CHAPTER II
REVIEW OF LITERATURE

The present work aims to develop a mathematical model of the rectangular spouted bed with tapered wall and draft plates and simulate its behavior. The review of literature consists of two parts. The first part is review of Distinct or Discrete Element Method (DEM). There are many applications of DEM in powder technology such as mixing in tumblers and centrifugal mills, fluidized bed and spouted bed. This part will cover the past research related to DEM simulation. The second part is review of the aerodynamic and heat transfer in a spouted bed.

2.1 Review of Discreate Element Method

P.A. Cundall and O.D.L. Strack (1979) developed the distinct element method (DEM) for describing the mechanical behavior of assemblies of discs and spheres. The method is based on the use of an explicit numerical scheme in which the interaction of the particles is modeled particle by particle. The method is validated by comparing force vector plots obtained from the computer program with the corresponding plots obtained from a photoelastic analysis. The photoelastic analysis used for the comparison is the one applied to an assembly of discs by De Josselin de Jong and Verruijt (1969). The force vector diagrams obtained numerically closely resemble those obtained photoelastically. The results showed that DEM were valid tools for research into the behavior of granular assemblies.

Y. Tsuji, T. Tanaka and T. Ishida (1991) used Lagrangian-type numerical simulation to investigate the plug flow of cohesionless, spherical particles conveyed in a horizontal pipe. The motion of individual particles contacting each other was calculated using the equations of motion and a modified Cundall model. Forces between particles were calculated by using the Hertzian contact theory. The fluid force acting on particles in a moving or stationary bed was expressed by the Ergun equation. The flow pattern obtained in this work is realistic. The wave-like motion of the flow boundary reported by previously researchers was observed clearly in the simulation. The results of the relation of height of the stationary deposited layer and the plug flow velocity were good agreement to those of experiment.

Y. Tsuji, T. Kawaguchi and T. Tanaka (1993) investigated the particles motion in two-dimensional fluidized bed. Contact forces between particles modeled by Cundall's Distinct Element Method, which expresses the forces by using a spring, dash-pot and friction slider. Gas was assumed to be inviscid and its flow was solved simultaneously with the motion of particles, taking into account the interaction between particles and gas. The simulation gives realistic pictures of particle motion. The results of formation of bubbles, slugs and particle mixing were agreement with those of experiment. The calculated pressure fluctuations compared well with measurement.

T. Kawaguchi, T. Tanaka and Y. Tsuji (1998) investigated particles motion in fluidized bed by Eulerian/Lagrangian-type numerical simulation with comparison between two- and three-dimensional models. Particle motion was calculated using Newton's equation of motion and contact forces were modeled by DEM. The locally averaged equations were solved for calculating the fluid motion by taking into account the interaction between fluid and particles. The results showed that the difference in the particles'motion calculated using a 2D model and 3D model is prominent at the beginning of the fluidization process. When the particles are fluidized, the flow patterns including the period of bubble formation in the simulation are agreement with those of experiments except for the motion of particles near the corners. In the 2-D model calculation, the particles near the corners move but they do not move in the experiment and in 3-D model.

T. Kawaguchi, M. Sakamoto, T. Tanaka and Y. Tsuji (2000) studied particles flow in a cylindrical spouted bed with a tapered bottom. A quasi-three-dimensional numerical simulation method for axisymmetric gas-solid flow was proposed in their work for reducing the computational load. Fluid motion was calculated two-dimensionally by solving the locally averaged equations written in cylindrical coordinates, in which the circumferential components were neglected assuming the axisymmetry. Particle motion was calculated three-dimensionally and was traced discretely by solving Newton's equation of motion for each particle. The DEM was employed to model the interaction between particles. The calculated spout diameter agreed quantitatively well with the experimental results. The calculated velocity profiles agreed qualitatively well with the experimental results in spite of the difference in the particle diameter.

Y. Kaneko, T. Shiojima and M. Horio (1999) studied the temperature behavior of particles and gas in a fluidized bed reactor for polyolefin (polyethylene and polypropylene) production by DEM. Simulation was performed using a numerical code (modified SAFIRE code) by modifying SAFIRE ver.1 of Mikami, Kamiya and Horio (1998) by incorporating the energy balance and the reaction rate. Heat transfer from a particle to gas was estimated using the Ranz-Marshall equation. The reaction rates were calculated by Arrenius type zero-th order kinetic expressions including the effect of catalyst weight. The results are fairly realistic concerning particle and gas temperature behavior and also the bubbling behavior in a gas fluidized bed at elevated pressure. Hot spot formation was observed on the distributor near the wall of the fluidizing column. When a large stable revolution flow is formed in the bed, a hot spot was found to form quickly. The degree of mixing can be used as an effective index to identify and prevent the hot spot formation.

P.W. Cleary (2000) investigated distinct element method (DEM) simulation of industrial particle flows. In case studies of dragline excavators, mixing in tumblers and centrifugal mills. The results of three case studies were as follows: For dragline, the blockiness of the material was found to significantly affect the shear strength of the particle microstructure and cause the bucket fill rates and bucket stability to decrease with increasing blockiness. In a rotating tumbler, the flow regime was shown to be critically dependent on both the rotation rate and the particle shape. Mixing rate were to be around six times slower for circular particles than for almost square particles. Microstructures of circular particles had very weak resistance to shear and the particle assembly flowed partly by avalanching and partly by slumping. In a centrifugal mill, comparison of charge profiles with high speed photographs were in very close agreement. For the 75 % and 50 % filled case, the simulation charge shows a steady stable charge profile that simply rotates with the mill whilst the granular material deforms smoothly.

T.Yuu, T.Umekage and Y. Johno (2000) applied DEM to the simulation of small particles in bubbling fluidized bed. They used 100,000 particles of 310 μm in diameter, which are classified as the B particles in the Geldart map. The results showed that the calculated results describe well the experimental instantaneous particle positions, and enable them to know the mechanisms of bubble formation, bubble coalescene and bubble disruption in a bubbling fluidized bed.

2.2 Review of Spouted Bed

T. Kudra, A.S. Mujumdar, G.S.V. Raghavan and M.I. Kalwar (1992) investigated some hydrodynamic, heat transfer and drying characteristics of two-dimensional spouted beds. The results showed that the minimum spouting velocity increases with entrance height. It also increases with increase in the spout width. The solids circulation rate depends on the entrance height, spout width and slant angle, and increase with increase all these parameters. The particle flow pattern in a two-dimensional spouted bed is controlled mostly by the slot width. The air velocity affects the solid circulation rate only up to a certain value above the minimum spouting velocity (estimated as 1.2 – 1.4 times the minimum spouting velocity). The drying rates are greatly affected by the inlet gas temperature and sloth width (the spacing between draft plates and the inclined side wall which controls the rate of grains entrained from the downcomer into the gas jet region).

M.I. Kalwar and G.S.V. Raghavan (1986) investigated circulation rate in two-dimensional spouted bed with draft plates. The results showed that the solids circulation rate was affected by entrainment zone height, draft tube width, slant angle, and varies with spouting velocity. The lowest solids circulation rate was observed in beds of wheat grains, followed by beds of shelled corn and soybean. Solids circulation rate through the downcomers of spouted beds increased as the bed length of the same spouted bed increased. Average cycle times of particles near the draft plates are shorter than those at the sidewall of the downcomer regardless of slant angle, draft tube width, entraintment zone height, or type of grain. The average cycle times were higher in the case in the case of slant angle of 45° than the slant angle of 60° because of a larger mass of grains at a lower flow rate than at the latter angle. The insertion of draft plates to form a tube in the two-dimensional spouted bed proved very effective in controlling solids circulation rate and to operate in plug flow manner.

Y.L. He, S.Z. Qin, C.J. Lim and J.R. Grace (1994) investigated particle velocity profiles and solid flow patterns in spouted beds. A fibre optic probe system was used to measure the profile of vertical particle velocities in the spout and fountain of a haft column and a full column spouted bed. A fibre optic image was also employed to measure vertical particle velocity profile in the annulus of the full column. In the spout, radial profiles of vertical particle velocities were of near Gaussian distribution. Particle velocities along the spout axis in the haft-column were 30 % lower than in the full column under identical operating conditions. In the haft column, particle velocities adjacent to the front plate were approximately 24 % lower than a few millimeters away. The fountain core expanded suddenly near the bed surface and then gradually contracted with height. The model of Grace and Mathur (1978) gave good predictions of fountain heights for the full-column. In the annulus region, there was a 28 % difference between particle velocities adjacent to the column wall and those only 2 mm away. The integrated upward solids mass flow in the spout and the downward solids flow in the annulus matched well at different bed levels.

L. Law-Kwet Cheong, K. Malhotra and A.S. Mujumdar (1986) studied some aerodynamic and solids circulation measurement in a slotted spouted bed of grains. The bottom of vessel is a flat plate. To improving spouting, two vertical plates were located centrally above the slot. Bed pressure drop, minimum circulation velocity and solids circulation rate were studied in two variations of the slotted spouted bed. It was found that an increase in the inlet slot width and the baffle spacing increased the air velocity required for the minimum circulation of solids and decreased the solids circulation rate considerably. In addition, the solids circulation rate decreased significantly with an increase in the height of the material in downcomer and a decrease in the spacing between the baffles and the inlet slot. At higher air flow rate, the bed pressure drop becomes insignificant compared with the pressure drop across the inlet slot.

Matsumoto and Pei (1984a) developed a mathematical model for the constant drying rate period in the pneumatic drying process. The mathematical model includes the coupling effects between the particle motion and the drying mechanism. Important variables such as gas temperature and humidity, solids loading, gas and solid velocities and consequently the heat and mass transfer coefficients were incorporated into the analysis. The study on the coupling behaviors as well as the effect of parameters, such as grain size, gas temperature, mass flow ratio and gas flow rate provided many design criteria applicable to an actual drying process. As a result, the following conclusions were obtained: (1) advantages of pneumatic drying are distinctly exhibited for smaller grain sizes, (2) as the gas velocity decreased due to a drop in gas temperature, the choice of the initial value of the gas velocity is very important to ensure the stability of pneumatic transport, (3) value of the mass flow ratio applicable is restricted by the gas temperature and the desired change of moisture change.

Matsumoto and Pei (1984b) established analytical solutions, on the basis of the diffusion equation, that described the rate of drying and the moisture content of grain during the falling rate period. The resistance of mass transfer in the connective layer of air at the outer surface of the grain was taken into consideration as well as resistance within the grain. The results pointed out that the surface moisture content would be nearly inequilibrium with the humidity of the ambient air at any time. Therefore, lower loading ratios should be recommended in drying the grains. Furthermore, the above analysis can be adopted to predict the drying curve of any material with known equilibrium data and internal diffusion coefficient during the falling drying rate period.

L.A.P. Freitas and J.T. Freire(2001) studied heat transfer in a draft tube spouted bed with bottom solids feed. Screened thermocouples were employed to measure temperatures in a draft tube spouted bed of 2.6 mm glass beads with bottom solids feed in steady state conditions. The air temperatures in the spout decreased sharply with axial position at intervals that corresponded to the recirculation section. Therefore, the recirculation section plays an important role for the heat transfer in bottom feed spouted beds. The annulus temperatures were found to be significantly uniform and much lower than spout temperatures, which indicates that the configuration studied here is suitable for unit operations using heat sensitive materials. The model adopted was useful for draft tube spouted beds with bottom feed since it could be solved using simple numerical techniques (e.g., the 4^{th} order Runge-Kutta method with adaptive step-size control). The comparison of experimental and predicted temperatures demonstrates reasonably low deviations (generally less than 5 % for air temperature in the spout, 3 % for air temperatures in the annulus, and 1 % for solids temperatures in the annulus).