CHAPTER II
BACKGROUND AND LITERATURE SURVEY

2.1 Background

IIT's hydrodynamic models and computer code, which were the fundamental of hydrodynamics, was explained on "Multiphase Flow and Fluidization, Continuum and Kinetic Theory Descriptions" by Gidaspow (1994) and based on Navier-Stokes equations. This program could solve two-dimensional hydrodynamic models for multiphase of continuous phase and dispersed phase. The code used model A and model B in Gidaspow's book (1994) and calculated the pressure drop in the continuous phase. The model B was unconditionally well posed, which was different from model A. If an initial value was problem, it could solve stable finite difference.

The program needed to specify the initial condition; for example, pressure of continuous phases, and the initial volume fraction and velocity of dispersed and continuous phase. This program worked for the appropriate boundary conditions after that it solved these finite-difference equations. This finite-difference form could use with either uniform or non-uniform computational mesh. Non-uniform mesh received more advantages to save the storage space and CPU time.

2.1.1 <u>The Governing Equations</u>

For the Governing Equations, the multiphase system consisted of many dispersed phases and a continuous phase, which the dispersed phases could be different sizes and densities. Continuity equation and momentum equation were discussed in several other works: Manger (1996), Sun (1996), Wu (1996), Neri (1998), Pape et al. (1998), Sun et al. (1999), Benyahia et al. (2000), Matonis (2000), Neri et al. (2000), Wu et al. (2000), Wang et al. (2001), and Mostofi (2002), Continuity Equation for phases

Fluid phases

$$\frac{\partial}{\partial t}(\varepsilon_f \rho_f) + \vec{\nabla} \cdot (\varepsilon_f \rho_f \vec{v}_f) = 0 \quad (2.1)$$

Solid phases

$$\frac{\partial}{\partial t}(\varepsilon_s \rho_s) + \vec{\nabla} \cdot (\varepsilon_s \rho_s \vec{v}_s) = 0 \quad (2.2)$$

Momentum Equations

Fluid phase

$$\underbrace{\frac{\partial}{\partial t}(\varepsilon_f \rho_f \vec{v}_f)}_{\text{accumulation}} + \underbrace{\vec{\nabla} \cdot (\varepsilon_f \rho_f \vec{v}_f \vec{v}_f)}_{\text{net flow}} = \underbrace{-\vec{\nabla} P_f}_{\text{pressure}} + \underbrace{\vec{\nabla} \cdot \tilde{\vec{T}}_f}_{\text{shear}} + \underbrace{\rho_f \vec{g}}_{\text{gravity}} + \underbrace{\beta_{fk} (\vec{v}_k - \vec{v}_f)}_{\text{drag}} \quad (2.3)$$

Solid Phase

$$\frac{\partial}{\partial t}(\varepsilon_k \rho_k \vec{v}_k) + \vec{\nabla} \cdot (\varepsilon_k \rho_k \vec{v}_k \vec{v}_k) = \vec{\nabla} \cdot \tilde{\vec{T}}_k + \varepsilon_k (\rho_k - \rho_f) \vec{g} - \beta_{fk} (\vec{v}_k - \vec{v}_f) \quad (2.4)$$

2.1.2 Constitutive Equations

Definition

$$\varepsilon_f + \sum_{k=1}^{N} \varepsilon_k = 1 \quad (2.5)$$

Equation of State for Air-Water System

$$\rho_f = \frac{P_f}{RT_f} \quad (2.6)$$

$$\rho_k = \rho_{sk}, (\text{cons}.) \quad (2.7)$$

Constitutive Equations For Stress

Fluid Phases Stress

$$\tilde{\tau}_f = \varepsilon_f \mu_f (\bar{\nabla}\bar{v}_f + (\bar{\nabla}\bar{v}_f)^T) - \frac{2}{3}\bar{\nabla} \cdot \bar{v}_f \tilde{I} \qquad (2.8)$$

Solids Phase Stress: k=1,2,3,...,N

$$\tilde{\tau}_k = \varepsilon_k \mu_k (\bar{\nabla}\bar{v}_k + (\bar{\nabla}\bar{v}_k)^T) - \frac{2}{3}\bar{\nabla} \cdot \bar{v}_k \tilde{I} \qquad (2.9)$$

Empirical Solids Viscosity and Stress Model

$$\nabla P_k = G(\varepsilon_f)\nabla\varepsilon_k \qquad (2.10)$$

$$G(\varepsilon_k) = 10^{-8.686\varepsilon_k + 6.385} \text{dynes} \quad / \text{cm}^2 \qquad (2.11)$$

$\mu_k = c\ \varepsilon_k$ poises (c is the viscosity of the fluid)

(2.12)

Fluid-Particulate Inter-phase Drag Coefficients: k=1,2,3,...,N

For $\varepsilon_f < 0.8$, (based on Ergun equation)

$$\beta_{fk} = \beta_{kf} = 150 \frac{(1-\varepsilon_f)\varepsilon_k \mu_f}{(\varepsilon_f d_k \psi_k)^2} + 1.75 \frac{\rho_f \varepsilon_k \mid v_f - v_k \mid}{\varepsilon_f d_k \psi_k} \qquad (2.13)$$

For $\varepsilon_f < 0.8$, (based on empirical correlation)

$$\beta_{fk} = \beta_{kf} = \frac{3}{4} C_D \frac{\rho_f \varepsilon_k \mid v_f - v_k \mid}{d_k \psi_k} \varepsilon_f^{-2.65} \qquad (2.14)$$

Where

$$C_D = \frac{24}{Re_k}\left[1 + 0.15 Re_k^{0.687}\right] \quad \text{for} \quad Re_k < 1{,}000 \qquad (2.15)$$

$$C_D = 0.44 \quad \text{for} \quad Re_k \geq 1{,}000 \qquad (2.16)$$

$$Re_k = \frac{\varepsilon_f \rho_f \mid v_f - v_k \mid d_k \psi_k}{\mu_f} \quad (2.17)$$

2.2 Literature Survey

Huilin et al. (1995) measured hydrodynamic attractors of gas-solid fluidization in IIT CFB by using γ-Ray. In 1996, Manger wrote the book about modeling and simulation of gas/solid flow in curvilinear coordinates. This book explained about IIT CFB and the kinetic theory. Gidaspow et al. (1996) measured viscosity of FCC particles in the IIT CFB by using CCD camera. His experiment was gas-solid fluidization. In 1997, he found viscosity on liquid-solid fluidization by using kinetic theory. His two experiments used CCD camera to find the random velocity. Later he (1998) created the new model to find the pressure in the dense regime because the hard sphere model was corrected for a cohesive pressure by using the minimum in the measured radial distribution. The code was used to conduct transient flow simulation and to predict phase separation for both types of Tee junction in gas-liquid flow by Hatziavramidis et al. (1997) and Sun (1996). Later, Sun (1996, and 1999) used the code for the fluidization VIII Benchmark to predict a new phenomenon: an off-center maximum flux. Wu (1996, and 2000) used this code to predict the hydrodynamic of methanol synthesis in gas-liquid and energy balances were added to the IIT code. Matonis (2000) simulated hydrodynamics of a gas-liquid–solid fluidization. Neri (1998) used the code to calculate multiphase flow of explosive volcanic eruptions and Neri (2000) used IIT code again to compute granular temperature distributions on the IIT CFB. The multiphase model simulation was considered important physical mechanisms in the reaction modeling based on single particle heat transfer by Pape (1998). It gave the results realistically for intense reaction propagation. Benyahia (2000) used a CFD package by Fluent to simulate particles and gas flow behavior in the rise of CFB using the kinetic theory. Recently, Wang (2001) simulated the hydrodynamics of fluidization by using a modified kinetic theory to compare with Gidaspow's model.