SENSIBILITY ANALYSIS OF 3D TRANSIENT MODEL OF FLUIDIZED BED COMBUSTOR[1]

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Abstract

The use of fluidized bed system earned status with combustion system uses and the mathematical models has proved their efficiency to simulate processes. Although when one model is developed it needs to be evaluated in term of accuracy and precision of generated results. To evaluate the influence of model parameters based on the kinetic theory to account the energy of particles fluctuation of gas-solid phases on the fluid dynamics of a fluidized bed combustor. This work aims to test the developed model investigating different conditions for fluidization. The present model consists of describing the phenomena that take place within an industrial scale reactor based on fluidized bed technology by general transport equation. The model is constructed based on transport equations of momentum, energy and chemical species of gas and pulverized phases. The PDE's are solved based on the finite volume method discretization and appropriated boundary and initial conditions are selected to represent the industrial operational conditions. Operating parameters are selected compatible with the behavior of industrial scale conditions. The model is used to investigate the bed behavior analyzing controlled operational parameters as pressure drop (ΔP) and expansion rate (H/H_0), when the initial conditions are modified. Simulation results indicated that the model is in good agreement with fluidizations carried out in laboratory scale and are extended to modeling industrial scale.

Key words: Fluidized bed; Model sensibility; Fluid dynamics

ANÁLISE DE SENSIBILIDADE DE UM MODELO DE COMBUSTOR DE LEITO FLUIDIZADO TRANSIENTE EM 3D

Resumo

O uso de sistemas de leito fluidizado ganhou crédito com uso em sistemas de combustão e os modelos matemáticos têm provado sua eficiência para simular processos. Porém quando um modelo é desenvolvido este precisa ser avaliado em termos de precisão e acurácia dos resultados gerados. Para avaliar a influência dos parâmetros de um modelo baseado na teoria cinética para contabilizar a energia de flutuação das partículas das fases gás-sólido na fluidodinâmica de um combustor de leito fluidizado. Este trabalho pretende testar o modelo desenvolvido investigando-o através de diferentes condições para a fluidização. O presente modelo consiste em descrever os fenômenos que ocorrem no interior de um reator em escala industrial baseado na tecnologia de leito fluidizado pela equação geral do transporte. O modelo é construído com base no transporte de momentum, energia e espécies químicas das fases gás e pulverizadas. As equações diferenciais são resolvidas utilizando método de volumes finitos e discretizadas com condições de contorno e iniciais selecionadas para representar as condições operacionais do processo. Os parâmetros operacionais são compatíveis com o comportamento das condições em escala industrial. O modelo é usado para investigar o comportamento do leito analisando parâmetros operacionais controlados como queda de pressão (ΔP) e taxa de expansão do leito (H/H_0), quando as condições iniciais são modificadas. Os resultados da simulação indicam que o modelo está de acordo com fluidizações conduzidas em escala laboratorial e que podem ser extendidas para modelar a escala industrial.

Palavras-chave: Leito fluidizado; Análise de sensibilidade; Fluidodinâmica.

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1 INTRODUCTION

Mathematical models have proved their efficiency to investigate optimum operational conditions and reproduce virtually the industrial processes. The objective of this work is to use a computational model that simulates the fluidized bed phenomena considering two phases. The model uses the multiphase concept to simulate the flow in a 3D fluidized bed reactor. Transport equations of mass, momentum and energy are solved by the finite volume method for non-orthogonal system implemented in a complex computational code written in FORTRAN 90/95.

The phases in this model are modeled using continuum mechanics principles where collection of particles is considered identical having a representative diameter and density. The solid phase momentum equation is modified by addiction of one term to account momentum exchange due to particle-particle collisions, this term including the kinetic theory model.(1) The granular temperature, Θ, is defined to represent the specific kinetic energy of velocity fluctuations or the translational fluctuation energy resulting from the particle velocity fluctuations.(2)

Granular flow, particle velocity fluctuations about the mean are assumed to result in collisions between particles being swept along together by the mean flow. The granular particle temperature equation can be expressed in terms of production of fluctuations by shear, dissipation by kinetic and collisional heat flow, dissipation due to inelastic collisions, production due to fluid turbulence or due to collisions with molecules, and dissipation due to interaction with the fluid.(1)

Many studies have shown the capability of the kinetic theory for modeling fluidized beds e.g. (Ding and Gidaspow, 1990), “Pain *et al*. (2001)”.(3-4) Despite of the development of models to simulate fluidized beds have been achieved maturity, the results validation with experimental measurements must be done, mainly because some correlations used in the models are empirical or semi-empirical. Another cause behavior of model when process parameters are modified, this fact is the objective of this work evaluates the model’s answer in front of some process parameter variation. The results showed very close agreements with previous behavior analyzed to process.

2 MATHEMATICAL MODEL

2.1. Transport Equation

The present model consists of describing the phenomena that occur in the interior of a semi-industrial fluidized bed reactor as a system of three phases that interact between it transferring mass, momentum and energy. The mathematical formulation follows hypothesis of the continuous media and as such can be formulated through transport equations. The phenomena of transference of mass, momentum and energy in the interior of a fluidized bed reactor are represented by the general transport equation (equation 1). Where the index i represent the considered phase. The effective diffusion coefficient (Γ_ϕ) assumes different meanings and models in agreements of equation to be solved, for example if the momentum equation is the equation to be solved the effective diffusion coefficient assumes the dynamic viscosity. The source term (S_ϕ) represents generation or consumption of mass, momentum and energy. In the source term are considered for example the phenomena of interaction among phases, mechanics interactions resulting in the coupling between the equations of conservation of mass, momentum and energy. The models of momentum and energy were obtained of literature and are detailed in another works for different studies.(2)

$$\frac{\partial\left(\varepsilon_i \rho_i \phi_i\right)}{\partial t} + div\ \left(\varepsilon_i U_i \phi_i\right) = div\ \left(\varepsilon_i \Gamma_{\phi_i} grad\ \ \phi_i\right) + S_{\phi_i} \tag{1}$$

The equation to consider the fluctuations energy of solid particles was introduced in the model and can be described by equation 2.(2)

$$\frac{3}{2}\left[\frac{\partial}{\partial t}\left(\varepsilon_s \rho_s \Theta_s\right) + grad\ \left(\varepsilon_s \rho_s \Theta_s \vec{v}_s\right)\right] = \left(-p_s \bar{I} + \bar{\tau}_s\right) : grad\,\vec{v}_s + grad\ \left(k_{\Theta_s} \cdot grad\,\Theta_s\right) - \gamma_{\Theta_s} \tag{2}$$

Where, (Θ_s) is the granular temperature, (I) is the admensional stress tensor, ($\bar{\tau}_s$) is the stress tensor, p_s is the solid pressure, (γ_{Θ_s}) is the collision energy dissipation.

2.2 Computational Simulation

The simulation of fluidized bed consists to solve the governing equations of mass, momentum and energy in a semi-industrial fluidized bed reactor. The kinetic theory of granular flow is used to consider the conservation of solid fluctuation energy; it was used to closure of the solid stress terms(2). The momentum exchange coefficients can be calculated by specifying drag functions. In this study the drag function used is the equation modified by Richardson and Zaki, which was modified to know the neighbors particles.(5) The drag function and drag coefficient are showed in the equations 3 and 4 respectively.

$$F_m = -C_{d_{g-s}}\left[\frac{3\varepsilon_s \rho_s}{4 d_s \varphi_s}\right]\left|\vec{U}_g - \vec{U}_s\right|\left(\vec{U}_g - \vec{U}_s\right) \tag{3}$$

$$C_{d_{g-s}} = \left[\frac{24}{\mathrm{Re}_{g-s}}\left(1 + a\,\mathrm{Re}_{g-s}^{b}\right) + \frac{c}{1 + \dfrac{d}{\mathrm{Re}_{g-s}}}\right]\left(\frac{\varepsilon_g}{\varepsilon_g - \varepsilon_s}\right)^{-4,65} \tag{4}$$

The terms a, b, c and d in the drag coefficient equation are functions of shape factor of solid (φ).(5) To the set of differential equations represented by equation 1 must be imposed initial and boundaries conditions that represents the process to be simulated. The simulation parameters can be sight in Table 1.

Table 1. Fluidized bed reactor simulation parameters.

Description	**Value**	**Comment**
Particle density, ρ_p	2600 kg/m^3	sand
Gas density, ρ_g	1.225kg/m^3	Air
Particle diameter, d_p	2.5mm	Uniform distribution
Restitution coefficient, e_{ss}	0.90	Literature value
Initial fraction on the bed, ε_{s0}	0.60	Fixed value
Gas superficial velocity, U	0.0857m/s	U_{mf}
Pressure of entry	1atm	Fixed value
Bed height	0.30m	Fixed value
Entry condition	Velocity	Gas velocity
Out conditions	Flow	Developed
Time steps	1s	Specified
Convergence criterion	10^{-6}	Specified

3 RESULTS AND DISCUSSION

The results presented below were obtained using the model to simulate variations in some process parameters. The Figure 1 shows the model behavior with different inlet gas velocities, four velocities were considered U_{mf}, $2U_{mf}$, $5U_{mf}$ and $8U_{mf}$. In the graph can be observed that velocity twice greater than minimum fluidization the ΔP values are greater than minimum fluidization. Therefore after process stabilization it presents values similar the minimum fluidization. To velocities five times greater than minimum fluidization ΔP reach high values, but after process stabilization shows values near minimum fluidization. However to velocities eight times greater than minimum fluidization ΔP shows behavior that oscillating near the values obtained to shorter velocities. This fact can be explained by pneumatic transport that happens in the beginning of process, when particles are carried the bed out by the air stream. This fact make the numbers of particles in the bed being shorter causing a decrease in the pressure drop, because the air passage into the bed has minor resistance. This results shows that the bed has the pattern function between (U_{mf} and $5U_{mf}$), because for velocities higher than $5U_{mf}$ particles will be carried out of the bed causing an unstable operation of process.

Figure 2 the graph can be observed the bed expansion rate H/H_0, where the great value is reached when the velocity is $8U_{mf}$ this fact confirms that particles are carried out of bed. Another fact that confirms this analyze is that time after one second the bed expansion rate suffer a drop, because mainly the amount of particles into the bed decrease.

The Figure 3 shows the variation in another process parameter that is the bed initial height H_0. Three values were used to test the model behavior. The obtained results shows that the model has behavior like expected compared with previous results. Therefore with more number of particles in the bed increase the pressure drop, because the gas flow is difficult by the bed weight. The drag force could extrapolate the weight to the particles starting the movement doing that ΔP decrease. However the ΔP values obtained to heights greater than pattern H_0 equal to 0.3m after the fluidization phenomena to be reached not approached the default that is around 105kPa. This is explained again for the particles weight into the bed this make that the default bed operation in the same initial conditions being above 110 kPa. The bed initial height can be taken across technical criteria and another operational parameters variation for keep the yield and efficiency of process.

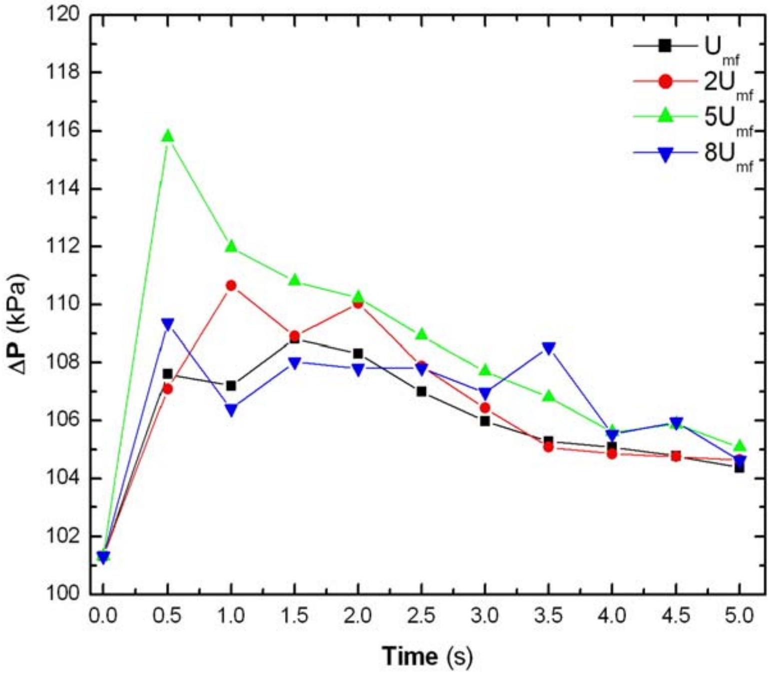

Figure 1. Pressure drop ΔP with different gas velocities.

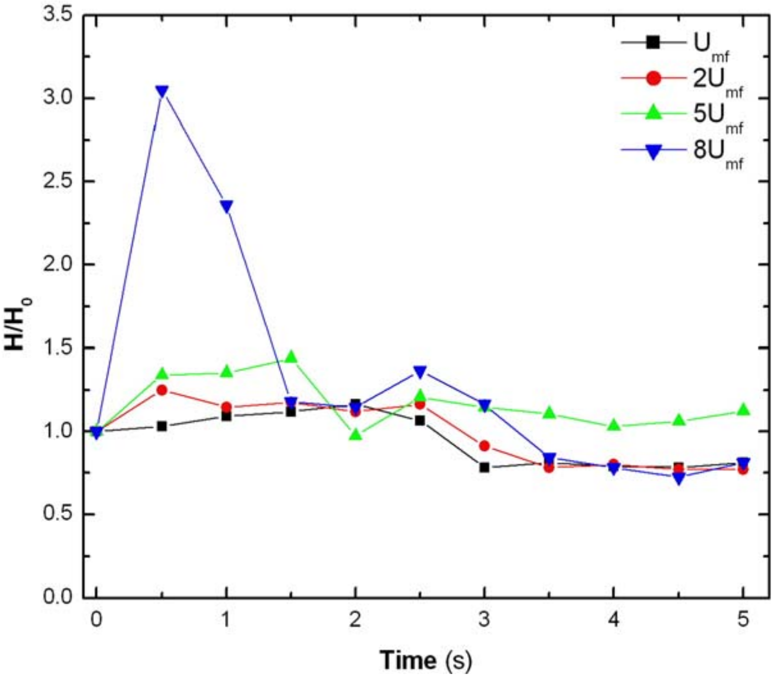

Figure 2. Bed expansion rate H/H_0 with different inlet gas velocities.

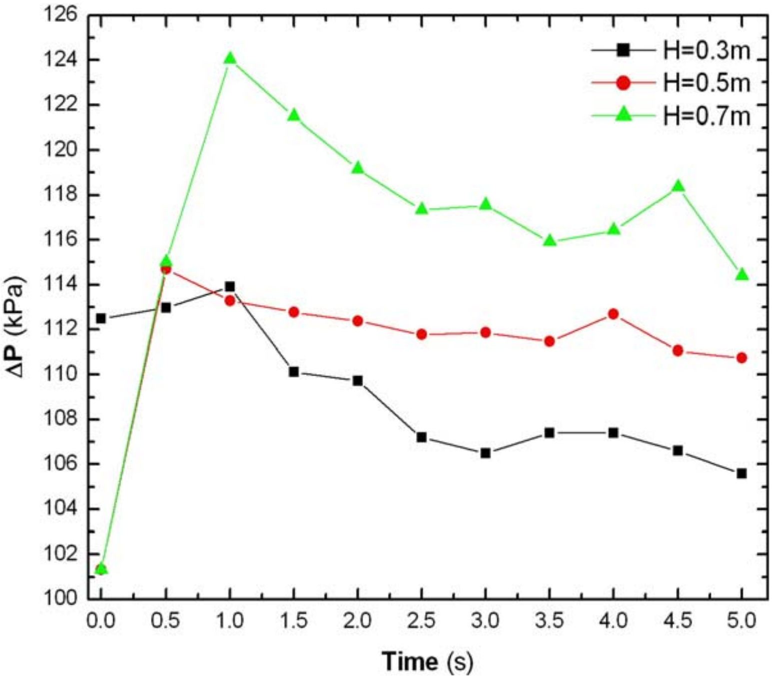

Figure 3. Pressure drop in the bed with different initial particles height .

The Figure 4 can be sight the pressure drop in the bed varying the restitution coefficient (e) of particle. No difference is observed in the results for the used values, this can be explained by two ways: The first says about the model of drag force equation that none consider (e) value directly in it equation. The second is explained by velocity used to the simulations have been the same and Goldschmidt et al. says that restitution coefficient effect is more pronounced when the inlet velocity of gas is higher than minimum fluidization velocity(6). This greatness was analyzed because the restitution coefficient values around 0.99 suggesting that all particle-particle energy during the collision is conserved. The restitution coefficient is likely minor to the packet bed, because the collisions among particles become less ideal, dissipating a largest energy fraction(2). The fact is that not variation in the fluidized bed is observed, because the fluidized bed shows considerable porosity to the gas flux.

The Figure 5 can be sight the (ΔP) results when the particles diameter is varied. Three diameters was used d= 2.5, 3.5, 4.5 mm respectively, The results show that 3.5 mm particles reach the largest (ΔP) value in the beginning of process showing that these particles were more difficult dragged by the gas flux. But were the same particles that after phenomena stabilization reach the minor (ΔP) value. While, the 2.5 mm particles, that are the size normally used in the process show minor variation than the others. Due the fact these were lesser and consequence lighter offering minor drag resistance. The 4.5 mm particles reach initial values lighter than 3.5 mm, however after phenomenon stabilization (t=5s) they show greater resistance to drag since the final value of the graph shows the trend of increase (Δ P) for times larger than 5s.

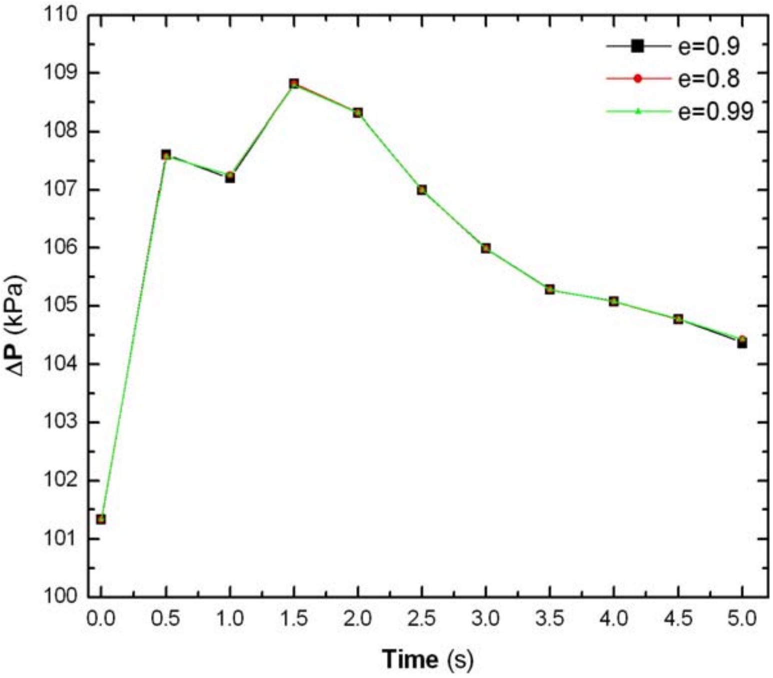

Figure 4. Pressure drop in the bed to different particle restitution coefficient (e).

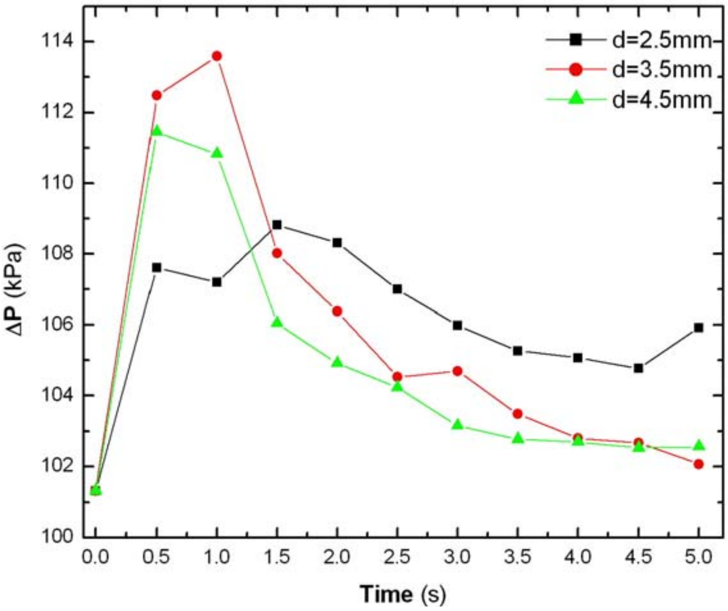

Figure 5. Pressure drop in the fluidized bed to different particles diameter (d).

The Figure 6 shows (ΔP) to simulation results with three different meshes, resulting in different control volumes, the used mesh and volumes amount were: 1-(20x20x40), 12312 control volumes, 2- (20x18x35), 9504 control volumes, 3- (20x18x30), 8064 control volumes. Can be understood by the graph for the crude mesh the obtained results to the pressure drop were taller than refined mesh. This fact shows that control volumes used to the calculus interfere directly in the results. Therefore, the mesh one or more refined meshes could be used to reliable an accurate results. However it is noteworthy that the choice of a mesh should take into account the time of simulation and computational effort required for the calculation. Because, very refined meshes demand high computational effort increasing greatly the time of simulation.

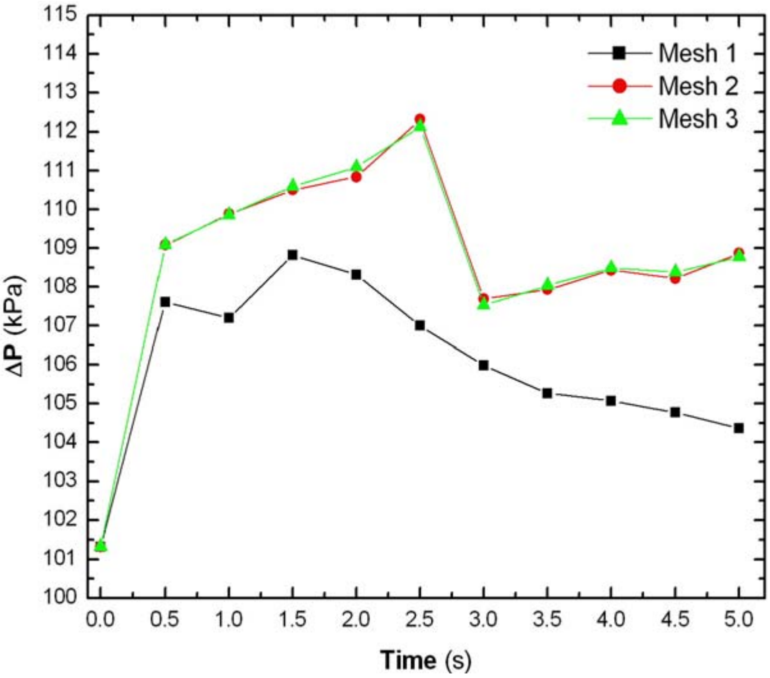

Figure 6. Pressure drop behavior to three different meshes.

4 CONCLUSIONS

The results obtained by the model presented good behavior to variables parameters used to evaluate it like the graphs showed. Although, another tests needs to be conducted to make it better and efficient. This tests including use of another drag function equations and coefficient, mainly someone that consider the restitution coefficient. However the developed model can be used yet to simulate fluidized bed reactor systems with very close agreements of behavior like preliminaries results showing.

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