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



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

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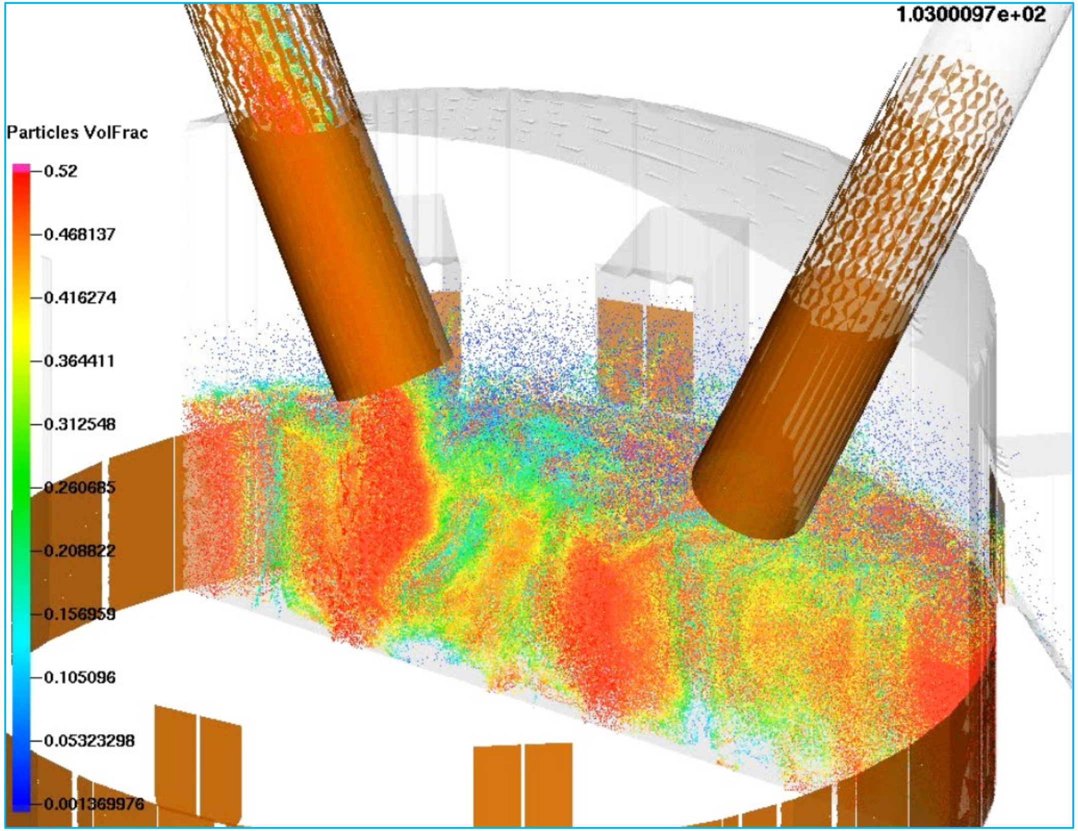
About HATCH Ltd.

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

For more info: www.hatch.com

CPFD Barracuda Virtual Reactor® Software

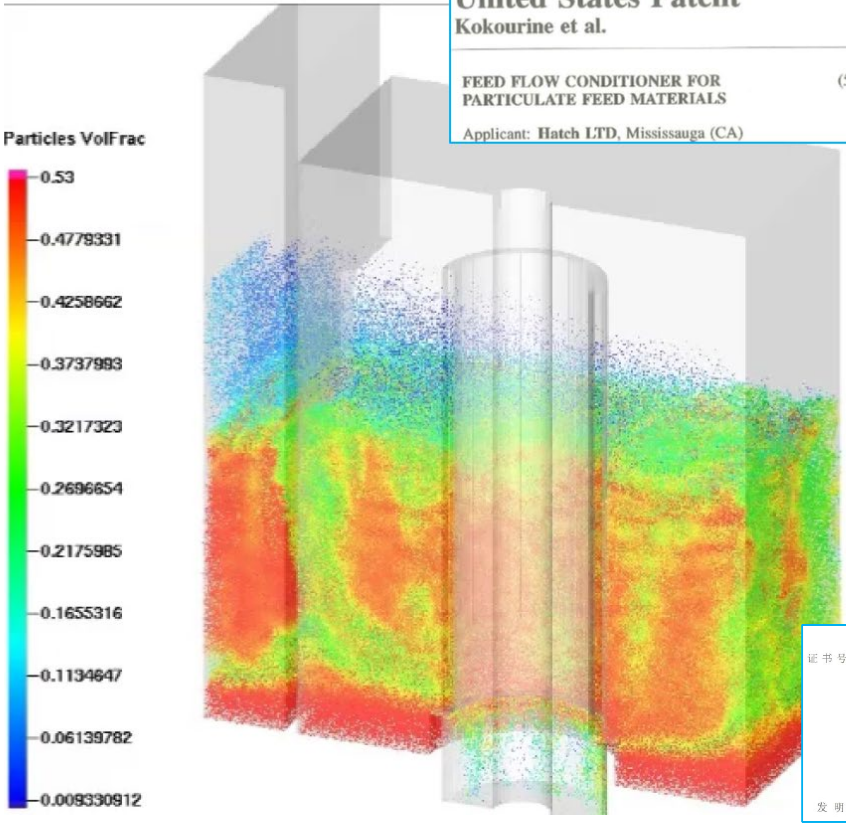
- Hatch uses **CPFD Barracuda** software since 2012
- Multiple Fluid Bed (FB) systems were designed and/or optimized:
  - ❑ Bubbling, Spouted and Circulating FBs
  - ❑ Roasters, Calciners, Dryers, and Unconventional Reactors
  - ❑ Cyclones, Classifiers, and Feed Systems

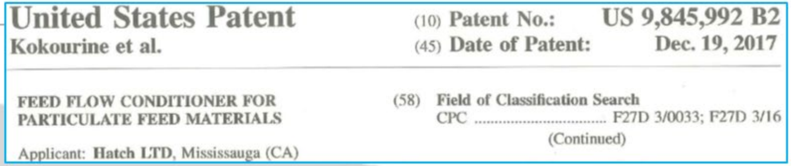


CPFD Barracuda Virtual Reactor® Software

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

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

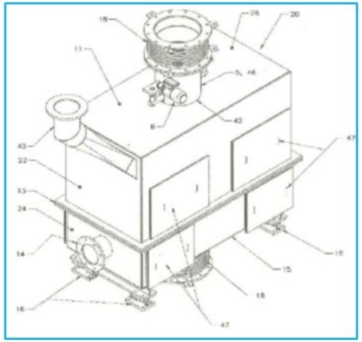



United States Patent (10) Patent No.: US 9,845,992 B2
Kokourine et al. (45) Date of Patent: Dec. 19, 2017

FEED FLOW CONDITIONER FOR PARTICULATE FEED MATERIALS

Applicant: Hatch LTD, Mississauga (CA)

(58) Field of Classification Search
CPC F27D 3/0033; F27D 3/16
(Continued)



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Segregation

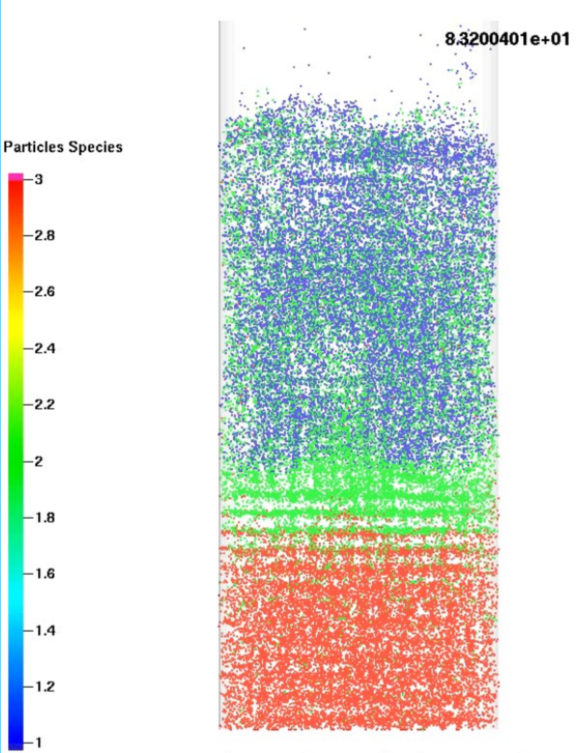
- Segregation of particles in fluid beds under aerodynamic drag and gravity occurs due to differences in particles density and size:
  - ✓ *Particle distribution in space vs. space velocity (pseudo steady state conditions)*
  - ✓ *Particle segregation in time (transient solution)*

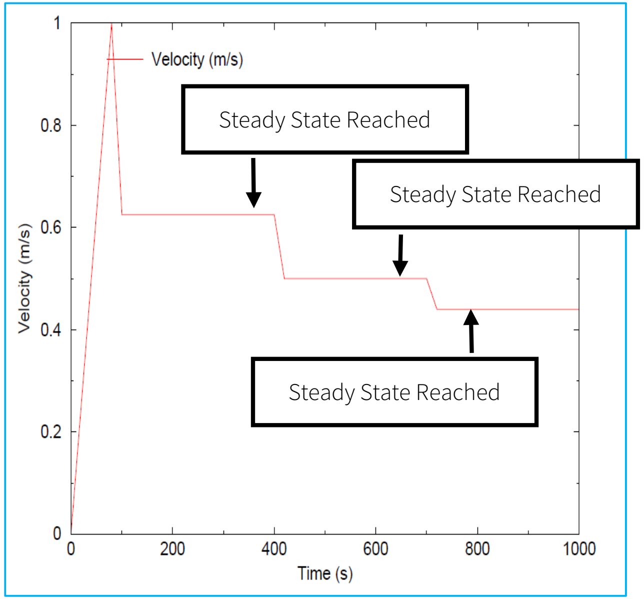
- Material segregation can cause process failure in FB reactors in mining and oil & gas industries when PSD and density of solids change during campaign. As such, process parameters adjustment is critical for:
  - ✓ *reflections of those variations*
  - ✓ *process efficiency optimization*

CPFD Investigation of Multicomponent Beds Segregation vs. Space Velocity

Multicomponent Bed (Three Species):

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





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

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]*

Three-component mixture:
same material, different particle size

- 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 %

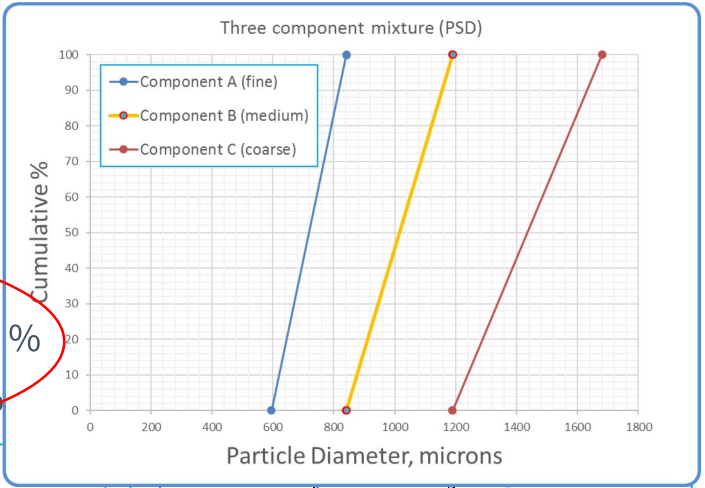
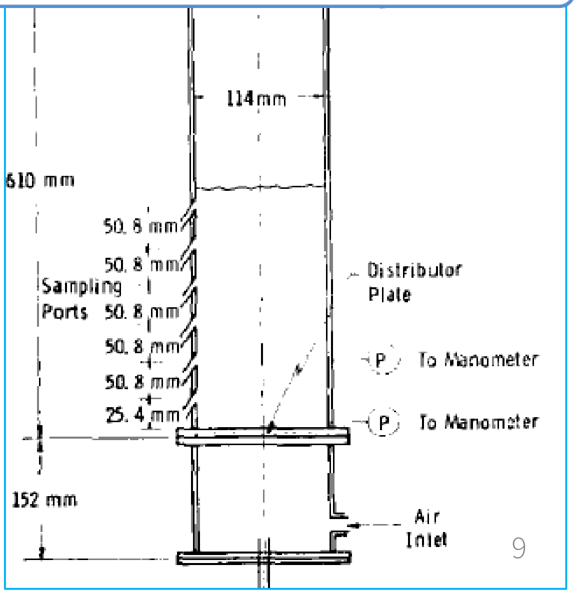


TABLE 4

PARTICLE DISTRIBUTION OF THREE-SIZE MIXTURE WITH THE U_{mf} RATIO OF TWO ADJACENT PARTICLES LESS THAN 2

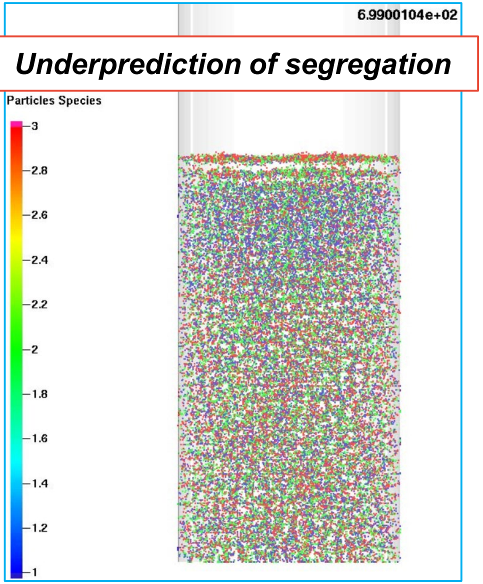
Bed Material – 33.3% 1680 × 1190 μm, 33.3% 1190 × 841 μm, 33.3% 841 × 595 μm
Bed Height – 0.2 m
Temperature – 24.4°C
Pressure – 101 to 122 kPa

Fludizing Velocity (m/sec)	Particle Size (μm)	U_{mf} (m/sec)	Bed Composition, Wt. Percent mm from Distributor: 0 – 38.1	95.2 – 121.0	171.0 – 197.0
0.625	1680 — 1190	0.824	57.6	30.8	31.1
	1190 — 841	0.580	26.2	30.6	27.8
	841 — 595	0.372	16.2	38.6	41.1
0.50	1680 — 1190	0.824	53.8	31.2	27.3
	1190 — 841	0.580	26.2	29.3	29.2
	841 — 595	0.372	20.0	39.5	43.5
0.44	1680 — 1190	0.824	52.3	34.4	26.2
	1190 — 841	0.580	26.6	27.8	29.8
	841 — 595	0.372	21.1	37.8	44.0



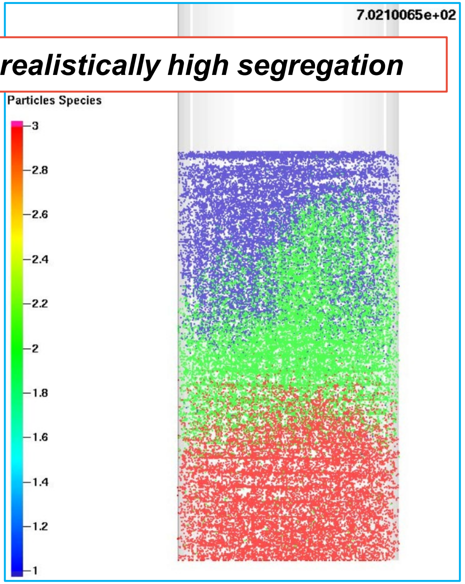
Three-component mixture: Qualitative Results

Underprediction of segregation



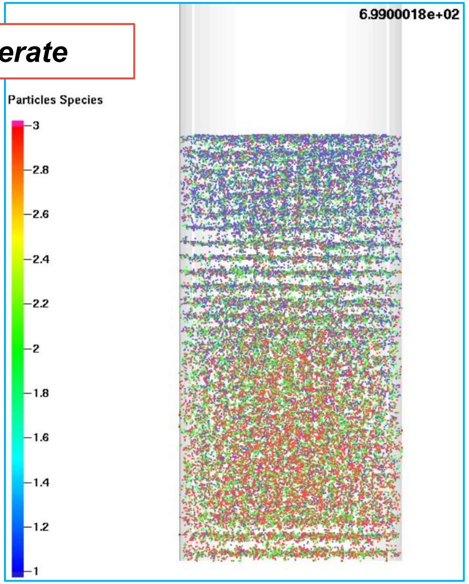
Wen-Yu drag model with BAM (by default)

Unrealistically high segregation



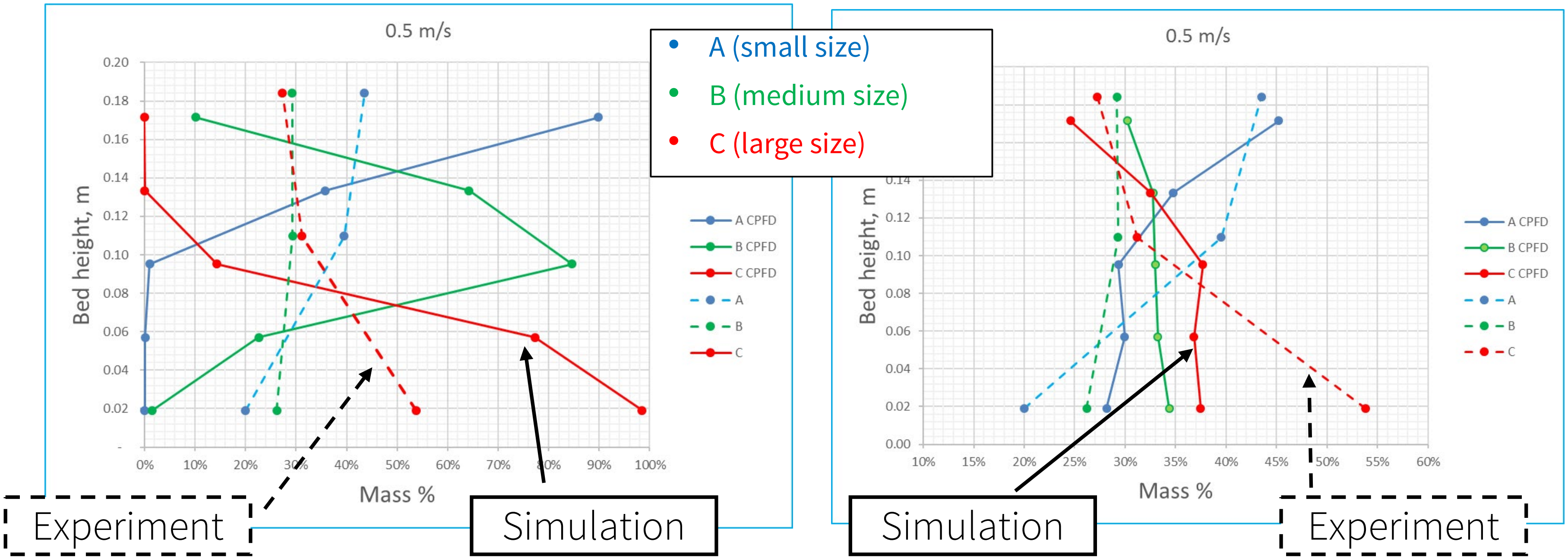
Wen-Yu drag model with BAM (tuned)

Moderate



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

Three-component mixture: Quantitative Results



Wen-Yu drag model with BAM (tuned)

Unrealistically high segregation

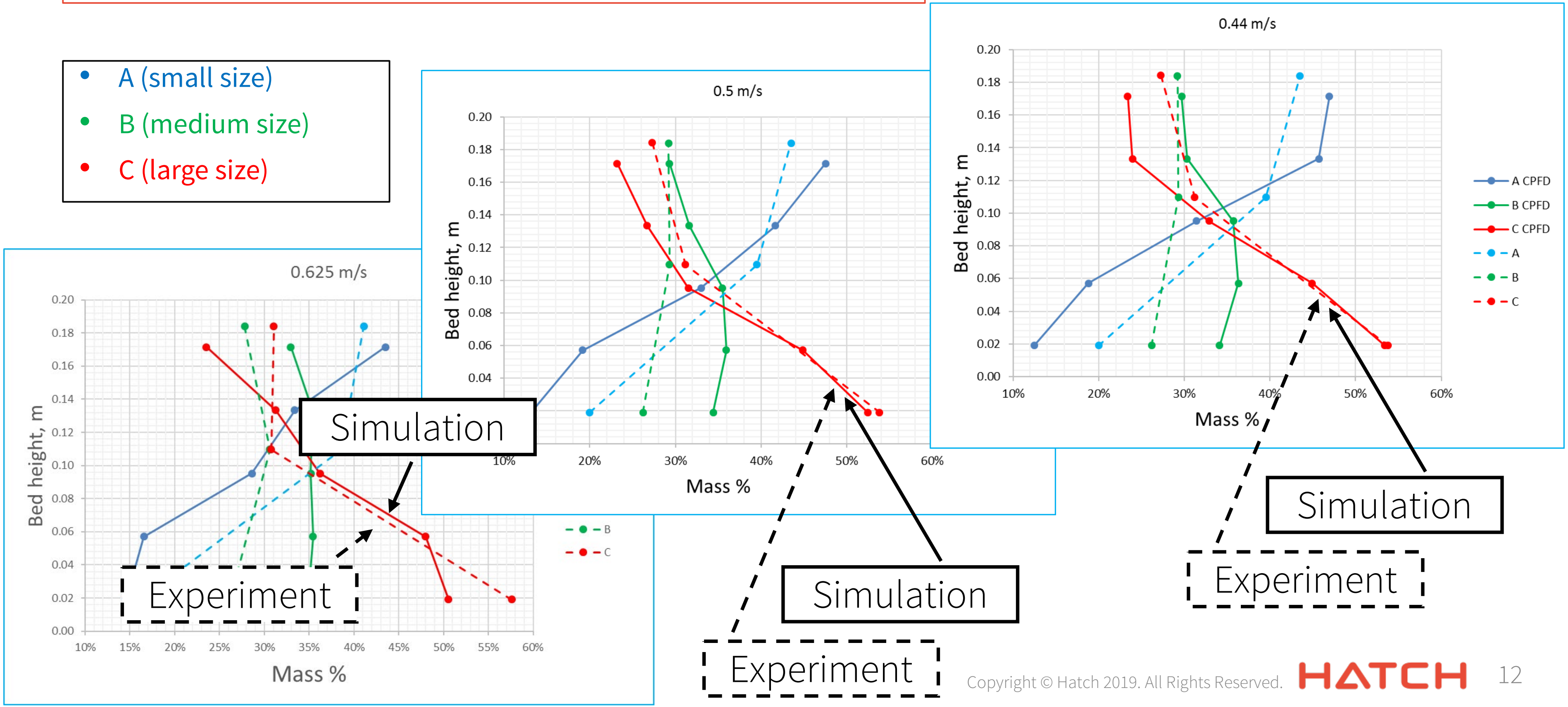
Wen-Yu drag model with BAM (by default)

Underprediction of segregation

Three-component mixture: best results

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

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



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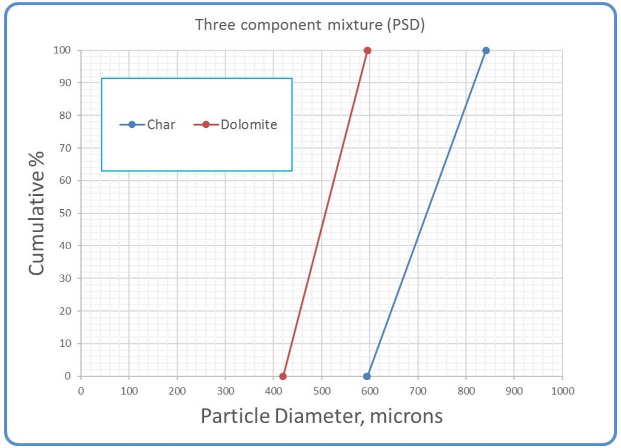
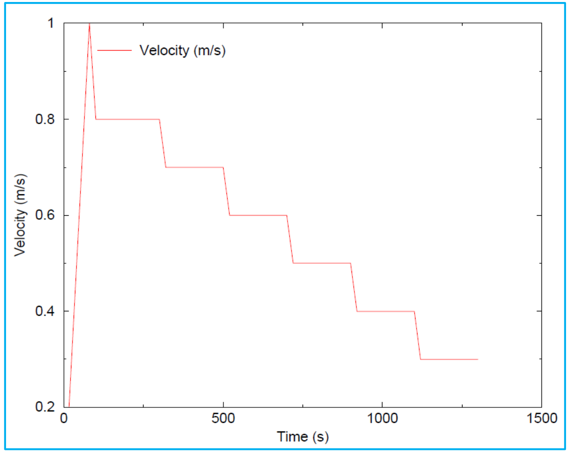
Two-component mixture: different (density), similar size

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





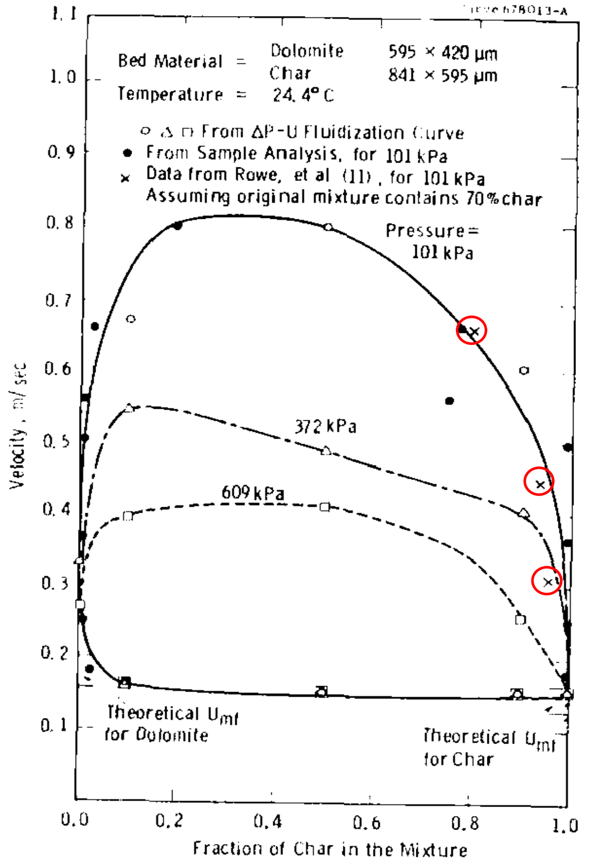
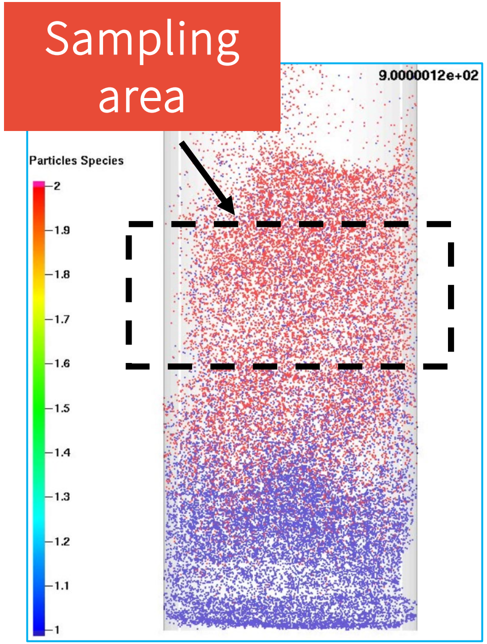
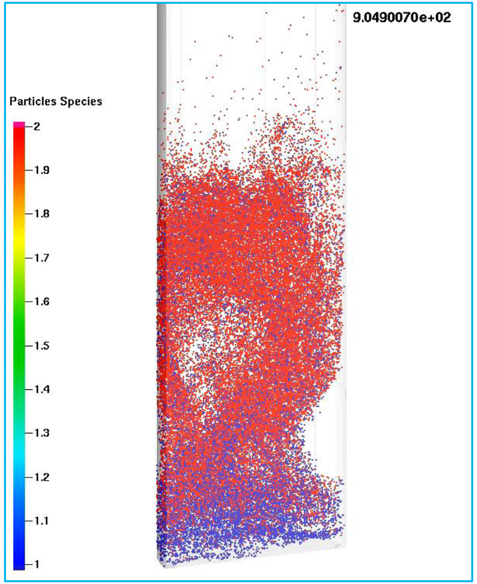


Figure 9 — Phase diagram for two-component char-dolomite mixture.

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

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





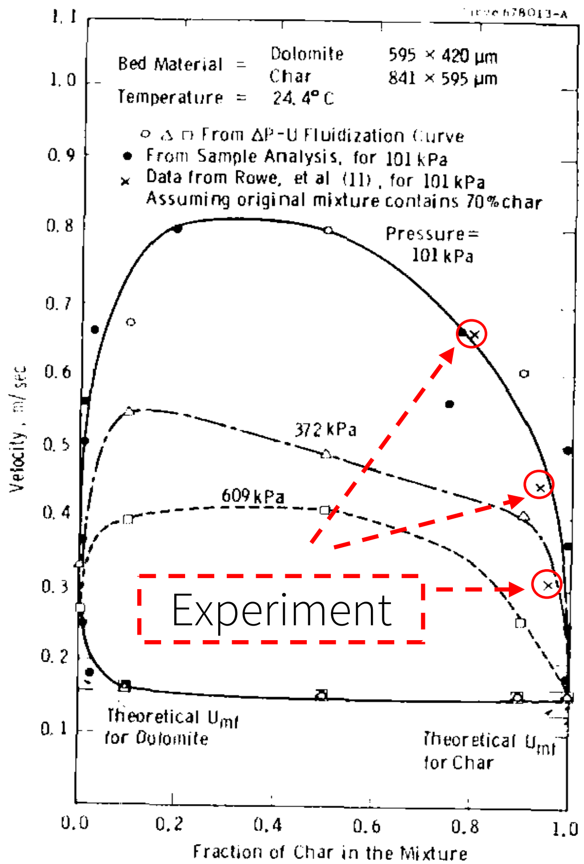
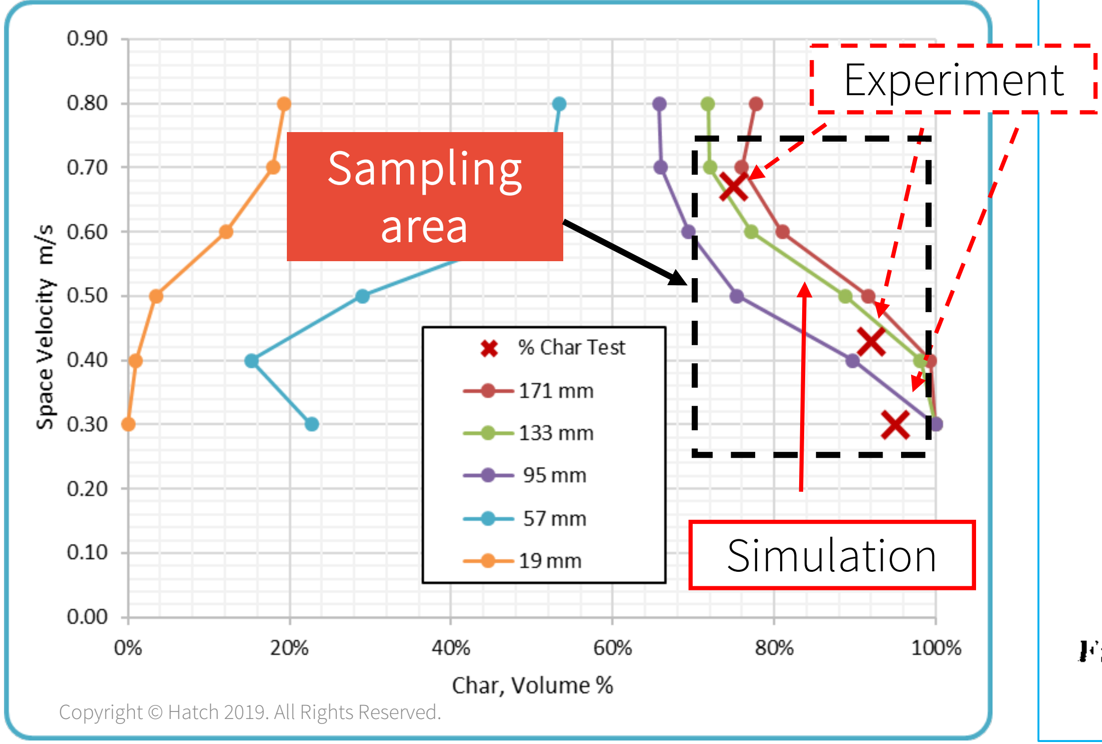


Figure 9 – Phase diagram for two-component char-dolomite mixture.

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

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



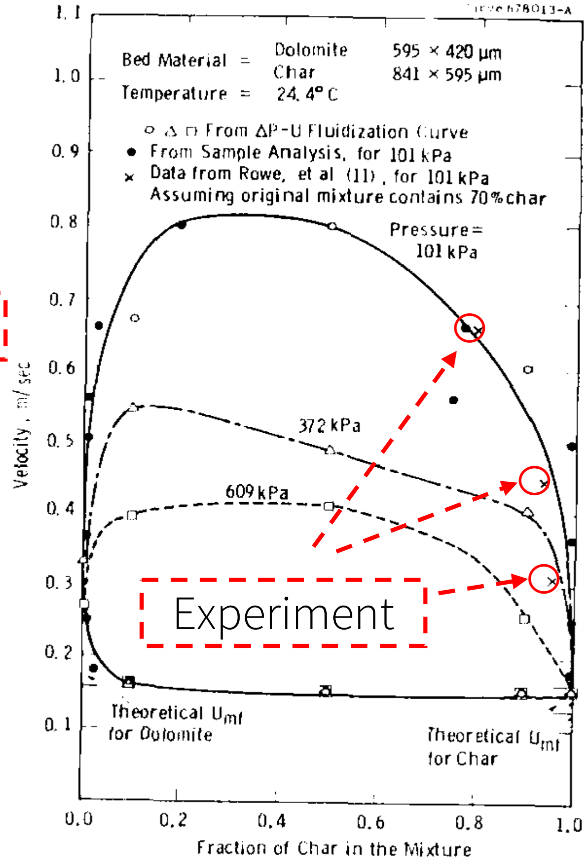
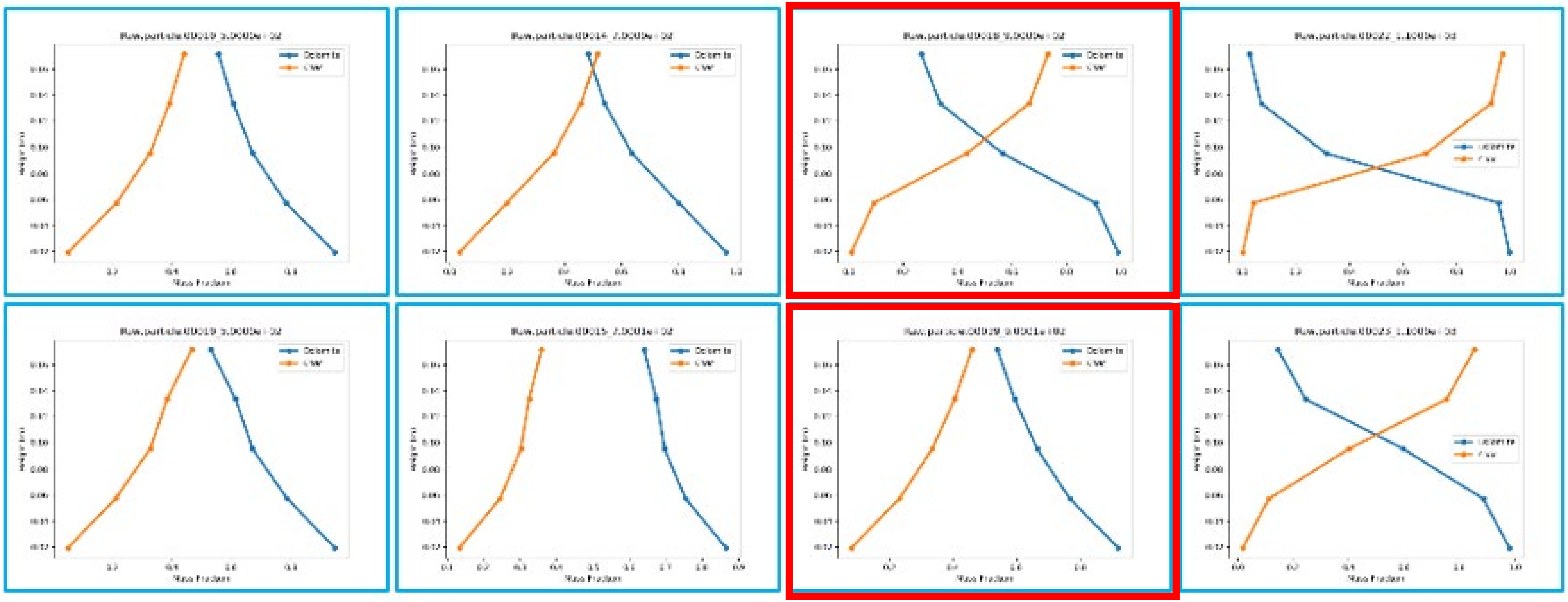


Figure 9 — Phase diagram for two-component char-dolomite mixture.

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).

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).

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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.

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

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.

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*

Thank you.

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