CPFD Model Optimization for Simulation of Segregation in Fluidized Bed of Particles with Different Sizes and Densities

Alex Kokourine and Kamal Adham, HATCH Ltd.

Fluidization XVI, Guilin, China, May 26-31, 2019

HATCH

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About HATCH Ltd.

- Engineering, Design and Project Management
- Serving Mining & Metals, Energy and Infrastructure for 60 years
- Projects in more than 150 countries
- Consulting: process and business development
- Operational support and plant engineering
- **Technologies: Furnaces and Fluid Beds**
- Employee-owned

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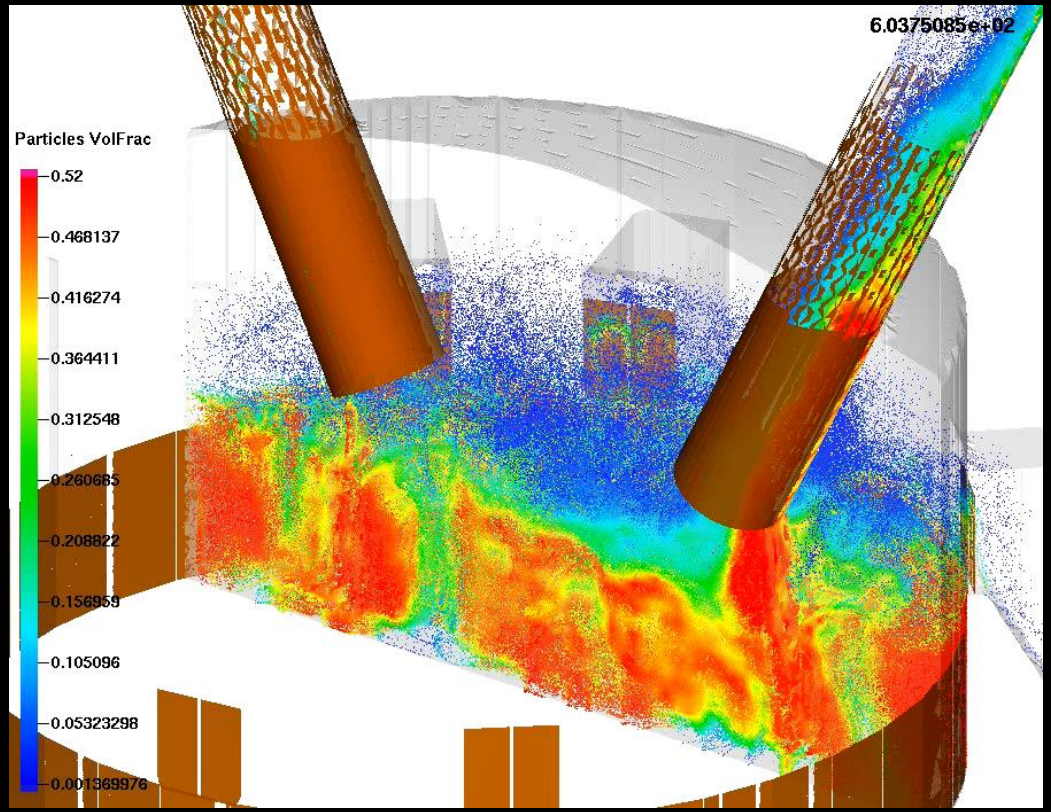
CPFD Barracuda Virtual Reactor® Software

- Hatch uses CPFD Barracuda software since 2012
- Multiple Fluid Bed (FB) systems were <u>designed and/or optimized</u>:
  - ❑ Bubbling, Spouted and Circulating FBs
  - ❑ Roasters, Calciners, Dryers, and Unconventional Reactors
  - ❑ Cyclones, Classifiers, and Feed Systems



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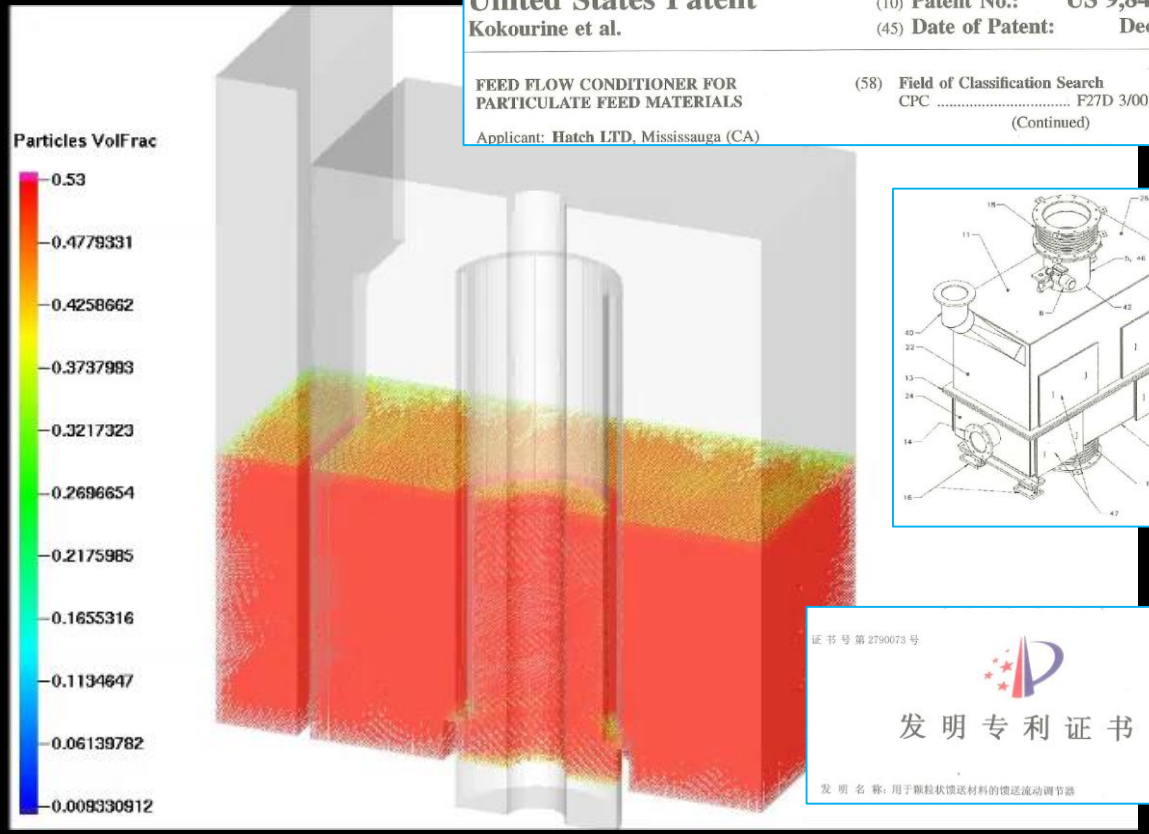
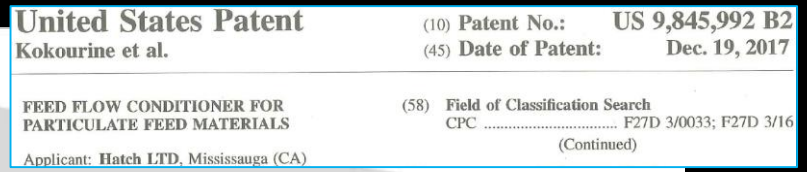
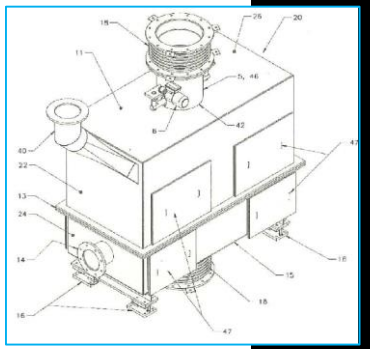
CPFD Barracuda Virtual Reactor® Software

- Main Focus on Hydrodynamics Phenomena*:
  - ❑ Local or total loss of fluidization
  - ❑ Elutriation
  - ❑ Segregation

**Chemistry simulation can be turned on in Barracuda solver*




United States Patent
Kokourine et al.
(10) Patent No.: US 9,845,992 B2
(45) Date of Patent: Dec. 19, 2017
FEED FLOW CONDITIONER FOR PARTICULATE FEED MATERIALS
(58) Field of Classification Search
CPC F27D 3/0033; F27D 3/16
(Continued)
Applicant: Hatch LTD, Mississauga (CA)



证书号第2790073号
发明专利证书
发明名称：用于颗粒状馈送材料的馈送流动调节器

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Segregation

- Segregation of particles in fluid beds under aerodynamic drag and gravity occurs due to differences in particles density and size:
  - ✓ *Particle distribution in space vs. space velocity (pseudo steady state conditions)*
  - ✓ *Particle segregation in time (transient solution)*

- Material segregation can cause process failure in FB reactors in mining and oil & gas industries when PSD and density of solids change during campaign. As such, process parameters adjustment is critical for:
  - ✓ *reflections of those variations*
  - ✓ *process efficiency optimization*

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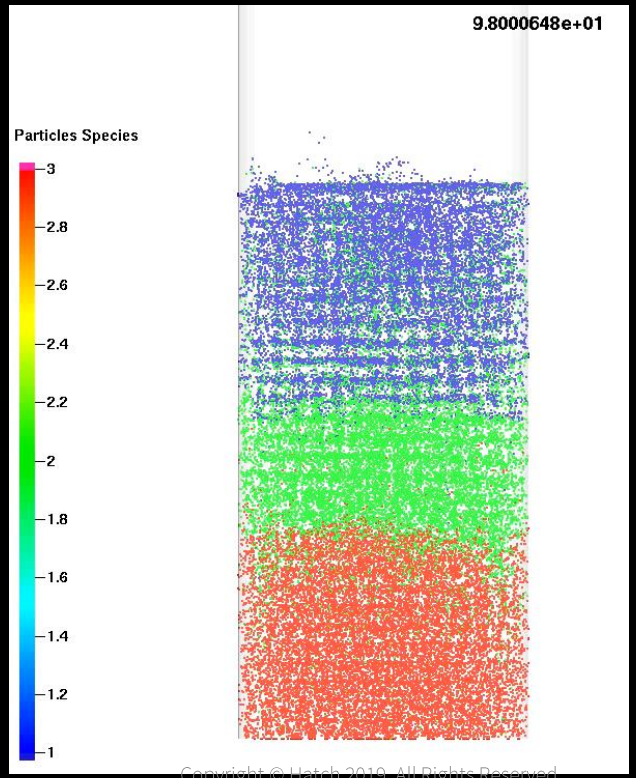
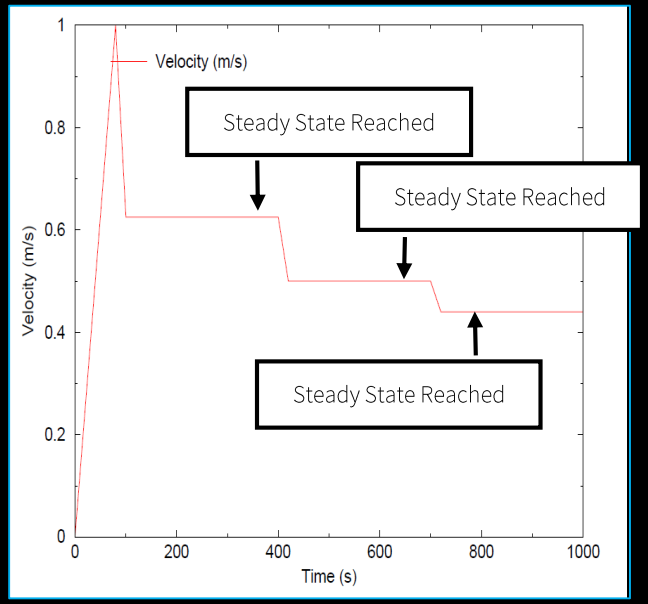
CPFD Investigation of Multicomponent Beds Segregation vs. Space Velocity

Multicomponent Bed (Three Species):

- A (small size)
- B (medium size)
- C (large size)





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Validation of Segregation Modeling

- CPFD Modeling of reported experiments [1]:

J. L.-P. Chen and D. L. Keairns, Particle Segregation in Fluidized Bed, *Chemical Engineering Research, Westinghouse Electric Corporation, The Canadian Journal of Chemical Engineering, Vol. 53, August, 1975.*

- Three-component mixture:
  same material, different particle size
- Two-component mixture:
  different materials (density), similar particle size

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Approach

- Accuracy of CPFD model in prediction:
  - ✓ *Particle distribution <u>in space (segregation)</u> vs. fluidizing gas space velocity at pseudo steady state conditions*
  - ✓ *Particle segregation <u>in time (transient solution)</u>*
- Adjustment of two Barracuda models was used for optimization:
  - ✓ *Blended Acceleration Model (BAM) [2]*
  - ✓ *Sauter Mean Diameter (SMD) based Drag Model [3]*

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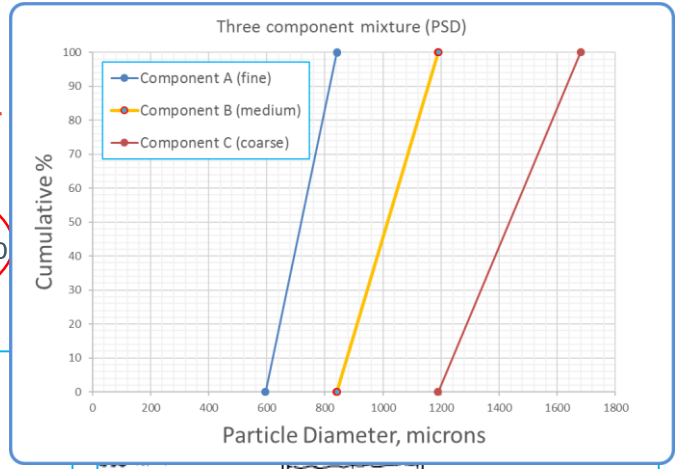
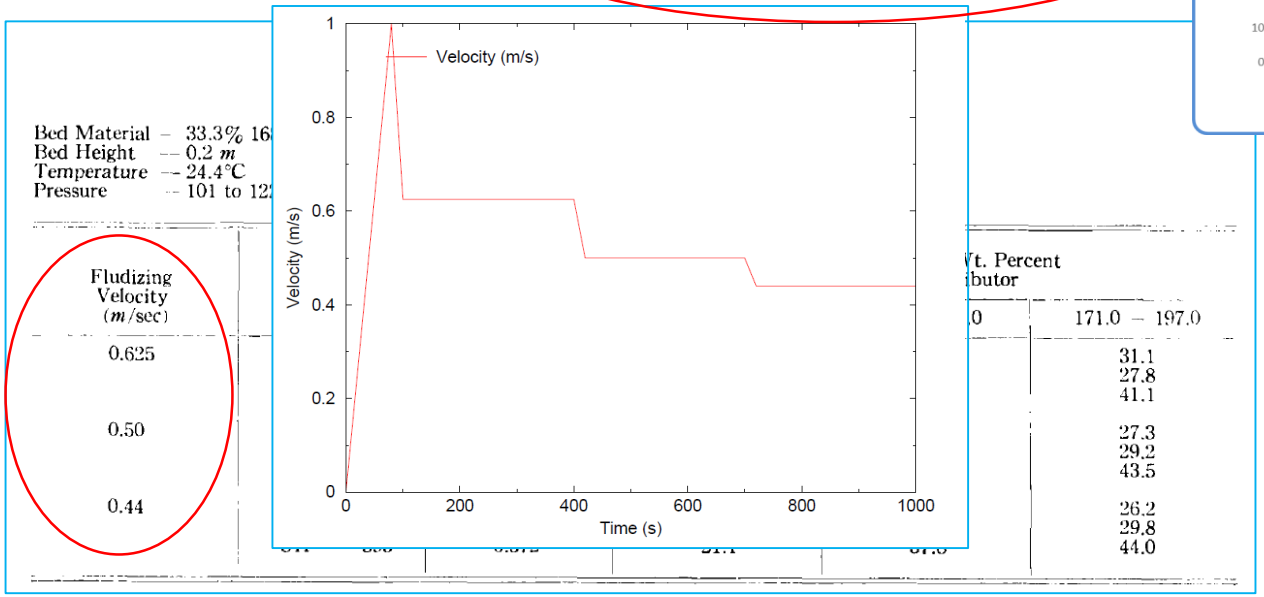
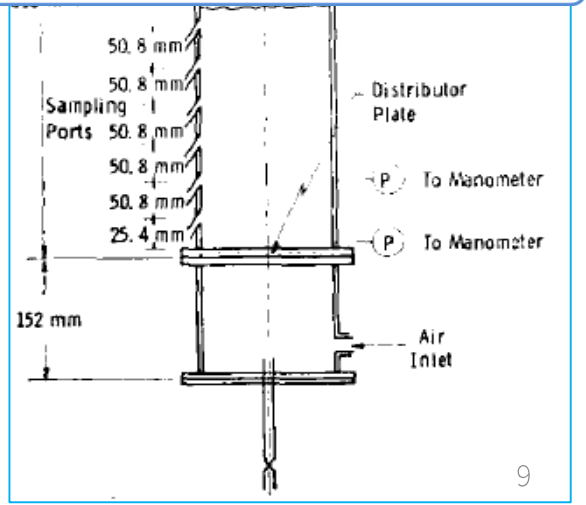
Three-component mixture: same material, different particl

- Component A (small size): 595-841 microns – 33.33 mass %
- Component B (medium size): 841-1190 microns – 33.33 mass %
- Component C (large size): 1190-1680 microns – 33.33 mass %







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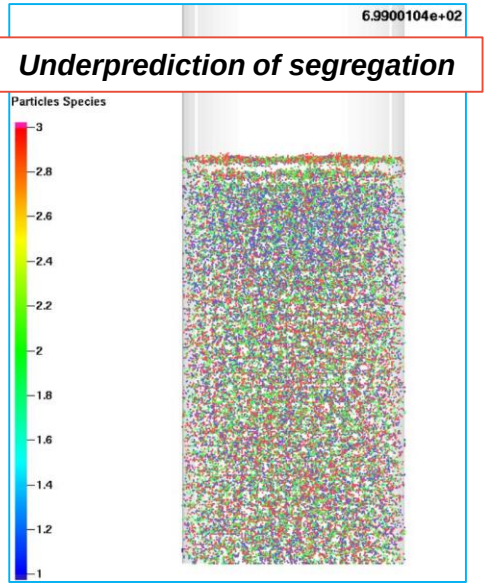
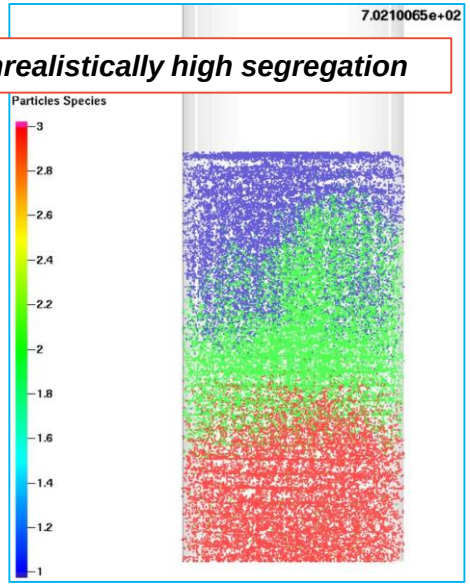
Three-component mixture: Qualitative Results

Underprediction of segregation



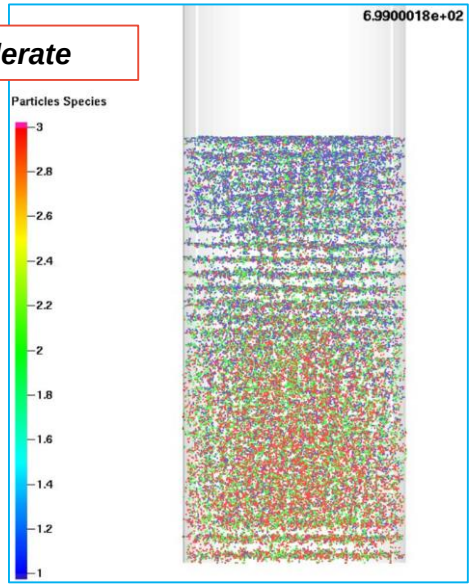
Wen-Yu drag model with BAM (by default)

Unrealistically high segregation



Wen-Yu drag model with BAM (tuned)

Moderate



Wen-Yu drag model with SMD correction and BAM (tuned)

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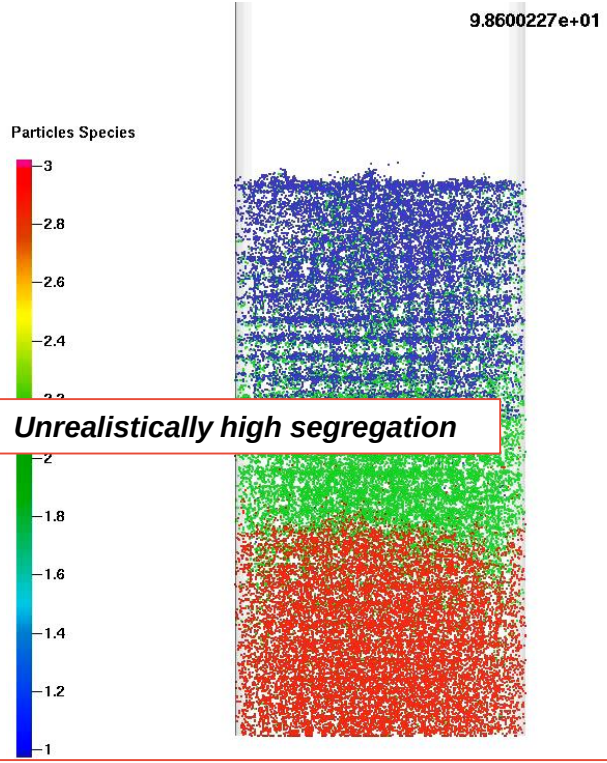
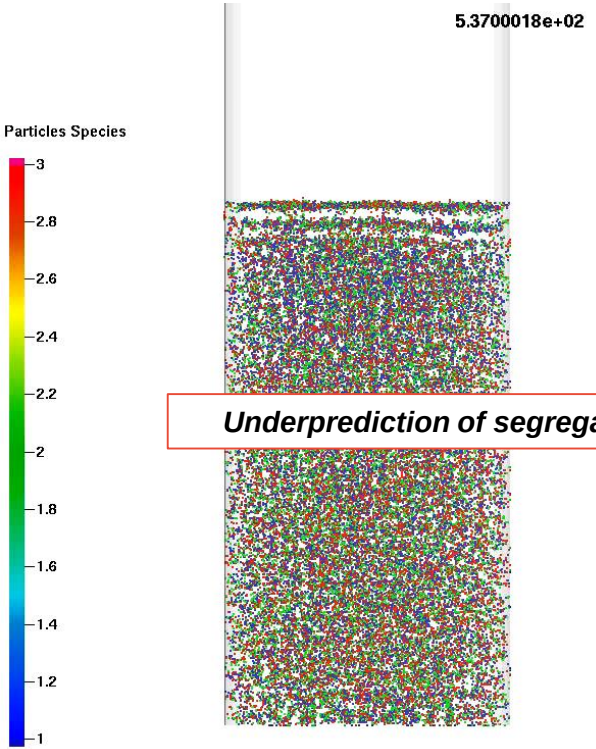
Three-component mixture: Qualitative Results



Unrealistically high segregation

Wen-Yu drag model with BAM (tuned)



Underprediction of segregation

Wen-Yu drag model with BAM (by default)

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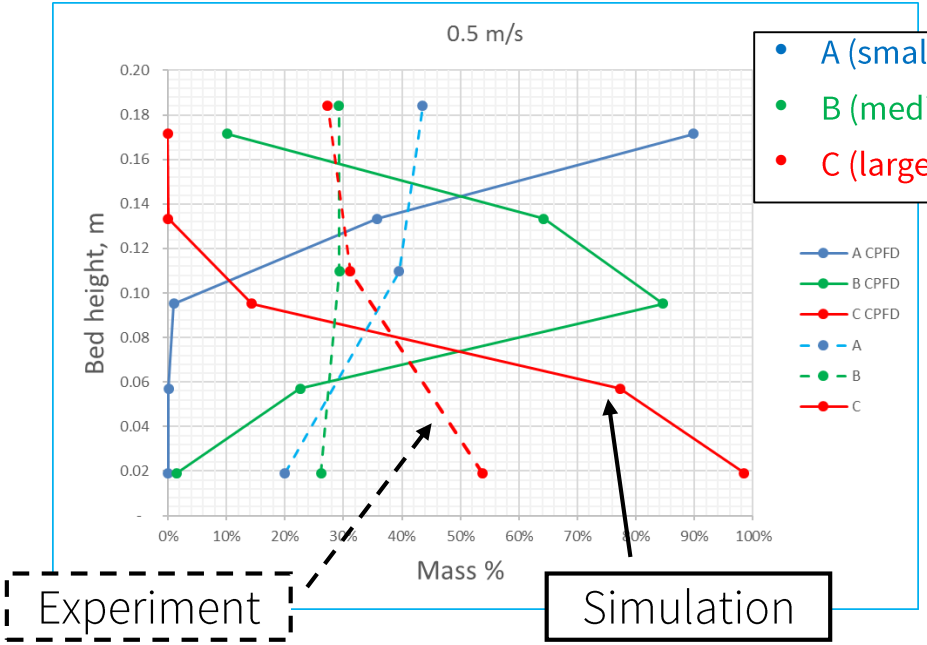
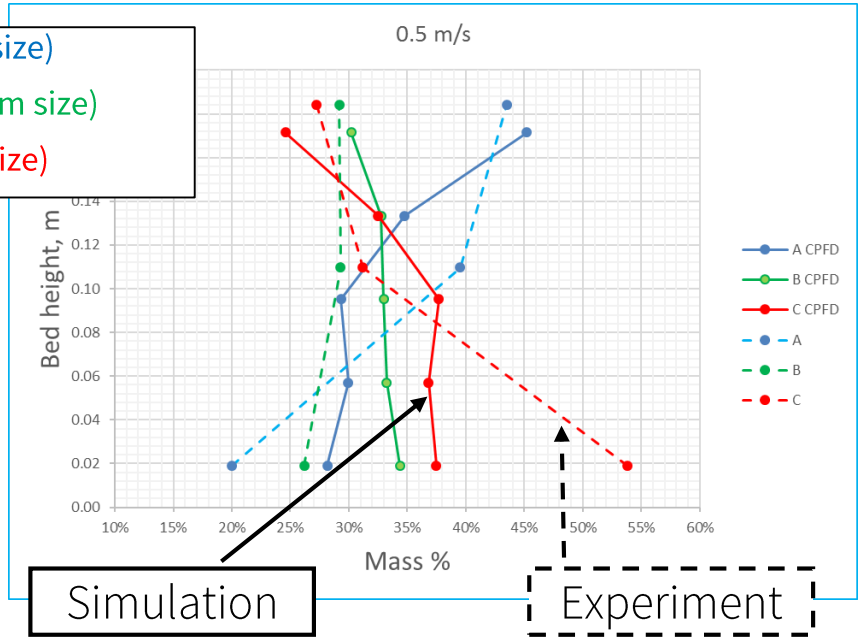
Three-component mixture: Quantitative Results



- A (small size)
- B (medium size)
- C (large size)



Wen-Yu drag model with BAM (tuned)

Unrealistically high segregation

Wen-Yu drag model with BAM (by default)

Underprediction of segregation

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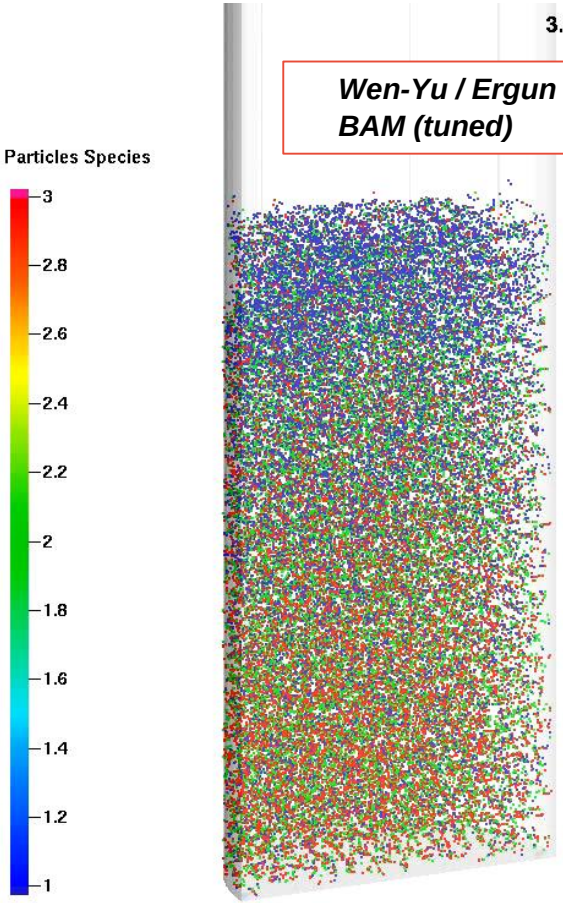
Three-component mixture: best matching results



Wen-Yu / Ergun model with SMD correction and BAM (tuned)

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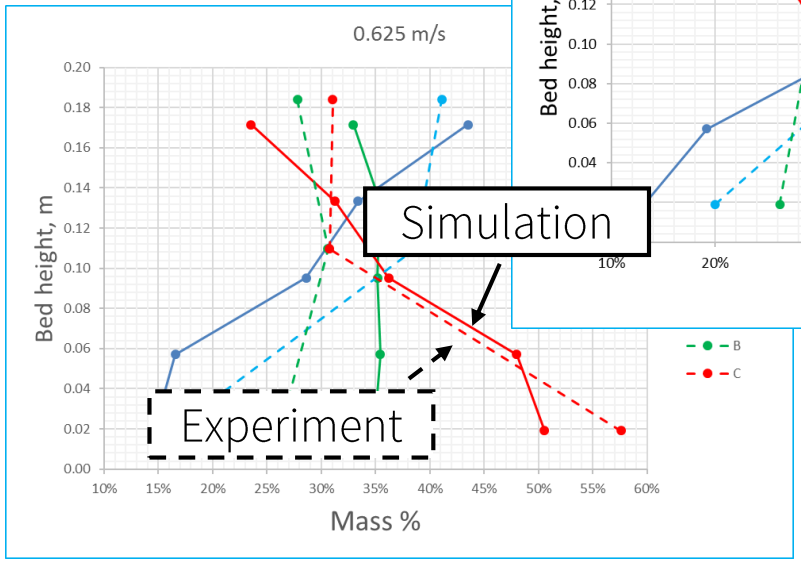
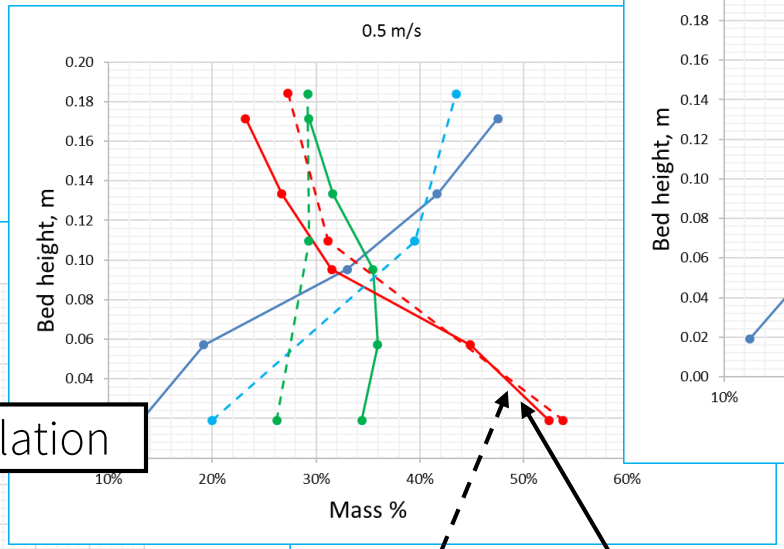
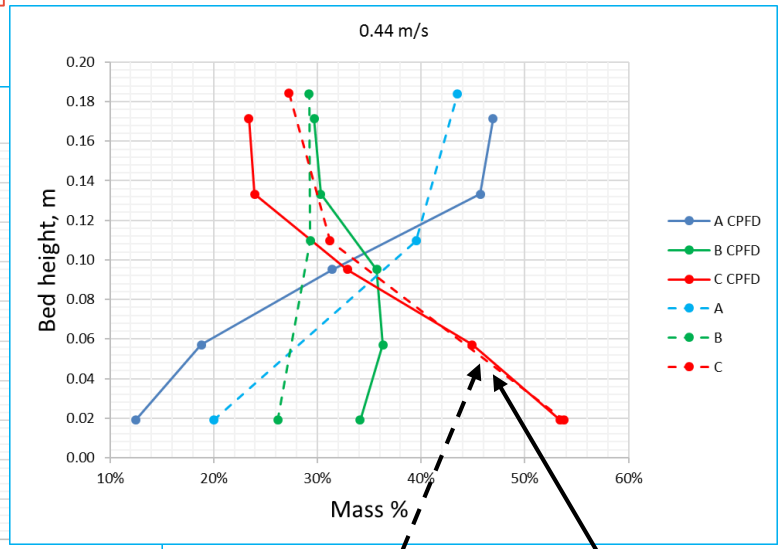
Three-component mixture: best results

Wen-Yu / Ergun model with SMD correction and BAM (tuned)

- A (small size)
- B (medium size)
- C (large size)

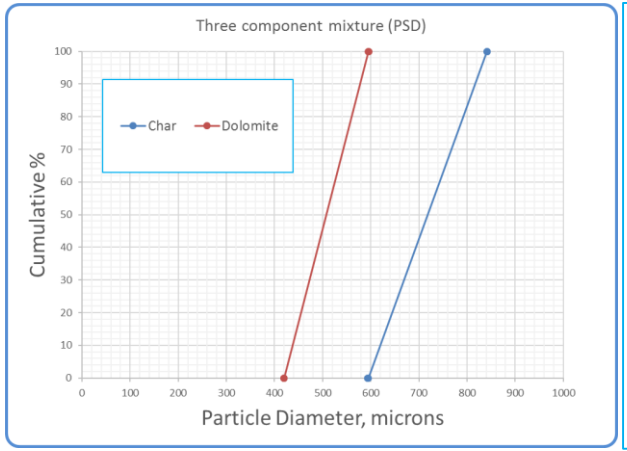


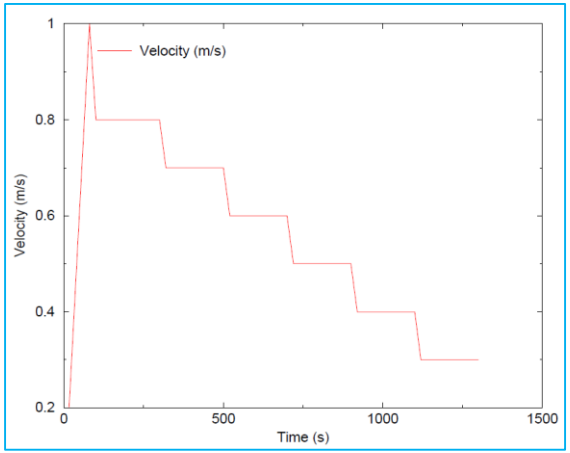




Two-component mixture: different (density), similar size

- Dolomite (2800 kg/m^3): 595-420 microns
  - 30 mass %
- Char (702 kg/m^3): 841-595 microns
  - 70 mass %





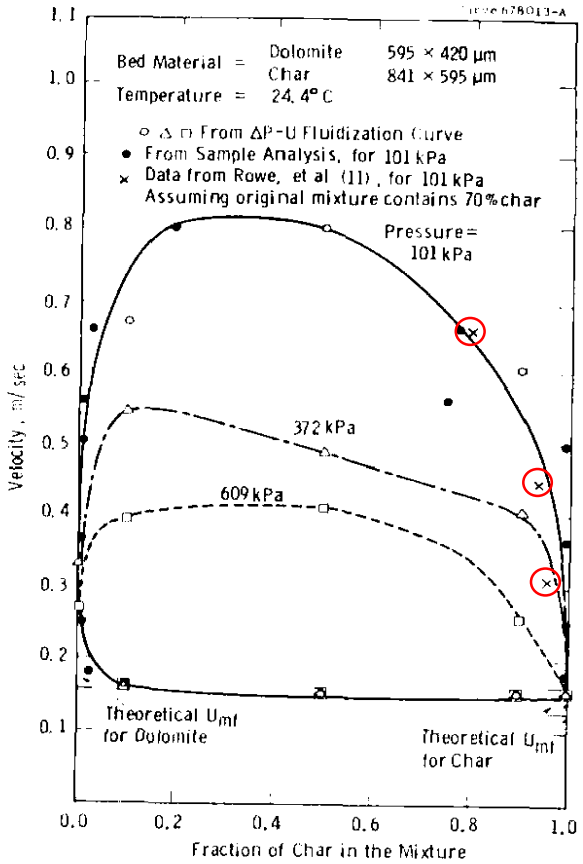


Figure 9 — Phase diagram for two-component char-dolomite mixture.

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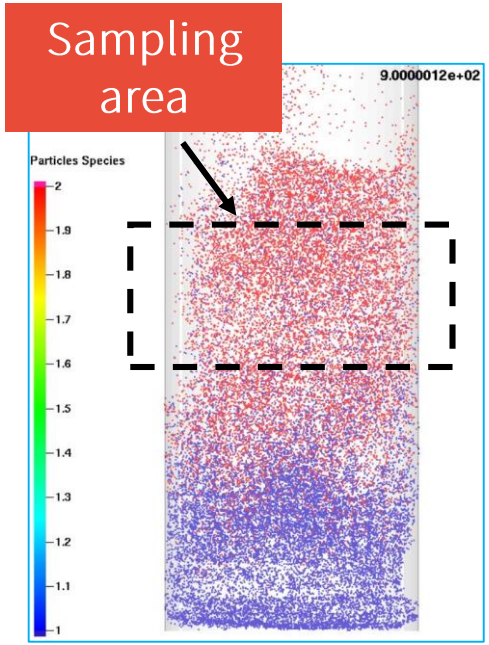
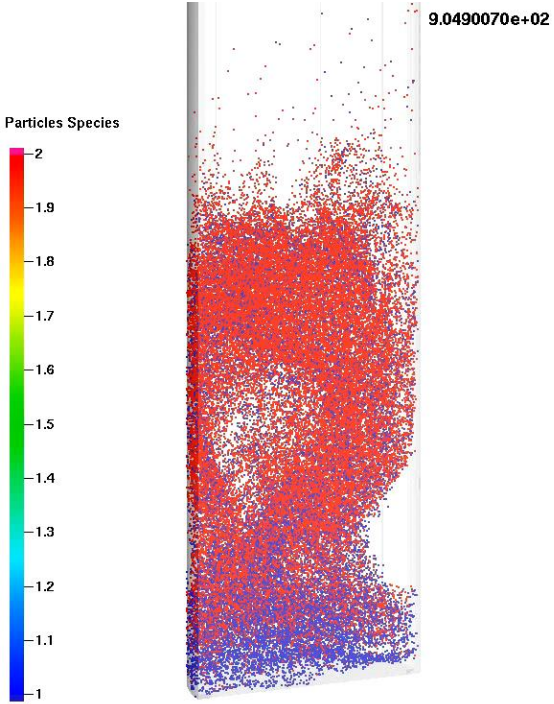
Two-component mixture: different (density), similar size

Wen-Yu / Ergun model with SMD correction and BAM (tuned)





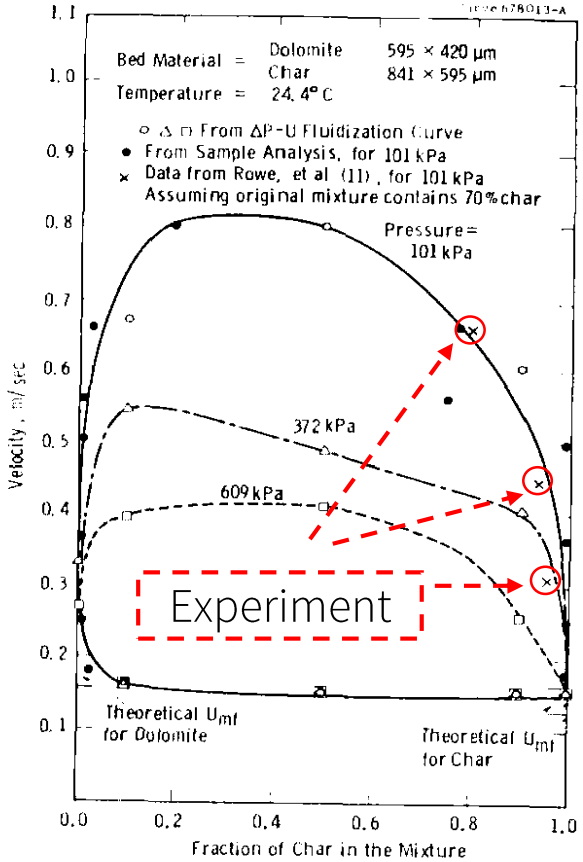


Figure 9 – Phase diagram for two-component char-dolomite mixture.

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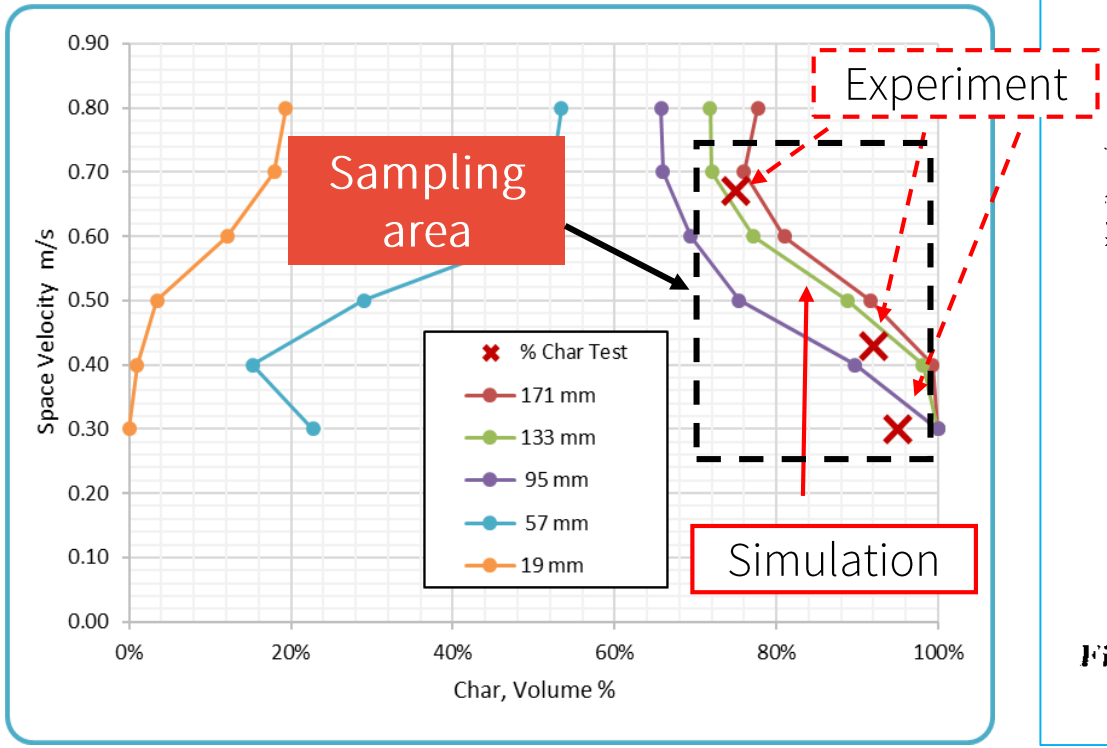
Two-component mixture: different (density), similar size

Wen-Yu / Ergun model with SMD correction and BAM (tuned)



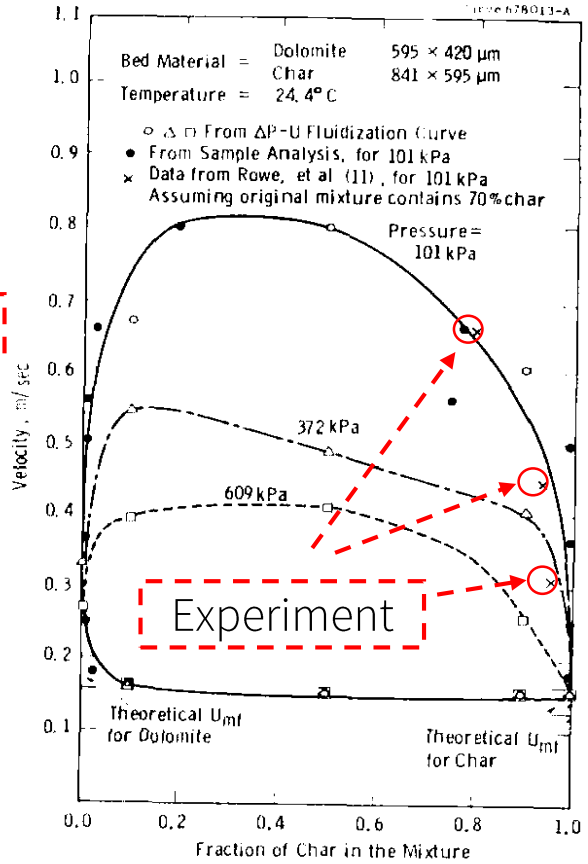


Figure 9 – Phase diagram for two-component char-dolomite mixture.

Transient Results

- Reported in [1] segregation time (~30 s) was much less than calculated in all CPFD simulations.
- Calculated segregation time was strongly dependent on number of computational particles (parcels).

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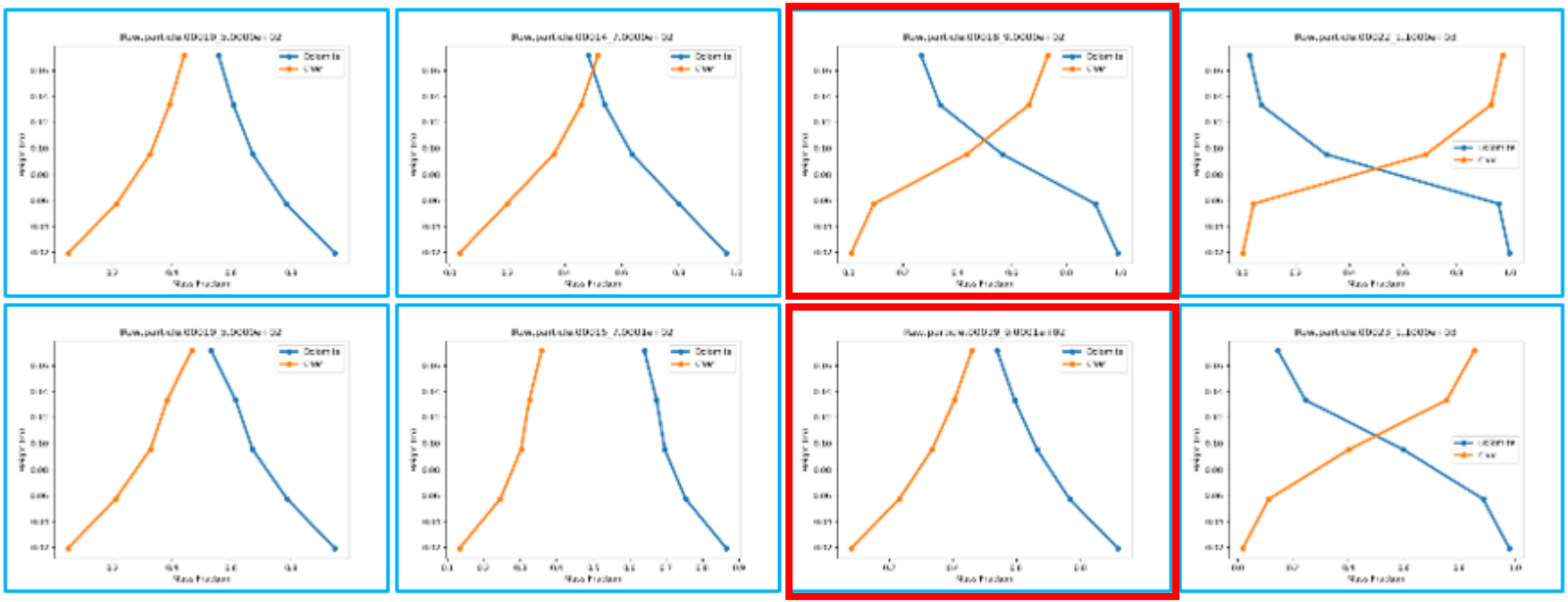
Transient Results: Segregation Time vs. Number of Computational Particles.



Particle separation in time for 300, 500, 700 and 900 s of simulated process time: 21 parcels per cell (top graphs); 39 parcels per cell (bottom graphs).

Transient Results

- In general, an increase of parcels or mesh refining increases the solution accuracy, but not for the segregation time: the more parcels - the longer predicted process time (*do not mix with computing time*) to reach steady state conditions.
- Higher number of computational particles improves accuracy for hydrodynamics, but significantly overestimates the time to reach steady state conditions of particles segregation.

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Conclusions

1. Accurate determination of a *threshold between uniform fluidization and segregation* is possible using CPFD Barracuda
2. Quantifiable optimization of the safety margin beyond that threshold can *increase efficiency of process industrial vessels* *(less grinding; reduced elutriation …)*
3. An accurate prediction of particle separation time can't be done using the CPFD-Barracuda software

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Acknowledgments

The authors would like to thank Matthew Hamilton and all the CPFD Barracuda team for constant and prompt technical support and participation in frequent discussions.

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Referenced Papers

1. *J. L.-P. Chen and D. L. Keairns, Particle Segregation in Fluidized Bed, Chemical Engineering Research, Westinghouse Electric Corporation, The Canadian Journal of Chemical Engineering, Vol. 53, August, 1975.*
2. *Peter J. O'Rourke and Dale M. Snider. A new blended acceleration model for the particle contact forces induced by an interstitial fluid in dense particle/fluid flows. Powder Technology, 256():39 – 51, 2014.*
3. *R. Beetstra, M.A. van der Hoef, J.A.M. Kuipers, Numerical study of segregation using a new drag force correlation for polydisperse systems derived from lattice-Boltzmann simulations, Chemical Engineering Science 62 (2007) 246 – 255*

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