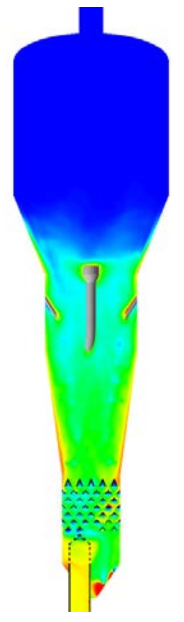
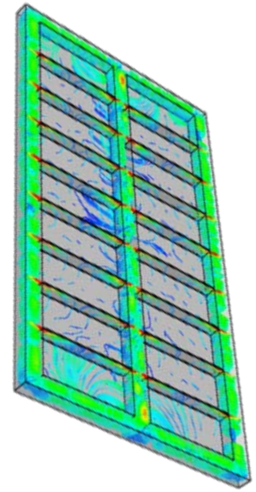
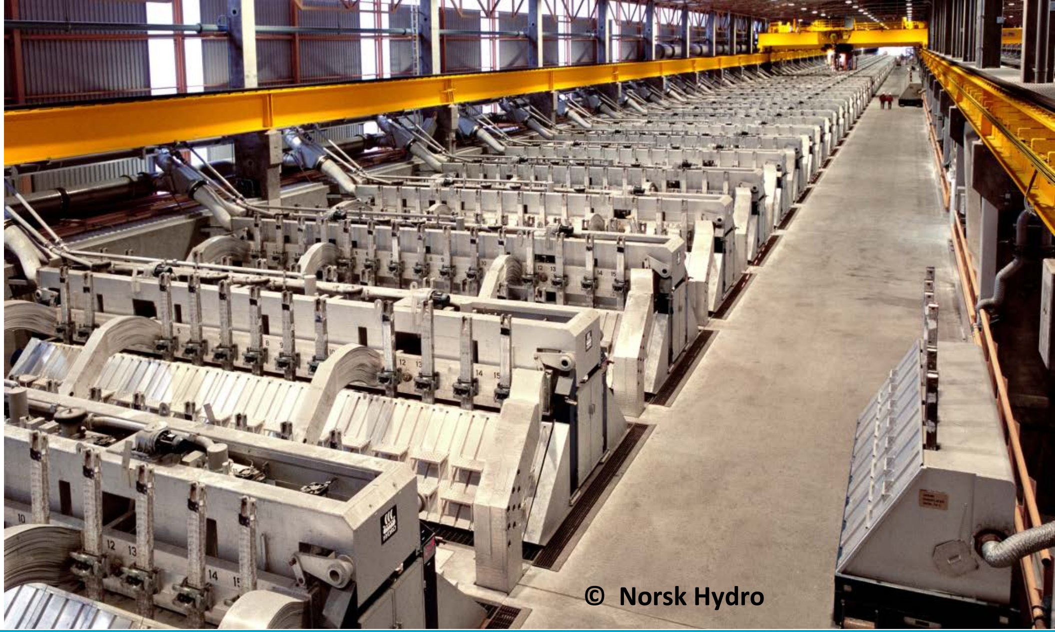


Multiphase CFD Modelling at CSIRO

Peter Witt[1], Yuqing Feng[1], Qinggong Wang[1,2] & Jon Boulanger[1]

[1]CSIRO Australia, [2]Tsinghua University, China

Peter Witt | Research Team Leader | Fluids Process Modelling

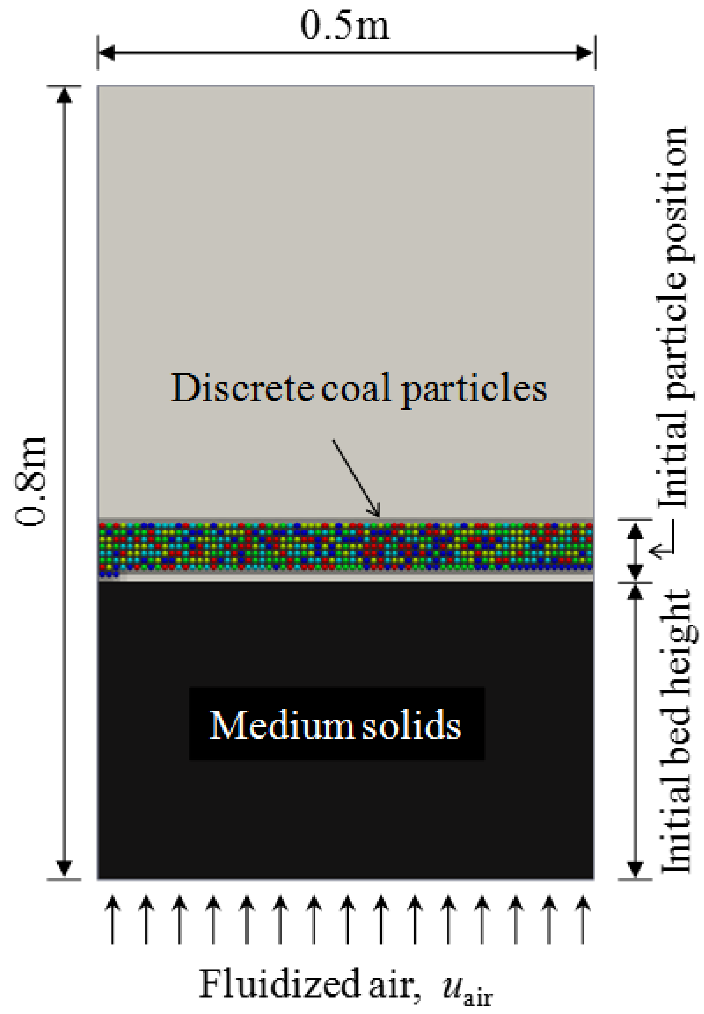
9 August 2016

Hybrid TFM-DEM

Coal Beneficiation Fluidised Bed

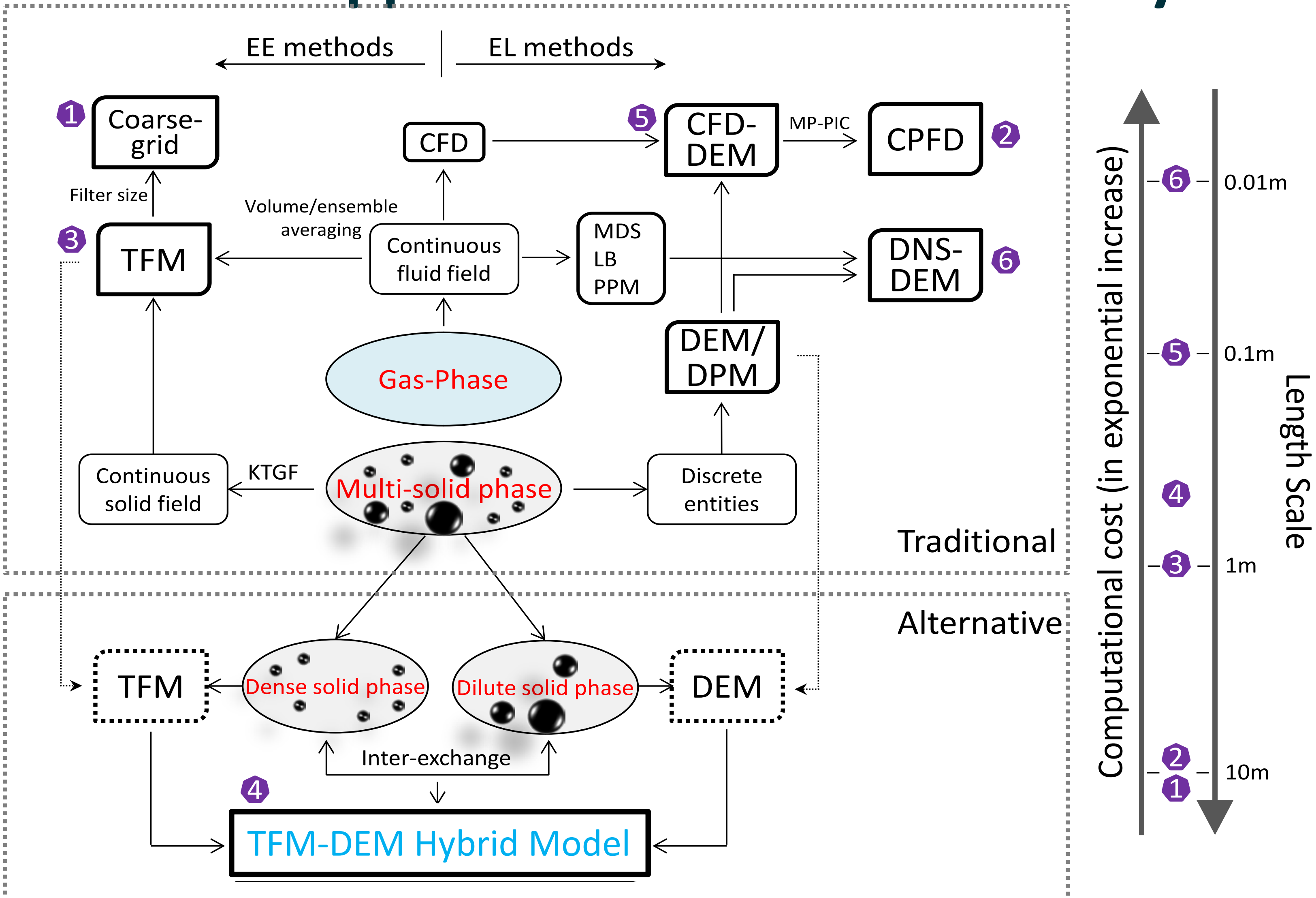
Coal Beneficiation Fluidized Bed

- Process for separating lighter coal from denser gangue particles
- Magnetite bed material
  ρ = 4200 kg/m^3 ϕ=200µm
- Fluidized with air @ 25°C
- Coal ρ = 1400-2700 kg/m^3 ϕ=1.3-6.7m



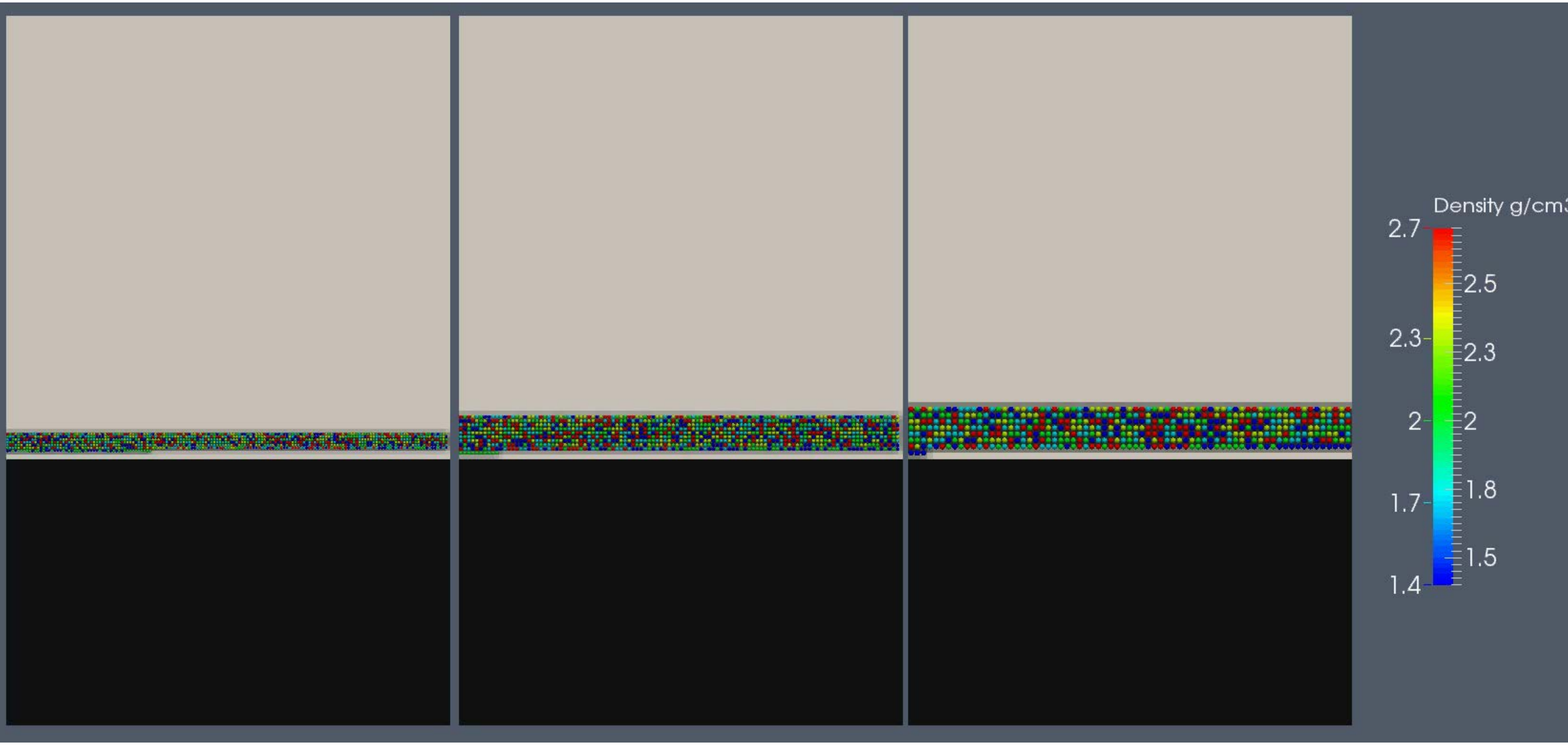
Qinggong Wang et al. (2015) Chem. Eng J. 260, 240-257

Numerical Approaches for Gas-Particle Systems



Segregation behaviour with coal diameter

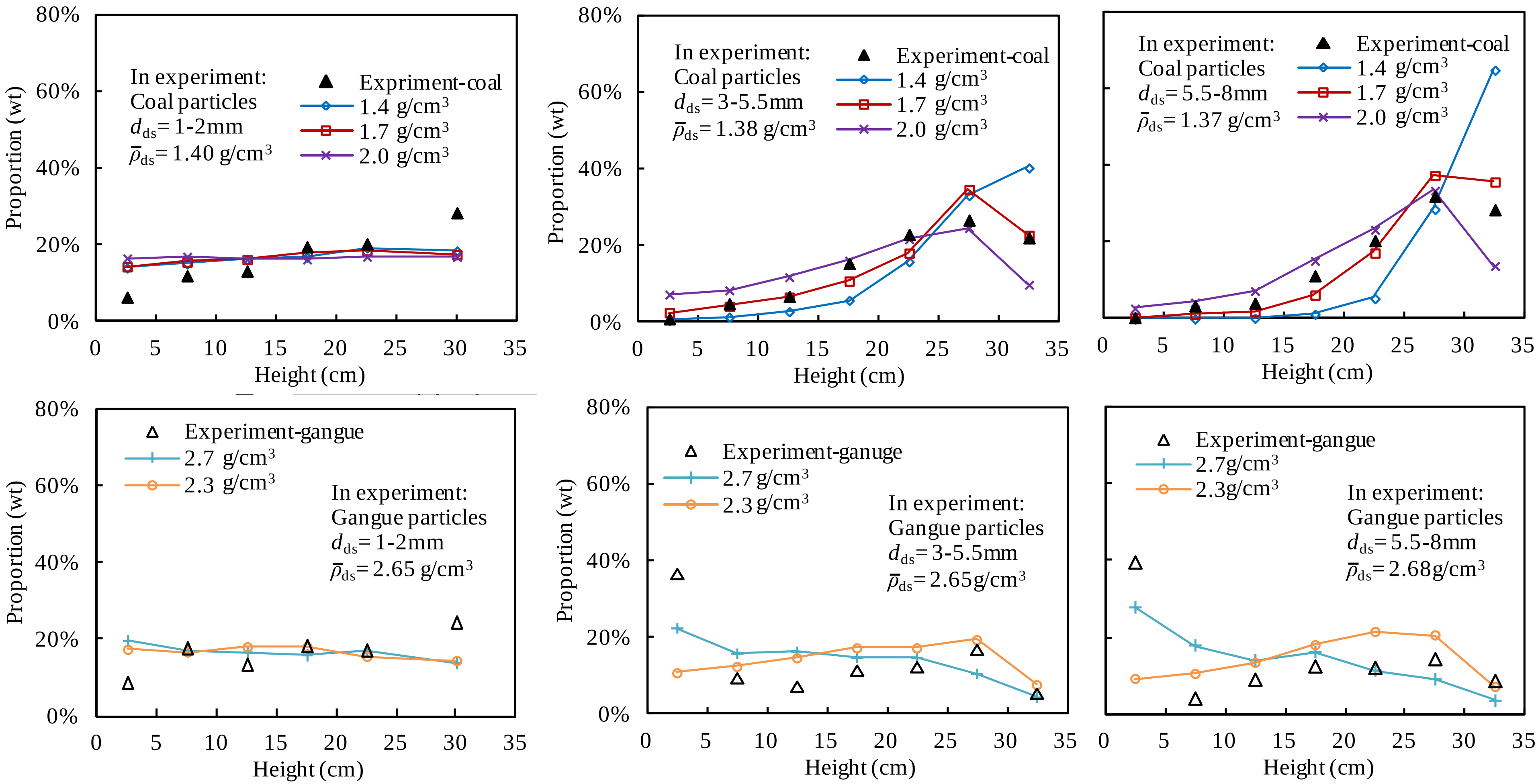
Coal particle ϕ3 mm | Coal particle ϕ4.3 mm | Coal particle ϕ6.7 mm



Air velocity 0.1 m/s = 1.5 U_{mf} | Bed of 200µm magnetite particles: ρ = 4200 kg/m^3

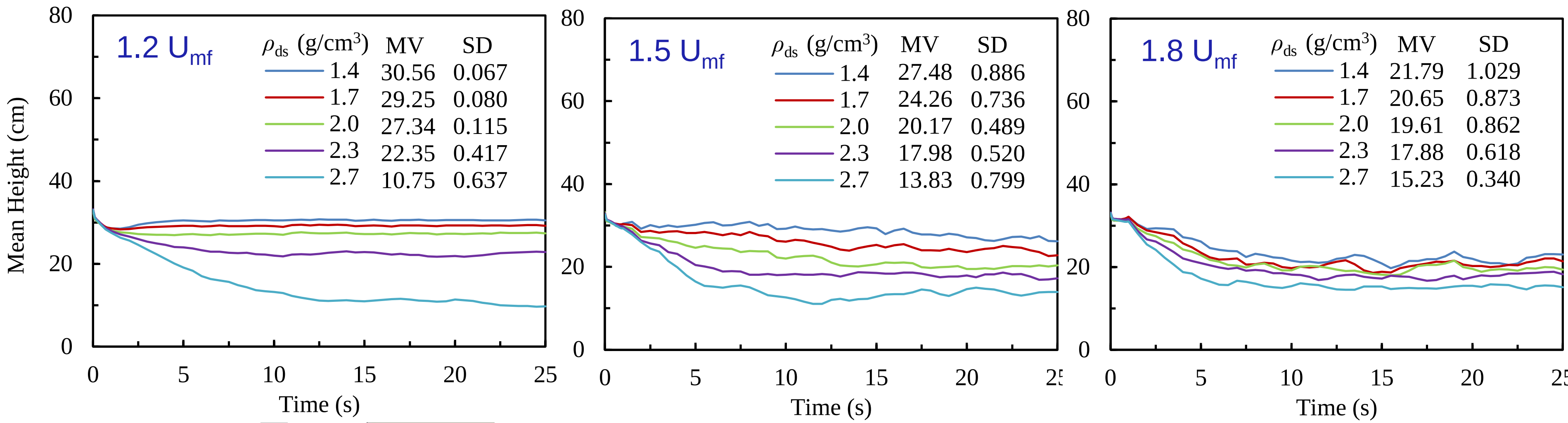
Qinggong Wang et al. (2015) Chem. Eng J. 260, 240-257

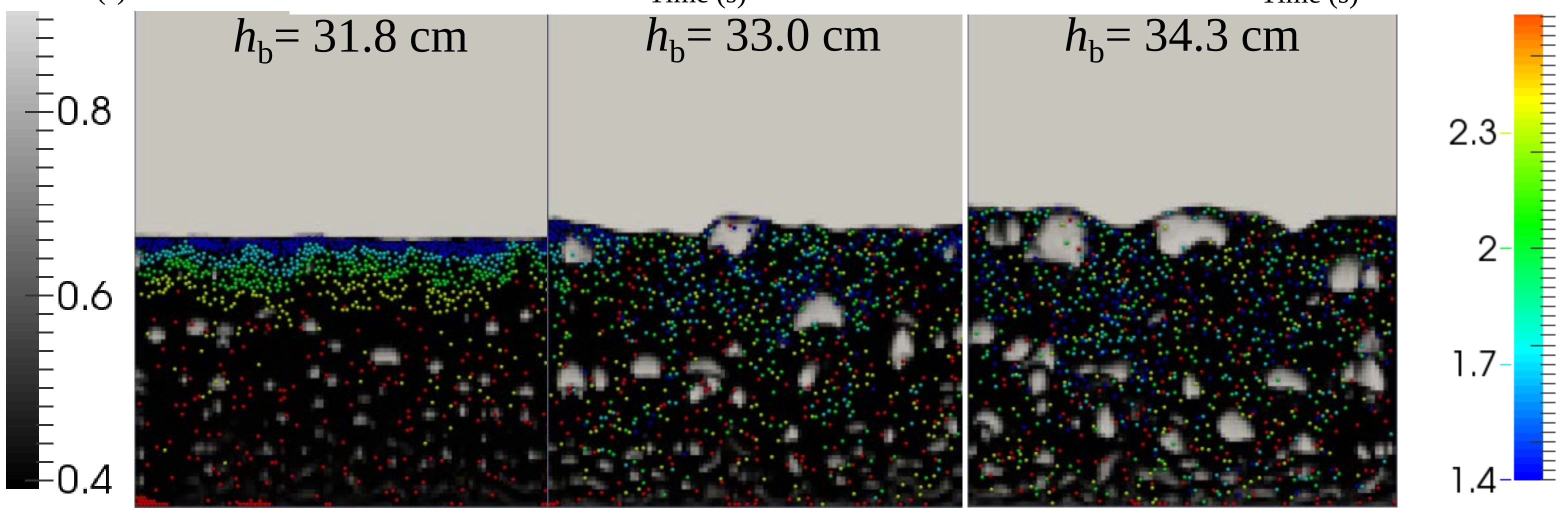
Predicted and Measured



Qinggong Wang et al. (2015) Chem. Eng J. 260, 240-257

Effect of fluidizing velocity



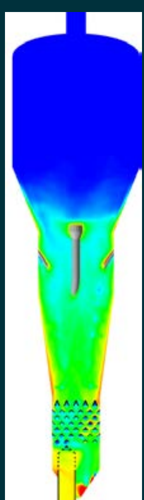


$1.2\ U_{mf}$ $1.5\ U_{mf}$ $1.8\ U_{mf}$

Qinggong Wang et al. (2015) Chem. Eng J. 260, 240-257

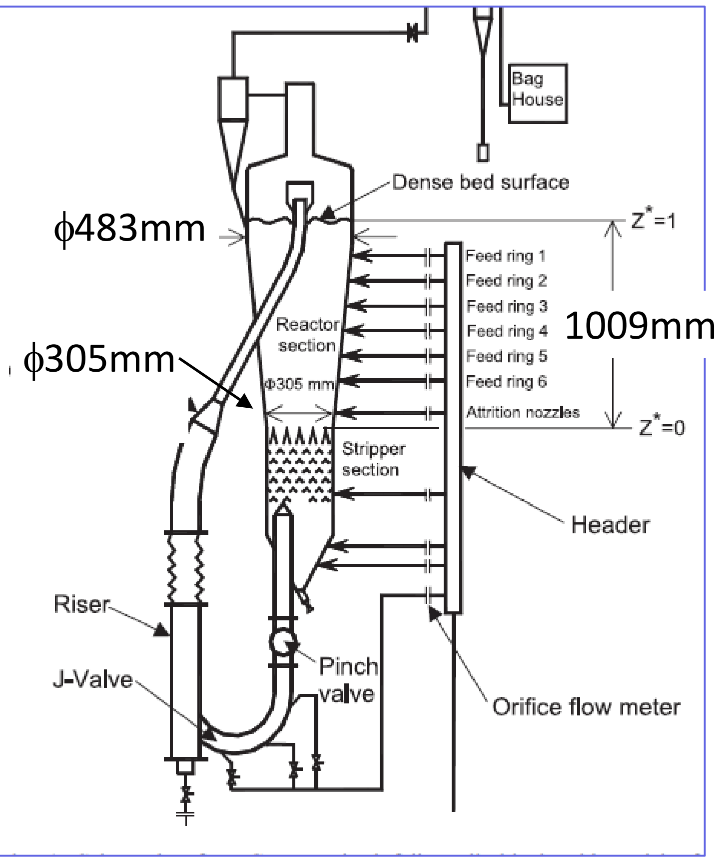
Fluidised Bed Coker

Coase Grain Modelling



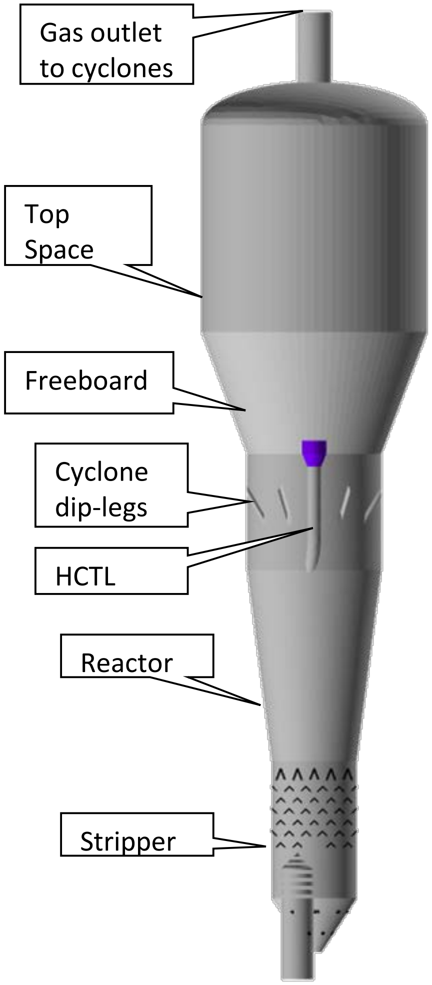
1/19th Scale Syncrude Coker Geometry & BCs

UBC Pressurised Cold Coker Model

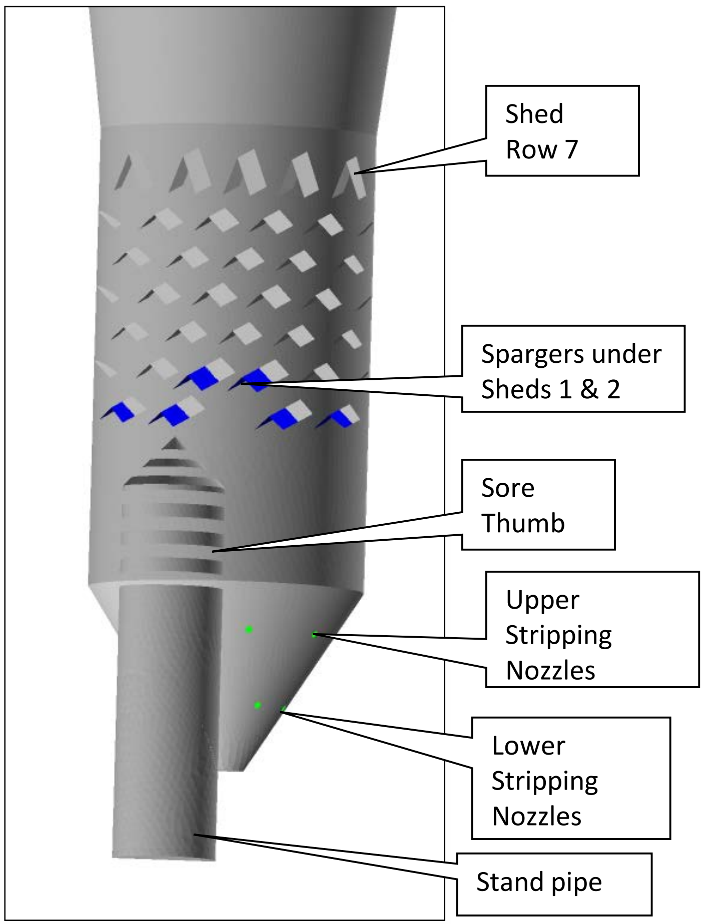


From Song et al. (2004) Powder Tech. 147, 126-136

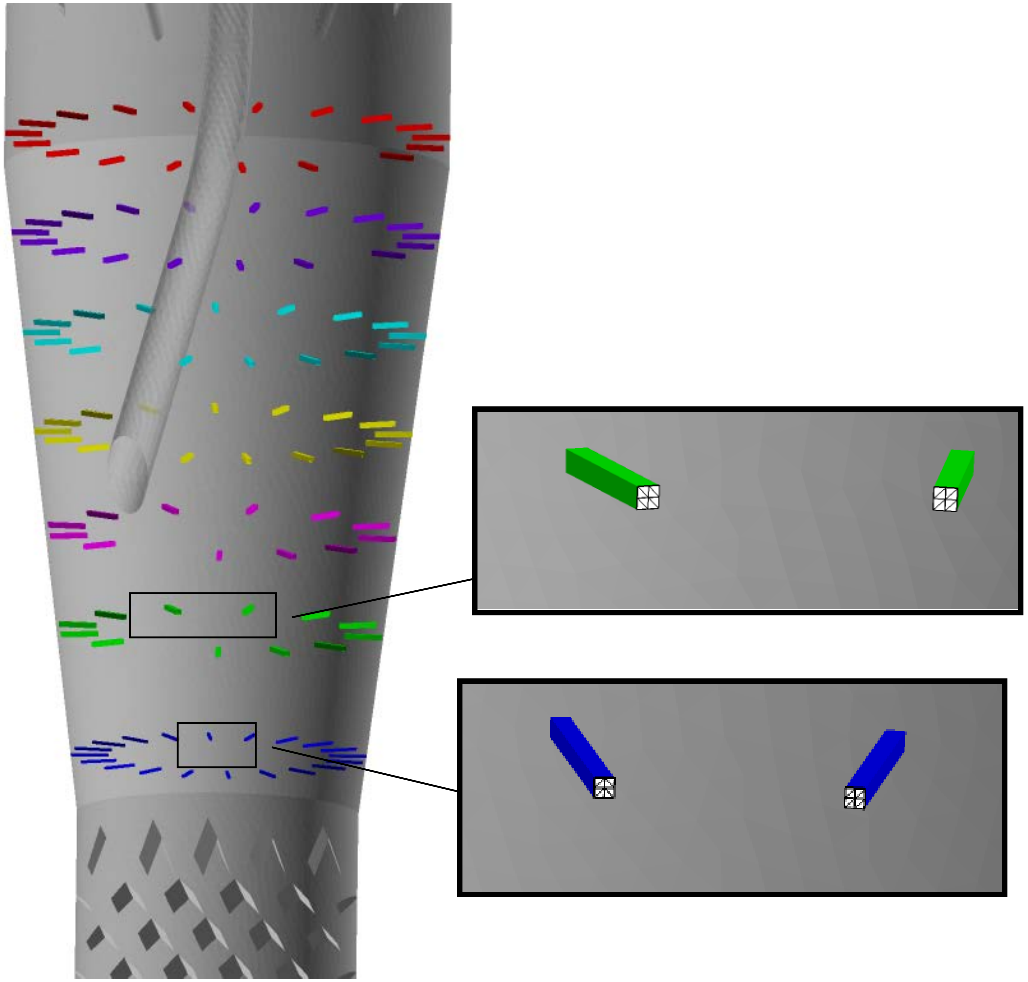
CFD Model Coker Geometry



CFD Model Stripper Geometry



Nozzle treatment - Resolved



- Six levels of feed nozzles
- Total of 92 feed nozzles
- 5.5mm square section

- 20 attrition nozzle
- 3mm square section

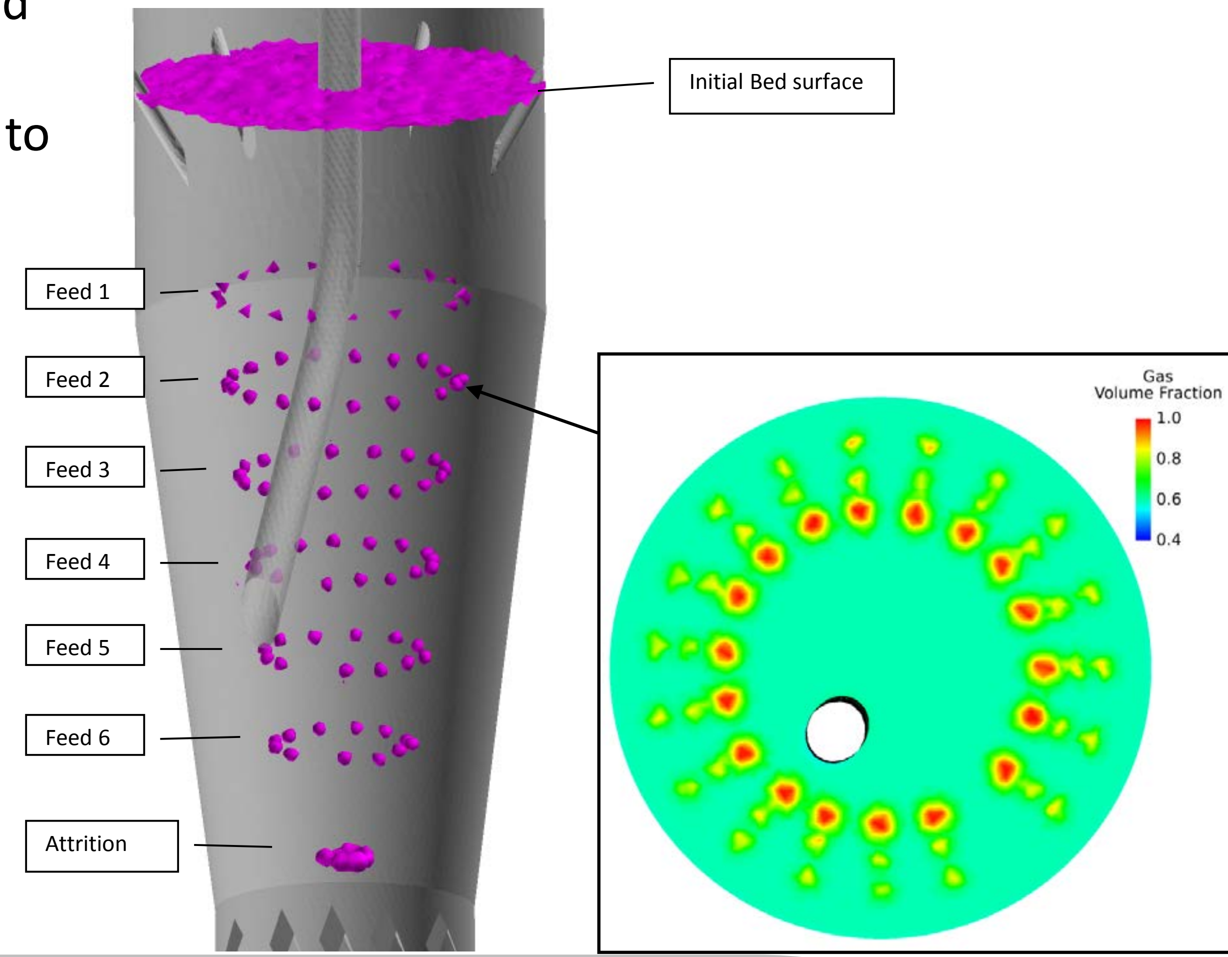
- Mesh not good resolution of nozzle exit

Nozzle treatment – Sources

- Nozzles not resolved
- Mass and momentum added using source terms
- Merry jet penetration used to calculate source location

$$\frac{L}{d_o} = 5.25\left[\frac{\rho_o u_o^2}{(1-\alpha_g)\rho_s g d_p}\right]^{0.4}\left(\frac{\rho_g}{\rho_s}\right)^{0.2}\left(\frac{d_p}{d_o}\right)^{0.2} - 4.5$$

- Jet length taken as 58% of Merry length
- Based on Li (2009) GLAB report
- Distributed along length of jet
  mass : 15%, 15%, 70%
  mom : 40%, 50%, 10%



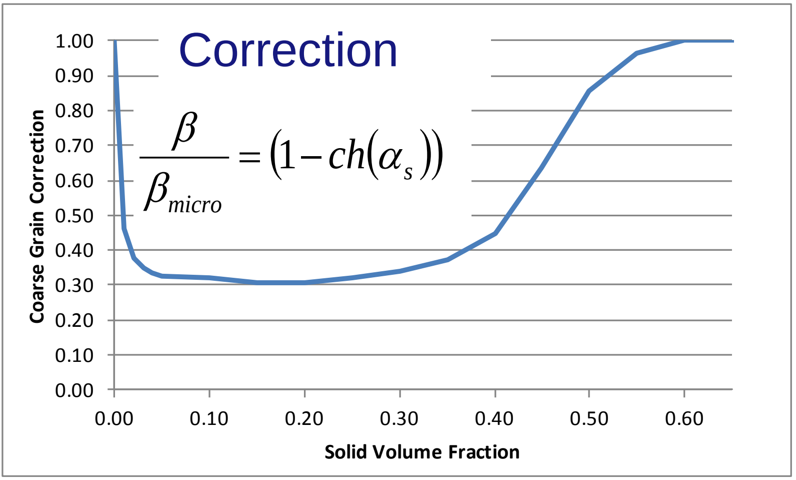
Stage 2 – Coarse Grain Model - Drag

- Coarse grain model of Igci-Sundaresan.
- Corrections to drag, solids viscosity and solid pressure to account for sub-grid clustering effects

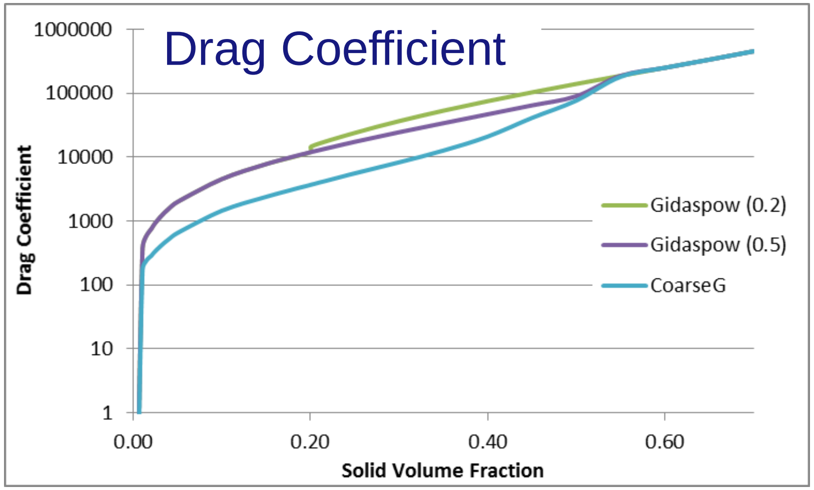
$$\beta = \beta_{micro}\left[1-\frac{Fr_{filter}^{-1.6}}{Fr_{filter}^{-1.6}+0.4}h(\alpha_s)\right]$$

$h()$ is a complex function of volume fraction
Fr_{filter} is Froude number based on filter length

Where β_{micro} is the micro-scale drag term, Gidaspow model used here.

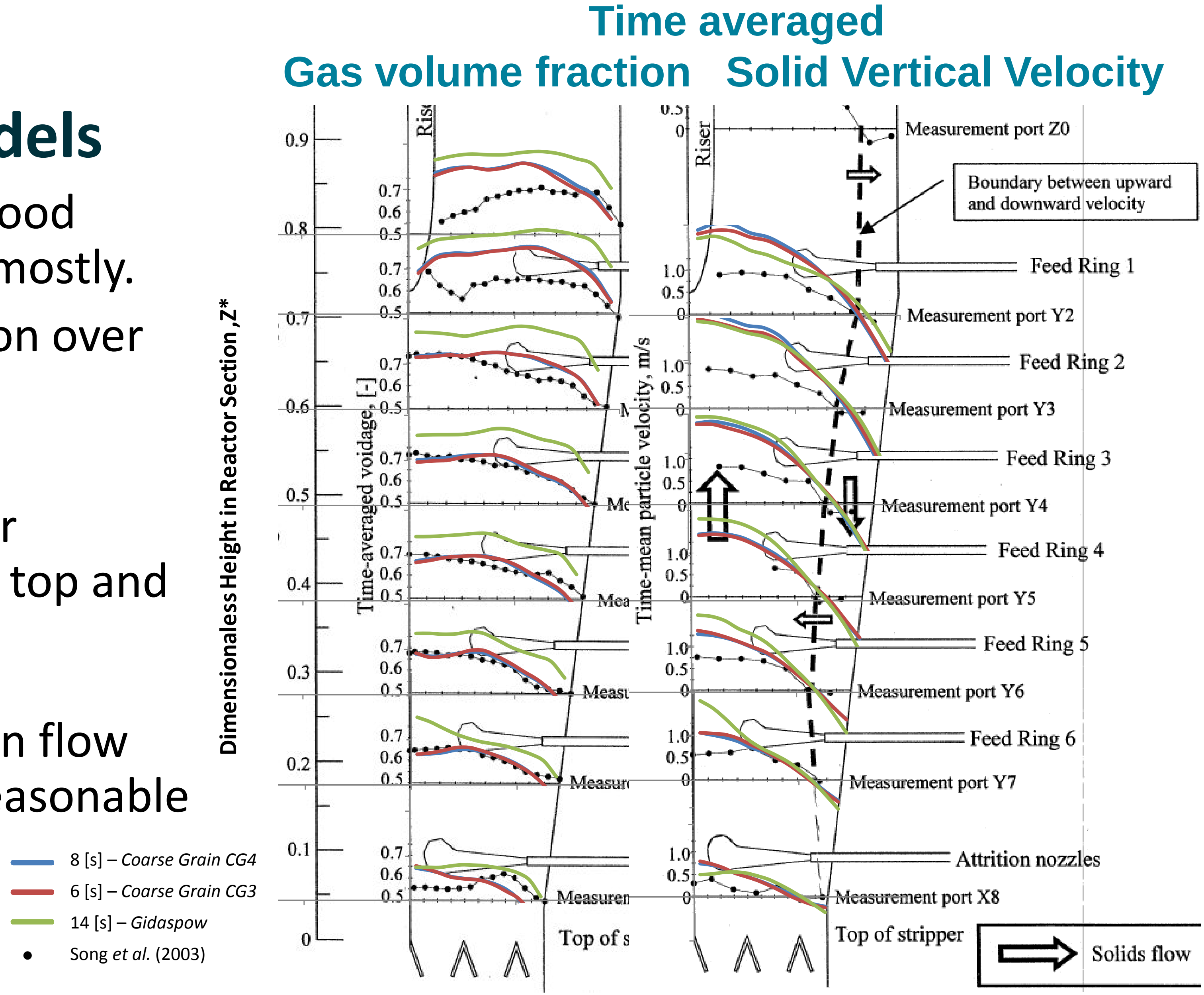


Igci, Pannala, Benyahia & Sundaresan (2012)



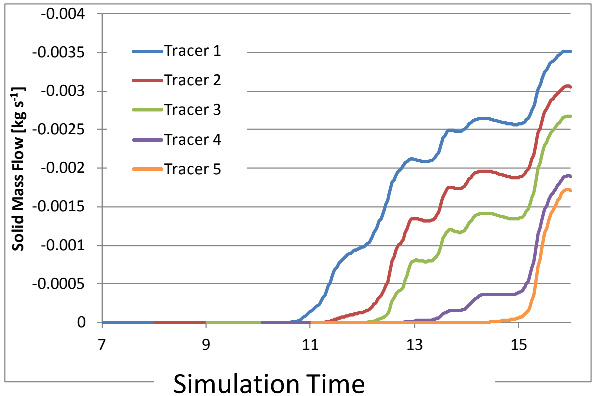
Results – Drag Models

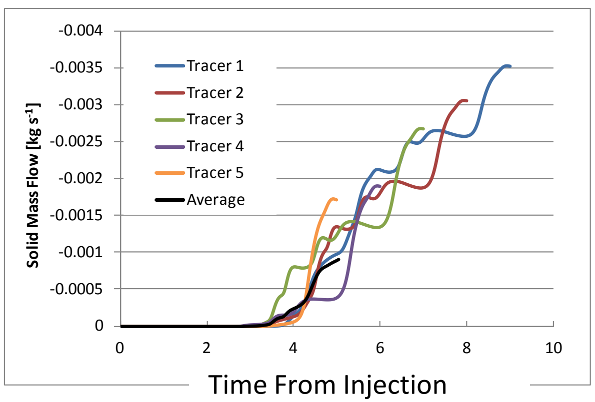
- Voidage – Good agreement mostly.
- Upper section over predicted
- Velocity over predicted in top and centre
- Up and down flow boundary reasonable



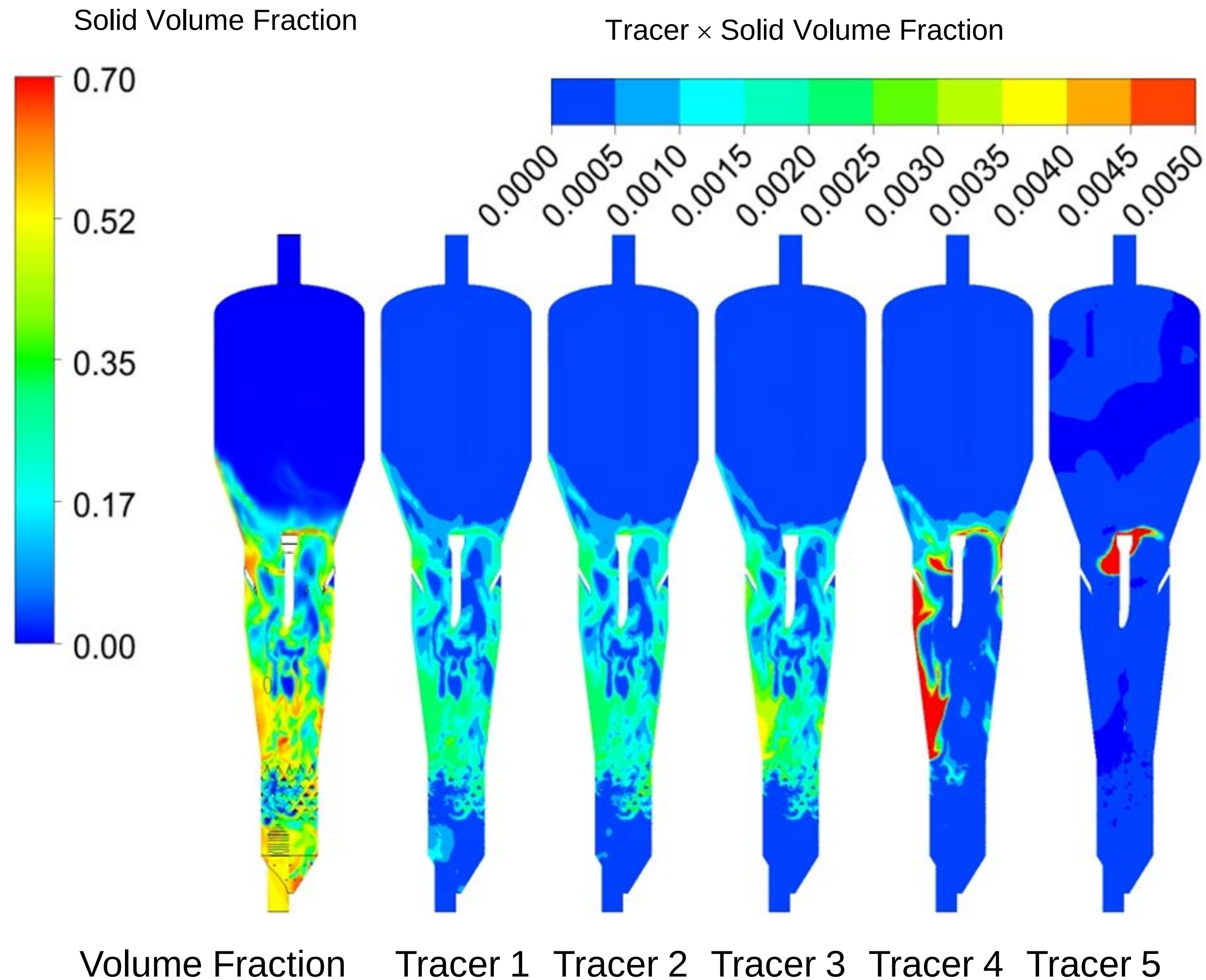
Solid Tracers

Solid Tracer at standpipe

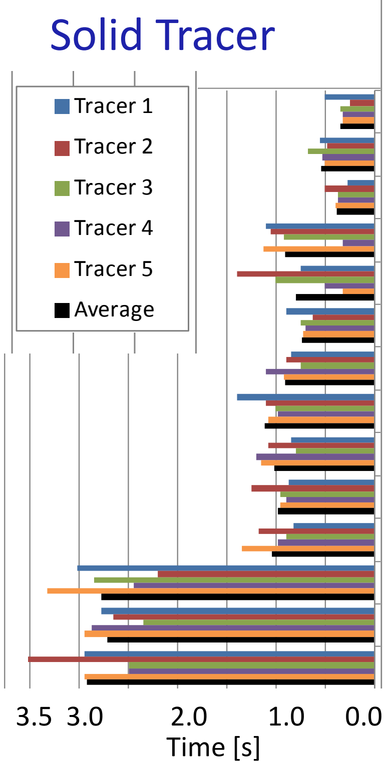


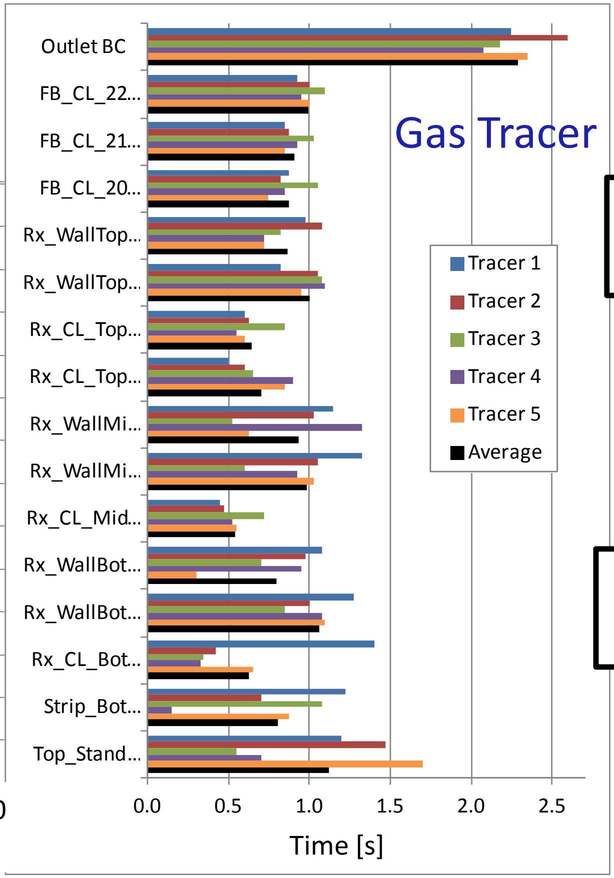


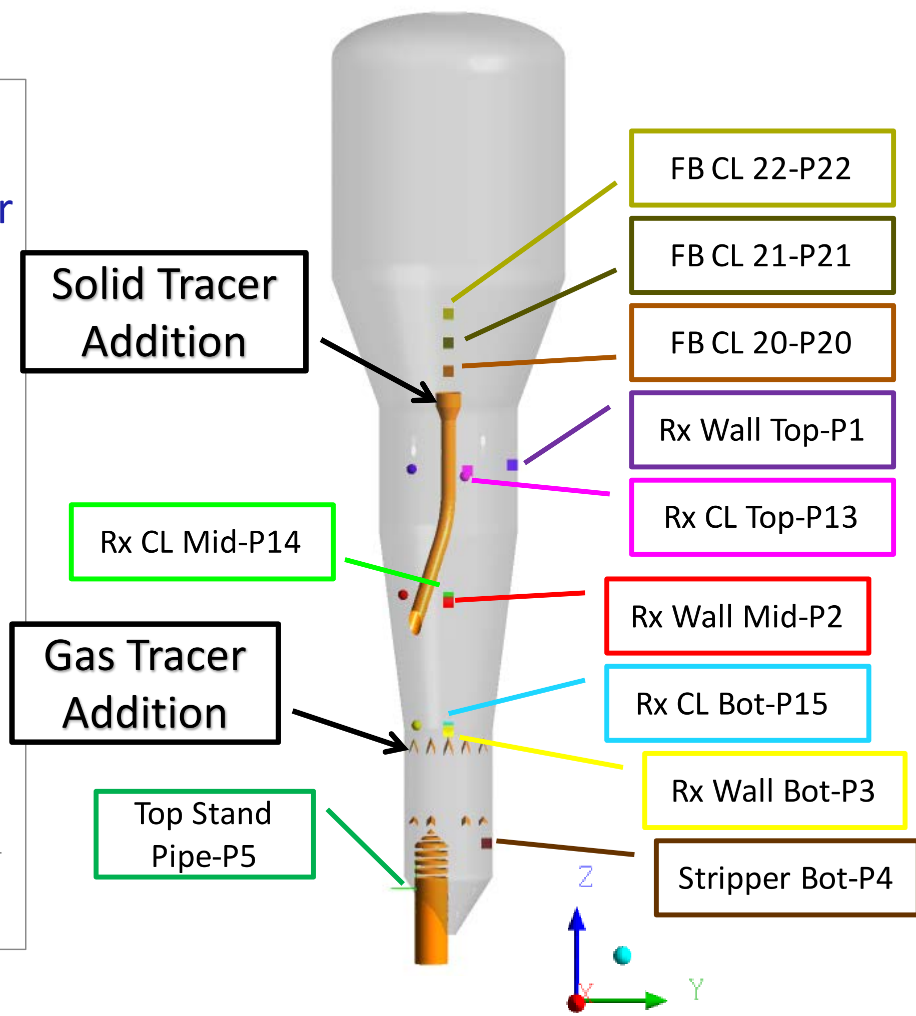
Gives average solid velocity of 1.6 [m/s]
c.f. measured velocity of 0.9 [m/s]



Tracer Residence Times







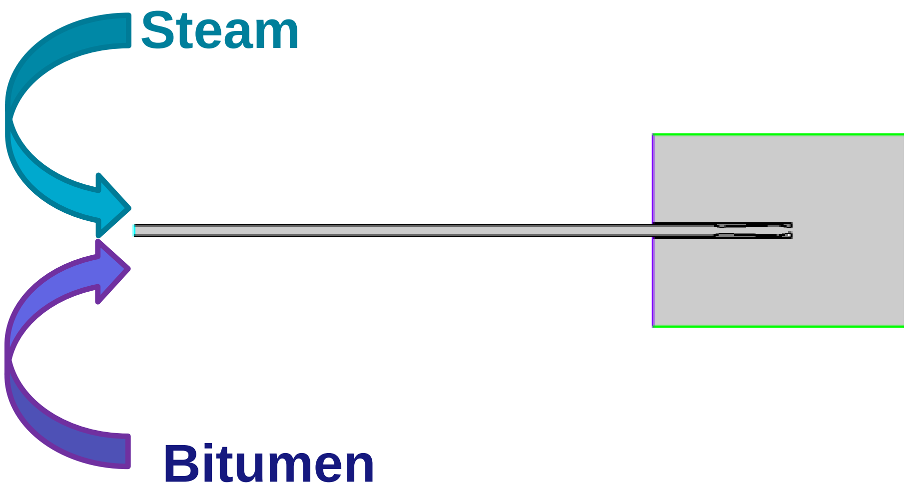
Tracer Break Through Times

	Tracer 1	Tracer 2	Tracer 3	Tracer 4	Tracer 5	Average
Solid Break through Time [s]	0.61	0.55	0.49	0.6	0.66	0.582
Gas Break through Time [s]	0.2	0.28	0.21	0.25	0.23	0.234

Gives average solid velocity of 1.6 [m/s] c.f. measured velocity of 0.9 [m/s]

Feed Nozzle Model

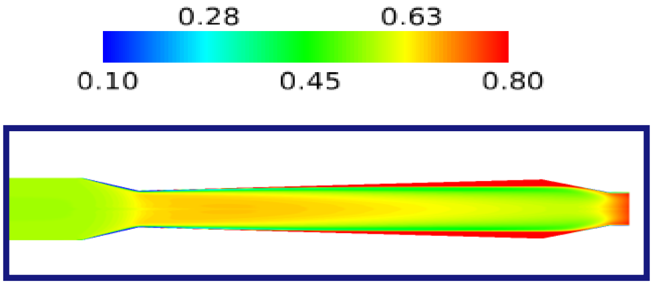
- 2D axi-symmetric
- 2 / 3 Phase
  steam / bitumen
  steam / bitumen / coke
- Phase inversion bubble to drops
- Number density model for bubble/drop diameter
- Based on work from UBC Pougatch *etal.*



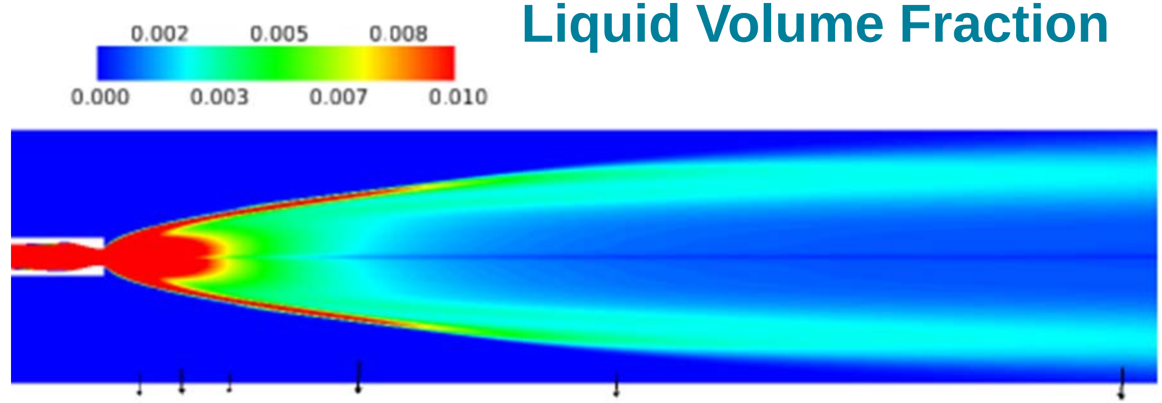
Feed Nozzle Model

Discharging into air

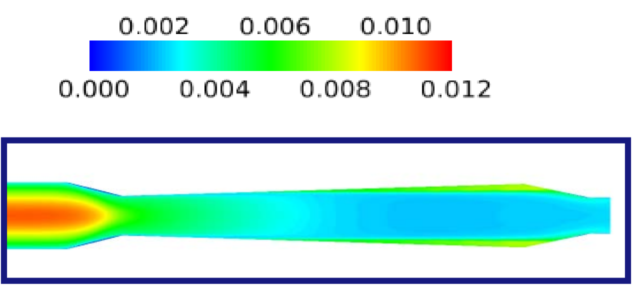
Gas Volume Fraction



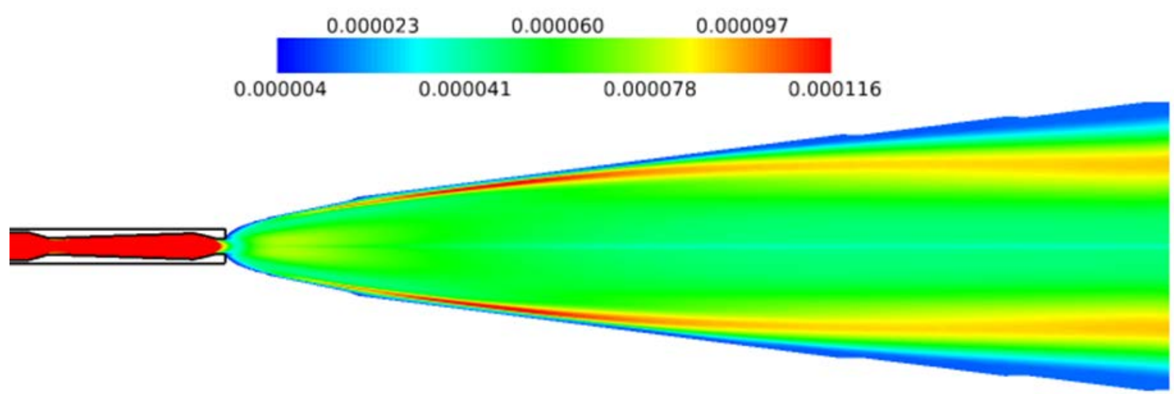
Liquid Volume Fraction



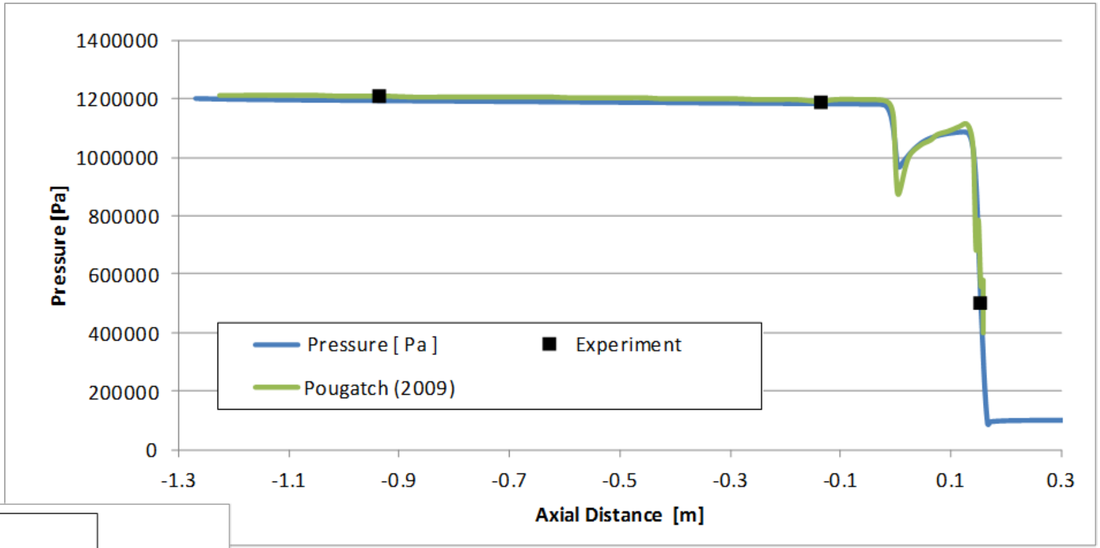
Bubble Diameter [m]

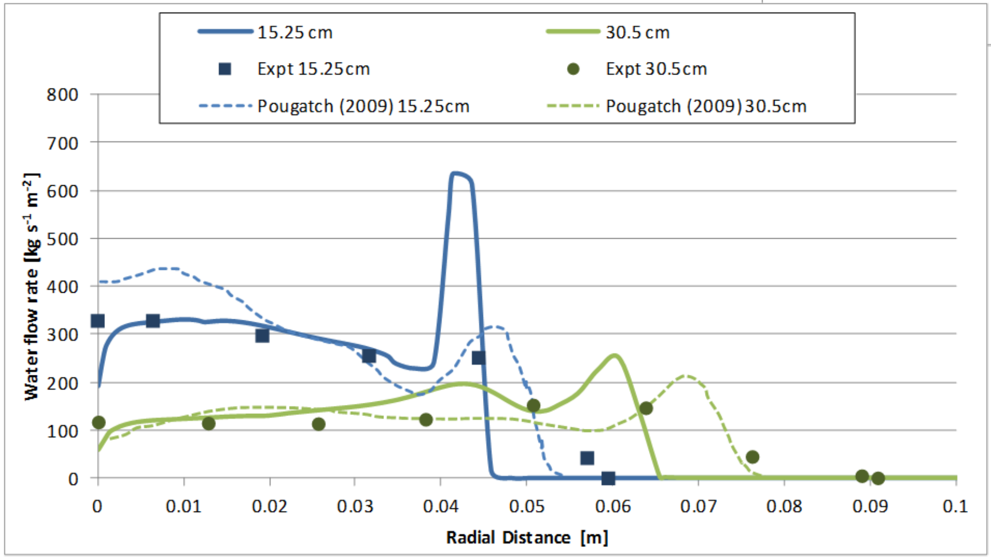


Drop Diameter [m]



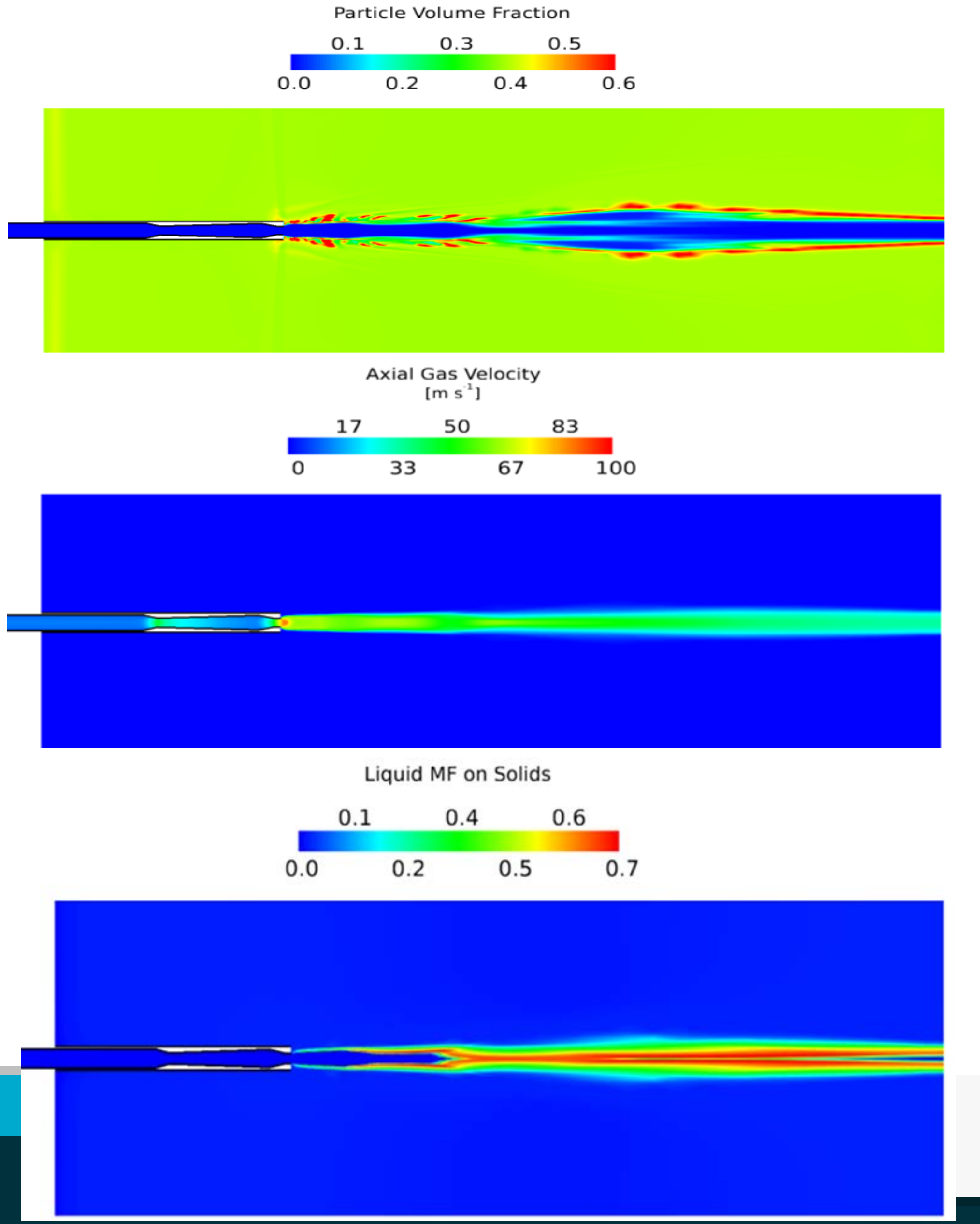
Comparison to Measurements





Feed Nozzle into a Fluidized Bed

- 2D model not really adequate
- 3D transient model needed
- Sources for momentum, gas and liquid deposition could be determined
- Sources used in full coker model to improve results



Thickener Modelling

Two phase slurry flow with Population Balance

AMIRA P266 Improved Thickener Technology

- Multi sponsor project over 20 yrs
- 21 Industrial Customers
- Over $750mil NPV savings
- Multiphase slurry flow
  - CFD & UVP measurements
- Flocculation Expt. & Population balance, CFD
- Slurry unified rheology:
  - Hindered settling
  - Sedimentation
  - Yield stress
- Raking
- Control

P266F Sponsors

ALCOA
Alunorte Alumina do Norte do Brasil S.A.
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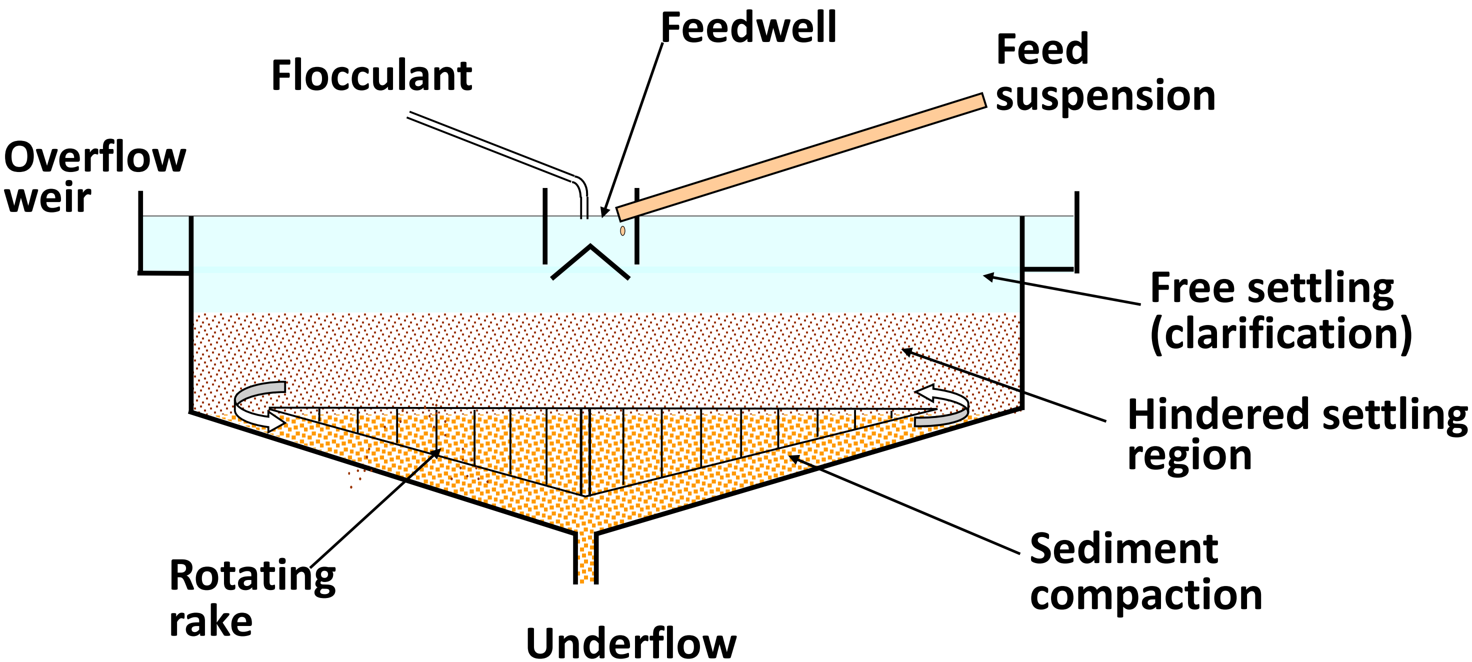
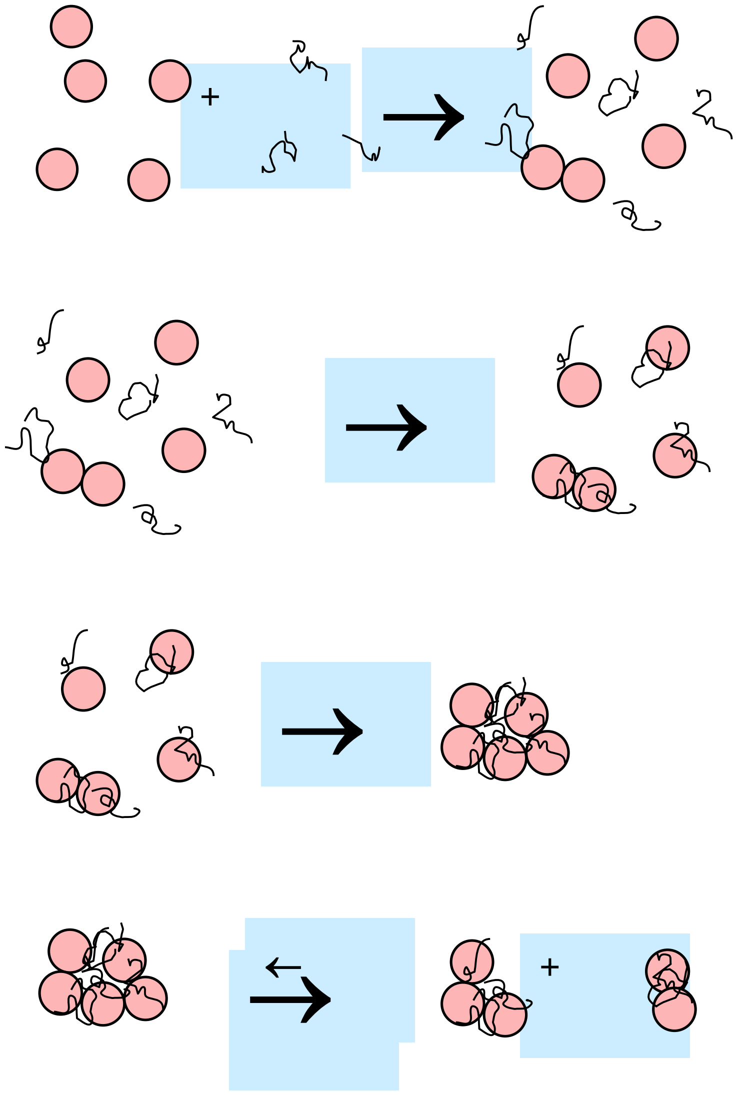
Freeport-McMoRan Copper & Gold
HATCH
metso
MMG
NALCO
Outotec
RioTinto
RUSAL Russian Aluminium Mill Products
Teck
TOTAL
WesTech Process Equipment. Process Driven.

Solid-liquid separation in thickener/clarifier



- Continuous gravity settling tank
- High solid underflow, clear overflow
- Feedwell dissipates feed momentum + mixing chamber to flocculate particles to increase settling rate.

Flocculation Process



Turbulent flocculant/particle mixing

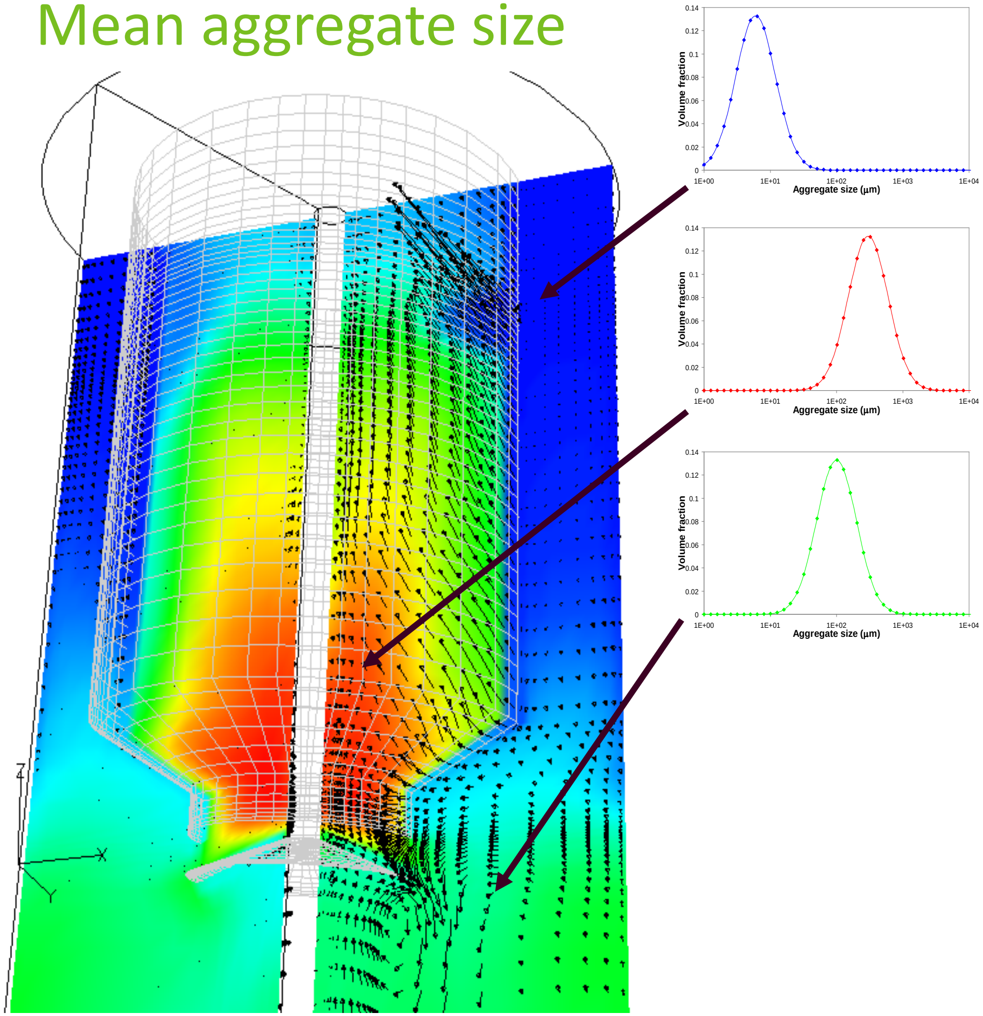
Flocculant adsorption (turbulent collision)

Aggregation (turbulent collision)

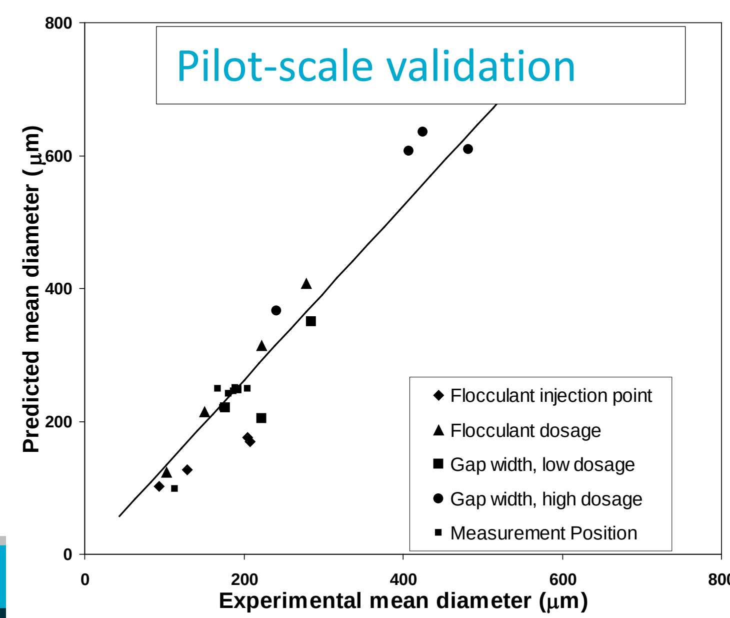
Breakage (turbulent shear)

Combined population balance & CFD model

Mean aggregate size



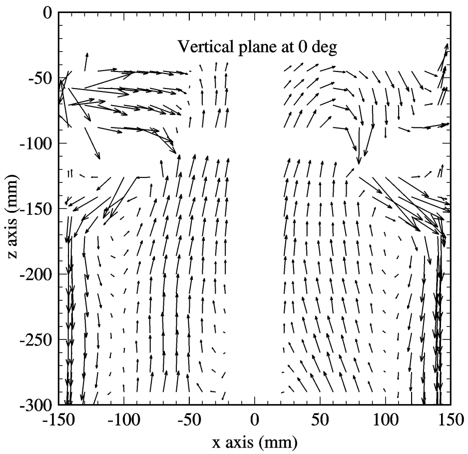
- Full PB size distribution in each cell
- ~100,000-500,000 nodes
- Coded as Fortran subroutine in CFX-4, CFX-5 & OpenFOAM
- Fully coupled to flow solution (viscosity, settling velocity, shear)
- Allows feedwell optimisation (geometry, flocculant addition point, dilution)

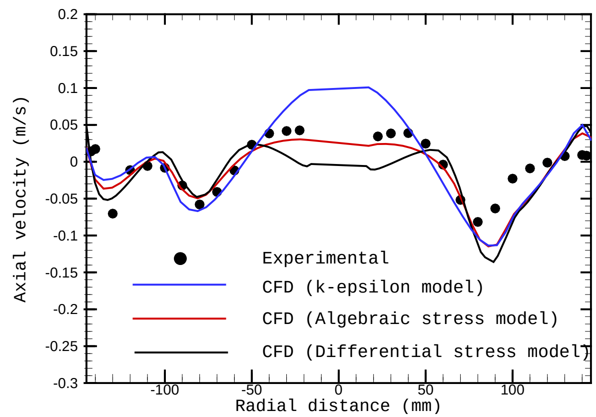


Nguyen, Heath, Witt, (2006), *5th Int. Conf. CFD in the Minerals and Process Industries*

CSIRO

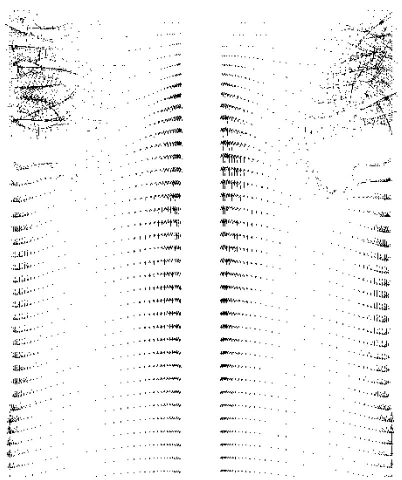
Feedwell sub-model validation

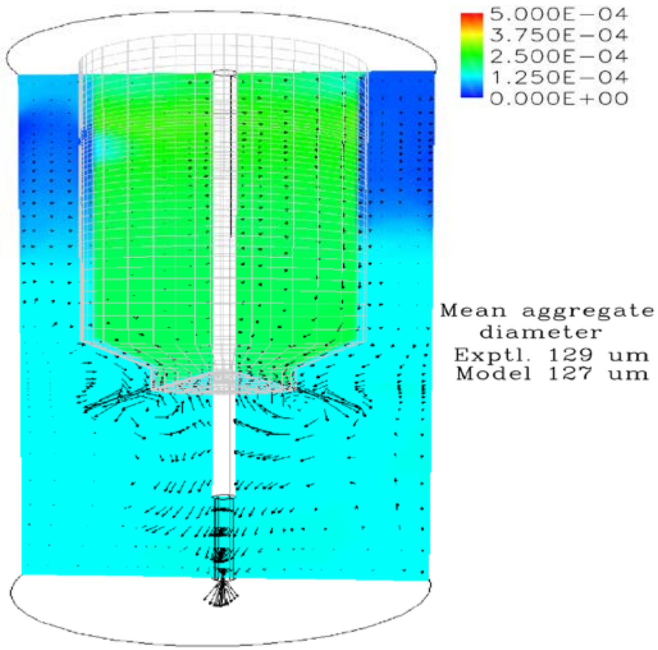




CFD simulation:

- very similar flow structures
- velocity profiles agree well



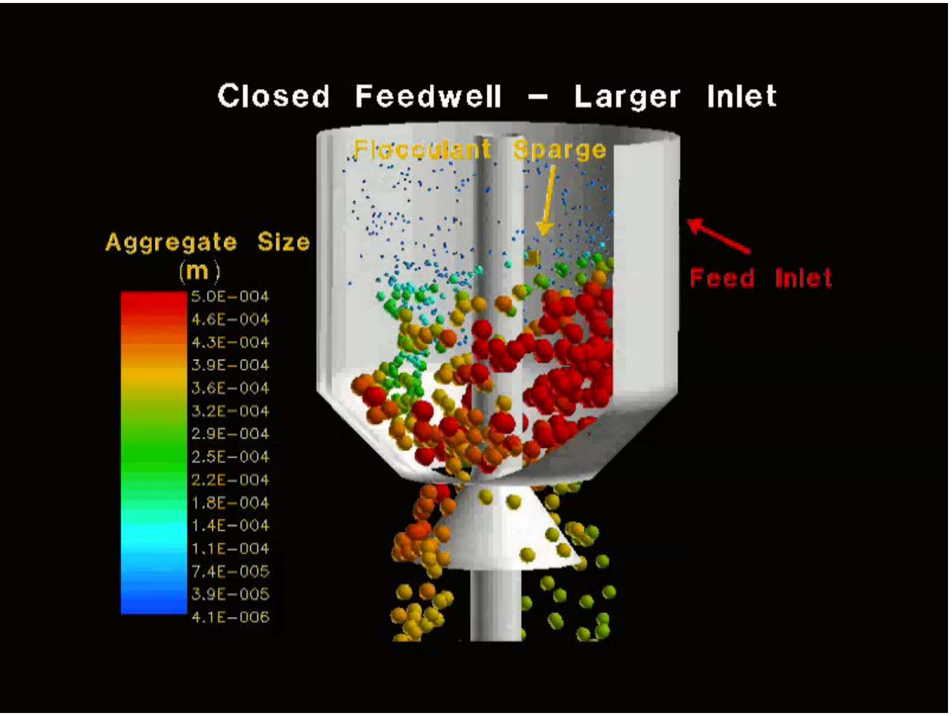


Aggregate size measured by Lasentec probe at feedwell outlet and compared to CFD prediction.

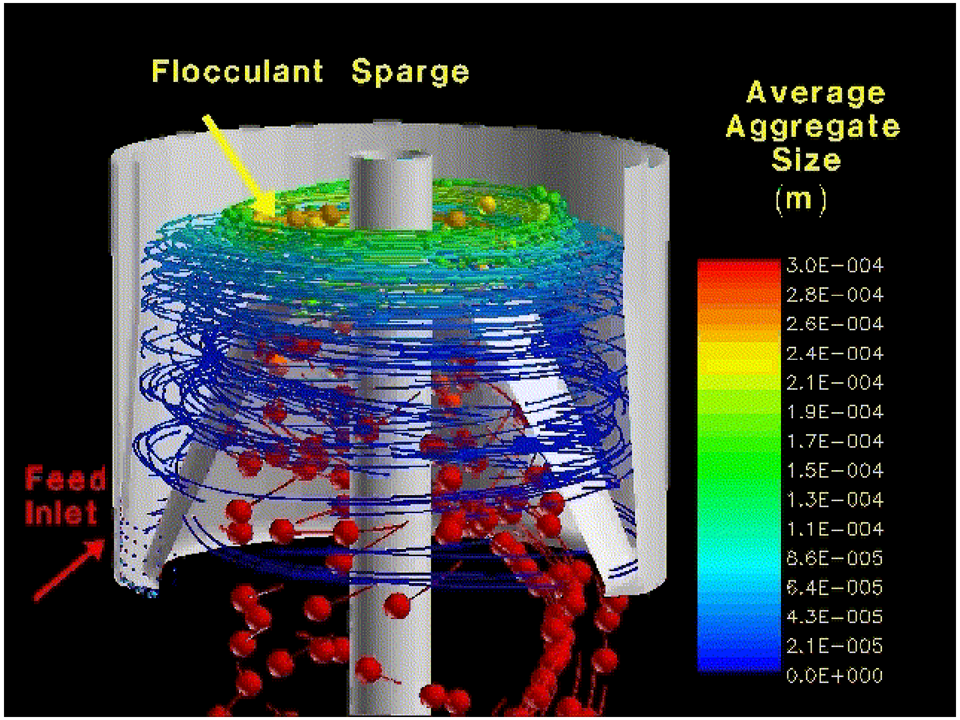
LDV time-averaged velocity measurements in a model feedwell

Feedwell Design Improvements

Closed feedwell – current design



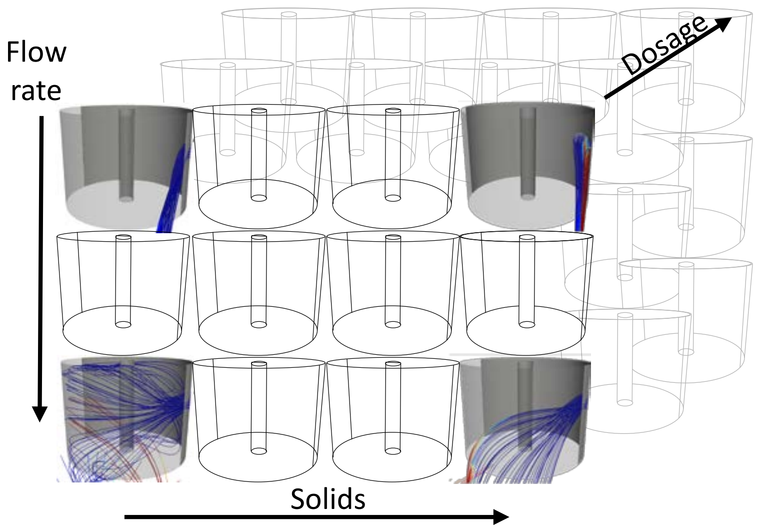
CSIRO Novel feedwell



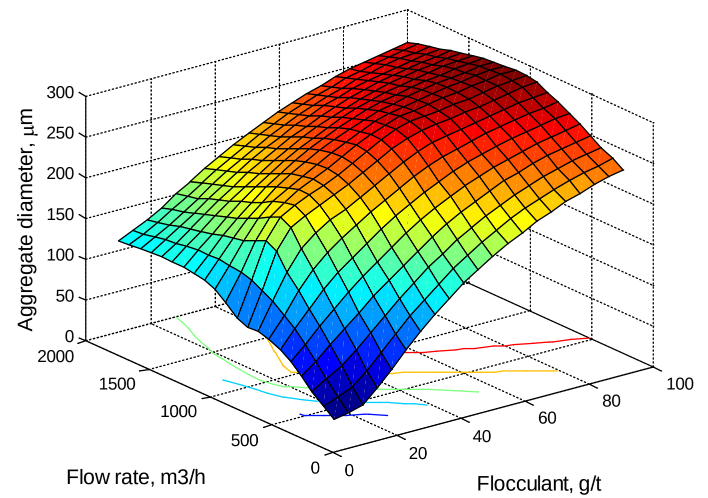
Main features:

- **New concept: separate zones for momentum dissipation and flocculation**
- **Ability to cope with wide range of feed variations**
- **Simple design and easy to manufacture and retrofit**

Potential for Control …



Carry out a matrix of CFD simulations

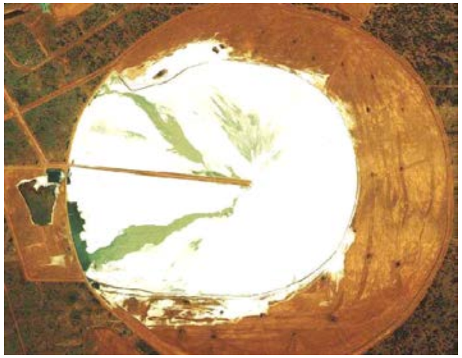


Develop surrogate models to cover the window of operating conditions

- **CFD is not being used for control.**
- **Interrogation of surrogates is simple/rapid.**

Interrogate surrogates as part of thickener control on the basis of monitored feed properties

Example 1-to-1 CFD (Sunrise Dam)



Problem:

- Paste thickener treating gold tailings that are then pumped to a central tailings discharge area.
- Low underflow density 55 wt%, low yield stress (7-12 Pa).
- Severely shear thinning; zero beach angle limits storage capacity.

Approach:

- CFD model used to determine factors limiting flocculation efficiency within the full-scale feedwell.

Recommendation:

- Install half-shelf and remove existing baffles.
- Add flocculant through two specific sparges locations.

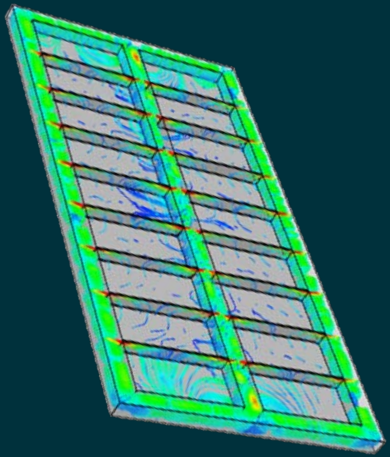
After:

- Underflow density increased to 60-66 wt%, gave beach angle 2°.
- Eliminated need to duplicate Tailings Storage Facility (saved $20 m).
- Increased water recovery, reduced flocculant dosage, reduced cyanide to tailings (saved >$0.15 m pa).

Images and outcomes courtesy of AngloGold Ashanti

Aluminium Electrolysis Process

Multi-phase & Multi-physics Modelling

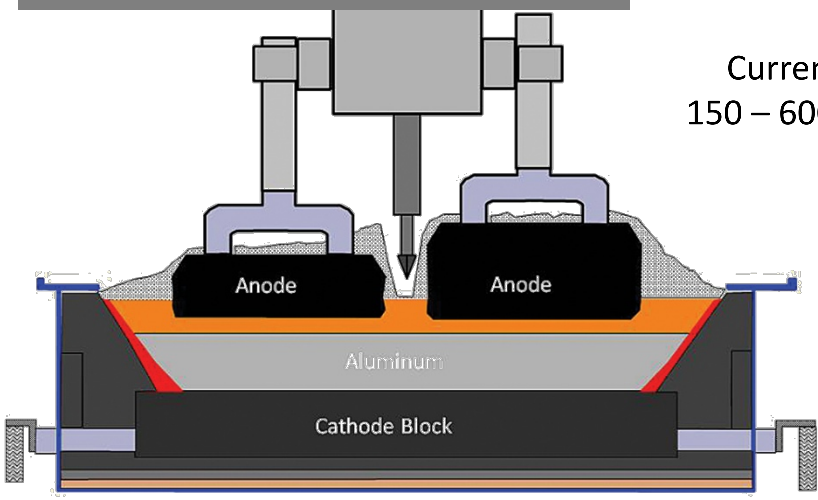


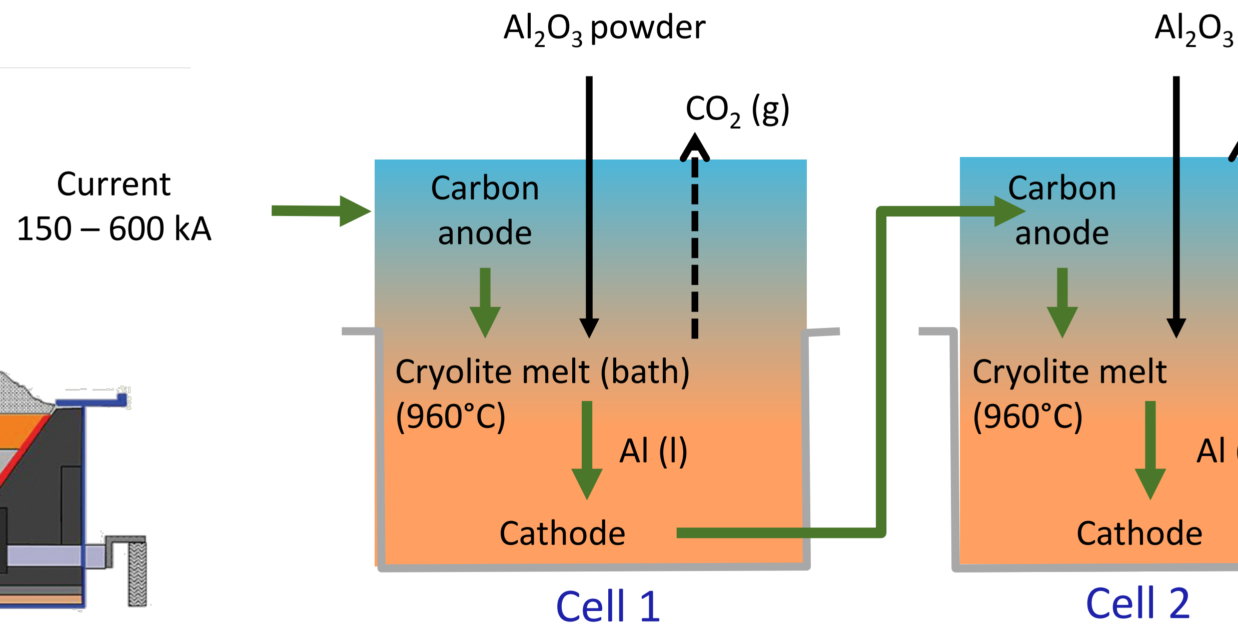
Reduction of Alumina to Al Metal

Aluminium Electrolysis Process

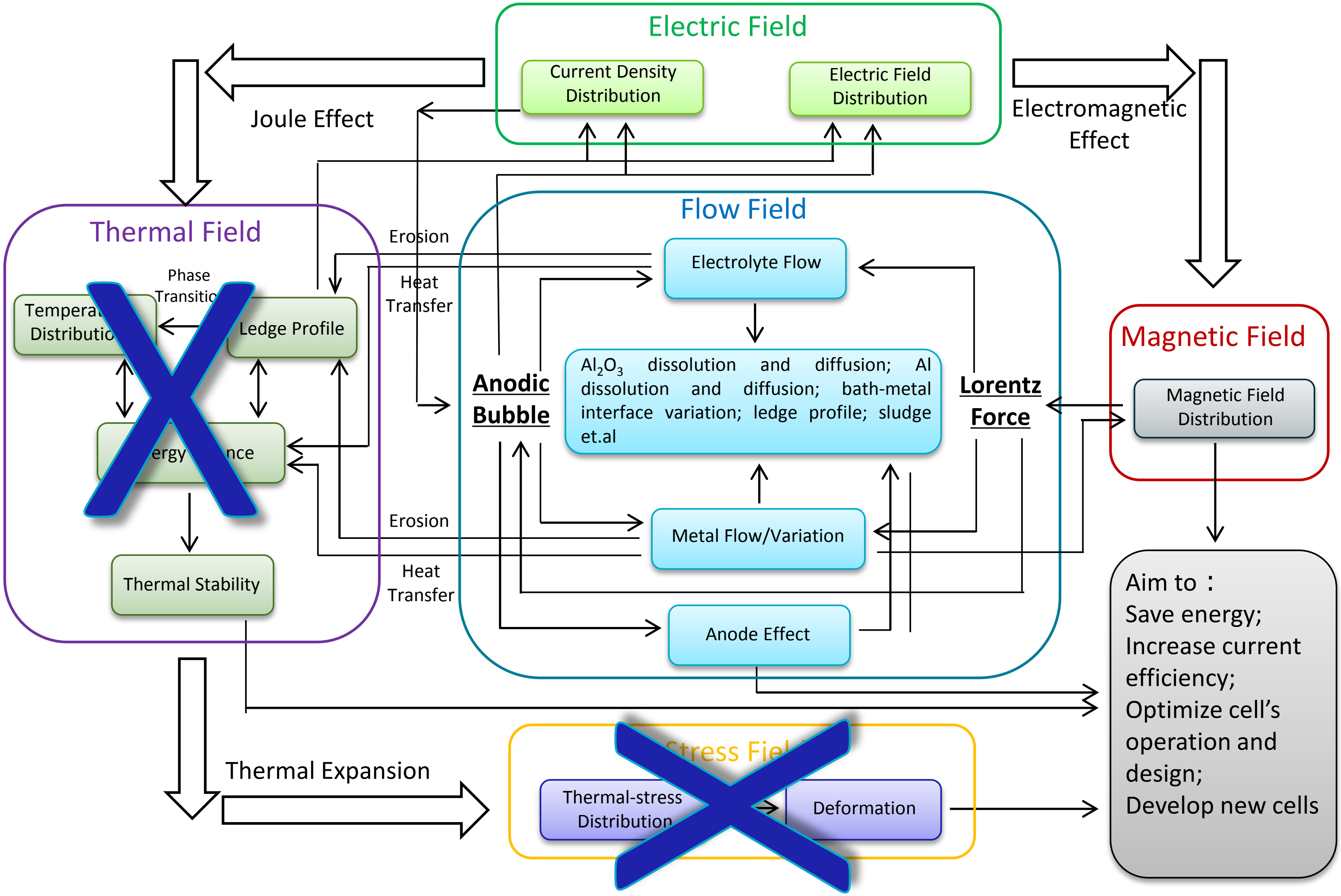
- 15g Coke can requires 0.9kWh elec. 40W globe 23hrs or 11 laptop batteries @ 0.08kWh
- Aluminium metal refined from alumina.
- Operates at ≈960°C.
- Very high electric currents and magnetic fields.
- Lorentz, Marangoni & electro-chemical effects

The schematic diagram of one cell



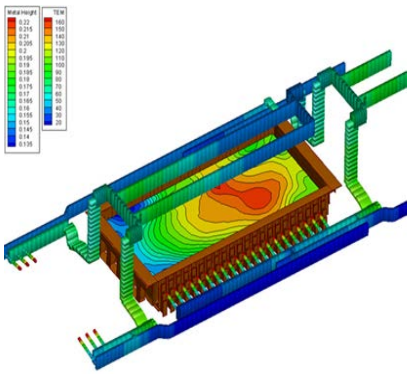


Multi-physics in Al Reduction Cells

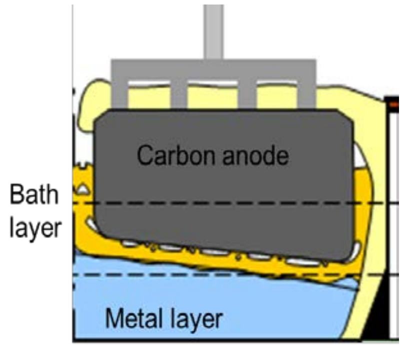


Multi-scale, Multi-physics Simulation Environment

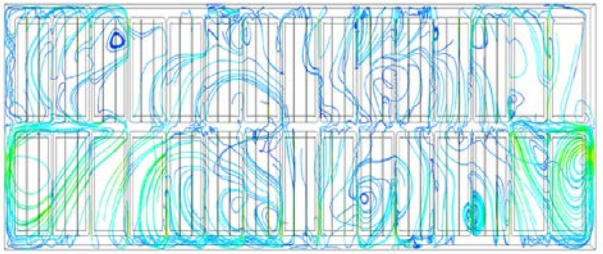
Prep



MHD flow

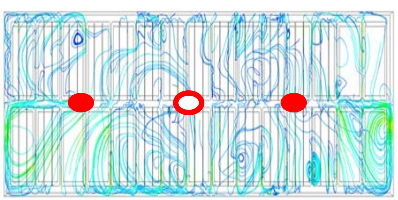


Bubble flow

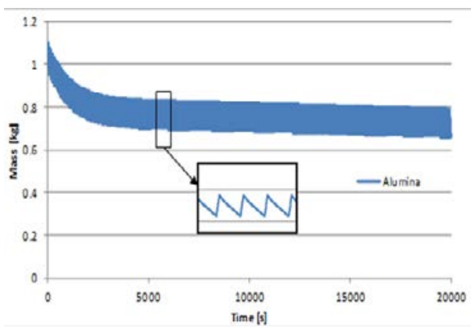


Bath flow

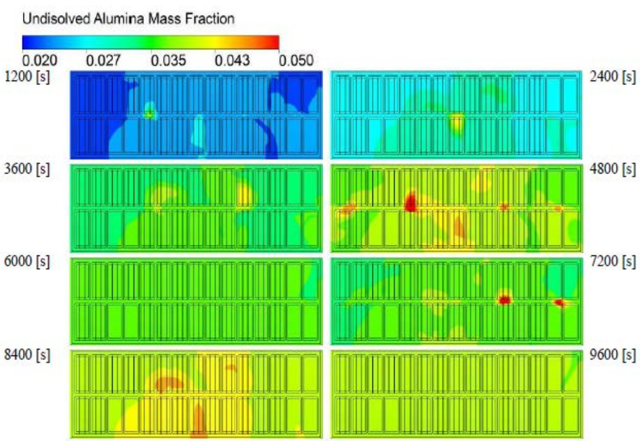
Proc



Bath flow



Transient feeding curve



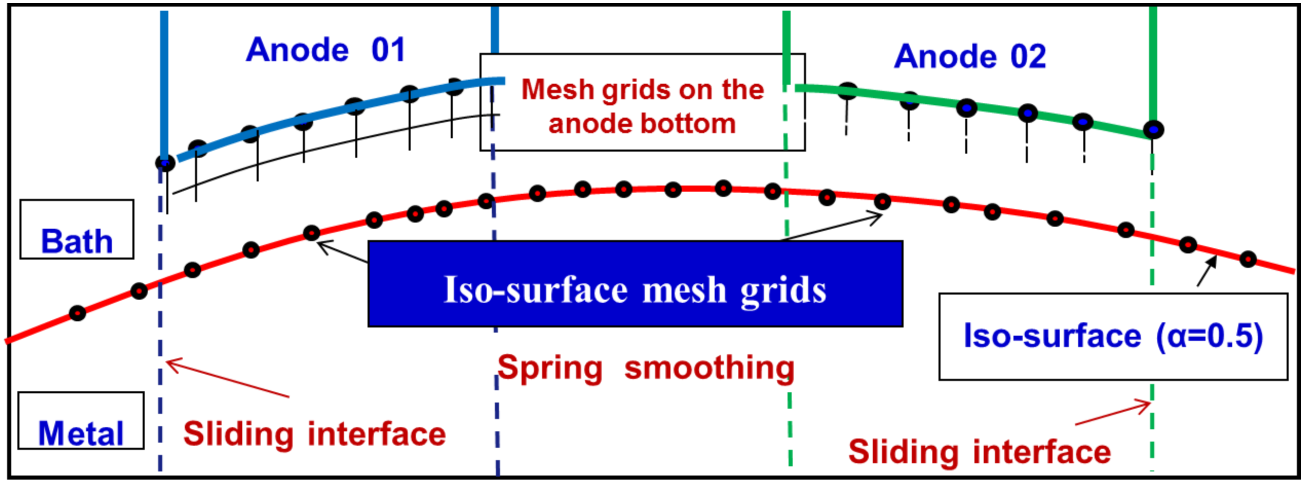
Species concentrations

Eick, Bai, Einarsrud, Feng, Hua, Witt, (2015) 11th Int. Conf. CFD in the Minerals and Process Industries

Steady state metal pad profile and MHD prediction

Mesh adjustments:

- Dynamic tracking of Bath/Metal interface using Fluent VOF (volume fraction 0.5) and sliding mesh approach to adjust anode bottom shape to metal pad profile

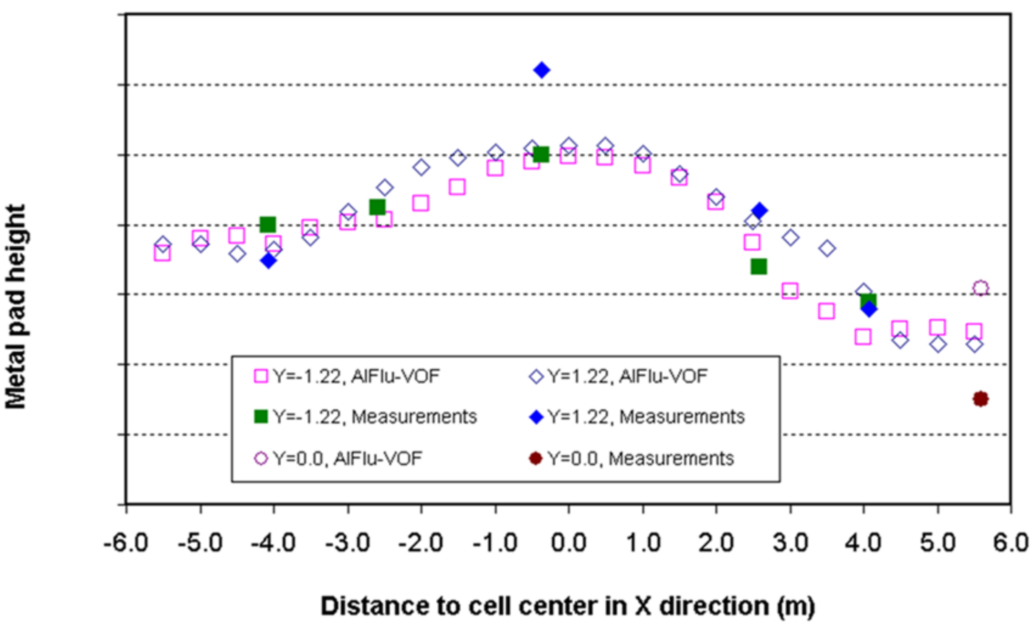


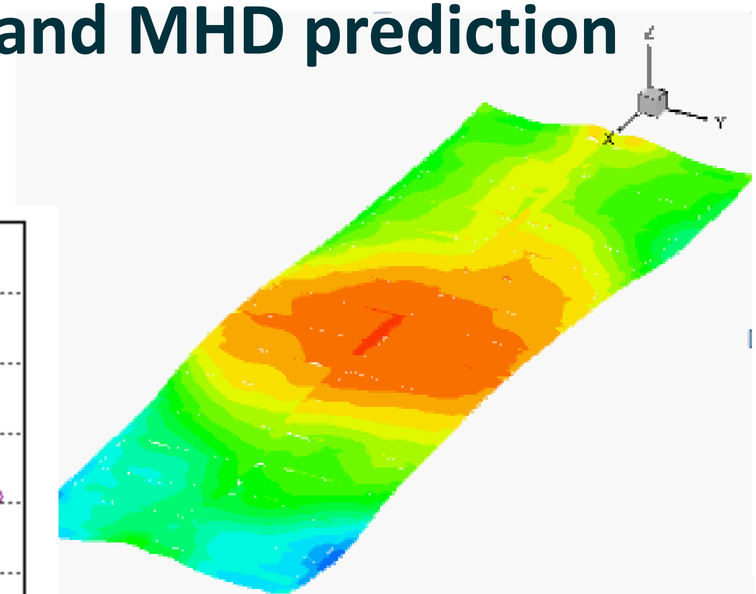
- Spring smooth is used to improve volume mesh quality

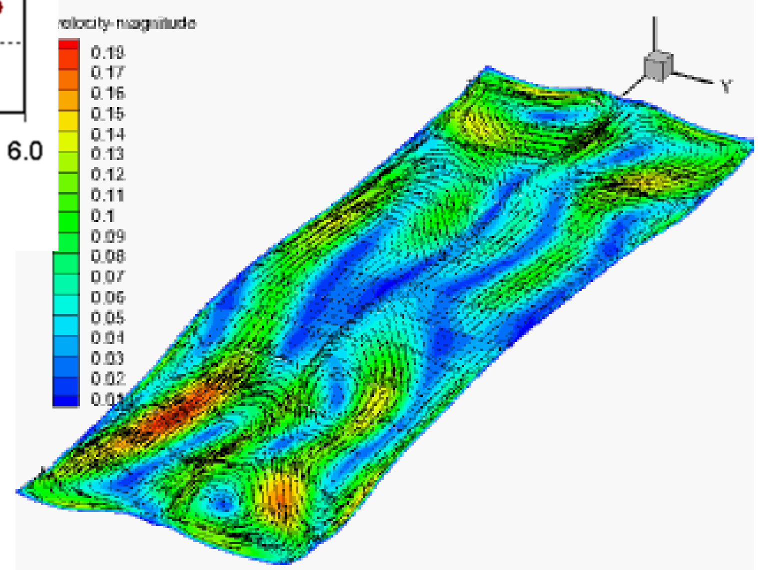
J. Hua et al, Light Metals 2014, 691

Steady state metal pad profile and MHD prediction

Simulation result:







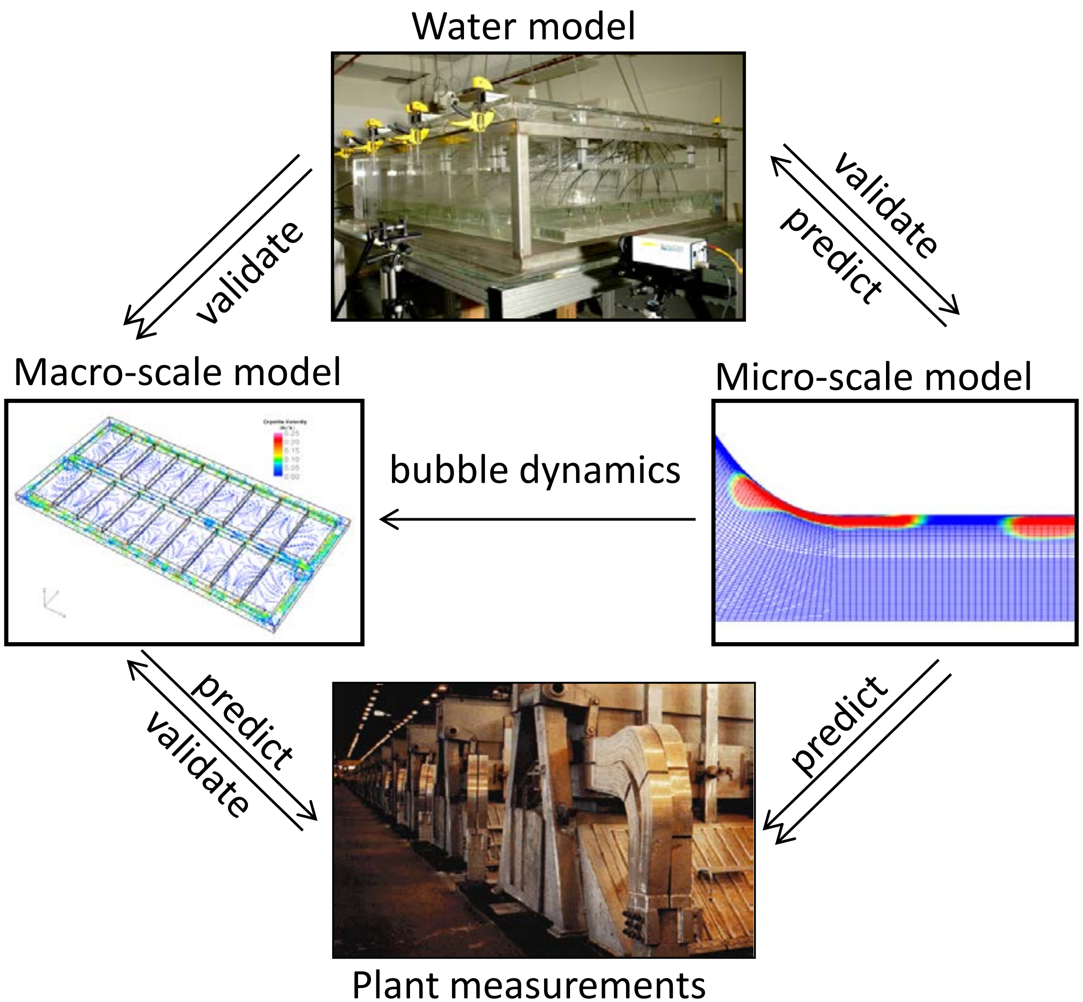
Metal surface speed

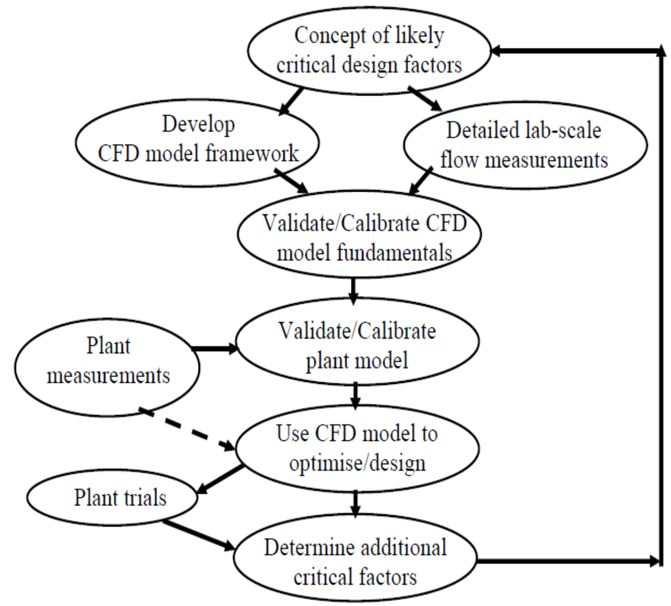
- Metal pad surface speed transferred to full cell bath flow model

J. Hua et al, Light Metals 2014, 691

CSIRO's integrated modelling approach to electrolyte modelling

CFD model development cycle



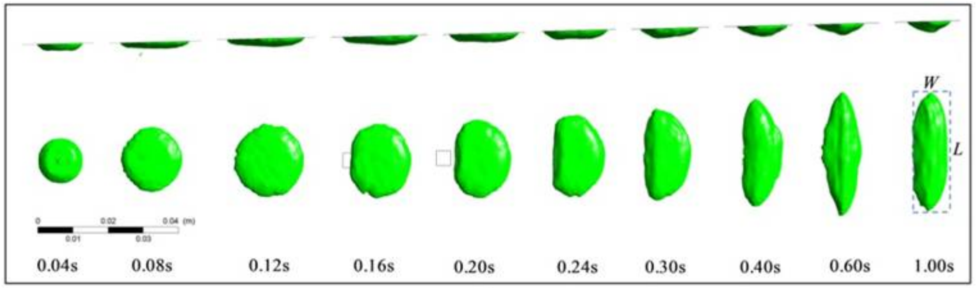


Air-Water flow in CSIRO 3 anode model

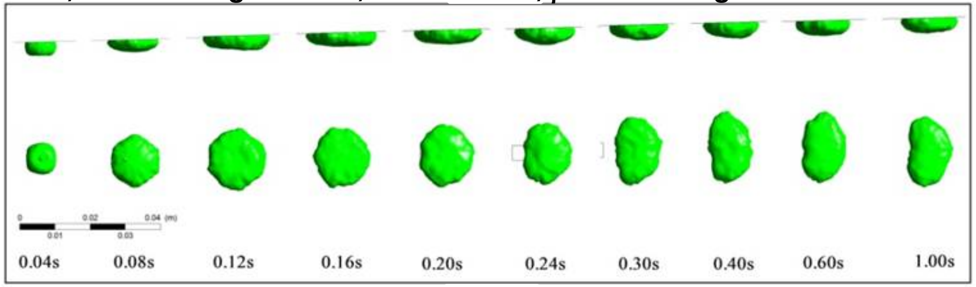
Feng et.al., (2010) J. Comp. Multiphase Flows 2(3) 179-188

Bubble dynamics in ACD

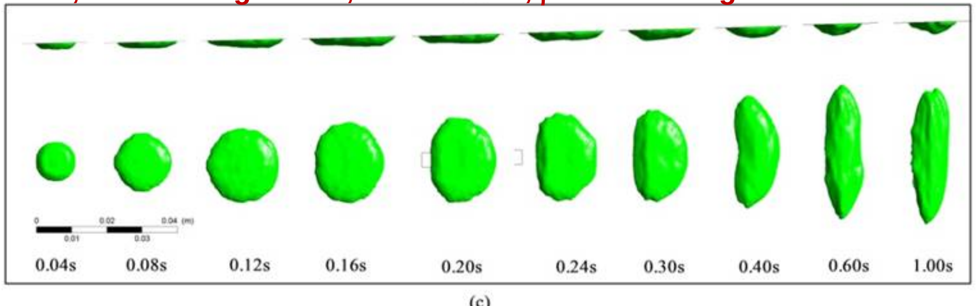
Case 1 CO_2-cryolite, contact angle 60°, σ 0.132 N/m, ρ 0.4 / 2100 kg/m³

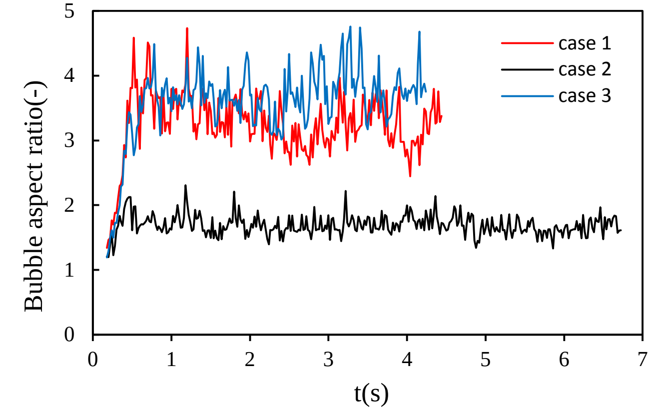


Case 2 Air-water, contact angle 120°, σ 0.072 N/m, ρ 1.2 / 998 kg/m³

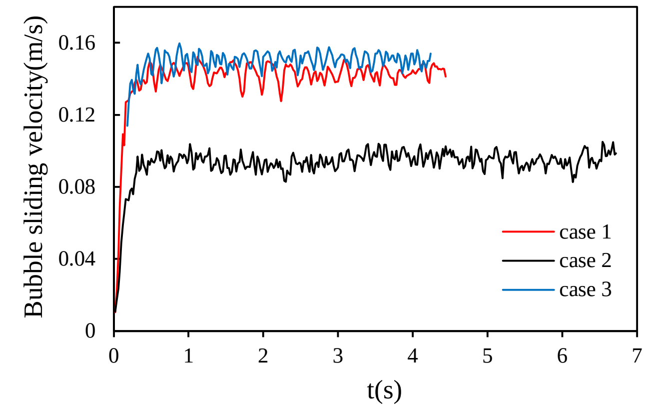


Case 3 Air-water, contact angle 60°, σ 0.132 N/m, ρ 0.4 / 2100 kg/m³





Bubble sliding aspect ratio with time



Bubble sliding velocity function with time

Using bubble flow and resolved bubble models to improve two fluid model closures

Zhao, Zhang, Feng et.al., (2014) Australasian Fluid Mechanics Conference, Melbourne, Australia

Steady State Full Cell Bath Flow Model

Bath Flow Model – Steady State

- Eulerian-Eulerian, two-fluid model
- Conservation equations for phase mass and phase momentum (gas and cryolite)
- MHD forces & current density included (no induced currents and fields*)
- Modified κ-ε turbulence model in liquid phase only.
- Bubble drag and phase turbulence from zero equation model.
- Time averaged gas distributions, gas & liquid velocities and turbulence quantities.
- Anode shape, metal pad profile & velocity boundary condition.

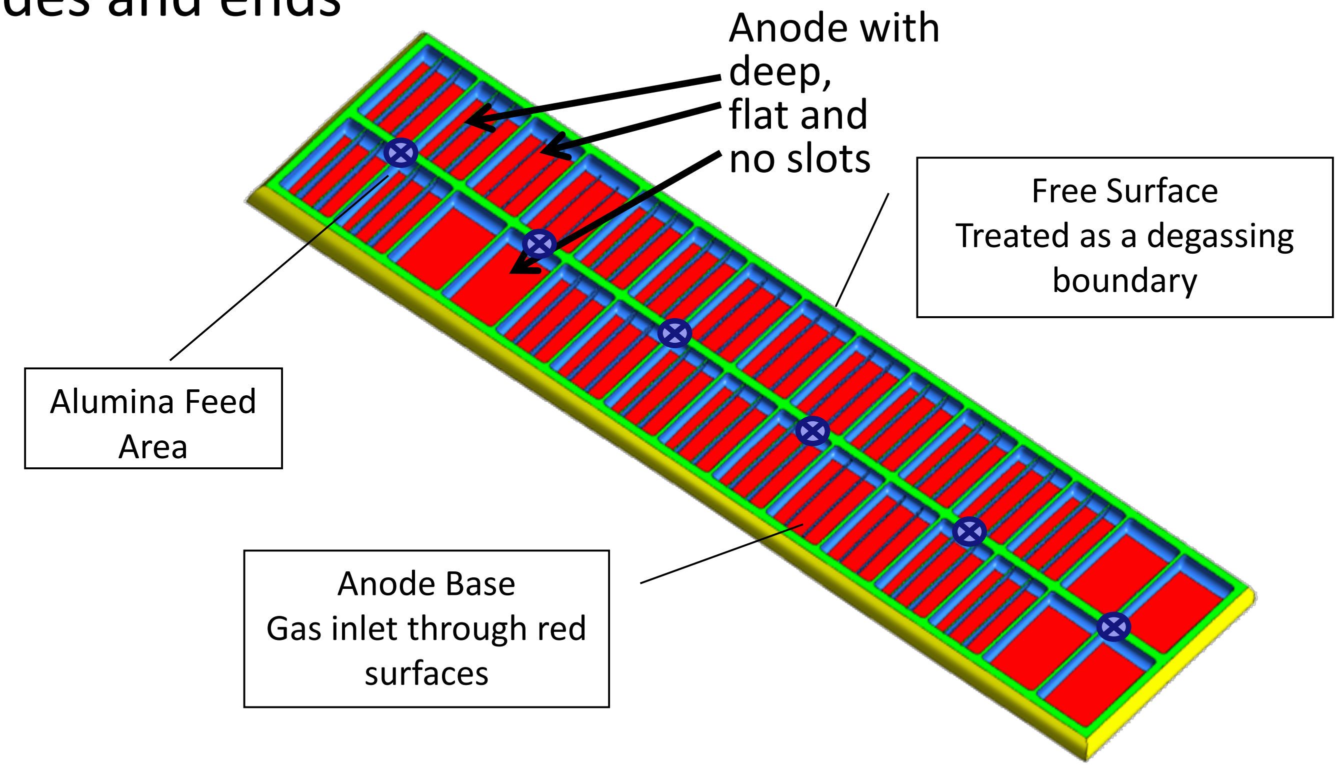
*) σ_{bath}=250 S/m, σ_{Al} = 3000000 s/m

Witt et al, 10th Int. Conf. on CFD in Oil & Gas, Metallurgical &Proc. Ind. Trondheim, Norway

Steady State Full Cell Bath Flow Model

Modelling implementation

- Anodes of different age considered
- Ledge profile of sides and ends
- Metal pad profile



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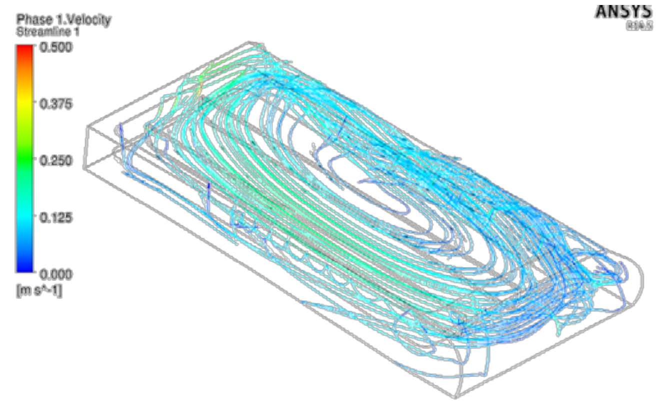
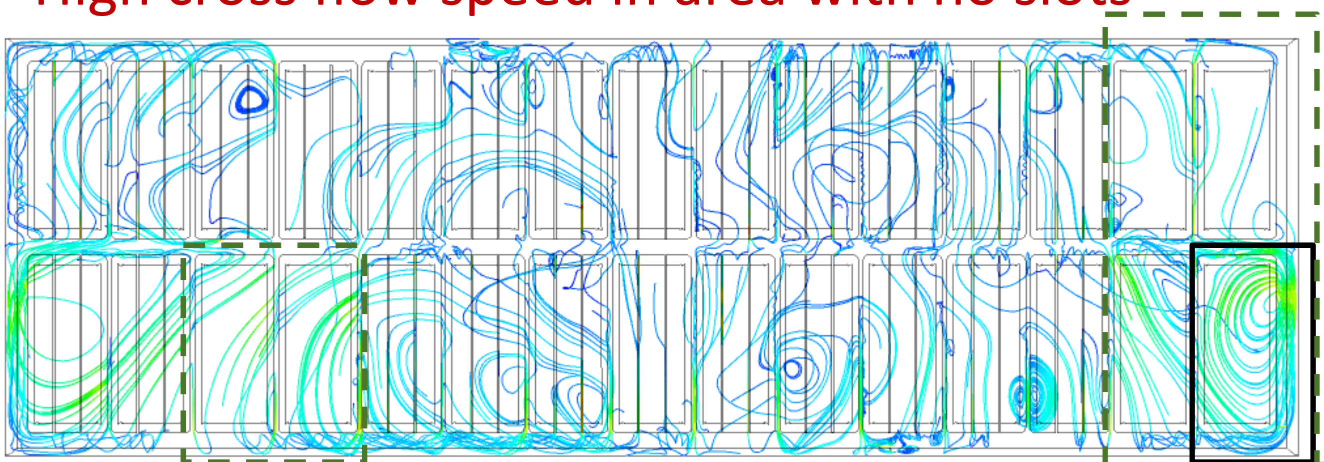
Steady State Full Cell Bath Flow Model

Simulation results

- Velocity field stable against temperature changes
- Velocity field stable against viscosity changes
- Turbulent viscosity 1000 time higher than bath viscosity
- High cross flow speed in area with no slots



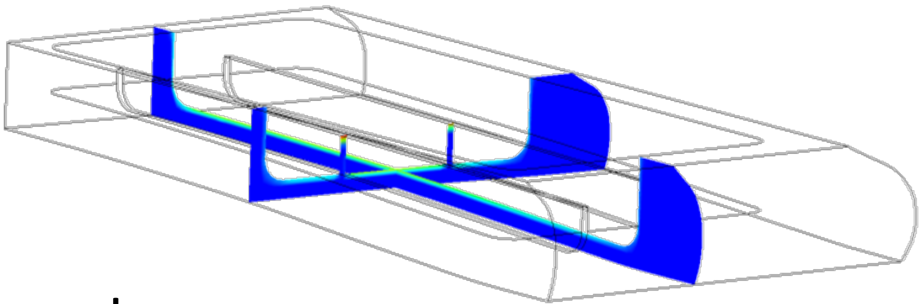


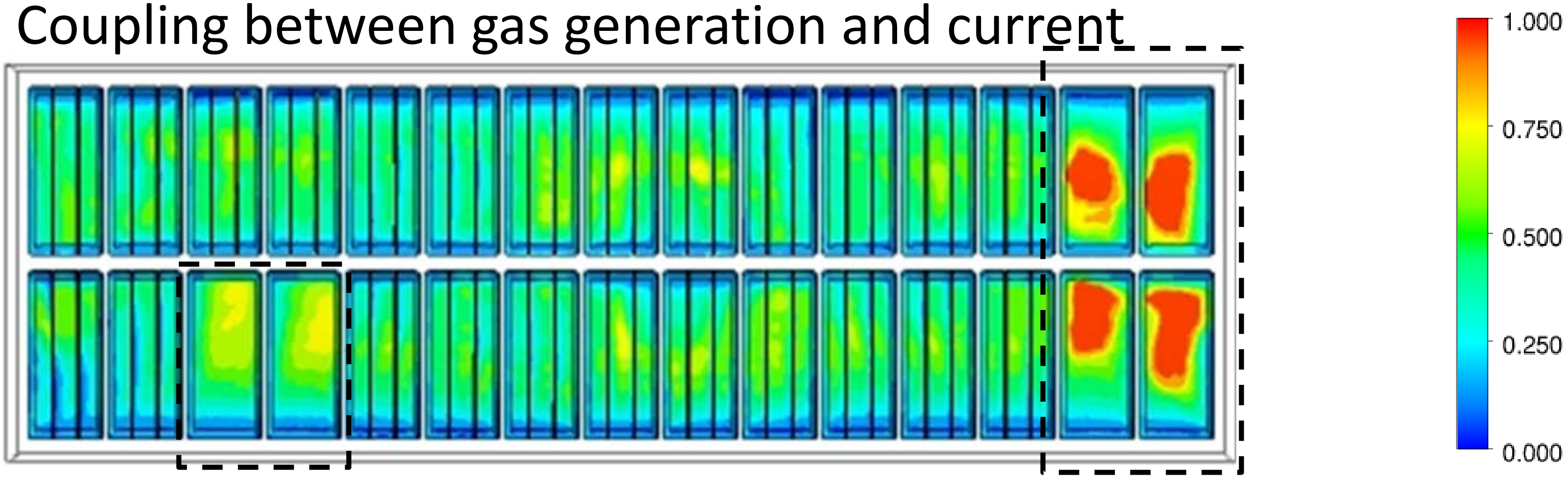
Witt et al, 10th Int. Conf. on CFD in Oil & Gas, Metallurgical &Proc. Ind. Trondheim, Norway

Steady State Full Cell Bath Flow Model

Simulation results

- Gas accumulation below anode and in slot visible
- Simulation indicating performance deficit of anode toward end of anode cycle
- Reduced current flow under old anodes
- Coupling between gas generation and current

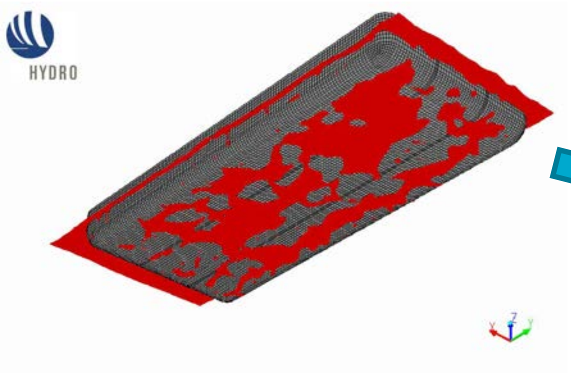


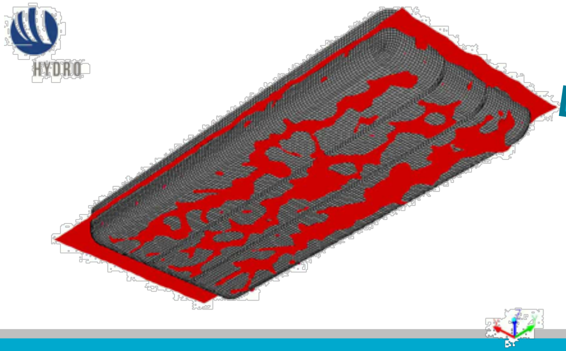


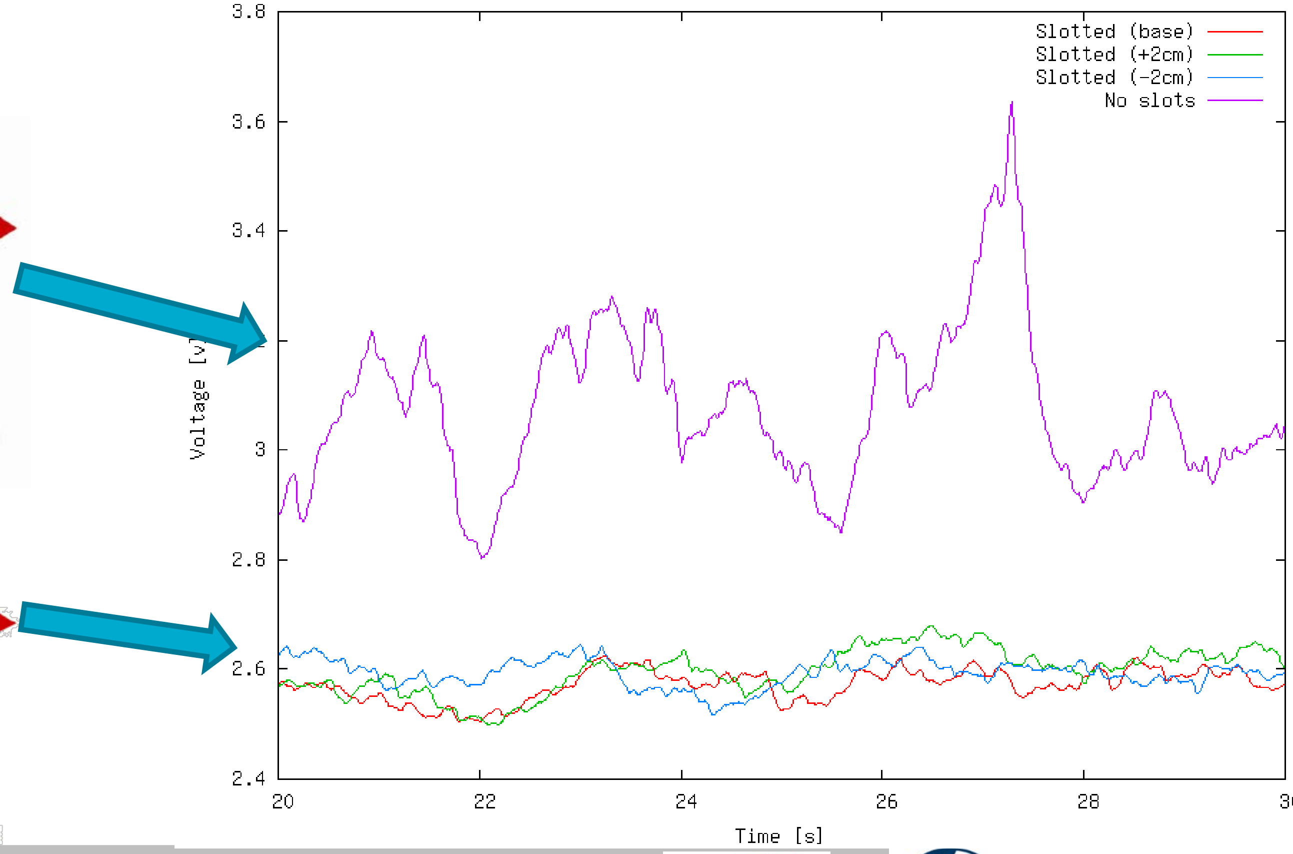
Transient Bubble and Chemical Reaction Flow Model

Model application

The impact of the slots for guiding the bubble from the anode bottom







Transient Alumina Reaction and Distribution Model

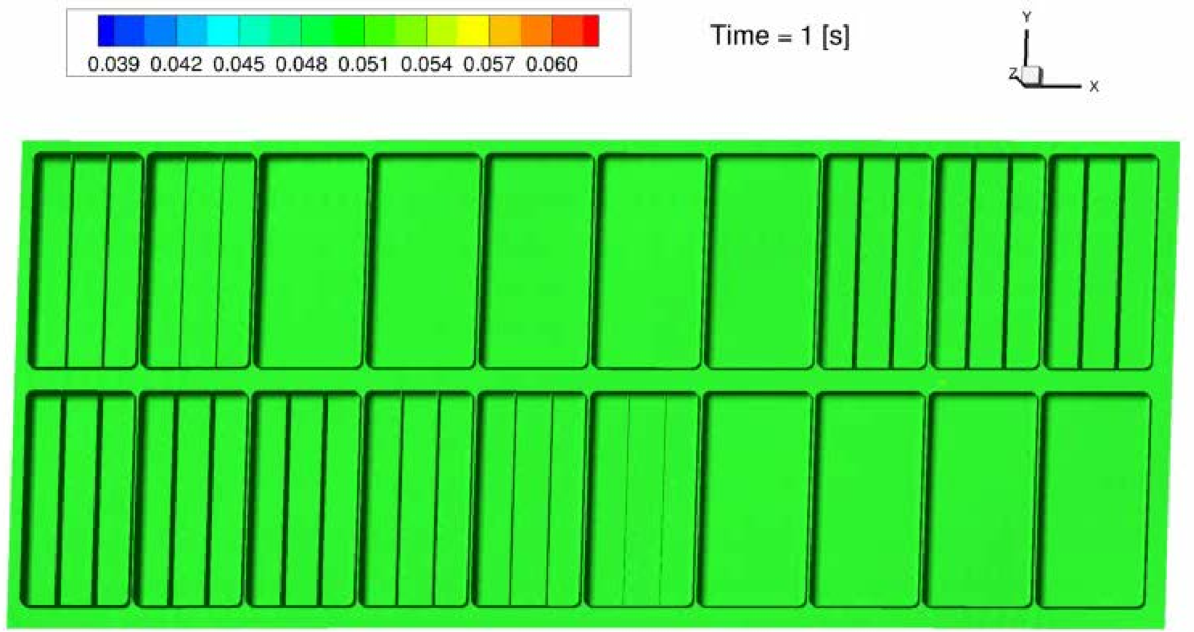
Simulation results – Full Cell

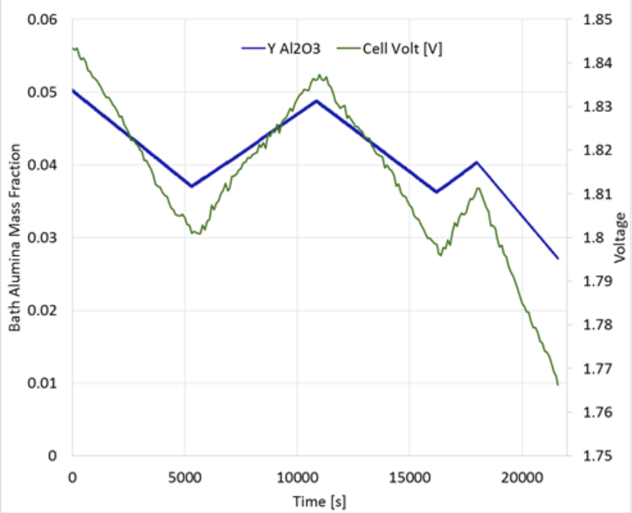
- Underfeeding and overfeeding cycles can be evaluated

Critical areas can be identified

To low concentration => anode effect

To high concentration => sludging





Modelling approach

Transient transport model

- Time averaged fluxes used to transport of reacting species
- Steady state bath flow field is fixed boundary condition.
- Chemical reaction model with 6 species developed

Conclusion

Presented multi-scale & multi-physic examples of where we have used CFD for industrial applications including:

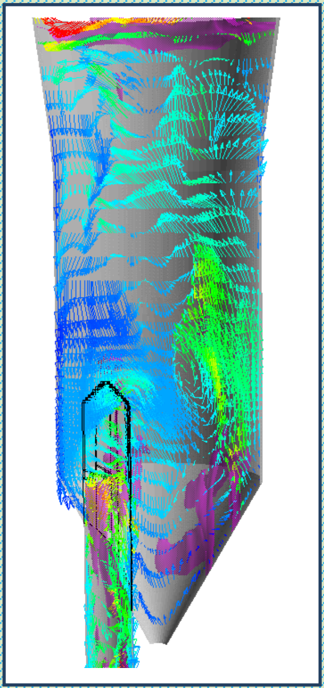
- Hybrid TFM-DEM model for Coal Beneficiation Fluidised Bed
- Coase grain simulation of a coker
- Population balance model for slurry flow in a thickener
- Hall-Héroult aluminium reduction cell

Further improvements needed in sub-model (drag, turbulence..)
Better ways to link resolved models to large scale “process” models

CFD computational fluid dynamics

Twelfth International Conference on **Computational Fluid Dynamics** in the Oil & Gas, Metallurgical and Process Industries

30 May – 1 June 2017, Trondheim, Norway



Announcement:

SINTEF to organise next conference in Norway.

Industries Covered:

- Pragmatic industrial modelling
- Oil & Gas pipeflow & processing
- Chemical processing
- Multiscale modelling
- CFD in Cardiovascular medicine
- Metallurgical applications
- Others…

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Jan Eric Olsen– Chairman

www.cfd.com.au/cfdconf

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