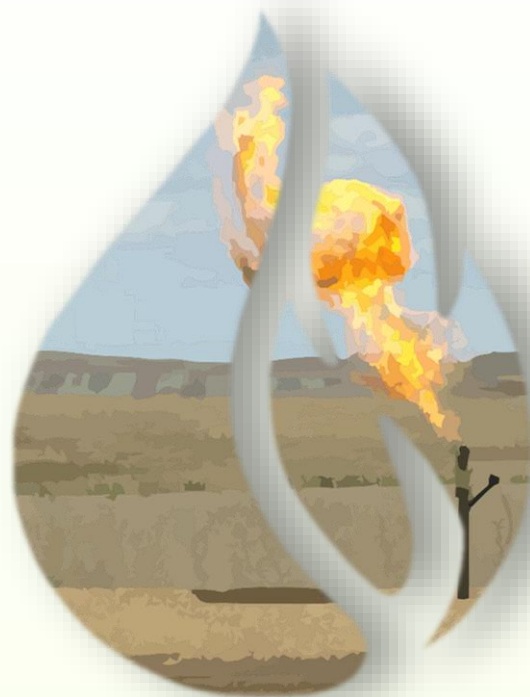


Spinning Fluids Reactor

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1st LoCaGas Project Conference
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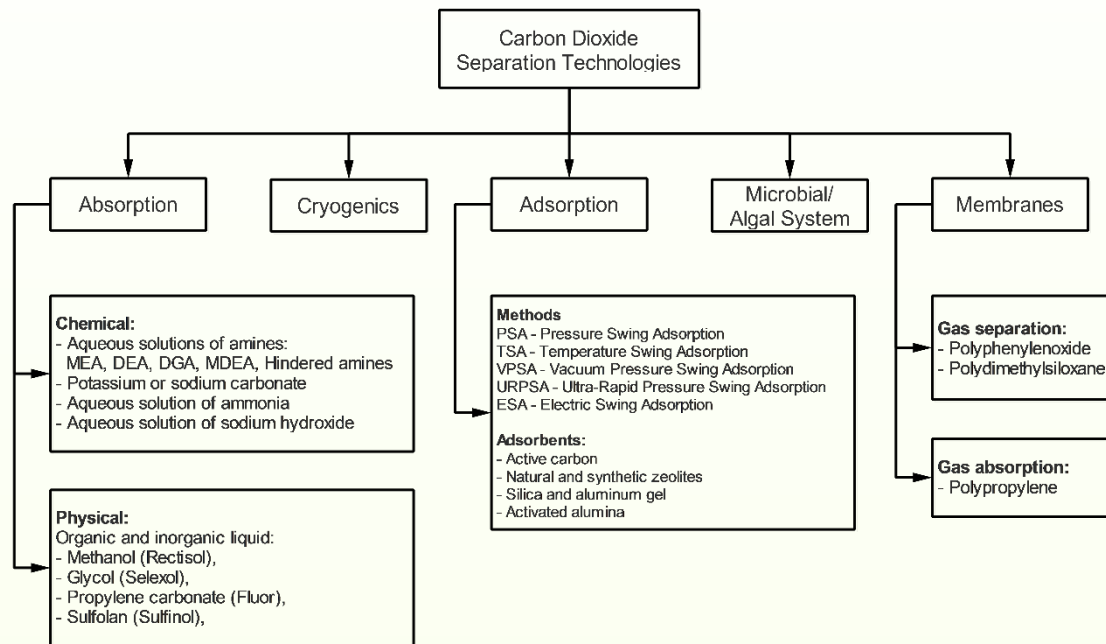


Outline of presentation

1. Introduction
2. Principle of design and operation of SFR
3. Flow hydrodynamics in SFR
4. Time of the hydraulic retention time in SFR
5. Interfacial area generated in SFR
6. SFR for biogas upgrading

Introduction

Biogas valorisation methods



Introduction

Gas absorption equipment

- The liquid is dispersed in the form of droplets or discontinuous films in a continuous gas phase:
 - Spray tower
 - Packed tower
 - Venturi scrubber
- The gas is dispersed in liquid in form of bubble:
 - Mechanically agitated vessel
 - Tray Column
 - Bubble Column
- Both gas and liquid phases are continuous (for example, “a falling film contactor” which is used for gas-liquid reactions)

The main parameters affecting the gas absorption are:

- Resistance to gas flow
- Gas-liquid interface
- Liquid to gas ratios
- Liquid hold-up
- Flexibility to change gas and liquid phase flow
- Operating temperature range

Intensification of the mass transfer in absorption can be achieved by increasing:

- Gas-liquid interfacial area
- Increased mass transfer coefficient

Introduction

Mechanism of bubble generation in stagnant liquid

$$\vec{F}_\delta = \vec{F}_b$$

$$2\pi r_k \sigma = \frac{\pi d_p^3}{6} (\rho_l - \rho_g) N_g g$$

$$d_p = \sqrt[3]{12 \frac{r_k \sigma}{(\rho_l - \rho_g) N_g g}}$$

where:

F_σ - surface tension force,

F_b - buoyant force,

r_k - capillary radius,

σ - surface tension of liquid,

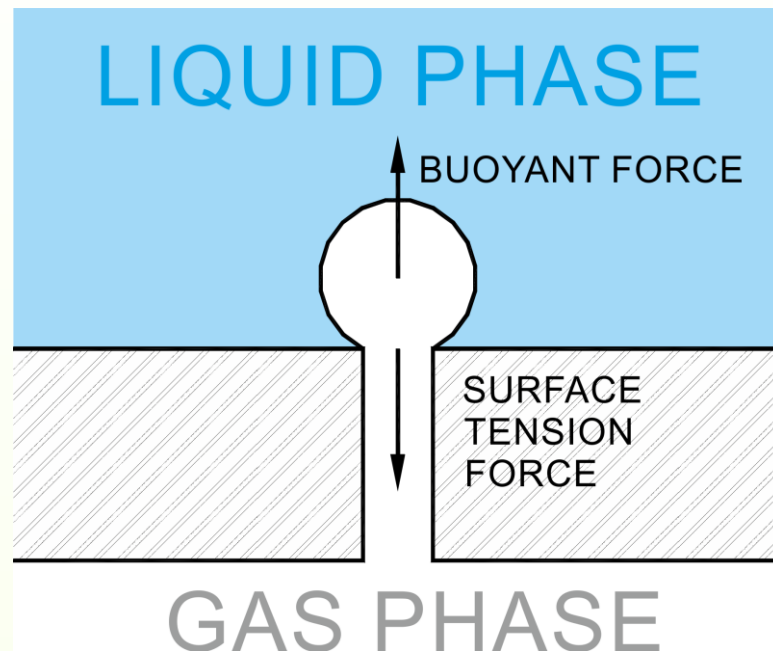
d_b - bubble diameter at laminar flow,

ρ_l - liquid density,

ρ_g - gas density,

N_g - dimensionless centripetal acceleration,

g - gravity acceleration



Introduction

Mechanism of bubble generation in flow liquid

$$\begin{aligned}\vec{F}_\delta &= \vec{F}_w + \vec{F}_s \\ \vec{F}_s &= \xi \frac{\rho_l u^2 \pi d_b^2}{2 \cdot 4} \\ 2\pi r_k \sigma &= \frac{\pi d_p^3}{6} (\rho_l - \rho_g) N_g g\end{aligned}$$

Laminar flow

$$d_l = \sqrt[2]{\frac{16 r_k \sigma}{\xi \rho_l u^2}}$$

where:

F_σ - surface tension force,

F_b - buoyant force,

r_k - capillary radius,

σ - surface tension of liquid,

d_b - bubble diameter at laminar flow,

ρ_l - liquid density,

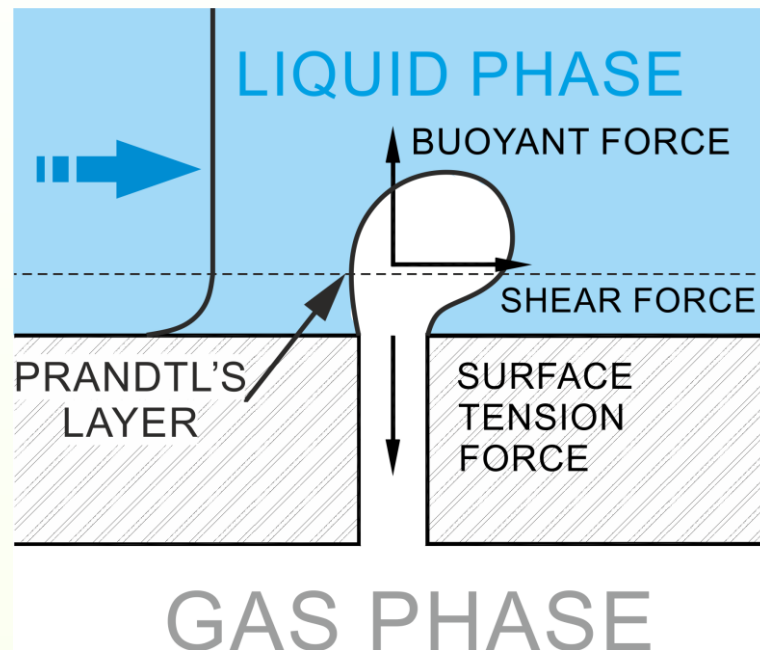
ρ_g - gas density,

N_g - dimensionless centripetal acceleration,

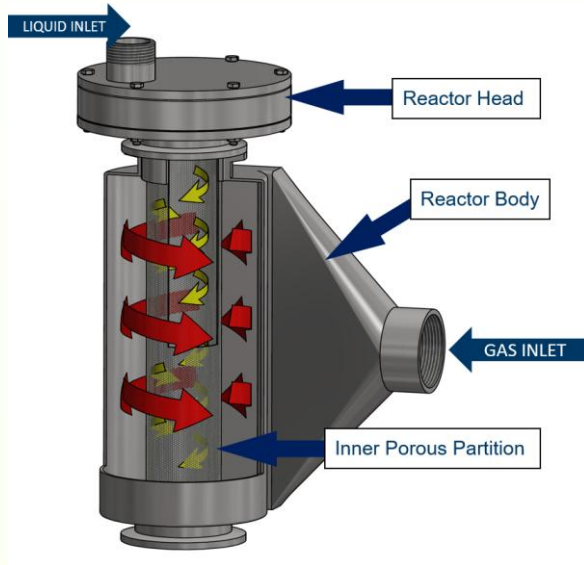
g - gravity acceleration

Turbulent flow

$$d_t = \frac{1}{4} \sqrt[4]{\frac{r_k \sigma \eta^2}{f^2 \xi \rho_l^3}}$$



Principles of Spinning Fluids Reactor operation



J.D. Miller, J. Hupka, and R. Aranowski, Spinning fluids reactor, 2012, Patent US 20110223091 A1; WO 2010014918 A3



CFD simulation of gas-liquid interface formation in SFR. Performed by Krzysztof Tesch.

Pressure drop during gas flows through a liquid layer

$$\delta P_L = \int_{R-\delta}^R \rho_L \frac{u_t^2(r)}{R} dr$$

where:

u_t - tangential velocity,

R - radius of the porous partition,

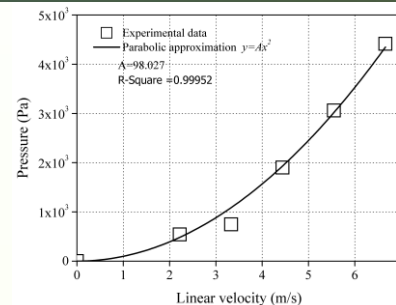
r - radius,

δ - thickness of the spinning liquid layer

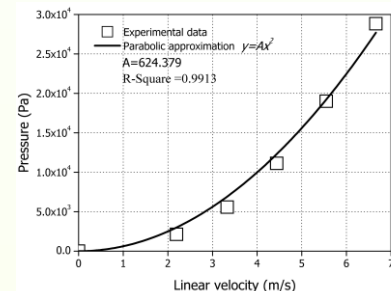
ρ_L - liquid density

$$P_c \propto u_t^2$$

Type of porous partition	The thickness of the spinning liquid layer (mm)
Cylindrical	2.5
Conical (1.5°)	8.0
Conical (3.0°)	11.6

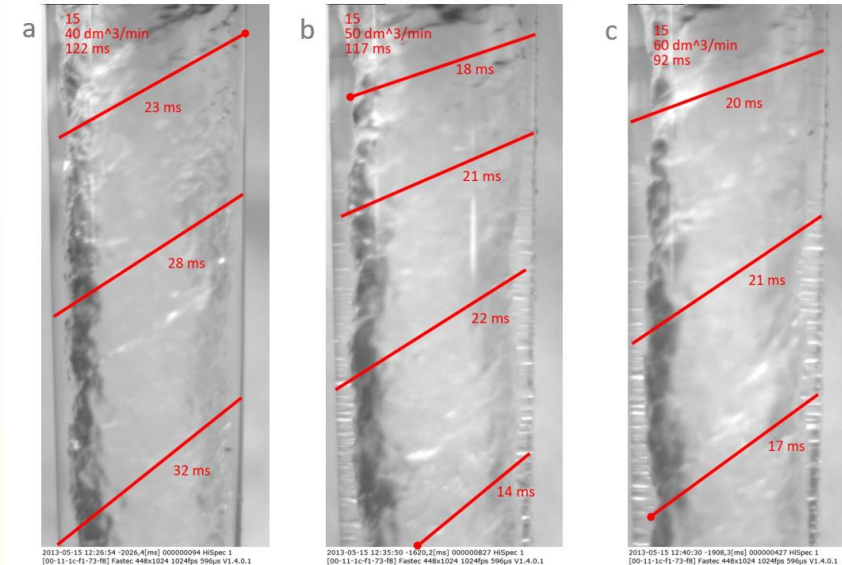


Pressure exerted on the inner wall of the cylindrical porous partition by the spinning liquid layer vs. Linear inlet velocity



Pressure exerted on the inner wall of the conical porous partition (3.0°) by the spinning liquid layer vs. linear inlet velocity

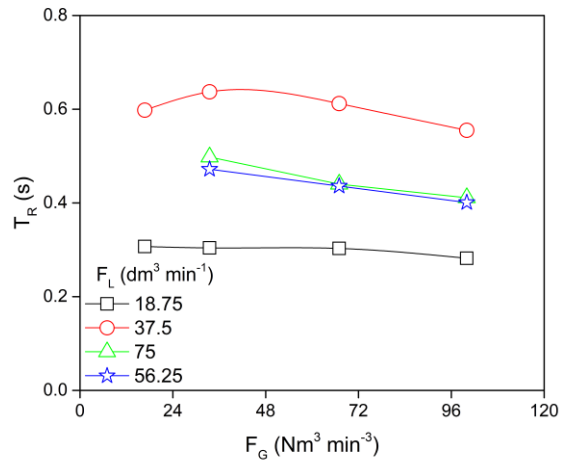
Optical measurement of the hydraulic retention time in SFR



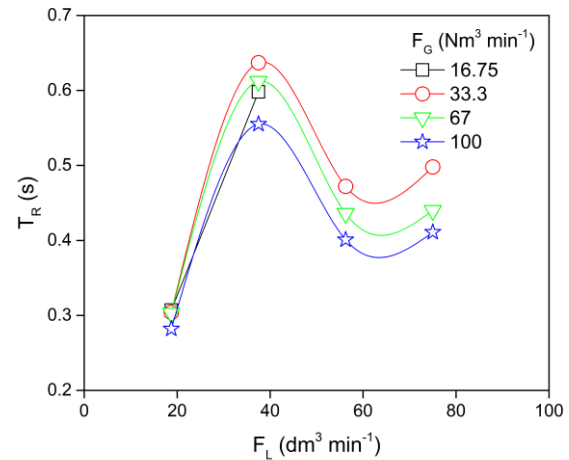
Trajectory of the liquid streamline in SFR for varied inlet velocities: a) 4.40 m·s⁻¹, b) 5.51 m·s⁻¹, c) 6.61 m·s⁻¹

The hydraulic retention time in SFR is in the range of 0.09-0.3 s

Hydraulic retention time

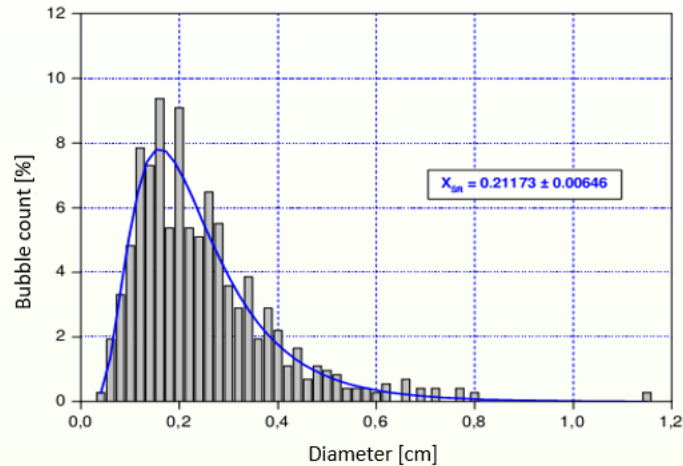


Hydraulic retention time vs. flow rate of the gas phase

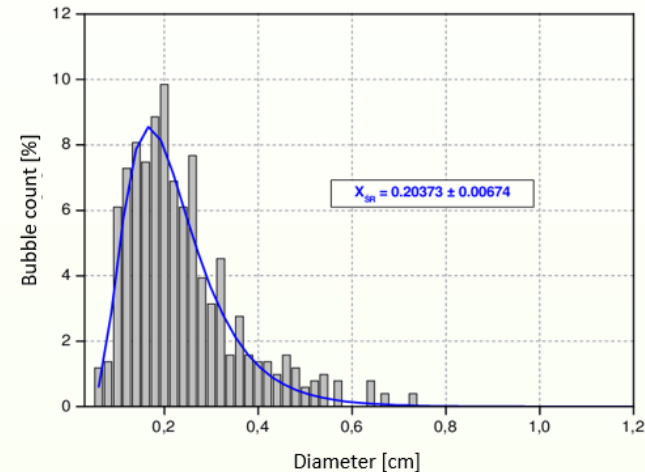


Hydraulic retention time vs. flow rate of the liquid phase

Size Distribution of Gas Bubbles Generated in the SFR



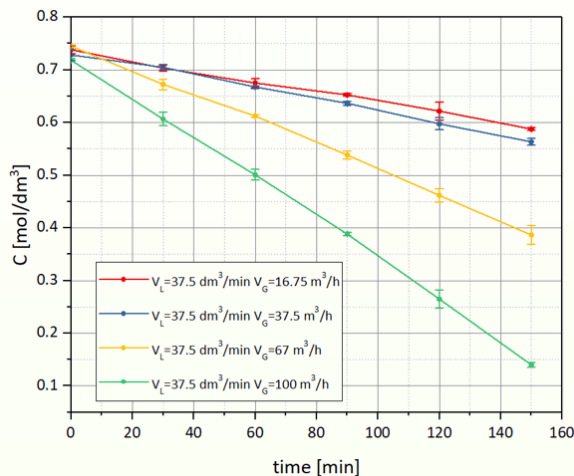
$$Q_W = 20 \text{ dm}^3 \cdot \text{min}^{-1}, Q_G = 25 \text{ m}^3 \cdot \text{h}^{-1}$$



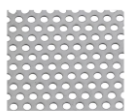
$$Q_W = 20 \text{ dm}^3 \cdot \text{min}^{-1}, Q_G = 55 \text{ m}^3 \cdot \text{h}^{-1}$$

Aranowski R, Wojewódka P, Zielińska-Jurek A, Bokotko R, Aranowski R, Wojewódka P, et al. Spinning Fluids Reactor: A new design of a gas – liquid contactor. Chem Eng Process Process Intensif 2017;116:40–7. <https://doi.org/10.1016/j.cep.2017.03.005>.

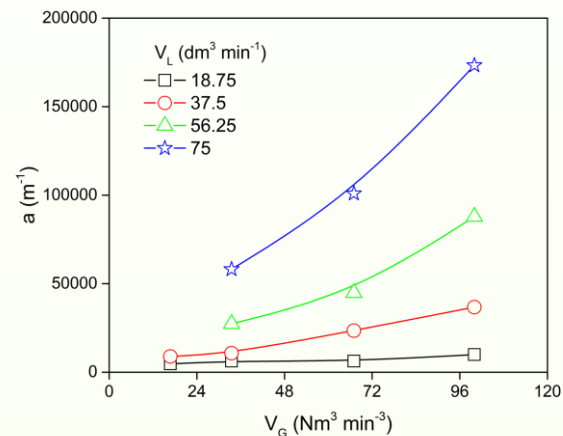
Interfacial area generated in the SFR



Change in sulphite concentration vs. aeration time



Perforated metal sheet Rv1-2 with round meshes ($d=1$ mm) was used as porous partition.

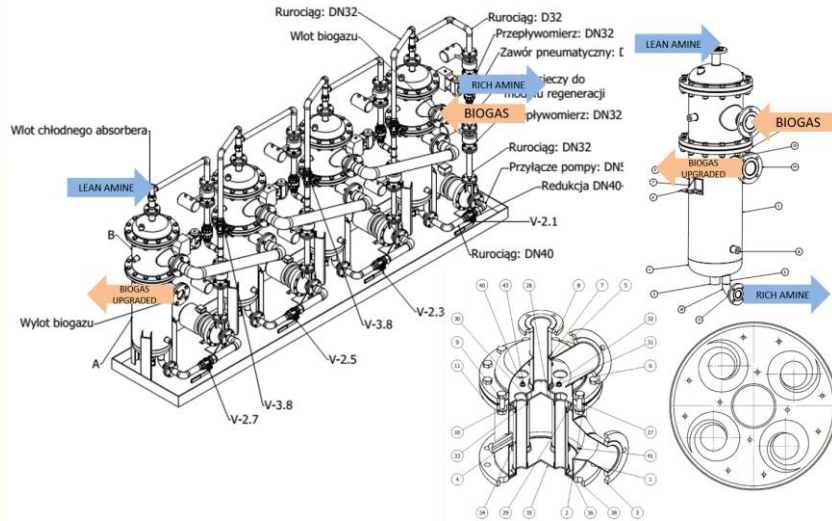


Interfacial area generated in the SFR vs. gas phase flow

Comparison of interfacial area and mass transfer coefficient of SFR with various absorption equipment

Absorption equipment	a [m ² /m ³]	$k_{La} \cdot 10^2$ [s ⁻¹]
Packed Columns (countercurrent)	10-350	0.04-7
Packed Columns (co-current)	10-1700	0.04-100
Sieve plate Columns	100-200	1-40
Bubbling Columns	50-600	0.5-24
Packed Bubbling Columns	50-300	0.5-12
Scrubbers	10-100	0.07-1.5
Stirred Tank Reactors	210-450	12.5-29.1
Jet reactor	1000-7000	0.1-3.0
Venturi Reactor	160-2500	8-25
Cyclone Centrifugal Bubbling Reactor	1000	-
Airlift Multistage Reactor	70-300	1-5
SFR	2190-162800	74.8-5935

Confirmation of SFR effectiveness



Directions of investigation in the LoCaGas project

Absorbent selection and development:

Assumptions:

- Desorption at low temperatures (80–90°C)
- Low capital expenditure (CAPEX)
- Fast CO₂ absorption kinetics
- High resistance to oxidation and degradation

Optimization of SFR design and operating parameters:

- Enhance contact time and interfacial area by optimizing the design of dispersive structures.
- Optimize rotational speed and flow rate to enhance mass transfer
- Validate performance under realistic capture and desorption conditions

- SFR is an extremely effective device for contacting the gas and liquid phases.
- Due to the short retention time, the SFR should be used in processes with fast kinetics.
- The gas phase pressure drop in the SFR does not exceed a few kilopascals.
- SFR system can be used for biogas upgrading for small and medium flow rate of raw biogas (up to several hundred m^3h^{-1}).
- Due to its small size of SFR, it can be built in a container system.
- SFR has a simple design that guarantees reliable operation

THANK YOU FOR ATTENTION

Do you have any question?

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project number: STHB.02.01-IP.01-0011/23, <https://locagas.eu>