

# Effect of superficial air velocity on pressure drop off Fluidized chamber experimentally and computationally

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**ABSTRACT:** *Forming deposits, which remains unutilized and frequently cause ecological issues, could play an important role as energy source to fulfill the energy requirements. Present investigation has been carried out in a cold bed set up to know the hydrodynamic parameters of fluidized bed at atmospheric conditions. To execute this work a round cross-sectional vessel of 0.09 m internal diameter and 1.2 m height was fabricated using 4 mm thick transparent acrylic resin tube. Sand is chosen as an inert bed with mean diameter 0.4, 0.66 and 0.93 mm. Experiments are then conducted at different fluidizing velocities various from 0.272 to 0.544 m/s with three different fuels rice husk, saw dust and groundnut shells. The impact of sand molecule size on fluidization velocity of two components bio-fuel and sand is studied and recommended to use sand molecule of size 0.4 mm for rice husk, saw dust and 0.66 mm sand particle size for ground nut shells. Group of simulations are done through ANSYS FLUENT16; keeping bed conditions is same as that of experiment. The outcomes are presented in the form of contour plots with volume fraction of sand and biomass particles. Experimental data were compared with the simulation the results followed almost the same trend.*

**KEYWORDS:** *Fluidization, mixing behavior, Volume Fraction, CFD model*

## I. INTRODUCTION

Renewable energy sources are endless and being regenerated always in nature. Improvement and advancement of human being are closely related to sources of energy. In the present situation, all the nations of the world have connected with themselves in seeking and creating non-conventional energy sources that would be extremely basic to continue the existence of an individual, biomass is one of them. India is very rich in agriculture products, the leftover material after harvesting all those agriculture products such as rice husk, bagasse, and groundnut shell, these wastes are used as fuel for generating energy, by burning these byproducts the released energy has many applications, for example, creating power, warming homes and process heat for industries. Anil Kumar et al. [1] discussed about biomass energy and their potential in India. They discussed surplus agricultural and forest area produces about 500 million tons of biomass per year. Finally, they concluded the need to develop biomass energy sector. Anil Tekale et al [2] said that no of power plants are available based on conventional energy sources. The drawback of all these plants CO<sub>2</sub> emission leads to global warming and also cost enrichment of these fuels.

To overcome these problems they developed biomass power plants. Maninder et al. [3] expressed that millions of tons of agricultural byproducts are generated every year and it was burned inefficiently in loose form preceded by air pollution. These byproducts can be recycled and reuse as a renewable energy source without adding any additives. .M.J.C.Van et al [4] stated biomass resources lead to produce various liquid and gaseous products also discussed biomass upgrading for production of biofuels by adopting suitable technologies. Peter McKendry [5] stated development of civilization is closely related to energy utilization, at present conventional energy (fossil fuels) sources are major contributors to develop energy needs and causing global warming. Considering drawbacks from fossil fuels utilization need to shift to generate energy by biomass one of the potential source of renewable energy.

Goyal et al. [6] said that a huge demand for energy due to the rapid of urbanization and population. At present, the energy need is fulfilled by the major conventional energy resource. Biomass is one of the primary renewable energy sources which can be converted into useful products, by opting different conversion methods that include combustion and gasification. Goyal et al. [7] reported, due to rapid growth in urbanization and population consuming a huge amount of fossil fuels getting extinct. Biomass considered one of the renewable energy. They discussed various conversion processes that convert biomass into energy products. They studied various parameters viz. temperature and size of the particle to achieve good yield during the conversion process. K.v.n.s. rao and Reddy [8] expressed the energy levels in biomass are low, for maximum conversion of existing energy from biomass is done by implementing effective conversions methods. They introduced a fluidized bed methodology which helps to liberate the maximum percentage of energy from biomass. They also introduced mixing characteristics of biomass and sand; they also suggested a suitable association to decide the least fluidization velocity for the particular biomass fuels and sand mixture.

In the previous research done by many researchers, there are many biomass waste materials are available and for the current study, we have chosen rice husk, sawdust, and groundnut shell. Selection of sand particle is critical due to a large variation in the density of sand and biomass. From the literature review, it is found that most of the work done related to the performance of the fluidized bed combustion system using coal as fuel.

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**II. MATERIALSAND METHODOLOGY**

Test setup for hydrodynamic studies as shown in Fig 1. It is around cross-sectional fabricated structure has following dimensions 00.09 m diameter and a height of 01.20 m, made-up from 4mm thick transparent acrylic resin tube. To measure required parameters facilities are provided along its length an interval of 135 mm along the column and are connected to water tube manometer. Centrifugal blower of 1 HP, 2720 rpm is provided to supply the required air.



**Fig 1. Experimental Setup for Hydrodynamic Studies**

In this research work, biomasses of different fuels (rice husk, saw dust, and groundnut shells) are used as raw material, irrespective of sizing. Properties of fuels, proximate and ultimate analyses are carried out to find the fuel composition; the results are given in the table 1, 2 and 3. Characteristics of bed material used for experimentation are shown in the table 4.

**Table 1 Properties of different fuels**

Property	Rh	Sd	Gs
Calorific value, kcal/kg	3459	4464	4712
Mean particle size, mm	002.146	000.658	009.480
Particle density, kg/ m <sup>3</sup>	588.940	715.920	680.400
Bulk density, kg/ m <sup>3</sup>	116.90	285.80	121.30

**Table 2 Proximate analysis of different fuels**

Property	Rh	Sd	Gs
% Moisture	9.64	8.23	12.13
% Volatile matter	66.046	81.24	82.125
% Ash	15.149	2.454	2.4
% Fixed Carbon	9.248	8.746	4.143

**Table 3 Ultimate analysis of different fuels**

Property	Rh	Sd	Gs
% Hydrogen	05.02	04.36	05.42
% Nitrogen	00.00	00.32	00.76
% Carbon	39.34	48.56	48.70
% Sulphur	00.04	00.05	00.00
% Oxygen	33.45	27.23	31.60

**Table 4 Features of inert sand**

Parameter	Sand-1	Sand-2	Sand-3
Mean particle size, d <sub>p</sub> in mm	0.93	0.66	0.4
Particle Density, ρ <sub>p</sub> in Kg/m <sup>3</sup>	2520	2520	2519
Bulk Density, ρ <sub>b</sub> in Kg/m <sup>3</sup>	1500	1520	1600
Terminal Velocity of the particle, U <sub>t</sub> in m/s	7.341	4.894	3.18
Static voidage , ε <sub>0</sub>	0.4	0.392	0.36

**III. EXPERIMENTATION**

Experiments are carried at different fluidizing velocities ranging from 0.272 to 0.544 m/s. The minimum fluidization velocity and suitable size of sand particle are recommended for finer blending of rice husk; saw dust and groundnut shells with the bed along with other fluidization parameters. Three sand sizes are selected i.e. 0.93, 0.66, and 0.4 mm for good blending with the fuel particle, Conducted experiment for corresponding mass ratios of fuel to sand (MR) for the three different bio mas particles: rice husk, MR<sub>r</sub> = 1:13 sawdust, MR<sub>s</sub> = 1:5 and groundnut shell MR<sub>g</sub> = 1:12. Fluidized air is supplied through the distributor with a centrifugal blower. The air supplied is measured with an orifice meter. Pressure drop over the bed is estimated with the help of water filled manometer.

**Experimental procedure for Hydrodynamic Studies**

At first, the sand with chosen mean particle size is poured through the top of the vessel until it achieves the static bed height of 30 mm. Biomass is set over above the sand bed at a height of 60 mm. Fluidized air is provided at bottom of the vessel with a centrifugal type blower. The quantity of air supplied is measured with an orifice meter. A pressure drop across the bed is estimated with the help of water filled manometer. The heights of the bed are measured to evaluate the impact of fluidizing speed on bed expansion and mixing characteristics.



#### IV. RESULTS AND DISCUSSION

##### Effect of superficial velocity on pressure drop

###### Case – 1 Rice Husk

Pressure drops  $\Delta p$  verses fluidized velocity curves for rice husk shown in Fig 2, velocity for the molecule size of 0.93, 0.66 and 0.4 mm have been seen at 0.54, 0.5 and 0.48 m/s. While observing above data low velocity was observed for 0.4 mm is used as bed material. For the same bed material, when the fluidizing velocity is greater than 0.65 m/s, rice husk particles are found to elutriate out of the bed. Therefore, the operating air velocity for rice husk in fluidized bed should be between 0.48 m/s and 0.65 m/s.

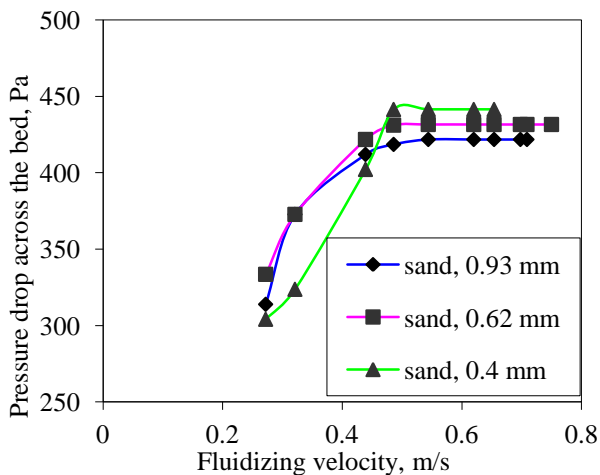


Fig 2 Pressure Drop across the Bed versus Fluidizing velocity for mixture of Rice husk and Sand

###### Case – 2 Saw Dust

Fluidization characteristics of saw Dust and sand mixture with mean particle size of sand - 0.93, 0.66 and 0.4 mm as shown in Fig 3. When the bed contains sand size 0.93 and saw dust, when it is fluidized channeling effect has been observed. The low-pressure drop profile as shown in Fig 3 for sand size 0.93 indicates this phenomenon. This is an irregular behavior of bed that showing maximum fuel particles are passing up like a column.

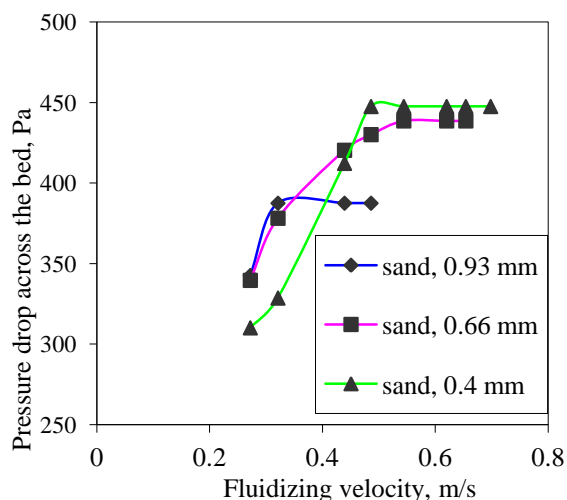


Fig 3 Pressure drops across the bed versus Fluidizing velocity for mixture of Saw Dust and Sand

It was also observed from the same Fig 3 while decreasing the sand size pressure drop also decreasing. While observing the three curves 0.4 mm is more appropriate for the fluidization of saw dust due to relatively low minimum fluidization velocity i.e. 0.48 m/s when compared with 0.54 m/s for 0.66 mm size sand bed. It has also been observed that the particles began to leave the vessel when the fluidization velocity is enlarged beyond 0.69 m/s. Thus, the effective gas velocity for saw dust in fluidized bed should lie in-between 0.48 and 0.69 m/s. The operating velocities of rice husk and saw dust is found to be very close to each other. Particle size is more pronounced in sawdust when compared to rice husk.

###### Case – 3 Groundnut Shell

Similar experiments are conducted for groundnut shell, fluidization characteristics of Groundnut Shell and sand mixture with mean particle size of sand - 0.93, 0.66 and 0.4 mm as shown in Figure 4

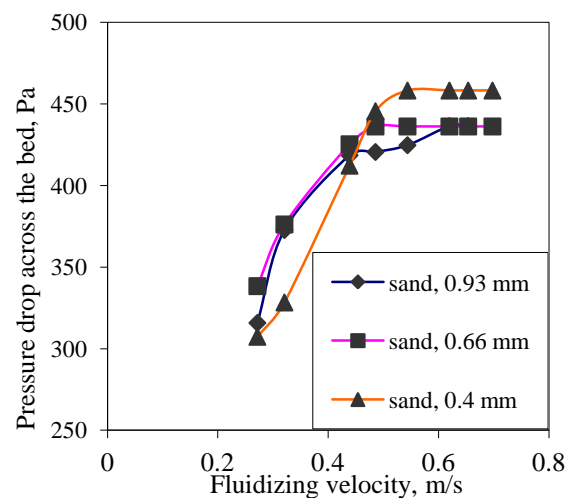


Fig 4 Variation of bed pressure against fluidizing velocity for groundnut shells and sand mixture

Pressure drop due to fluidizing velocity for three different particle sizes of sand groundnut has shown in Fig 4. The minimum fluidization velocity (0.48 m/s) has been observed sand of 0.66 mm and 0.54 m/s for sand of 0.93 and 0.4 mm respectively.

#### V. COMPUTATIONAL METHODOLOGY

Computational fluid dynamics (CFD) is one among of the parts mechanics of fluids that utilizes arithmetical techniques and procedures to predict and analyze the problem related to fluid flow. CFD technology becomes more popular by utilizing advanced computer efficiencies and improved numerical techniques.

##### General Governing Equations

In this study, the Eulerian-Eulerian method is adopted. The general equations for the momentum and conservations of mass are given below. The following equations are fluid flow governing equations for gas-solid two-phase flow.

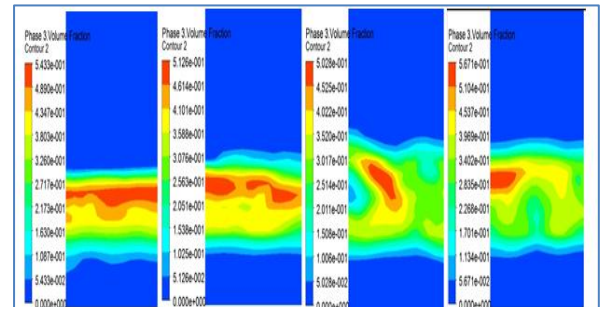
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \quad (1)$$



$$\frac{\partial}{\partial t} (\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\vec{\tau}) + \rho \vec{g} + F \quad (2)$$

$$\frac{\partial}{\partial t} (\alpha q \rho q h q) + \nabla \cdot (\alpha q \rho q u q \vec{h} q) = \alpha q \partial P q \partial t + \vec{\tau} : \nabla u q - \nabla q q \vec{v} + S q + \sum_{P=1}^N (Q p q + \dot{m} p q h p q - \dot{m} q p h q p) \quad (3)$$

$$\frac{\partial}{\partial t} (\rho Y_i) + \nabla \cdot (\rho \vec{v} Y_i) = -\nabla \cdot J_i + R_i + S_i \quad (4)$$



0.272m/s 0.321m/s 0.439m/s 0.544m/s  
Fig 6 Contour plots of volume fraction of Saw dust at different air velocities

**Standard k-ε Model**

To simulate the turbulent flow the standard k-ε model is used due to its suitability for a wide range of wall-bounded and free- shear flows. All k-ε models have similar forms only difference is to calculate the turbulent viscosity

$$\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k u_i) = \frac{\partial}{\partial x_i} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right] + G_k + G_b - \rho \epsilon - Y_M + S_k \quad (5)$$

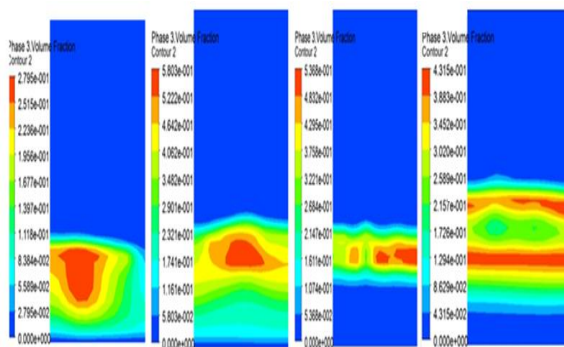
$$\frac{\partial}{\partial t} (\rho \epsilon) + \frac{\partial}{\partial x_i} (\rho \epsilon u_i) = \frac{\partial}{\partial x_i} \left[ \left( \mu + \frac{\mu_t}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_i} \right] + C1 \epsilon \frac{\epsilon}{k} (G_k + C3 \epsilon G_b) - C2 \epsilon \rho \frac{\epsilon^2}{k} + S_\epsilon \quad (6)$$

Computational fluid dynamics simulations are carried for cylindrical bubbling fluidized bed gasification chamber for better understanding of internal working conditions and will be compared with experiment. Initial static bed condition is same as that of experiment. In the present work three types of biomass fuels (i.e. rice husk, saw dust and groundnut shells) are selected and their fluidization characteristics are estimated in the presence of sand bed

**Effect of Fluidization Velocity on Biomass and Sand Bed**

**Case – 1 Rice Husk**

Simulated results of rice husk at different velocities of fluidizing medium (0.272 – 0.544 m/s).are shown in Fig 5. It is observed that the bed starts to expand at minimum air speed (0.272 m/s) but bed growth becomes zero, this indicates weight of particle is dominating the upward drag force.



0.272m/s 0.321m/s 0.439m/s 0.544m/s  
Fig 5 Contour plots of volume fraction of Rice Husk at different air velocities

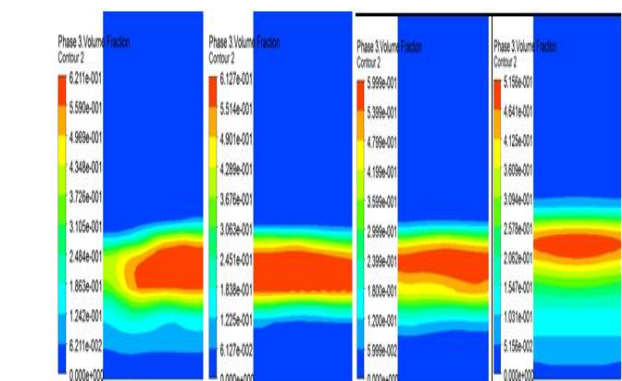
Scale indicating its value. Further increasing air velocity (0.544 m/s) there is small growth in bed height the bubbles are within the static bed without any bed expansion. The contour plots in Fig. 5 indicate small growth in the solid volume fraction along the wall instead of central region. The solid sand particles occupies at the bottom.

**Case – 2 Saw Dust**

Contour plots of saw dust and inert bed behavior is presented in Fig. 6 it was observed; maximum percentage of saw dust was occupying at one location not proper mixing with sand. It was observed from the contour plots shown in Fig 6 for all velocities of air sand occupying at the bottom, sawdust was lifted up and passing through central plane as a group this behavior is known as channeling effect. Occurrence of this state may be the density difference between sand and the sawdust and also the shape and size of sawdust particles. Also observes higher volume fraction at upper region for smaller size particle like sawdust.

**Case – 3 Groundnut shell**

Contour plots of Groundnut shells and sand at different velocities as shown in Fig 7 Volume fraction of Groundnut shell at velocities 0.272 m/s to 0.439 m/s, there was no proper mixing was observed.



0.272m/s 0.321m/s 0.439m/s 0.544m/s  
Fig 7 Contour plots of volume fraction for Groundnut Shell at altered velocities

Further increasing the velocity (0.544 m/s) starts mixing tendency; it is observed from the contour plots the bed expansion is maximum at 0.544 m/s velocity. It is also observed low bed expansion with bigger particle size cause behind this phenomenon is higher drag forces are required to lift up bigger particles and the light weight particles.

**Variation of Bed Height at Different Velocities**

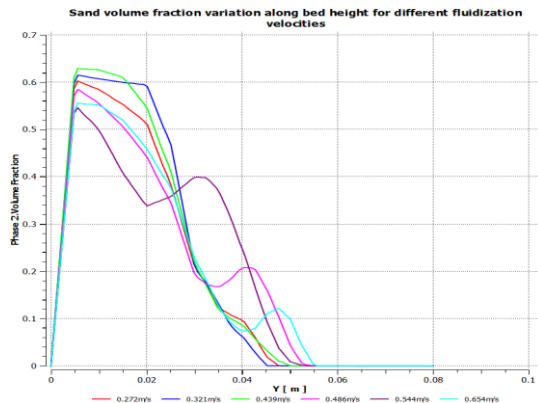


Fig 8 Sand volume fraction variation along the bed height at different fluidization Velocities

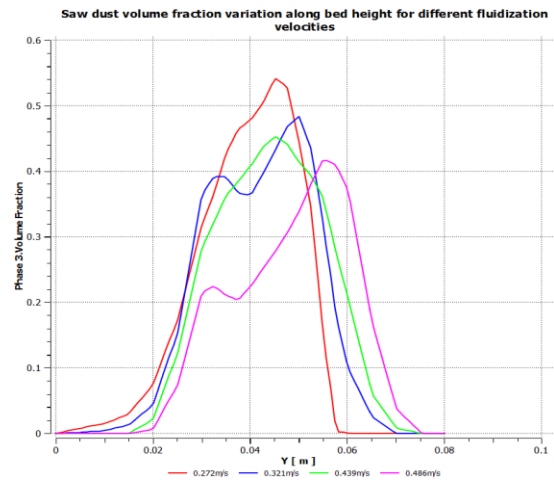


Fig 11 Saw Dust volume fraction variation along the bed height at different fluidization velocities

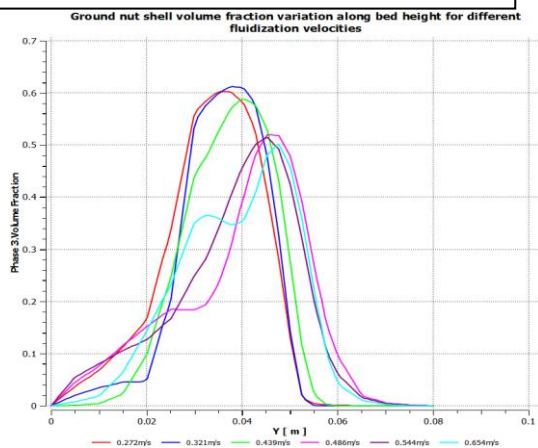


Fig 9 Ground nut shell volume fraction variation along the bed height at different fluidization velocities

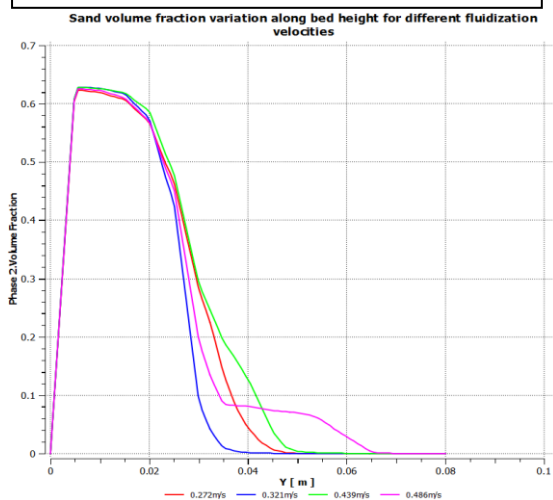


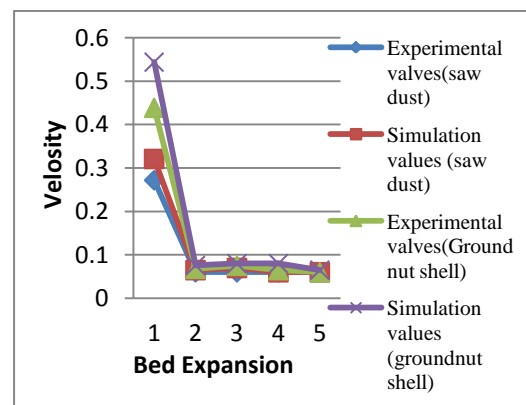
Fig 10 sand volume fraction variation along the bed height at different fluidization Velocities

**Comparison of Bed Height Experimental and Simulations**

Computational and experimental values of bed height for saw dust and groundnut shell at different velocities are shown in the table 5. Comparison plots of bed expansion as shown in Fig 12

**Table 5 Comparison of bed height experimental and simulations**

Velocity	Saw Dust		Groundnut shell	
	Experimental	Simulations	Experimental	Simulations
0.272	0.06	0.06	0.06	0.06
0.321	0.065	0.07	0.06	0.06
0.439	0.068	0.075	0.065	0.06
0.544	0.076	0.08	0.08	0.065



**Fig 12 Comparison of bed height Experimental and Simulations**

Comparison plots of bed expansion with superficial velocity for saw dust and groundnut shell is shown in above Fig 12. Bed expansion increases up to certain limit after which it remains constant when all the bed materials are fluidized. Similar trends also observed in simulation. It is evident that the CFD method which is following is correct.

## VI. CONCLUSIONS

From the experimental and computational investigation, the following conclusions are drawn: The operating air velocity for rice husk should be in between 0.48 m/s and 0.65 m/s, the effective gas velocity for saw dust lies in between 0.48 and 0.69 m/s. The operating velocities of rice husk and saw dust is found to be very close to each other. Segregation behavior of rice husk particles with inert sand particles is observed. Channeling effect is observed in the sawdust and sand mixture. Fairly well mixing of groundnut shell with sand is observed

## REFERENCES

1. Anil Kumar, Nitin Kumar, Prashant Baredar, Ashish Shukla (2015), A review on biomass energy resources, potential, conversion and policy in India, *Renewable and Sustainable Energy, Reviews* 45-530-539.
2. Anil Tekale, Swapna God, Balaji Bedre, Pankaj Vaghela, Ganesh Madake, Suvarna Labade (2017), *Energy Production from Biomass: Review*, *International Journal of Innovative Science and Research Technology*, Volume 2, Issue 10, ISSN No: - 2456 – 2165.
3. Maninder, Rupinderjit Singh Kathuria, Sonia Grover, *Using Agricultural Residues as a Biomass Briquetting: An Alternative Source of Energy*, *IOSR Journal of Electrical and Electronics Engineering (IOSRJEET)*, ISSN: 2278-1676 Volume 1, Issue 5 (July-Aug. 2012), PP 11-15.
4. M.J.C. van der Stelt, H. Gerhauser, J.H.A. Kiel, K.J. Ptasiński (2011), *Biomass upgrading by torrefaction for the production of biofuels: A review*, *Biomass and Bioenergy*, Volume 35, Issue 9, Pages 3748-3762.
5. McKendry, P (2002), *Energy production from biomass (Part 1): Overview of biomass*. *Bioresour. Technol.* 83, 37-46, *Bioresource Technology* 83(1):37-46, with 6,838
6. H.B. Goyal, Diptendu Seal, R.C. Saxena (2008), *Bio-fuels from thermochemical conversion of renewable resources: A review*, *Renewable and Sustainable Energy Reviews*, 12, 504-517.
7. H. B. Goyal, Rakesh CHANDRA Saxena (2008), *Bio-fuels from thermochemical conversion of renewable resources: A review*, *Renewable and Sustainable Energy Reviews* 12(2):504-517
8. K. V. N. S. Rao, G. V. Reddy (2012), *Cold Flow Studies of Rice Husk, Saw Dust, and Groundnut Shell Fuels in a Fluidized Bed*, *Energy Sources, Part A*: 32:18, 1701-1711

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