Modelling and Simulation of Fluidized Bed Granulator for the Manufacturing of Coated Urea

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DEDICATION

"This thesis is dedicated to family, teachers and friends for endless motivation, support and encouragement throughout the research"

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Abstract

Hydrodynamics of air-urea (gas-solid) flow in fluidized bed coater is studied using the commercial CFD package ANSYS FLUENT® 18.0 on 2D and 3D geometry the multiphase behavior of air-urea flow is simulated using CFD. The model uses the EE-TFM approach in combination with kinetic theory of granular flows. In this study, three different drag models GP, SMB and mod SMB are used. These drag models are used to determine the interfacial phenomena between different phases. It is detected that the drag models have a substantial effect on the air-urea flow behavior and the change in dynamics of urea particles with influence of superficial gas velocity is studied. The modified Syamlal O Brine (modified SMB) shows better agreement with the homogeneous fluidization as compared to Gidaspow (GP) and Syamlal O Brine (SMB) drag model.

List of Abbreviations

Nomenclature

FBC	Fluidized bed coater
EL	EulerianEulerian
EE	Eulerian Langragian
GP	Gidaspow
SMB	Syamlal O Brine
C_D	Drag coefficient
TFM	Two Fluid Model
T	Time
$\overrightarrow{v_a}$	Air phase velocity vector
$\overrightarrow{v_s}$	Urea phase velocity vector
$v_{r,s}$	Terminal velocity
$v_{s,w}$	Vertical comment of velocity
K_{as}	Interphase Momentum exchange coefficient
P	Pressure
P_s	Urea phase pressure
I	Unit Tensor
e_{ss}	Restitution coefficient of particle
Re	Reynolds Number

Greek letter

α_a	Air phase volume fraction
α_s	Urea phase volume fraction
ρ_a	Air phase density
ρ_s	Urea phase density
μ_s	Urea phase shear viscosity
λ_s	Urea phase bulk viscosity
τ_a	Air phase shear stress tensor
τ_s	Urea phase shear stress tensor

Subscript

a	Air
s	Urea
max	Maximum value
min	Minimum value

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Chapter 1

Introduction of Fluidized Bed Coating

1.1. Background of Research

Coating is technique in which thin polymeric film is coated around the particle for the controlled release, taste making or to increase the shelf life of the particle.[1] Although coating has been used in many industries for years like pharmaceutical industry. It has also been applied to other industries such as fertilizer industry for the slow release and to improve the quality of the fertilizer.[2] Mostly the coating is done through fluidized bed because of efficient mixing of particle, less operational cost, large scale continuous production and all the essential need for coating is covered in single apparatus. However, there are some drawbacks of fluidized bed coater like agglomeration of particles, which occurs with collision of wet particles, attrition of particles by collision with other particle and with the wall of fluidized bed coater, early evaporation of droplets from the particle. Many researchers have made attempts to avoid these problems. The agglomeration can be avoided by up bringing the kinetic energy of fluidized particles by amassed the volumetric flow rate. This will increase the production cost and effect the overall efficiency of the system. Numerous numerical gear like computational fluid dynamics (cfd) are gaining hobby which will recognize the phenomena taking location within the gadget and also be considered to optimize the machine to make method greater efficient

1.2. Agriculture

Agriculture is basically defined as "the cultivation of land or using various resources hence off; for the production purposes". Pakistan, as a developing country, agriculture plays a vital role in economic stability and growth. It is the main source of food for the population. Nearly half of the country labor is directly engaged in this sector. Almost 70 % of population is directly or indirectly related to this sector. That's why it is consider as a backbone of the country. It contributes 25 % to the GDP other than any sector. It provides the basic raw material and provisions to the industries.

Pakistan fertilizer industry has enormous potential and can emerge as fertilizer exporters in the South-Asia region. Being an agrarian country, it is heavily dependent on the fertilizers. According to recent reports and surveys, it has been concluded that demand and supply always mismatch in fertilizer industry.

In the 2018, the general sale of urea multiplied by means of 45% to 1. Sixty three million heaps and dap income is going upto 6% to 434,000 heaps. The global marketplace price of urea and dap is $240 and $385 per ton. T

1.3. Limitations of conventional Fertilizers:

Fertilizer industry faces various issues over the quality of products and slow release of the nutrients in the soil from several years. The main goal of fertilizer industry is to provide the nutrients in sufficient amount to the plants for the sustainable growth and optimal cultivation of the crops. Nitrogen, as the most common form used in fertilizers, should be used in controlled manner due to its mobility in the soil. If not controlled, nitrogen volatilization and leaching causes adverse impact on the efficiency, cultivation proficiency and environment. To overlook this problem, natural or synthetic fertilizers are present in bulk quantities in markets. The major three elements present in a fertilizer is nitrogen, potassium and phosphorous.

Among various forms of synthetic fertilizers, "Urea" is an important one. It provides basic nutrients to the soil. From the table **1**, it is seen that urea demand in non-fertilizer application is approximately 15 % of the world demand in 2013. From the table we can overlook at the demands for several years.

Table 1 Overview of urea demand in the recent years

Year	2016	2017	2018
Supply			
Full capacity	237.13	244.33	244.98
Supply	204.74	211.41	215.97
Demand			
Demand of fertilizer	155.53	157.61	159.51
Demand of non-fertilizer	38.18	40.51	42.95
% supply	5	6	6

The present use of conventional urea is not so suitable due to excessive loss of nitrogen from soil. The potential hazards and environmental pollution has banned use of urea as a fertilizers.

In the past studies, results had shown that approximately 20 to 70 % of urea had been released directly or indirectly to environment due to leaching, nitrification or volatilization process. Higher level of nitrates had been recorded in the soil which had harmful effect on the crops. Hence it is important to improvise the use of urea or how it is dissolved into the soil which will improve the quality and quantity of both the soil and crop. Nitrogen cycle taking place in environment.

1.4. Slow release coating remedies:

Synthesis of urea takes region by the reaction of anhydrous ammonia with carbon dioxide at higher stress and temperature. It is than drawn into the forms of pellets or granules to be used as a fertilizer. It is the most common form of synthetic fertilizer containing 46% of nitrogen and is highly soluble in water. Due to its greater content of nitrogen, urea provides more amount of it as compared to other solid fertilizers. The “slow release coating technology” provides the continuous release of nitrogen to the soil while preventing the contaminations.. It is designed for the gradual release of nutrients while synchronizing it with the need of plants. The European Standardization Committee has the following recommendations for the release of the nutrients:

Transformation of chemicals through degradation, dissolution and hydrolysis. Slow release: the discharge of nutrients from a coated fertilizer must be in a controlled way than the conventional ones.

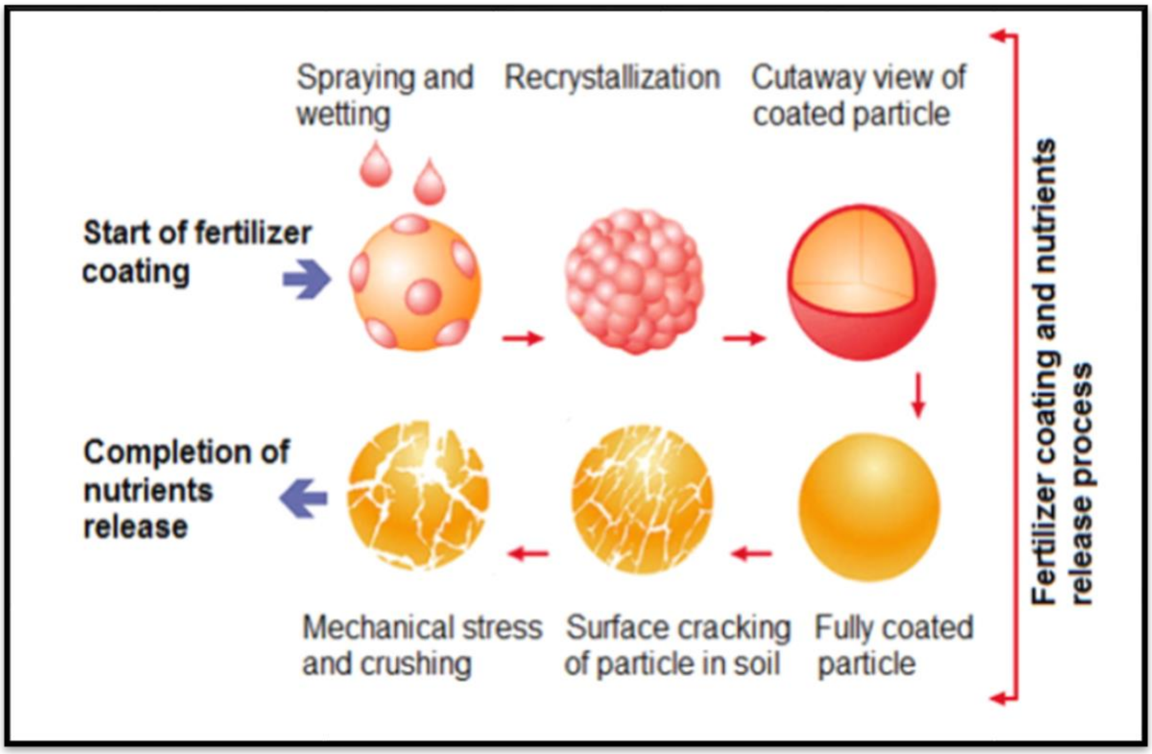


Figure 1Slow release fertilizer coating process and release rate

1.3. Introduction of coating

In this chapter, a brief overview is discussed related to the application of coating technique being used in the industry.as this work focuses on producing coated urea particle by using fluidized bed coater. The important bodily characteristics contain in fluidized bed coating might be mentioned that consists of fluidization, coating principle and the numerical tool (CFD) used for the study of the coater[3]. The process of the coating of urea particles is described by the continuous formation of thin film around the solid particles such as urea for the controlled release of nutrients such as urea. [4]. The coated microcapsules release their content at a controlled rates at specific conditions according to the application required [4]. Whent the size of coated particles is less than 1 μm these are called nanocapsules and when their size is greater 1 μm these are called microcapsules**.** microencapsulation is widely used in scientific and industrial area so it is topic of interest for the reserchers to add value in that field that has scope in phramcueticals, agriculture, pesticides and enzymes. [5].For the coating of urea particles Microencapsulation has been used to coat particles for the controlled release if nitrogen in the soil. [6]

1.4. Microcapsule materials

The material selected for microencapsulation depends on the substrate to which it is coated. The coating material is deposited to create a single particle structure, multi walled structure and the aggregate structure.[7] As this research focus on the coating of urea particle, so there are number of material available for coating such as gelatin, neem oil, molasses etc. All the required propertied is not achieved in a single coating material so they are used with a combination of two or three coating material to achieve the desired properties [8]. Following parameters are kept in mind while selecting the coating material;

- The chemical as well as physical properties the coating and the core material in the process.
- The physical compatibility between them.
- The mechanism of nutrients release
- The cost of the coating material

1.5. Release mechanisms

The mechanisms used for controlled launch in fertilizers include moisture and temperature launch for hydrophilic particles [10].The release rate of core material at a specific location and time by means of these mechanisms:

- Mechanical break of the particle wall.
- Dissolution of the coated film.
- Melting of the film coated on the particle.
- Diffusion of nutrient through the wall[9].

1.6. Factor affecting the selection of microencapsulation

There are number of techniques available for coating of single wall particle. The selection of the technique is based upon:

- Cost effectiveness of coating operation
- Properties of the coating and the core material
- Finished product properties of the coated particle

1.7. Introduction of Coating

There are various techniques of coating used industrially. Among them fluidization is the most feasible option for coating of fertilizers, additives and other food ingredients [11]. Fluidized bed coating technique is first used by Dale Wurster for the coating of tablets. In this method the tablets are covered by a layer of coating material. In the recent year, fluidized bed coating has gained much importance due to efficient mixing of particles. The fluidized bed coating phenomena has been shown in figure 2.

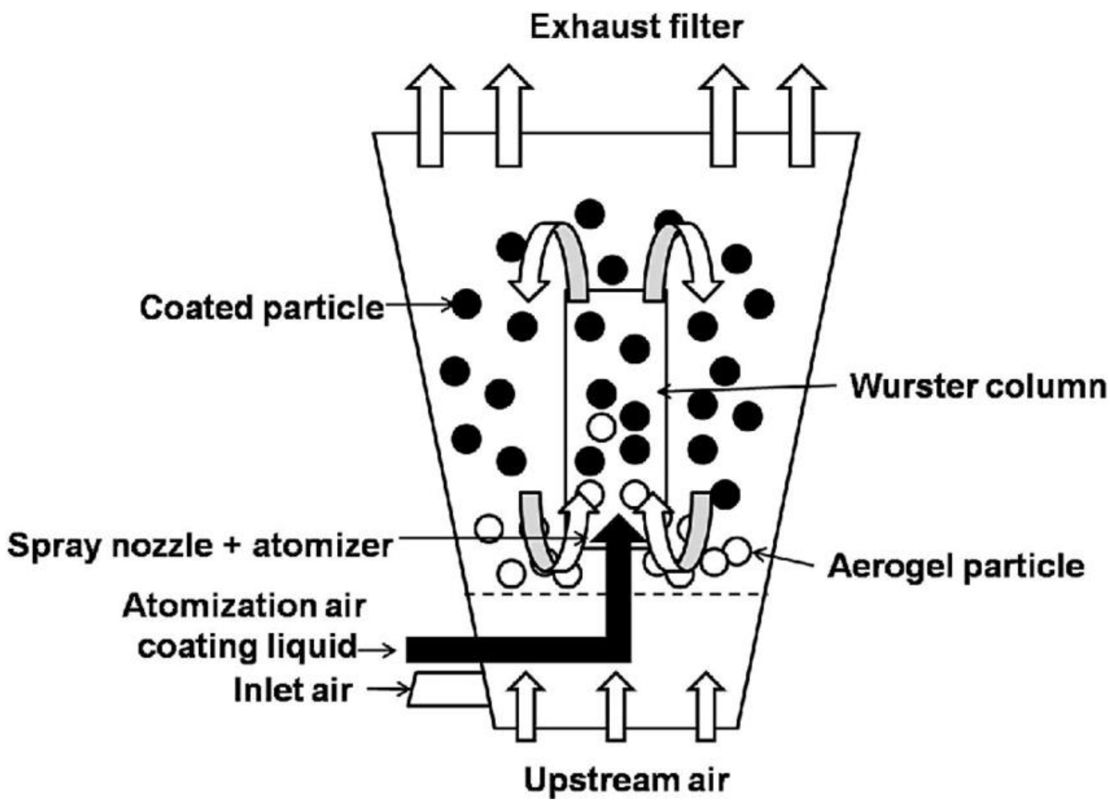


Figure 2Fluidized Bed Coating Phenomena

1.8. Description of Fluidization

Fluidization is the phenomena in which the drag force is exerted by a fluidizing medium such as air on the particle. When the velocity of air is less than the minimal fluidization pace the constant mattress regime exist.. With the increasing velocity of the force on the particle increases which lifted the particles in the upward direction leading to the fluidization[12]. Further increase in the velocity creates a bubbling regime and when the velocity of air equals to the terminal velocity the suspension of fluidized bed arisen. The basic principle of fluidized bed to maintain the particle in a suspended state[13]. The state of fluidized bed rely on the residences of the fluidizing medium and the characteristics of the particles, that effects in unique regimes of the fluidized mattress.. .the velocities to be considered in the fluidization are terminal velocity which is also refereed as settling velocity and the minimum fluidization velocity at which the drag force is enough to lift the fluidized bed for lifting of particle**.**

Fluidization:

$$U_t = \left[\frac{4 g d_p(\rho_p - \rho_g)}{3 \rho_g C_D}\right]^{0.5} \qquad (1)$$

Where cd is the drag coefficient, which relies upon at the particle reynold's wide variety.

$$Re_p = \frac{\rho_d v_g d_p}{\mu_g} \qquad (2)$$

vg the gas velocity (m s^{-1}),

dp particle diameter (m),

ρ_p particle density(kg m^{-3})

μ_g Viscosity of gas (kg m^{-3}).

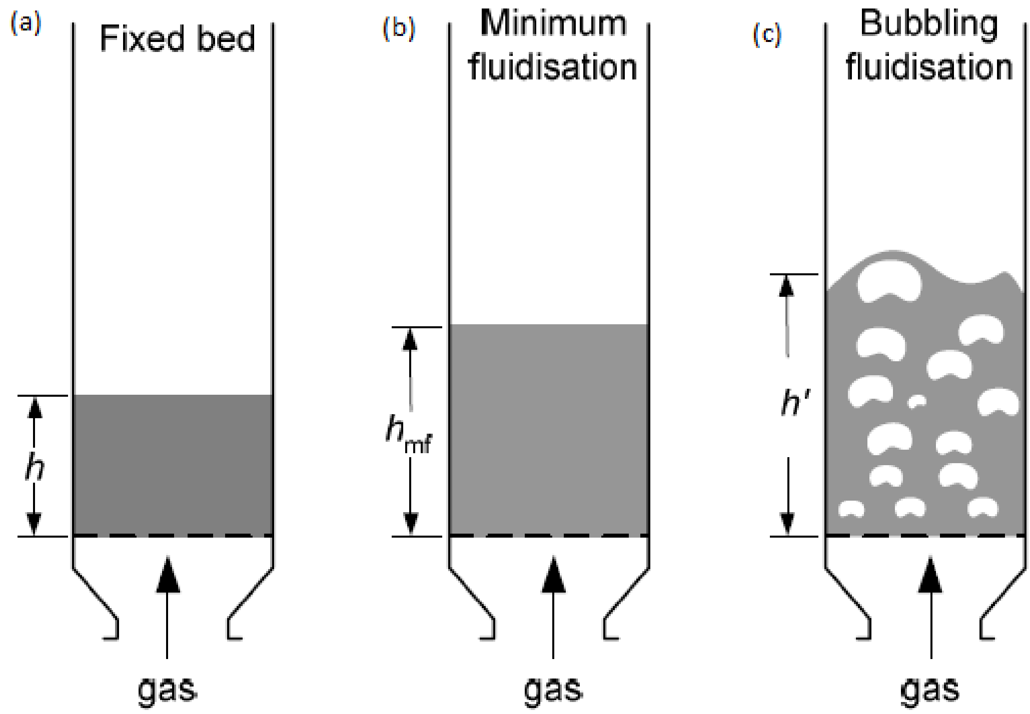


Figure 3. (a) Fixed Bed (b) Homogeneous Fluidization (c) Bublling Fluidization

The other factor effect the fluidization is minimum fluidization velocity Umf that is the minimum velocity required for a fluidizing medium to suspend the particle. Many researchers have proposed the relationship for the minimum fluidizing velocity [14].

1.9. Powder classification

In gas- solid fluidization, the distribution of fluidizing medium is affected by the size of particle, which affect the quality of fluidization. Therefore, the properties of solid particle and fluidizing medium play important role to define the type of fluidization. According to Geldart work, the powder are categorized into four different groups according to the size of particle and density of fluidizing medium. The powder are designated into a Group A, B, C and D[15, 16].

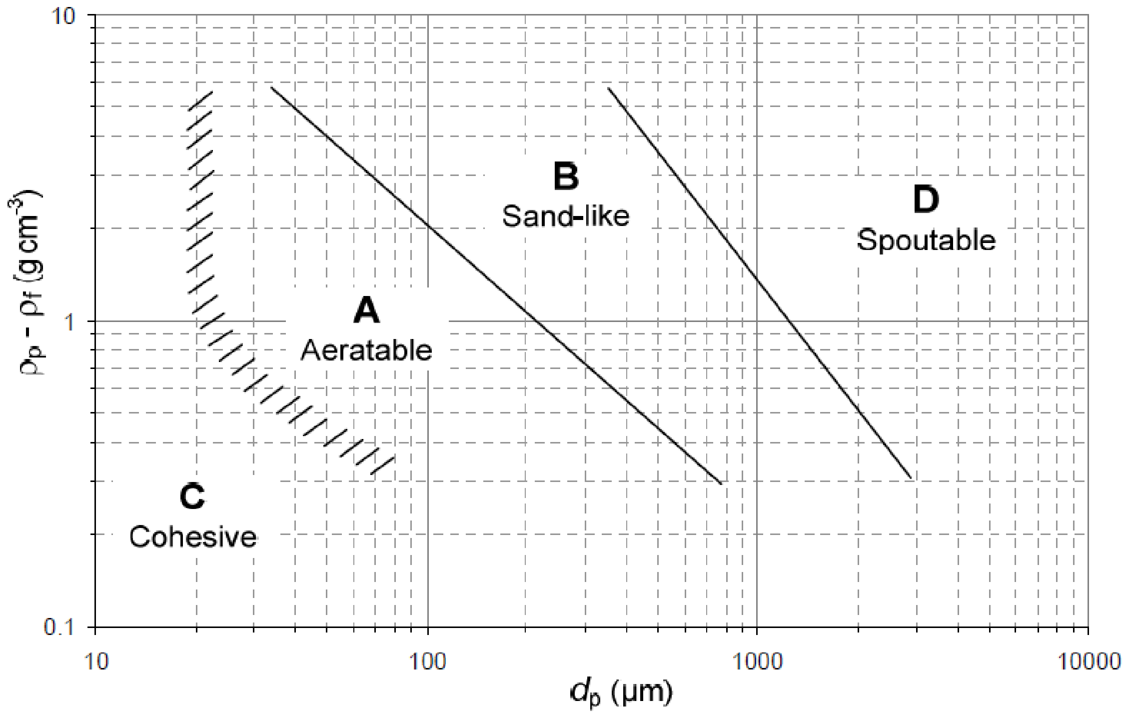


Figure 4GeladartTheGeldart (1973) powder classification scheme

particles from group A and B are suitable for the fluidization, while Group C particle are problematic to fluidize due to cohesion.

1.10. Bed properties

The fluidized bed phenomena is a multifaceted unit operation in which continuous flow of particles involved in the fluidized bed. As the fluidized bed system is involved in many applications due to efficient heat and mass transfer and limited pressure drop. The process parameters are also easy to control for the desired heat and mass transfer rates [17]. Having similar properties to a fluid bed properties are:

The density is calculated by [18],:

$$\rho_{app} = (1 - \alpha_g)\rho_p \qquad (3)$$

Where α_g is the voidage,

The apparent viscosity is calculated by:

$$\mu_{app} = \frac{1+0.5(1-\alpha_g)}{\alpha_g^4} . \mu_g \qquad (4)$$

Where μg is the gas viscosity.

In the fluidization express, the weight drop over the fluidized bed is equivalent to the weight of the bed per unit region:

$$\nabla P = \left[\frac{M}{\rho_p A_b}\left(\rho_p - \rho_g\right)\right] . g \qquad (5)$$

M is the mass (kg)

A_b cross-sectional area (m^2).

1.11. Fluidized bed coating process

The basic principal of fluidization phenomena is discussed schematically in Figure.3. Three phases are involved in fluidized bed coating:

- solid
- liquid
- gas

At the first the particle inside the bottom of the coater are fluidized with the help of fluidizing medium such as air[18]. When the particle are is suspended state the coating solution is pumped through binary nozzle in which air and the coating material is lifted up[18, 19]. The air is used for better lifting of coating solution. The coating solution makes contact with the particle result in in the wetting of particle. The hot fluidizing air is used to for evaporation of water and dry coated particle are obtained.

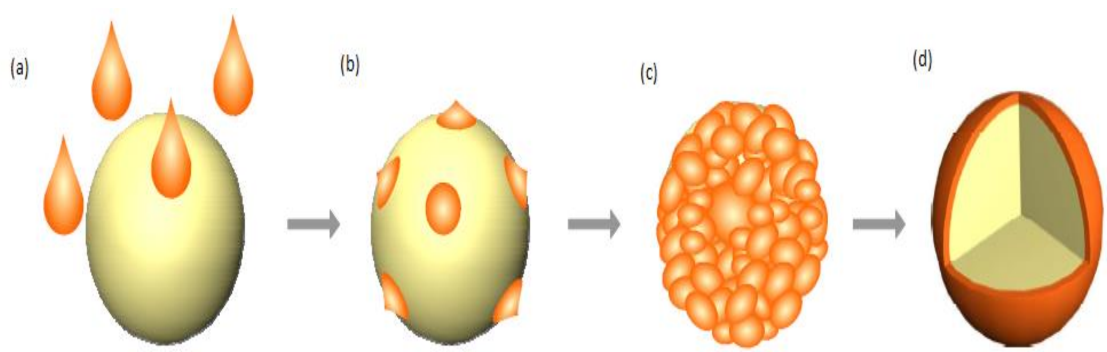


Figure 5(a) Droplet Atomization (b) Droplet Wetting (c) Droplet Spreading (d) Coated Particle

1.12. Fluidized bed configurations

There are diverse type of fluidized bed configuration are used for the coating of particle which are discussed below

- Top spray fluidized bed
- Bottom Spray fluidized bed

1.13. Top spray fluidized bed

In top spray fluidized bed the coating solution is sprayed from the top of fluidized bed coater. As In terms of deposition of coating solution the quality was poor and also effect the drying in top spray fluidized bed coater [20]. This is most common type of fluid bed used for process of coating. In this process, there is a counter current movement of powder particles and coating solution. The fluidized bed coating has the advantages of large batch size, having fast processing, and easy access of particle to the coating solution. The mixing of particle is also very efficient in top spray fluidized bed coating process. The limitations of top spray fluidized bed coating process is that solid –liquid contact area is not well defined and the chances of agglomeration is also higher

1.14. Bottom spray fluidized coater

In bottom spray fluidized bed coater, the coatingsolution is sprayed from the bottom. The probability of droplet-particle collision is increased and drying of particles is reduced leads tohigher coating efficiency[21]. However, in bottom spray fluidized bed coater the risk of agglomeration is increased due to the high concentration of wetted particle [22]. The major advantages of fluidized coating process are uniform mixing of particles and the contact of sold liquid are is also well defined. The major limitations of bottom spray fluidized bed coating process are slow processing of operation. The contact of coating solution to the particle is also limited and homogeneous fluidization is required.

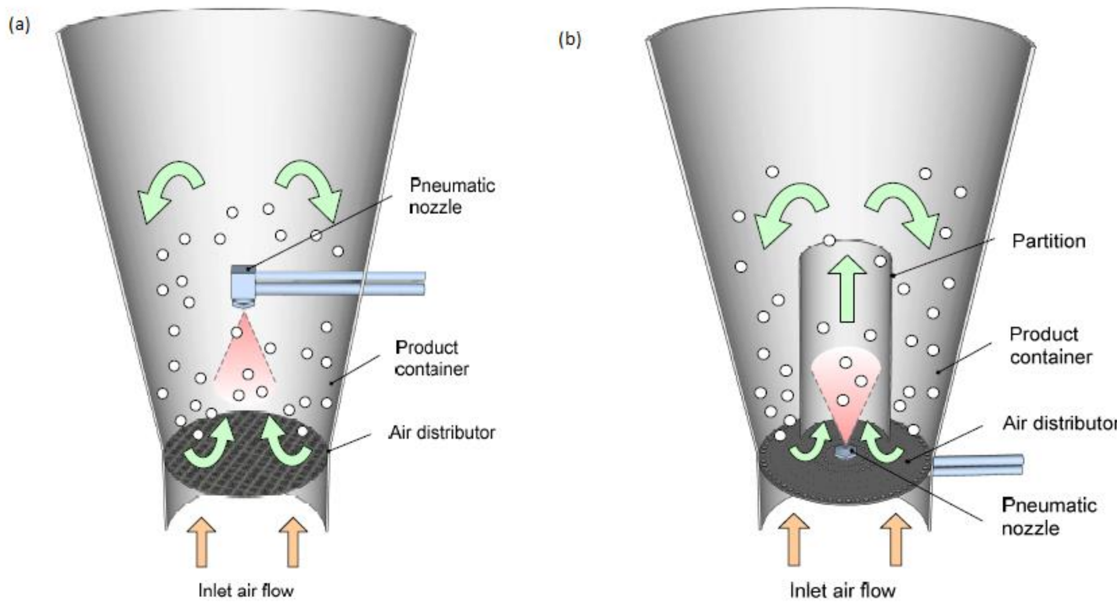


Figure 6 (a) Top Spray Fluidized Bed Coater (b) Bottom Spray Fluidized Bed Coater

1.15. Computational Fluid Dynamics

1.15.1 Introduction

CFD is a numerical tool implemented arithmetic, that is used to investigate the methods and structures which contain heat mass and momentum transfer[23]. In the recent years, CFD technique has been in many applied fields both in the industrial and non-industrial sector for the analysis and designing of the systems. Since 1950s, firstly CFD has been applied in aerospace industry for the designing and development of aircraft engines and the body of aircrafts. The aerospace and auto mobile industry used the CFD to calculate drag force and air flow in the body [24]. From the recent decade, CFD has been applied in chemical and process sector such as simulation of combustion process[14, 26]. Now a day, CFD has become the integral part for the optimization and lately cfd has been used to expect the flows and overall performance of system's designing of equipment and process. As results, CFD has been used to all aspects of fluid dynamics in Spray coating and spray during heat exchanger and other equipment. CFD is a numerical tool used to predict the flow field, heat and mass transfer rates. Furthermore the phases changes (such as evaporation condensation),chemical reaction rates and mechanical movement of the parts such as turbine can also be analyzed [27]. However, in the recent years CFD has been applied in the multiphase flows mechanism such as coating to understand the multifaceted flows and their thermal physical and rheological properties. [28].

1.15.2. Performing CFD analysis

To analyses the problem in CFD, the scientific knowledge is to interoperate mathematically.by adding the required information in software, the software expresses the stated problem in scientific term. The CFD solve the problem in three different parts.

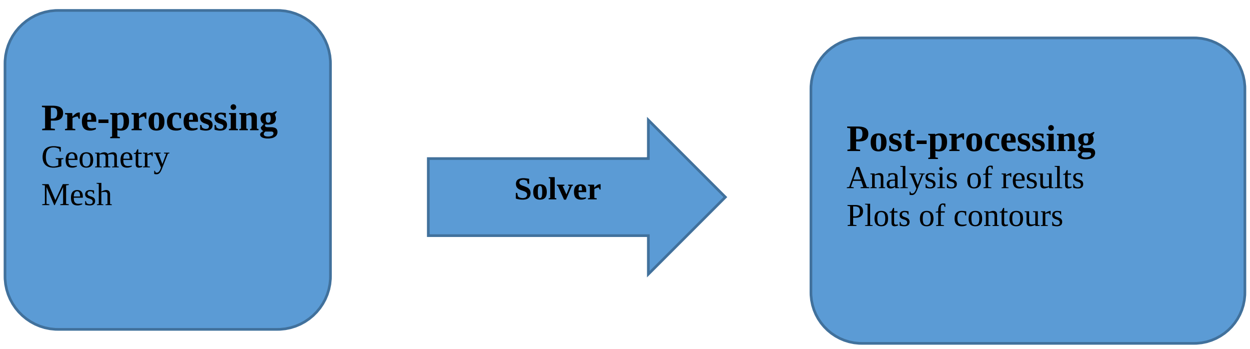


Figure 5. Steps of computational Fluid Dynamics analysis

To carry out the computational fluid dynamics (cfd) the problem must be stated inside the mathematical form. To perform the CFD simulation the scientific knowledge is to expe=ress mathematically in the solver than the post processing using that mathematical information convert the mathematical data into scientific form. CFD solve the problem in three main parts.

1.15.2. a. Pre-processing

The first step to solve the CFD simulation is to define the problem domain by creating geometry by means of software such as SOLIDWORKS, DESIGN MODELER and SPAACECLAIM etc. The geometry is than exported for the discretization of domain in to numerous cells or elements in software ICEM ANSYS MESHING etc. After creating the domain the initial condition is to be specified and physicals properties of the domain.

1.15.2. Solving

After completing the meshing of the geometry the computational part is solved .the geometry is imported in the solver program. Following are the different techniques to solve the CFD:

- Finite Volume Method
- Finite Element Method
- FINITE Difference Method

When the grid generation is generated the computational Fluid Dynamic par can be initialize. the generated mesh is to exported to solve program where the CFD has to be done .the CFD solver require the initial boundary conditions valves which has to be given in pre-processing.

- The governing equation is solve by integration of flow field, heat and mass transfer equation in computational domain.
- Discretization, of governing equation which convert the integral equation into algebraic equation using Finite Difference approach
- The algebraic equation is solved by iteration either in steady state or in transient state.

The CFD solve thousands of equation on each node to achieve the convergence.

1.15.2. c. Post-processing

After solving modeling equations, the model results are evaluated and analyzed .in the post processor the model results are visualized both numerically and graphically in both 2&3D representation. There are many ways to analyses and compare the data in the post processor.

1.16. Computational Fluid Dynamics Overview:

CFD is the process of solving fluid flow, mass and heat transfer by solving the governing equation on the control volume. The rate of change of the components is same to the cross ponding components applied force**.** The process of solving a fluid flow problem with the use of governing equation is shown in table2. The table also describes how to CFD analyze the practical flow field with the mathematical model. With the consideration of momentum, mass and energy as conserved quantity the rate of change of all component is equal to the applied force. The mass conservation energy conservation and thee equation from Newton Law Motion are. The flow rates are obtained from these equation which is discussed later.

:

Table 2 Overview of Performing CFD

Mass conservation equation	Continuity equation
Newton's second law of motion	Eulerian-Eulerian equations, Navier-Stoke equations
Energy conservation equation	First law of thermodynamics

Velocity	u(x, y, z,t), v(x, y, z, t),w(x, y, z, t)
Pressure	p(x, y, z,t)
Density	(x, y, z,t)
Temperature	T (x, y, z,t)

Deduced flow behaviour	flow separation : efficiencies (turbine)
	: heat transfer
	force on bodies (, drag,skin friction lift)

1.17. Governing equations

The governing equations of momentum mass and energy are represented by conservation laws of physics:

- The law of conservation of momentum (Newton Second Law)
- The conservation of mass (Equation of Continuity)
- The conservation of energy (the first law of thermodynamics).

By applying these laws over a self-assertive control volume the rate mass transition is equivalent to the aggregate of powers following up on the body,. As the principal law of thermodynamics clarifies that the Kinetic vitality is equivalent to the warmth move rate is not as much as pace of work done by the framework. The subsequent conditions are:

1.17.1Conservation of mass equation:

$$\frac{\partial\rho}{\partial t} + \nabla.(\rho.v) = 0 \qquad (6)$$

The mass conservation or continuity equation which can be written in Cartesian coordinates in most applications as shown in equation

$$\frac{\partial\rho}{\partial t} + \nabla.(\rho u) + (\rho v) + (\rho w) = 0 \qquad (7)$$

1.17.2. Conservation of momentum:

$$\rho\frac{Dv}{Dt} = \rho\vec{f} - \nabla p + \bar{\tau}$$

This is known as the Navier-Stokes equation. It tends to be written in Cartesian Coordinates, as

x – Momentum: $\rho\frac{Du}{Dt} = \rho f_x - \frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}$ (7)

y – Momentum: $\rho\frac{Dv}{Dt} = \rho f_y - \frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}$ (8)

z – Momentum: $\rho\frac{Dw}{Dt} = \rho f_z - \frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}$ (9)

1.17.3. Conservation of energy:

$$\rho \frac{Dh}{Dt} - \frac{Dp}{Dt} = \Psi - \nabla . q \qquad (10)$$

Where the heat transfer rate due to conduction,

T, as

$$q = -k\nabla T \qquad (11)$$

In Cartesian coordinates, can be expressed as and with h and Ψ as defined further.

$$\rho \frac{Dh}{Dt} - \frac{Dp}{Dt} = \Psi + \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\partial T}{\partial z}\right) \qquad (12)$$

Where Ψ is given by

$$\Psi = 2\mu \left(\frac{\partial u}{\partial x}\right)^2 + (\frac{\partial v}{\partial y})^2 + (\frac{\partial w}{\partial z})^2 + \frac{1}{2}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)^2$$

$$+ \frac{1}{2}\left(\frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)^2 + \frac{1}{2}\left(\frac{\partial w}{\partial z} + \frac{\partial u}{\partial x}\right)^2 - \frac{2}{3}(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z})^2 \qquad (13)$$

μ kinematic viscosity (m^2s^{-1}),

u, *v*, *w* are the components of velocity

, *e* the internal energy

h Enthalpy linked to the temperature

$$e = c_v(T - T_{ref})$$

And

$$h = c_p(T - T_{ref})$$

Where *cp and* c_v are the specific heats

1.17.4. Equations of state

The thermodynamic equilibrium is described by ideal gas equation.

$$P = \frac{n}{v} RT \qquad (15)$$

When compressible fluids flows are involved there are momentum, energy and continuity equation are interlinked. Which occurred due to change in temperature and pressure in the flow field.

Without energy momentum and continuity equation the flow field only solve Naiver Stokes Equation, the energy equation is only solve when the temperature is involved in the flow field [29].

1.2. Research objectives

The research on this thesis deals with the computational fluid dynamics look at of the technique of bottom-spray fluidized bed coating. The major objective of the studies provided on this proposal is the advancement of a hydrodynamic model, which correctly predicts the urea particle conduct in a fluidized bed coater. The major objectives of the research are:

- Urea-solid flow behavior in a tapered fluidized bed coater
- To find a appropriate drag model
- Study the homogeneous fluidization in 2&3 D geometry
- To study the heat transfer during evaporation.

Chapter 2

Literature Review

2.1. Application of CFD in Industry

The application of coating applied industrially on 1954, from than the technique of coating of coating is improved and modified for the variety of purposes. The CFD is used to gain knowledge of the issue to be analyzed .CFD give solution in the mathematical form rather than of a physical model, the prediction of the model is made accordingly.CFD is a very vast numerical tool to study the various phenomena occurring for designing, operating and analyzing the phenomena. With the devolpment in computational sciences, modern numerical tools and fluid mechanic theory , CFD is used in modelling of chemical processes, the designing of chemical reactors.As the coating methodology is developed in pharmaceutical industry, It has also been used in other industries like fertilizer, food and fragrance for the slow release of ingredeints.in the fertilizer industry microencapsulation is directly related to the coating of fertilizer to provide effective barrier for the slow release of nutrients[30].

With the advancement in the computation science and computational power the CFD is used in major sectors of industry like automotive, aerospace nuclear, modelling of industrial processes and have extended into fertilizer industry[31]. CFD is a powerful analysis and designing tool in process sector for the process like drying, mixing sterilization and reaction kinetics[32].
Main computational fluid dynamics utility are used in aerospace, automobile and nuclear industries which has been extended into fertilizer enterprise which will model business strategies.[33]. In the recent application in which CFD is widely used is coating in which CFD is used to check the non-uniformity of coated particle in fluidized bed coater.[34]

2.2. CFD modelling of gas-solid fluidized beds.

The application of gas-solid fluidized bed is widely used in many industries like environmental, chemical, petrochemical and metallurgy etc. for the operation of coating, granulation, drying, and catalytic cracking. The major advantages of fluidized bed is good mixing and uniform distribution of temperature. The complex multiphase behavior during fluidization lead to difficulty in designing and scaling of industrial scale fluidized bed.in this situation CFD is valuable tool for the understanding of fluidized bed. To understand the complex multiphase behaviors the CFD is a most reliable numerical technique for solving the multifaceted system and their interactions[35].as the CFD is based on the Navier stokes equation so the fundamental laws describe the multiphase system very Cleary[36]. With the increase of computational power the system can be analyzed so the experimentation cost can be avoided with such development..[37]

In literature gas-solid fluidization is solved by two techniques. Eulerian Langragian and Eulerian Eulerian, in Eulerian lagrangian the expansion of bed and slip velocity of the particle both can be simulated, however in this techniques a lot of computational effort is required so this approach is not commonly used.[38]. Eulerian Eulerian is another approach to sole gas-solid fluidization. this approach is computationally less demanding as in industry massive numbers of particles are involved so continuum approach is more applicable than the discrete approach. Many researchers have worked on the Eulerian Eulerian approach and examined the gas-solid fluidization phenomena and validated it with the experimental results[39]. The effect of fluidizing medium velocity pressure drop bubbling and slugging in the gas-solid fluidized bed is also investigated by the Eulerian Eulerian approach. With the increasing research on Eulerian Eulerian approach the expansion of bed and study of homogeneous fluidization and its transition to heterogeneous fluidization[40] is also investigated later on CFD is used to study the gas-solid heat transfer due to inlet gas velocity is studied.[28].

The hydrodynamics modelling of gas–solid phenomena in fluidized bed was studied through experimental technique and numerical simulation and in order to analyze the effect of drag models on the hydrodynamics of fluidization. CFD is also used to study the fast pyrolysis fluidized reactor for fluid-particle interaction.. The model analyzed the heat, momentum and mass transfer between the fluidization medium and the silica sand.in the recent years CFD simulation of gas flow behavior through the gas distributor in a multi-stage biomass gasifier was studied by the Eulerian-Eulerian model approach.

2.3. Fluidized bed coating process

Fluidized bed coating, developed for pharmaceutical industries, but it is also used for coating of other core ingredients for the controlled release. Many design modifications have been implemented in the coating process to improve the coating efficiency and reduce the cost of coating process. Because of that flexibility it has found a widespread usage in fertilizer and other industries

Coating uniformity plays important role in coating of the particles. It is directly resulted from system design, process type and product variables. Furthermore, supersonic attrition nozzles have been used in gas–solid fluidized beds [10]. In recent years, some researches have been conducted on mathematical modelling of hydrodynamics, heat transfer and mass transfer phenomena in fluidized bed. Simulated in these investigations were the deposition behavior and particle dynamic populations of fluid bed in spray granulation process. Although many approaches such as black box modelling, population balance modelling, lumped region models and combined thermodynamic and population balance model, have been used for modelling fluidized bed coating, but limited researchers applied CFD model. CFD model has the advantage of being case independent. When tuned for a particular range of conditions, CFD model can produce predictions, for conditions other than this range, which are more likely to be accurate in comparison with those of other models. Also, CFD model can evaluate the effect of system geometry (such as design of baffle and inner pipe in fluidized bed) on coating efficiency. Fluidized bed coating process consists of three major steps including fluidizing solid particles, atomizing coating solution on the bed of fluidized particles, and drying the coated particles to evaporate the solvent out of coating solution. The atomized droplets consist of a solute, acting as a covering layer, and a solvent in which coating material is solved or with which coating material forms a slurry solution. Once came in contact with solid particles, liquid droplets spread over the surface of the particles before fluidizing gas can evaporates the solvent leaving a layer of coating material on particles surface. Particles usually grow through mechanisms: (1) the agglomeration of excellent particles because of liquid bridging among two or greater smaller particle; (2) the growth of coating layer on a particle. The first procedure happens when the liquid bridge is robust sufficient to keep particles collectively. The fluidizing air resources required evaporative potential to get rid of the ultimate solvent at the surface of the fluidized particles. While liquid binders are introduced to a fluidized bed, two unique states of particle boom are possible, depending at the mass transfer of binder to the fluid particles and the evaporation ability inside the bed. This type of particle growth is called “agglomeration”. Fluid bed spray agglomeration is similar to the fluid bed granulation. However, when fluidized beds operate under drying conditions, evaporation capacity of the bed increases sufficiently drying the particle surface before collision thus terminating the formation of liquid bridges.

The modelling of FBC process is taken by two approaches as discussed earlier Eulerian-Eulerian and Eulerian Langragian. To model the liquid solid interaction and occurring of agglomeration Discrete Element Model is used as this approach require a lot of computational effort because motion of every particle is counted with the droplet interaction and fluidizing medium treat as a continuum.[41] In other approach modeling of homogeneous fluidizing condition and mass and heat transfer from the spray to solid phase can be calculated and drying of particle is also studied. The coupling of CFD-DEM approach is also used to model the coating phenomena to study the wetting on single particle.to calculates the wetting of particle residence time inside the spray zone is calculated. Other approaches are also used to combine population balance modeling with Eulerian approach. The version advanced is analyzed for heat and mass transfer and examine the spray of liquid for granulation and Coating. The particle length distribution and seed formation version turned into coupled with populace stability model to simulate the spouted bed.

Chapter 3

Methodology

3.1. Eulerian-Eulerian Two Fluid Model

Fluidization is one of the most versatile techniques and had found wide scale of application in major chemical and process industries. The most commonly used applications of fluidization is in coating, drying, granulation and catalytic cracking. Among these applications coating has gain much importance especially in the field of fertilizers, where urea is coated with a polymer solution to achieve slow release characteristics. Coating is the most novel phenomena in recent decade to increase the efficiency of urea fertilizer and with the advancement in process industry it is important to optimize the process with minimum use of energy to meet the required demand. The coated particles are finished with detailed and specified properties generally for slow release of nitrogen to meet the end user requirements.

The major advantages of FBC over other coating techniques are excellent mass, heat and momentum transfer. The physical parameters of particles can be controlled to some extent by controlling the operation parameters. Thus, the hydrodynamic modeling of FBC for urea particles is important for detailed understanding of coating process in fertilizer industry and to the best of authors' knowledge such modeling computational fluid dynamics (CFD) is yet to done.

Despite of much application of FBC, the modeling is still a challenging task because of the multifaceted flows inside the bed. The essential problem encountered in modeling of fluidized bed is the interaction between the phases that can only be studied under a limited range of condition. With the increase of computational resources CFD has become a powerful tool for solving the multiphase flows in fluidized bed. Multiphase flows are solved in CFD by two models Eulerian-Eulerian (EE) and Eulerian Langrangian (EL).In Eulerian Langrangian model fluid phase act as a continuous media while the particle phase solve by Newtonian equation of motion for each particle**.** Eulerian-Eulerian model required less computational effort for the study of hydrodynamics in fluidized bed, this makes EE model is the most suitable choice for FBC hydrodynamics studies. In this work we studied various hydrodynamics behaviors of FBC are studied for urea-air mixture. CFD simulation was performed on commercial software ANSYS Fluent 18.0 by means of Eulerian-Eulerian approach**.** The hydrodynamic behavior of a 2 & 3D air-urea tapered FBC is studied.The research work presented in this thesis has been solved for the same set of model equations however the drag model is is altered for different cases using the Syamlal O'Brien (SB), Gidaspow (GP), and modified Syamlal O brein (modified-SMB) drag models. Generally, the GP drag law is a theoretical drag law, used for coarse mesh and give better result for homogeneous fluidization and SMB model convert the terminal velocity correlation into drag correlation], whereas, in modified SMB the terminal velocity correlation constants is tuned according to the initial condition for the better agreement of results. The effect of parameters like particle volume fraction, velocity magnitude and dynamic pressure in the FBC are studied

The EE-TFM assumes both phases as interpenetrating continua. Hence, the conservation equations of mass, momentum, and energy can be appropriately obtained through principal of conservation of mass, momentum ad energy equation.. This model treats each phase as interpenetrating continua where the volume of one phase is not occupied by the other phase. The sum of the fraction of each phase is equal to 1.The equation of phasic volume fraction is given by:

$$\sum_{q=0}^{n} \alpha_q = 1 \qquad (16)$$

The volume fraction of each phase is represented by α_q and n represents the total number of phases. In this study two phases are present (1) primary Air phase and (2) secondary urea phase which are represented by ‘a’ and‘s ’respectively. The EE-TFM model is the complex multiphase model. It solves a set of n continuity and momentum equation. The continuity and momentum equation are given below

3.2. Continuity Equation

The continuity equation for air ‘a ‘and urea’s’ phase is

$$\frac{\partial}{\partial t}(\alpha_a \rho_a) + \nabla.(\alpha_a \rho_a v_a) = 0 \qquad (17)$$

$$\frac{\partial}{\partial t}(\alpha_s \rho_s) + \nabla.(\alpha_s \rho_s v_s) = 0 \qquad (18)$$

3.3. Conservation of momentum

The momentum conservation term for the air phase is

$$\frac{\partial}{\partial t}(\alpha_a \rho_a \overrightarrow{v_a}) + \nabla.(\alpha_a \rho_a \overrightarrow{v_a}\overrightarrow{v_a}) = -\alpha_a \nabla p + \nabla.\overline{\overline{\tau_a}} + \varepsilon_a \rho_a \vec{g} - K_{as}(\overrightarrow{v_a} - \overrightarrow{v_s}) \quad (19)$$

The air phase stress –strain tensor and is given by:

$$\overline{\overline{\tau_a}} = \alpha_a \mu_a \left(\nabla \overrightarrow{v_a} + \nabla \overrightarrow{v_a^T}\right) + \varepsilon_a \left(\lambda_a - \frac{2}{3} * \mu_a\right).\nabla \overrightarrow{v_a} \bar{I} \quad (20)$$

The momentum exchange term for the solid phase is written as

$$\frac{\partial}{\partial t}(\alpha_s \rho_s \overrightarrow{v_s}) + \nabla.(\alpha_s \rho_s \overrightarrow{v_s}\overrightarrow{v_s}) = -\alpha_s \nabla p - \nabla p_s + \nabla \overline{\overline{\tau_s}} + \alpha_s \rho_s \vec{g} - K_{as}(\overrightarrow{v_a} - \overrightarrow{v_s}) \quad (21)$$

Solid phase stress tensors are given by:

$$\overline{\overline{\tau_s}} = \alpha_a \mu_s \left(\nabla \overrightarrow{v_s} + \nabla \overrightarrow{v_s^T}\right) + \varepsilon_s \left(\lambda_s - \frac{2}{3} * \mu_s\right).\nabla \overrightarrow{v_s} \bar{I} \quad (22)$$

Where μ_s is the solid shear viscosity

$$\mu_s = \frac{\alpha_s d_s \rho_s \sqrt{\Theta_s \pi}}{6(3-e_{ss})}[1 + \frac{2}{5}(1+e_{ss})(3e_{ss}-1)\alpha_s g_{0,ss} \quad (23)$$

The solid bulk viscosity (λs) accounts for the resistance of the granular particles to compression and expansion

$$\lambda s = \frac{4}{3}\alpha_s^2 \rho_s d_s g_{0,ss}(1+e_{ss})\left(\frac{\Theta_s}{\pi}\right)^{\frac{1}{2}} \quad (24)$$

As the product of the momentum exchange coefficient, and the slip velocity

3.4. Gas-solid interaction

The gas solid exchange coefficient is explained by

$$K_{as} = \frac{\alpha_s \rho_s f}{\tau_s} \quad (25)$$

f depends on the exchange coefficient model

τ_s is particulate relaxation time and it is defined by

$$\tau_s = \rho_s d_s^2 / 18\mu_g \qquad (26)$$

$d_s$the diameter of solid particle and the term f include a drag coefficient C_D.

3.5.Drag Models

3.5.1. Gidaspow Drag Model

The GP drag model which is combination of Wen and Yu model and the Ergun equation is used to calculate the gas solid momentum exchange coefficient

$$K_{as} = \frac{3}{4} C_D \left(\frac{\alpha_s \alpha_a \rho_a (v_s - v_a)}{d_s}\right) \varepsilon_g^{-2.65}, \ \alpha_a > 0.8 \qquad (27)$$

$$150 \left(\frac{\alpha_s (1-\alpha_s) \mu_s}{\alpha_a d_s^2}\right) + 1.75 \left(\frac{\rho_s \alpha_s (v_s - v_a)}{d_s}\right), \ \alpha_s \leq 0.8 \qquad (28)$$

Where the drag coefficient for smooth particle is

$$C_D = \frac{24}{\alpha_a Re_s} [1 + 0.15(\alpha_a Re_s)^{0.687}], Re < 1000 \qquad (29)$$

0.44, Re>1000 (30)

3.5.2. Syamlal O brine Drag Model

SMB drag model that is used in this study to calculate the gas solid momentum exchange coefficient has following form:

$$f = \frac{C_D Re_s \alpha_a}{24 v_{r,s}^2} \qquad (31)$$

The f is same whereas the drag coefficient term is

$$C_D = \left(0.63 + \frac{4.8}{\sqrt{\frac{Re_s}{v_{r,s}}}}\right)^2 \qquad (32)$$

The Reynolds number is a function of slip velocity of the solid phase

$$Re_s = \frac{\rho_g d_s (v_s - v_a)}{\mu_g} \qquad (33)$$

The fluid solid exchange term is

$$K_{as} = \frac{3\alpha_s \alpha_a \rho_g}{4 v_{r,s}^2 d_s} C_D\left(\frac{Re_s}{v_{r,s}}\right)(v_s - v_a) \qquad (34)$$

And the terminal velocity correlation is

$$v_{r,s} = 0.5(A - .06Re_s + \sqrt{(0.06Re_s)^2 + 0.12Re(2B - A) + A^2}) \qquad (35)$$

And

$$A = \alpha_a^{4.14} \qquad (36)$$

And B is

$$B = P\alpha_a^{1.28}, \text{ for} \alpha_a \leq 0.85 \qquad (37)$$

$$B = \alpha_g^Q \qquad \text{For} \alpha_a \geq 0.85 \qquad (38)$$

3.5.3. Modified Syamlal O Brine model:

To enhance the applicability of the existing SMB model user defined function is used to modify the existing SMB model. To modify the model the value of B is changed by altering the values of P (initially=0.8) until v_a is calculated. The value of Q (initial, Q = 2.65) is then corrected by equation B.6. Finally, the gas-solid exchange coefficient can be modeled by using the new values of P and Q.

Specifying the values of P and Q

$$\mathrm{v_a} = \mathrm{Re_t} \frac{\alpha_a \mu_a}{\rho_{a d_s}} \qquad (39)$$

$$\mathrm{Re_t} = \mathrm{v_{rs} Re_{ts}} \qquad (40)$$

Re_t=the Reynolds

$$Re_t = v_{rs} Re_{ts} \mathrm{s} \qquad (41)$$

Re_{ts}=the Reynolds number under terminal settling velocity

$$Re_{ts} = \left(\sqrt{\frac{4.8^2+2.32\sqrt{\frac{4A_r}{3-4.8}}}{1.26}}\right)^2 \qquad (42)$$

And Archimedes is expressed by

$$A_r=\frac{(\rho_s-\rho_a)d_p^3\rho_a g}{\mu_a} \qquad (43)$$

By combining the equation

$$V_{rs}\text{-}\frac{A+.06BRe_{ts}}{1+.06Re_{ts}} \qquad (44)$$

The following equation can be used to correct the value of Q:

Q=1.28+log (P)/log (0.8) (45)

3.6.Heat Transfer Model

3.6.1Heat transfer in evaporation

The energy equation in the model

$$\frac{\partial}{\partial t}(\alpha_i\rho_i H_i) + \nabla.(\alpha_i\rho_i u_i H_i) = -\alpha_i\frac{\partial p_i}{\partial t} + \tau_i{:}\,\nabla u_i + Q_{ij} + S_{hj} \qquad (46)$$

where Qji is the heat exchange between gas and urea phases

Sh,i is the transfer of energy due to evaporation.

The heat exchanged between the phases through convection:

$$Q_{pg}=\frac{6\alpha_p\alpha_g h_{pg}(T_p-T_g)}{d_p} \qquad (47)$$

The correlation given by gunn for heat transfer become used to estimate the warmth switch coefficient"

$$Nu_s = \left(7-10\alpha_g+5\alpha_g^2\right)\left(1+0.7Re_s^{0.2}Pr^{\frac{1}{3}}\right)+(1.33-2.4\alpha_g+1.2\alpha_g^2)Re_s^{0.7}Pr^{1/3} \qquad (48)$$

$h_{sg} = \frac{k_g Nu_s}{d_s}$ (49)

Re=$\frac{\rho v D}{\mu}$ (50)

Pr=$\frac{c_p \mu}{\kappa}$ (51)

Where $h_{sg}$is the heat transfer coefficient.

The correlation given by Gunn for heat transfer was used to estimate the heat transfer coefficient. The value of Reynolds number and prandtl number in the correlation to get the heat transfer coefficient.

To account for the energy required to evaporate moisture, a source term is brought to the energy equation inside the urea phase:

$S_{hp} = S_{wp} H_{vap,w}$ (52)

Where Hvap,w is the energy for evaporation of water obtained

$H_{vap} = 3006300 - 1428.1T_p - 1.5534T_p^2$ (53)

3.7. Initial boundary condition

The 2&3-D fluidized bed model shown schematically in figure 1&2. The inlet diameter of the taper fluidized bed coater is 9.54cm. The length of the coater is 88.1 cm and the outlet diameter is 23cm.The fluidizing medium ‘air’ is introduced with a uniform velocity of 0.2,0.5 and 0.8 m/s. A no slip boundary condition is used for the wall and outlet was defined on the principle of ‘pressure outlet’ condition was used. The volume fraction is 0.5. The Inlet conditions details are shown in Table 2.

.

Table 3 Initial boundary and simulation conditions

Parameter	Value
Urea density	1330(kg/m^3)
Air density	1.2(kg/m^3)
Diameter of urea	.002m
Initial Solid Packing	0.63
Superficial air velocity	0.2,o.5,0.8m/s
Static bed height	0.25m
Initial boundary condition	Velocity inlet
Outlet boundary ccondition	Pressure outlet
Under relaxation factor	
Pressure	0.5
Momentum	0.2
Volume Fraction	0.4

3.8. Simulation procedure:

The geometry was made on a commercial software solid works than it is exported to ICEM for meshing where hexagonal mesh was created, the mesh was then exported to commercial CFD package 'ANSYS FLUENT 18.0® to study the different drag laws, where the equation are solved using finite volume approach. The 2D computational domain was discretized by6.0 x 10^{5}cells. The quality of mesh is 0.99 where as in 3D computational model the body is discretized into 9.74x10^{5}033 cells and quality of mesh is 0.49. A transient simulation was run with a time step of 0.001 s for 14 seconds. With 20 iterations in step with time step become chosen. This new release was ok to gain convergence . First-order discretization schemes for the convection phrases are used. User Defined Function for the modification of SMB drag model is compiled in fluent also. Time average data calculated and discussed in the results

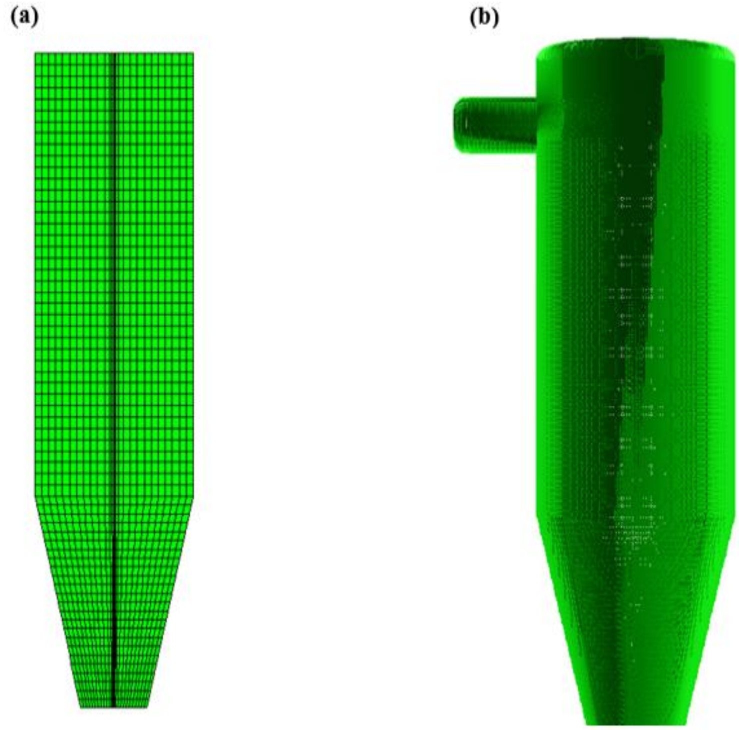


Figure 7Fluidized Bed Coater geometry (a 2D (b) 3D

Chapter 4

Results and discussion

4.1. Comparison of drag laws

Results obtained after the successful simulations are discussed here as follows:

Hydrodynamic study of gas-solid FBC on 2D model has been performed with the inclusion of drag models modified SMB, SMB, and GP model, for the height of 0.6m. The monitoring height is chosen to ensure that, below is the top height of fluidized bed.

4.1.1. Gas solid hydrodynamics:

Figure 8 shows the velocity magnitude profile along the axial direction for a height of 0.6 m. For GP drag law a moderate increase in momentum is observed. As the GP drag law does not account for the fact of vicious forces, therefore, after the fluidized bed zone at a height of 0.3 m the velocity increase is very sharp and no decelerating region (a characteristics of fluidized bed) is formed .In case of SMB model, a slight increase in momentum of urea particles is observed throughout the fluidized region, but an exponential increase in the urea velocity is observed afterwards. As in SMB drag model, the terminal velocity is considered as a fixed constant, it predicts high terminal velocity of solid phase, which overestimate these results.

However in case of mod SMB model the terminal velocity to inlet velocity correlation constant is readjusted per iteration, the results obtained are in complete agreement to homogeneous fluidization phenomenon as shown in figure 9. The results depicts the development of an accelerating region at the inlet of bed and decelerating region at the exit of the bed. The urea particles gain momentum at the inlet of fluidized coater and reach to maximum at a height of about 0.28m, then the velocity of urea particles decreases and gradually falls toward zero

The trends of particle volume fraction are also in agreement with the velocity profiles and a shown in figure 9. Since GP model is principally derived on the account of volume fraction, which does not change in the simulated scenario. Consequently, no change in the simulated results is observed. As in case of SMB drag model the figure shows small variation in volume fraction of solid phase. The terminal velocity correlation did not predict the value for fluidization due to high value of constants. The simulated result of modified SMB result show that, at the inlet volume fraction of urea is minimum and increasing along the bed height the tendency is attributed to adjustment of terminal velocity constants, this increases the urea fraction. Therefore, the urea volume fraction is maximum at a height of 0.28m and afterwards volume fraction gradually falls toward zero. Resultantly the mod SMB predict the more accurate behavior of volume fraction variation of urea inside the coater.

The dynamic pressure of urea in the fluidized bed coater for different drag laws are shown in Figure 10. However in case of GP model, the dynamic pressure variation is very insignificant along the fluidized bed region. The dynamic pressure change after the height of 0.25m is very sharp but there is no presence of urea which overestimates the results. The simulated results for modified SMB show that at height of 0.28 m the dynamic pressure reaches to maximum and it gradually fall towards zero afterwards. This phenomenon is attributed to the increase in urea velocity.

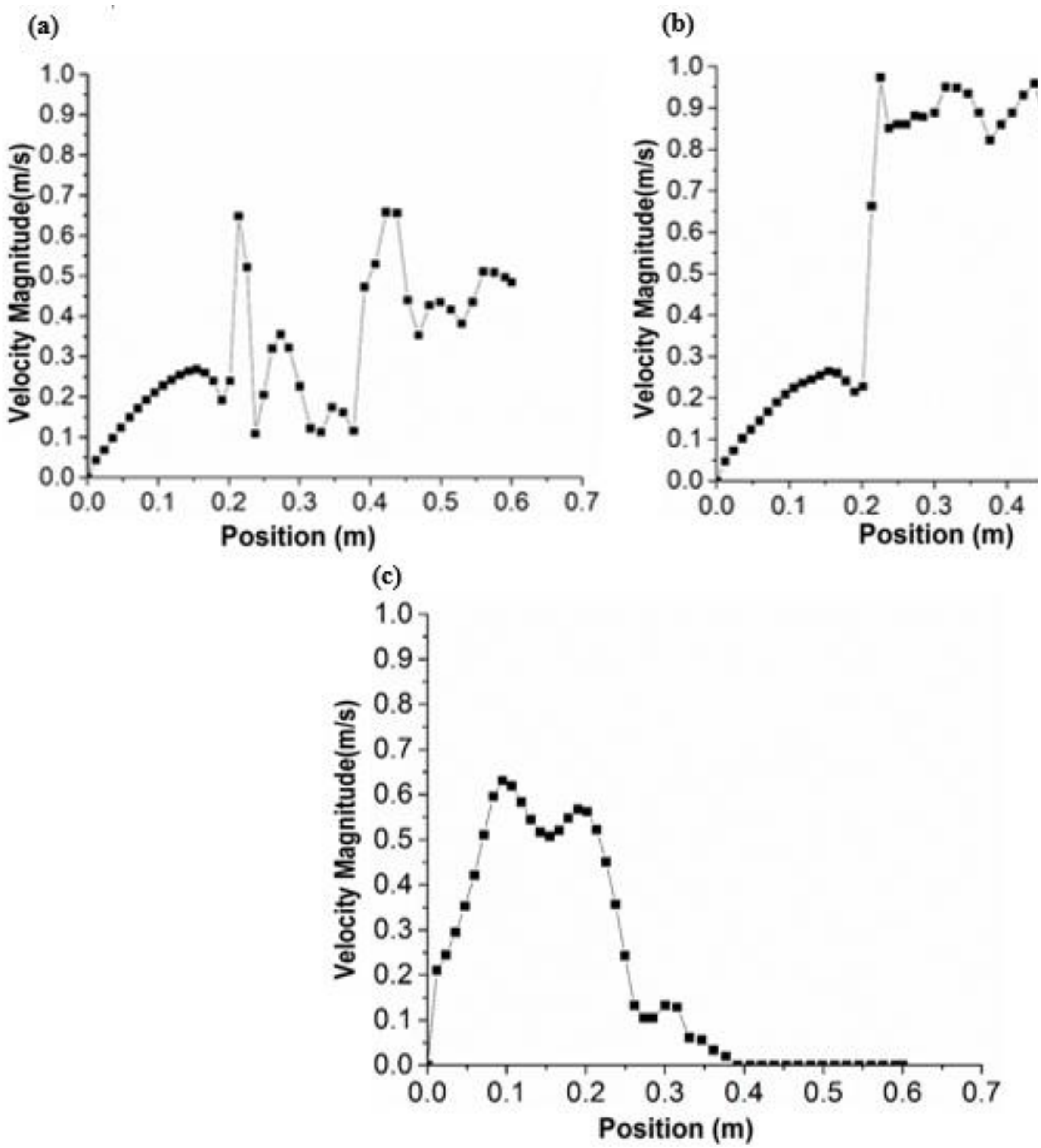


Figure 8Velocity Magnitude along the axial direction at a height of 0.7m and 0.2 m/s velocity (a) GP drag Model (b) SMB Drag Model(c)mod SMB Drag Model

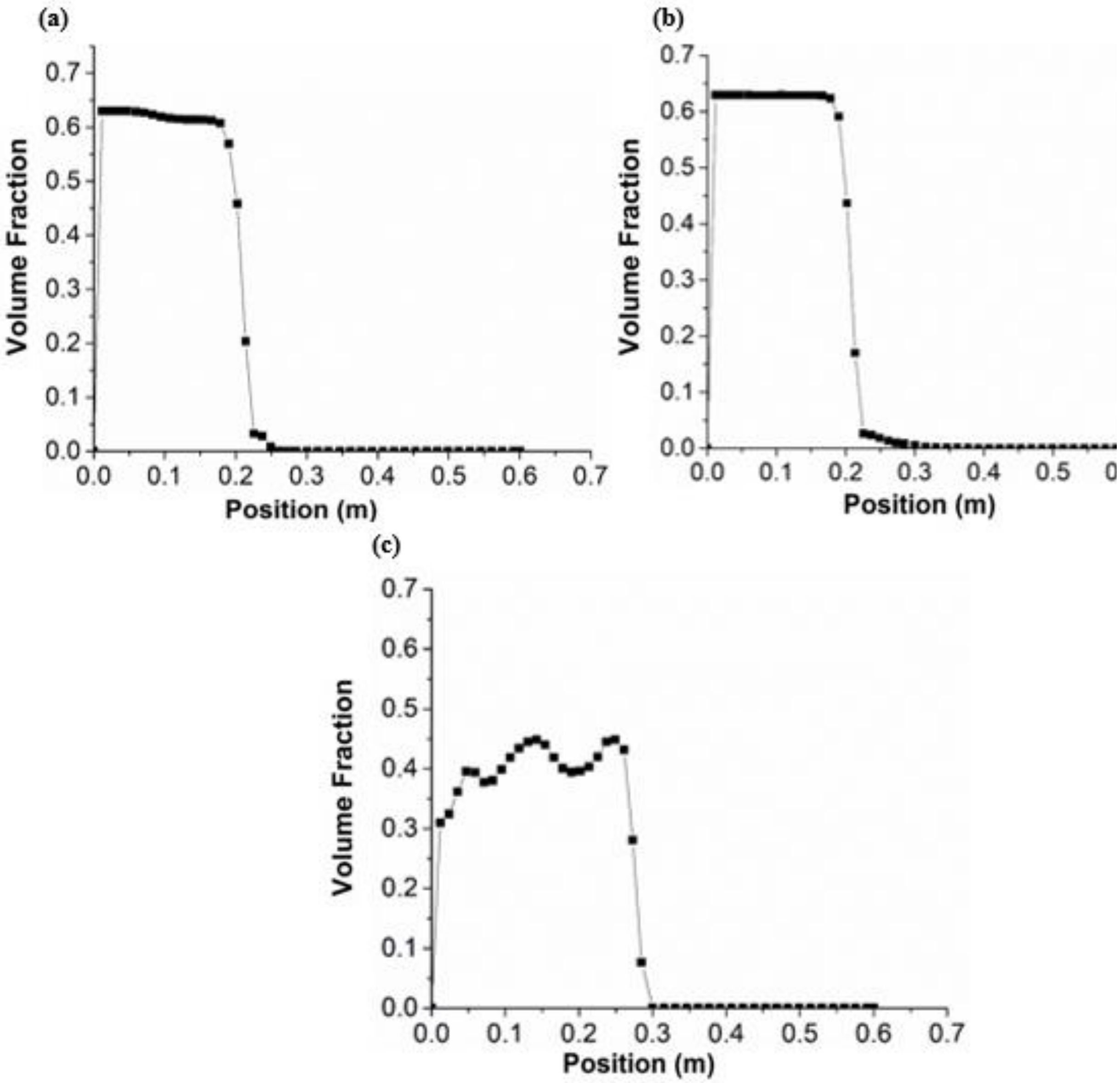


Figure 9Volume Fraction along the axial direction at a height of 0.7m and 0.2 m/s velocity (a) GP drag Model (b)SMB Drag Model(c) mod SMB Drag Model

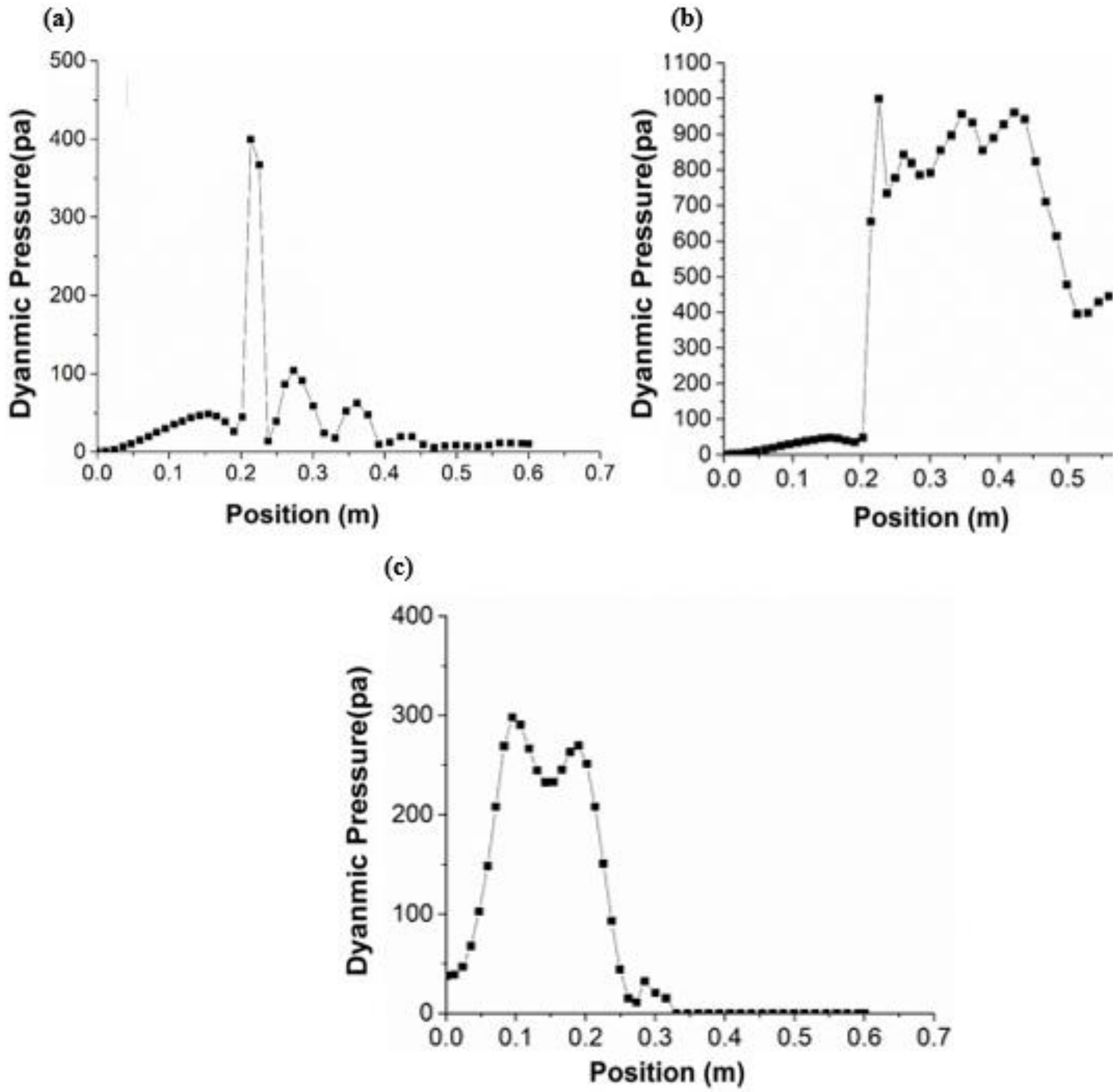


Figure 10 Dynamic Pressure along the axial Direction at a height of 0.7m and 0.2 m/s velocity (a) GP dragModel (b) SMB Drag Model (c) mod SMB Drag Model

4.1.2. Volume fraction contours

Volume fraction contours of modified SMB shows that along the axial direction the urea particles shows homogeneous fluidization as shown in figure 11. In the case of GP model slight variation of volume fraction along the axial direction is found, similarly SMB model the variation of volume fraction along the axial direction is also negligible.

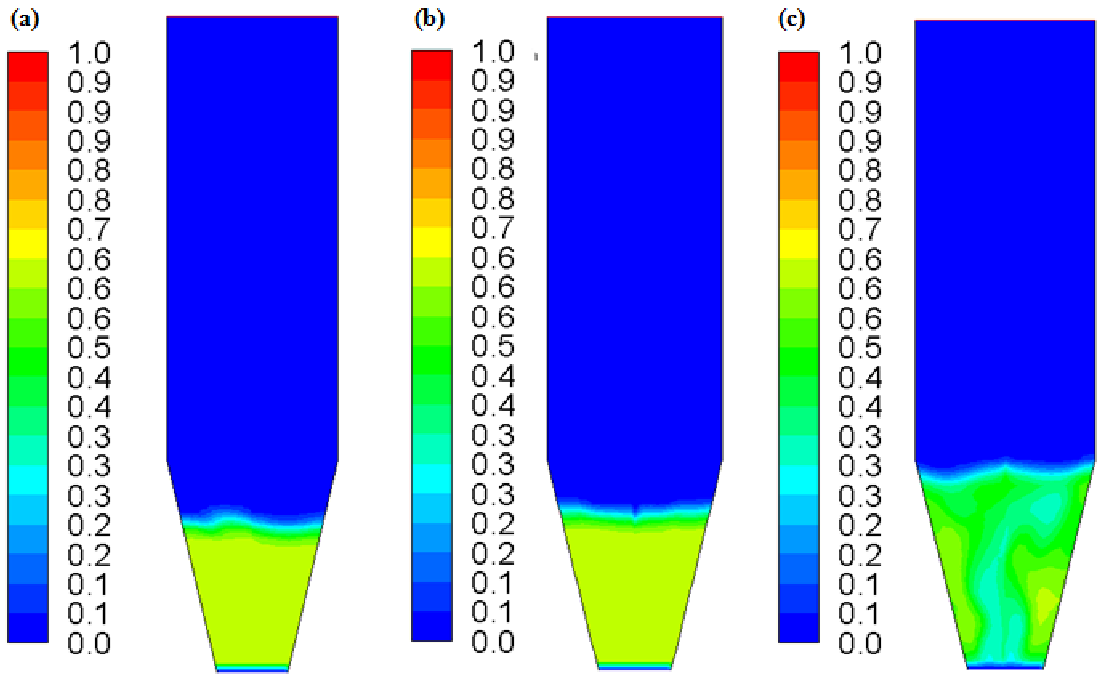


Figure 11Volume Fraction contours of urea at 0.2m/s velocity (a) GP Drag Model (b)SMB Drag Model (c) mod SMB Model

This study concludes that mod-SMB model is better agreement with practical fluidization phenomena and is further examined for air-urea hydrodynamics at different velocities**.**

4.2. Comparison at different Velocities (modified SMB)

Simulated result of modified SMB at different velocities 0.2, 0.5 and 0.8m/s are discussed below

4.2.1. Gas Solid Hydrodynamics:

The velocity magnitude of urea at different velocities is shown in figure 12. At a velocity of 0.8m/s the expansion of bed is higher with the increase volumetric flow rate of air. The result shows no formation of fluidized bed. At a velocity of 0.5m/s velocity the velocity magnitude of urea shows a heterogeneous behavior of fluidized bed due to increased volumetric flow rate of air. At 0.2m/s the bed show homogeneous fluidization as the velocity of urea increased gradually along the fluidized bed region. The urea particles attain maximum velocity of 1m/s at a height of 0.28mand after wards velocity of bed gradually falls toward zero. Thus only at 0.2m/s the homogenous behavior of bed is seen.

The results of dynamic pressure at different velocities are shown in Figure 13. At 0.8m/s the formation of fluidized bed region is not depicted. The increase in dynamic pressure results in the formation of slugs at different regions inside the coater. At 0.5m/s the results shows the heterogeneous fluidization. This is due to increase in dynamic pressure of air. At 0.2 m/s the figure show the homogeneous behavior of fluidization. The pressure gradually increases from the inlet and reaches to maximum at a height of 0.28m and then gradually falls toward zero.

The particle volume fraction of urea at different velocities is represented in figure 14. For 0.8m/s the results for volume fraction shows uneven behavior of particle and no formation of bed is depicted. While in case of velocity at 0.5m/s the urea particles shows heterogeneous behavior due to increased volumetric flow rate of urea. However, at 0.2 m/s, the volume fraction of urea shows homogeneous fluidization. The inlet volume fraction of urea increased gradually and reaches to maximum at a height of 0.28 in this particular case. So the optimum result obtained at 0.2m/s. the same results can also be seen in volume fraction graph f 3D models as shown in figure 9.

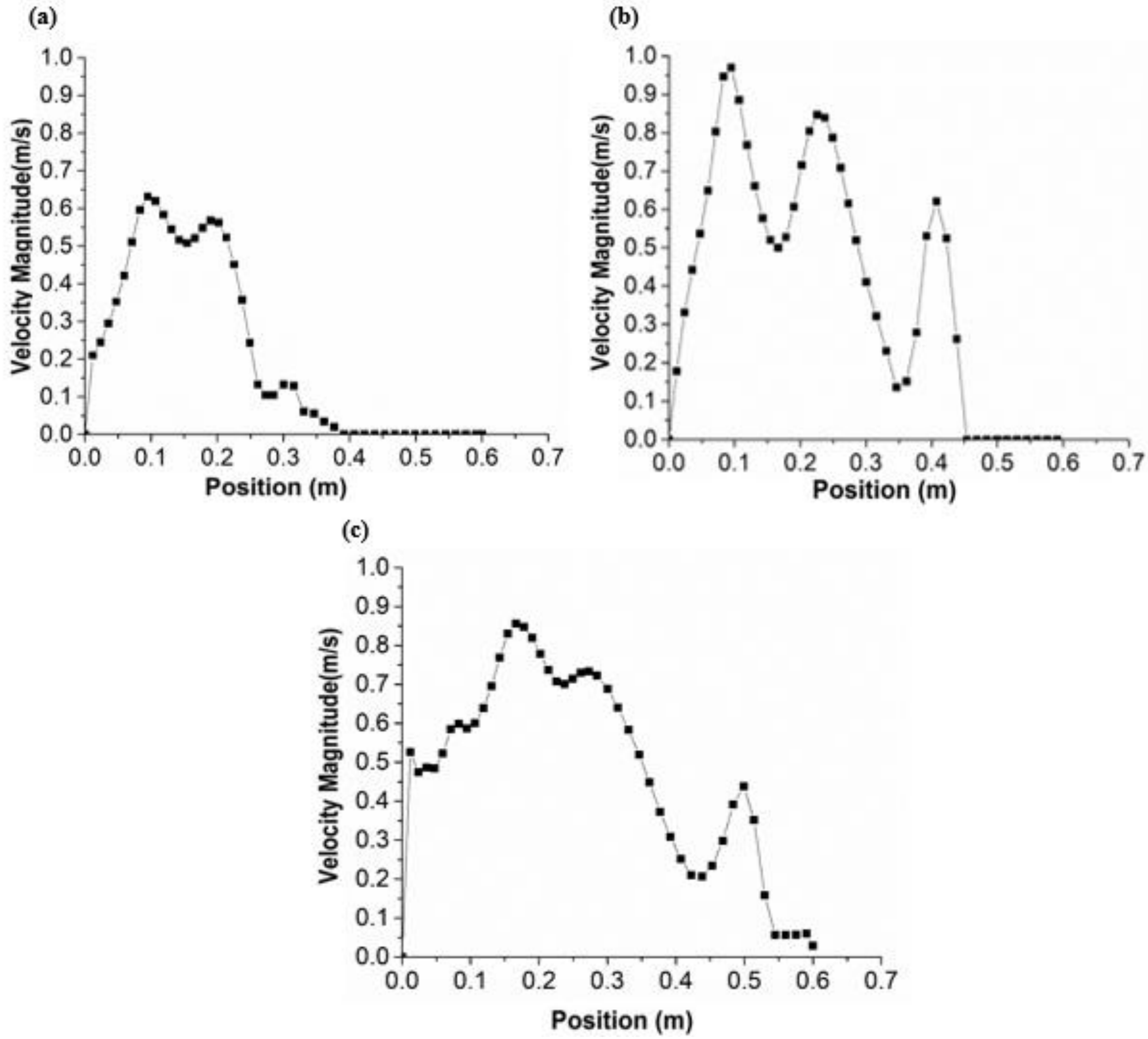


Figure 12Velocity Magnitude along the axial direction at a height of of 0.7m(a) mod SMB,0.2m/s (b) mod SMB, 0.5 m/s (c) mod SMB, 0.8m/s

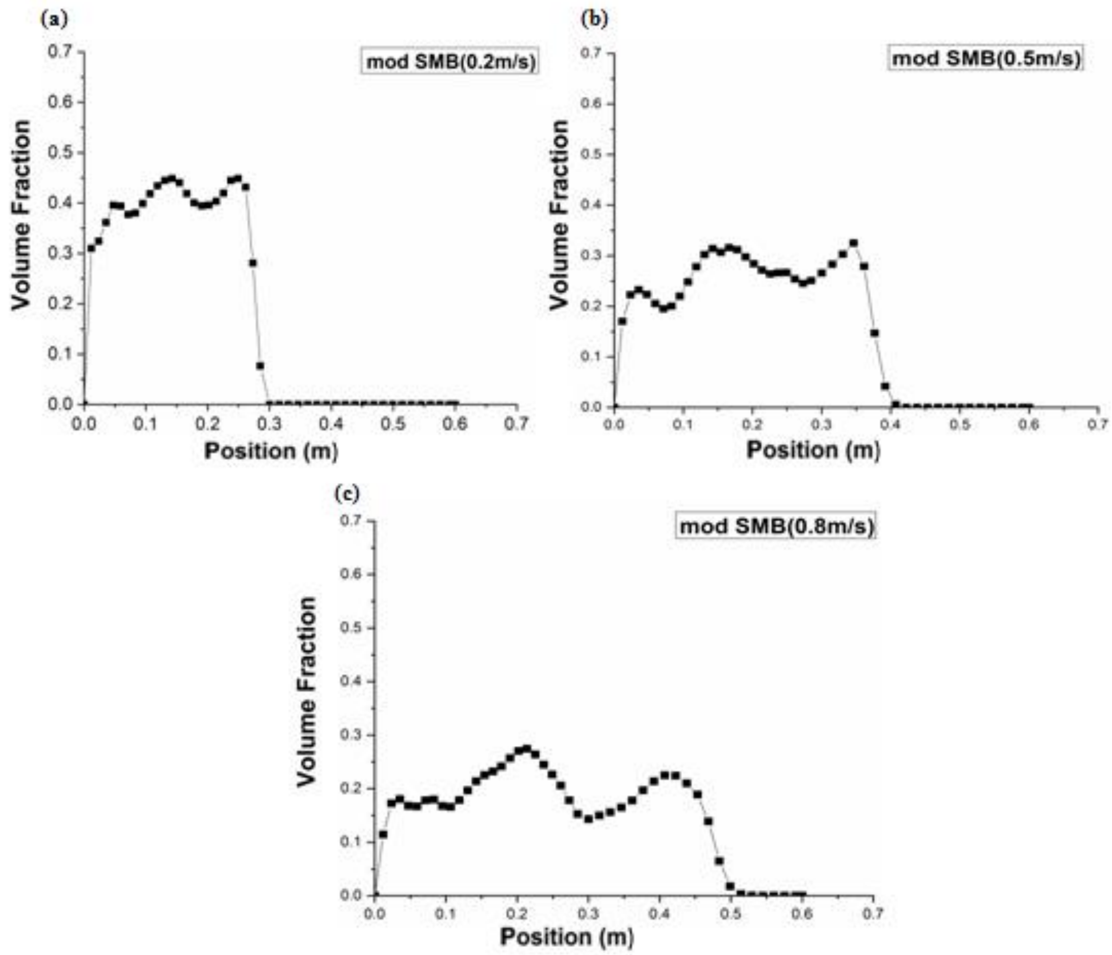


Figure 13Volume Fraction along the axial direction at a height of of 0.7m(a) mod SMB,0.2m/s (b) mod SMB, 0.5 m/s (c) mod SMB, 0.8m/s

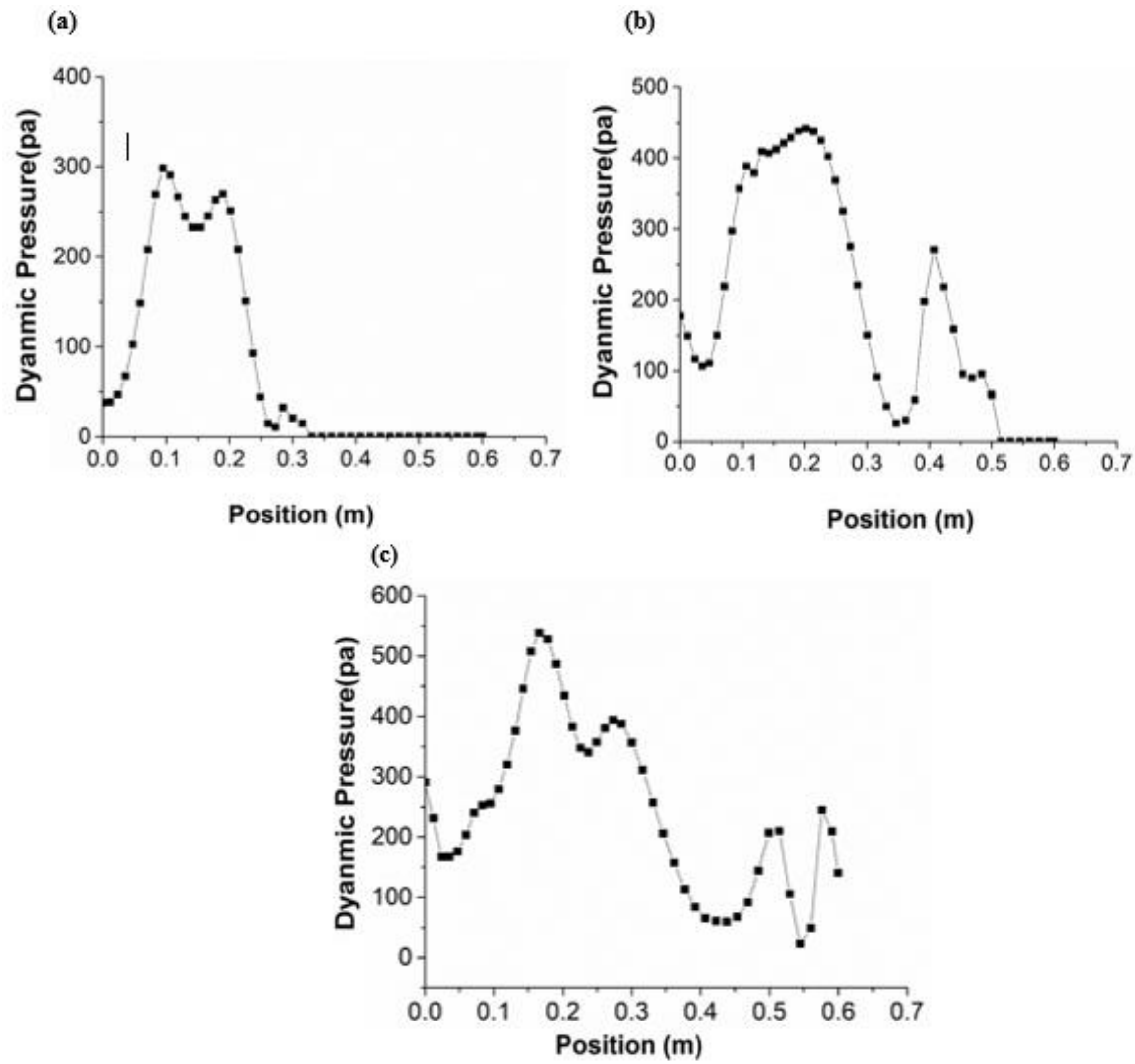


Figure 14Dynamic Pressure along the axial direction at a height of 0.7m (a) mod SMB,0.2m/s

4.2.2. Volume fraction contours

The figure 15 shows the volume fraction contours at different velocities. In case of 0.8m/s there is no formation of bed. As the velocity of air increases the formation of slugs arisen inside the coater. At 0.5m/s the fluidized bed region shows the heterogeneous behavior. The expansion of bed is also greater due to increased velocity. At velocity of0.2m/s the bed expanded homogenously.

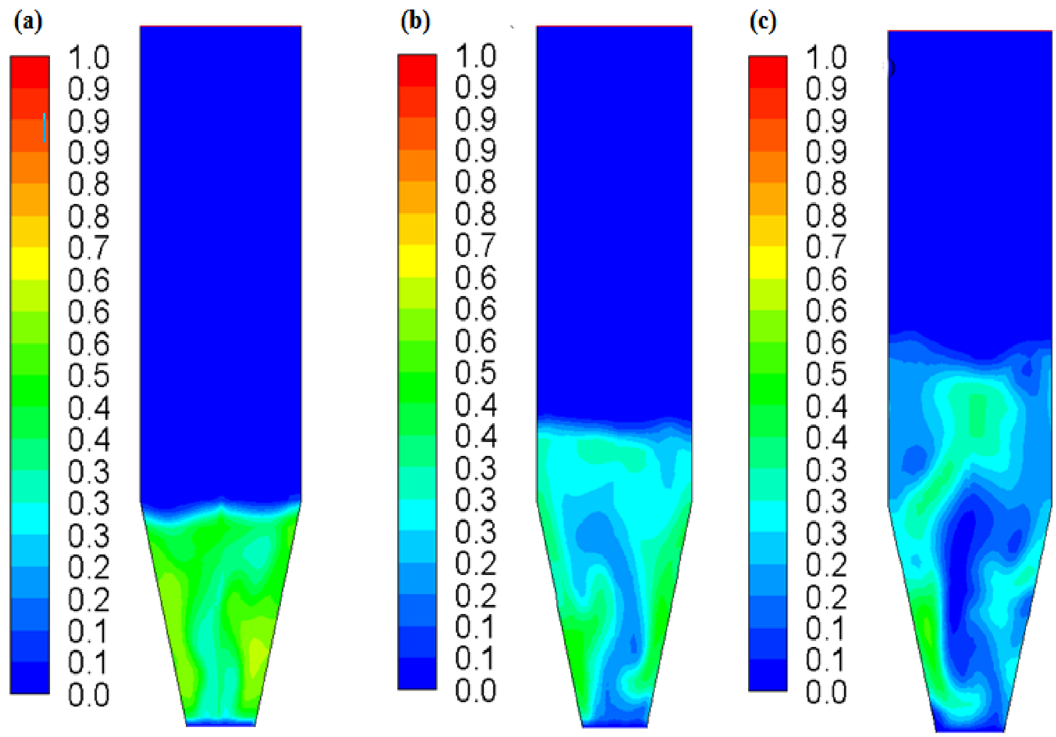


Figure 15.Volume Fraction Contours of urea at (a) mod SMB 0.2m/s,(b)mod SMB 0.5 m/s and (c) mod SMB 0.8m/s

4.3. 3D Model

Hydrodynamic study of gas-solid fluidized bed on 3D model has been performed with the inclusion of modified SMB. The monitoring height is chosen 0.6m to ensure that below is top height of fluidized bed. The results are discussed below

4.3.1.Gas Solid Hydrodynamics: M

The results of 3D geometry for mod-SMB model at 0.2m/s velocity are shown in figure 16.It is observed that at the inlet velocity increase is small, however after the height of 0.15m the velocity increase gradually shows the homogeneous fluidization. After the height of 0.3m the velocity of urea gradually falls toward zero.

The dynamic pressure results are shown in figure 10.From the results it is depicted that, the bed shows a homogeneous behavior throughout the fluidized bed region. After the height of 0.3m the dynamic pressure gradually falls toward zero.

The volume fraction results shown in figure 11. The results shows complete agreement with the previous result. At the start the volume fraction is high. As the velocity of urea increases the homogeneous fluidization is observed for a region of 0.15m to 0.3m height. After the height of 0.3m the volume fraction falls toward zero.

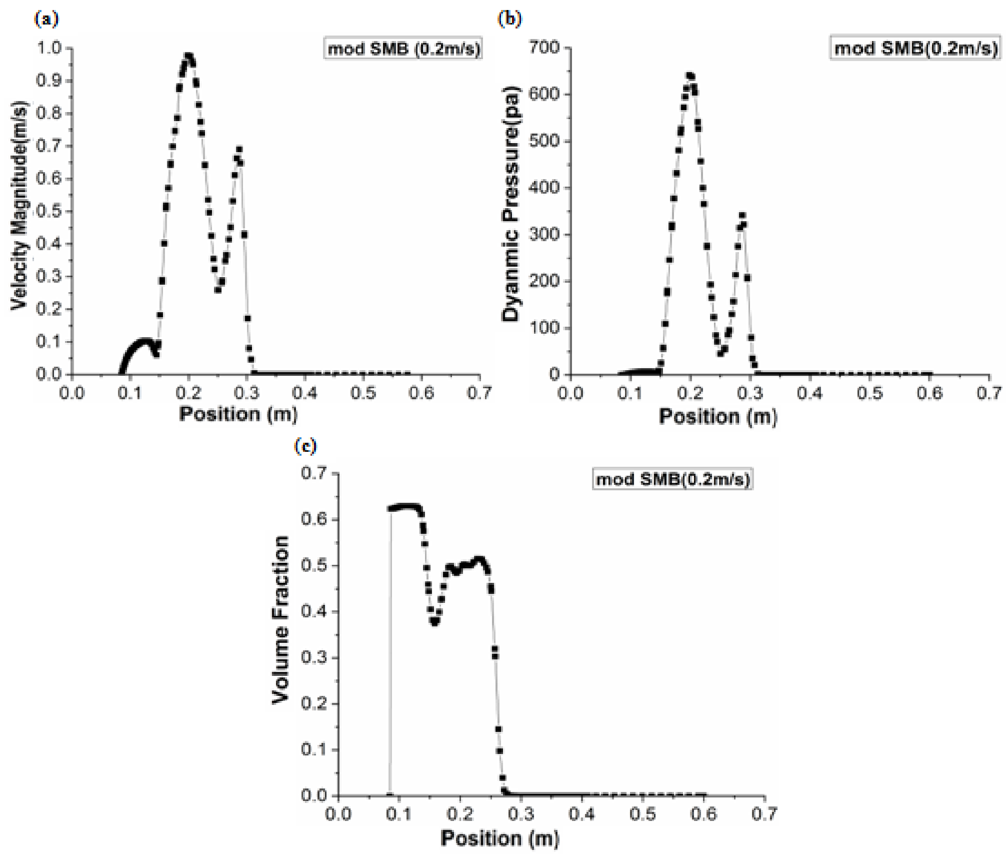


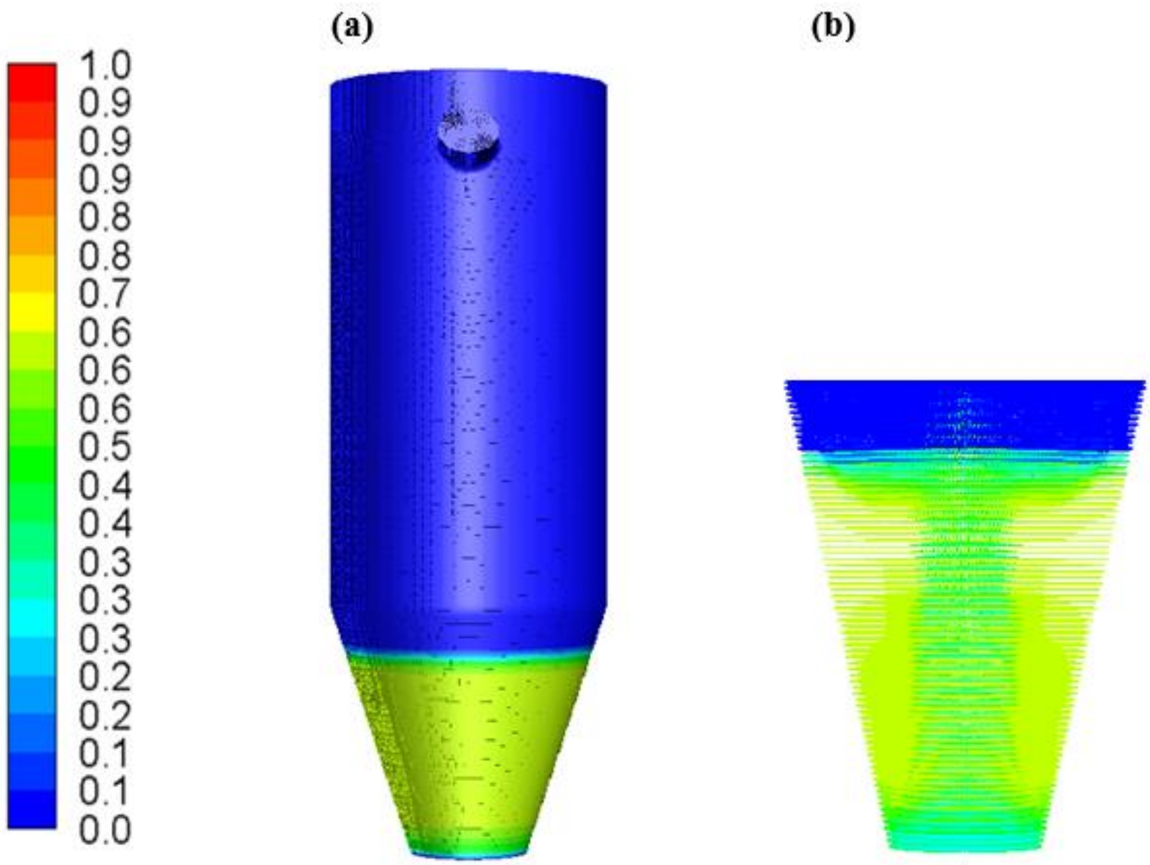
Figure 16.(a)Velocity Magnitude along the axial direction at a height of 0.7m of mod SMB Drag Model

(b) Dynamic Pressure along the axial direction at a height of 0.7m of mod SMB Drag Model

(c) Volume Fraction along the axial direction at a height of 0.7m

4.3.2. Volume fraction contours

The volume fraction results of 3 D model indicate nearly complete agreement with the 2D model as shown in figure 17. From the result it is clearly depicted the bed is homogeneously fluidized along the axial direction. The fluidized bed region is formed near the center to the top of the bed.



.Figure 17Volume Fraction Contours of Urea at 0.2 m/s velocity of mod SMB Drag Model

4.4. Temperature of Air and Urea Phase after Evaporation

The Figure a shows the temperature profile of hot air. The temperature of air is decreasing along the axial height of FBC.As the hot provide the latent heat for the vaporization of water from the urea surface so the temperature of air is decreasing along the axial height and 325K at outlet which is comparable to the experimental setup that is 325 to 330 K .The Figure b shows the temperature profile of urea during evaporation as the water on surface of urea get the heat for vaporization which lowers the temperature from the urea surface which is around 290K.

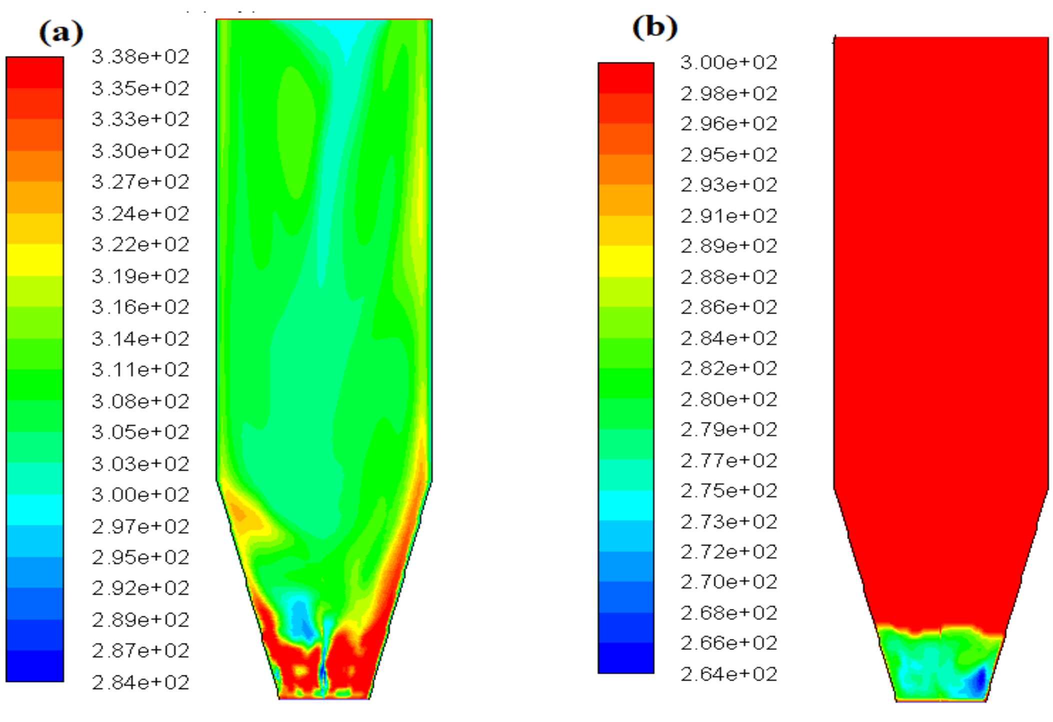


Figure 18. (a)Temperature of air (K) (b) Temperature of urea particles

Conclusion

The hydrodynamics of tapered FBC is simulated though EE-TFM with the inclusion of kinetic theory of granular flows. The simulations were performed on 2&3D geometry .Time average results of urea velocity magnitude, urea dynamic pressure and urea volume fraction are computed by using Three different drag models namely GP model, SMB model and modified SMB model. The obtained results are able to describe the complex transient features of air-urea flow inside the FBC. Comparing the results of particle dynamics by using different drag laws is evaluated. From the results it is clearly depicted that modified SMB model shows complete agreement with the homogeneous fluidization at 0.2m/s. As the flow of urea shows good agreement with the fluidization phenomena. The urea volume fraction and dynamic pressure results also supported the argument of homogeneous fluidization at 0.2m/s. The GP and SMB drag model results could not predict the fluidization behavior and shows the overestimated results

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