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COMPUTATIONAL FLUID DYNAMICS MODELING OF FLOW OF DRY FOAM IN A PIPE

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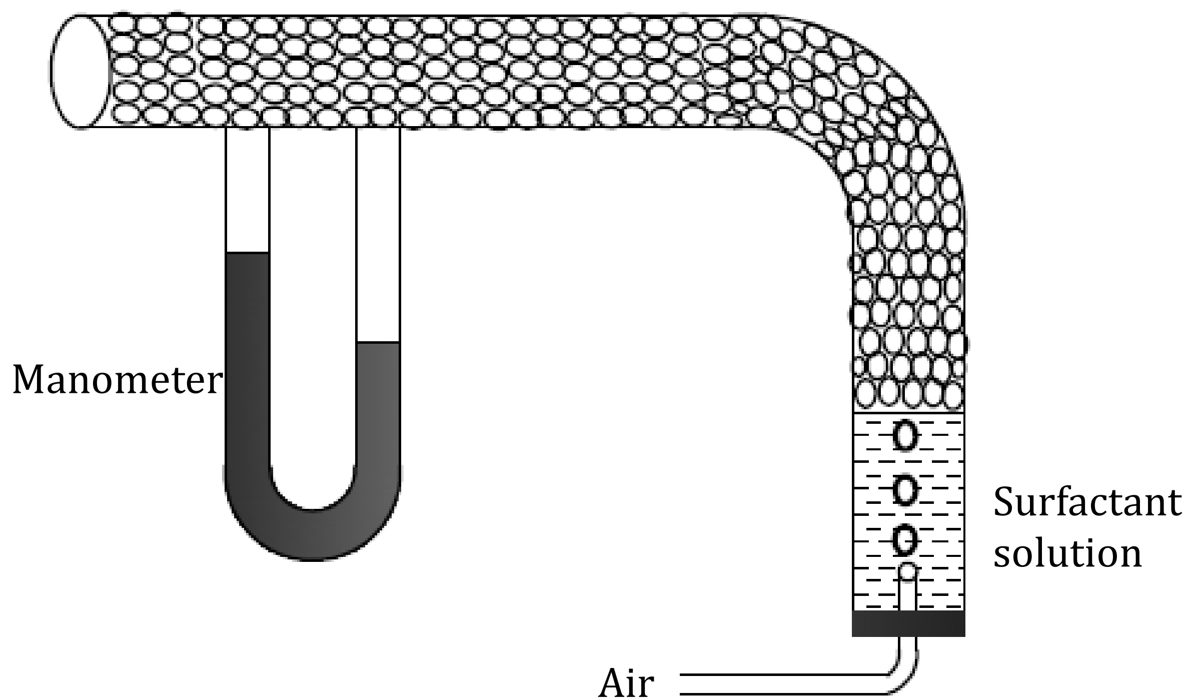
A Typical foam flow set-up for measuring ΔP vs. flow rate



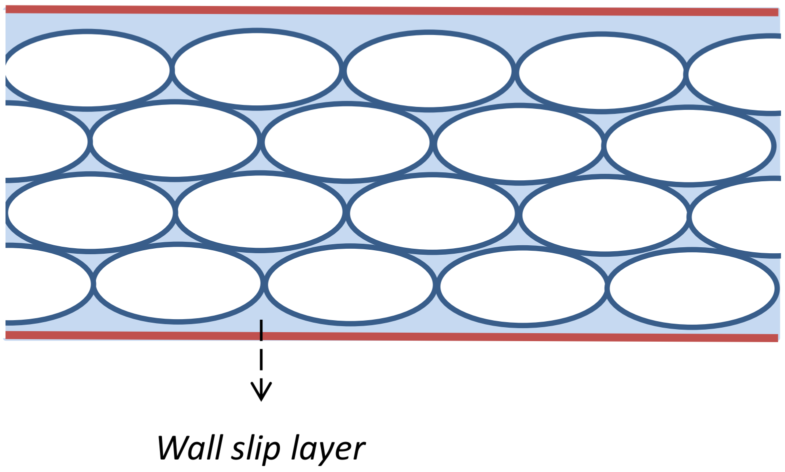
Models of foam rheology

Reference	Empirical Model	K (Pa s^n)	n	τ_y (Pa)
Wenzel et al, 1970	$\tau = \tau_y + k\gamma^n$	1.73 -6.8	0.13 – 0.69	1.32 -12.05
Thondavadl and Lemlich, 1985	$\tau = k\gamma^n$	1.43	0.61	
de Kransinki and Fan, 1984	$\tau = k\gamma^n$	18.5	0.5	
Enzendorfer et al, 1995	$\tau = k\gamma^n$	2.5	0.34	
Boissonnet et al, 1997	$\tau = k\gamma^n$	0.26	0.6	
Gardiner et al, 1998	$\tau = k\gamma^n$	2.29	0.29	

Source: Data taken from Gardiner (1999)

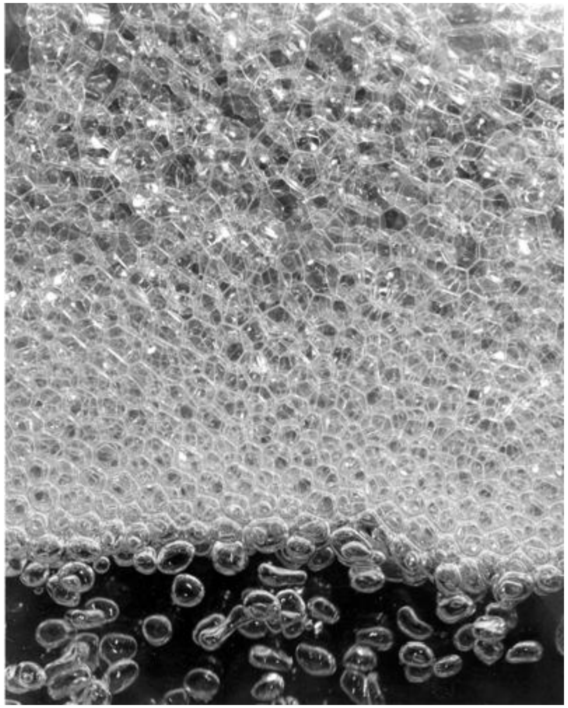
Processes involved in foam flows

- *Yield stress*
- *Wall slip layer*
- *Slipping of bubbles past each other*
- *Compressibility*
- *Film drainage*



Parameters influencing rheology

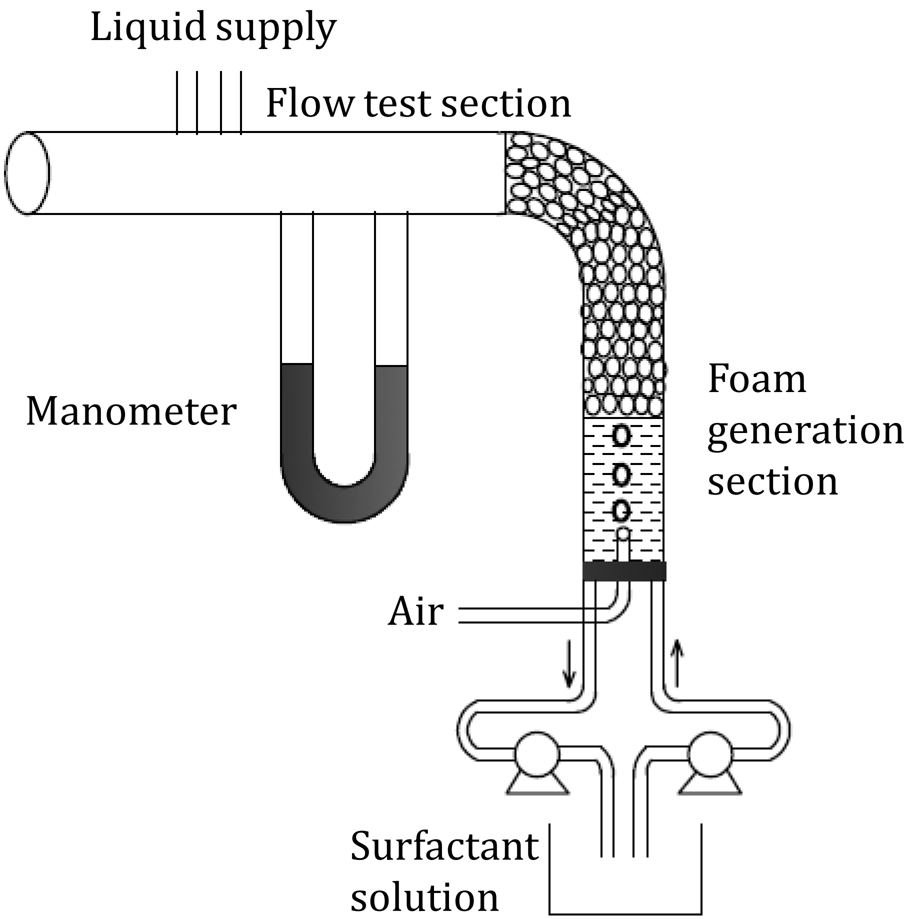
- *Flow rate*
- *Liquid fraction*
- *Bubble size*
- *Pipe diameter*
- *Wall roughness*



Source: www.tcd.ie/physics/foams/liquid.php
accessed on 14.06.12

Empirical models are not satisfactory due to poor control on parameters

Experimental predictions on foam flow by Choudhary (2002)



Flow rate (ml/s)	$\frac{\Delta P}{L}$ (N/m³)	Bubble size (mm)
7.2	90.8	3.9
9.1	115.7	3.9
11.3	140.4	3.9
12.8	157	3.9

Experimental predictions on foam flow by Choudhary (2002)

ΔP *correlation:*

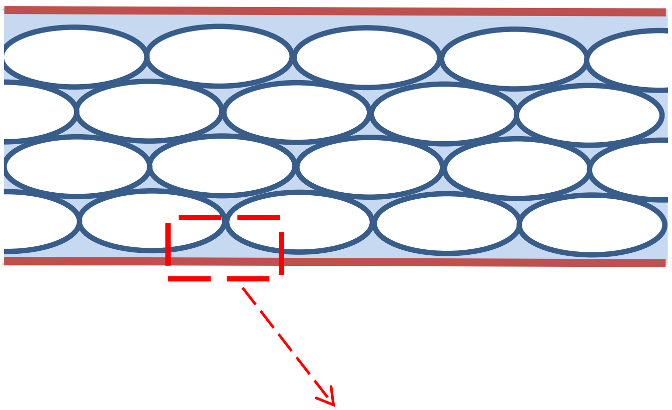
$$\Delta p \propto \frac{Q^{2/3}}{R^2}$$

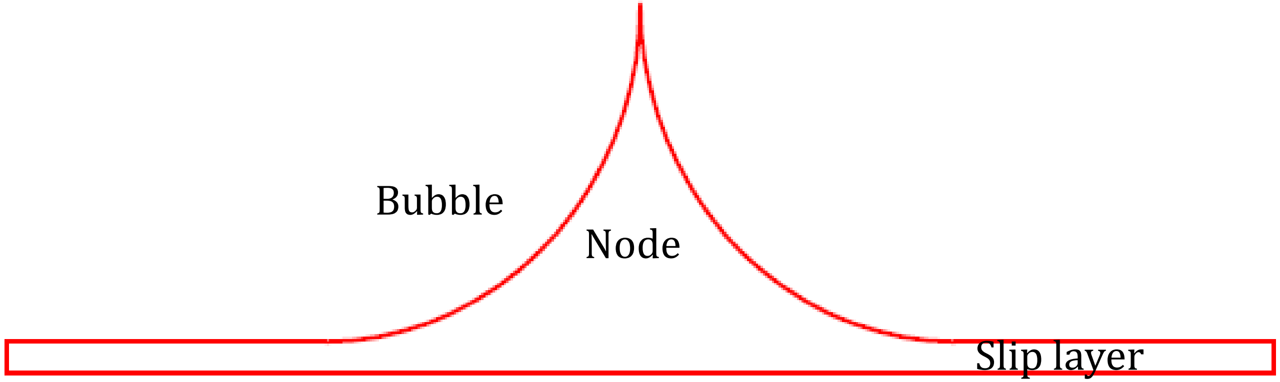
Lesser dependence on flow rate than a laminar flow!

Objective of the present work

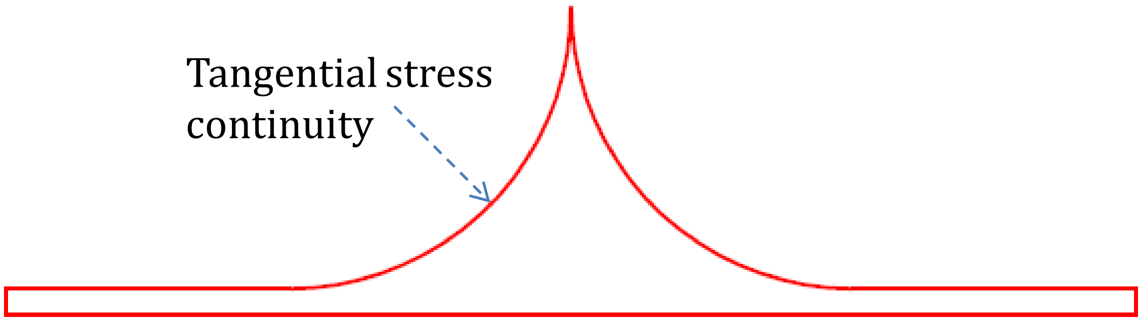
- **A model to explain the reduced dependence of ΔP on flow rate.**

Simulated Zone





Boundary conditions: Momentum transport



Tangential stress condition at interface,

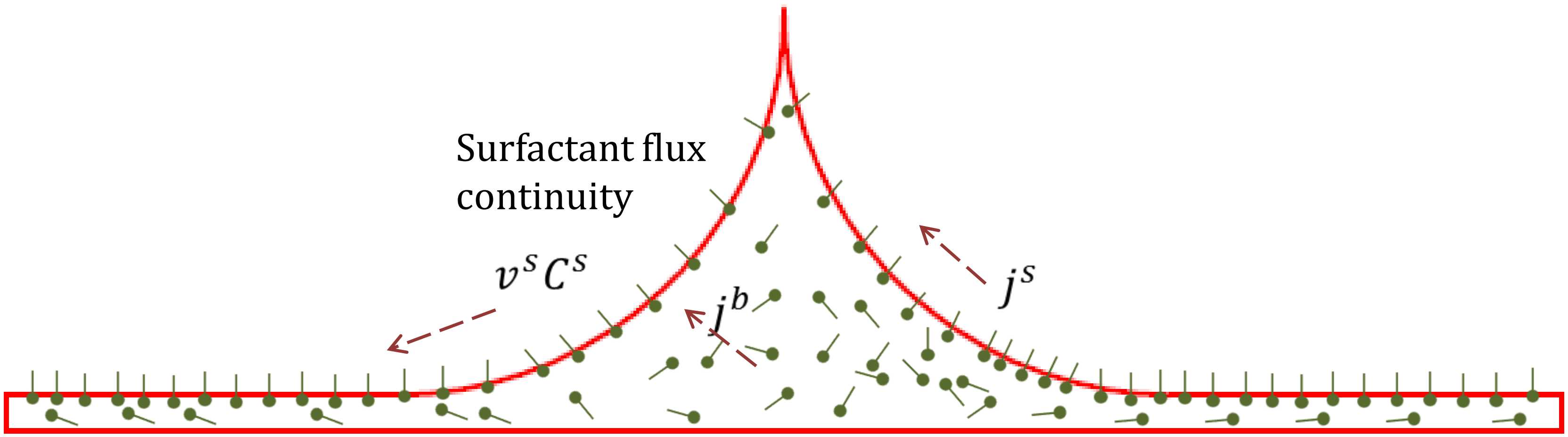
$$(n.\tau_l) - [(n.\tau_l).n]n \quad = \quad (\mu^s + \mu^d)\nabla_s \nabla_s . v^s + \nabla_s \sigma$$

Tangential stress felt on liquid side near interface

Surface viscous stress

Marangoni stress

Boundary conditions: Species transport

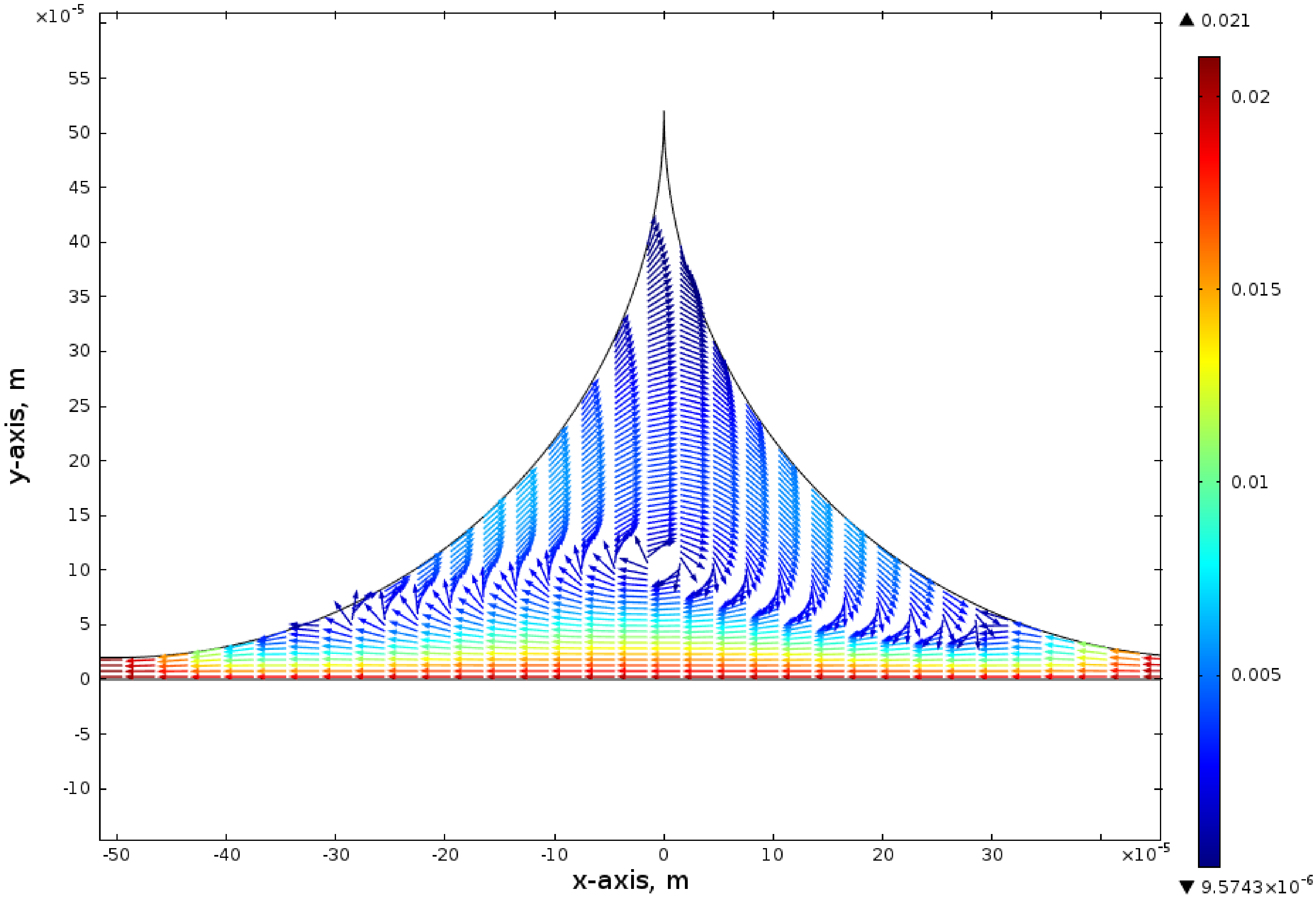


Surfactant flux condition at interface,

$$\nabla_s.(v^s C^s) \quad + \quad \nabla_s.(j^s) \quad = \quad n.j^b$$

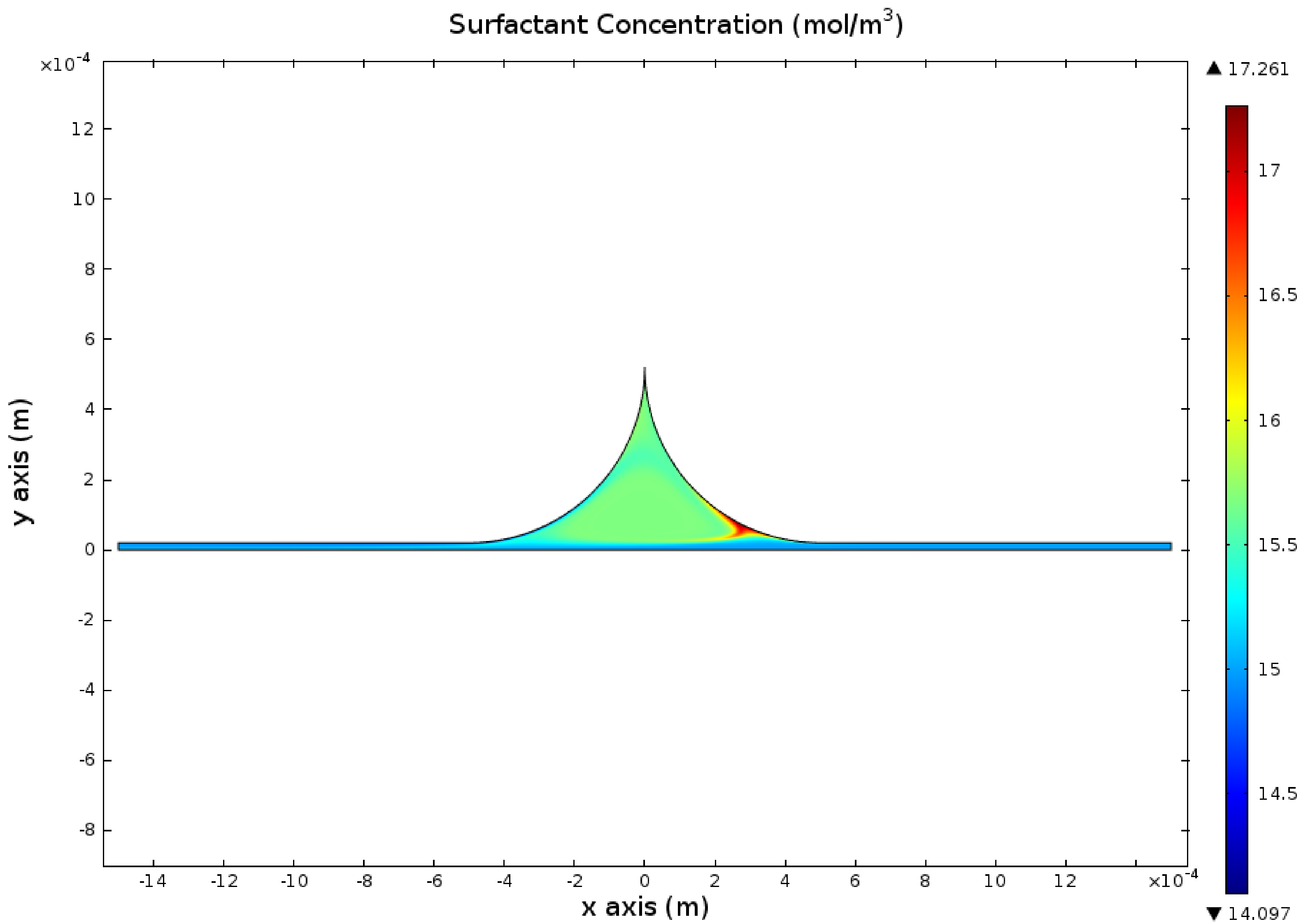
Convective surface flux — *Diffusive Surface flux* — *Flux from the buk to interface*

Velocity Field (m/s) in a Frame Moving with Bubble Velocity

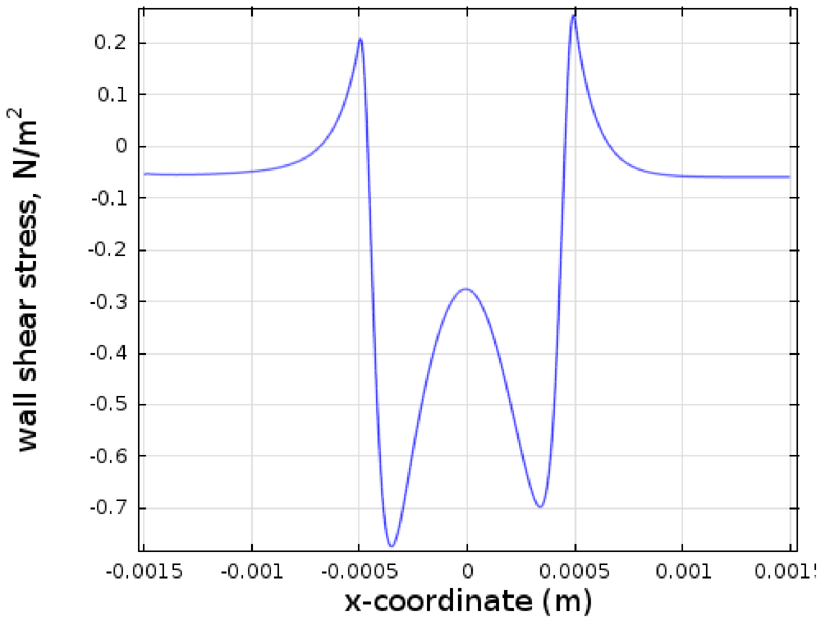


Velocity field, m/s (wall velocity - 2 x 10^-2 m/s)

Surfactant Concentration Profile



Pressure Drop vs. Flow Rate Predictions



Wall shear stress

Pressure drop calculation :

$$\Delta p\, \pi R^2 = \tau_w\, 2\pi R$$

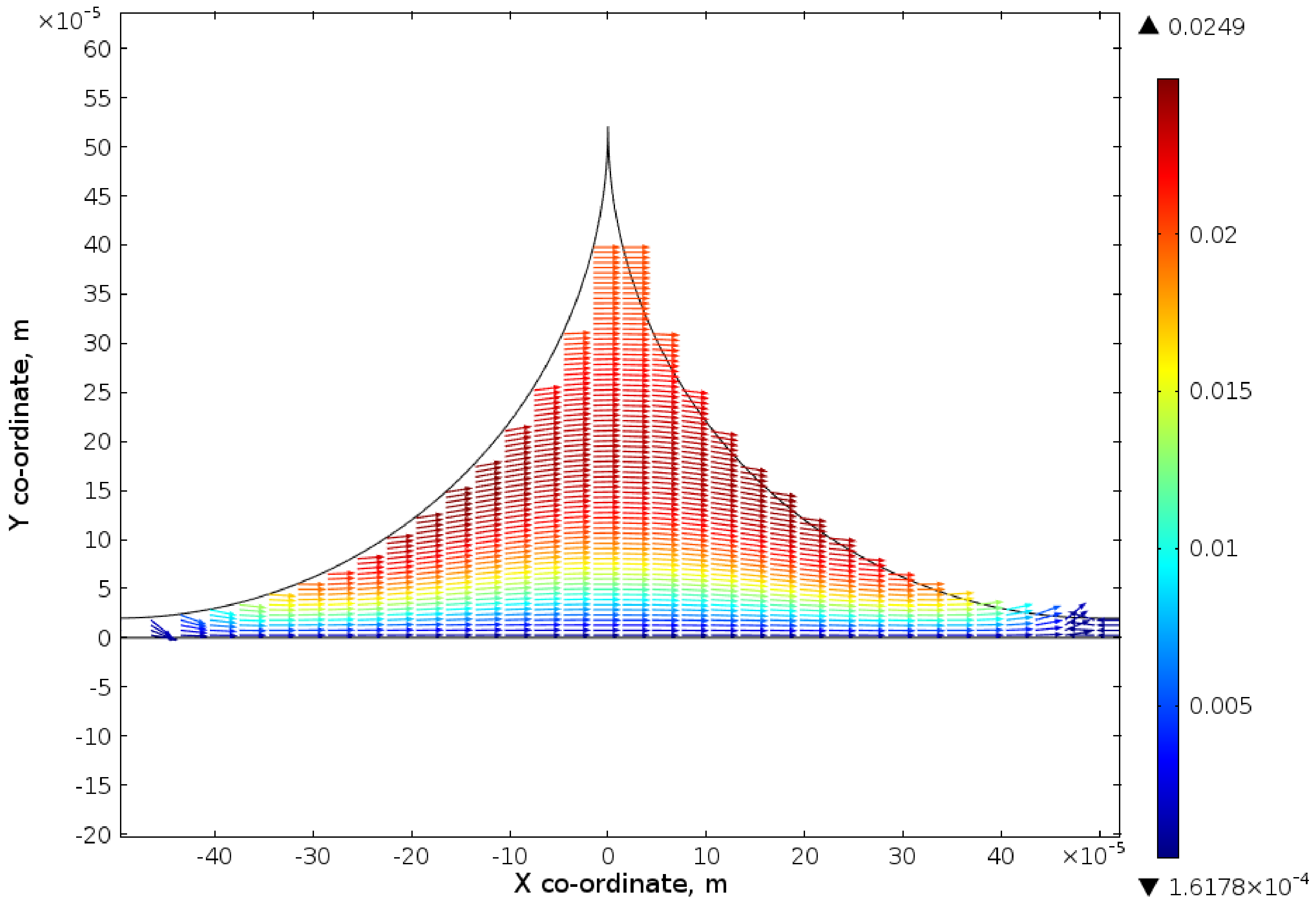
Pressure drop vs. Flow rate

$$\Delta p = aQ^b + c$$

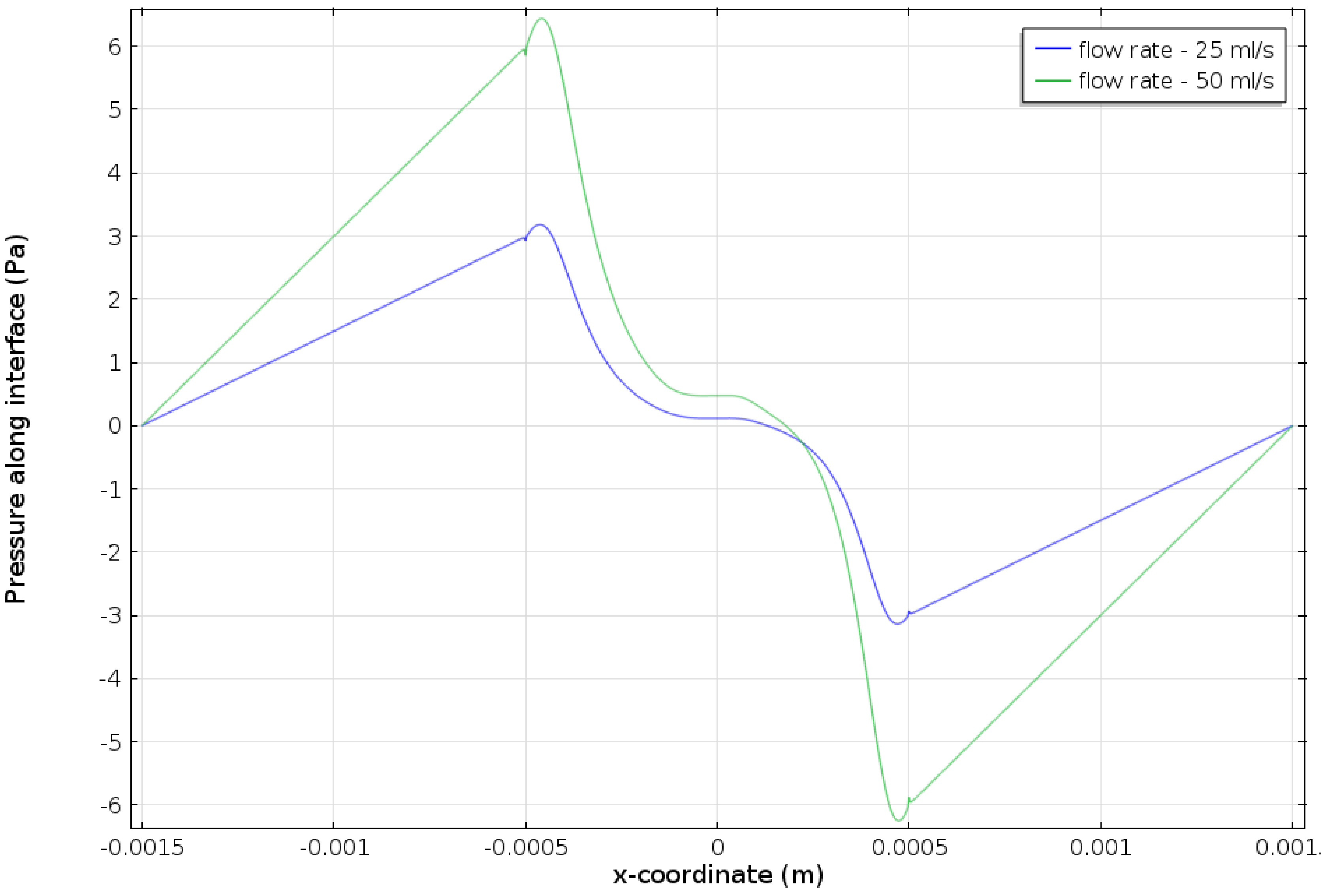
Surfactant concentration mol/m³	*a*	*b*	*c*
15	1339	0.9137	0.0006
30	1365	0.9351	0.0005
40	1395	0.9474	0.0005
50	1404	0.9534	0.0005
65	1416	0.9607	0.0005
70	1419	0.9624	0.0004

Effect of slip layer thickness

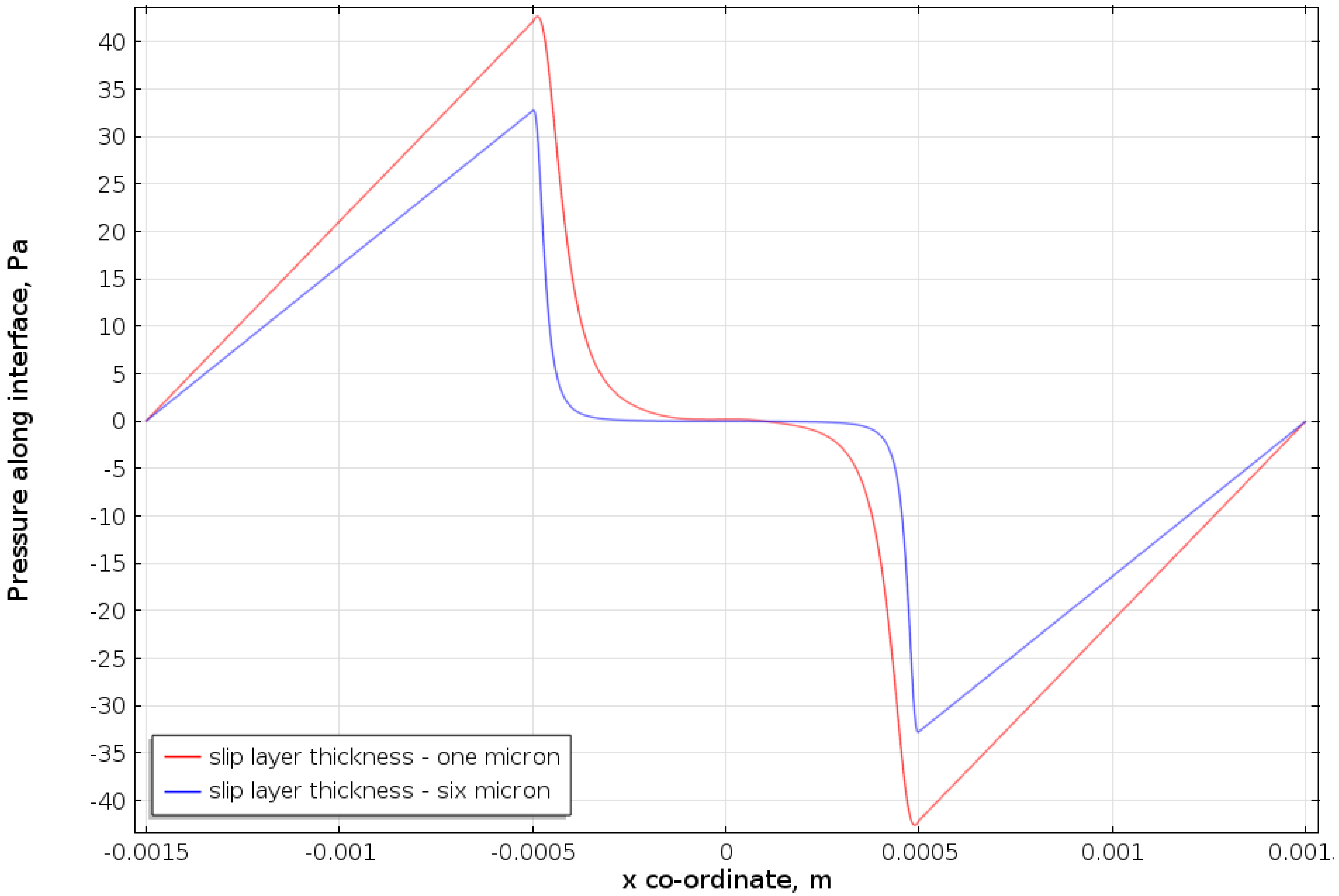
Velocity Field (m/s) in a Stationary Frame of Reference



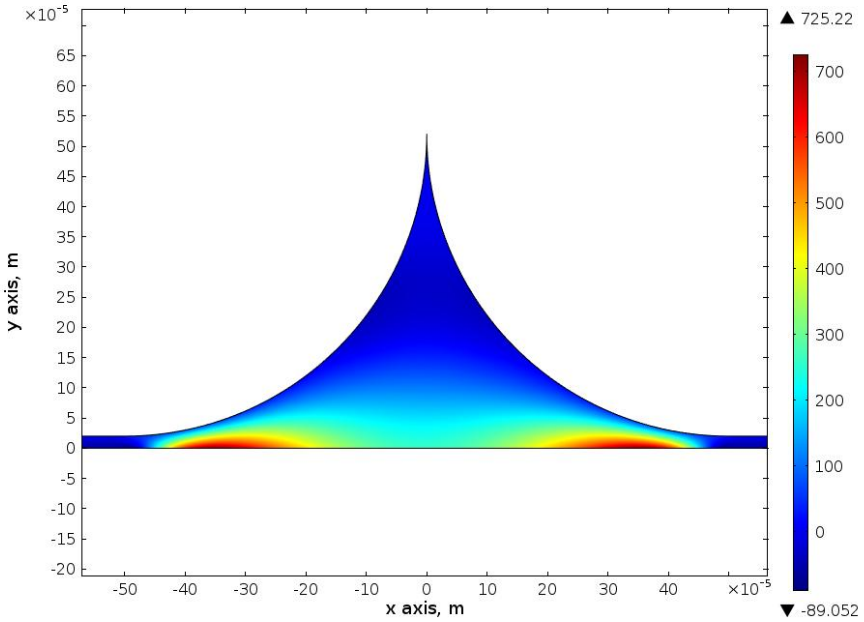
Effect of slip layer thickness



Effect of slip layer thickness

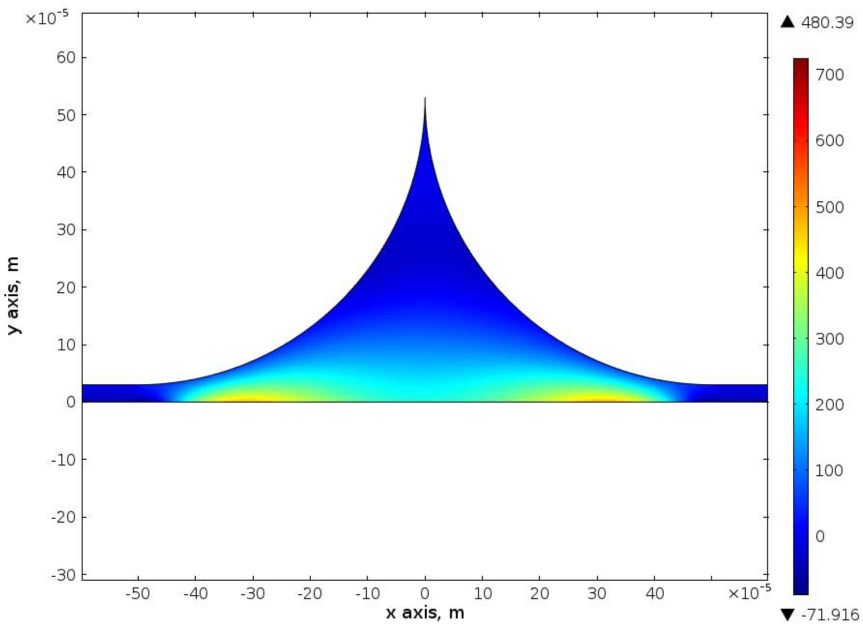


Shear rate ($\partial v_x/\partial x$) plot, 1/s

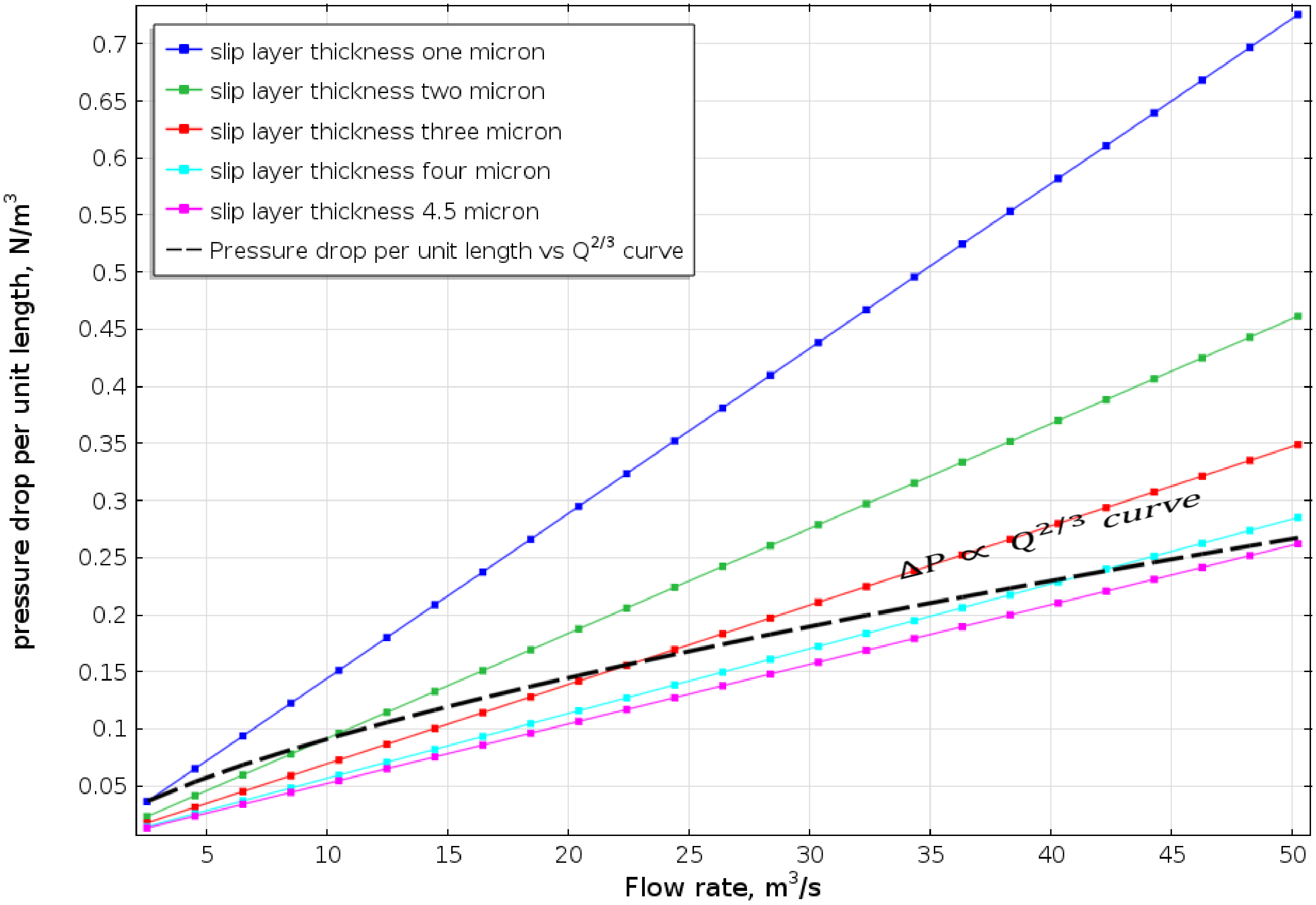


$\delta = 20\ \mu m$

$\delta = 30\ \mu m$



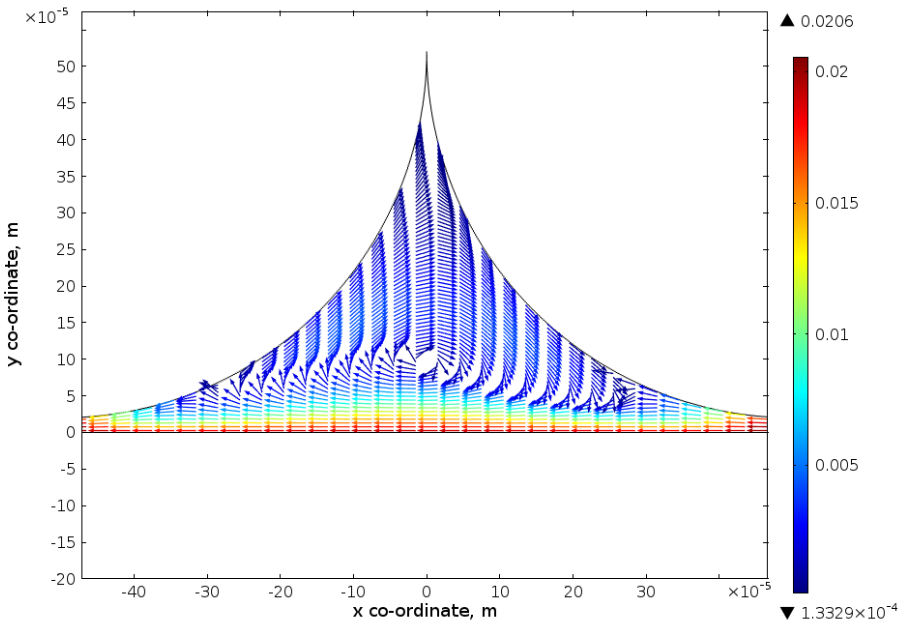
Effect of slip layer thickness



Experimental Validation:

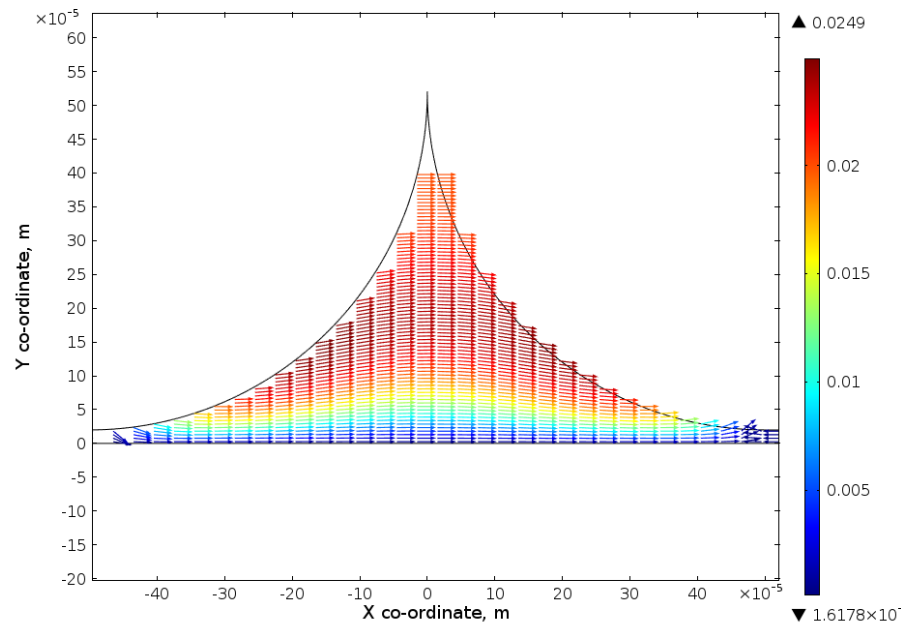
Thondavadi, N. N., & Lemlich, R. (1985). Flow properties of foam with and without solid particles. Ind. Eng. Chem. Process. Dev.

Summary

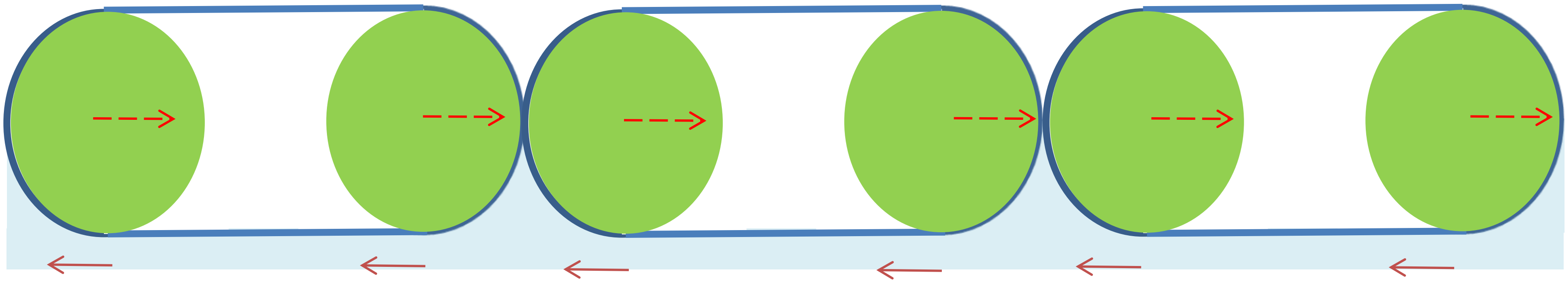


Moving frame of reference

Stationary frame of reference



Portrait of Foam flow



Thank You