Comments on mean bed pressure drop in SSCP-I

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Early in 2013, the NETL Multiphase Flow Science (MFS) Team formulated a new fluidization modeling challenge problem in the same vein as orginally proposed by Prof. John Chen at Fluidization VII in 1992. Unlike the three preceding challenge problems [1, 2, 3], the new problem targeted a much smaller scale, thus named SSCP-I: the first small-scale challenge problem [4]. The purpose of the scale reduction was two-fold. For one, the small size allows the problem to be simulated by a variety of numerical methods. (*The number of particles is selected so as to ensure that two fluid models, MP-PIC, and DEM simulations can be performed.*) Secondly, it was assumed that the table-top design would help reduce measurement uncertainties, ultimately producing higher-fidelity data. (*The purpose of SSCP-I is to improve the reliability of computational modeling of multiphase flows by validating with accurate and well defined experimental data.*)

Unfortunately, the mean bed pressure drop reported as part of the SSCP-I seems to contain significant measurement error. Nearly all of the responses to the SSCP-I showed an over-prediction of mean bed pressure drop compared to the experiments [5, 6]. Although MFS team members were not a part of the blind study, internal simulations have yielded analogous results. For example, see Fig. 1. for representative MFiX-DEM and MFiX-PIC results. Similar findings have been almost universally found in simulations of the SSCP-I reported in the literature since its release [7, 8, 9, 10, 11, 12].

Typically experimental data is treated as truth, or at least the most accurate estimation of reality, and discrepancies with a numerical simulation are the result of model form error [13], i.e., deficiencies in the model due to missing physics. However, this exercise appears to be a case of CFD informing experiments. In addition to the overwhelming numerical evidence, the simulated beds are in better agreement with simple back of the envelope intuition.

Neglecting contributions due to wall drag, we expect the full bed pressure drop to equal the weight-over-area of the bed, $DP_{tot} \approx |\boldsymbol{g}| M/WD$ just at or beyond minimum fluidization. Given the amount of material, $M = 1.9$ kg, and bed dimensions, $W = 23$ cm and $D = 7.5$ cm in width and depth, respectively, we have $DP_{tot} = 1080$ Pa. The reported static bed height, $h_{bed} = 15.24$ cm, falls between the pressure taps of the main bed pressure drop measurement at elevations of 4.13 cm to 34.61 cm. Therefore, assuming the pressure drop varies linearly gives $DP_{bed} = DP_{tot} * (15.24 - 4.13)/15.24 = 787$ Pa. We note further that beyond U_{mf}, bubbling is expected to expand the effective bed volume, moving material from below the 4.13 cm pressure tap to the main measurement interval, thus increasing DP_{bed}. For example, given the reported static bed height and assuming the particles are monodisperse with uniform diameter $d_p = 3.256$ mm and density $\rho_p = 1131$ kg/m^3, the static packing fraction is $\phi_0 \approx N_p(\pi/6)d_p^3/h_{bed}WD = 0.639$. Roughly taking the bed to expand uniformly to only $\phi = 0.5$, the bed pressure drop (in the main bed section) increases to 850 Pa, in fairly good agreement with the numerical results.

Conversely, the experimental measurement is below the minimum fluidization pressure drop. The most obvious explanation for a decrease in DP_{bed} is that material has been thrown above the upper pressure tap at 34.61 cm. However, the reported pressure drop in the upper region is negligibly small for the two lower flow conditions, $U = 2$ and $3U_{mf}$. (There is a non-negligible pressure drop in the upper section for the higher flow condition, hence the drop in DP_{bed} at $U = 4U_{mf}$.) Another explanation could be that the bed packing is non-uniform and more particles are located below the lower pressure tap than expected. However, this seems unlikely given that the uniform bed packing is already quite high, $\phi_0 = 0.639$. For reference, the lower 4.13 cm of the bed would need to have a solids packing of $\phi \approx 0.83$ in order to reduce the bed pressure drop in the main region to 700 Pa. This simply does not seem plausible at flow conditions of $2U_{mf}$ and above.
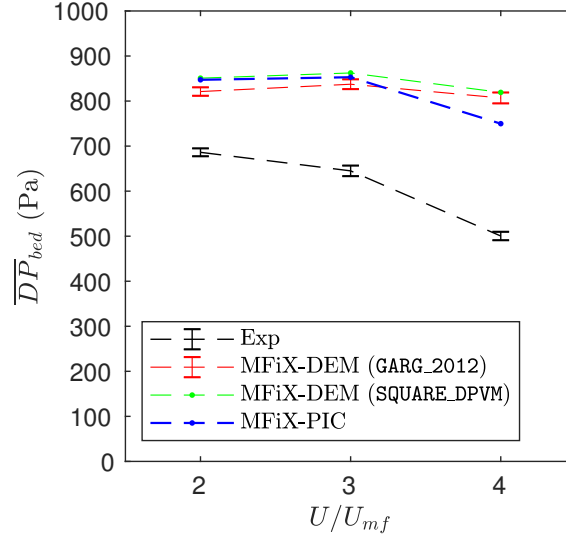
Figure 1: Time-averaged mean bed pressure drop measured from elevations of 4.13 cm to 34.61 cm above the distributor/inlet. MFiX-DEM simulation results provided by WDF carried out on Release 2016.1 codebase. MFiX-PIC simulation results provided by MAC carried out on Release 19.1 codebase.

Although the ultimate cause of the low pressure drop remains a mystery, we believe that the most likely culprits may be:

- Some of the material was mechanically supported by the bed and not fluidized by the gas, potentially due to corrosion in the distributor plate.

- Incorrect bed mass, either by an incorrect/inaccurate original bed mass measurement or if some of the material was lost during the experiments.

- Instrumentation/measurement bias, e.g., from improperly calibrated equipment.

Though the outcomes may not have been ideal, nor intended, the SSCP-I exercise underscores the challenges associated with particulate multiphase flow measurement, especially at small scales, and highlights the dangers of over-calibrating models to match experimental data.

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