Fluidization Characteristics of Tongo Gypsum in a Fluidized Bed Combustor

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***Abstract*— This work presents fluidization characteristics of Tongo gypsum, crushed and ground, particle sizes in a 'cold' fluidized bed combustor. Fluidization experiment was carried out in a test rig that consists of centrifugal fan, fluidized bed combustor, air suction blower, cyclone and filter. During the experiment, air flow rate and particle sizes were varied while quantity of Tongo gypsum particles collected were weighed. The aerodynamic parameters such as minimum fluidization velocity, Reynolds number, terminal velocity and fluidization velocity were deduce from the experiment using empirical corelations and fluid mechanics equations. The result of minimum fluidization velocity for gypsum particles size of 0.3 mm was 0.12 m/s. The Reynolds number obtained for Tongo gypsum particle size of 0.3 mm was 2.143 while 2.41 m/s and 0.681 m/s were obtained for terminal velocity and fluidization velocity, respectively. Tongo gypsum particle sizes range of 0.212 mm-0.3 mm respond well to changes of air flow rates during fluidization than particle sizes range 0.3 mm-0.412 mm and 0.412 mm-0.6 mm.**

***Index Terms*— fluidization, aerodynamic, particle size, bed materials.**

I. INTRODUCTION

Fluidization is a process in which bed of solid particles are suspended in a fluid by upward sufficient air velocity. Fluidization is when solid particles (fuel and inert material) placed on top of grate are blown from beneath, is lifted above grate and reciprocates in vertical plane. Initially, as air flows into perforated plate through bottom of bed, increase in air velocity gradually causes solid particles to begin to bubble and increase in volume and this is called incipient fluidization. When there is additional increase in air velocity, the solid particles mix with each other and the bed transform into fluid like boiling state called fluidization. The very large surface area of the fuel particles exposed to fluid (air) is an advantage during combustion and in heat transfer applications. Fluidization also implies vigorous mixing of solid fuel particle sizes and air to increase combustion efficiency of thermal power plant.

In fluidized bed combustor, particle sizes of bed materials exert a lot of influence on combustion processes and heat transfer [1]. The mean particle diameter for fluidized bed combustion ranges from 0.03-3 mm [2]. In addition, size grading and distribution of bed materials greatly affects combustion and heat transfer application [3]. The ease with which solid particle sizes fluidize and the operating condition that sustain fluidization depends on several factors; these factors are size and size distribution of solids, type of combustor geometry, gas inlet arrangement, and type of solid [4]. Solid fuels may vary in particle sizes from 2 mm to 6 mm depending on air flow rate and pressure of the fluidized bed combustor [4]. Biomasses and solid fuels crushed to less than 3 mm are common in fluidized bed [5]. Crushing, grinding and screening are processes to prepare solid fuel and bed materials to specific sizes to meet combustion requirements.

Nigerian bed materials are silica sand, limestone, ash, gypsum, zircon and ceramic but little information about their aerodynamic properties are known. Bed materials used in fluidized bed combustor are also controlled by drainpipe from air distributor through plenum [6]. The presence of sulphur in solid fuel will require use of calcium based bed materials such as gypsum, limestone or dolomite to remove sulphur [7]. The addition of gypsum at molar ratio of 20-30, can remove over 80% suphur in fuel [2]. Tongo gypsum *lotto* pits are located at Tongo town, along Gombe-Nafada road, in Funakaye local government of Gombe State, Nigeria. Gypsum is a soft material of about 1.5-2.0 on Mohr's scale, non-abrasive, non-toxic, non-radioactive and flame retardant with specific gravity from 2.5 to 3.5 [8].

The aim of this research is to experimentally fluidize Tongo gypsum and use empirical correlations to determine the aerodynamic properties of Tongo gypsum particles in a fluidized bed combustor.

II. METHODOLOGY

A. Fluidization Experiment

Fluidization test was conducted on crushed and ground gypsum particles using centrifugal fan that provided air into combustion chamber of the fluidized bed combustor through air distributor at the bottom of bed. The air lifts the solid particles, which filled up the combustion chamber. At certain air flow rate, the bed material particles elutriate out of freeboard to cyclone. The flue gas duct conveyed air, dust and particulates through to inlet of a cyclone. The shape and design of cyclone induces air to swirl while centrifugal force hurls dust and particulates to the cyclone walls where particles are slow down and settle out of air stream. Most dusts were collected into drum beneath the conical part of the cyclone. The fine dust and air exit upward out of the cyclone and extracted by suction blower into a filter. Clean air passes through the filter while fine dust and particulates are collected into a drum clamped to the open end of the filter as shown in Fig. 1.

The test was performed to determine the average height reached and total mass collected within a period by

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different particle sizes of gypsum at room temperature and to inspect quality of fluidization. The particle sizes were in three ranges namely 0.212 mm-0.3 mm; 0.3 mm-0.42 mm and 0.42 mm-0.6 mm. For each size tested, a given quantity of Tongo gypsum was introduced into the bed, the air flow rate was increased from 12 to 40 l/s and mass of the particles collected and quality of fluidization were observed. The rate of Tongo gypsum lifted was plotted against air flow rate for different sizes as shown in Fig. 2. The air flow from air distributor was uniform and there is good mixing of gypsum particles with air. With high quality of fluidization, smaller solid particles sizes results in higher heat transfer coefficient than coarse sizes [4]. Hence, aerodynamic parameters of Tongo gypsum were deduced from particle sizes of 0.212-0.3 mm instead of 0.3 mm-0.42 mm and 0.42 mm-0.6 mm.

B. Aerodynamic Parameters of Tongo Gypsum in Fluidization

The absorbent gypsum particle diameter ranges from 212 µm -600 µm in this work. Therefore, the air distributor orifice for gas inlet should not exceed $3d_p$ to avoid seepage into plenum where d_p is the particle diameter [9]. To achieve good fluidization, orifice diameter (air distributor) of 720 µm was selected [2].

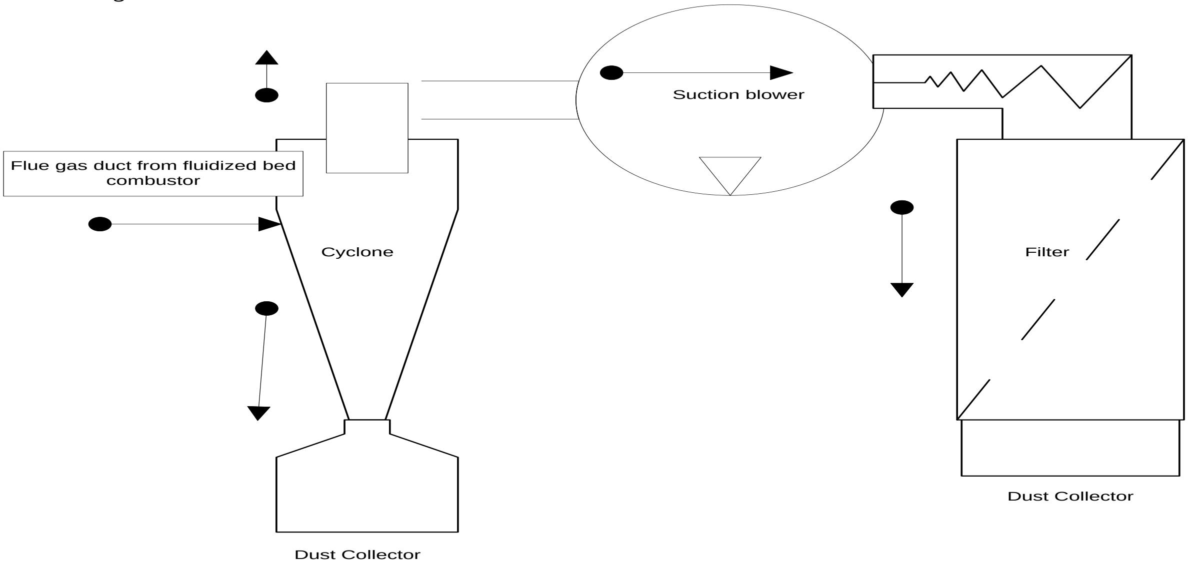

Fig. 1: Fluidization Test Rig.

a) Minimum fluidization velocity

The minimum fluidization velocity (U_{mf}) that corresponds to incipient fluidization beyond which bubbling fluidization sets is given as [10]:

$$U_{mf} = \frac{d_p^2(\rho_p - \rho_g)g(\varepsilon^3)(\theta^2)}{150\mu(1-\varepsilon)} \qquad (1)$$

where;

d_p is particle size of Tongo gypsum (average value of d_p =300 µm)

ρ_p is gypsum density = 2700 kg/m^3 [8]

ρ_g is air density at 30 ^{o}C = 1.2 kg/m^3

g is acceleration due to gravity = 9.81 m/s^2}

ε is voidage of gypsum particles = 0.54 [4]

θ is sphericity of gypsum particles = 0. 66 [4]

μ is air viscosity =2 x 10^{-5} kg/ms [4]

Substituting the values into (1):

$$U_{mf} = \frac{(0.0003^2)(2700-1.2)\times 9.81\times(0.54^3)(0.66^2)}{150\times 0.00002\times 0.46}$$

$$= 0.12\ m/s = 12\ cm/s$$

i. Reynolds number

The Reynolds number (*Re*) is given as:

$$\mathrm{Re} = d_p U_{mf} \rho_g/\mu \qquad (2)$$

Substituting the values into (2):

$$\mathrm{Re} = 0.0003\times 0.12\times 1.2/0.00002 = 2.143$$

b) Terminal velocity

If a particle falls freely under gravity in the atmosphere, it will accelerate until its velocity is such that drag exerted by surrounding air is equal to gravitational force. This is called terminal velocity (U_t), which for a sphere of diameter d_p is given as [2]:

$$U_t = \left[\frac{4(\rho_p - \rho_g)gd_p}{3\rho_g C_D}\right]^{1/2} \qquad (3)$$

where;

C_D is experimentally determined drag coefficient defined as [4]:

$$C_D = \frac{10}{Re_p^{0.5}} \text{ for } 0.4 < Re_p < 500$$

The relationship above expresses the variation of drag coefficient with Reynolds number.
Substituting for the expression of C_D into (3) and squaring both sides gives:

$$U_t^2 = \frac{4(\rho_p - \rho_g) g d_p}{3\rho_g (\frac{100\mu_g}{\rho_g U_t d_p})^{0.5}}$$

$$U_t^4 = \frac{16(\rho_p - \rho_g)^2 g^2 d_p^2}{9\rho_g^2 \left(\frac{100\mu_g}{\rho_g U_t d_p}\right)}$$

Simplify the equation.

$$U_t^3 = \frac{16(\rho_p - \rho_g)^2 g^2 d_p^3}{900 \mu_g \rho_g}$$

Substitute values to obtain U_t

$$U_t^3 = \frac{16(2700 - 1.2)^2 \times 9.81^2 \times 0.0003^3}{900 \times 0.00002 \times 1.2} = 13.91$$

$$U_t = 2.41 \; m/s$$

c) Fluidization velocity

The fluidization velocity (U_o) is determined using the relation [11]:

$$\frac{H}{H_{mf}} = 1 + \frac{10.978(U_o - U_{mf})^{0.738} \rho_p^{0.376} d_p^{1.006}}{U_{mf}^{0.937} \rho_g^{0.126}}$$

(4)

Bubbling fluidized bed has restriction suggested as [4]:

$$1.2 < \frac{H}{H_{mf}} < 1.4 \quad (5)$$

For the design, a value of 1.3 for the ratio $\frac{H}{H_{mf}}$ was selected [11] and U_o was found to be:

$$1.3 = 1 + \frac{10.98 \times (U_o - 0.11925)^{0.738} \times 2700^{0.376} \times 0.0003^{1.006}}{0.11925^{0.937} \times 1.2^{0.126}}$$

$$U_o = 0.681 \; m/s$$

The velocity ratio may be determined as follows:

$$\frac{U_o}{U_t} \quad (6)$$

Substitute values of U_t and U_o into (6):

$$\frac{U_o}{U_t} = \frac{0.681}{2.41} = 0.2826$$

III. RESULTS AND DISCUSSION

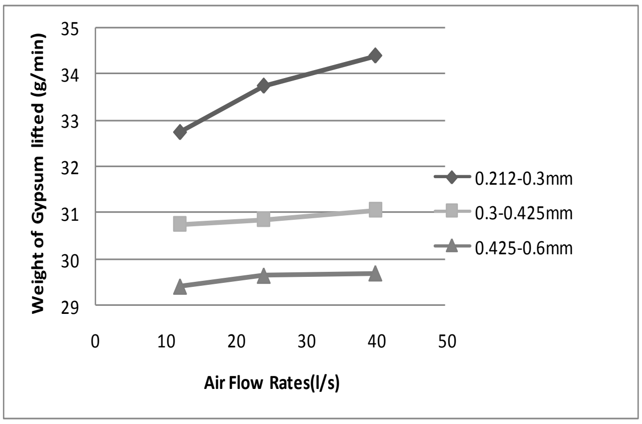

Fig. 2: Fluidization of Absorbent Bed Material (Gypsum).

The highest rate of ground Tongo gypsum lifted was observed for particle size ranging from 0.212 mm-0.3 mm at the air flow rate of 40 l/s. The decreasing flow rates of solid particles at higher particle sizes (0.3 mm-0.425 mm and 0.425 mm -0.6 mm) may be attributed to air-density ratio which also fluidize heterogeneously as shown in Fig. 2. The variation in the air flow rates were achieved by variation of damper valve (with operating knob) installed in transition pipeline from centrifugal fan. Table 1 shows aerodymic parameters of gypsum fluidization in the fluidized bed combustor. The minimum fluidization velocity of 0.12 m/s was obtained for Tongo gypsum particles as against 0.07 m/s obtained for rice husk [11]. The difference might be due free flowing of gypsum while rice husk is sluggish and liable to clump. The Reynolds number obtained was 2.143, which is less than 20, an indication of satisfactory minimum fluidization [4]. The ratio of fluidization velocity to terminal velocity was determined to be 0.2826, which is similar to a ratio of 0.3 for bubbling fluidized bed combustor [2].

Table 1: Aerodynamic parameters of gypsum fluidization

S/No	Description	Valve
1	Minimum fluidization	12 cm/s
2	Reynolds Number	2.143
3	Terminal Velocity	2.41 m/s
4	Fluidization velocity	0.681 m/s

IV. CONCLUSION

In this work, the aerodynamic parameters and fluidization experiment of Tongo gypsum in a fluidized bed combustor are presented. Gypsum enhances heat transfer with little degradation when use as bed material in fluidized bed combustor. The Tongo gypsum deposits apart from other uses can also be utilized along with Nigeria's over 4 billion coal deposits (excluding other solid fuels) in fluidized bed combustion power plant to provide needed electricity.

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