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Mathematical Modelling of Bubbling Fluidized Bed Combustor of 12.5 MW Power Plant Based on Rice Husk

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Abstract— **In this paper, mathematical modelling of fluidized bed combustion based on rice husk has been done by taking the data required for the models, from a 12.5 MW fluidized bed combustion plant at Satia Industries Limited, Shri Muktsar Sahib. Biomass or agriculture wastage a non conventional fuel is used and it is ensured that the use of non conventional fuel minimize the environmental degradation and also minimize the stress associated with mining, processing and transporting of conventional fuel. The numerous variables such as bed temperature, gas velocity, excess air, particle size distribution, bed and free board height that affect the combustion make the experimentation in full-scale furnaces very expensive. Therefore the best method to optimize the performance of furnaces is mathematical modelling. Bubbling fluidized bed as a combustion method is suitable for wide range of fuels even those fuel that have low quality. Percentage of Carbon dioxide in flue gas decreases with increase in the fraction of excess air. However the percentage of oxygen in the exit gas increases with increase in the fraction of excess air. With the increase in the bubble diameter, the oxygen conversion decreases. All the results from the model for rice husk are coming within permissible limits.**

Keywords*— *Modelling, Bubbling Fluidized Bed, Combustor, Fluidization, Rice Husk.

I. INTRODUCTION

Use of energy in these days is largely dependent on fossils fuels. In future, these fossil fuels make the development very difficult to keep going. During combustion there is rapid release of polluting products from the fossil fuels and these polluting products have effective change in the composition and behavior of our atmosphere. To generate electricity from the fossil fuels, there is a significant amount of the carbon dioxide emissions. Day by day demand for electricity is growing very fast which results in the increase in the use of fossil fuels and increase in the use of fossil fuels will further increase the carbon dioxide emissions and some other pollutants. So there is a need of some other fuels that can be used in place of the fossil fuels. Biomass or agriculture wastage a non conventional fuel is used and it is ensured that the use of non conventional fuel minimise the environmental degradation and also minimise the stress associated with mining, processing and transporting of conventional fuel.

There are large quantities of residues which can be used for the production of energy. Fossil fuels like coals are limited in availability but residues are not only limited in availability and these are also renewable. Some of the agricultural residues are not economically good to make use of because large investments required for collection, transportation and storage. However there is some biomass residues concentrated at specific location, where demand for energy also exists. They include rice husk at the rice mills, rice straw in the fields and bagasse at the sugar mills [Natarajan et al. 1998]. Utilization of biomass as an energy resource has various environmental advantages such as reduction in the emissions of toxic gases i.e. SOx, NOx. It is due to the low contents of sulphur and nitrogen present in the biomass fuels. Another benefit is to reduction in the amount of solid waste and utilization of agricultural or agro industrial residues and minimization of waste disposal [Kulah et al, 2010]. Various types of gases which emits by burning the rice husk as a fuel are as NOx, CO, and negligible SOx. The emissions of SOx in case of rice husk are not a big concern because of low contents of sulphur. The emission of NOx depends on the combustion temperature, fuel composition and stages of air during combustion. By controlling these parameters the NOx emissions is controlled and COx emissions reduced by controlling the temperature of furnace. There are many ways to control the temperature in the furnace i.e. furnace area, air distribution during combustion and flue gas recirculation.

Rice is also known as paddy. Husk is the outer cover of the rice grain and is in the form of hull. So the other name given to rice husk is rice hull or paddy husk or paddy hull. The rice husk is renewable and also it is less polluting due to its low sulphur and heavy metal contents. On weight basis, the weight of rice husk is about 20% of the weight of the rice [Armesto et al. 2002]. Rice is cultivated in more than 100 countries in the world. China is at first place in the cultivation of rice and India is on second place. India is basically an agriculture country and in India the production amount of biomass is plenty. So these different biomasses can be used to increase in demand of the electricity. Punjab produces about 11% of country's rice. 2% of world's rice is produced in Punjab. The rice husks from various rice mills are collected and then it will be transported to the rice husk processing plant. A special rice husk combustion unit generates steam and the rice husk ash is separated in hoppers. The main part of the steam is feed into a steam turbine generator set which generates electric energy. The electric energy is either partly used for the rice mill and for the rice husk processing plant and the main part of electric energy is sold to the public grid. Various types of technologies are used for the combustion process.

Different Combustion Processes for biomass are as

1. Fluidized Bed Combustion
2. Stoker Bed Combustion
3. Grate Technology

Proper technology must be selected base on the required cost, available fuel, required steam conditions, and emissions to be reached. BFBC technology is more advanced than other available technologies.

The numerous variables such as bed temperature, gas velocity, excess air, particle size distribution, bed and free board height that affect the combustion make the experimentation in full-scale furnaces very expensive. Therefore the best method to optimize the performance of furnaces is mathematical modeling.

II. Fluidization and Bubbling fluidized bed Technology

Fluidization is a well established fluid solid contacting technique. Fluidization is a process where the solid particles are transformed from a static solid like state to a dynamic fluid like state through contact with fluidizing medium like air.

Types of Fluidization Technologies:

1. Bubbling Fluidized bed Combustion
2. Circulating Fluidized bed combustion
3. Pressurized Fluidized Bed combustion

When the air velocity is gradually increased, a point is reached when the individual sand particles are forced to move upwards these particles begin to move about within a bed, which were supported by the air stream. With further increase in the air velocities the change occurs, due to the rapid mixing of the particles the bed becomes very turbulent. A bed of solid particles in this state is said to be fluidised, because it has not only the appearance, but also some of the properties of a boiling fluid. There are two limits of air velocity that is lower and upper limits between which fluidisation of sand will take place. The velocity of the air stream causing fluidisation is termed fluidising velocity.

In these days, bubbling fluidized bed is mostly used for small scale applications. Bubbling fluidized bed as a combustion method is suitable for wide range of fuels even those fuel that have low quality. Abrupt changes in fuel quality can be dealt with ease [Jokivirta, 2010]. Solids fluidization occurs when the air passes through a bed of solid particles at high velocity that is above the minimum fluidization velocity. . Primary air is injected through the bottom grid to fluidize the bed. Primary air is about thirty percent of the combustion air and the remaining air injected through the secondary and tertiary air ports above the furnace. The velocity of fluidising air is 1.2 m/sec at full load. Combustion temperature is typically between 800 and 950 ºC, and the usual bed temperature is 850ºC [Alberto and Pena, 2011].

Literature survey (combustion of rice husk and Modeling of fluidized bed reactors): Kataja and Majanne described a dynamic model of a bubbling fluidized bed boiler. Air flue gas model and a model for water steam circuit were described. In air flue gas model combustions processes in furnace were explained and in water steam model describes the heat transfer from the hot flue gases to water and steam, separation of the steam in drum section and super heating of the steam. By taking account of fuel quality parameters a versatile furnace model was prepared for the simulation of the effect of moisture, particle size and heat value. The validation of the model describe the static and dynamics gains very well of the process. Combustion efficiency was not dependent on the fluidization velocity and excess air but it would minor dependent on the temperature. With the increase in fluidization velocity the carbon mono oxide emission increases and it also increases with increase in temperature. Sulphur dioxide and nitrogen oxides had less emission than carbon mono oxide emission (Preto et al). The major differences between the two correlations were the shape factor and the minimum fluidization voidage. It was believed that if the wall effect was neglected, then the minimum fluidization voidage should depend only on the shape factor regardless of the diameter of the particle (Wen and Yu). The equation obtained from the two correlations was simple, gives great accuracy and also expressed in a convenient graphical form for a rapid estimation of the minimum fluidization velocity. The minimum fluidization velocity increases with the increase in the mass fraction of rice husk particles in the bed (Qiaoqun et al) and it was also found that the rice husk particles gives a lower fluctuation energy, while the sand particles had a higher kinetic energy of fluctuations. El-Halwagi and EL-Rifai studied the mathematical modelling of catalytic fluidized bed reactors-I. The multistage three-phase model. Development of the model for gas-solid fluidized bed catalytic reactors had been done. The three phase theory of fluidization had been developed by considering the fluid bed to be consisted of a number of equivalent stages in series. In three phase theory the bubble phase, cloud- wake phase and emulsion phase were described. Within each stage exchange of gas taken place between these three phases. Model parameters were expressed in terms of readily obtainable properties of bed. The validity of the multistage three-phase model was confirmed by the experimental data on reactant conversions and concentration profiles, and concluded that this model is useful for design and scale-up of fluid-bed reactors. The three phase theory of fluidization had been developed by considering the fluid bed to be consisted of a number of equivalent stages in series (Reddy and Mohapatra), in three phase theory the bubble phase, cloud- wake phase and emulsion phase were described. For shrinkage particles, the single film theory of char combustion had been considered by reaction of carbon with oxygen to produce carbon dioxide.

The conversion of oxygen in the fluidized bed combustion boiler plant decreases with the increase in the excess air. It was feasible to burn the rice husk in a fluidized bed reactor successfully and normally attained the high combustion efficiency (Natarajan et al). Bubbling velocity of husk was same as that of char and mixture and also observed that the fluidization behaviour of husk char was little better than that of char but not as good as that of ash. Fluidization of mixed husk, ash and char showed the poor movement of individual particles at low air velocities (Sen and Ghosh). Production of sulphur and nitrogen dioxide was reduced by using the low bed temperature up to 800°C. A solid population model was used to calculate the bed carbon load and carbon utilization efficiency. It was found that with the increase in the depth of bed the concentration of oxygen decreases and percentage of carbon dioxide increases. The problem found was the defluidization of bed exists which causes to stop the operation of the bed due to the agglomeration and the agglomeration was due to potassium, magnesium and sodium present in the rice husk (Singh et al).

III. Plant Detail

A 12.5 MW Satia Industries Ltd. (SIL) Plant, Shri Muktsar Sahib has been discussed with plant details, collection of samples and their analysis. The plant has been selected for the present study and the plant is based on biomass fuel. The combustion technology used in Satia industries ltd. is bubbling fluidized bed combustion technology. The plant is very friendly with the environment. Plant data was collected and analyzed in the laboratories. The plant is located at district Shri Muktsar Sahib because the area of Shri Muktsar Sahib is very helpful mainly for the two fuels i.e. rice husk and cotton.

Figure 3.2 shows the actual picture of atmospheric bubbling fluidized boiler at Satia industries ltd. where the combustion of fuel is done to obtained heat energy. All the main controls of plant like turbine parameters, boiler parameters and other performance parameters can be handled from single computer placed inside control room. . Any type of biomass rice husk, rice straw, baggase, tree chips, cotton waste, and cow dung cakes etc. can be used.

During the study period only rice husk is used at Satia Industries Ltd. Plant. The data collected with respect to rice husk from Satia industries ltd. is used to validate the exit gas composition model and the solid population balance model. Several difficulties like excessive heat near the furnace and too much noise was faced during the study. Biomass is the main fuel in the SIL plant. Rice husk is a biomass fuel which does not have considerable amount of sulphur in it. Therefore, the sulphur dioxide produced is within acceptable limits. The height of chimney is according to the terms of local pollution control board. The nitrogen dioxides produced in firing is also within acceptable limits. The design idea of the SIL project activity is in such a way of providing the energy with no contact on the environment.

Plant Parameters	Values
Boiler capacity	75 T/h
Type of bed	AFBC
Types of fuel used	Rice husk
Feed Rate of fuel (g/s)	5277.778
Air flow rate (cm^3/s)	25000000
Rate of steam generation (g/s)	18888.88
Main steam temperature (˚C)	490
Area of fluidized bed (cm^2)	194400
Type of distributor	Nozzle
Total no. of holes	3150
Bed voidage	0.48
Bed height at minimum fluidization (cm)	35
Average bed temperature (˚C)	810
Rice husk Density(g/cm^3)	0.12
Fly ash collector	ESP

Table 3.1 – Important Parameters of the plant

Figure 3.2 Fluidized bed combustion boiler at SIL.

IV. RESULTS AND DISCUSSIONS

The input data required for the models was taken from a 12.5 MW fluidized bed combustion plant at Satia Industries Limited, Shri Muktsar Sahib, Punjab, India details of which have been already explained. During the time of study, the plant uses the feed of rice husk in the combustor. The proximate analysis and ultimate analysis of rice husk fuel have been done and results are shown in Table 4.1. The physico-chemical parameters are taken from 12.5 MW plant. The model has been used to calculate the consumption of oxygen in the combustor, which makes it feasible to calculate the

PROXIMATE ANALYSIS		ULTIMATE ANALYSIS	
COMPONENTS	PERCENTAGE	COMPONENTS	PERCENTAGE

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Moisture	11.84%	Carbon	35.50%
Ash	16.27%	Hydrogen	5.85%
Volatile matter	56.44%	Sulphur	0.68%
Fixed carbon	15.45%	Oxygen	41.12%
		Nitrogen	0.58%

Table 4.1 Proximate and ultimate analysis of rice husk sample

gas composition outlet and variation of average oxygen concentration along with the height of the bed. The fraction of cloud wake phase has been used as changeable parameter and it is equals to 0.3. It can be seen that conformity between the real plant data and the simulated results is reasonably good and best results are obtained using $f_{cw} = 0.3$.

In Figure 4.1 the percentage of carbon dioxide and oxygen in flue gas with fraction of excess air is shown. The amount of combustibles available in the bed remains same due to which the percentage of carbon dioxide in flue gas decreases with increase in the fraction of excess air as shown in Figure 4.1. However the percentage of oxygen in the exit gas increases with increase in the fraction of excess air. Figure 4.2 show the variation of fractional conversion of oxygen with the excess air and Figure 4.3 show the variation of diameter of bubble with excess air. The fractional conversion of the oxygen is decreases with increase in the fraction of excess air as shown in Figure 4.2. As shown in Figure 4.3 there is increase in the diameter of bubble as the fraction of excess air increases. This is because of the reason that when the superficial gas velocity increases with increase in the fraction of excess air, then there is increase in the diameter of bubble.

With the increase in the bubble diameter, the oxygen conversion decreases. Also with the increase in the diameter of bubble, there is increase in expanded bed height. Figure 4.4 shows the variation of expanded bed height with the excess air. As shown in Figure, the expanded bed height increases with increase in excess air.

In Figure 4.5 the variation of diameter of the bubble versus moisture percentage is shown and it is clear from the Figure 4.5 that the diameter of bubble decreases when there is increase in the moisture percentage. As the fuel has different percentage of moisture content in it and during the rainy days the percentage of moisture in the fuel is quite high, which is not good for the efficiency of plant, because with high moisture contents in the fuel there is problems during burning of the fuel and also it will choke the feeder and also it leads to the agglomeration. Figure 4.6 shows the variation of expanded bed height versus the moisture percentage. The expanded bed height decreases with increase in the moisture percentage because with increase in the moisture percentage the diameter of bubble decreases which further results in decrease in the expanded bed height.

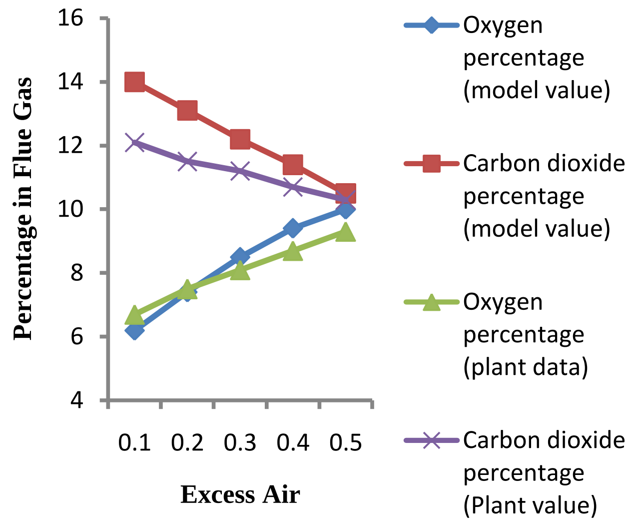

Figure 4.1 Variation of percentage in flue gases versus excess air

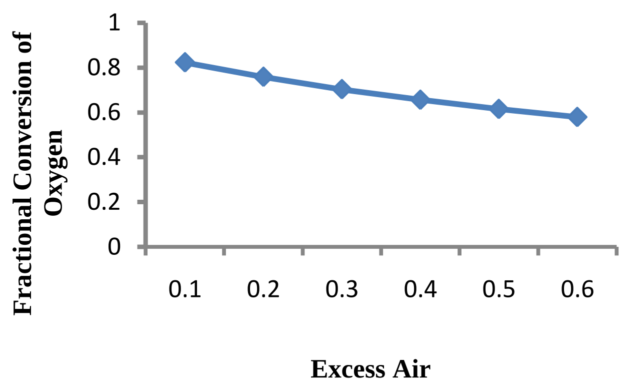

Figure 4.2 Variation of fractional conversion of oxygen versus excess air

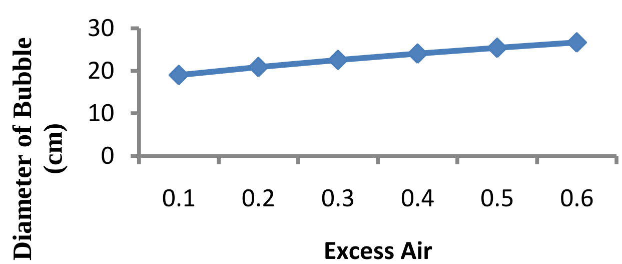

Figure 4.3 Variation of diameter of bubble versus excess air

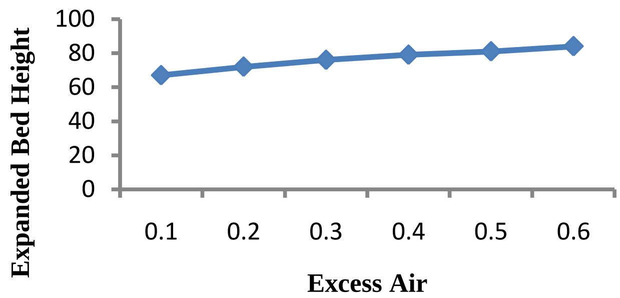

Figure 4.4 Variation of expanded bed height versus excess air

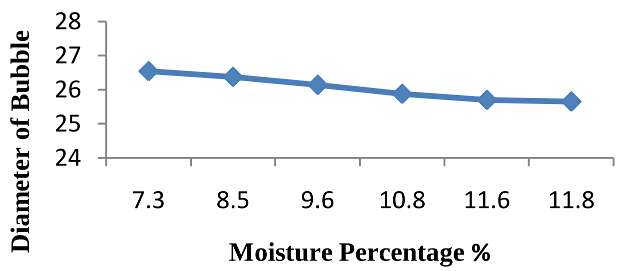

Figure 4.5 Variation of diameter of bubble versus moisture percentage

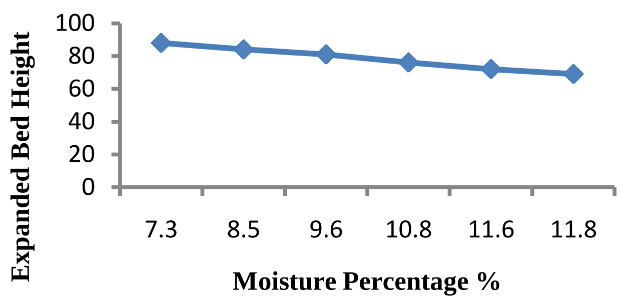

Figure 4.6 Variation of expanded bed height versus moisture percentage

V. Conclusions

- Percentage of Carbon dioxide in flue gas decreases with increase in the fraction of excess air. However the percentage of oxygen in the exit gas increases with increase in the fraction of excess air.
- With the increase in the diameter of bubble, the fractional oxygen conversion decreases.
- The expanded bed height increases with increase in the excess air.
- Bubble diameter increase with increase in the excess air.
- Diameter of bubble decreases with increase in the moisture percentage.
- The expanded bed height decreases with increase in the moisture percentage

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