Influence of Internal Baffles on Mixing Characteristics of Biomass in a Fluidized Sand Bed

*K. N. Patil, Assistant Researcher
R. L. Huhnke, Professor
D. D. Bellmer, Associate Professor

Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, OK 74078
*Corresponding author email: krushna.n.patil@okstate.edu

ABSTRACT

The influence of coil, half-circle plate, and annular plate internal baffles on the mixing characteristics of chopped switchgrass in a sand fluidized bed was studied to increase biomass gasification efficiency. A cold fluidized bed model, dimensionally equivalent to a 250-mm (10-inch) internal diameter fluidized bed gasifier was used for this study. Chopped switchgrass was used at 1% by weight in the biomass-sand mixture. For each baffle type studied, the Mixing Index (MI), the ratio of local- to overall- concentration of chopped switchgrass in sand media, was determined along the bed height to define the quality of mixing. The bed without baffles showed distinctive segregation of chopped switchgrass particles (MI = 0.66 to 1.2). The annular plate baffle provided the best mixing of biomass (MI = 0.89 to 1.09) compared to coil (MI = 0.76 to 1.28) and half-circle plate (MI = 0.81 to 1.18) baffles.

Keywords: Fluidization, biomass, baffle, mixing index

1. INTRODUCTION

Segregation of low density biomass particles can occur in the reactor bed of fluidized bed gasifiers, resulting in excessively high temperature spots. Tests were conducted using a cold fluidized bed to study the fluidization characteristics of biomass-sand mixtures (Patil et al., 2005). The segregation of biomass particles on the top of the bed occurred due to major differences in the bulk densities of biomass and sand particles. Similar observations have been reported by other researchers who studied the fluidization of different low density biomass materials with sand (Pilar et al., 1992a and 1992b; Rao et al., 2001). Studies on the mixing characteristics of low bulk density biomass materials with sand also indicate segregation behavior of the biomass particles (Delebarre et al., 1994, Wu et al., 1997, Sun Qiaoqun et al., 2005). Biomass mixing can be a crucial factor in thermal reactors like fluidized bed gasifiers to maximize conversion efficiency while reducing the risk of agglomeration caused by localized high temperatures. Different types of internal baffles have been used to alter the fluidized bed characteristics, appropriate for different applications. Patterson (1975) studied the donut-shaped baffles for fluidizing petroleum coke, coal char and sawdust. The baffles were installed throughout the 58-inch height of an 8-inch diameter bed spaced 8-inch apart. Researchers reported better control of the fluidization while minimizing slugging. Horizontal screen-like baffles were used by Hartholt et al. (1997) to study the influence on mixing and segregation of an equal-density mixture of two types of glass ballotini having different surface mean diameters. Baffles were reported to be effective in de-mixing the mixture.

The primary objective of the present study was to determine the influence of coil, half-circle plate, and annular plate baffles on the mixing characteristics of biomass in a sand fluidized bed.

2. MATERIALS AND METHODS

2.1 Biomass Analysis

Switchgrass at approximately 10% wet basis moisture content was chopped using a Haybuster H-1000 tub grinder (DuraTech Industries International, Inc. Jamestown, North Dakota) with a 25-mm screen and placed into a storage container. Representative samples of chopped switchgrass were taken from the storage container, one each from the top, middle and bottom thirds. Two sieving setups were used. Biomass samples were first sieved using four screens with square openings having diagonal lengths of 5.4, 5.0, 4.6 and 4.1 mm. These screens were installed in a mechanical shaker (Screen Vibrator, Seedburo Equipment Company, Chicago, IL). The duration of sieving was set at 3 minutes. The material that passed through the fourth screen was subjected to particle size distribution using USA standard testing sieves (Nos. 7, 10, 12, 16, 25, 30, 50 and 100) for five-minute duration. Length, width, and thickness of the particles retained on each screen were measured manually with a digital caliper (Digimatic, Mitutoyo, Japan) having a resolution of 0.1mm. For bulk density determination, the chopped switchgrass samples were poured into a 473-ml container from 100 mm above and weighed. The bulk density was determined by dividing the weight of the biomass by the volume of the container.

2.2 Sand and Particle Size Analysis

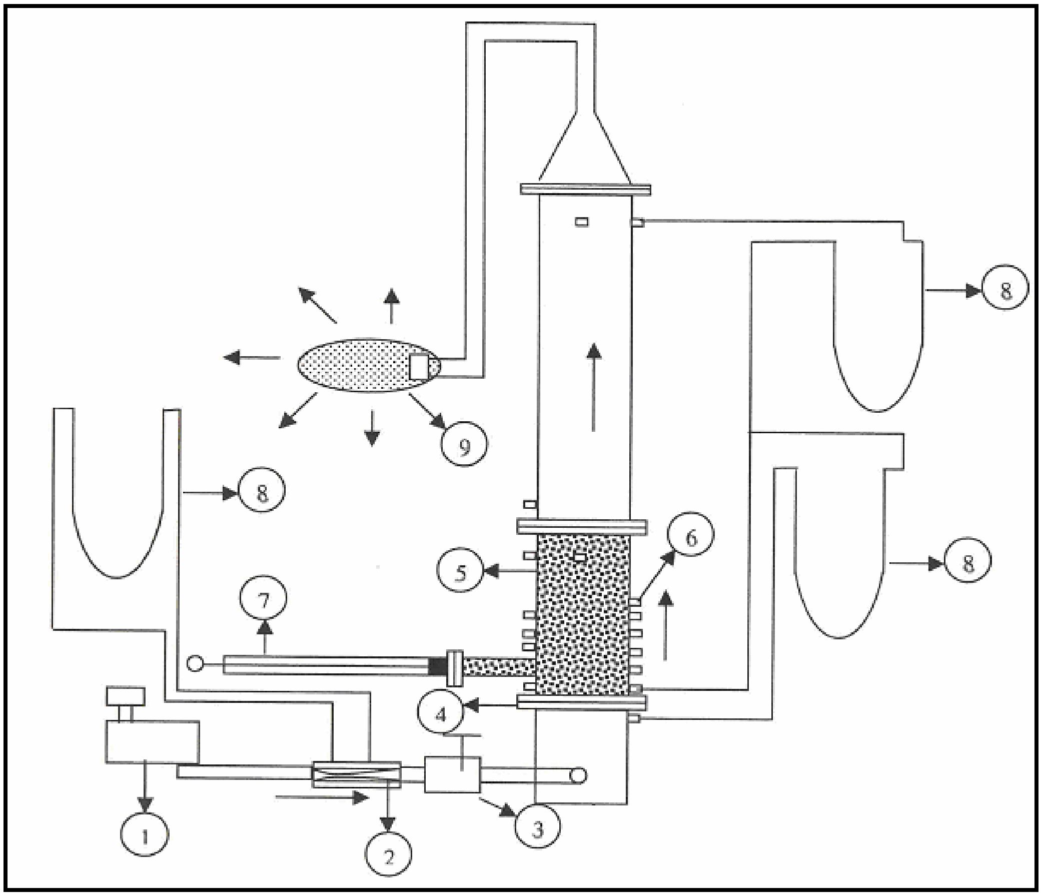
Silica sand (Oglebay Norton Industrial Sands, Inc., Brady, TX) was used in the study. Its particle size distribution was determined according to ASTM standard, ANSI/ASAE S319.3 JUL97 (ASAE, 2000). A motorized sieve shaker (CSC Scientific, Fairfax, VA) was used to automate the sieving process. The duration of sieving was set at five minutes. Geometric mean diameter (GMD) and geometric standard deviation of particle diameter by mass were calculated. Bulk density values were determined.

2.3 Fluidized Bed Setup and Baffles

A schematic of the transparent PVC cold fluidized bed used in the study is shown in Figure 1. The fluidized bed details are provided in Patil et al., 2005. It was dimensionally identical to a 250-mm (10-inch) fluidized bed gasifier being investigated at Oklahoma State University.

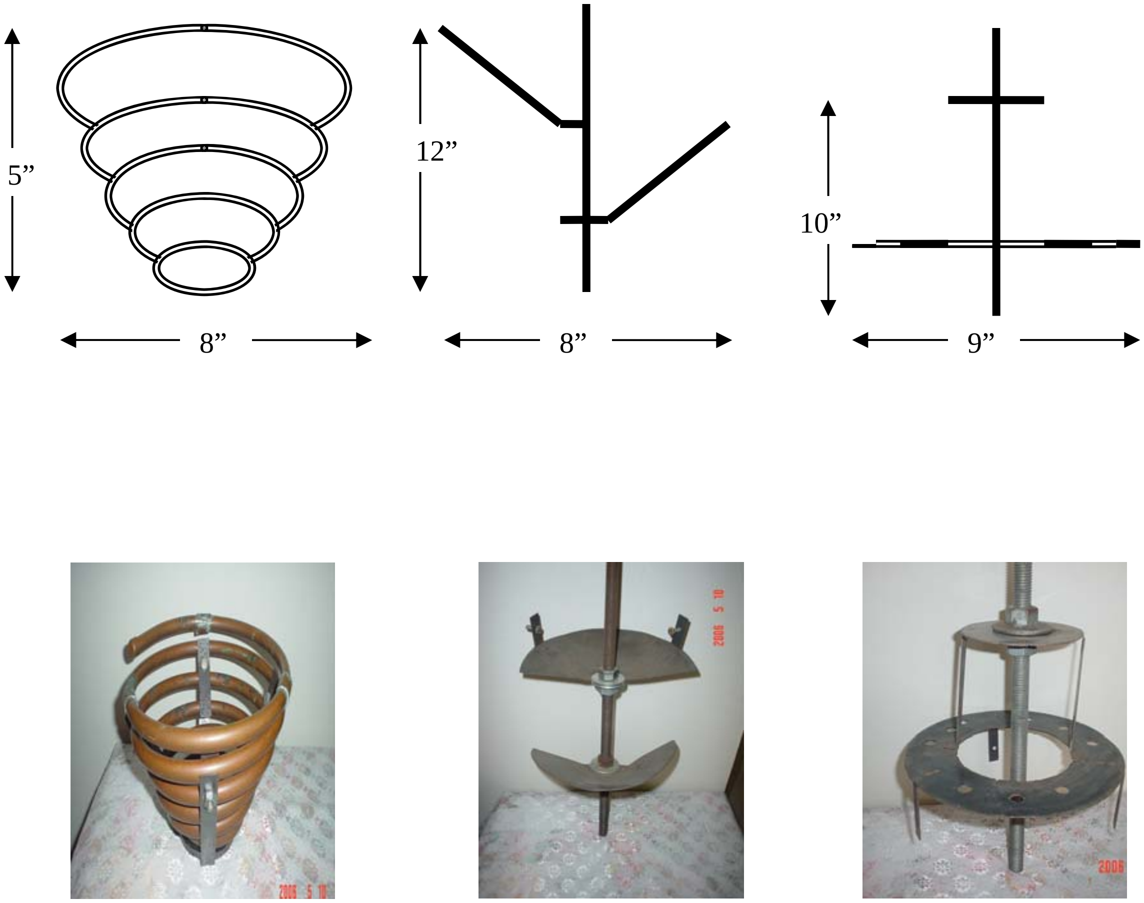
The major components of the experimental setup included a custom-made PVC fluidization column with a 5-mm thick bottom air distribution plate having 177 evenly spaced 2-mm diameter holes, ports for sampling of the bed material and for pressure measurements, an air blower (5HVF, Fuller company, Sutorbilt Products, Compton, CA) coupled to a variable frequency drive, differential pressure transmitters (PX274-30DI for pressure drop measurement), K-type thermocouple for temperature measurement, and a vacuum-cleaner filter bag (Great Value brand, Y-Type Microfilter) for capturing elutriated mass.

Three different baffle configurations were tested. The coil type baffle was identical in shape to the heating element employed in the fluidized bed gasifier. The configurations of half circle and annular plate type baffles were selected based on the test results on coil type baffle. The half circle baffle consisted of two half circled metal discs of 4” radius fitted on a central metal rod. The annular baffle was made of two circular metal plates fitted 4 “ apart on a central metal rod. Photographs and sketches of the three types of baffles studied are shown in Figure 2.



1. Electric blower with variable frequency drive and air filter, 2. Venturi meter, 3. Temperature sensor, 4. Air distributor, 5. Fluidized bed, 6. Ports for pressure, 7. Plunger based biomass feeder, 8. U-tube manometer, 9. Filter bag

Figure 1. Schematic of the Fluidized-bed Setup



Coil **Half-circle** **Annular plate**

Figure 2. Baffles used inside Fluidized bed Column

2.4 Test Procedure

The procedure adopted for fluidization tests was based on extensive review of similar work (Patterson, 1975, Delebarre et al., 1994, Hartholt et al. 1997, Wu et al., 1997, Patil et al., 2005). The minimum fluidization velocity of 45 cm/s was used having been determined in an earlier study (Patil, et al., 2005) for the biomass-sand mixture (200g of chopped switchgrass and 20 kg sand). The baffle to be studied was first fitted in the column. The column loading sequence of biomass and sand was based on how switchgrass feeding is accomplished in the fluidized bed gasifier, i.e. switchgrass enters immediately above the air distribution plate. Therefore, to replicate that situation, chopped switchgrass was first loaded in the cold fluidization column followed by silica sand.

To determine the appropriate duration for fluidization, a series of experiments was conducted at a fluidization velocity of 45 cm/s for 5, 10 and 15 minutes in duration. It was previously observed that at this air velocity, fluidization was intense and deemed satisfactory (Patil et al., 2005). The variation of bed pressure drop with change in air velocity is shown in Figure 3.

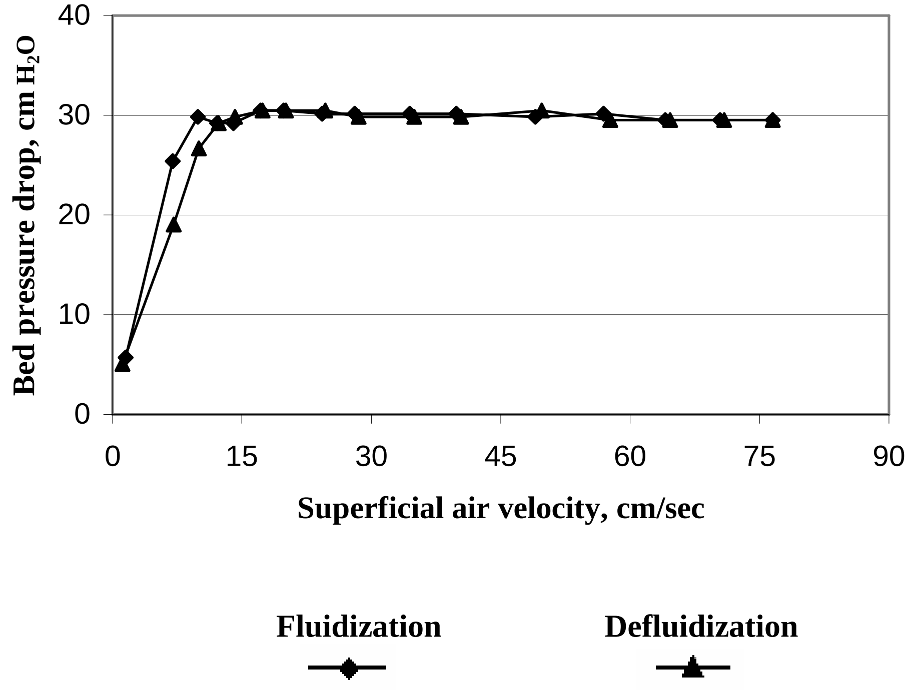


Figure 3. Air velocity-bed Pressure drop Curve for Switchgrass-sand (375 µm GMD) Mixture with 1% switchgrass) (Patil et al., 2005)

Fluidization for 5 minutes in duration was found to be sufficient to study the effect on mixing profile. Data recorded during the fluidization included the pressure drops across the bed and venturi, and temperature and humidity of air. Visual observations of the nature of fluidization and bed expansion were also noted. The air flow was abruptly stopped after 5 minutes to fix the mixture profile. The bed at rest was divided into three sections: the lowest being just above the distributor plate (0 - 7 cm), middle (7 - 16 cm), and top of the bed (16 - 25 cm). Material was removed from each section starting at the top of the bed using a vacuum pump. Depending on the baffle type, the sampling ports of the column at the middle and the bottom (above the air distributor plate) were also used to remove the bed material from the respective section. The material removed from each section and the elutriated masses collected in the filter bag at the exit were analyzed for proportions by weight of the two components i.e. biomass and sand. Mixing Index (MI), defined as the ratio of local to overall concentration of biomass in the mixtures was used as a defining parameter for the quality of mixing. A MI value of 1.0 indicates perfect mixing.

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution and Physical Properties of Chopped Switchgrass and Sand

The percent weight distribution and physical properties of chopped switchgrass are shown in Table 1. Approximately 60% (by weight) of the material had a particle length of about 17 mm, 37 % ranged from 1.0 mm to 14.7 mm, and the remaining 3% powdery mass. The average bulk density for the chopped switchgrass was 138 kg/m^3. The sand geometric mean diameter was 375 μm with a standard deviation of 1.48. The sand bulk density was 1596 kg/m^3.

Table 1. Percent Mass Distribution and Physical Properties of Chopped Switchgrass

Screen No.	Sieve opening diagonal length, mm	Total on screens[a] % mass	Cumulative undersize % mass	Length[b], mm	Width[b], mm	Breadth[b], mm
1	5.4	1.03	98.97	27.2 ± 11.2	2.78 ± 1.34	1.24 ± 1.16
2	5	59.25	39.72	17.2 ± 8.8	1.93 ± 1.10	0.62 ± 0.54
3	4.6	0.94	38.77	17.2 ± 7.9	1.25 ± 0.83	0.29 ± 0.21
4	4.1	3.81	34.96	11.0 ± 6.6	0.73 ± 0.57	0.22 ± 0.16
5	3.95	0.34	34.62	14.7 ± 6.8	0.58 ± 0.51	0.18 ± 0.12
6	2.83	3.24	31.38	7.8 ± 4.5	0.44 ± 0.37	0.15 ± 0.09
7	2.36	2.13	29.24	5.9 ± 3.5	0.56 ± 0.47	0.20 ± 0.16
8	1.68	4.01	25.24	4.5 ± 2.5	0.36 ± 0.37	0.15 ± 0.10
9	0.99	11.49	13.75	2.6 ± 1.6	0.29 ± 0.25	0.14 ± 0.11
10	0.85	3.95	9.8	3.0 ± 1.0	0.27 ± 0.22	0.10 ± 0.02
11	0.42	6.9	2.91	2.2 ± 1.0	0.30 ± 0.22	0.12 ± 0.04
12	0.21	2.28	0.63	Not measured	Not measured	Not measured
Pan	0	0.63	0	Not measured	Not measured	Not measured
Total		100				

[a] average of 3 observations; [b] average of 75 observations

3.2 Mixing Characteristics for each Baffle Configuration

Mixing Index (MI) values obtained are shown in Figure 4. Without a baffle, fluidization of switchgrass-sand bed resulted in most of the chopped switchgrass particles migrating to the bed top (MI = 1.2) while a low concentration of switchgrass particles were located at the bottom (MI = 0.66). Similar observations regarding the segregation of biomass particles on the top of the fluidized bed were previously reported (Patil et al., 2005). This phenomenon occurs due to the density difference between biomass and sand particles. Among the three baffles studied, the annular plate showed the best performance in terms of developing the bed with comparatively more uniform concentration of switchgrass particles throughout the bed height. MI values obtained for the annular baffle varied from 0.89 at the bottom to 1.09 at the top. No major segregation of switchgrass particles was observed. Studies by Patterson (1975) on the baffles of donut shape, reported similar observations about the absence of segregation of the light particles at the bed top. For the coil baffle, MI values varied from 0.76 in the bottom section to 1.28 in the top. In this case, the biomass particles which traveled to the bed top through the conical coil structure were unable to recirculate to the bottom of the bed. As a result, segregation of biomass particles occurred at the bed top. The half-circle plate baffle slightly improved mixing results compared to the coil plate (MI = 0.81 at the bottom and 1.18 at the top). Recirculation of particles occurred only in flows below both plates. Recirculation of solid particles within each stage of horizontal screen-like baffles is also reported by Hartholt et al. (1997).

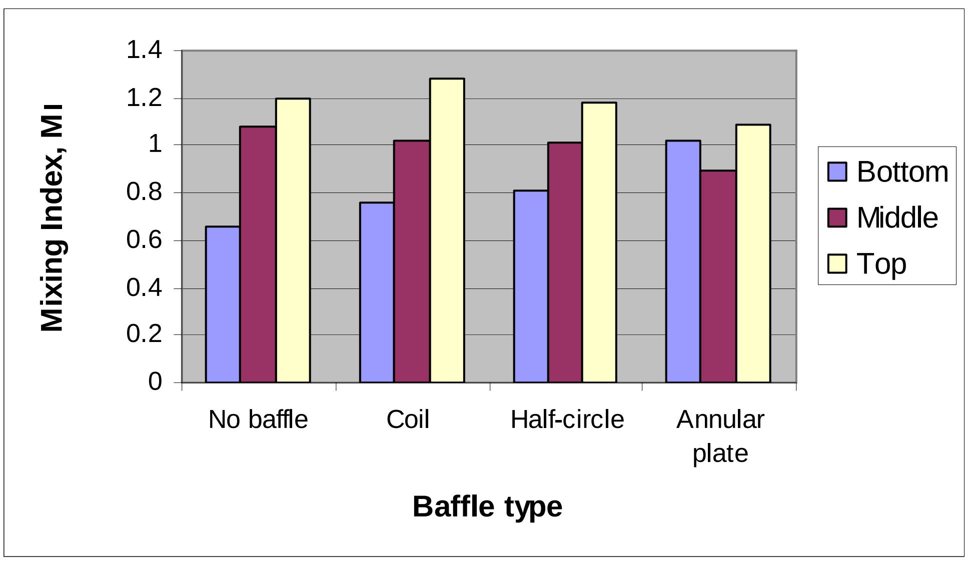


Figure 4. Mixing Index for Fluidization Column with no Baffle and at 3 different Baffle Configurations with a Minimum Fluidization Velocity of 45 cm/s and 5 minute Testing time

Table 2 provides the mean mixing index for each section based on three experiments for each baffle type. As shown, the annular plate baffle performed better, with MI closer to 1.0 at both the top and bottom sections. Statistically, the MI for the annular plate was significantly different from all other baffle configurations at both the middle and bottom of the bed. The fact that the annular plate showed superior mixing at the bottom is especially important because biomass enters this section in the fluidized-bed gasifier.

Table 2. Mean Mixing Index for fluidization column with no baffle and at 3 different baffle configurations with a minimum fluidization velocity of 45 cm/s and 5 minute testing time

	Top	Middle	Bottom
No baffle	1.20 [a]	1.08 [a]	0.66 [a]
Coil	1.28 [a,b]	1.02 [b]	0.76 [a,b]
Half-circle	1.18 [a,b,c]	1.02 [b]	0.81[b]
Annular plate	1.09 [c]	0.89 [c]	1.02[c]

[a,b,c] Means followed by the same letter are not statistically different within columns at the 0.05 level using a paired t-test.

4. CONCLUSIONS

A fluidized bed model was used to study the influence of internal baffles on the mixing characteristics of biomass and sand in a fluidized bed. The baffle types were coil, half-circle plate, and annular plate. To measure quality of mixing, a Mixing Index (MI - the ratio of local to overall concentration of chopped switchgrass in sand media) was used where an MI = 1.0 is an ideal condition. Based on test results, the following conclusions were developed:

1. Fluidization of the switchgrass-sand bed without baffles resulted in particle separation. Most of the switchgrass mass accumulated on the bed top where MI = 1.2.
2. Internal baffles were effective in altering the fluidization of biomass-sand mixtures.
3. Of the baffles tested, the annular plate showed the best performance (MI = 0.89 at the bottom of the bed and 1.09 at the top).
4. Both coil and half-circle plate baffles caused staged recirculation of the biomass-sand mixture, resulting in the formation of localized high concentrations.

5. ACKNOWLEDGEMENTS

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