MODELLING OF LIQUID STEEL, SLAG IN AN ARGON GAS BOTTOM BLOWN REACTOR

Nelson JOUBERT 18/06/19
Sorbonne Université, Institut Jean le Rond d'Alembert
PhD advisor S. Zaleski
PhD co-advisor S. Popinet

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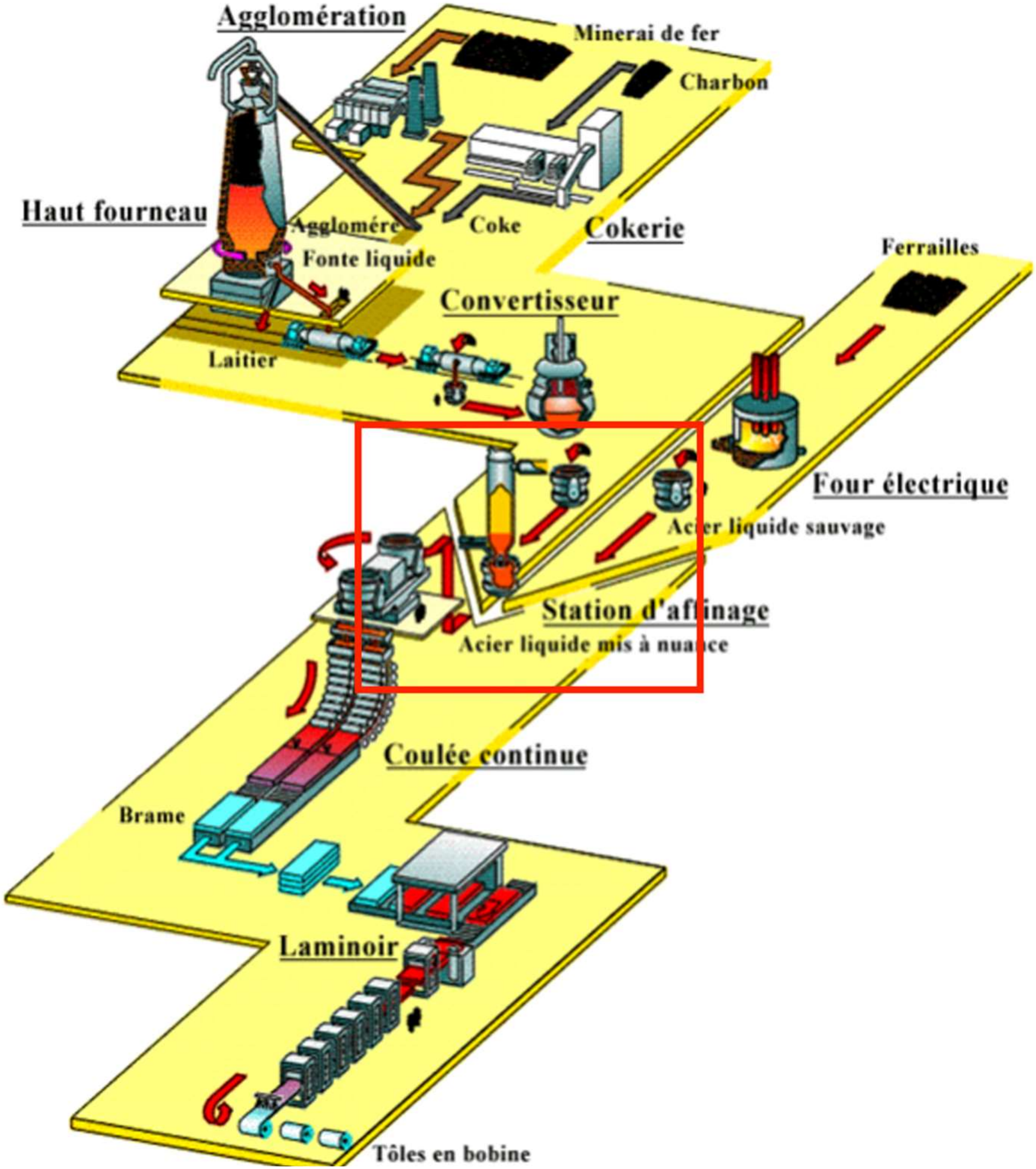
Overall description of a steel mill



Slag :

by-product of metal contain metal oxides and silicon dioxide

2700kg/m³,7.10^{-2}Pa.s, 1,2 N/m

Secondary metallurgy:

Liquid steel at 1600°C

treated in 200 ton ladle

7000kg/m³; 5.10^{-3}Pa.s, 1,5 N/m

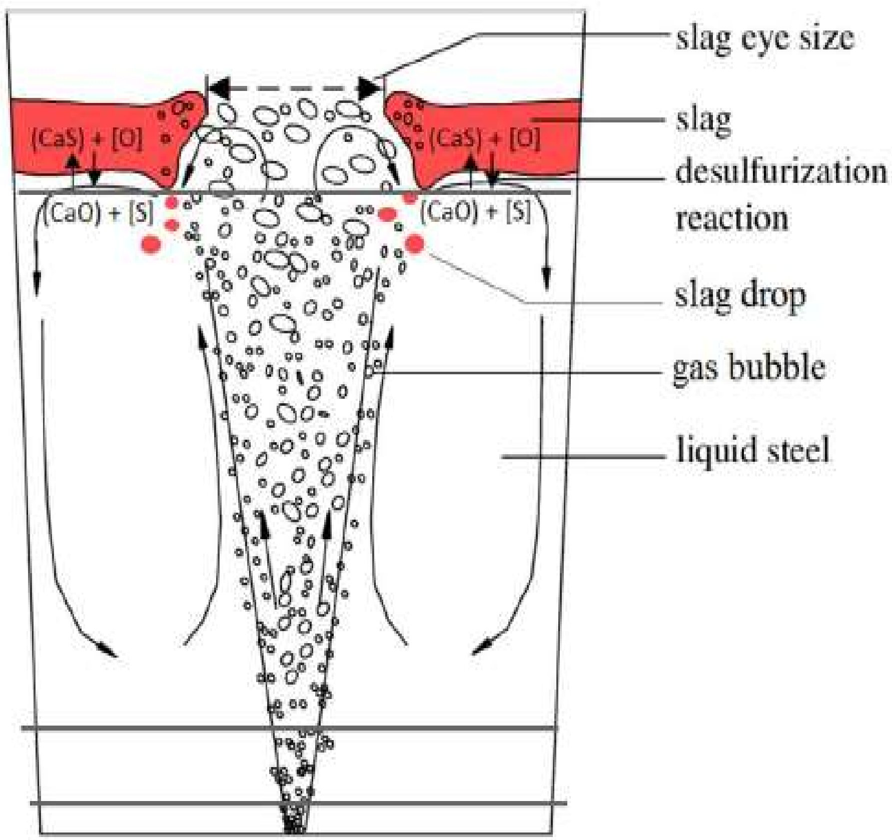
- Refinement of liquid steel:

- Desulfurization of liquid steel by chemical reaction with slag:

$$[S] + (CaO) \leftrightarrow (CaS) + [O]$$

- Ladle is stirred with Argon bubbling to produce:

- renewal of steel in contact with slag



Summary

I- Simulation and experiment of the process

II- Comparison of numerical and experimental results

III- Conclusion

Process - model

- Use a scale model based on the work of S.H. *Kim et al.* 1987

Froude similarity between scale and industrial ladle

$$\lambda_1 = \frac{d_{0Kim}}{d_{0model}} = 2{,}2;\ \lambda_2 = \frac{d_{0industrial}}{d_{0mode}} = 16{,}6$$

$$N'_{Fr} = \frac{(\rho_g u_0)^2}{\rho_l \rho_g g L}$$

$$N'_{Fr} = C\,\frac{\dot{Q}_g{}^2}{L d_0^4}$$

$$\dot{Q}_{Kim} = (\lambda)^{\frac{5}{2}} \dot{Q}_{model}$$

$$\dot{Q}_{industrial} = 1{,}038(\lambda)^{\frac{5}{2}} \dot{Q}_{model}$$

Process - model

Three phases air, water, oil at 20°C :

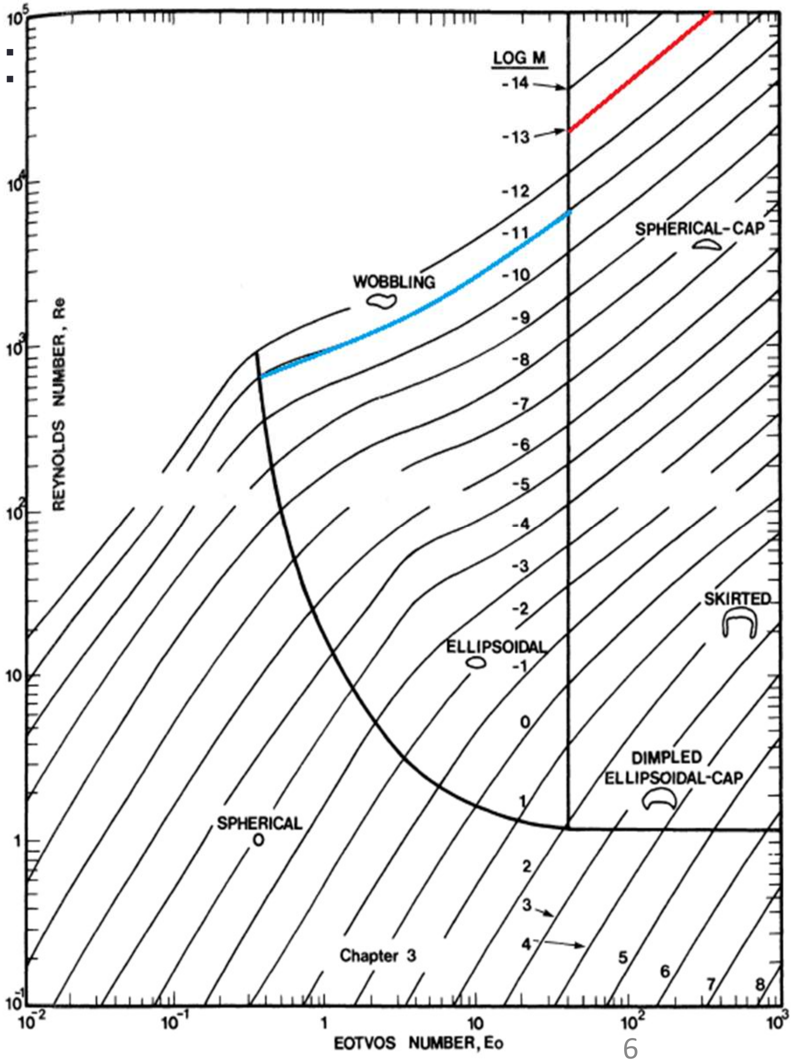
- oil⟶ slag
- water⟶ liquid steel
- air⟶ argon gas
- $M = \dfrac{g{\mu_l}^4\Delta\rho}{{\rho_l}^2{\sigma_{g/l}}^3}; Bo = \dfrac{\Delta\rho g d^2}{\sigma_{g/l}}$

• $D_{b,industrial} = 12cm$

- $M_{industrial} = 2.6E-13$
- $Eo_{industrial} = Bo = 715$

• $D_{b,model} = 8.2mm$

- $M_{model} = 2.65E-11$
- $Eo_{model} = Bo = 9$



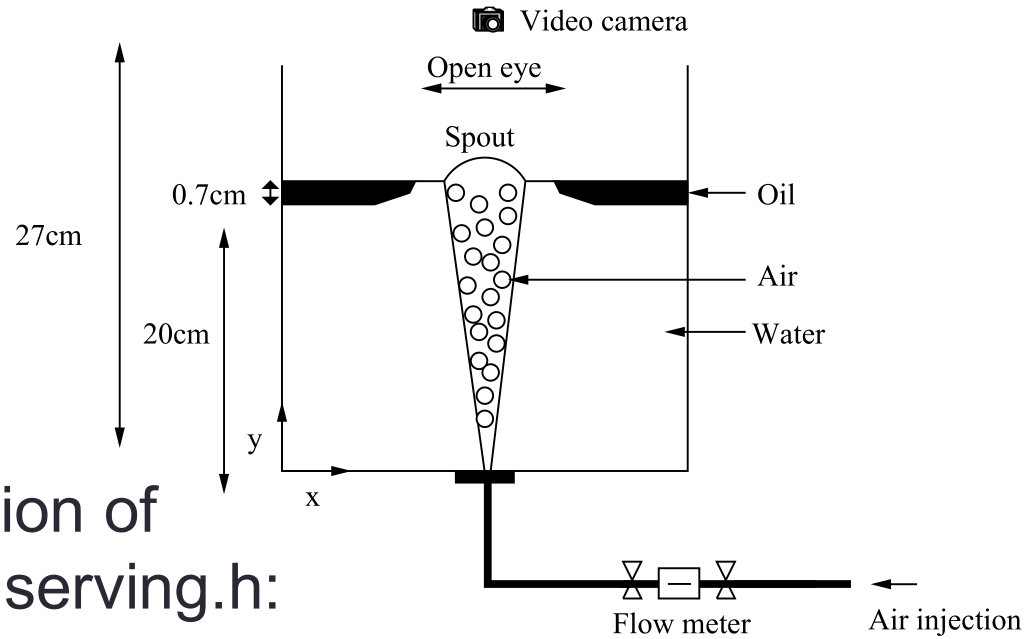
Process - model

- $D_i = 7.9mm$

f1=air

f2=water

f3=oil



- Use three-phase extension of the two-phase.h and conserving.h:

- http://basilisk.fr/sandbox/joubert/three-phase.h

Add a third phase explicitly.

- http://basilisk.fr/sandbox/joubert/conserving3f.h

Modify the function to have momentum conservation for three explicit phase.

Process simulation - setup

We set for numerical reasons $\rho_a' = 10\rho_a = 12{,}25\,\frac{kg}{m3}$

Oka & Ishii (1998), Tryggvason, Cano-Lozano (2016)

- Water/air density ratio R=82
  Water/air viscosity ratio M=54
- $\rho(\chi) \equiv f_1\rho_1 + f_2\rho_2 + f_3\rho_3$
- $\mu(\chi) \equiv f_1\mu_1 + f_2\mu_2 + f_3\mu_3$
- $\sigma_{12} = \sigma_1 + \sigma_2$

  K.A Smith et al. 2002

  X. Chen et al. 2017 (Gerris)

$$\chi_{kn}(x,t) = \frac{\chi_k(x,t)}{\sum_i^n \chi_k(x,t)}$$

Process -experimental results – visualisation

Face view of hydraulic model, zoom at interface at Qg=5,0L/min with Dinj= 2,35mm

Process simulation- numbers

Flow rate =0.6l/min

Simulation on
16 nodes*28 cores
=448 cores

Tphysical = 6s

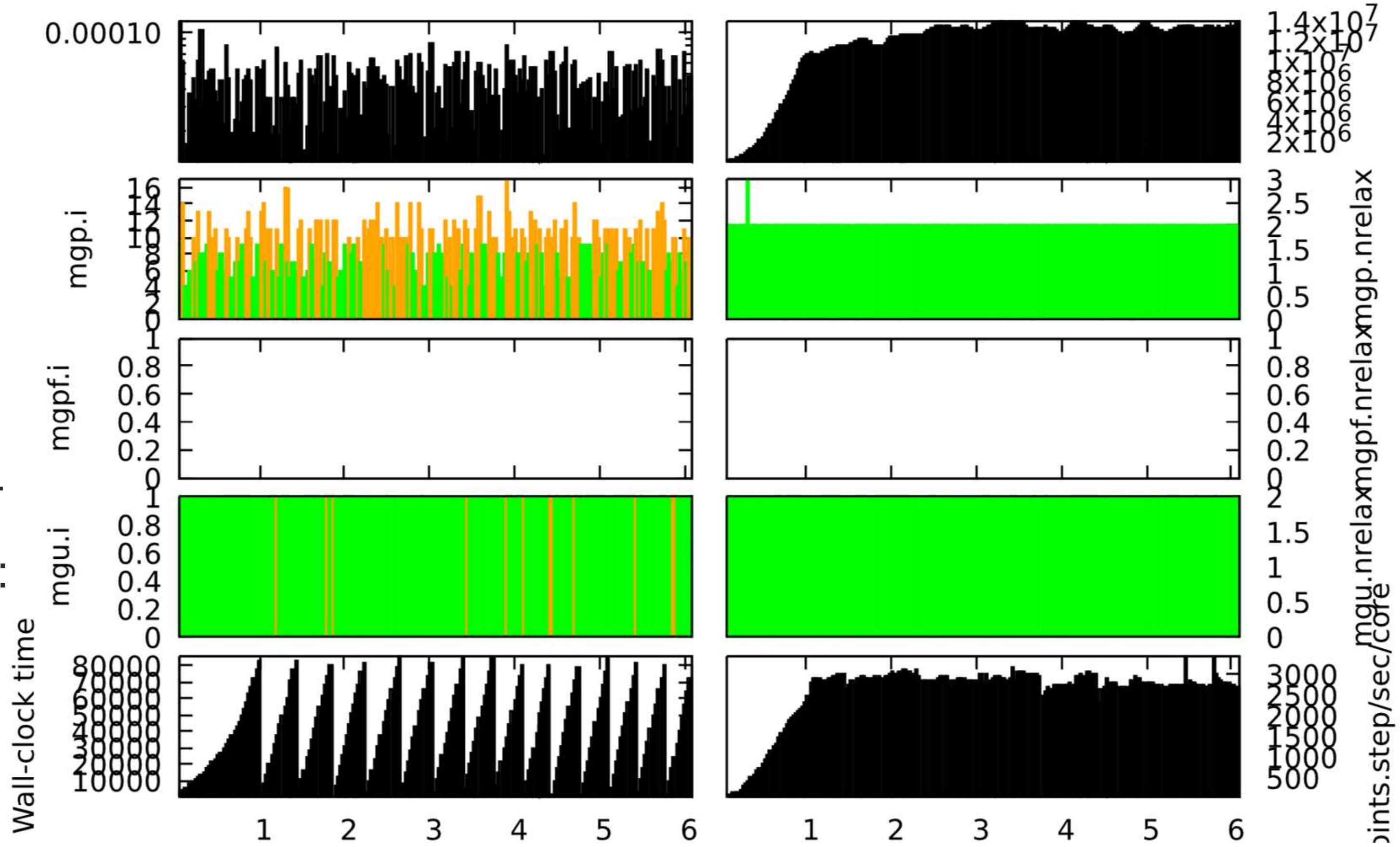
Max cell number in 1 direction 2^10=1024

Adaptative meshing :

14 500 000 cells

15 jobs ~161k h

min mesh size
=0,27/1024
=264μm



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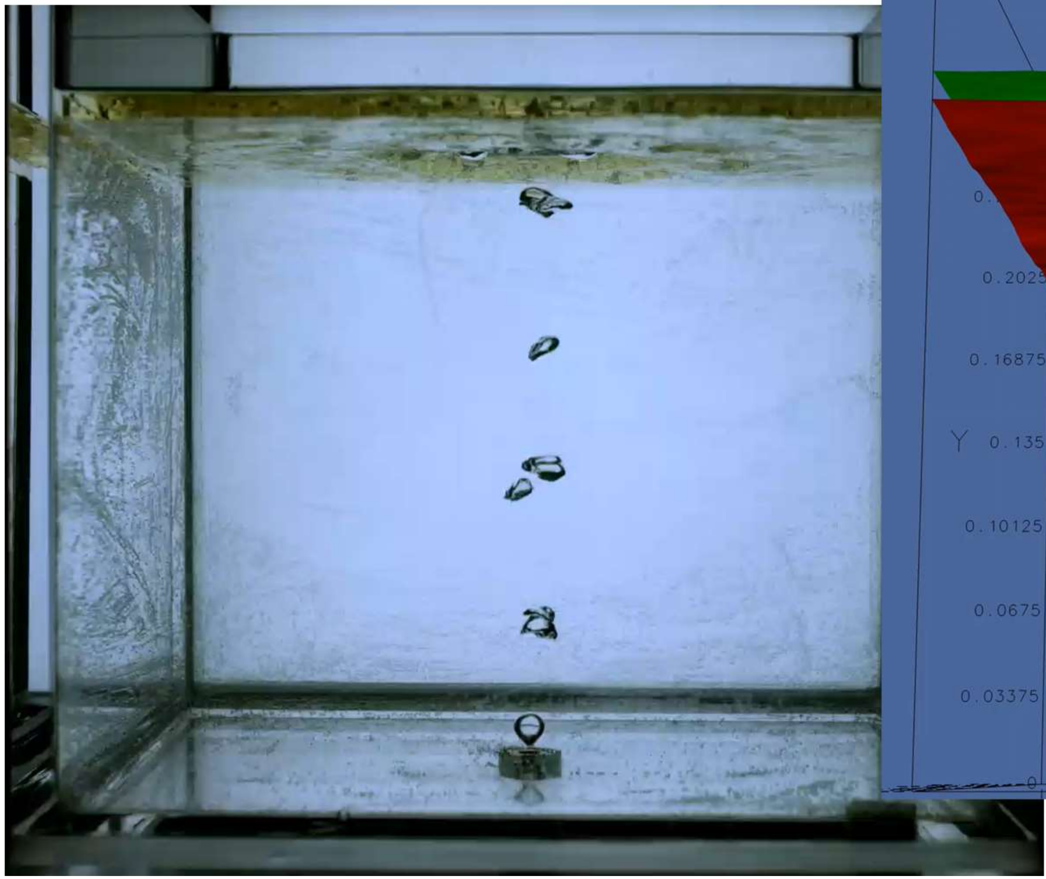
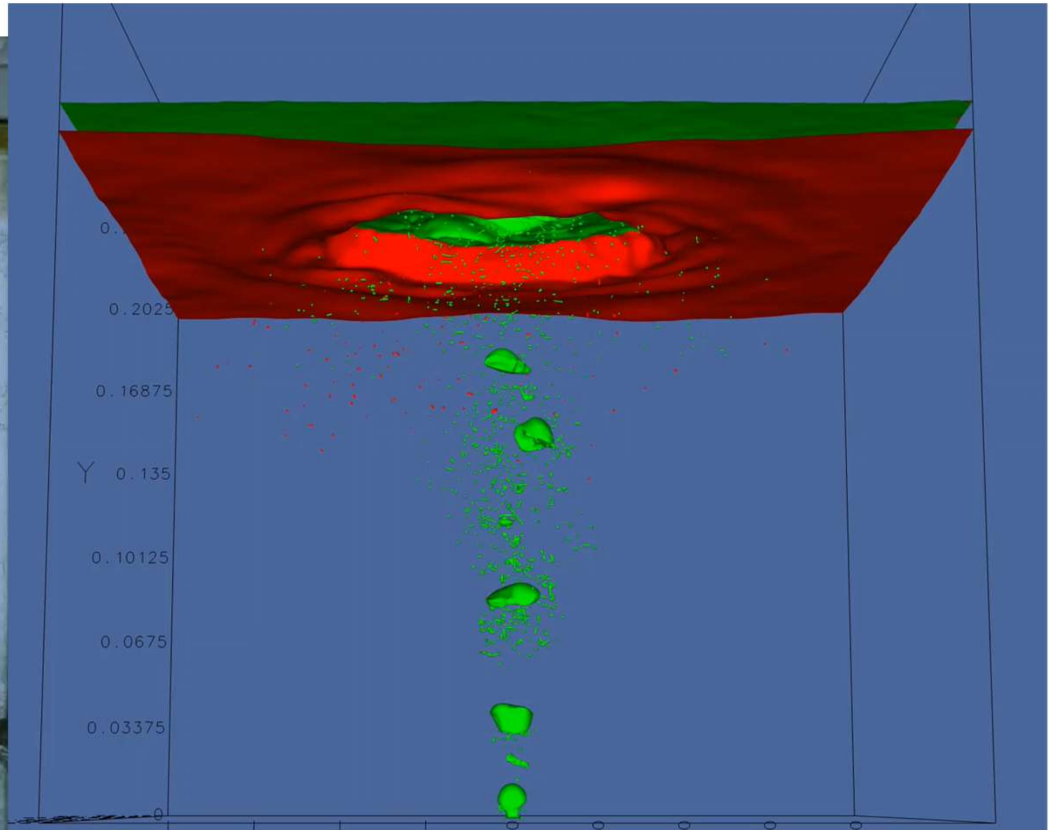
Process simulation – Results

Front view model:
with fast camera

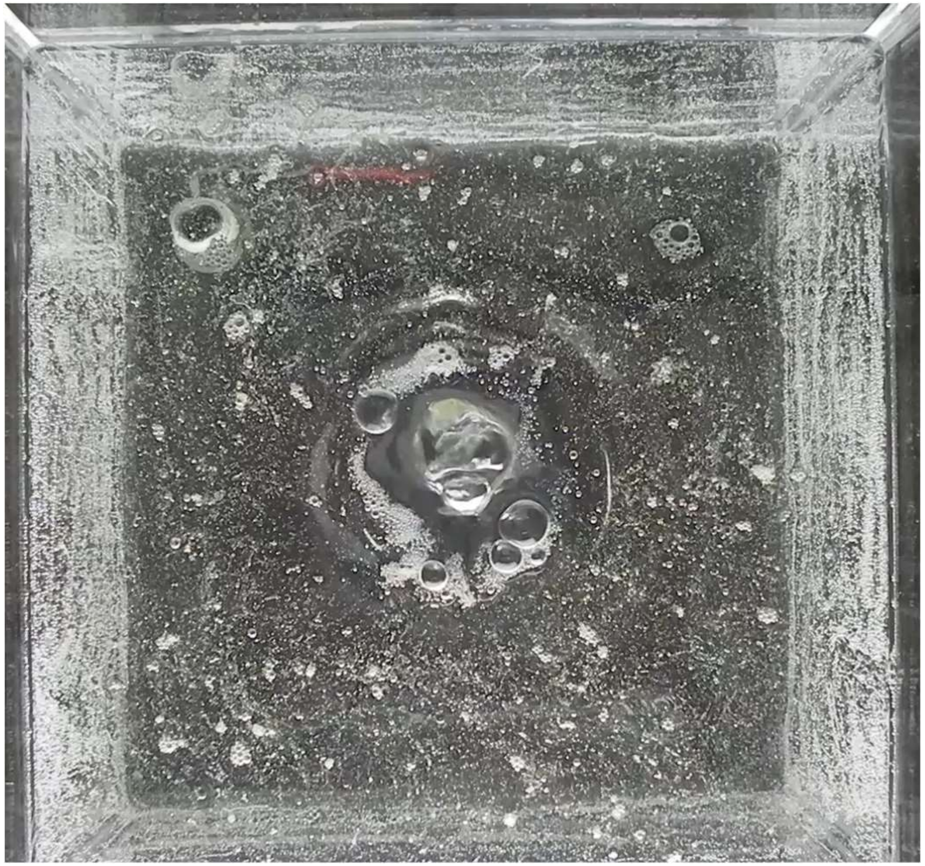


Front view simulation:
oil interface in red, air in green

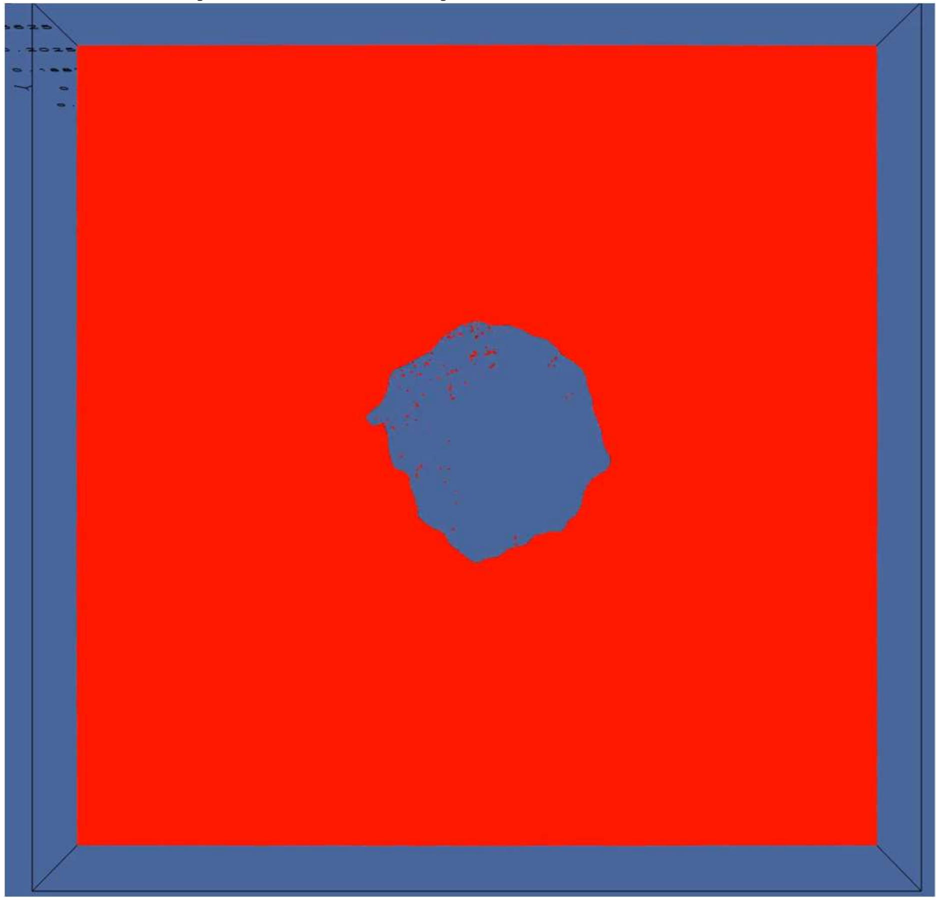


Process simulation – Results

Topview model with camera;

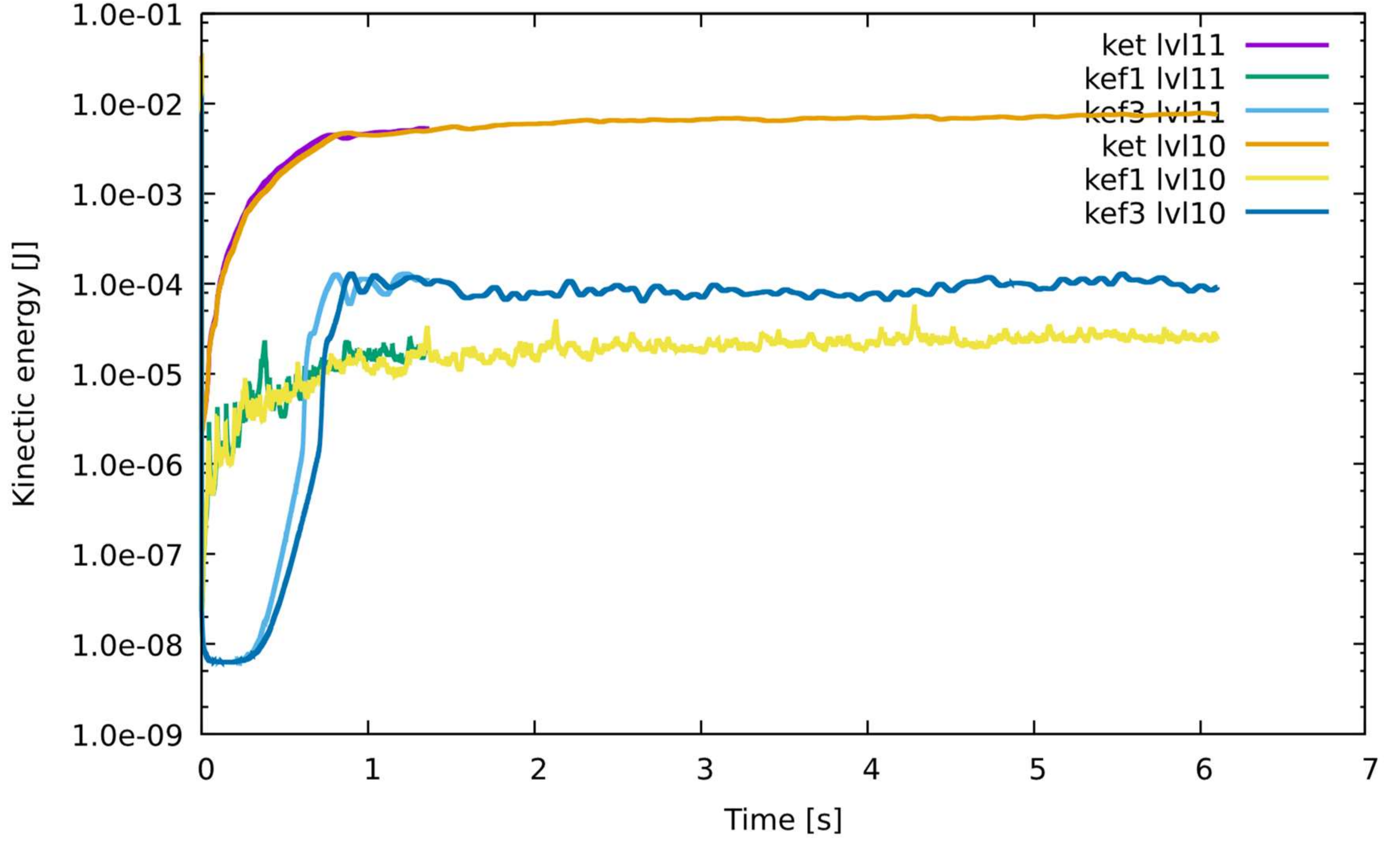


Topview oil phase in red

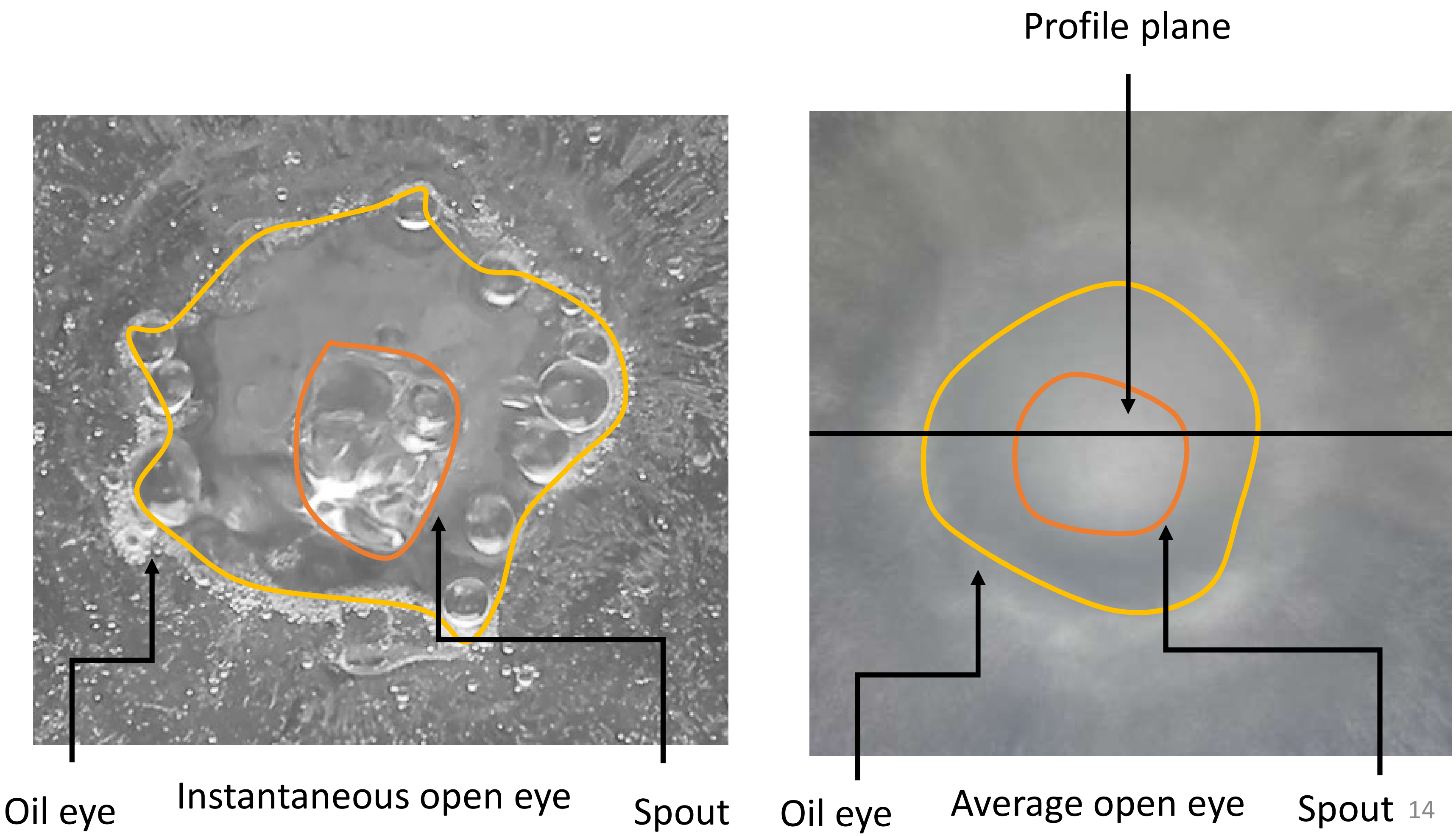


Process simulation – Results

Evolution of kinetic energy with time

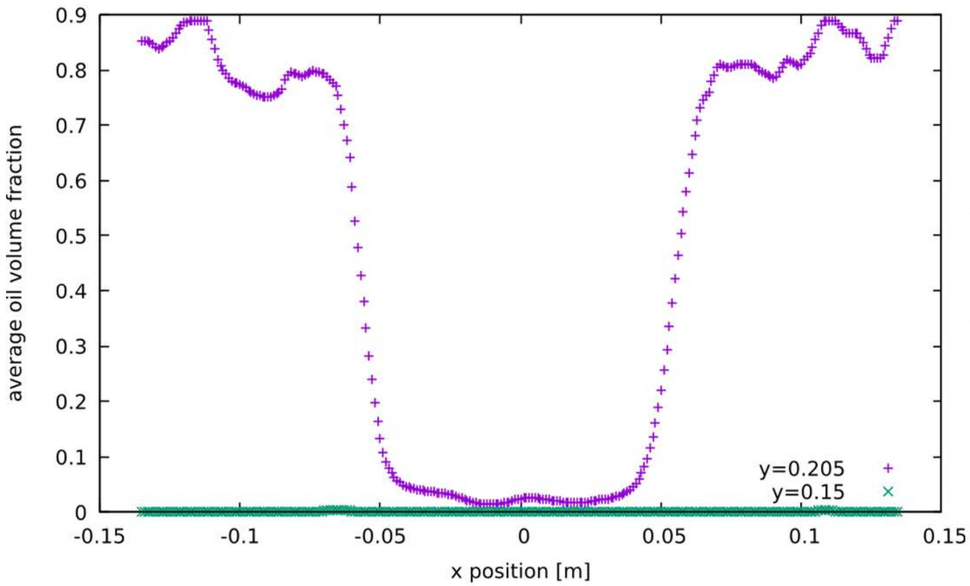


Process experimental visualisation - Open eye

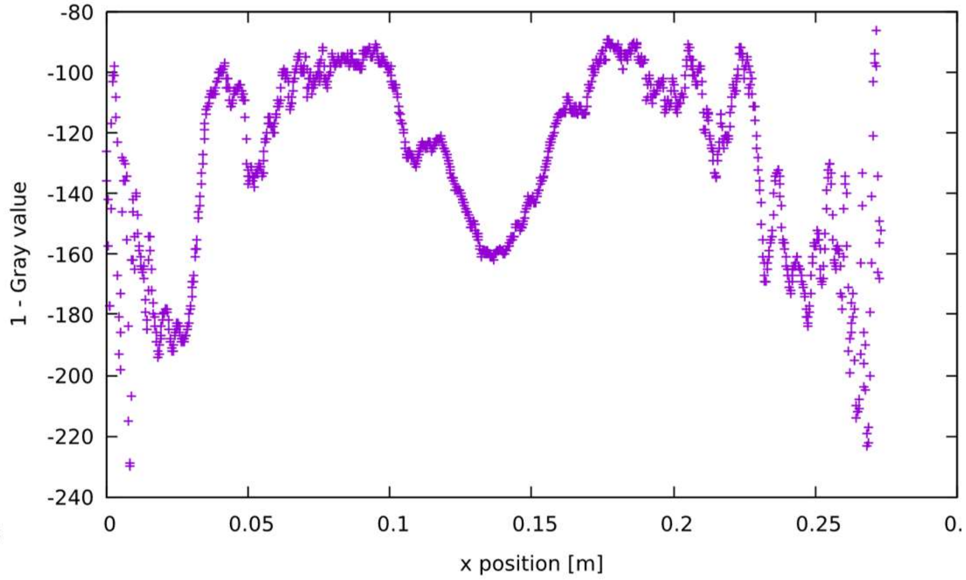


Comparison of numerical and experimental – Results

Average oil volume fraction along x in the middle of the domain at t=3.4s



Average open eye 1 - Gray value profile along x axis



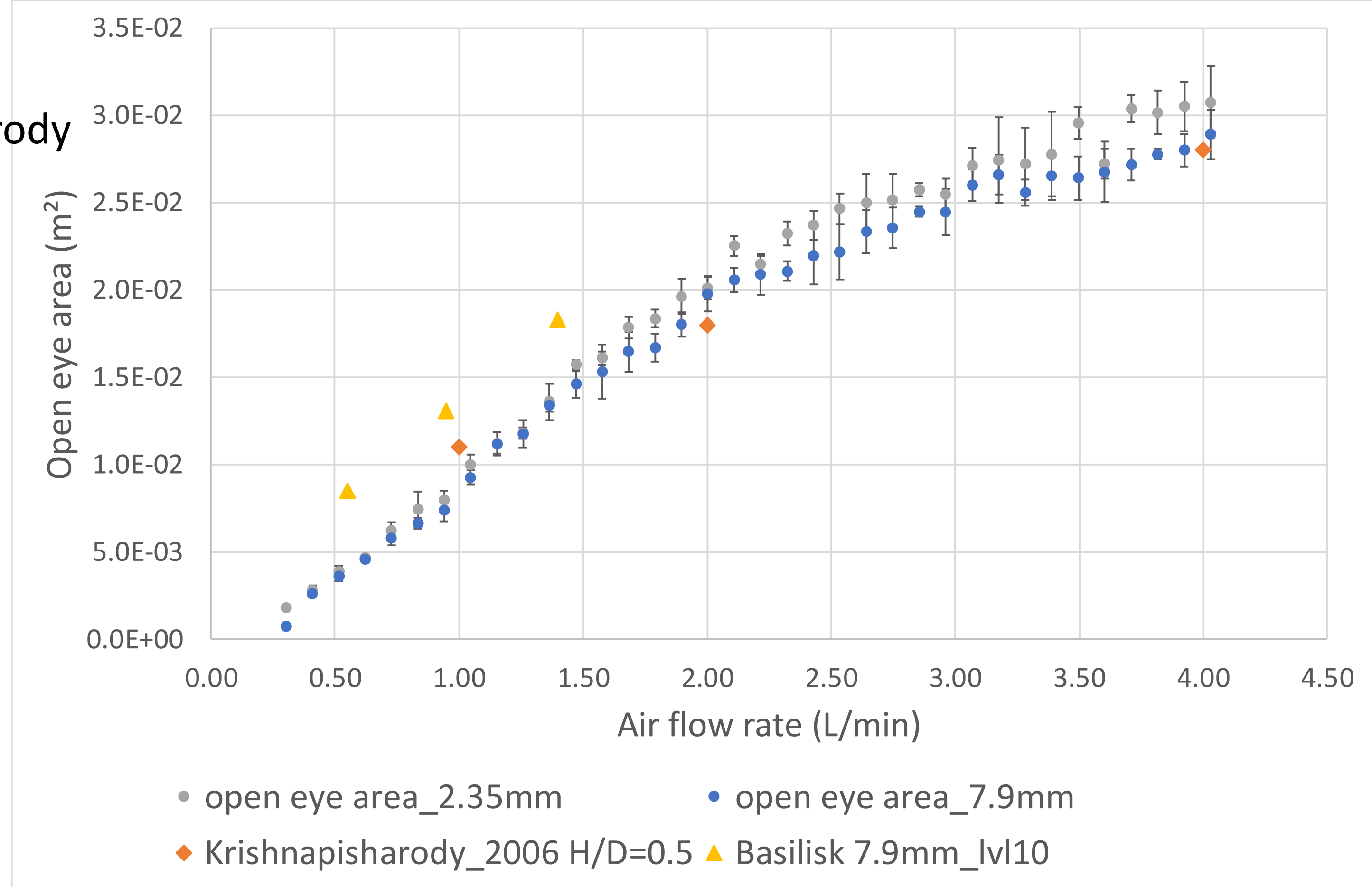
For now manual post-processing with 4 frames per gas flow rate

Comparison of numerical and experimental – Results

Open eye area comparison with literature and simulation:

Krishnapisharody et al. 2006 :
Density
870 kg/m3
Viscosity
0.065 kg/ms

Our model:
Density
920 kg/m³
Viscosity
0.079 kg/ms



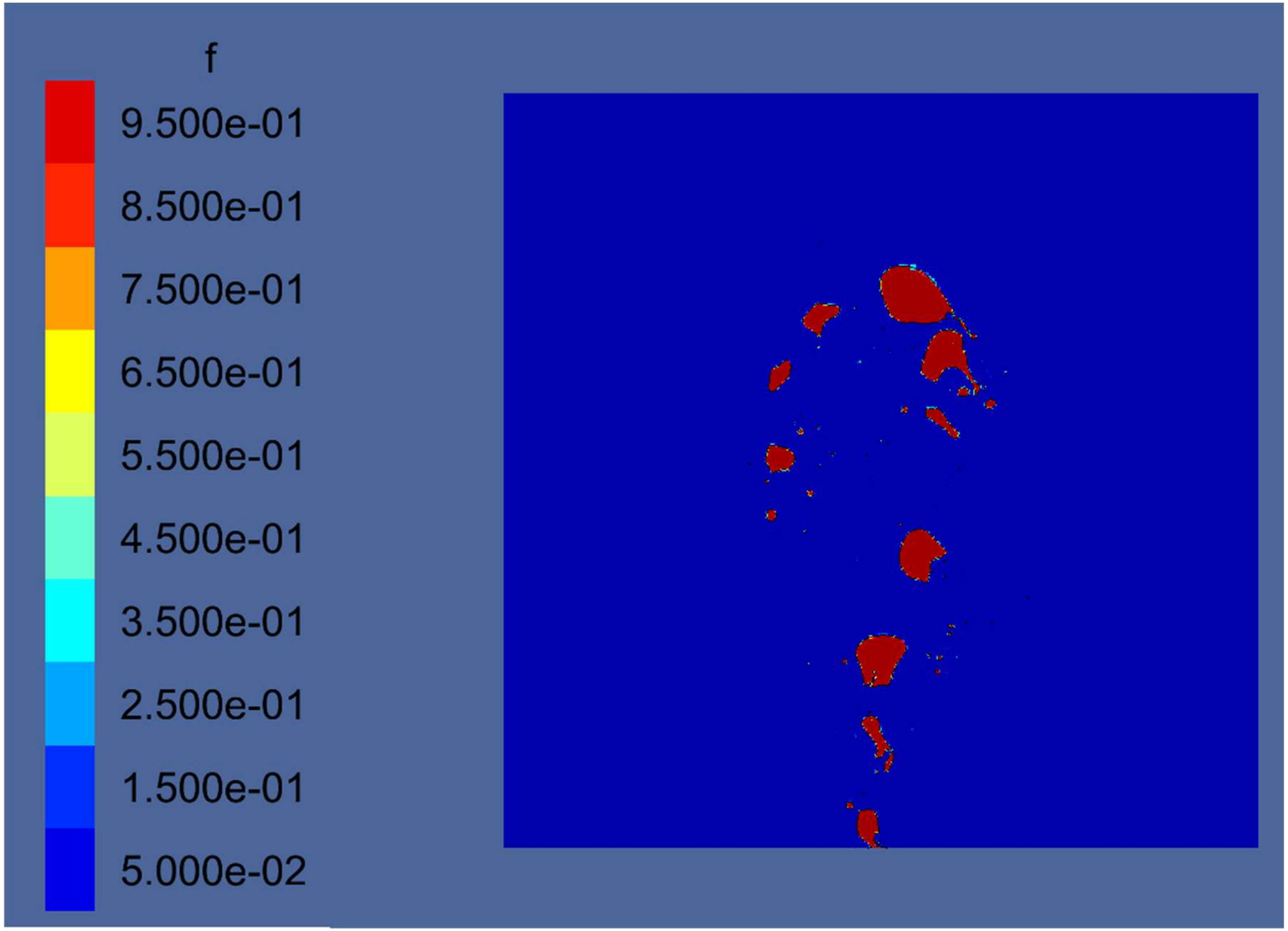
Conclusion

- Establish a simple workable three phase model with three surface tension values.

- Results comparison from simulations and from image analysis of the experiments gives reasonable agreement.

- Evaluate mass transfer of a chemical species between water and oil through different method.

Questions


f
9.500e-01
8.500e-01
7.500e-01
6.500e-01
5.500e-01
4.500e-01
3.500e-01
2.500e-01
1.500e-01
5.000e-02