CFD modelling of G/L flow in milli channels

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Background

Structured reactors and energy saving

- In the Netherlands, Chemical & Refining Industry uses 40% of the total primary energy consumption with partial oxidation processes as large energy consumers.
- Structured reactors with Taylor flow (TF) (Fig. 2) have improved heat and mass transfer, enabling high selectivity and conversion
- Energy savings is possible because of decreasing of energy consumption down stream

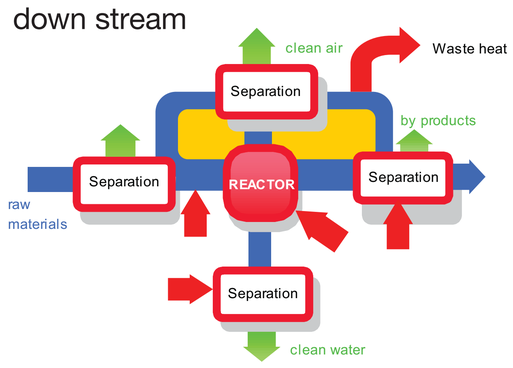


Figure 1: Energy usage in process industry

Figure 2: Taylor flow

CFD geometric model of Y-mixer and TF channel

The domain is characterized by:

- Y-junction has 120° between the legs,
- Channel diameter is 1.5 mm,
- Inlet legs are 10 mm long,
- Channel is 50 mm long,
- Y-junction has rounded edges.

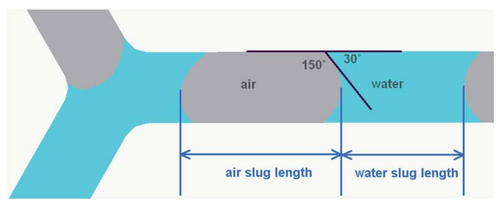


Figure 4: Definition of contact angle and slug length

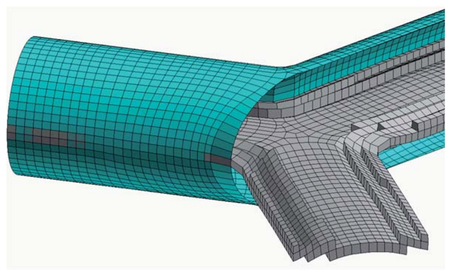
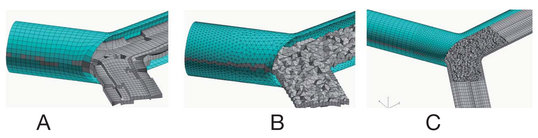


Figure 3: Example of defining mesh

System defination

- Water air system
- Blue → water
- Grey → air



A B C

Figure 5: Definition of mesh

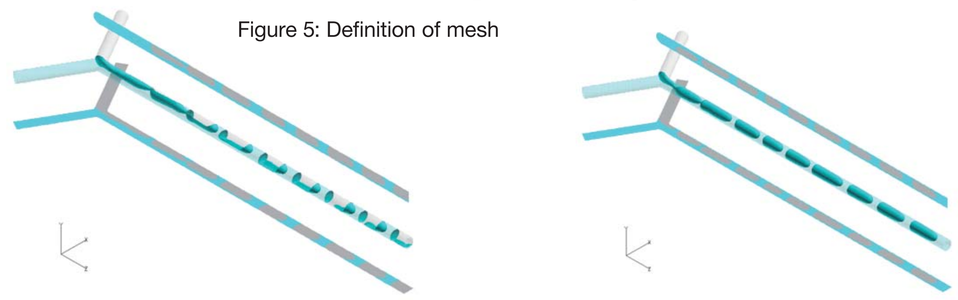


Figure 6: Development of film formation with 0.1 (A), 0.01(B) mm mesh size

- Shape: Hexahedral (A) vs tertahedral (B) vs polyhedral (C) (Fig. 5)
- Size: 0.1, 0.05 and 0.001 mm
  - ✓ Polyhedral mesh best fit geometry
  - ✓ 0.1 mm no film formation → reasonable simulation time (Fig. 6A)
  - ✓ 0.001 mm always film formation → extremely long simulation time (Fig. 6B)
  - ✓ No difference in slug lengths between 0.1 and 0.001 mm mesh

Objective

- Development of a CFD model for describing Taylor flow in milli channels
- Determining sensitivity of process parameters
- Experimental verification of the kinetic model

Modeling Approach

Two-phase flow in millimeter-sized channels has been simulated using computational fluid dynamics (CFD) codes with the volume of fluid method (VOF method). Open-FOAM (Open Field Operation and Manipulation) was selected as the simulation tool for the modeling of two-phase flows in small channels.
The solver for problems involving VOF is inter-Foam

Results

Variable	Stability region	Slug length	Film present
Mesh size	None	< 0.2 mm	V_L↑ mesh↓
Δp	Shrinkage V_G↓	none	none
σ	↑with σ↑	↑with σ↑	---
θ	---	↑ with θ↑	---

Table1: Parameter influence (tertahedral mesh 0.1 mm)

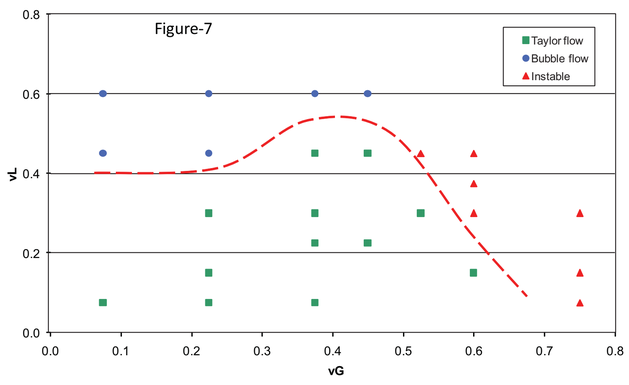


Figure 7: Modeling and experimental verification 120°, channel size 1.5 mm

		slugG	slugL	slugG	slugL	slugG	slugL	slugG	slugL	slugG	slugL	slugG	slugL	slugG	slugL
0.450	1.5 mm					1.54	1.28								
	3 mm					bubble instable									
	6 mm					Taylor instable									
	12 mm					stratified									
0.375	1.5 mm														
	3 mm	bubble instable													
	6 mm														
	12 mm														
0.300	1.5 mm					1.78	1.33			3.00	1.45			Taylor instable	Taylor instable
	3 mm	1.98	2.94	bubble instable		bubble instable				Taylor instable				Taylor instable	Taylor instable
	6 mm	bubble instable				Taylor instable				Taylor instable				connected slug	connected slug
	12 mm					stratified								stratified	stratified
0.225	1.5 mm														
	3 mm	2.83	4.40	3.47	2.83	4.77	3.00	5.78	2.69	Taylor instable					
	6 mm	4.13	5.80	Taylor instable		Taylor instable									
	12 mm														
0.150	1.5 mm	2.38	3.58	3.00	2.18	3.14	1.44								
	3 mm	4.86	7.55	4.43	2.77	6.52	2.84	9.10	3.31	11.47	3.07	Taylor instable			
	6 mm	7.20	8.33	9.66	5.67	Taylor instable									
	12 mm														
0.075	1.5 mm	3.37	2.58	4.83	1.94	4.86	1.18								
	3 mm	6.70	4.95	8.86	3.25	12.80	3.13	18.90	3.60	23.33	3.40	25.20	3.20	Taylor instable	
	6 mm	18.56	15.60	22.40	7.07	Taylor instable									
	12 mm														
		0.075		0.150		0.225		0.300		0.375		0.450		0.525	0.600

gas velocity (m/s)

Figure 8: Influence of channel diameter

Conclusions

- Model predictions in agreement with experimental work on flow pattern mapping and theoretical predictions of channel diameter influence.

Future work

Sensitivity analysis of channel design parameters using the developed CFD model

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