

A COLD MODEL STUDY OF EROSION IN A GAS FLUIDIZED BED OF SAND

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ABSTRACT

The erosion of tubes placed at various positions in a cold model of a gas fluidized bed of sand was studied. The bed, with a 23 cm static height of sand, has a cross sectional area of $2.44 \times 1.2 \text{ m}^2$. The fluidizing air is introduced into the bed through a sparger-type air distributor. PVC tubes were used as sample tubes in order to reduce the testing time. Both in-bed and over-bed tubes are placed horizontally. Results showed that the erosion rate of in-bed tubes is significantly higher than the over-bed tubes and tube wall. The position of significant erosion occurs at the bottom part (circumferential angle of 90° and 270° from the vertical centre line) for both in-bed and over-bed tubes, while the sparger tube shows the significant erosion at the top part (circumferential angle of $0-90^\circ$ and $270-360^\circ$ from the vertical centre line). The tube wall was found to have maximum erosion rate at the fin tip. An increase in sand size also enhances the erosion rate. Based on hardness property and the cold model results, the estimated maximum erosion rate is about 0.1 mm per year if stainless steel (304) and conventional boiler tubes are used.

1. Introduction

Fluidized bed combustion has been recognised as an efficient technique for burning low-grade coal with environmentally acceptable emissions. The heat generated inside the bed is normally extracted by immersion tubes that contain water or steam. Problems caused by the high wastage rate of these in-bed tubes have been reported in the literature and summarised by Stringer [1]. He also reviewed the causes of tube wastage, the possible variables

affecting metal wastage, and methods for reducing the wastage rate. High erosion rate was also noted in the splash zone, where bed solids ejected from the surface hit neighboring bed components [2]. While the wastage processes of metal within a bed are not well understood, it seems likely that this is due to erosion/abrasion rather than corrosion [1-2]. It was thus suggested that research on corrosion problems be de-emphasized in favour of increased study of erosion. As reviewed by Jansson [2], the cold model test of erosion is extensively used

by researchers to study the effects of fluidizing velocity, type and size of bed material, and in some cases also tube arrangement in a fluidized bed [3].

This paper presents the results of a study on tube erosion in a cold model of a gas fluidized bed equipped with a sparger-type air distributor. The effect of sand size on the erosion rate is also studied.

2. Apparatus And Procedure

Figure 1 illustrates the fluidized bed

used in this study. It was constructed from plywood sheet having dimensions of 1.2x1.2x 2.44 m, 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 1. The distributor consisted of arrays of PVC tubes (4 cm dia.) with two rows of air outlet holes underneath (6 mm dia. at 135° and 225° from vertical centre line) spaced 5 cm apart.

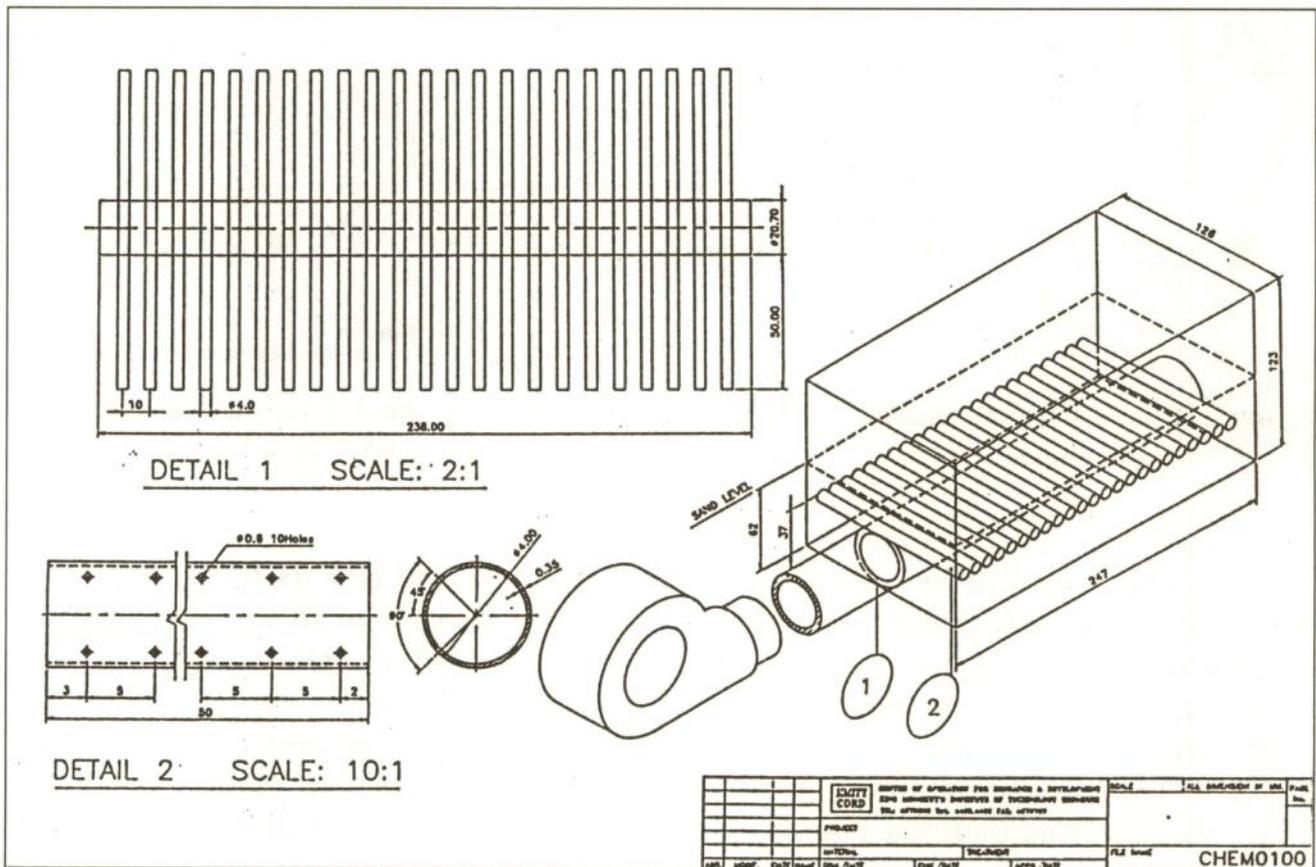


Figure 1. Schematic diagram of the cold fluidized bed test system.

Three samples of PVC tube with 4 cm dia. and 50 cm length were perpendicularly connected to the vertical tube wall by using standard tees (Fig. 2). The tube wall was fabricated from 2 PVC tubes (4 cm dia.) welded to each side of the angle PVC strip (120°). On each sample tube, a removable section (8 cm long) which was tightly fixed during the experiment, was provided at the middle of the tube

for thickness measurement at specific time intervals, while a 3 cm length was provided for the tube wall. One of the air distributor tubes at the middle of the array was also selected and fitted with a 8 cm removable section, as described previously. These removable numbered sections and their placement are represented by the shaded area, as depicted in Fig. 2.

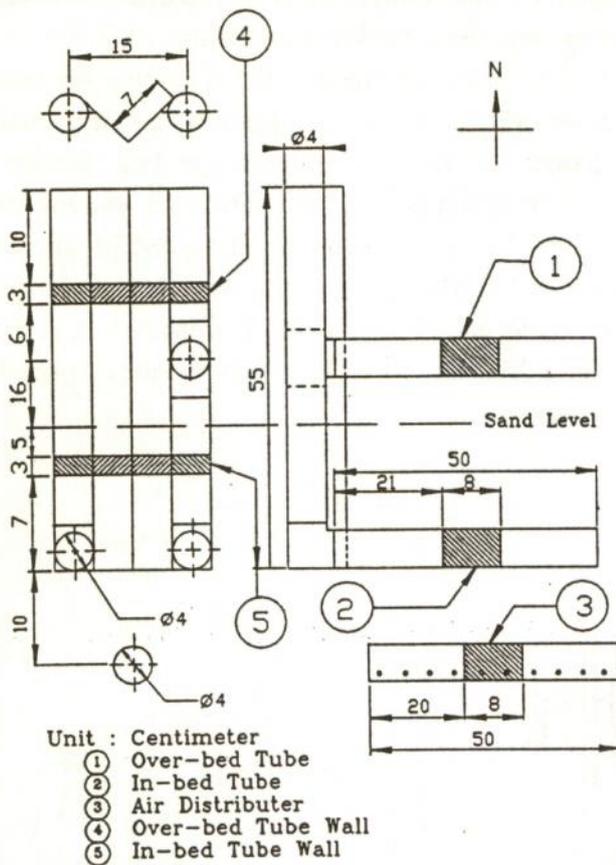


Figure 2. Dimensions and placement of PVC sample tubes.

Air was introduced into the bed at a fixed superficial velocity (2 times the minimum fluidized velocity, $U = 2U_{mf}$). At each pre-selected time interval, the air blower was stopped and the sample tubes and tube wall were taken off for thickness measurement using a micrometer. Details of measurement positions are presented in Fig. 3. The static bed height of sand was fixed at 23 cm. Two sand sizes (average diameter 356 and 444 μm) were used in this study and the corresponding minimum fluidizing velocities obtained from the experiment are 0.073 and 0.218 m/s, respectively. The total testing time was about 300 h for each sand size.

In-bed and Over-bed Tubes

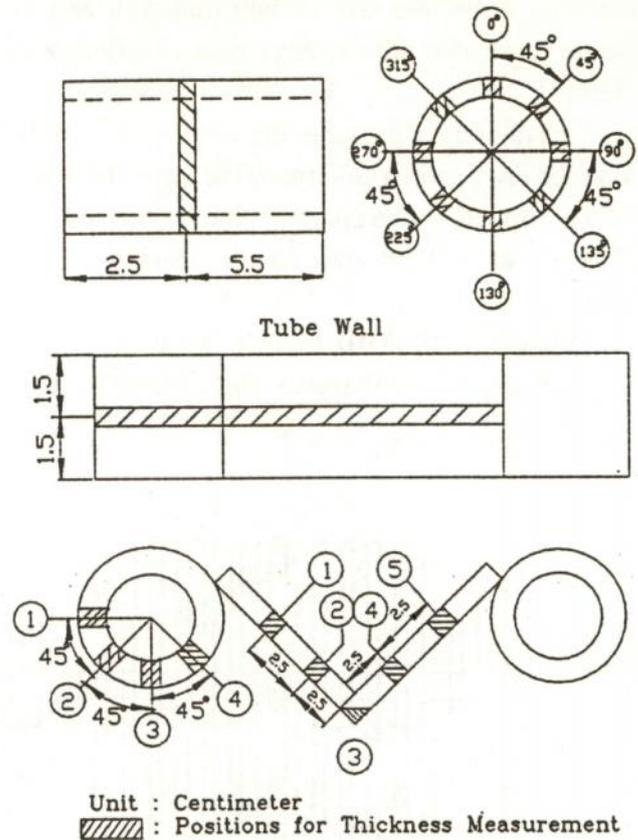


Figure 3. Positions for thickness measurement on the PVC sample tubes.

3. Results and Discussion

3.1 Erosion rate from cold model study

a.) In-bed and over-bed tubes

Figure 4 shows the erosion rate of sample tubes when fine and coarse sand were used as bed material. The over-bed tube, as expected, has the lowest erosion rate, followed by the air distributor tube, while the in-bed tube showed maximum erosion. This results from the lower abrasion/impact between sand particles and the over-bed tube. Both over-bed and in-bed tubes have relatively high erosion rates at the circumferential angle of 90-270° from the vertical centre line (bottom part). This can be attributed to the rising of gas bubbles through the in-bed tube which causes both impact/abrasion action between the coalescent sand particles and its bottom part. In case of the over-bed tube, the eruption of bubbles at the bed surface will eject the sand particles into the

freeboard and impinge on its bottom part. Different result was observed for the air distributor tube which showed a high rate of erosion at the circumferential angle of 0-90° and 270-360° from vertical centre line (top part). This is due to the abrasive movement of sand from the top of the tube to replace sand around the underneath air outlet orifices (see Fig. 1) which is blown off by the high velocity air jet. It should be noted that erosion around these sample tubes was found to be quite symmetrical, especially for the air distributor tube. Although the obtained results could not represent actual erosion which may occur in a fluidized bed combustor, it is nonetheless potentially useful for locating the primary points that are likely to suffer serious erosion. Using these results, anti-erosion devices, such as pins, studs, and fins can be provided at the design stage.

The effect of sand size on the erosion rate when the bed was operated at $U/U_{mf} = 2$ is clearly seen in Fig. 4. A higher rate was observed when coarse sand was used as bed material, especially in the case of the in-bed tube. This may be due to the higher momentum of coarse sand impacting during the process.

Tube wall

The tube wall is composed of two parts which are tube and fin (Fig. 3). Their erosion rates, which are effected by sand size and position (i.e. over-bed and in-bed), are presented in Fig. 5. In the case of in-bed position, the erosion rate was significantly high at the fin tip for both sand sizes when compared to other points (Fig. 5a). The same trend was also observed for over-bed position however, the rate was still 2-3 times lower than the case of in-bed position. This difference in erosion rate may arise from the difference in gross circulation rate of sand particles between the regions of freeboard and bed near the tube wall, and hence the abrasive action on the tube wall. Coarse sand, as mentioned previously, has a higher momentum than fine sand and as a result, the erosion rate created by coarse sand is higher as depicted in Fig. 5a.

The erosion rate of tubes at the various measured points for each sand size and placement was nearly the same (Fig. 5b). In-bed position shows a slightly higher rate of erosion than the over-bed position for both sand sizes. This results from the difference in circulation rate of sand as explained above. In this experimental case, however, it is difficult to reach any firm conclusion on the effect of sand size on the erosion rate.

3.2 Estimation of erosion rate for metal tube

As reviewed and discussed by Stringer [1], tube wastage in fluidized bed boiler appears to decrease with increasing temperature. The reason is that the formed oxide film might be regarded as more erosion resistant than the

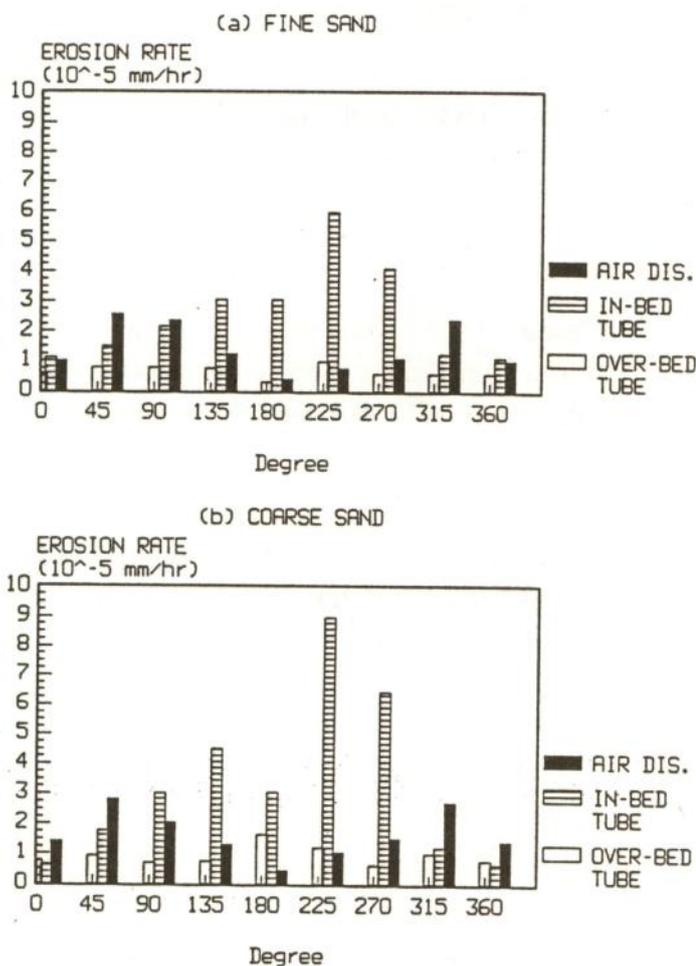


Figure 4. Erosion rate of PVC sample tubes: (a) fine sand and (b) coarse sand.

bare tube surface. Therefore, test results obtained from this cold model study can be regarded as the worse case for estimation of the erosion rate of metal tube, which is used in our small-scale fluidized bed boiler project (no in-bed tube)[4]. Assuming that the erosion rate is proportional to the hardness of tube, the maximum of estimated erosion rate for stainless steel (304) air distributor, boiler tube wall (BS3059, grade 320), and steel fin (JIS G3101 SS41) are less than 0.02 mm/y. If stainless steel (304) or boiler tube (BS3059, grade 320) is used as in-bed heat exchanger tube, the maximum erosion rate is estimated to be about 0.09 mm/y. These values are significantly lower than the commercially acceptable corrosion rate for boiler tube (0.3 mm/y)[1].

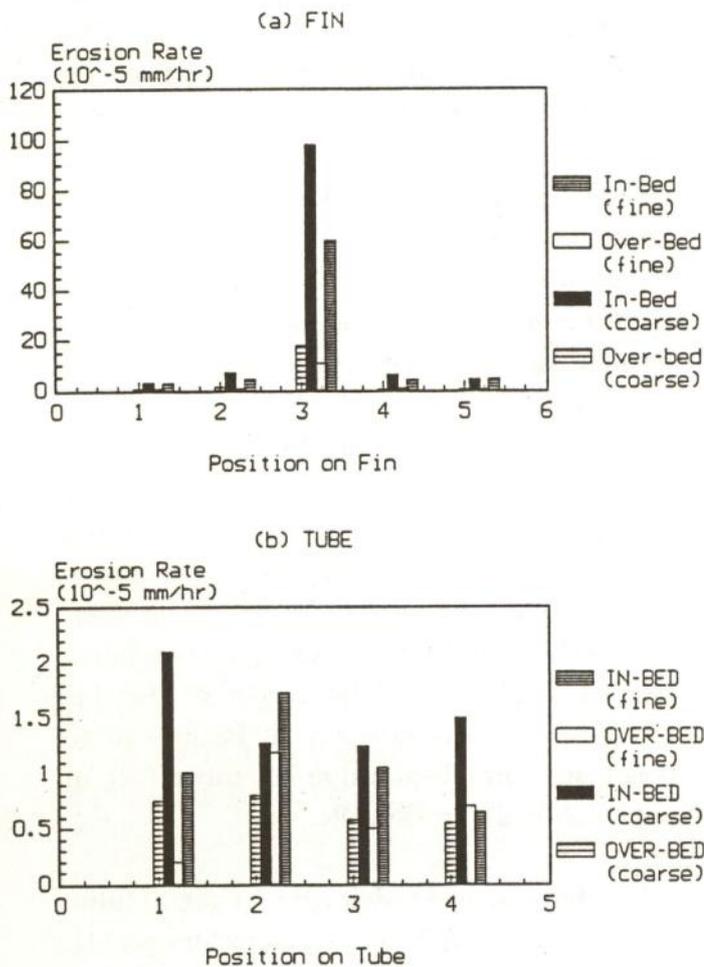


Figure 5. Effect of sand size and placement on erosion rate of PVC tube wall: (a) fin and (b) tube.

4. Conclusions

Cold model study of tube erosion in gas fluidized bed was carried out using PVC as sample tubes. Among air distributor, tube wall, in-bed and over-bed tubes, the highest erosion rate was observed for in-bed tube. Both in-bed and over-bed tubes showed maximum erosion rates at the bottom part of the tube while for the air distributor tube, this occurred at the top section. These results can be used to identify points on the tube circumference that are most likely to suffer serious erosion, and hence suitable protection methods can be provided. Estimation of erosion rate for metal tube based on cold model results was also made and it was found that the erosion rate was two times lower than the commercially acceptable corrosion rate for boiler tube.

5. Acknowledgements

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6. References

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