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MIXING OF FUEL PARTICLES IN A FLUIDISED BED OF SAND

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ABSTRACT

The mixing of rice hulls and lignite particles in a shallow fluidised bed of sand has been studied. The experiments were carried out at room temperature in a 2.4 x 1.2 m^2 fluidised sand bed having sparged tubes as the air distributor. Two sizes of sand with static bed height of 0.23 m were used. A layer of fuel particles (0.5 x 0.6, about 1% of bed weight) was placed on the bed surface adjacent to the 1.2 m wall. After air introduction, concentration profiles of fuel in the upper and lower sections of the bed were determined as a function of time by direct sampling. The results showed that the completely mixed state of fuel particles within the bed was obtained in about 7-12 minutes depending on superficial velocity of fluidising air. The fuel types have insignificant effect on the mixing time. The effective dispersion coefficient of fuel particles in the bed, which can be used in designing the fuel feeding system for a fluidised bed combustor, were also estimated.

INTRODUCTION

Mixing and dispersion of fuel particles can have a direct influence on the performance of a fluidised-bed combustor. The high concentration of fuel near the feed point will cause excessive combustion of volatiles in the bed/freeboard as well as the formation of CO due to insufficient supply of oxygen. Oxygen depletion and CO formation effect both combustion and sorbent utilisation efficiencies [1]. The distribution of fuel mass also dictates the number and location of feed points in large-scale combustion units.

Previous investigation based on various tracer techniques [2-6] have shown that mixing of solid particles in gas fluidised beds is governed by the lateral movement of solids, which could be described by the diffusion model. The estimated dispersion coefficient was found to depend significantly on gas velocity, static bed height, and sizes of fuel particles and bed material. These parameters were believed to affect the sizes and growth of bubbles which contribute to particle mixing. However, most of this work was restricted to experiments on small-scale units and fuel particles of relatively small sizes. This paper presents results of a cold-model experiment on the mixing of rice hull and lignite particles in an industrial-scale fluidised bed. This work was performed to support our project on fluidised bed boiler for steam production [7].

THEORY

There has been ample evidence that solid mixing in the axial direction is much greater than lateral mixing. Because of the random motion of solid particles, it is customary to approximate lateral dispersion by the one-dimensional model [8]. Figure 1 shows a schematic diagram of the model. The inherent assumptions are that the tracer concentrations are uniform over the whole height of the bed and that there is no convective transport in the lateral direction. The model equation can be described as :

$$\frac{\partial C}{\partial t} = D_s \frac{\partial^2 C}{\partial x^2} \tag{1}$$

Initial and boundary conditions are :

$t = 0, \quad 0 \leq x \leq L_0, \quad C = C_0$

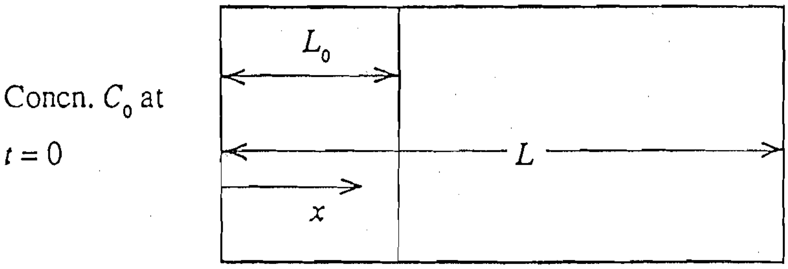


Fig. 1. Schematic diagram of one-dimensional diffusion model.

$t = 0, \quad L_0 \leq x \leq L, \quad C = 0$

$t \geq 0, \quad x = 0 \text{ and } x = L, \quad \partial C/\partial x = 0$

The analytical solution to Eq. (1) is

$$\frac{C}{C_0} = \frac{L_0}{L} + \frac{2}{\pi} \sum_{n=1}^{\infty} \left[\frac{1}{n} \sin\left(\frac{n\pi L_0}{L}\right) \cos\left(\frac{n\pi x}{L}\right) \exp\left(-n^2\pi^2 D_s t/L^2\right) \right] \tag{2}$$

where C_0 and C are the concentration of fuel in terms of weight fraction at $t = 0$ and t, respectively, D_s = dispersion coefficient, L_0 = bed section that has the fuel concentration of C_0 at $t = 0$, L = total bed length, t = time, and x = distance in the direction of bed length.

If experimental concentration data were fitted with Eq. (2), the appropriate value of dispersion coefficient (D_s) could be estimated.

According to the work of Salam *et al* [8], the following correlation was proposed for the dependence of coal dispersion coefficient on bed conditions and characteristics :

$$D_s = 0.91 \left[\frac{U - U_{mf}}{U_{mf}}\right]^{1.16} H^{0.54} \left[\frac{d_p}{d_s}\right]^{0.25}, \ cm^2/s \tag{3}$$

where U = gas superficial velocity (cm/s), U_{mf} = minimum fluidization velocity (cm/s), H = static bed height (cm), d_p = particle size of fuel (cm), and d_s = particle size of sand (cm).

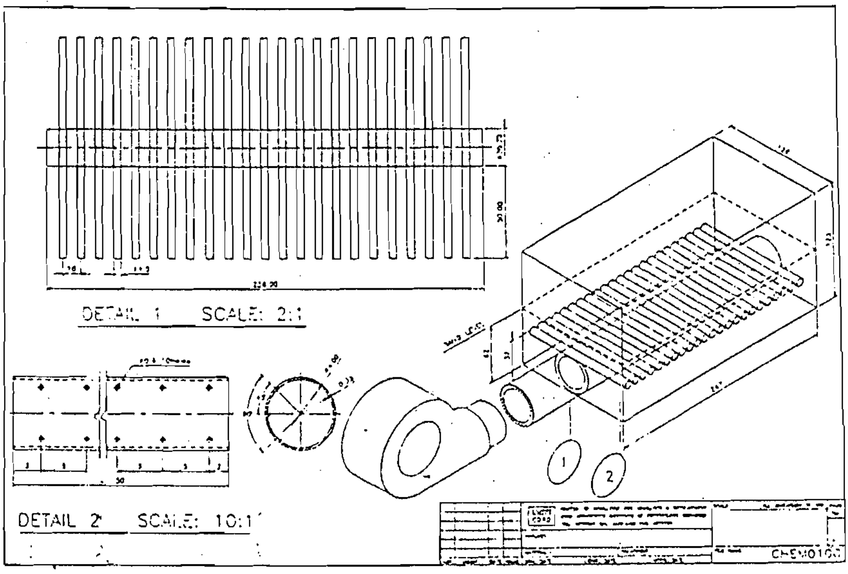
APPARATUS AND PROCEDURE

A schematic arrangement of experimental apparatus is shown in Figure 2a. The fluidised bed consisted of a rectangular vessel of dimensions 1.2 x 1.2 x 2.44 m, fabricated from plywood sheet with two front glass windows for bed observation. Air was supplied by a centrifugal blower (30 hp) and entered the bed through a sparger-type air distributor, as shown in Figure 2a. The distributor consisted of arrays of PVC tubes (3.75 cm dia.) with two rows of air outlet holes underneath (6 mm dia. at 45° from horizontal centre line) spaced at 5 cm distance. Rice hull and lignite were used as fuel particles and two sizes of sand were used as bed material. Two air velocities (0.39 and 0.56 m/s) were selected for running fine sand and one air velocity of 0.56 m/s for coarse sand conditions. Test conditions are summarised in Table 1.

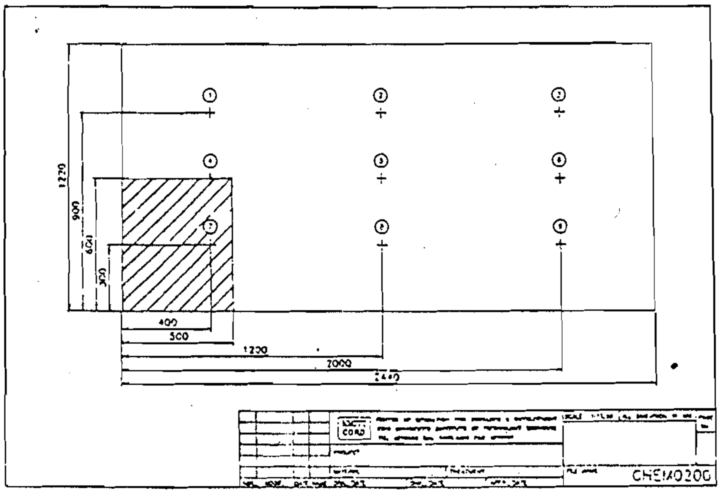
TABLE 1
EXPERIMENTAL CONDITIONS

FUELS	
Lignite :	
mean diameter	9.9 mm
bulk density	104 kg/m³
Rice hull :	
mean diameter	1.63 mm
bulk density	840 kg/m³
BED MATERIAL	
Fine sand :	
mean diameter	0.373 mm
density	2600 kg/m³
Coarse sand :	
mean diameter	0.554 mm
density	2600 kg/m³
Static bed height	23 cm
Min. fluidising velocity	
fine sand	0.177 m/s
course sand	0.303 m/s

Known weight of fuel, ~~0.05~~ 0.7% bed wt. for rice hull and 2.0% for the case of lignite, were placed on the bed surface forming a layer of 50 x 60 cm next to the 1.2 m wall (Figure 2b). The bed was brought to fluidised state by permitting the air in at a set flow rate. At the end of a selected time interval, the air flow was stopped and a sampling tube was vertically inserted into the bed from the top surface down to the distributor position. The sample taken was divided into upper-half and lower-half sections, each of which were analysed for fuel concentration by screening and weighing. Samples were taken at nine locations, as indicated in Figure 2b, to determine the axial and lateral distribution of fuel in the bed.



(a)



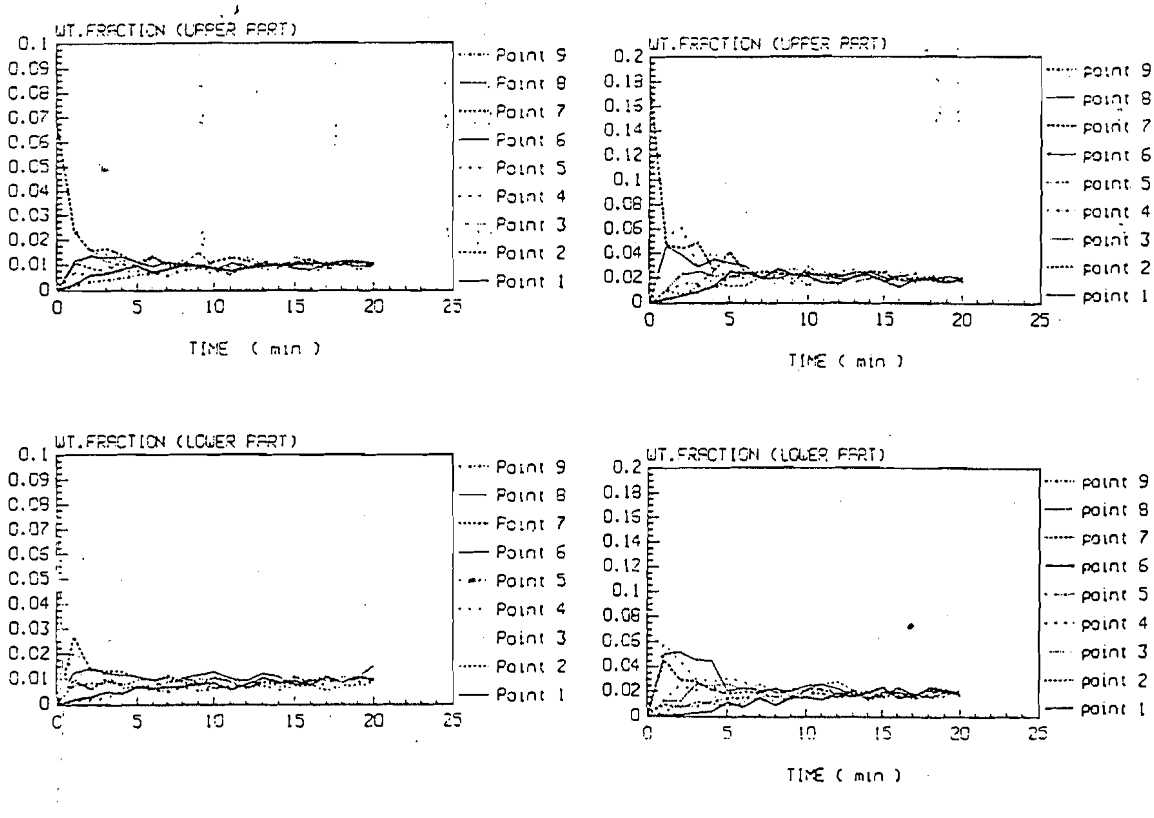
(b)

Fig. 2. Schematic diagram of (a) experimental apparatus and (b) locations of fuel layer and sampling points.

RESULTS AND DISCUSSION

Figure 3 shows typical concentration variation of rice hull and lignite particles as a function of time for the upper-half and lower-half sections of the bed. In general, the variation pattern follows the expected trend, i.e. the concentration decreases with time in the supply zone (the sampling points 1, 4, 7) and increases with time for the remaining points outside this region. As time proceeds, all the curves eventually attain a final fully-mixed concentration at approximately 7 minutes, seemingly independent of fuel type. The results from all test conditions showed that the completely mixed state of fuel particles within the bed was obtained in about 7-12 minutes depending on fluidizing velocity and sand size. It was observed that fuel concentration at each location in the upper and lower zones are almost the same, indicating rapid mixing in the axial direction of the bed. Since the concentration also appears to be uniform across the bed width (positions 2,5,8 for example), it is therefore concluded that for the rectangular fluidised-bed (length:width = 2:1) operated within the conditions tested, the mixing of the fuel particles depends only on the lateral movement of solids.

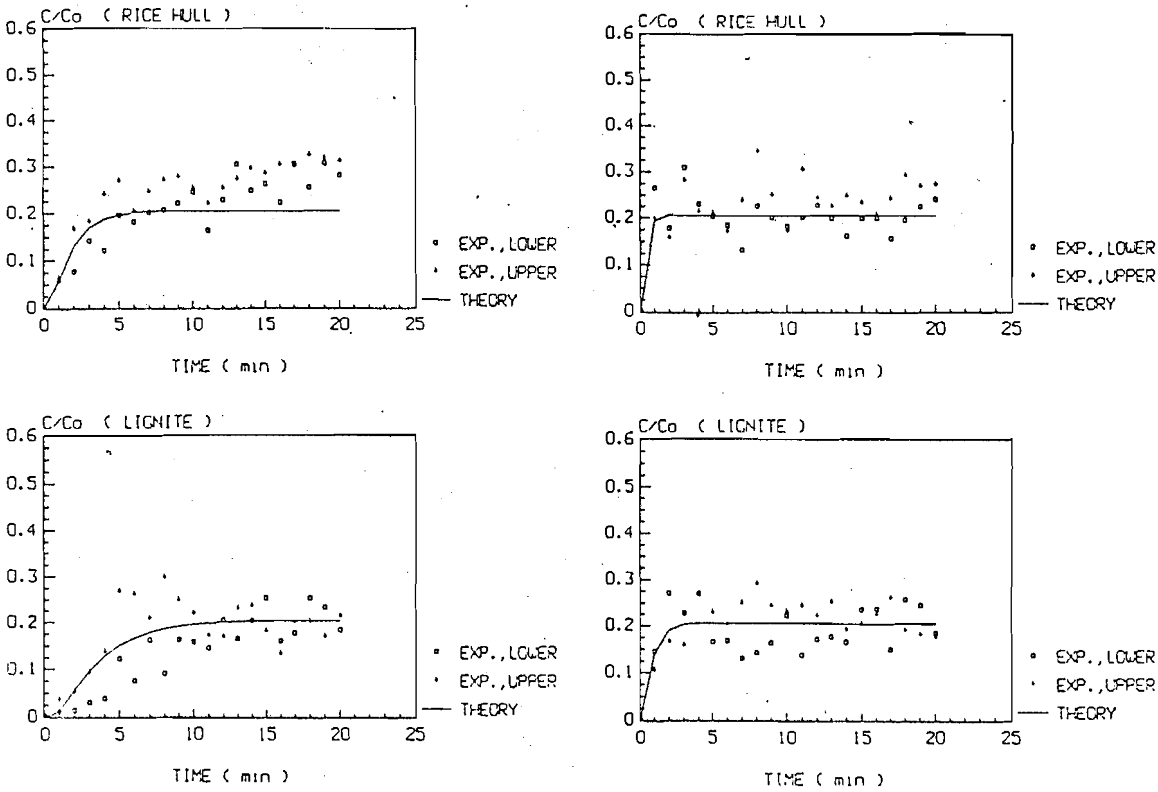
Since the motion of particles is a random process, the one-dimensional diffusional model (Eq.1) may be used to describe the lateral dispersion of fuel particles. A least square fit computer program based on Hook & Jeeps search method was used to estimate the solid diffusion coefficient (D_s) from Eq. (2) utilising experimental data from position 6. Figure 4a compares the normalised solid concentration (C/C_0) between experimental and model prediction based on estimated value of D_s. The agreement is reasonable within experimental accuracy. The derived D_s was then used to predict fuel concentration



(a)

(b)

Fig. 3. Weight fraction of fuel particles in upper and lower parts of bed for the case of fine sand and $U = 0.56$ m/s: (a) rice hull and (b) lignite.



(a)

(b)

Fig. 4. Comparison of fuel concentration between experiment and theory for the case of fine sand and $U = 0.56$ m/s: (a) point 6 and (b) point 5.

at position 5 as presented in Figure 4b. The experimental points show random fluctuation around the predicted curves, proving the validity of model estimation.

Experimental values of D_s are compared with predicted values in Table 2, and plotted with respect to U/U_{mf} in Figure 5. The experimental values of D_s are comparable to those reported by other investigators [8,9]. As expected, D_s increases with fluidising air velocity. For a fine sand bed, rice hull gives a higher D_s as compared to lignite particles, which may be attributed to the greater density difference between the fluidised bed and rice hull. As a result, rice hull is more effectively dispersed by the sand movement. Similar reasoning could probably be used to describe better mixing action of lignite particles in the coarse sand bed of which the bulk density has a higher value than that of the fine sand bed. Furthermore, the formation and behaviour of bubbles in gas fluidised beds of different sand size could also affect the lateral mixing of fuel particles. The values of D_s estimated from Eq. (3) proposed by Salam *et al* [8] for coal mixing in a fluidised bed using a bubble-cap air distributor are lower than the experimental values in all cases. This is probably due to the application of Eq. (3) to predict D_s for the fluidised system using a different type of air distributor in the extrapolated range of coal sizes. However, the prediction for coal is much better than for rice hull, especially for fine sand conditions. This may be due to the ambiguous definition of mean diametre for rice hull particles which have a long narrow shape, as compared to a more rounded shape for coal particles.

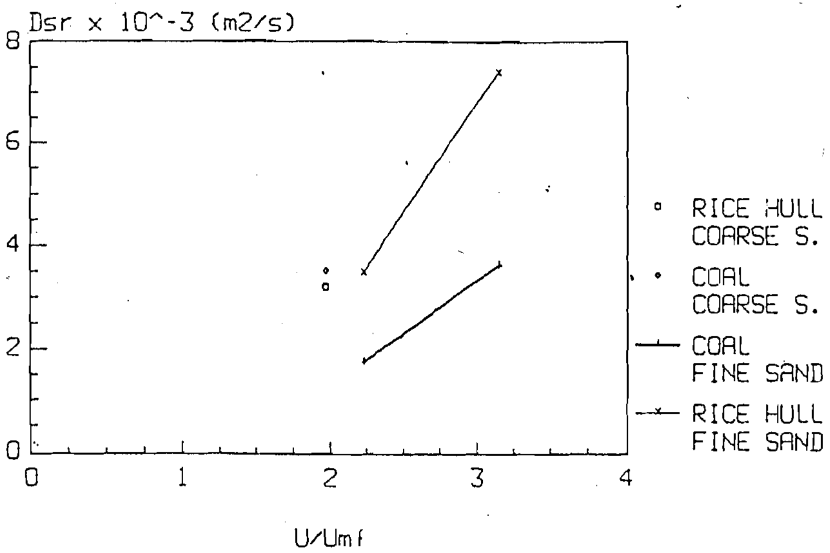


Fig. 5. Dispersion coefficient as a function of U/U_{mf}.

TABLE 2
COMPARISON OF EXPERIMENTAL AND PREDICTED DISPERSION COEFFICIENTS OF FUEL PARTICLES IN FLUIDISED BED OF SAND

	Gas velocity m/s	Dispersion coefficient, x10^{-3} (m^2/s)	
		Experiment	Prediction [Eq.(3)]
Fine sand			
Rice hull	0.39	3.47	0.91
	0.56	7.38	1.74
Lignite	0.39	1.74	1.44
	0.56	3.60	2.73
Coarse sand			
Rice hull	0.59	3.17	0.62
Lignite	0.59	3.48	0.99

CONCLUSIONS

The lateral movement of fuel particles in a fluidised bed of sand is considerably (for s slower than the axial direction. This lateral movement can be reasonably described by a one-dimensional diffusion model. The estimated values of the lateral dispersion coefficient increase with fluidising air velocity and are within the same order of magnitude with those reported in the literature. The effect of sand size on D_s was also observed. The results from this study can be used to design the suitable feed point for large-scale fluidised bed combustors.

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