

CENTRIFUGAL FLUIDIZED COMBUSTION OF COAL

Quarterly Report for the
Period April - June, 1977

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Date written - July, 1977

Under Contract No. E(49-18)-2516

PREPARED FOR
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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by

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ABSTRACT

Most of the activity during the third quarter dealt with design and fabrication of equipment. The new test section for batch experiments was completed and installed and some data on minimum fluidization and bed pressure drop were obtained. The experimental results continue to be in good agreement with the theoretical model. The design of the test sections for solids feed and removal was completed and fabrication was begun; and the probes for measuring air velocities and air flow rates were calibrated.

OBJECTIVE AND SCOPE OF WORK

Conventional fluidized bed combustors, with the bed material fluidized against the force of gravity, have many desirable features. However, for large capacity power generation applications or with very fine bed material, these systems require extremely large distributor areas, causing difficulties with startup, solids feed, bed mixing and turndown. The centrifugal fluidized bed (Fig. 1) rotates about its axis of symmetry and the fluidizing air flows radially inward through the porous cylindrical surface of the distributor. The inward drag force of the fluidizing air on the bed material is balanced by the large radial accelerations caused by the rotational motion, permitting much larger air flow rates per unit volume than are possible with a conventional fluidized bed operating against gravity. By varying the speed of rotation of the bed, the flow rate of air, and the bed temperature, it should be possible to achieve considerable variation in system power output providing the capability for operating over a wide range of part load conditions. In addition, the added flexibility due to bed rotation and the small size of the system should ease the problem of startup. With a bed material of dolomite or limestone to capture SO_2 , the centrifugal combustor could be used to burn high sulfur coal or coal char.

The centrifugal combustor would be operated as an adiabatic device with sufficient excess air to maintain bed temperatures in the desired range. For power generation applications, it might be used as the combustor in a combined gas turbine/steam turbine cycle (Fig. 2).

The successful development of the centrifugal fluidized bed concept would provide a system for coal or char combustion which would be compact, clean, efficient, and which would have the capabilities of being operated at full or part load conditions. The system might be used for utility size plants or for smaller industrial power generation applications.

The objective of the program is to determine the feasibility of operating a centrifugal fluidized bed in a continuous mode. Task I consists of a series of experiments using a model of a fluidized bed combustor operated at room temperature and pressure. Fluidized bed materials which simulate coal and/or coal char in specific gravity, particle size and distribution will be used to determine the requirements for minimum fluidization, bed pressure drop, freeboard pressure drop and the extent of particle elutriation. The constraints affecting the addition and removal of material from the bed will be determined.

The second task involves experiments to study the fluid mechanics of confined vortex flows without particles. Previous work on confined vortex flows indicates nonuniformities in radial velocity, secondary flow patterns, and flow instabilities can occur in a single phase vortex gas flow. If these persist in the bed region of a centrifugal fluidized bed, they could affect bed stability, minimum fluidization and particle elutriation. This work is intended to develop criteria for the flow regimes in which significant secondary flow patterns occur. Once the proper criteria are established, comparisons will be made with the experiments on rotating fluidized beds to determine if the nonuniformities affect the bed stability and the quality and uniformity of fluidization.

SUMMARY OF PROGRESS TO DATE

Laboratory test units for batch experiments on bed stability, minimum fluidization, and startup were built; and experiments on bed startup and minimum fluidization were begun. The design and fabrication of test sections for solids feed experiments were initiated; and an analysis for bed pressure drop, minimum fluidization and bed shape was developed. One of the batch test sections was modified, adapting the unit for measurement of tangential and radial velocity profiles within the rotating chamber. A probe traversing mechanism was designed and hot wire probes for measurement of air velocity were calibrated.

A project schedule is given in Figure 3.

DETAILED DESCRIPTION OF TECHNICAL PROGRESS

TASK I

● Batch Experiments with Conical Distributors

All of the results contained in the first two quarterly reports [1,2] were obtained using the first rotating fluidized bed test section built at Lehigh. This apparatus, which was built hurriedly to obtain preliminary data on bed behavior, vibrated badly over certain ranges of test conditions, but particularly at high rpm with thick beds. To permit experiments over the full range of conditions, the design of a new, sturdier, and better balanced test section was initiated. During the last quarter, fabrication of this test section was completed; and it was installed in the laboratory and calibrated.

Like the first test section, the new unit consists of a 12 inch diameter by 6 inch high distributor contained in a square plenum. The distributor is tapered to assist in startup and its surface is fabricated from reinforced fine mesh screen. The top end wall is transparent plexiglass for visualization of the bed. A variable speed motor is used to rotate the distributor by means of a shaft connected to the bottom end wall of the test section. Room temperature air is supplied to the plenum from a set of compressors. This system can be operated with air flow rates to 1200 scfm and with distributor angular velocities above 350 rpm.

A series of experiments was initiated using the new apparatus to determine the effects of the taper angle of the distributor, grid pressure drop, particle diameter, mass of bed material and angular velocity on minimum fluidization, bed pressure drop, bed expansion, and particle elutriation. The range of test conditions which will be studied are shown in Table 1.

Results for a particle diameter of 475 microns and angular velocities of 200 and 350 rpm are shown in Figures 4 and 5. These data, obtained with

TABLE 1
RANGE OF TEST CONDITIONS FOR BATCH EXPERIMENTS

Air flow rate	0 → 950 scfm	
Angular velocity	200 → 350 rpm	
Particle diameter	121, 351, 475 μm	
Particle density	2.7 g/cm ³	
Bed mass	0.5 → 4.5 kg	
Packed bed thickness	0 → 2.5 cm	
Distributor taper angle	2°, 4°, 6°	
$\frac{\Delta P_{\text{GRID}}}{\Delta P_{\text{BED}}}$	minimum value	maximum value
	<< 1	≈ 1

a grid angle of 4° and a moderate value of grid pressure drop, show the effect of the bed mass on minimum fluidization and bed pressure drop. The solid lines on the figures are the values computed for bed pressure drop as a function of air flow rate using the analysis described in [2].

- Feed and Removal of Solids

The design of the two new test sections for studies of solids feeding and removal were completed during this past quarter. The test sections are presently in the shop being fabricated and they should be ready for installation by mid to late July. The air distribution system for these test sections has been installed and the pitot probe meter is presently being calibrated for measuring air flow rates.

- Plans for Next Quarter

During the next quarter the batch experiments will be continued to complete the study of the effect of distributor half angle, grid pressure drop, bed charge weight, and particle diameter on fluidization, as specified in Table 1. The test sections for the solids feed and removal studies will be installed and calibrated and experiments will be initiated.

TASK II

Modification of the test section used for the preliminary batch experiments on fluidization was completed to permit hot wire anemometer

measurements of air velocity within the rotating chamber. Calibration of the hot wire probes was begun; and typical calibration data for a single wire probe are shown in Figure 6, where the voltage output of the anemometer is plotted as a function of the air velocity perpendicular to the wire. Figure 7 shows the effects of the orientation of the wire on voltage output. A probe traversing mechanism was designed to permit translation of the probe within the test section in the radial and axial directions. This traversing mechanism is presently being fabricated in the machine shop.

- Plans for Next Quarter

Probe calibration will be completed and preliminary experiments will be initiated on measuring velocity profiles within the rotating chamber. This information will be used to construct a flow regime map, indicating those ranges of conditions over which serious nonuniformities in radial velocity can be avoided.

CONCLUSIONS

Most of the activity during the third quarter dealt with design and fabrication of equipment. The new test section for batch experiments was completed and installed and some data on minimum fluidization and bed pressure drop were obtained. The experimental results continue to be in good agreement with the theoretical model. The design of the test sections for solids feed and removal was completed and fabrication begun. The work required to prepare the laboratory for the solids feed and removal experiments and the experiments on the fluid mechanics on confined vortex flows was initiated and calibration of probes for measuring air velocities and air flow rates was begun.

REFERENCES

1. E. Levy and J. C. Chen, "Centrifugal Fluidized Combustion of Coal", Quarterly Report for the period Sept. - Dec., 1976 (FE 2516-1).
2. E. Levy and J. C. Chen, "Centrifugal Fluidized Combustion of Coal", Quarterly Report for the period Jan. - March, 1977 (FE 2516-2).

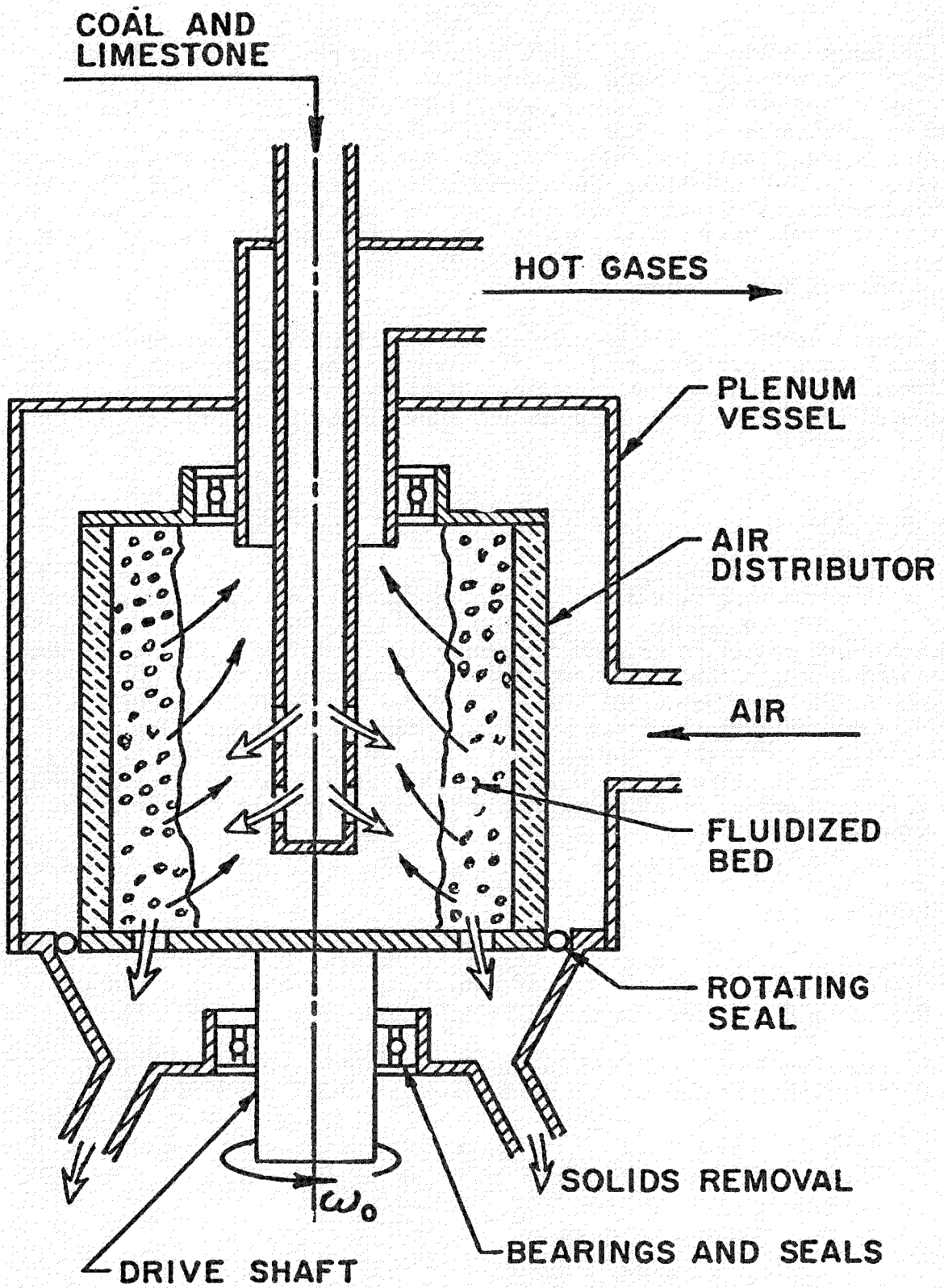


Fig. 1 Conceptual Drawing of Centrifugal Fluidized Bed Combustor

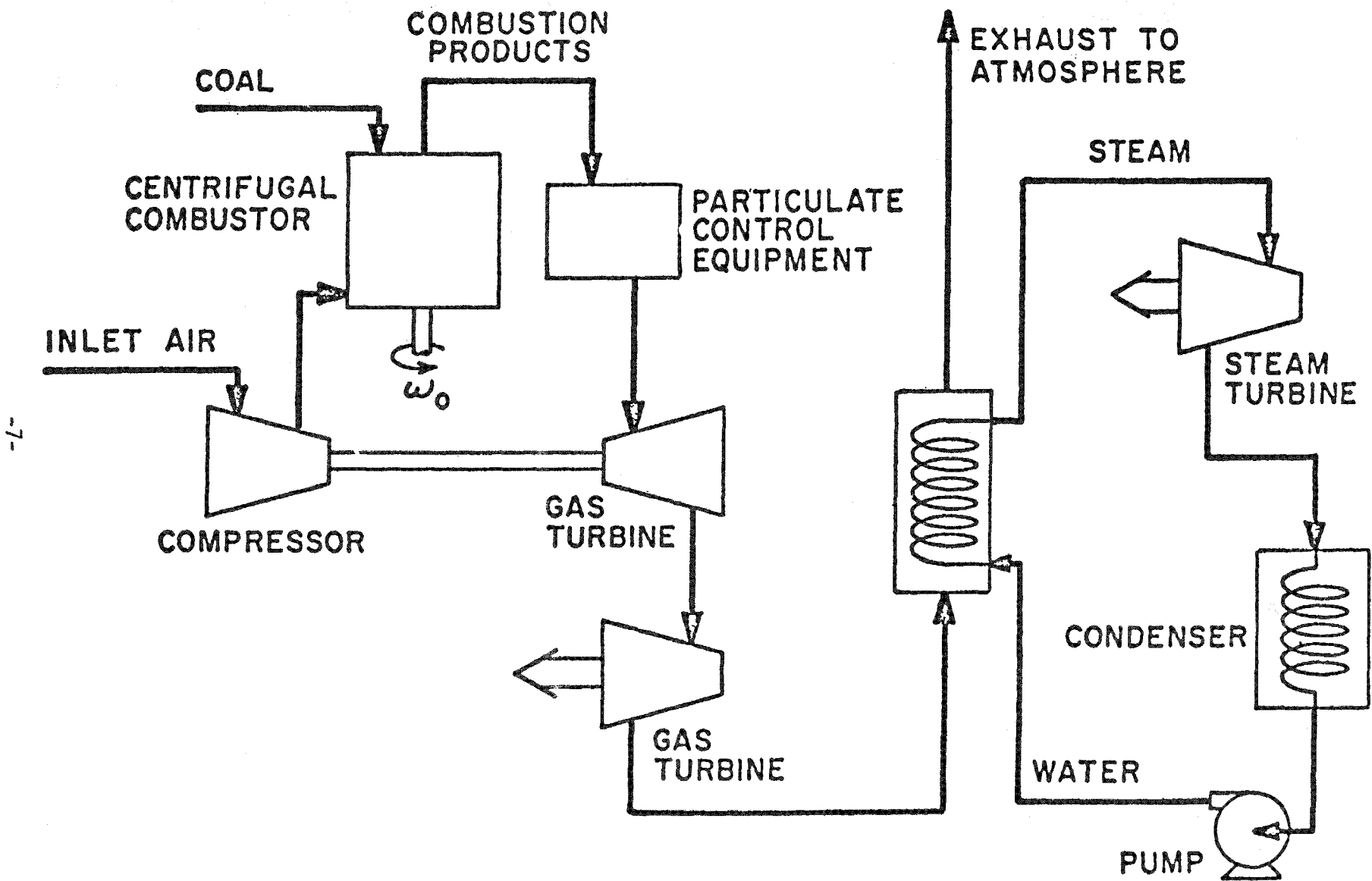


Fig. 2 Adiabatic Combined Cycle Power Plant

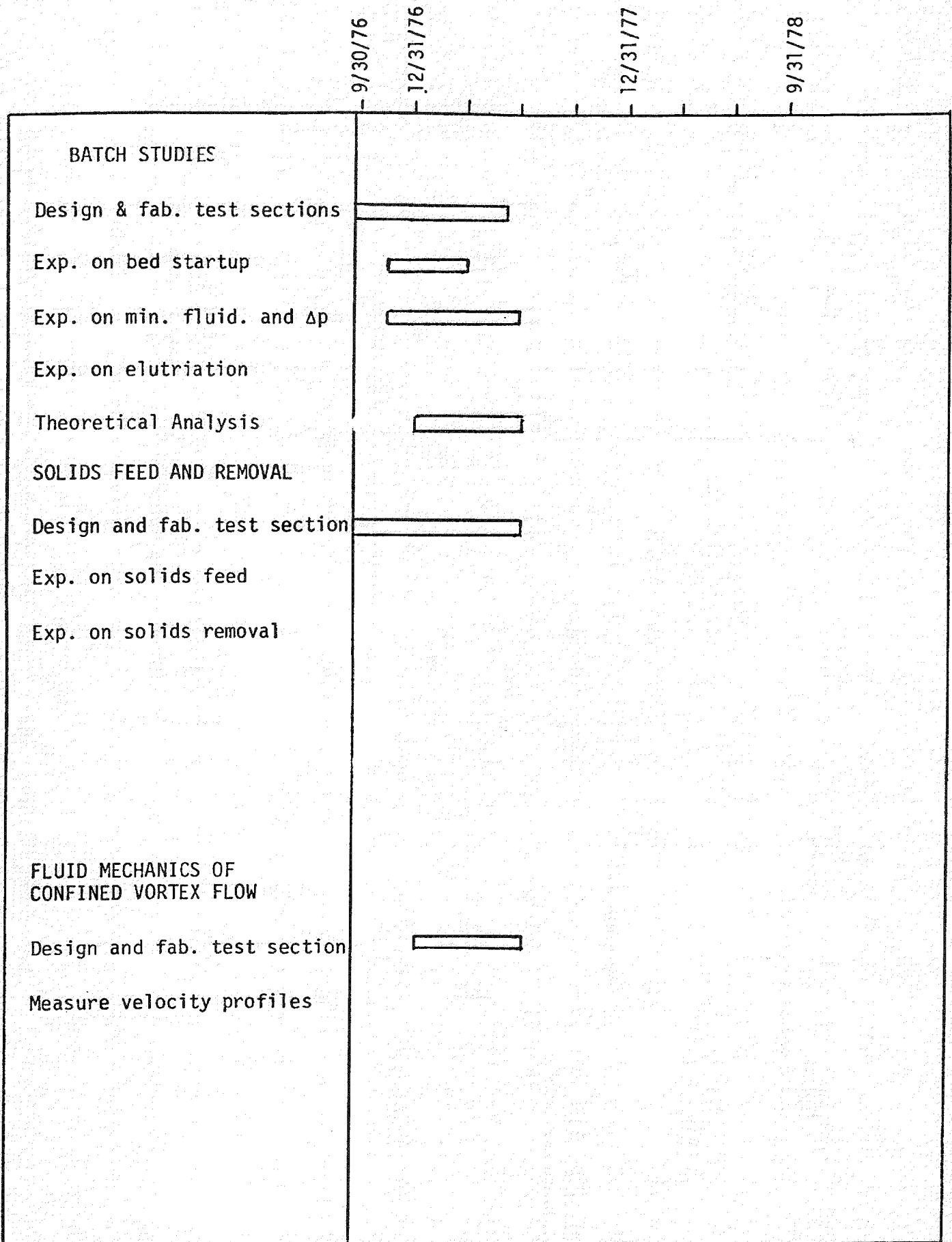


Fig. 3 Project Schedule

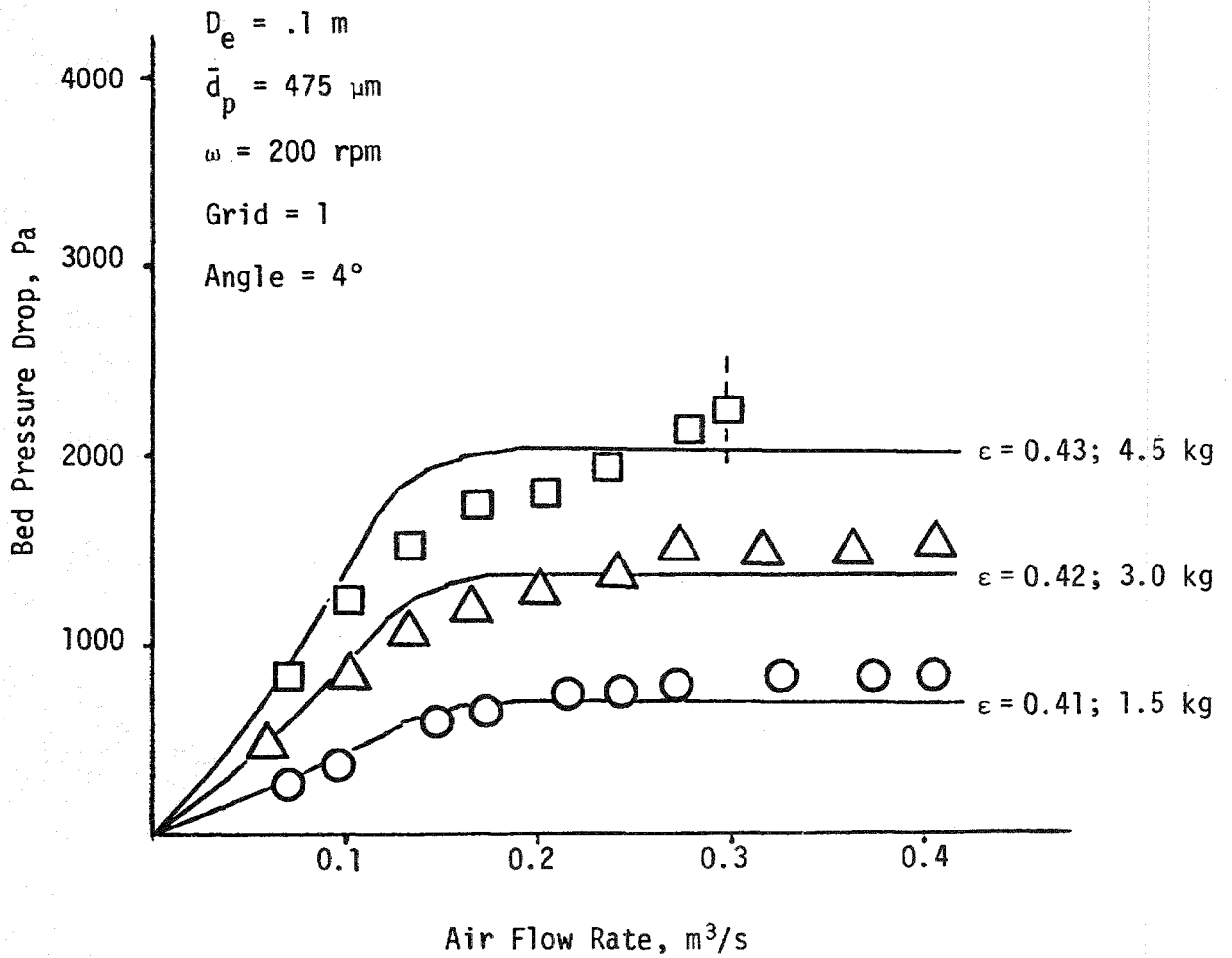


Fig. 4 Effect of Bed Mass on Fluidization at 200 rpm

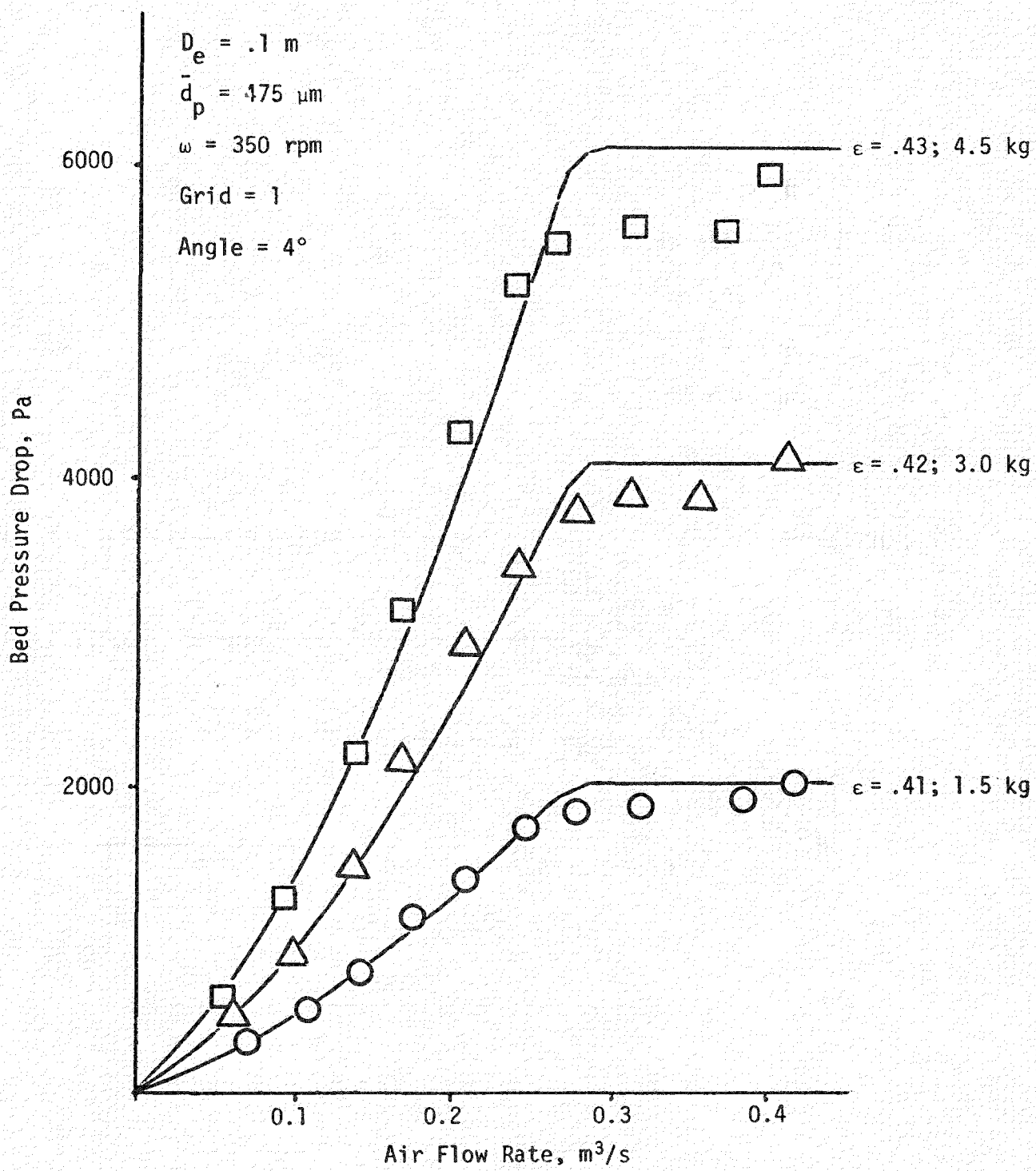


Fig. 5 Effect of Bed Mass on Fluidization at 350 rpm

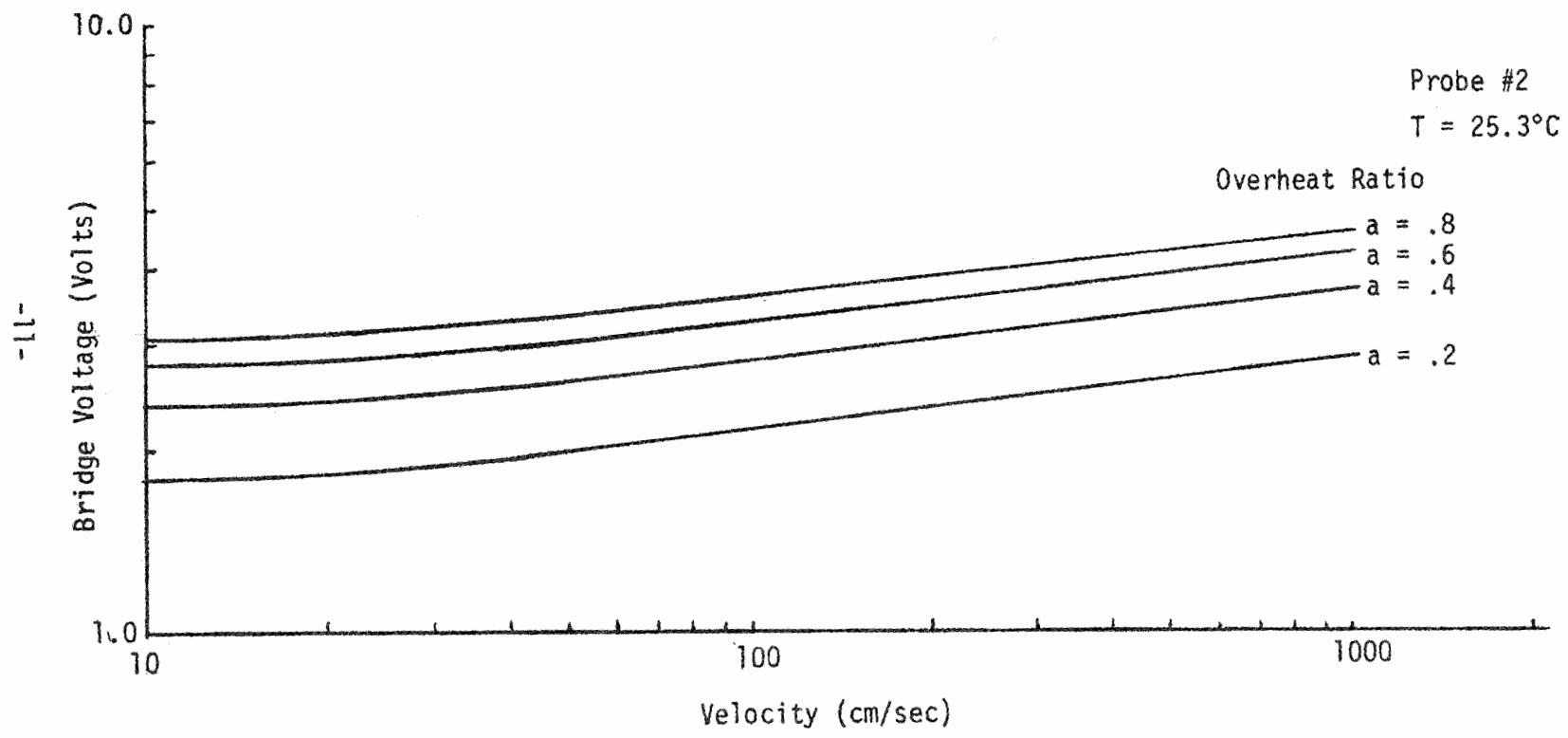


Fig. 6 Probe Calibration Curves

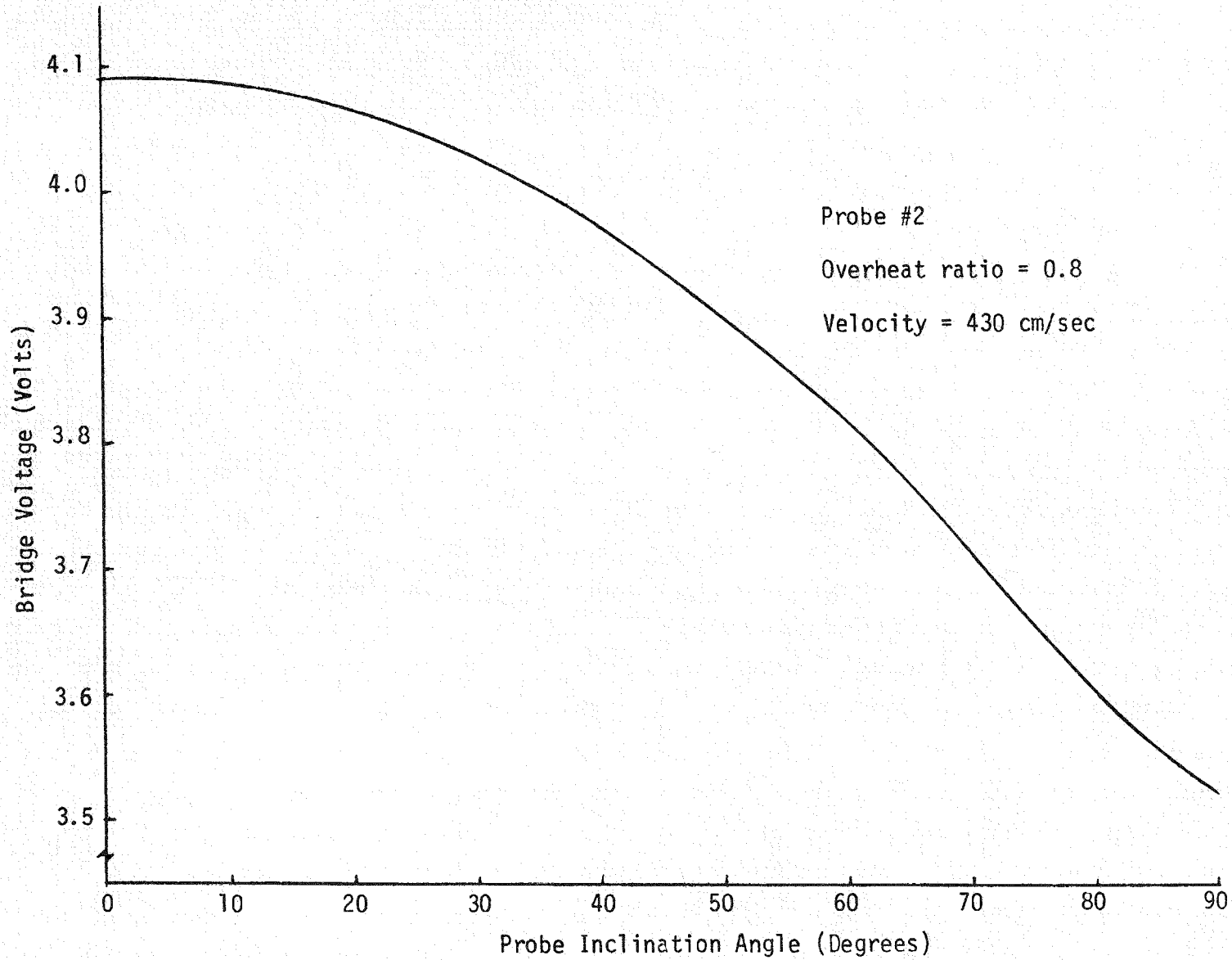


Fig. 7 Probe Angular Sensitivity