Mathematical Model of a particle in gas solid suspension by applying Electric Field

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Abstract- Gas solid two phase flows are important in many engineering applications and industrial processes. Understanding the physical mechanisms governing these flow is essential for the optimal design of these industrial processes, and for optimal design of these industrial processes,and for modelling these natural phenomena. One of the major drawback of such a process is the carry over of particles at high gas velocity .In order to control this phenomena ,it is observed that effect of electric field to suspension of particles is one of the remedy . In the present study we have applied an electric field and developed a mathematical model for the velocity at which it just start suspending .The model developed is a relationship between the minimum fluidization velocity with field to velocity in absence of field and is given by u mfE = u mfE=0 (1+kE)

Keywords-Mathematical Model ,Electro Fluidized Bed

I. INTRODUCTION

Fluidization is an operation by which a bed of solid particles acquires fluid like properties by passing a gas or liquid through it Their liquid like behavior and continuous movement of particles allow for good heat transfer and temperature control. The .occurrence of gas bypass or broadening of the residence time distribution due to bubble formation , coalescence and growth is unwanted for heterogeneous state attained . To negate these effects control over the number or size of bubbles is needed. There are different ways to accomplish this ,such as baffles or special gas distributors (for example a fractal injector) in the bed or effect of superimposed fields for the particles exhibiting the specific properties.

The fluidized bed reactor is one of the most important technologies for gas solid heterogeneous operations ,chemical or petrochemical considering catalytic or non catalytic processes (kunni and levenspiel,1991)

II. PROPOSED ALGORITHM

Fluidized bed Phenomena

Consider a hollow column at the base of which a wire mesh or perforated plate is fitted and is attached with a hollow portion for the entry of gas The fluidizable particles poured in the column will remain in the static position .Such a bed is called as fixed bed. The gas flow through a bed of particles initially maintains its condition as fixed bed with a viodage Eg =0.4.The increase in gas velocity will start loosening of particles in the fixed bed and at the condition upthrust of gas equal to the weight of the particles , the velocity at the condition is called as minimum fluidization velocity. Further increase in gas velocity , the bubbles will appear and their size will increase with increasing gas velocity approaching the terminal velocity of particles will have carry over.

Application of Electric Field

The application of electric field to fluidizable particles of semi –conducting or conducting particles with a gas velocity beyond the minimum fluidization velocity constitutes an Electro –fluidized bed (EFB).The conventional fluidization characteristics such as minimum fluidization velocity , bed expansion ,bubble size, bubble velocity , particle velocity are significantly altered by the applied electric field .

Encouraged by the exploratory investigation of Katz and Sears(1969),Dietz and Melcher (1978a,1978b).Johnson and Melcher (1975) and Ogata etal .(1980) studied the behavior of EFB at incipient fluidization .According to their experiments in a cross flow EFB,S the following features at incipient fluidization were observed :a) The minimum fluidization velocity Umf_E increases with increasing applied voltage .b) The bed height increases with increase in applied voltage .c) An excess pressure drop is required for incipience of fluidization under the influence of electric field .Zhan and Rhee(1984) and Moissis and Zhan (1986) describe experiments that are built on Melchers work .They focus on AC fields and include the mechanisms of polarization and charge built up around particle contacts .Zhan and Rhee stated that under the influence of AC fields it is possible that attracting particles unlock twice each period .When the fields go through zero ; so that bed retains its fluidity .Wittman et al .(1987) continued along the line stated by Zhan and coworkers and reported the reduction in the size of bubbles in fluidized systems .In a detained set of experiments they found a change in bubble shape towards an ellipsoid under the influence of DC fields .Colver (1977.2000) presented an interparticle force model for semi-insulating powder in alternating fields and compared the model to several experimental data .They verify their trends experimentally on the basis of bed expansion .

Development of Mathematical Model

Literature Survey on the EFB provides an information on the experimental studies to obtain Umf with field based on the measurement of pressure drop and its variation with field .The sequence of increase in gas velocity to a maximum velocity and the defluidization data with decreasing velocity till a fixed bed is attained at a particular field intensity so that a point of intersection between these gives minimum fluidization velocity with field.

The Umf is a very important parameter as it is a transition point between fixed bed and fluidized state. The theoretical development of formulating the minimum fluidization with field will help us in studying the mechanism at the transition point . In the present investigation we developed a mathematical model for Umf with field.

A Mathematical model for the motion of particle in presence of electric field (E) and absence of electric field (E = 0)

Consider a column at the two ends of which an electric field of intensity E is applied. A particle of mass m is dropped at the top and moves under the influence of gravity and electric field.

According to the Newton's second law

Rate of change of momentum = Forces acting on the particle

Forces = gravity force + buoyancy + drag force + electric field intensity (1)

gravity force = mg

buoyancy $= \frac{m}{\rho_p}\rho \ \ g$ (acting apposite to the motion of particle) (2)

Drag force $= \frac{1}{2} C_D \ \rho \ \mu_P{}^2$ (3)

C_D – drag coefficient

ρ □ density of gas

A – Area exposed during the fall of particle

μ_P – particle velocity

Electric force acting on the particle $= Q_P E$

Q_P = Charge on the particle

Rate of change of momentum $= \frac{d(m\mu_p)}{d_t} = m.\ \frac{d\mu_p}{d_t}$ (4)

The equation of motion based on Newton,s second law

$$m.\ \frac{d\mu_p}{d_t} = mg - \frac{m}{\rho_p}\rho\ \ g - \frac{1}{2} C_D\, A\, \mu_P{}^2 + Q_P E$$

$$m\frac{d\mu_p}{d_t} = mg\left(1 - \frac{\rho}{\rho_p}\right) - \frac{1}{2} C_D\, A\, \mu_P{}^2 + Q_P.E \qquad (5)$$

We define the Reynolds number

$$R_e = \frac{d_p.\mu_p.\rho}{\mu}$$

For particles of small diameter with low Reynolds number (Re < 1), the drag force is given by

$$C_D = \frac{24}{R_e} = \frac{24}{d_P \mu_P \rho}$$

μ – viscosity of gas $\left(\frac{g_m}{c_m \sec}\right)$

ρ – density of gas (gm/cm^3)

$$A - \frac{\pi}{4} d_p{}^2$$

Drag Force= 3 $\prod$ d_p μU_p

Divide the equation (6) by m and substitute the value of the drag force

$$\frac{d\mu_p}{d_t} = \frac{mg}{m}\left(1 - \frac{\rho}{\rho_p}\right) - \frac{3\pi d_p \mu U_p}{m} + \frac{Q_p E}{m} \qquad (6)$$

The density of gas (air) ρ = 1.2 kg/m^3

For the glass beads ρ_P = 2500 kg/m^3

Hence the ratio $\frac{\rho}{\rho_p} << 1$ and can be neglected.

Rearranging equation (6)

$$\frac{d\mu_p}{d_t} = \left(g + \frac{Q_P.E}{m}\right) - \frac{3\pi d_p \mu U_p}{m}$$

Or $$\frac{d\mu_p}{d_t} + \left(\frac{3\pi d_p \mu U_p}{m}\right) = \left(g + \frac{Q_P.E}{m}\right) \qquad (7)$$

This is a first order differential equation. Solving the above equation

$$\frac{du_p}{dt} + k\,u_P = g + \frac{Q_P.E}{m}$$

Integrating factor = $e^{\int kdt} = e^{kt}$.

$$\frac{d(u_p.e^{kt})}{dt} = \left(\frac{mg \ \ + Q_P E}{m}\right) e^{kt} \qquad (8)$$

Integrating the above equation with the boundary condition

at t = 0, $U_p = 0$

$$\int d\left(u_p e^{kt}\right) = \int \frac{(mg \ \ + Q_p.E)}{m} e^{kt}.dt + C$$

$$u_p e^{kt} = \left(\frac{mg \ \ + Q_p.E}{m}\right).\frac{e^{kt}}{k} + C \qquad (9)$$

Here C is the constant of integration

With the boundary condition

$$0 = \frac{(mg \ \ + Q_p.E)}{m} \frac{1}{k} e^0 + C$$

$$\therefore C = -\frac{1}{k}\left(\frac{mg + Q_p.E}{m}\right)$$

Substituting this in equation (10)

$$u_p e^{kt} = \left(\frac{mg \ \ + Q_p.E}{m}\right).\frac{1}{k} e^{kt} - \frac{(mg \ \ + Q_p.E)}{m}\frac{1}{k}$$

Divide by e^{kt} – and call this velocity in presence of electric field as u_{PE}

$$u_{PE} = \left(\frac{mg + Q_p.E}{m}\right).\frac{1}{k}(1-e^{-kt}) \qquad (10)$$

For the motion of particle in absence of electric field, E = 0,

the particle velocity we define as $u_{PE=0}$

$$u_{pE=0} = \left(\frac{mg}{m}\right)\frac{1}{k}(1-e^{-kt}) \qquad (11)$$

The ratio of equation (10) to (11)

$$\frac{u_{PE}}{u_{PE=0}} = \frac{\frac{(mg + Q_p.E)}{m} * \frac{1}{k}(1-e^{-kt})}{\frac{mg}{m} * \frac{1}{k}(1-e^{-kt})}$$

$$\frac{u_{PE}}{u_{PE=0}} = \left(1+\frac{Q_p.E}{mg}\right) = (1+ kE) \qquad (12)$$

Put $\left(\frac{Q_p}{mg}\right) = k$

From equation (12) we conclude that the velocity of particle with field will be higher than in absence of field and will increase as field intensity increases.

E = 10, 20, 30, ……………… kv.

The single particle model developed in the present study in its final form gives the following relationship.

$$u_{mfE} = u_{mfE=0}(1+kE) \qquad (13)$$

where

u_{mfE} = velocity of the single particle in presence of electric field

$u_{mfE=0}$ = velocity of the single particle in absence of electric field

k = constant

E = electric field intensity

III. CONCLUSION

The mathematical model developed shows a linear relationship with field to without field.

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