented in an **alternative reactor concept** [1]. Existing process operation data from a cascade of bubble columns hint at a **mass transfer limitation** of the gas-liquid reaction.

Problem: The current process is to be transferred to and investigated in a single **Jet Loop Reactor** (JLR) [2]. This reactor type should significantly **increase** the **specific interfacial area** [3] between gas and liquid, and thus **increase mass transfer**.

Loop reactors get their name from the **internal liquid circulation loop**. This loop is divided into an upward and a downward flow (see blue arrows in **Figure 1**). The driver behind the loop is an input of **impulse** and **energy**. In a JLR, this input is provided by a liquid jet. The result is **excellent mixing** and a **high interfacial area** between the phases.

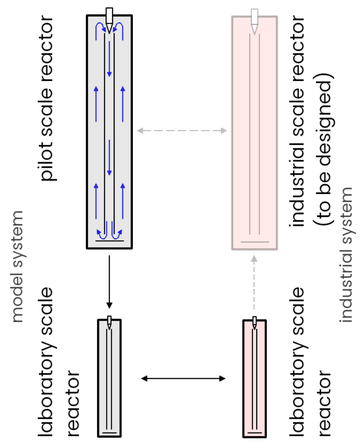

Figure 1: Schematic representation of the scale-up; investigations are conducted in the model system water/air (grey), while the industrial system (apricot) is investigated in the laboratory scale.

Objective:

- First investigations at IMS of **hydrodynamics** in water/air **model system** in existing **pilot plant**
- Scaling of pilot plant setup to **laboratory scale**
- **Design** and **manufacturing** of two **laboratory set-ups**; one for model system at IMS, one for industrial system at project partner
- **Characterisation** of **setups**, **systems, reaction** to have a **basis** for a **future scale-up** of the process in the JLR system to the **industrial scale**

SCALE-UP STRATEGY & EXPERIMENTAL PROCEDURE

Scaling of two-phase contact apparatuses is complicated due to the amount of design **parameters** and their **interactions**. Scale-up **strategies** can focus on a variety of parameters, like constant gas hold-ups, bubble sizes, etc.
In the presented project, the following aspects are considered in descending order as **scale down criteria**:

- a constant **volumetric gas input** $\dot{V}_\mathrm{g} \cdot V_\mathrm{l}^{-1}$
- a constant **specific energy dissipation rate** ε
- **geometric similarity** based on the scaling factor μ
- a constant **residence time** τ_l of the liquid within the reactor

The integral specific energy dissipation rate ε has a significant influence on mixing, the interface between the phases and thus mass transfer in a JLR and is defined as:

$$\varepsilon = \frac{P}{V_\mathrm{l}} = \frac{\dot{E}}{V_\mathrm{l}} = \frac{\dot{V}_\mathrm{l} \cdot \rho_\mathrm{f} \cdot w_{n,l}^2}{2 \cdot V_\mathrm{l}} \qquad [4]$$

The reactor systems are characterised and compared in regard to **bubble sizes**, **gas hold-ups**, **volumetric mass transfer coefficients** and the **stability** of the **loop**. During these investigations, the specific energy dissipation rate is varied (see Table 1), while three gassing rates (see Table 2), representing different stoichiometries, are chosen. **Bubble sizes** are gathered by **digital image evaluation**, **gas hold-ups** by measuring **filling levels** during operation. For the determination of the volumetric **mass transfer coefficient**, the **dynamic method** is used. For the **stability** of the loop, **break-down points** are determined optically. The reactors offer **2** and **130 L** of liquid volume, respectively.

RESULTS

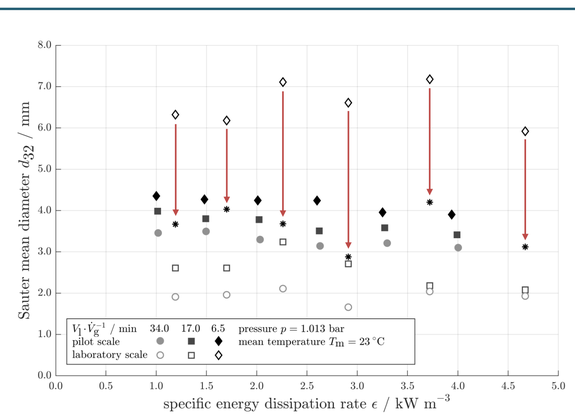

Figure 2: Comparison of Sauter mean diameters. Asterisks (*) denote data points cleaned from outliers due to coalescence

- Bubble size distributions are **different**
- Increased **coalescence** for high gassing in the laboratory setup; influence of scaling and surfaces/materials
- Sauter mean diameter can be **adjusted for outliers** (0.7% of bubbles)

→Sauter mean diameters are in **similar ranges**

- **Key aspect:** overcome **mass transfer** limitations of existing process
- Deviation for **high gassing** and **low** spec. **energy** dissipation rates: **larger bubbles** in draft tube of laboratory system, thus **lower** interfacial area and **mass transfer**

→Overall **similar performance** of pilot and laboratory scale

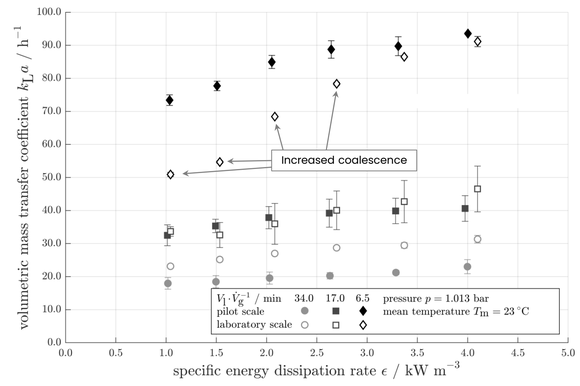

Figure 3: Comparison of mass transfer coefficients.

OUTLOOK

← **Figure 4:** Completely assembled and equipped twin setup [1]

- Systematic **experiments** with **industrial material system** on site of the project partner with pressure- and chemical-resistant twin of reactor setup
- First experiments: **significant decrease of residence time** achievable
- Investigation of **setup improvements**
- Gather data and accompany **scale-up** of the JLR system to **industrial scale**

Table 1: Investigated specific energy dissipation rates

spec. energy dissipation rate ε / kW m^{-3}	1.02	1.50	2.03	2.63	3.29	4.00
setup	volume flow rates $\dot{V}_\mathrm{l}$ / L min^{-1}					
pilot scale	47.9	54.5	60.3	65.7	70.8	75.6
laboratory scale	1.06	1.20	1.33	1.45	1.56	1.67

Table 2: Investigated gassing rates

ratio $V_l \cdot \dot{V}_g^{-1}$ / min	34.0	17.0	6.5
setup	gassing rates $\dot{V}_\mathrm{g}$ / L min^{-1}		
pilot scale	3.80	7.60	20.00
laboratory scale	0.06	0.12	0.31

List of Symbols

ε	specific energy dissipation rate / kW m^{-3}	τ_l	residence time / s	V_l	liquid volume / m^3
μ	scaling factor / -	$\dot{E}$	kinetic energy flux / W	$\dot{V}_\mathrm{g}$	gas flow rate / m^3 s^{-1}
ρ_f	Fluid density / kg m^{-3}	$k_\mathrm{L}a$	volumetric mass transfer coefficient / h^{-1}	$\dot{V}_\mathrm{l}$	liquid flow rate / m^3 s^{-1}
		P	Power / W	$w_{n,l}$	liquid velocity at nozzle exit / m s^{-1}

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[1] Maly, M.; Schaper, S.; Kuwertz, R.; Hoffmann, M.; Heck, J.; Schlüter, M.: "Scale-Up Strategies of Jet Loop Reactors for the Intensification of Mass Transfer Limited Reactions". *Processes*, 2022
[2] Blenke, H.; Bohner, K.; Schuster, S.: „Beitrag zur optimalen Gestaltung chemischer Reaktoren". *Chemie Ingenieur Technik*, 1965
[3] Behr, A.; Becker, M.; Dostal, J.: "Bubble-size distributions and interfacial areas in a jetloop reactor for multiphase catalysis". *Chemical Engineering Science*, 2009
[4] Schlüter, M.; Warnecke, H.J.; Zehner, P., „Reaktoren für Fluid-Fluid-Reaktionen: Schlaufenreaktoren". *Handbuch Chemische Reaktoren*, 2019

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