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

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Multiphase Flow Science Workshop
August 16-18, 2011
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.


\(^2\) Benyahia, S. AIChE J. doi: 10.1002/aic.12603
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

- Process temperature: 297 K
- Process pressure: 1.01 x 10^5 Pa
- Air density: ~1.2 kg/m³
- Air viscosity: 1.8 x 10^-5 Pa·s
- Gas-phase turbulence length-scale: 0.01 m
- Solids density: 930 kg/m³
- 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

Coarse grid simulation results

<table>
<thead>
<tr>
<th>Drag model</th>
<th>Wen-Yu</th>
<th>EMMS</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids mass flux (kg/m²s)</td>
<td>205</td>
<td>16.9</td>
<td>14.3</td>
</tr>
<tr>
<td>Standard deviation (kg/m²s)</td>
<td>25.2</td>
<td>5.59</td>
<td>-</td>
</tr>
</tbody>
</table>

![Data visualization]

**Wen-Yu drag**

**EMMS drag**

**Time-averaged**
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

\[ e = 0.9 \]

\[ e = 0.79 \text{ (simulated higher friction)} \]

experiment
Effect of particle-wall friction

\[ \phi = 0.0001 \]

\[ \phi = 0.01 \]

\[ \phi = 0.1 \]

Li, T; Benyahia, S. *AIChE J.* doi: 10.1002/aic.12728
Effect of polydispersity

- Monodisperse (EMMS)
- Monodisperse (Wen-Yu)
- Polydisperse (EMMS)
- Polydisperse (Wen-Yu)
- experiment

- dp30
- dp60
- dp115

- solids hold-up (polydisperse)
- solids hold-up (monodisperse)
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

<table>
<thead>
<tr>
<th>Grid resolution</th>
<th>Solids mass flux (kg/m²s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60x450</td>
<td>205</td>
</tr>
<tr>
<td>60x4500</td>
<td>200</td>
</tr>
<tr>
<td>90x10500</td>
<td>140</td>
</tr>
<tr>
<td>EMMS</td>
<td>16.9</td>
</tr>
<tr>
<td>Experimental</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Coarse 60x450

60x4500

90x10500 or 1 mm² cells
Fine-grid simulation results
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.