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Pressure Fluctuations as a Diagnostic Tool for Fluidized Beds

Technical Progress Report for the Period
January 1, 1995 - March 31, 1995

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Abstract

A series of preliminary experiments were conducted at the Iowa State University power plant circulating fluidized bed boiler (CFB). Pressure fluctuation measurements were recorded from a pressure transducer located immediately above the primary air distributor at the base of the CFB boiler under normal operating conditions. The purpose of these initial experiments was to examine the general pressure fluctuation structure of the fluidized bed boiler in order to assess what further signal processing techniques may be necessary for valid pressure fluctuation analysis and analytical characterization. These initial results show that the CFB boiler pressure fluctuations obtained are highly periodic. Due to the dominance of this periodic component (and its subsequent harmonics), the Bode plots of these pressure fluctuation signals are difficult to interpret. While an overall system roll-off is apparent, neither the overall system order nor the system time constants can be adequately estimated from this initial data. Further data recorded from other locations in the CFB boiler should provide a more complete explanation of the nature of boiler pressure fluctuations. This initial experimentation suggests that a better description of pressure fluctuations could be attained using signal filtering techniques.

Numerous experiments were also completed using the 2.0 inch diameter cold-model CFB, completing the first stage of a comprehensive set of similitude experiments. This bed was pressurized, and fluidized with 0.15 and 0.2 mm steel shot. A variety of operating conditions were selected such that similitude parameters could be matched in a 4.0 inch diameter CFB model exactly twice the scale of this small CFB. Currently, the final similitude tests in the small CFB with 0.1 mm steel shot are being performed. The corresponding experiments in the LCFB will be started immediately following these tests. From this first stage of cold-model experiments, it can be concluded that the reactor loading is an important CFB operating parameter, in addition to U, ρ_s, ρ_g, G_s, and the primary bed dimensions. It was observed that while operating under identical dimensionless parameters, a change in the reactor loading significantly changes not only the axial voidage profiles, but also the pressure fluctuation structure.

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Objective

The purpose of this project is to investigate the origin of pressure fluctuations in fluidized bed systems. The study will asses the potential for using pressure fluctuations as an indicator of fluidized bed hydrodynamics in both laboratory scale cold-models and industrial scale boilers.

Progress

ISU Power Plant CFB Boiler Experiments

A number of preliminary tests were completed to determine the general nature of industrial scale CFB Boiler pressure fluctuations. These tests were the first in a series of experiments that will focus on determining whether CFB pressure fluctuations can be used as diagnostic indicators in industrial scale CFB boilers, and also whether these signals can be related to similar pressure fluctuations observed in small-scale cold-model CFBs. Two 170,000 lb/hr steam Pyropower CFB boilers are located on the campus of Iowa State University. The initial pressure fluctuation data taken from ISU's CFB Boiler #1 was recorded from a 0-60" H_20 pressure transducer measuring the absolute static pressure at a location immediately above the gas distribution plate. The boiler has a square cross-section (14'x14'), and a height from distributor to top of CFB riser of around 65'. Under standard operating conditions, the boiler operates with 137,000 lb/hr fluidizing air and 74,000 lb/hr secondary air. The bed material consists of particles which predominantly range between 100 and 800 micrometers in diameter. The pressure measured at the bottom of the bed under these conditions ranges from 14-18 in H_20, and the bed temperature is maintained at around 1600° F. The fluctuation data was sampled at 20, 50, 90, and 400 Hz, with data set sizes ranging from 123,000 to 620,000 data points to insure adequate Bode plot resolution. Characteristic Bode plots and power spectral density plots of the pressure fluctuations were produced using standard FFT analysis techniques discussed in previous reports.

Small Cold-Model CFB Experiments

The remainder of the experiments this semester were completed using the CFB cold-model with the 2.0 inch (5.08 cm) diameter riser. Steel shot of 0.15 mm, and 0.20 mm diameter was used as the fluidized media. To match similitude parameters with a CFB that is twice as large as this small model, the fluidizing gas density must be increased in the small unit. To do this, the small CFB is operated at bed pressures up to 30 psig. Differential pressure fluctuations were measured at five locations along the entire height of the CFB using 0-10" H_20 and 0-20" H_20 pressure transducers. These pressure fluctuations were also analyzed using standard spectral analysis techniques.

Results and Discussion

A typical pressure fluctuation signal for the ISU CFB boiler is shown in Figs. 1 & 2. It is evident that a dominant period, on the order of a cycle every 3 to 5 seconds, is observed in the signal. This dominant frequency at 0.26 Hz is very pronounced in the power spectral density of this signal shown in Figs. 3 & 4. Examining the low frequency region of the Bode plot (see Fig. 5), the fluctuations do seemingly exhibit a system behavior that rolls-off at around -40 dB/decade (or greater). These initial results are not fully conclusive and difficult to interpret due to the presence of strong harmonics as illustrated in Fig. 6. It very difficult to estimate the system characteristics such as the system order and time constants from this pressure fluctuation Bode plot. Before any significant conclusions can be drawn from spectral analysis of CFB boiler fluctuations, additional pressure fluctuations data should be taken from different locations within the combustor. Prior to spectral analysis these signals may need appropriate filtering. This further experimentation should help provide an explanation for the presence of the 0.26 Hz dominant frequency in the spectrum.

According to Glicksman, hydrodynamic similitude in circulating fluidized beds can be achieved by matching the following dimensionless parameters

$$\frac{\rho_g U dp}{\mu},\ \frac{U^2}{gdp},\ \frac{Gs}{\rho_s U},\ \frac{\rho_g}{\rho_s},\ \frac{H}{dp},\ \frac{D}{dp}$$

To match these parameters in the large and small cold-model CFBs at a variety of operating conditions, a set of 42 experiments was developed. Out of the 42 total runs planned, approximately 14 have been completed to date (For valid results each run takes an average of 3 hours to complete. This includes set-up, data acquisition, and analysis). The 0.15 mm and 0.2 mm steel shot runs have been completed in the small CFB. No conclusions can be drawn regarding the applicability of pressure fluctuations to similitude studies until after the large CFB runs have been completed. In addition to these similitude tests, a number of tests were completed to determine the effect of the reactor loading on the pressure fluctuation response. While operating the small CFB under identical conditions ($U = 2.8$ m/s, $Gs = 30$ kg/m^{2}s, $dp = 0.15$ mm, bed pressure = 28 psig) the reactor loading was varied from 800 mL, to 650 mL, and then to 500 mL. As is evident from the axial voidage profiles shown in Fig. 7, the overall bed voidage decreases with increasing solids loading, with the greatest change evident in the lower dense bed region. The reactor loading also effects the pressure fluctuation structure at a 75% bed height as seen in Figs. 8 through 10. Increasing the reactor loading increases the amount of damping of the dominant frequency observed in these PSD plots. Consequently, the reactor loading is a important parameter that should not be neglected in similitude studies.

Conclusions and Future Work

The preliminary results from the industrial scale CFB boiler require further experimentation to determine the origin of the dominant frequency observed in the pressure fluctuations immediately above the distributor nozzles and also to determine if this signal is characteristic of the entire boiler. The application of signal processing tools may allow more information to be obtained from the Bode plot profiles. In small cold-scale models the reactor loading does play a significant role in the overall CFB hydrodynamics.

The immediate goal of our future work is to complete the comprehensive similitude study in the cold-model CFBs. Once this has been completed more experimentation will be completed at the ISU power plant CFB boiler.

Figure 1: CFB boiler pressure fluctuations (10 minutes)

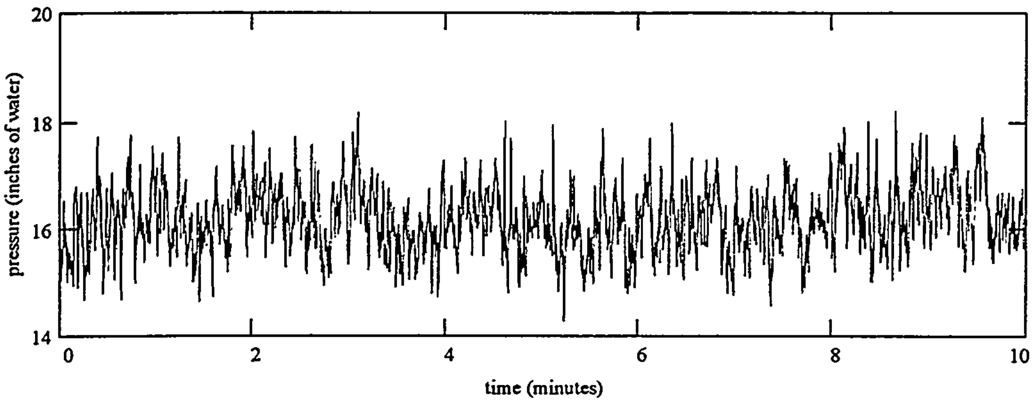

Figure 2: CFB boiler pressure fluctuations (60 seconds)

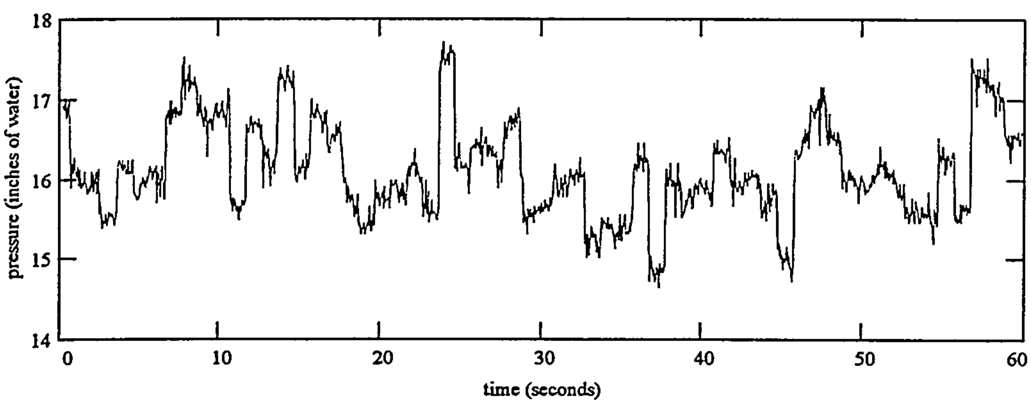

Figure 3: Power Spectral Density of CFB Boiler pressure fluctuations (0 to 10 Hz)

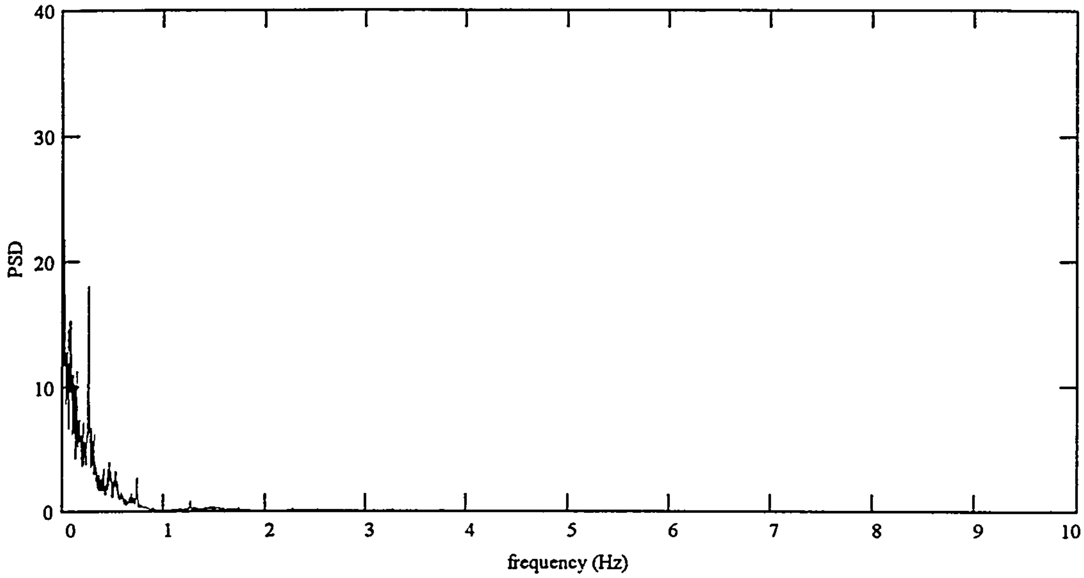

Figure 4: Power Spectral Density of CFB Boiler pressure fluctuations (0 to 1 Hz)

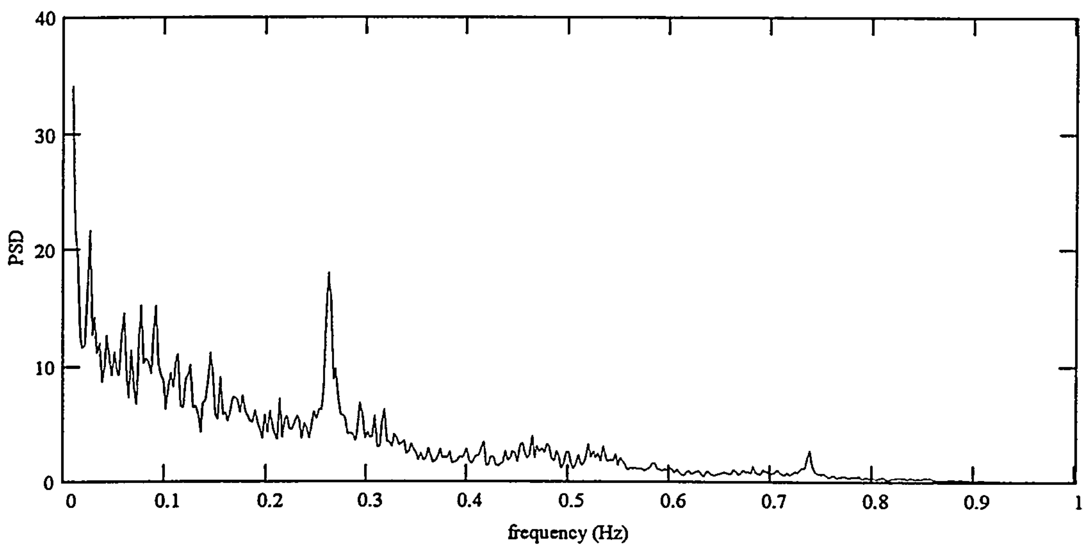

Figure 5: Bode Plot of CFB boiler pressure fluctuations (partial spectrum)

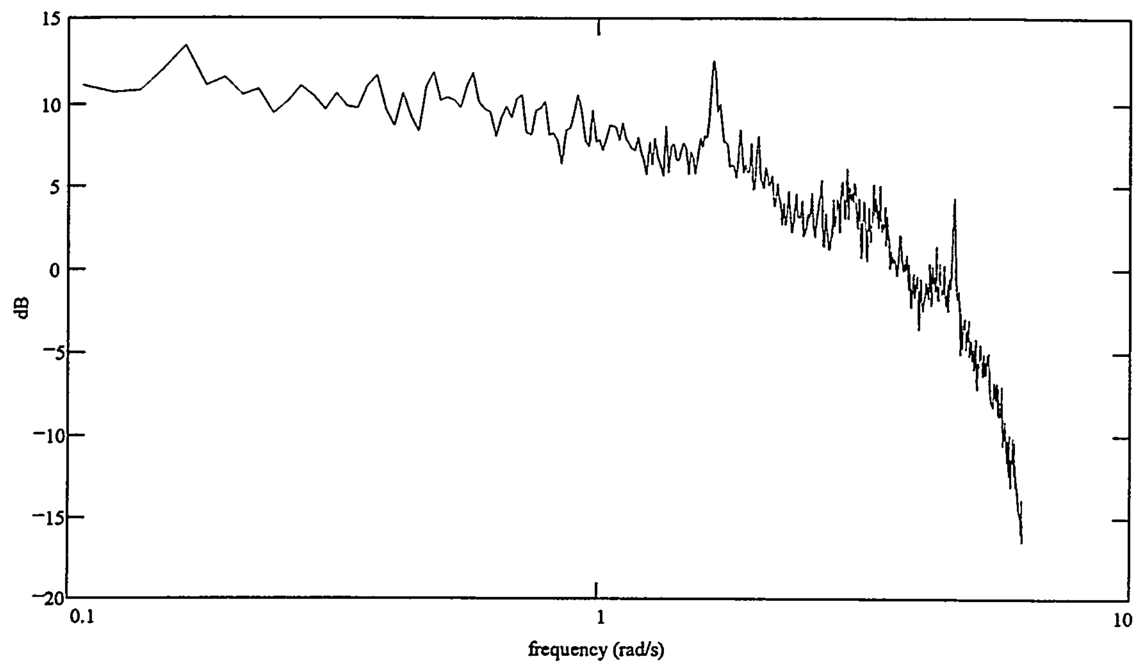

Figure 6: Bode Plot of CFB boiler pressure fluctuations (full spectrum)

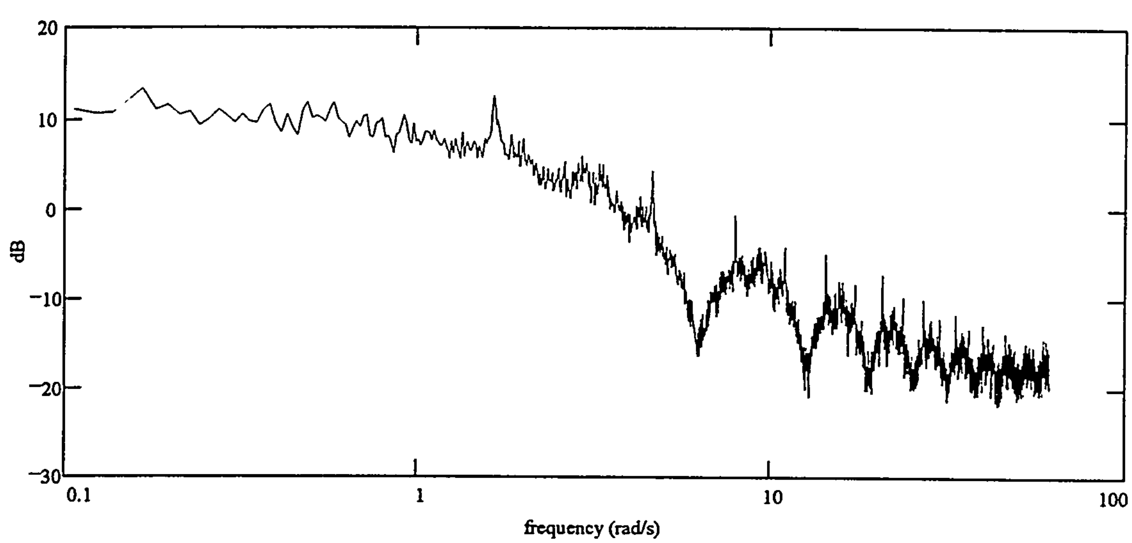

Figure 7: Axial voidage profiles of cold-model CFB

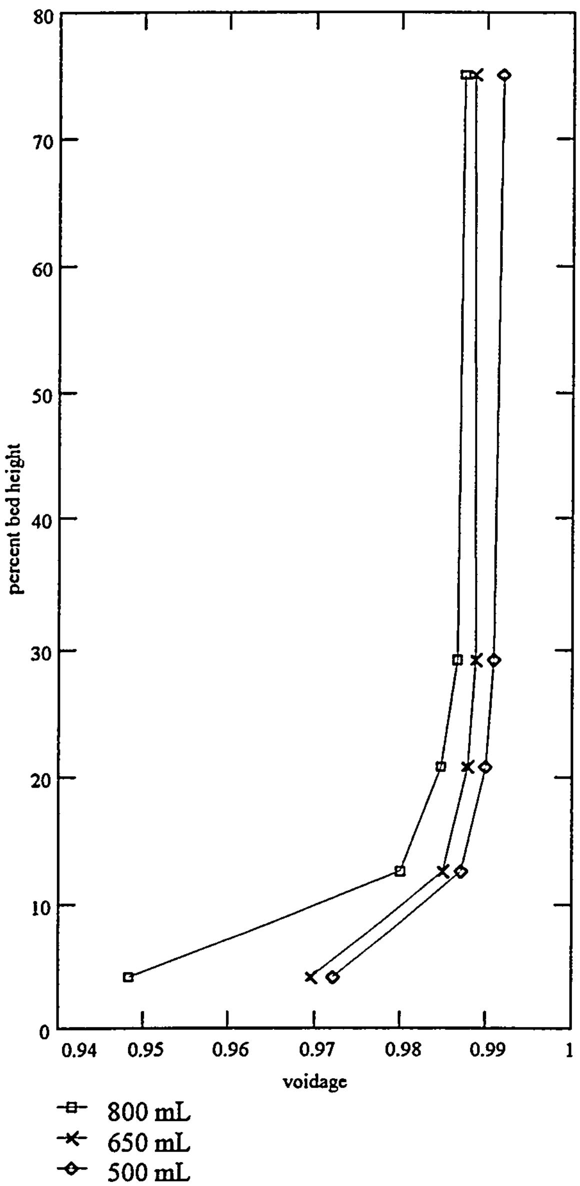

Figure 8: PSD of cold-model CFB pressure fluctuations (800 mL reactor loading)

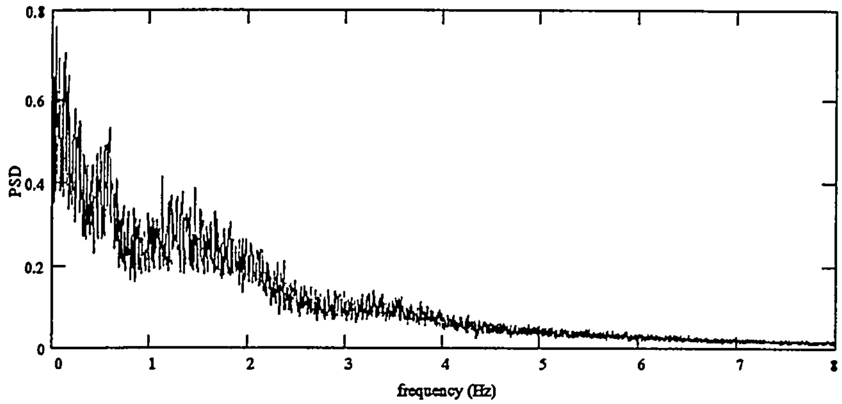

Figure 9: PSD of cold-model CFB pressure fluctuations (650 mL reactor loading)

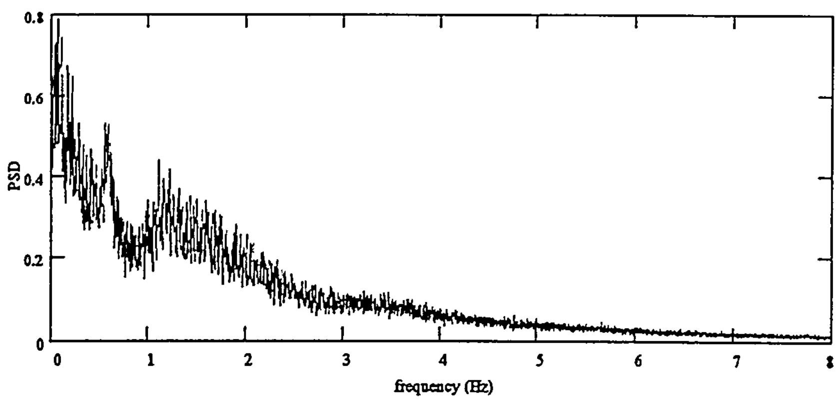

Figure 10: PSD of cold-model CFB pressure fluctuations (500 mL reactor loading)