

CFD Analysis of Gas–Liquid Flow Dynamics in a Spinning Fluid Reactor for Landfill Gas Utilization

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1. Introduction

Efficient gas–liquid interaction is crucial in many energy and environmental processes, including biogas upgrading, CO₂ absorption, and the valorisation of low-calorific gases within the LoCaGas project. Hydrodynamics play a key role in determining mass transfer, reaction rates, and overall process efficiency.

This work presents a CFD study of multiphase gas–liquid flow in Spinning Fluids Reactor (SFR), the schematic of which is shown in Fig. 1, with a focus on liquid film formation, interfacial behaviour, and flow structures under relevant operating conditions [1].

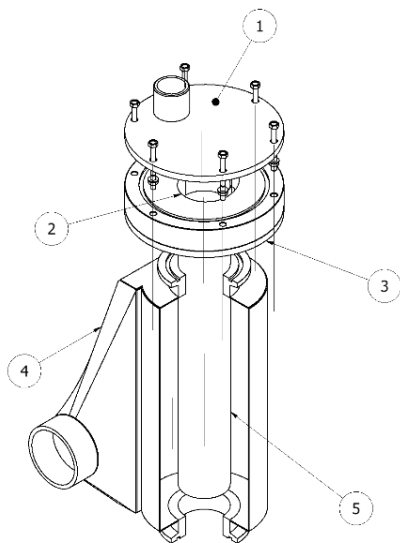


Figure 1. Schematic drawing of SFR working principle. 1 - SFR head cover, 2 - pattern generating the vortex motion, 3 - head base, 4 - SFR housing, 5 - porous tube.

Particular attention is given to liquid film thickness, gas–liquid interaction, and the influence of reactor geometry and inlet design. In addition, a comparison of various approaches to turbulence (k – ω SST and pseudo-DNS) is performed. The results provide a basis for optimising reactor design to enhance gas–liquid contact and improve SFR performance.

2. Methodology

The simulations were performed using CFD methods for two-phase flow in OpenFOAM, with the liquid phase represented via a volume fraction approach. The key parameter describing the interface is the liquid volume fraction α_l , from which the average film thickness was determined [2-3].

The mean liquid film thickness was calculated using the relation (1):

$$\bar{G} = \frac{1}{2}D \left(1 - \sqrt{1 - \frac{1}{|S|} \iint_S \alpha_l dS} \right) \quad (1)$$

Where \bar{G} denotes the average film thickness over the surface S , D is the inner diameter of the pipe, S is the cross-sectional area perpendicular to the z -axis, and $|S|$ is the area of S . The parameter α_l represents the liquid volume fraction. The integral is evaluated based on CFD simulation results.

This formulation allows direct evaluation of film properties from CFD results (see Fig. 2).

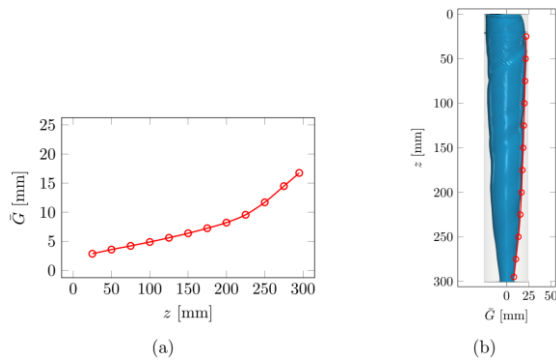


Figure 2. The figure illustrates an example of a methodology for determining film thickness based on CFD simulations: a) the film thickness calculated according to Eq. (1), b) the film thickness mapped onto the interface.

Several SFR system configurations were analysed, including pipe diameters of 10, 25, and 50 mm and reactor heights ranging from 55 to 300 mm. Gas was introduced either through a single inlet or via multiple injection points, including distributed perforated. Liquid was supplied through one side injection or distributed inflow configurations.

Two modelling approaches were used: RAS $k-\omega$ SST model – standard engineering turbulence model and pseudo-DNS approach – higher-resolution simulations capturing detailed flow structures. Time step sensitivity was also analysed for selected cases.

3. Results and Discussion

The simulations show that liquid film formation is strongly influenced by liquid inlet configuration, gas flow rate, and reactor scale. Stable films were obtained for larger porous tube diameters (50 mm), although some asymmetry was observed depending on the liquid inlet positioning. In contrast, smaller diameters (10 mm) exhibited unstable behaviour, including ligament and droplet formation, indicating a transition from film to dispersed flow regimes.

Gas injection significantly affected the hydrodynamics. At low gas flow rates,

continuous films with smooth velocity profiles were observed. Increasing gas flow led to interfacial instabilities, wave formation, and recirculation, while high gas flow (e.g., multi-hole injection) resulted in strong mixing and film breakup. Systems with a large number of gas inlets exhibited highly turbulent flow, enhancing mixing but reducing film uniformity.

Among the analysed geometries, the 25 mm porous tube provided the best compromise between film stability and mixing efficiency, whereas 10 mm systems were prone to droplet formation and 50 mm systems exhibited more stable but less mixed flow. Gas inlet design also had a significant impact on velocity fields and liquid distribution.

The pseudo-DNS approach offered improved resolution of vortex structures and interfacial phenomena, but at a substantially higher computational cost. Since the global flow characteristics were comparable, the $k-\omega$ SST model is sufficient for engineering applications, while pseudo-DNS is better suited for detailed flow analysis.

4. Conclusions

SFR hydrodynamics depend strongly on porous tube diameter and phase flow rates. Small diameters (10 mm) cause unstable, dispersed flow, while large ones (50 mm) ensure stable films but weaker mixing. Higher gas flow enhances mixing but destabilises films.

5. References

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