Technical Report

STUDY OF GAS-SOLID FLUIDIZED BED - TUNING SYAMLAL O'BRIEN DRAG MODEL

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Introduction

The inter-phase momentum transfer between gas and solid phase is accounted for by the drag force. Several researchers [6, 4, 2, 3] have proposed correlations for modeling drag for gas - particle flows. In this report, we will be focusing on the steps needed to tune the Syamlal O'Brien drag law.

Governing equations

At minimum fluidization condition, force balance yields the following equation -

$$\frac{A_D}{\alpha_g}.(v_{mf}) = (1-\alpha_g).(\rho_s-\rho_g).g. \tag{1}$$

where,

$$A_D = \frac{3}{4}.\frac{\alpha_s.\alpha_g.\rho_g}{d_s}.C_D.|v_{mf}|. \tag{2}$$

The idea of the tuning process is to get correct estimate of C_D for given minimum fluidization velocity, v_{mf}, such that equation 1 is satisfied.

Equation 1 can be re-cast in the following form,

$$\frac{3}{4}C_{Ds}Re_{ts}^2 = \frac{3}{4}C_D Re_t^2 = Ar \tag{3}$$

The above relation holds for a single particle as well as a cluster of particles. C_{Ds} is the drag coefficient for a single particle. Re_{ts} is the Reynolds number based on terminal settling velocity of single particle. The quantities without the s subscript are those for a group of particles. Ar, the non-dimensional Archimedes number, is a function of the known quantities and given by,

$$Ar = \frac{\rho_g}{\mu_g^2}\ d_p^3\ (\rho_p-\rho_g)\ g. \tag{4}$$

It is useful at this point to define V_r as the ratio of single particle terminal velocity to that of a cluster of particles.

$$V_r = \frac{Re_t}{Re_{ts}}. \tag{5}$$

Substituting for V_r in equation 3, yields following relation between single and multi-particle drag coefficients,

$$C_D = \frac{C_{Ds}}{V_r^2}. \tag{6}$$

Syamlal-O'Brien Drag Law

The single particle drag law employed by Syamlal-O'Brien is that given by Dalla Valle:

$$C_{Ds} = \left[0.63 + \frac{4.8}{\sqrt{Re_{ts}}}\right]^2. \tag{7}$$

To complete the modeling, Syamlal-O'Brien choose a analytical formulation for V_r as proposed by Garside and Al-Dibouni:

$$V_r = 0.5\left[A - 0.06\mathrm{Re}_t + \sqrt{0.0036\mathrm{Re}_t{}^2 + 0.12\mathrm{Re}_t\left(2B - A\right) + A^2}\right] \tag{8}$$

where

$$A = \epsilon^{4.14} \tag{9}$$

and

$$B = \begin{cases} C_2\, \epsilon^{1.28} & \epsilon \le 0.85 \\ \epsilon^{C_1} & \epsilon > 0.85 \end{cases} \tag{10}$$

The default values of C_1 and C_2 are 2.65 and 0.8 respectively.

To ensure continuity of B, C_1 and C_2 are related by the following relationship:

$$C_1 = 1.28 + \frac{\log C_2}{\log 0.85} \tag{11}$$

Adjustment of Syamlal-O'Brien Drag law

From the known quantities, the Archimedes number can be estimated using equation 4. Substituting eqn. 7 in eqn. 3 gives an explicit formula for Re_{ts}.

$$Re_{ts} = \left[\frac{\sqrt{4.8^2 + 2.52\sqrt{\frac{4\mathrm{Ar}}{3}}} - 4.8}{1.26}\right]^2 \tag{12}$$

For fluidized beds where information about the minimum fluidization velocity, U_{mf} is available, the multi-particle Reynolds number can be calculated as follows,

$$Re_t = \frac{\rho_g\, U_{\mathrm{mf}}\, d_p}{\epsilon_{\mathrm{mf}}\mu_f}. \tag{13}$$

Note that since the minimum fluidization velocity is specified as the superficial velocity, we need to divide it by the gas volume fraction at minimum fluidization condition, ϵ_{mf}. Typically we assume $\epsilon_{\mathrm{mf}} = 0.4$.

For small particles or for small Reynolds numbers ($Re_t < 20$), the following expression obtained from first term of Ergun equation can be used to estimate $\epsilon_{\rm mf}$,

$$U_{mf} = \frac{d_p^2\left(\rho_p - \rho_g\right)\, g}{150\mu_g}\frac{\epsilon_{\rm mf}^3}{1-\epsilon_{\rm mf}}. \tag{14}$$

Knowing Re_{ts} and Re_t, V_r can be estimated using eqn. 5. Note that during the tuning process, the void fraction, ϵ, used in equations 9 and 10 should be $\epsilon_{\rm mf}$.

Finally, C_2, can be estimated from eqn. 8.

The parameter C_1 is obtained from C_2 using equation 11.

Demo case

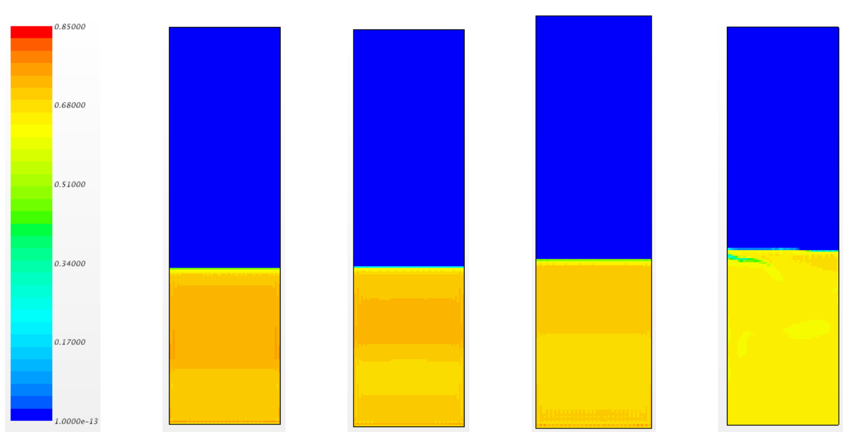
To demonstrate the effectiveness of the described tuning process, the case reported by Taghipour et.al.[5] has been chosen. Several simulations were computed using the Eulerian multiphase model in STAR-CCM+. The parameters used in the simulations have been listed in Table 1.

Results and Discussions

According to the experimental results of Taghipour et.al. [5] the minimum fluidization velocity(determined experimentally) and the pressure drop at that condition were 0.065 m/s and 4400 Pa, respectively. The static bed height used in the present study is 0.47 m while that in the experiments is 0.4 m. However according to the study of Karnik et. al[1], the minimum fluidization velocity is independent of the initial packing height of the column. The fluidization velocity at the inlet was varied from 0.9 - 1.5U_{mf}, to check if the Syamlal model predicts correct fluidization conditions with original parameters. These parameters were then tuned using the procedure described before and the modified parameters demonstrate better agreement with the experimental results. Simulations were run for 5s of physical time and quantities have been averaged during the period of 3-5s. The screen-shots of the column at 3s have been shown in the Figure 1, for different velocities with original value of C_1 and C_2(0.8 and 2.65 respectively).

Table 1: Simulation parameters

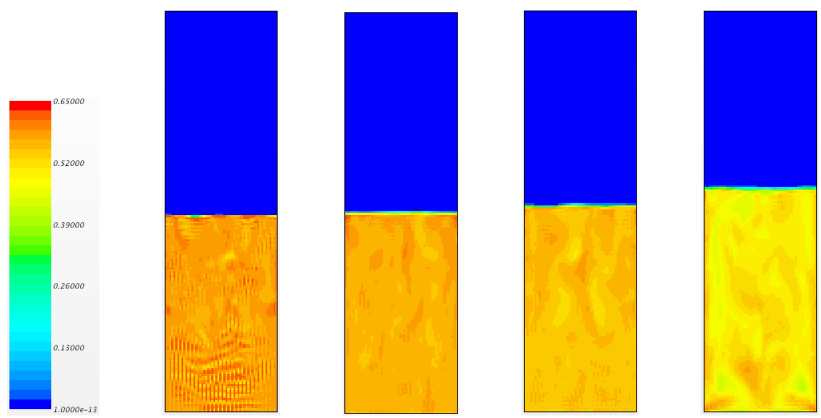
Description	Value	Comment
Particle density, ρ_P	2500 kg/m^3	Glass beads
Gas density, ρ_g	1.225 kg/m^3	Air
Mean Particle Diameter, d_p	275 μ m	Uniform distribution
Restitution coefficient, e_{ss}	0.9	From literature
Initial solids packing, α_{s0}	0.60	Fixed value
Superficial gas velocity, U	0.14625-0.325 ms	0.9- 2U_{mf}
Bed width	0.28 m	Fixed value
Bed height	1 m	Fixed value
Static bed height	0.47 m	Fixed value
Grid interval spacing	0.005 m	Specified
Inlet boundary condition	Velocity	True velocity
Outlet boundary condition	Pressure	
Time-step size	0.001 s	Specified
Maximum number of iterations	20	Specified



(a) Volume Fraction of Particle (b) $0.9U_{mf}$ (c) $1.0U_{mf}$ (d) $1.1U_{mf}$ (e) $1.5U_{mf}$

Figure 1: Solid Volume Fraction snapshots at different fluidization velocities (C_1=0.8 and C_2 = 2.65)

The figure 1 clearly shows that no fluidization has occurred in the bed even with fluidization velocity of $1.5\mathrm{U_{mf}}$. This can be verified numerically by looking at the values of drag as predicted by the Syamlal-O'Brien model at $\mathrm{U_{mf}}$, which is as follows:
The effective weight of particles in the bed taking into account the buoyancy force is = 1933.57 N, while the drag value from Syamlal-O'Brien model is($\frac{A_D}{\alpha_g}$.(v_g - v_s).Volume of bed) = 914.537 N, which is much less than the effective weight and hence we do not see any fluidization in the bed.
Thus it is very clear that the Syamlal-O'Brien drag model needs to be tuned to get better agreement with the experimental results. In their numerical study, Taghipour et.al. [5] suggested C_1 and C_2 values of 9 and 0.28 respectively. These values were then employed in the present work and the particle volume fractions in the bed at different velocities have been shown in Figure 2.

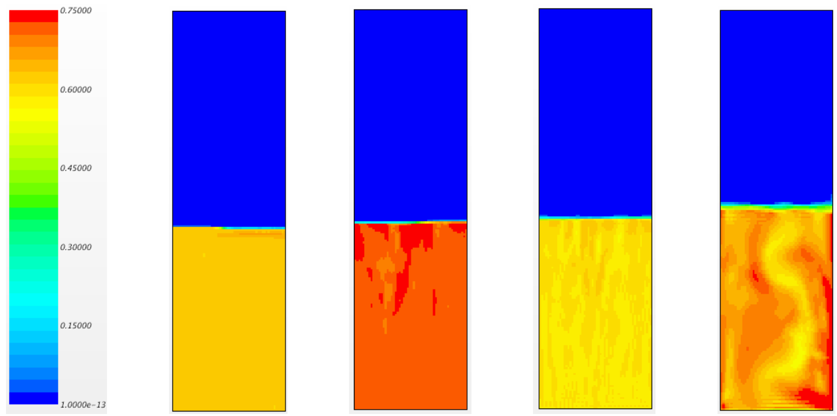


(a) Volume Fraction of Particle (b) $0.9\mathrm{U_{mf}}$ (c) $1.0\mathrm{U_{mf}}$ (d) $1.1\mathrm{U_{mf}}$ (e) $1.5\mathrm{U_{mf}}$

Figure 2: Solid Volume Fraction snapshots at different fluidization velocities (modified $\mathrm{C_1}$=9 and $\mathrm{C_2}$ = 0.28)

In the Figure 2, it can be seen that there are disturbances in the bed even at fluidization velocity of $0.9\mathrm{U_{mf}}$ and an apparent bed expansion is also visible in all four cases. This suggests that with the parameters employed by Taghipour et.al.[5], the fluidization occurs much before $0.9\mathrm{U_{mf}}$. A quick calculation of the value of drag with these parameters give the drag as = 2675.68, which is higher than the effective bed weight suggesting that we should obtain an earlier fluidization with these parameters.

As has already been mentioned that the parameters can also be modified to satisfy equation 1. So, $\mathrm{C_1}$ and $\mathrm{C_2}$ were calculated to satisfy the equation 1 (assuming $\alpha_g = \epsilon_{\mathrm{mf}} = 0.4$). This gives the value of $\mathrm{C_1}$ and $\mathrm{C_2}$ as 7.23 and 0.38 respectively. The simulations were then carried out using these parameters and snapshots of the volume fraction of particles in the column have been shown in Figure 3.



(a) Volume Fraction of Particle | (b) $0.9U_{mf}$ | (c) $1.0U_{mf}$ | (d) $1.1U_{mf}$ | (e) $1.5U_{mf}$

Figure 3: Solid Volume Fraction snapshots at different fluidization velocities (modified C_1=7.23 and C_2 = 0.38)

It is very apparent from the Figure 3 that bed does not fluidize till fluidization velocity of U_{mf} and disturbances in the bed along with expansion starts to occur at $1.1U_{mf}$. Also the value of drag with these parameters at the minimum fluidization condition is = 1915.71 N, which is very close to the effective weight of the bed.

Table 2: Height of the bed for different cases (Initial height of the bed being 47 cm)

U/U_{mf}	C_2 = 0.8	C_2 = 0.28	C_2 = 0.38
0.9	39 cm	48.5 cm	45.5 cm
1.0	40 cm	50.25 cm	47 cm
1.1	40.5 cm	51.75 cm	48.25 cm
1.5	44 cm	87.75 cm	51.75 cm

The height of the bed for various cases was also calculated (having at least 10% of particles by volume) and has been mentioned in Table 2 . This data clearly further endorses the idea that with corrected parameters (i.e. tuning Syamlal-O'Brien drag model with the given method), fluidization can be predicted rather accurately.

References

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