Numerical Study of Gas-Solids Hydrodynamics in Downer

Bhuvaneswari G[1,*], Jakka Sarat Chandra Babu[2], T.K.Radhakrishnan[3]

[1,2,3] – Department of Chemical Engineering, National Institute of Technology – Tiruchirappalli, Tiruchirappalli, Tamil Nadu - 620015.

*Corresponding author: *gpbhuvaneswari@gmail.com*

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*Corresponding author: *gpbhuvaneswari@gmail.com*

ABSTRACT

In this work, investigation of the hydrodynamics of a gas – solids in a downer using a combination of Euler-Euler Computational Fluid Dynamic (CFD) numerical model is presented. Solids are modeled as pseudo fluid using kinetic theory of granular flow. In addition to the mass and momentum conservation equations, transport equation for fluctuating kinetic energy of the solids is solved. Interphase momentum exchange coefficient is determined using Gidaspow drag model. The main focus of this work is the systematic investigation of the most appropriate closure for the various interaction in the system of interest. Simulations are conducted with Petcoke particles (60 µm mean diameter) as solid phase and air as gas phase in a downer of diameter 8 inch and height of 8 m. Effects of radial and axial gas velocities, mean solids velocity, solid holdup distribution, and solid circulation pattern have been investigated. The numerical (CFD) predictions with effective closure provides useful basis for further work on understanding the characteristics of Downer and a key for developing a robust CFD model, has a predictive capability over a wide variety of flow conditions.

Key words: CFD, Closure, Downer, Hydrodynamics, Petcoke.

1. Introduction

Multiphase flow processes are widely employed in many chemical processes. One of the major interest in chemical process industries is to make more efficient practice of designing reactors and to improve the efficiencies in much more tailored fashion. The goal of process engineer is turning towards innovative design of reactors to characterize the contacting pattern of multiphase flow and its reaction. The complex structure with its dynamic variation is the common characteristic of a complex multiphase system, causing the difficulties for the study of the system. The downer configuration is characterized one such mechanism to deal with multiphase flow systems. From the literature review, downer is claimed to possess unique hydrodynamic characteristics which are uniform and efficient gas solids contact, short gas solid contacting time, narrow residence time distribution, forward mixing and low gas-solid particle back mixing [Zhu et al. [1]]. Studies concerning the flow developments and distribution of solid particles especially with petroleum coke are carried out in early 2000's by many researchers[2,3]. However radial distribution of solid particles is still under a question in the system of interest. Zhang et al. [4] described that the solid particles are uniformly distributed in radial direction. The reason for uniform distribution of solid particles along radial direction in the downer is that the flow is same in the direction of gravitational acceleration compared to other mode of contact in circulating fluidized bed riser.

However other group of researchers claim a non-uniform distribution can be observed in the downer similar to the riser.

During last two decades, numerous studies on flow phenomena have been reported by many researchers. Li et al.[5] observed clusters in the riser using micro-camera. Lackermeier et al.[6] visualized flow phenomena in CFB with the combination of high speed video with laser sheet technique. Harris et al.[7] developed a correlation for predicting the properties of clusters such as cluster size, cluster velocity, cluster shape and properties of cluster. Sharma et al.[8] used capacitance probe measurements for studying the cluster characteristics. However, with gas-solids flow behaviors in downers researched further, studies on flow phenomena in a downer, especially with respect to clusters are attracting the researchers worldwide. This study focuses on numerical study of the flow phenomena in a downer. The downer simulated using Eulerian approach with kinetic theory of granular flow can be used to explain the flow phenomena in a complex system. Different modeling parameters were varied and the flow phenomena with effective closure is explored.

2. Modelling equations in Computational Fluid Dynamics (CFD)

This numerical study employs commercial CFD program FLUENT[9] for modelling the system. The Eulerian approach with kinetic theory of granular flow is recommended to apply for modelling the system of interest, downer. In this study the effects of various modelling parameters are explored. The summary of governing equations[9] employed in the case system condition are as discussed below:

2.1 Governing equations for Gas-Solids flow

2.1.1 Conservation equations

The mass and momentum conservations for the gas and solid phases as well as the solid fluctuating kinetic energy or granular temperature conservation are considered under the assumption that the hydrodynamic characteristic of the system studied under isothermal condition. Based on the assumption, the energy conservation for both the gas and solid phases could be ignored. The primitive conservation equations from which the equation solved are derived as presented below:

2.1.1.1 Mass conservation equations:

The accumulation of mass in each phase is balanced by the convective mass fluxes. The mass conservation equations for the gas phase, g and the solid phase, s are:

Gas Phase:

$$\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g\right) + \nabla.\left(\varepsilon_g \rho_g u_g\right) = 0 \qquad (1)$$

Solids Phase:

$$\frac{\partial}{\partial t}\left(\varepsilon_s \rho_s\right) + \nabla.\left(\varepsilon_s \rho_s u_s\right) = 0 \qquad (2)$$

where ε_g is the volume fraction of the gas phase, ε_s is the volume fraction of the solid phase, ρ_g is the density of the gas phase, ρ_s is the density of the solid phase, u_g is the velocity of gas phase, u_s is the velocity of solid phase and t is the time.

Each computational cell is shared by the inter-penetrating phases, so that the summation of all volume fractions is unity.

$$\varepsilon_s + \varepsilon_g = 1 \qquad (3)$$

2.1.1.2 Momentum conservation equations

The accumulation of momentum on each phase is balance by the convective momentum fluxes and the other forces due to pressure, stress tensor, gravity and momentum interphase exchange coefficient respectively as shown in equation below:

The momentum conservation equations for the gas phase, g and the solid phase, s are:

Gas Phase:

$$\frac{\partial}{\partial t}(\varepsilon_g\rho_g u_g) + \nabla.(\varepsilon_g\rho_g u_g u_g) = -\varepsilon_g\nabla P + \nabla.(\varepsilon_g\tau_g) + \varepsilon_g\rho_g g + \beta(u_s - u_g) \quad (4)$$

Solids Phase:

$$\frac{\partial}{\partial t}(\varepsilon_s\rho_s u_s) + \nabla.(\varepsilon_s\rho_s u_s u_s) = -\varepsilon_s\nabla P - \nabla P_s + \nabla.(\varepsilon_s\tau_s) + \varepsilon_s\rho_s g + \beta(u_g - u_s) \quad (5)$$

where P is the pressure of the gas phase, τ_g is the stress tensor of the gas phase, τ_s is the stress tensor of the solid phase, P_s is the Pressure of solid phase, g is the gravitational acceleration or gravity force and β is the interphase exchange coefficient of drag force.

2.1.1.3 Solid fluctuating kinetic energy conservation equation for granular temperature

The fluctuating kinetic energy conservation equation for the solid particles, as derived from the kinetic theory of granular flow expressed as:

$$\frac{3}{2}\left[\frac{\partial(\varepsilon_s\rho_s\Theta_s)}{\partial t} + \nabla.(\varepsilon_s\rho_s u_s\Theta_s)\right] = (-P_s I + \varepsilon_s\tau_s):\nabla u_s - \gamma_s - \nabla(\kappa_s\nabla\Theta_s) \quad (6)$$

where Θ_s is the solid fluctuating kinetic energy, κ_s is the conductivity of solid fluctuating kinetic energy and γ_s is the collisional dissipation of solid fluctuating kinetic energy.

2.1.2 Constitutive equations:

The constitutive equations based on the kinetic theory of granular flow are needed to close the conservation equations for solving this system of equations. The behavior of the solid phase is described by taking into account the energy associated with the solid particles that arises out of solid particle fluctuating motions and collisions. The constitutive equations used in this study are summarized below.

2.1.2.1 Stress Strain Tensor Equations:

The stress tensor can be expressed as the sum of deviatoric and spherical stresses which tend to change the volume of the stressed body. The stress tensors for the gas phase, g and solid phase, s are described as,

Gas Phase:

$$\tau_g = \varepsilon_g\mu_g(\nabla u_g + \nabla u_g^T) - \frac{2}{3}\varepsilon_g\mu_g(\nabla.u_g)I \quad (7)$$

Solid Phase:

$$\tau_s = \varepsilon_s\mu_s(\nabla u_s + \nabla u_s^T) + \varepsilon_s\left(\xi_s - \frac{2}{3}\mu_s\right)(\nabla.u_s)I \quad (8)$$

where, μ_g is the viscosity of the gas phase, μ_s is the viscosity of the solid phase, ξ_s is the bulk viscosity of the solid phase and I is the unit tensor.

2.1.2.2 Solid Pressure Equation:

The solid pressure is composed of a kinetic term that dominates in the dilute regions and a collisional term that governs in the dense regions.

$$P_s = \varepsilon_s\rho_s\theta[1 + 2g_0\varepsilon_s(1+e)] \quad (9)$$

where, g_0 is the radial distribution function and e is the restitution coefficient between solid particles.

2.1.2.3 Solid Shear Viscosity

The solid shear viscosity is also composed of a kinetic and a collisional term arising from the solid particle momentum exchange due to translation and collision.

$$\mu_s = \frac{4}{5}\varepsilon_s\rho_s d_p g_0(1+e)\sqrt{\frac{\theta}{\pi}} + \frac{10\rho_s d_p\sqrt{\pi\theta}}{96(1+e)g_0\varepsilon_s}\left[1 + \frac{4}{5}g_0\varepsilon_s(1+e)\right]^2 \quad (10)$$

where, d_p is the solid particle diameter.

2.1.2.4 Solid Bulk Viscosity

The solid bulk viscosity accounts for the resistance of the solid particles due to compression and expansion.

$$\xi_s = \frac{4}{3}\varepsilon_s\rho_s d_p g_0(1+e)\sqrt{\frac{\theta}{\pi}} \quad (11)$$

The radial distribution function is a correction factor that indicates the probability of collision between solid particles when the solid particles become dense.

$$g_0 = \left[1 - \left(\frac{\varepsilon_s}{\varepsilon_{s,max}}\right)^{1/3}\right]^{-1} \quad (12)$$

where $\varepsilon_{s,max}$ is the volume fraction of solid phase at maximum packing condition.

2.1.2.5 Conductivity of solid fluctuating kinetic energy

The conductivity of the solid fluctuating kinetic energy specifies the diffusion of granular energy as:

$$\kappa = \frac{150\rho d\sqrt{\theta\pi}}{384(1+e)g}\left[1+\frac{6}{5}\varepsilon g(1+e)\right]^2 + 2\rho\varepsilon d(1+e)g\sqrt{\frac{\theta}{\pi}} \quad (13)$$

2.1.2.6 Collisional dissipation of solid fluctuating kinetic energy

The collisional dissipation of the solid fluctuating kinetic energy shows the dissipation arte of granular energy within the solid phase due to collisions between solid particles.

$$\gamma_s = 3(1-e^2)\varepsilon_s\rho_p g_0\theta\left(\frac{4}{d_p}\sqrt{\frac{\theta}{\pi}}\right) \quad (14)$$

The interphase exchange coefficient model defines the resistance force to the translation of solid particles. Here, the conventional interphase exchange coefficient or Gidaspow model is preferred. This interphase exchange coefficient model was proved to successfully predict the system with low solid mass flux or low solid density system.

The Gidaspow interphase exchange coefficient model is:

For $\varepsilon_g \leq 0.80$:

$$\beta_{gs} = 150\,\frac{(1-\varepsilon_g)^2\mu_g}{\varepsilon_g d_p^2} + 1.75\frac{(1-\varepsilon_g)\rho_g|u_g-u_s|}{d_p} \quad (15)$$

For $\varepsilon_g > 0.80$,

$$\beta_{gs} = \frac{3}{4}\frac{(1-\varepsilon_g)\varepsilon_g}{d_p}\rho_g\left|u_g-u_s\right|C_{D0}{\varepsilon_g}^{-2.65} \quad (16)$$

with $Re < 1000$,

$$C_{D0} = \frac{24}{Re}\left(1+0.15Re^{0.687}\right)$$

$Re \geq 1000$, $C_{D0} = 0.44$;

where, $Re = \frac{\rho_g\varepsilon_g|u_g-u_s|d_p}{\mu_g}$

2.2 System description

The downer system considered in the present study is shown as schematic sketch in Fig 1.

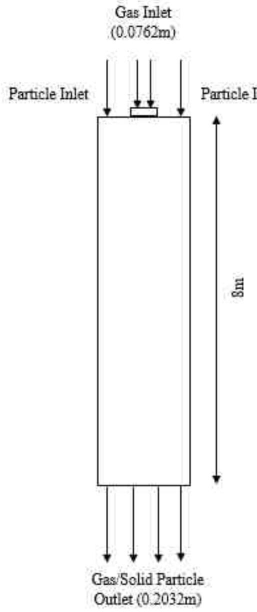

Figure 1. Schematic sketch of Downer System

The numerical study is carried out for the system of diameter 0.2032 m and height 8 m. The solid particles in the system considered is Petcoke of solid particle density 1735.1 kg/m^3 and mean solid particle diameter 60 µm. The objective is to validate the hydrodynamics of the downer system. A three dimensional model of the downer is considered irrespective of computation time to completely understand the hydrodynamics with respect to axial and radial direction as well. The gas phase is fed to the top of the downer through an annular inlet of diameter 0.0762 m. The gas and solid fed from top of the downer as depicted in Fig 1. The gas and solid particles exits the system through system outlet at the bottom of the downer. The other base case modeling parameters employed in the simulation are listed in Table 2.

Table 2: Numerical parameters used in base case CFD simulation of downer.

Downer specification	Diameter, m	0.2032
	Height, m	8
Gas Properties	Gas density, kg/m^3	1.2922
	Gas viscosity, kg/m.s	1.2e-5
Solid Properties	Solid particle density, kg/m^3	1735.1
	Solid particle diameter, µm	60
Inlet boundary Condition	Inlet gas velocity, m/s	0.5
	Inlet solid velocity, m/s	0.5
	Inlet solid volume fraction	0.2
	Inlet solid mass flux, kg/m^2.s	0.01
	Outlet system pressure, Pa	101425
KTGF parameters	Granular temperature, m^2/s^2	0.001
	Specularity coefficient (SC)	0.9
	Restitution coefficient between solid particle and wall (RC)	0.9
	Restitution coefficient between solid particles (RC)	0.9
	Interphase exchange coefficient model	Gidaspow
Wall boundary condition	Gas phase	No-slip condition
	Solid phase	Johnson Jackson
Outlet boundary condition	Gas and solid phase	Pressure outlet
Numerical method	Pressure-velocity coupling	Phase coupled SIMPLE
	Discretization	First order upwind
Under relaxation parameters	Pressure	0.3
	Density	1.0
	Body forces	1.0
	Momentum	0.7
	Volume fraction	0.2

2.3 Computational Domain

The computational domain consists a total of 5872284 computational cells. The computational fluid dynamics models were solved in HP Workstation Z820.

At the inlet, the velocity inlet boundary conditions is used while at the outlet, the pressure outlet boundary condition is being used. At elsewhere, the wall boundary condition is applied.

2.4 Initial and Boundary conditions

Initially, there was no gas and solid phases in the downer. At the velocity inlet boundary condition, the velocity and volume fraction for each phase is specified. On the other hand, at the pressure outlet boundary condition, the system pressure is also specified. At the wall boundary condition, a no slip condition is applied for all velocities, except for the tangential velocity $(u_{t,W})$ of the solid phase and the granular temperature. Here the boundary conditions of Johnson and Jackson are used. They are:

$$u_{t,W} = -\frac{6\mu_s\varepsilon}{\pi\varphi\rho\varepsilon g\sqrt{3\theta}}\frac{\partial u_{s,W}}{\partial n} \quad (17)$$

$$\theta_W = -\frac{\kappa_s\theta}{\gamma_W}\frac{\partial\theta_W}{\partial n} + \frac{\sqrt{3}\pi\varphi\rho_s\varepsilon_s u_{s,slip}^2 g_0\theta^{3/2}}{6\varepsilon_{s,max}\gamma_W} \quad (18)$$

$$\text{with } \gamma_W = \frac{\sqrt{3}\pi(1-e_W^2)\varepsilon_s\rho_s g_0\theta^{3/2}}{4\varepsilon_{s,max}} \quad (19)$$

where $u_{s,W}$ is the velocity of the solid phase at the wall, φ is the specularity coefficient, n is the unit vector, $u_{s,slip}$ is the slip velocity of the solid phase at the wall and e_W is the restitution coefficient between solid particle and wall.

3. Results and Discussion

The results in this study are separated into sections as effect of various modeling parameters on the system hydrodynamics and characteristics of downer at various section heights. The modeling parameters include specularity coefficient, restitution coefficient between solid particles and between solid particle and wall.

3.1 Effect of modeling parameters on the system hydrodynamics

The modeling parameters of multiphase flow which includes, specularity coefficient, restitution coefficient both between solid particles and between solid particle and wall have been studied.

3.1.1 Specularity coefficient

The specularity coefficient is one of the crucial modeling parameter effecting the hydrodynamics of downer. It represents the fraction of collision solid particles which transfer the momentum to wall, used to specify the wall shear condition. The specularity coefficient varies between values of zero to one. A value of zero represents smooth wall is used or free slip boundary condition is applied at the wall while a value of one indicates rough wall is employed or partial slip boundary condition is applied at the wall.

In this study, the specularity coefficient is selected in the range of values as 0, 0.0001, 0.01, 1 with reference to literature. The factors such as axial velocity and radial velocity represents the hydrodynamics. The four different heights were used to represent the system hydrodynamics in each part of the downer, includes a) Inlet part (0.5 m from the inlet) b) Center parts (2.5 m from the inlet and & 5 m from the inlet) c) Outlet Part (7.5m from the inlet).

From Fig. 2 and Fig. 3 , it is evident that specularity coefficient did not have larger effect near the inlet part which is because of the larger effect of the inlet boundary condition than the wall boundary conditions applied. As the downer height increases, the wall boundary conditions have impact on the hydrodynamics which is highlighted in both cased of radial air and solid velocity. The higher value of specularity coefficient makes the wall rough and raises the wall flow resistance.

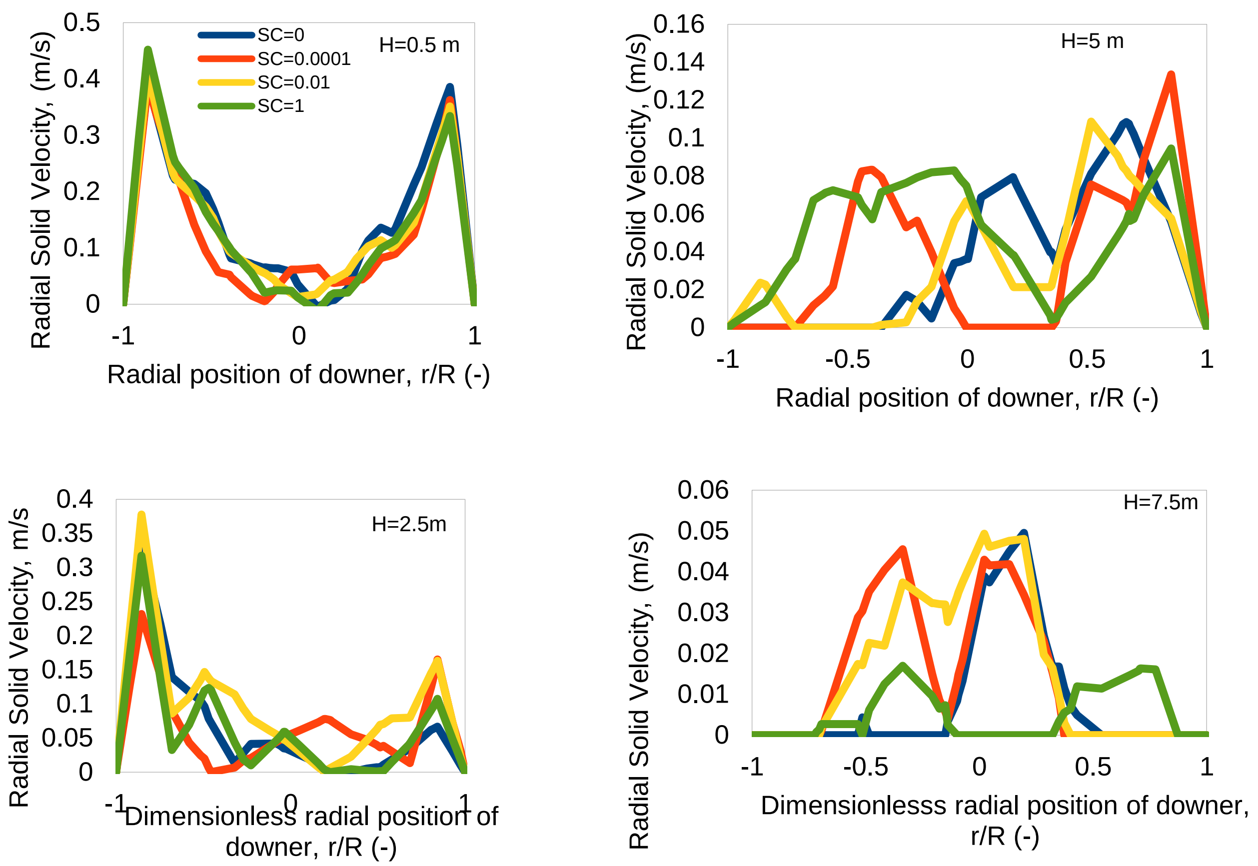

Figure 2. The effect of specularity coefficient on radial distributions of computed radial solid velocity at four different downer heights

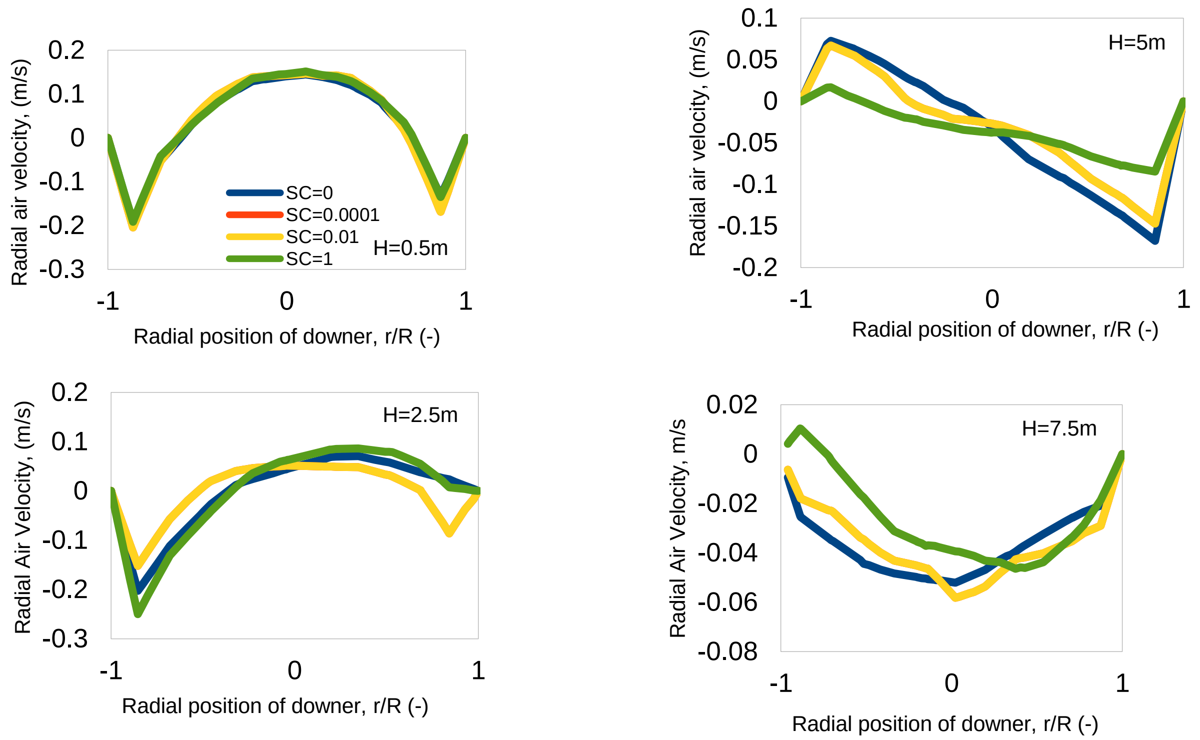

Figure 3. The effect of specularity coefficient on radial distributions of computed radial air velocity at four different downer heights

3.1.2 Restitution coefficient between solid particles

The restitution coefficient between solid particles represents the dissipation of solid fluctuating kinetic energy due to collision. The restitution coefficient between solid particles also varies in the range of zero to one. A value of zero indicates much amount of solid fluctuating kinetic energy is dissipated (inelastic collision) while a value of one means that no solid particle turbulent kinetic energy is dissipated (elastic collision).

In this study, the restitution coefficients between solid particles is selected in the range of values as 0.7, 0.8, 0.9 and 0.999.

Fig.4 and Fig.5 shows the radial distributions of radial solid and air velocity at four different downer heights respectively. From the Figures, the restitution coefficient found to have slight effects at the inlet part. This is due to collision occurring all over the downer diameter.

However, it is found that the collision becomes prominent as downer height increases. At low value of restitution coefficient, high solid fluctuating kinetic energy dissipation is observed, which tends to shift the peak towards the center. This phenomena can be observed in Fig.4 at height of 7.5m from the inlet of the downer.

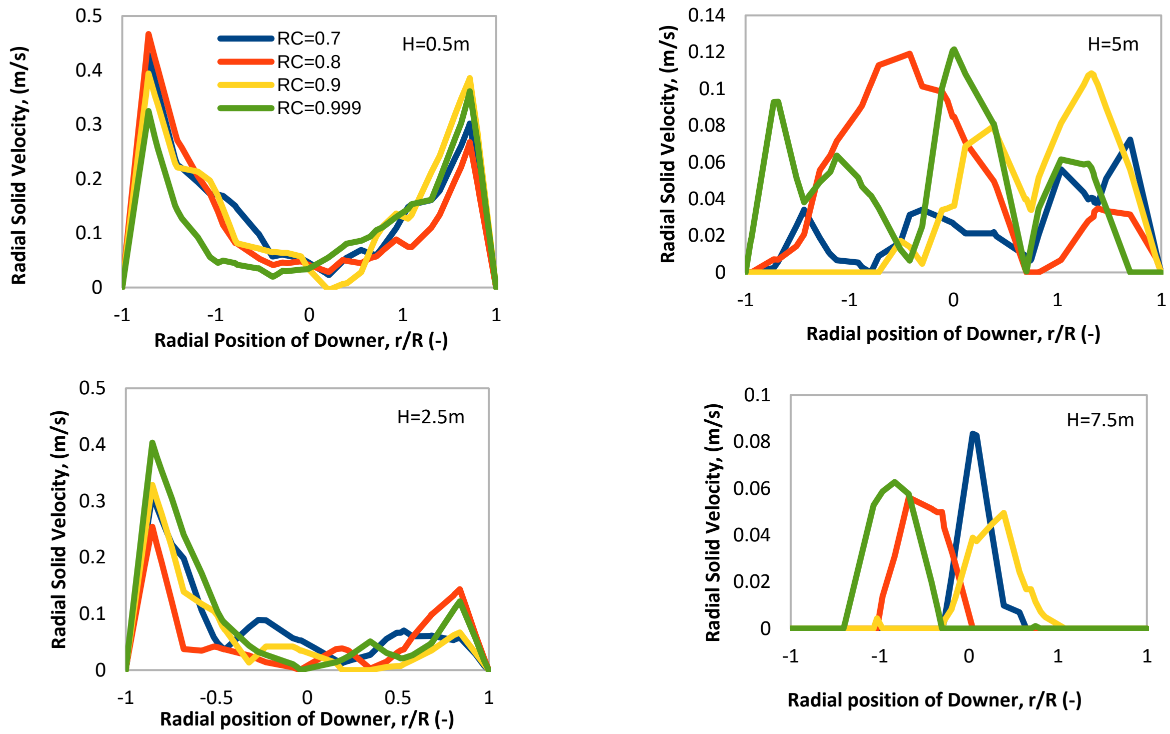

Figure 4. The effect of restitution coefficient on radial distributions of computed radial solid velocity at four different downer heights

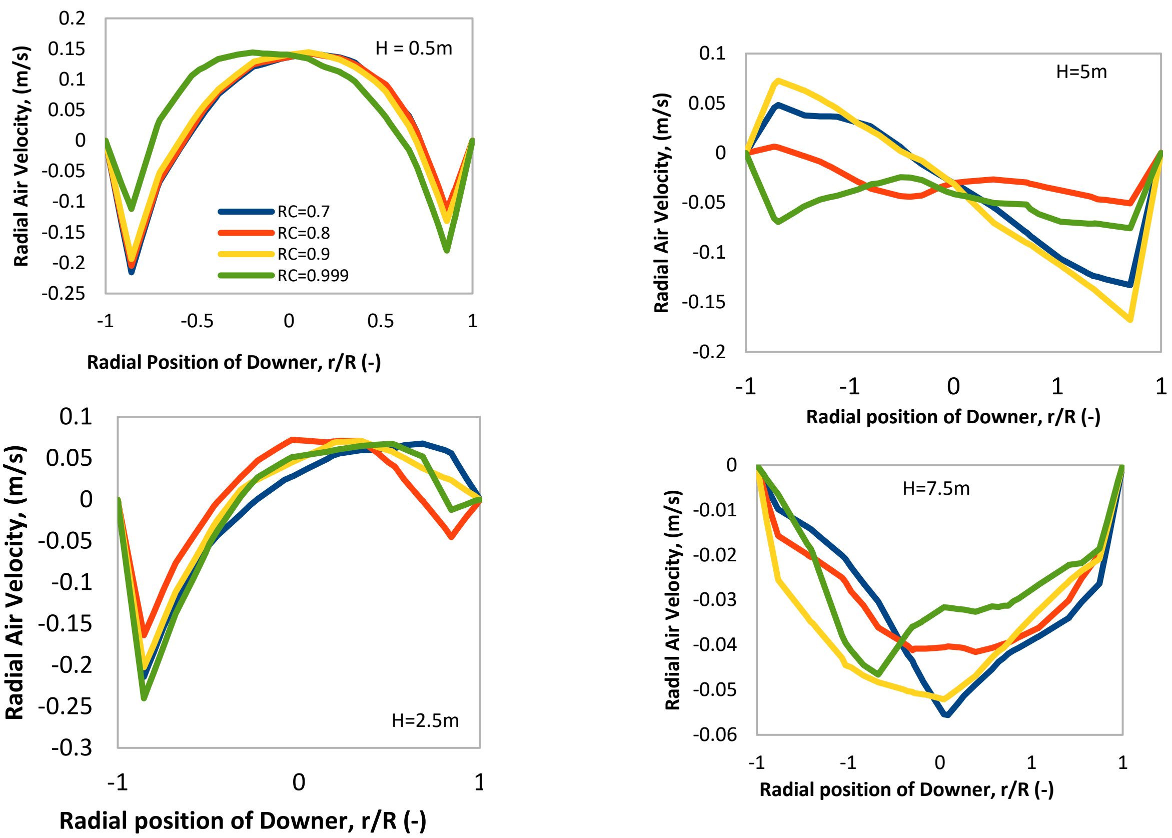

Figure 5. The effect of restitution coefficient on radial distributions of computed radial air velocity at four different downer heights

3.1.3 Restitution coefficient between solid particle and wall

The restitution coefficient between solid particle and wall implies the dissipation of solid fluctuating kinetic energy due to collision between solid particle and wall similar to restitution coefficient between solid particles. Here, two kinds of restitution coefficients exist as normal and tangential, and both of the restitution (friction) coefficients are important in the system. Here also, similar to specularity and restitution coefficient between solid particles, the value ranges from zero to one. A value of zero means, a significant amount of solid fluctuating kinetic energy is dissipated (inelastic collision) while a value of one means, no solid fluctuating kinetic energy is dissipated (elastic collision).

In this study, the restitution coefficient between solid particle and wall is varied in the range as 0.7, 0.8, 0.9 and 0.999. The effect of restitution coefficient between solid particle and wall does not significantly affect hydrodynamics in the downer system.

3.2 Downer system hydrodynamic characteristics

The radial distribution of computed radial solid and air velocities from Fig. 2 to 5 confirms the prediction of downer hydrodynamics. The numerical simulation confirms that very dilute flow is found to exist in the center region and a relatively dense phase near the wall region. Therefore this concludes the observed flow structure inside the downer system. In addition, as the downer height increases, the flow structure predicted more developed flow pattern. Fig.6 displays the axial air velocity at different height below the top of the downer at 0.5m, 2.5m, 5m and 7.5m. Fig. 7 illustrates the distribution of velocity vector magnitude at 50s simulation time. Fig. 8 and 9 illustrates the air and solid circulation pattern in the downer system after 50 s of simulation time involving base case simulation parameters discussed in Table 1. It is clearly evident from Fig. 8 and 9, that towards the inlet there is fluctuation in distribution of air/solid, whereas towards the exit of the reactor there exists a uniform distribution. The uniform distribution of the solid circulation pattern enhances the heat transfer and thereby reaction in future research.

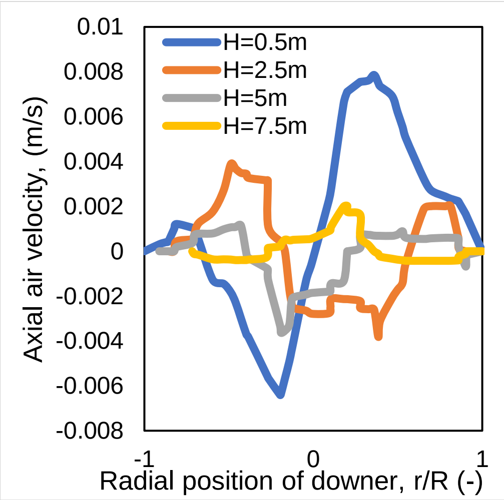

Figure 6. Variation of axial air velocity at different downer heights

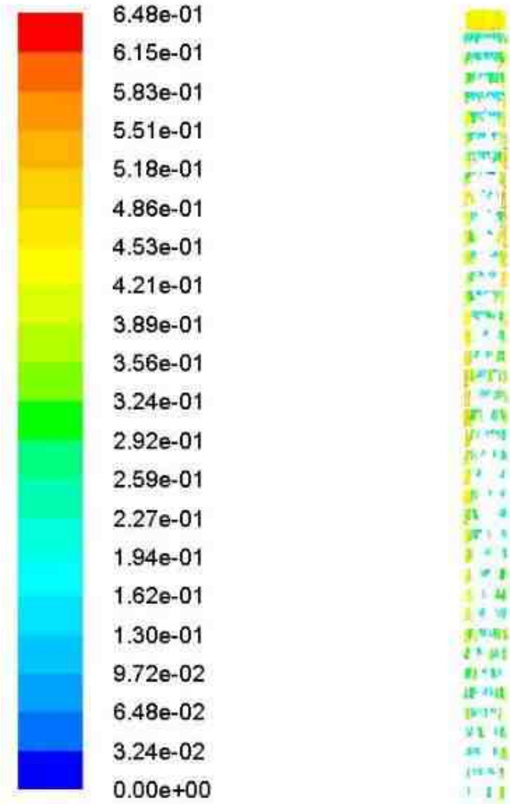

Figure 7. Distribution of solid velocity vector magnitude at 50 s simulation time

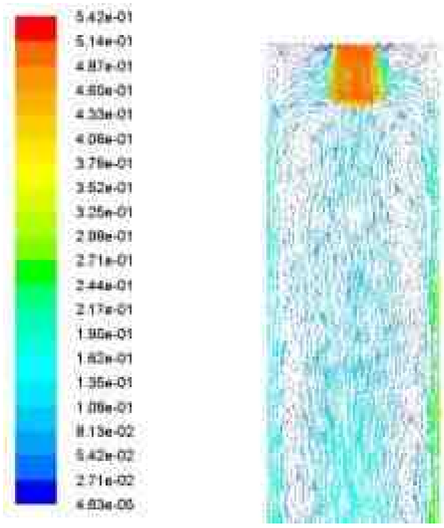

Figure 8. Distribution of air in the downer at U_g=0.5 m/s and Mass flux=0.01 kg/m^2.s

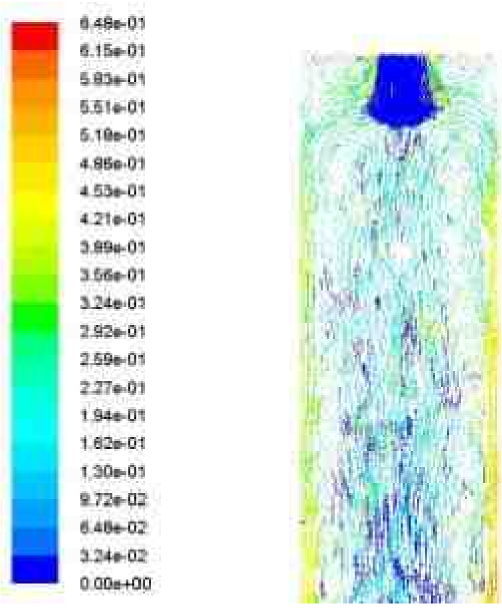

Figure 9. Distribution of solid in the downer at U_g=0.5 m/s and Mass flux=0.01 kg/m^2.s

4. Conclusions

The flow structure in a downer component is successfully modeled using CFD with the Eulerian approach, the kinetic theory of granular flow using solid as pseudo fluid. The effect of modeling parameters studied includes specularity coefficient, restitution coefficient between solid particle and wall, restitution coefficient between solid particles. The obtained result provides a best fitting modeling parameter for the system of interest. The suitable CFD model is applied to compute the system hydrodynamics and the turbulent properties which includes axial and radial velocity. The computed results can be used as an explanation for the in-depth analysis of the downer system flow phenomenon. While this work indicates promising results for the use of the developed CFD model in downer, clearly more experimental validation is necessary. Only higher order validations, in addition to matching of the profiles of velocity would be acceptable for rigorous use of such a model. Work on some of these experimental and theoretical aspects is underway and would be communicated in future.

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Nomenclature

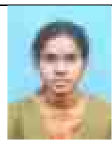
A Constant for Syamlal and O'Brien model (-)
B Constant for Syamlal and O'Brien model (-)
C_D Drag coefficient for Syamlal and O'Brien model (-)
C_{D0} Drag coefficient (-)
d_p Solid particle diameter (m)
e Restitution coefficient between particles (-)
e_W Restitution coefficient between particle and wall(-)
E Turbulent kinetic energy (m^2/s^2)
g Gravitational acceleration (m/s^2)
g_0 Radial distribution function (-)
I Unit tensor (-)
I Total number of time steps (-)
n Unit vector (-)
P Gas pressure (Pa)
P_s Solid pressure (Pa)
Re Reynolds number (-)
Re_s Reynolds number for Syamlal and O'Brien model (-)
t Time (s)
u Velocity (m/s)
$u_{s,slip}$ Slip velocity of solid phase at the wall (m/s)
$u_{s,W}$ Velocity of solid phase at the wall (m/s)
$u_{t,W}$ Tangential velocity of solid phase at the wall (m/s)
u' Velocity fluctuation (m/s)

Greek letter

β Interphase exchange coefficient of drag force (kg/s m^3)
ε Volume fraction (-)
$\varepsilon_{s,max}$ Solid volume fraction at maximum packing (-)
ρ Density (kg/m^3)
τ Stress tensor (Pa)
Θ Solid fluctuating kinetic energy or granular temperature (m^2/s^2)
Θ_t Turbulent granular temperature (m^2/s^2)
Θ_W Wall granular temperature (m^2/s^2)
κ_s Conductivity of solid fluctuating kinetic energy (kg/ms)
γ_s Collisional dissipation of solid fluctuating kinetic energy (kg/ms^3)
γ_W Collisional dissipation of solid fluctuating energy at the wall (kg/ms^3)
µ Viscosity (kg/ms)
ξ Bulk viscosity (kg/ms)
φ Specularity coefficient (-)

Subscripts

g Gas phase
s Solid phase

PRESENTING AUTHOR BIODATA	
Name	Bhuvaneswari G
Designation	Research Scholar
Company/Institute	National Institute of Technology – Tiruchirappalli
Qualification	M.Tech (Chemical Engineering, Specialization: Computer Aided Process and Equipment Design) – Completed Ph.D (Department of Chemical Engineering, National Institute of Technology Tiruchirappalli) – Ongoing
Area of Expertise	Fluid Mechanics, Heat Transfer, Computational Fluid Dynamics
Significant Achievements	Bhuvaneswari G., Reddy H.M., Ananthula V.V. (2016) CFD Studies on Pressure Drop for Low Reynolds Fluid Flows Across Orifice in Similarly Shaped Microchannel. In: Regupathi I., Shetty K V., Thanabalan M. (eds) Recent Advances in Chemical Engineering. Springer, Singapore.
Number of Papers Published in Conferences	6

Publication as Book Chapter

1. Bhuvaneswari G., Reddy H.M., Ananthula V.V. (2016) CFD Studies on Pressure Drop for Low Reynolds Fluid Flows Across Orifice in Similarly Shaped Microchannel. In: Regupathi I., Shetty K V., Thanabalan M. (eds) Recent Advances in Chemical Engineering. Springer, Singapore.

Papers Published in Conferences

1. Third Place for the paper titled “Corrosion Inhibition in sintered stainless steel” in Quintessence-10, Chemical Engineering Association, Coimbatore Institute of Technology (CIT), Coimbatore.
2. Best Poster Prize in Poster titled “Prospects of direct methanol fuel cells” in Chemfluence-10, A. C. Tech Anna University, Chennai.
3. Presented a solution for Industrial Defined Problem titled “Disposal of municipal solid wastes” given by Global Environmental Consultants in Institute of Chemical Technology (ICT), Mumbai.
4. Presented a poster titled “Effect of floatation reagents on enrichment of limestone slurry in cement manufacturing process”, ICT, Mumbai.
5. Third place for the paper titled “Membrane bioreactor” in Technofest-08, Chemical Engineering Association-CIT, Coimbatore.
6. First place for the paper titled “Tertiary treatment of distillery waste water by Nano filtration” in Pansophy-08, Sri Venkateshwara College of Engineering (SVCE), Chennai.