Fine-Grid Simulations of Gas-Solids Flow in a Circulating Fluidized Bed

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Introduction

- **Two-fluid or continuum model based simulations are commonly conducted on coarse computational mesh requiring subgrid model.**

- **Based on some publications[1], some doubts still remain if finely resolved two-fluid simulations can capture basic experimental observations of solids hold-up and pressure drop profiles in risers.**

- **We will first show some results[2] using subgrid models and then attempt to obtain similar results using grid-refined two-fluid simulations with no subgrid corrections.**

[1] Lu, B.; Wang, W.; Li, J. *Chem. Eng. Sci.* 2009; 64; 3437-3447.
[2] Benyahia, S. *AIChE J.* doi: 10.1002/aic.12603

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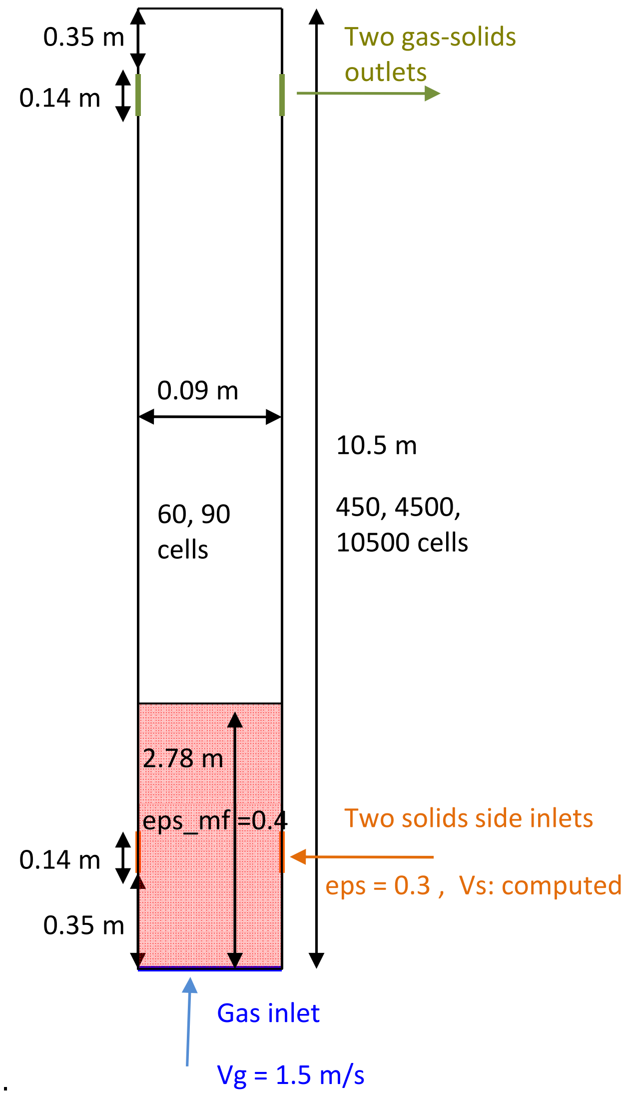
Purpose of this presentation

- **First show that coarse two-fluid simulations can provide reasonable accuracy with the help of subgrid models (this is a continuation of my last year presentation.)**
- **Then, demonstrate that two fluid simulations without subgrid models will predict the correct experimental observations as the grid is refined**
- **Finally, show the necessity to invest more research in the development of subgrid models due to significant computer time requirements to conduct these fine grid simulations.**

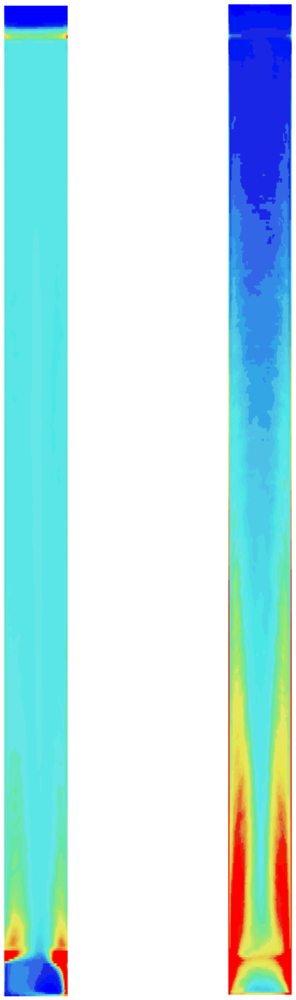
Two-fluid simulation conditions[1]

Process temperature	297 K
Process pressure	1.01 x 10^5 Pa
Air density	~1.2 kg/m^3
Air viscosity	1.8 x 10^{-5} Pa·s
Gas-phase turbulence length-scale	0.01 m
Solids density	930 kg/m^3
Particle diameter	54 micron
Single-particle terminal velocity	0.074 m/s
Particle-particle restitution coefficient	0.9
Particle-wall restitution coefficient	0.7
Specularity coefficient	0.0001
Particle-particle angle of internal friction	pi/6
Particle-wall angle of friction	pi/16
Void fraction at maximum packing	0.4
Void fraction at minimum fluidization	0.6



[1] Lu, B.; Wang, W.; Li, J. *Chem. Eng. Sci.* 2009; 64; 3437-3447.

Coarse grid simulation results

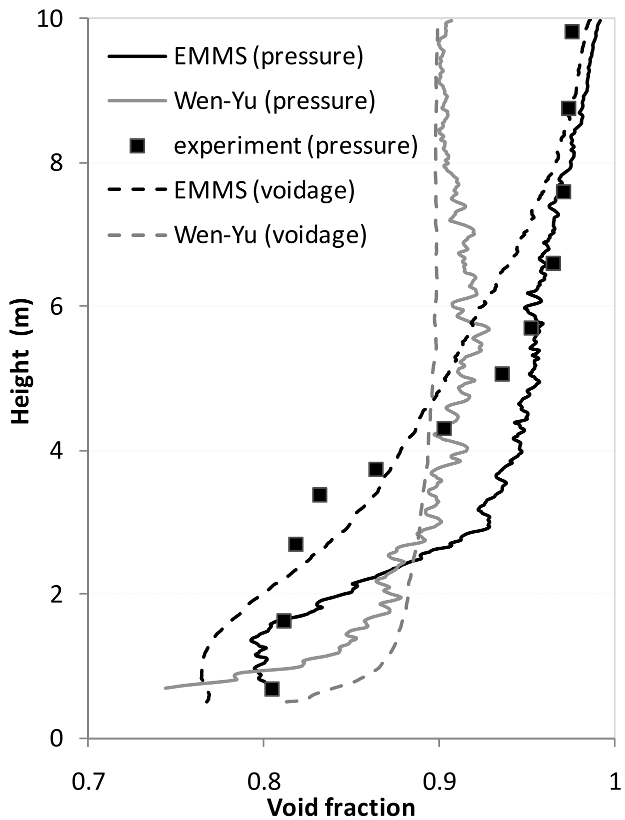


Wen-Yu drag

EMMS drag

Time-averaged

Drag model	Wen-Yu	EMMS	Experimental
Solids mass flux (kg/m^2s)	205	16.9	14.3
Standard deviation (kg/m^2s)	25.2	5.59	-



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Coarse-grid simulation results

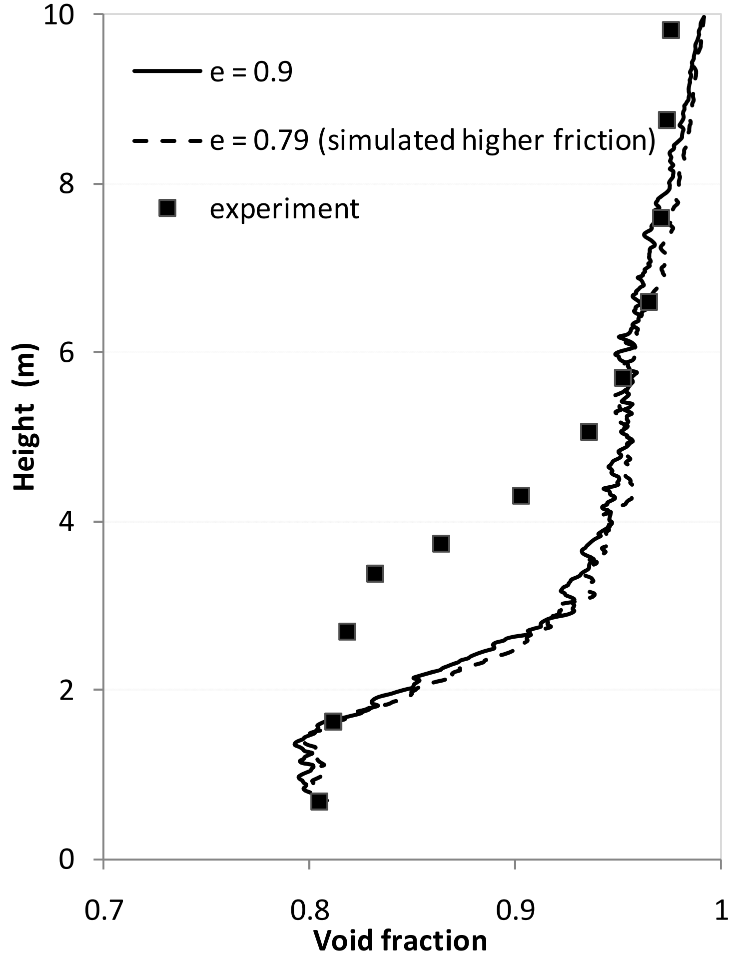
- **There is clearly a need to "correct" the drag force as coarse-grid simulations fail to predict the solids hold-up.**

- **There is a significant difference in the computed solids hold-up and the one deduced from pressure-gradient. Note that measurements are based on pressure*.**

- **So even with drag corrections, there is still disagreements between measurements and simulation data, which will be investigated in the next slides…**

*All subsequent results will be based only on our computed pressure gradient data.

Effect of particle-particle friction



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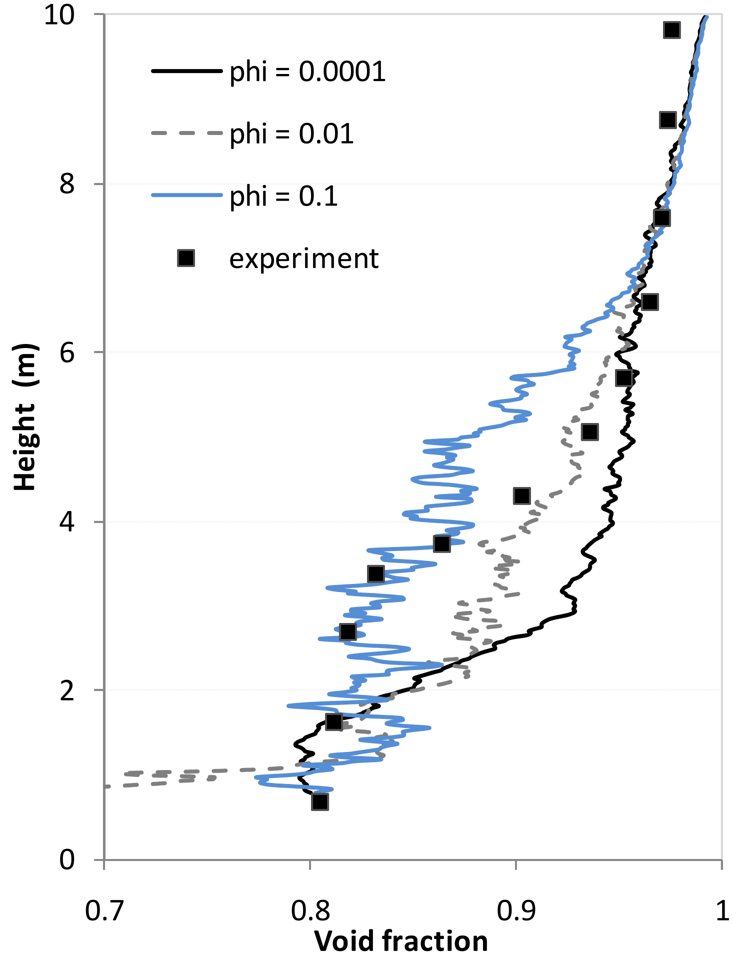
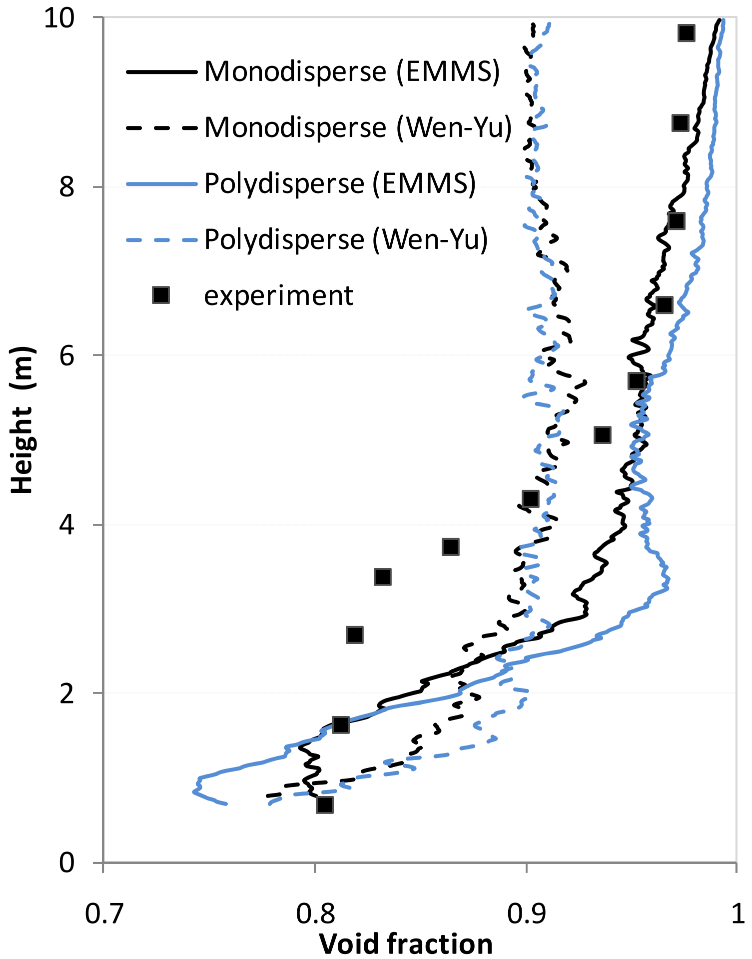
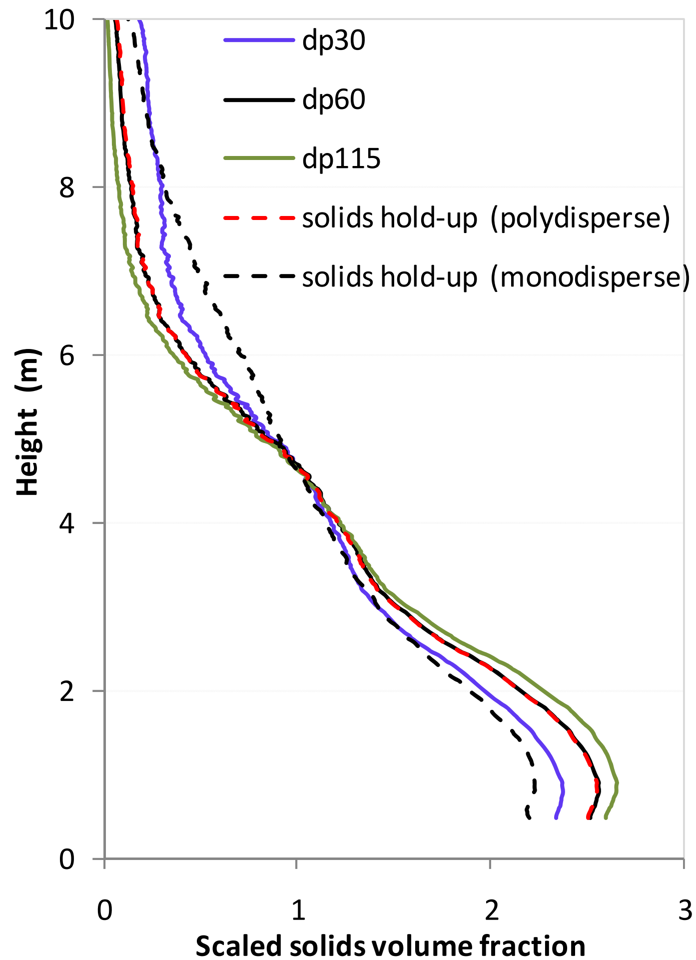
Effect of particle-wall friction



[3] Li, T; Benyahia, S. *AIChE J*. doi: 10.1002/aic.12728

Effect of polydispersity





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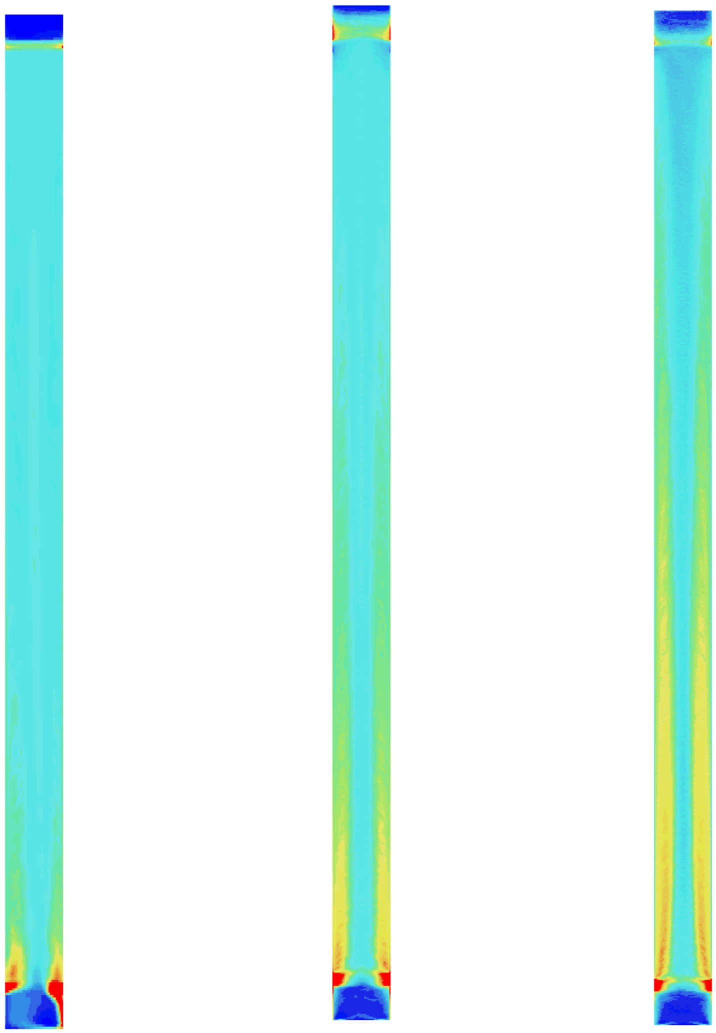
Coarse-grid simulation results

- **There is clearly a need to correct the drag force for both mono- and poly-disperse systems with a coarse grid.**
- **Next we present results of refined two-fluid simulations using a standard homogeneous drag correlation.**

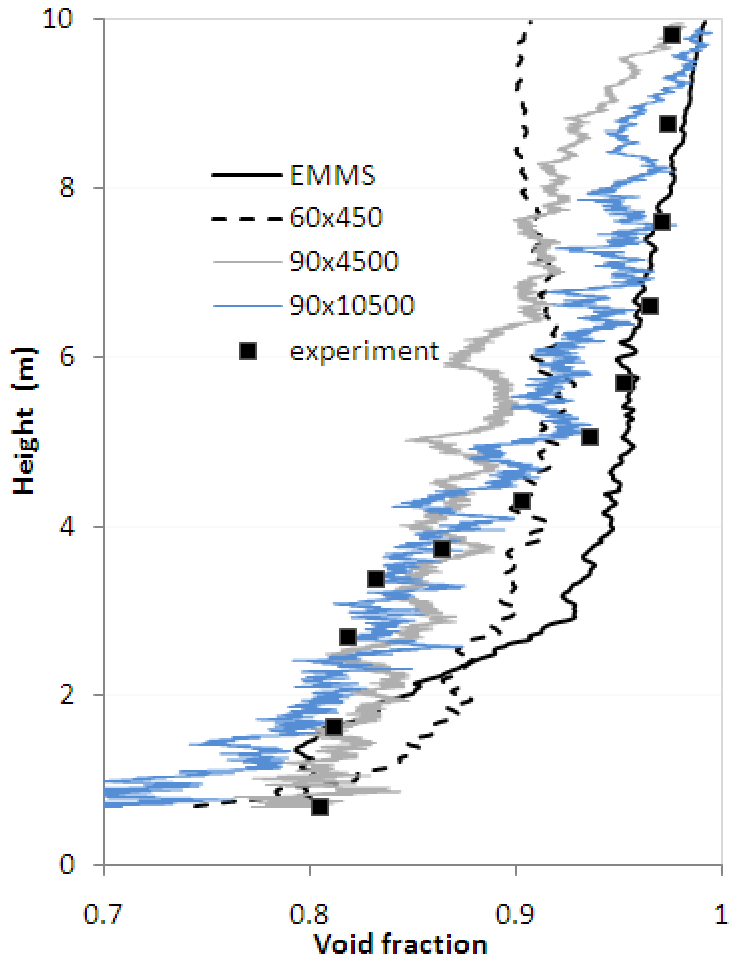
Fine-grid simulation results



Coarse 60x450 | 60x4500 | 90x10500 or 1 mm^2 cells

Grid resolution	Solids mass flux (kg/m^2s)
60x450	205
60x4500	200
90x10500	140
EMMS	16.9
Experimental	14.3

Fine-grid simulation results



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Summary

- **This study shows that more accurate results are obtained as the grid is refined, but a grid-converged[3] solution was not obtained even with 1 M cells!**

- **It is, therefore, necessary to include sub-grid corrections due to the large computational requirements and time needed to conduct fully-resolved simulations.**

[3] Wang, J.; van der Hoef, MA.; Kuipers, JAM. *Chem. Eng. Sci.* 2009; 64; 622-625.