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CFD Analysis of Loop Seal in the Circulating Fluidized Bed System System

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Abstract—*Circulating fluidized bed (CFB) technology is being used extensively now-a-days as it has several advantages which include use of biomass and low grade coal, good thermal control, high rate of heat and mass transfer due to high surface area-to-volume ratio of fine particles, compactness, eco-friendliness and better grip over toxic emissions. An important non mechanical valve used in CFB is loop seal, which provides leak tight operation in the loop. Very few literatures are available on its operation and working. The present work focuses on 3D model development of loop seal and its simulation using multi phase fluid flow with Eulerian-Eulerian approach. Several drag models on fluidized bed systems are available but Gidaspow drag force model has been used in the current study. The analysis is done using the commercial software Ansys Fluent 15.0.7 on Geldart-B particles i.e., silica sand having density of 2500 kg/m^3 with mean sauter diameter of 0.314 mm. Contours of volume fraction, dynamic pressure and velocity have been depicted accordingly. Graphs have been plotted to show volume fraction, dynamic pressure, velocity and molecular viscosity of two fluids with respect to position in the loop seal. The spatio-temporal results obtained are compared and validated with a series of experiments conducted under similar conditions.*

Keywords: *Circulating fluidized bed, loop seal, multiphase fluid flow, model.*

1. INTRODUCTION

Gasification is the commercial application of fluidized beds. There is an intense mixing of gas and solid in the case of fluidized bed systems. In circulating fluidized bed, the superficial velocity is within the limit of fast fluidization. Fuel is injected into the lower section of riser, either directly or through the loop-seal. A loop seal, one of the most widely used non-mechanical valves in circulating fluidized beds or the related processes acts as recycle agent that is leak tight, which allows the transfer of solid from high pressure standpipe to the low pressure riser but preventing the reverse flow of gas from bottom zone of the riser to the standpipe. [1-5]. Loop seal is divided into two parts i.e., supply chamber and recycle chamber. The supply chamber is the bottom most part of the standpipe and recycle chamber is connected to supply chamber by a small opening or (slit). The solid particles in the recycle chamber, is in the bubbling fluidized regime [6]. The solid particles flow into the recycle chamber where it is fluidized to overflow the weir and fall under gravity into recycle pipe and reaches the bed of riser [7]. The non-mechanical valves control the solid flow rate without the moving parts by aeration. For this to happen, the velocity of air supplied at the bottom of stand pipe through distributor plates should be less than the minimum fluidization velocity of the solid particles in the stand pipe. It is due to this effect that the solid particles along with air may flow against the gravity from stand pipe to the top of riser. If the aeration velocity is increased the bubbles in the loop seal expand up to weir and flows to the riser through recycle pipe [8]. In the present study, Eulerian model of two phases (air and sand) was developed and for the simulation of a 3D loop seal, commercial computational fluid dynamics (CFD) software ANSYS Fluent 15.0.7 was used.

2. MODEL DEVELOPMENT

The model has been developed to simulate gas-solid contacting process in loop seal of a circulating fluidized bed gasifier. It has been designed and developed to describe the overall process that occurs in the loop seal including pressure outlet, outlet velocity, volume flow rate of solids, particle size distribution effect on recycle pipe in loop seal. A three-dimensional, rectangular fluidized loop seal bed is modelled and shown in Fig. 1. Three different mesh were generated of total cell size 1,17,280; 1,18,792 and 1,19,124 respectively. Simulation results were done for all the mesh. It was found that the simulation results were within 7% deviation from each other. Hence, 2nd mesh i.e., 1,18,792 elements was selected for the present study.

Table 1: Input parameters for simulation of loop seal

Model	Multiphase Eulerian Model of Implicit scheme with two phases
Materials	Sand-Density=2500kg/m^3 Air-Density=1.225kg/m^3 Viscosity=1.7894e-05kg/m.s
Phases	Primary Phase= Air Secondary Phase=Sand Diameter =0.314mm Phase interaction= Gidaspow
Boundary Conditions	a)Velocity Inlet 1= 0.3m/s b) Volume fraction $_{sand}$ =0.6 c)Wall specularity coefficient =0.6
Time Step	0.0001s

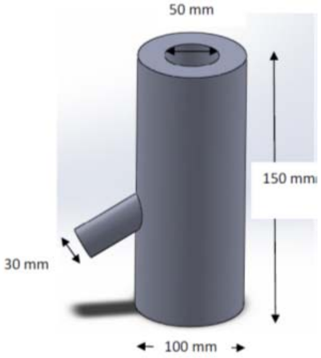
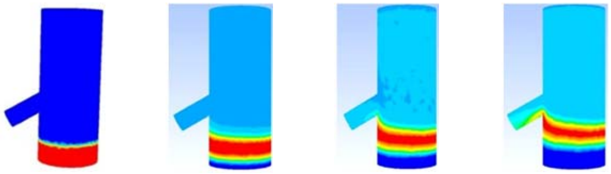


Fig. 1: 3D Geometry of loop seal

It is based on unsteady state, Eulerian-Eulerian multiphase model of which air and solid are the flow particles. The simulation has been done with a time step of 0.0001s. Here effects of particle diameter on different conditions are investigated.

3. SIMULATION OF LOOP SEAL

The Simulation is done for mean sauter diameter of sand particles 0.314 mm. Various input parameters have been presented in Table 1. Gidaspow drag model has been used for the current simulation as it shows better results for bubbling fluidized bed [9]. The initial solid bed height in loop seal is taken as 35mm. The fluid phase consisting of air which is used for aeration is injected with absolute velocity 0.3 m/s. At the pressure inlet, the volume fraction of sand is taken as 0.6. The dispersed phase particle with diameters of 0.314 mm is fluidized by air from bottom. At the pressure outlet, outflow of particles and gas takes place. Pressure drop in solid flow by aeration is expressed as equation.



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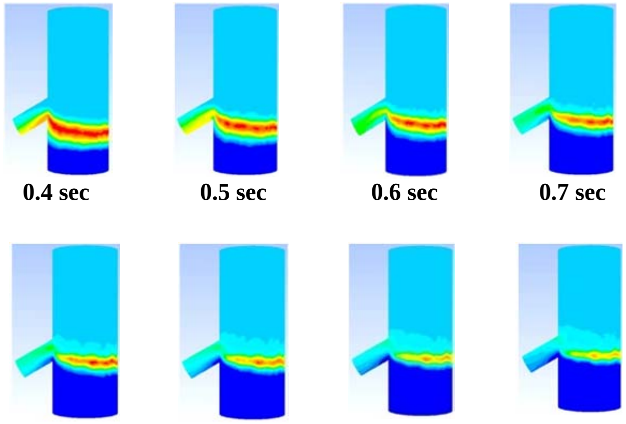

0.4 sec **0.5 sec** **0.6 sec** **0.7 sec**

0.8 sec **0.9 sec** **1.0 sec** **1.1 sec**

Fig. 2: Graphical representation of contours simulation

Governing Equations for CFD simulation

Mass conservation

Gas phase $\frac{\partial}{\partial t}(\varepsilon_g\rho_g) + \nabla.(\varepsilon_g\rho_g\vec{v}_g) = 0$

Solid phase $\frac{\partial}{\partial t}(\varepsilon_s\rho_s) + \nabla.(\varepsilon_s\rho_s\vec{v}_s) = 0$

Momentum conservation

Gas phase $\frac{\partial}{\partial t}(\varepsilon_g\rho_g\vec{v}_g) + \nabla.(\varepsilon_g\rho_g\vec{v}_g^{\,2}) = -\varepsilon_g\nabla P + \nabla.\bar{\bar{\tau}}_g + \varepsilon_g\rho_g\vec{v}_g + k_{gs}(\vec{v}_g - \vec{v}_s)$

Solid phase $\frac{\partial}{\partial t}(\varepsilon_s\rho_s\vec{v}_s) + \nabla.(\varepsilon_s\rho_s\vec{v}_s^{\,2}) = -\varepsilon_s\nabla P - \nabla P_s + \nabla.\bar{\bar{\tau}}_s + \varepsilon_s\rho_s\vec{v}_s + k_{gs}(\vec{v}_g - \vec{v}_s)$

Kinetic fluctuation energy

$$\frac{3}{2}\left[\frac{\partial}{\partial t}(\rho_s\varepsilon_s\theta_s) + \nabla.(\rho_s\varepsilon_s\vec{v}_s\theta_s)\right] = -(P_s\bar{\bar{I}} + \bar{\bar{\tau}}_s):\nabla.\vec{v}_s + \nabla.(k\theta_s\nabla\theta_s) - \gamma\theta_s + \emptyset_{gs}$$

Gidaspow drag law

For, $\alpha_g \le 0.8, K_{gs} = 150\frac{\alpha_s(1-\alpha_g)\mu_g}{\alpha_g {d_s}^2} + 1.75\frac{\alpha_s\rho_g|u_s-u_g|}{d_s}$,

When, $\alpha_g > 0.8, K_{gs} = \frac{3}{4}C_D\frac{\alpha_s\alpha_g\rho_g|u_s-u_g|}{d_s}{\alpha_g}^{-2.65}$,

where, CD is the standard drag coefficient of a spherical particle.

4. EXPERIMENTAL SETUP

A series of experiments were conducted on loop seal of circulating fluidized bed gasifier located at CSIR-CMERI Durgapur. The loop seal under consideration is made of stainless steel with one pressure tap at 50 mm height from the base. The material used for the study of hydrodynamics consists of common silica sand with mean sauter diameter 0.314 mm. Pressures were measured with the help of U-tube manometer connected to the pressure tap located in the loop seal. The experiments were performed with varying riser air velocity but the loop seal aeration was kept constant at 0.3 m/s which was the minimum condition for stability. The material used is common silica sand with range of size of sample between 0.100-0.425 mm. The mean sauter diameter of this sample is 0.314 mm and was obtained experimentally by use of standard sieves.

5. RESULTS AND DISCUSSIONS

The simulation results have been obtained for the mentioned sand samples. It was found from the results that almost 1.1-1.5 sec is required for 35 mm height of packed sand to get fully discharged to the connector pipe and ultimately to the riser. Fig. 3 is the graph plotted between mean static pressure and height of loop seal at 50 mm height. There is gradual drop in pressure from base of the loop seal to total height. This is as such because at the centre of the loop seal, there is uniformity.

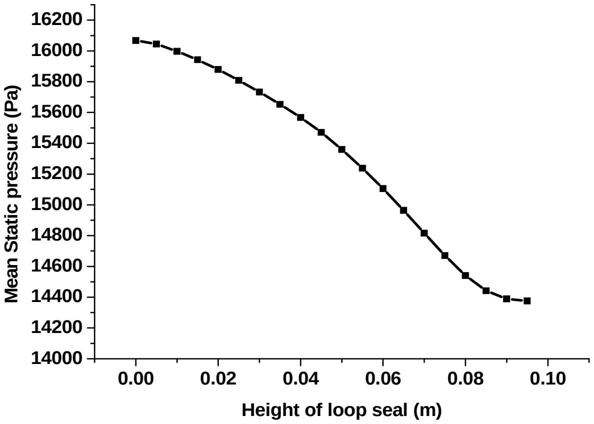

Fig. 3: Mean static pressure versus height of loop seal at x=50.0 mm

Fig. 4 reports the variation in mean static pressure and the lateral distance across the recycle pipe. It was found that there is sudden fall in pressure at exit of the pipe (from main body) from 4,200 Pa to 0 Pa at the end point of the recycle pipe.

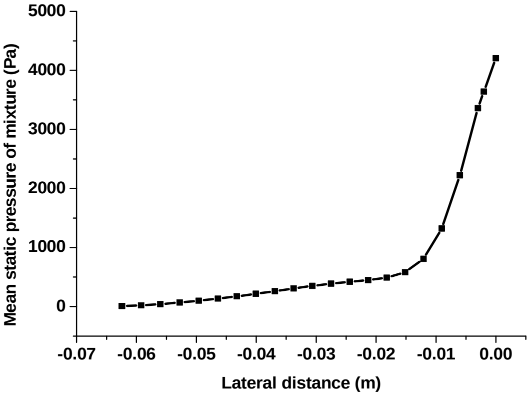

Fig. 4. Mean static pressure versus lateral distance throughout recycle pipe

Mean volume fraction of sand is plotted in Fig. 5 as against height of loop seal. It is clear from the Fig. that mean volume fraction rises up to 0.63 and is constant after attaining that value. Similarly in Fig. 6 mean volume fraction in the recycle pipe follows a parabolic path. It rises to a maximum value of 0.63 and then falls down.

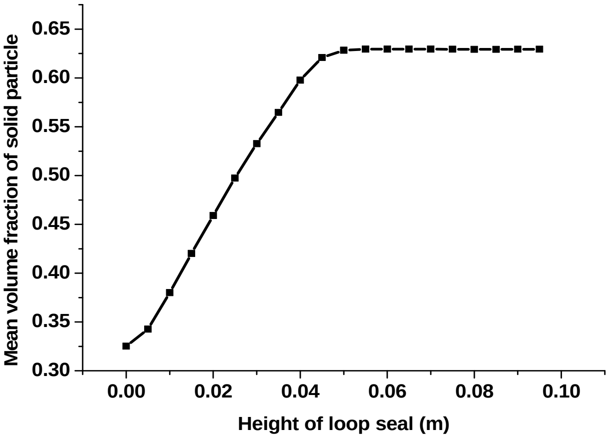

Fig. 5. Mean volume fraction of solid particle versus height of loop seal at x=50.0 mm

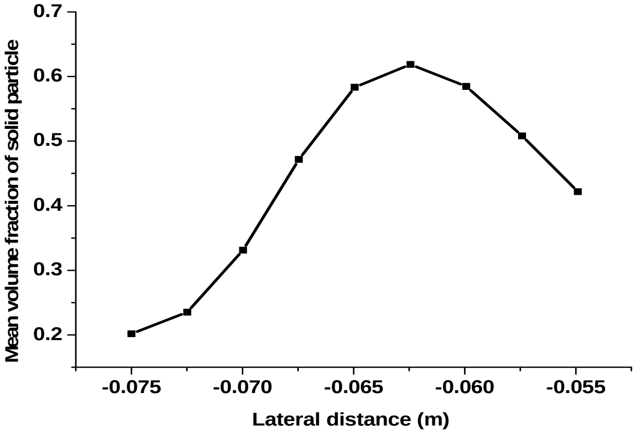

Fig. 6. Mean volume fraction versus lateral distance across loop seal discharge

Fig. 7 reports the mean velocity magnitude of solid particles with the height of loop seal at the central region. There is gradual rise and fall till 60 mm height but after that the velocity is found to follow a steep rise trend. This may be due to the fact that the number of particles which gets entrained is less but when they gets the velocity greater than the terminal velocity they rises quickly attaining higher velocity.

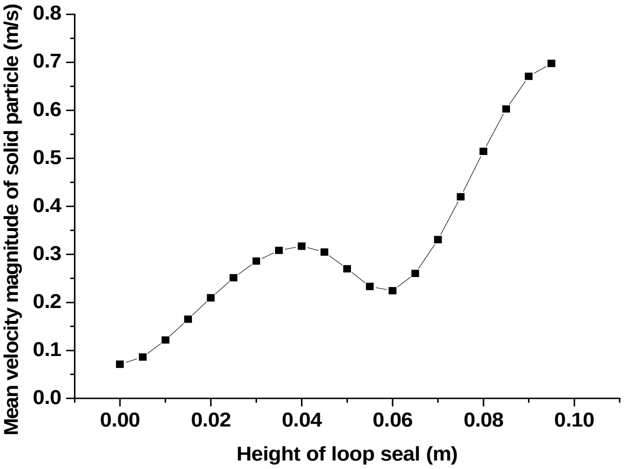

Fig. 7: Mean velocity magnitude of solid particle versus height of loop seal at x=50.0 mm

In Fig. 8, it may be observed that the mean velocity of sand particles increase up to 2.1 m/s from 1.35 m/s. After attaining that peak value of 2.15 m/s, gradual decrease in the velocity trend was observed. The results obtained were compared with experimental results from the pressure tap located at 50 mm height. The static pressure obtained from the water U-tube manometer is found to completely satisfy the simulation results. Experimental results were found to fluctuate between 15,300-15, 500 Pa which completely satisfies the obtained results.

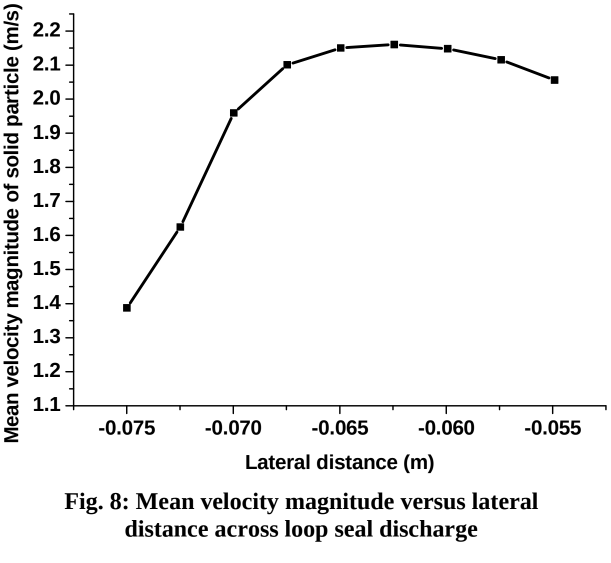

Fig. 8: Mean velocity magnitude versus lateral distance across loop seal discharge

6. CONCLUSION

Simulations were performed for cylindrical type loop seal, in order to understand its proper working. Gidaspow drag model was used to simulate the experimental results. Mean static pressure, mean volume fraction of sand and mean velocity of solids were considered for the study. It was found that the findings are very much analogous to the experimental results obtained. The mean pressure is found to follow a exponential decay at the centerline of the loop seal with peak value of 16, 100 Pa. The maximum value attained by the mean volume fraction of solids is 0.63 which is also the packing limit set in the ANSYS Fluent. Mean velocity of sand particles is found to get increased after centerline of the loop seal. The maximum attained velocity is 0.7 m/s. The simulation results obtained can be used for better design and technologically advanced loop seal for its use in different concerned industries.

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