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CENTRIFUGAL FLUIDIZED COMBUSTION OF COAL

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by

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ABSTRACT

Experiments with tapered distributors show strong effects of distributor angle, grid pressure drop, angular velocity, and bed mass on startup, minimum fluidization and bed pressure drop. Analyses were developed to predict the influence of these factors on system performance. Comparisons of preliminary theoretical results with available data are presented.

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 the 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. Experiments on bed startup and minimum fluidization were begun. The designs of test sections for solids feed experiments were initiated. An analysis for bed pressure drop, minimum fluidization and bed shape was developed. Modifications to one of the batch test sections were begun, adapting the unit for measurement of tangential and radial velocity profiles within the rotating chamber.

A project schedule is given in Figure 3.

DETAILED DESCRIPTION OF TECHNICAL PROGRESS

TASK I

- Batch Experiments with Conical Distributors

A series of experiments was performed on bed startup and fluidization with the apparatus shown in Figure 4, consisting 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 several layers of reinforced fine mesh screen. The top and bottom end walls are transparent plexiglass for visualization of the bed. A variable speed DC 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 blower. The system can be operated with air flow rates to 1000 scfm and with distributor angular velocities to 300 rpm, corresponding to radial accelerations to 15 g's. Experiments were performed with 0.0195 inch diameter glass beads for the bed material.

Results from the first series of experiments performed with a 4° half angle cone are shown in Figures 5, 6 and 7. Data showing the effect of grid pressure drop on fluidization are shown in Figure 5 where experiments were performed at 227 rpm with a 5 lb. bed charge. Because of nonuniformities in bed thickness from the bottom to the top of the distributor, it is important to design the system with sufficient grid pressure drop to achieve relatively uniform fluidization along the distributor and to minimize the possibility of premature particle elutriation due to localized high radial velocities. The data in Figure 6 show the effect of angular velocity on bed pressure drop. All the data here were obtained with the same amount of material in the bed and with the same grid pressure drop characteristic. The results in Figure 7 show the effect of the amount of bed material (charge weight) on bed pressure drop. The principle effect of changing the charge weight is to change the vertical distribution of bed thickness along the distributor.

Similar experiments were attempted with a 2° distributor but difficulties occurred in achieving a stable fluidized state. There are several possible reasons for these problems, and more work is planned to determine exactly why stable fluidization did not occur.

- Analysis of Fluidization

Generally for a given bed geometry and particle density, the important variables are:

- Total weight of bed material
- Distributor angle
- Distributor pressure drop
- Angular velocity of bed
- Particle diameter

These variables interact in a complex manner to govern bed start-up, minimum fluidization and particle elutriation. To attain a better understanding of these interactions and to provide the capability for designing centrifugal fluidized beds with specific performance objectives in mind, an analytical model was developed for predicting their effect on fluidization. To account for vertical variations in bed thickness and air velocity (see Figure 8) the analysis treats the system as a series of n elements, each of height Δz. The total pressure drop across the grid and bed is given for each element as

$$\Delta P_T = \Delta P_G + \Delta P_B \qquad (1)$$

where if the bed is packed locally

$$\Delta P_B = \frac{150\ (1-\varepsilon)^2}{\varepsilon^3\ (\phi d_p)^2}\ \mu u_o r_o\ \ell n\ ({}^{r}o/r_i) + \frac{1.75\ (1-\varepsilon)}{\varepsilon^3 \phi d_p}\ \rho (u_o r_o)^2 \left[\frac{1}{r_i} - \frac{1}{r_o}\right]$$

If the bed is fluidized locally and the tangential velocity in the bed is independent of radius,

$$\Delta P_B = (\rho_s - \rho_f)\ (1-\varepsilon)\ \omega_o{}^2 r_o{}^2 \ell n ({}^{r}o/r_i) \qquad (2)$$

A slightly different expression for ΔP_B results if the tangential velocity is assumed to vary linearly with radius.

The grid pressure drop is

$$\Delta P_G = Au_o + Bu_o{}^2$$

Where A and B specify the grid pressure drop characteristics. The radial velocity at minimum fluidization, calculated at the outer radius of the bed r_o for the case of uniform tangential velocity within the bed, is given by

$$Ga = \frac{150(1-\varepsilon)}{\varepsilon^3\ \phi^2}\ Re + \frac{1.75}{\phi\varepsilon^3}\ \left(\frac{r_o - r_i}{r_i\ \ell n\ {}^{r}o/r_i} \right)\ Re^2$$

where $Re = \dfrac{\rho_f u_o d_p}{\mu}$

and $Ga = \dfrac{(\rho_s - \rho_f)}{\rho_f}\ \dfrac{\omega_o^2\ r_o\ d_p{}^3}{\nu^2}$

For thin beds, this reduces to

$$Ga = \frac{150\ (1-\varepsilon)}{\varepsilon^3\ \phi^2}\ Re + \frac{1.75}{\phi\varepsilon^3}\ Re^2 \qquad (3)$$

The analytical procedure assumes a value for ΔP_T and uses equation 1 to compute $u_o(r_o)_i$ for each of the n elements. The total mass flow rate through the distributor is

$$\dot{m} \ (\Delta P_T) = \sum_{i=1}^{n} \rho \ u_{oi} \ 2\pi \ r_{oi} \ \Delta z_i$$

Figure 9 shows results for the variation of bed pressure drop with air flow rate for a 4°distributor. The dashed curves are computed for 3 values ε_{mf} and the circles are actual experimental data. Points A, B and C correspond to conditions where the bed is totally packed (A), partially fluidized (B) and totally fluidized (C). This is seen more clearly in Figure 10 where the computed vertical variations of radial velocity are shown for points A, B and C. In this case, the bed is thinner at the top; causing the radial velocities to increase with height. The bed first becomes fluidized at the top; and the transition from the packed to the fluidized region progresses downward as the air mass flow increases.

The analysis described above requires information on the shape of the inside surface of the bed. A separate analysis was performed to determine the vertical variation of the inner bed radius $r_i(z)$. Results in Figure 11 show the effect of charge weight and rpm on bed thickness with a 2° tapered distributor. Other results showing the effect of the angle of the distributor and charge weight on bed thickness are given in Figure 12 for 250 rpm. For the range of rpm considered in the study, very serious nonuniformities in bed thickness can occur, and the effects are particularly severe at the lower charge weights. In Figure 13, Equation 3 for minimum fluidization is compared to minimum fluidization data reported in References 1 and 2. The results show excellent agreement over a wide range of operating conditions. In Figure 14 the bed pressure drop criteria given by equation 2 is compared to data from Reference 2. Here, too, the agreement between theory (solid lines) and experiment is good.

- Test Section Design

The design of a new test section for batch experiments on fluidization was completed and the test section was fabricated. The design of two separate test sections for studies of solids feeding and removal continued.

- Plans for Next Quarter

During the next quarter the batch experiments will be continued to study in more detail the effects of distributor half angle, grid pressure drop, and bed charge weight on bed startup and fluidization. Design and fabrication of the test sections for the feed studies will be continued.

TASK II

Work was begun to modify the test section, used for the preliminary batch studies on fluidization, for future hot wire anemometer and pitot probe measurements of air velocity within the rotating chamber. It is planned to use this test section to obtain preliminary data on velocity profiles and flow distributions. This information will be used to construct a flow regime map indicating those ranges of conditions over which serious nonuniformities in radial velocity occur.

Conclusions

Stable fluidization, bed startup and proper operation of a centrifugal fluidized bed depend on parameters such as distributor angle, bed thickness, rotational velocity and grid pressure drop. Over the range of angular velocities and effective gravities studied here, the bed thickness varies in the vertical direction from the top to the bottom of the distributor. A quantitative understanding of how these variations affect minimum fluidization and particle elutriation is needed to permit detailed engineering design of these systems. An analytical model was developed of the bed startup problem. The first results of the model are in excellent agreement with available experimental data. More work is needed to verify the model completely.

References

1. Levy, E.K., and Chen, J.C., "Centrifugal Fluidized Combustion of Coal, Quarterly Report for the Period Sept. to Dec., 1976", ERDA Report FE-2516-1, January 1977.

2. "Rotating Fluidized Bed Reactor for Space Nuclear Propulsion, Annual Report: June 1971 - June 1972", Brookhaven National Laboratory Report BNL 50362, Sept. 1972.

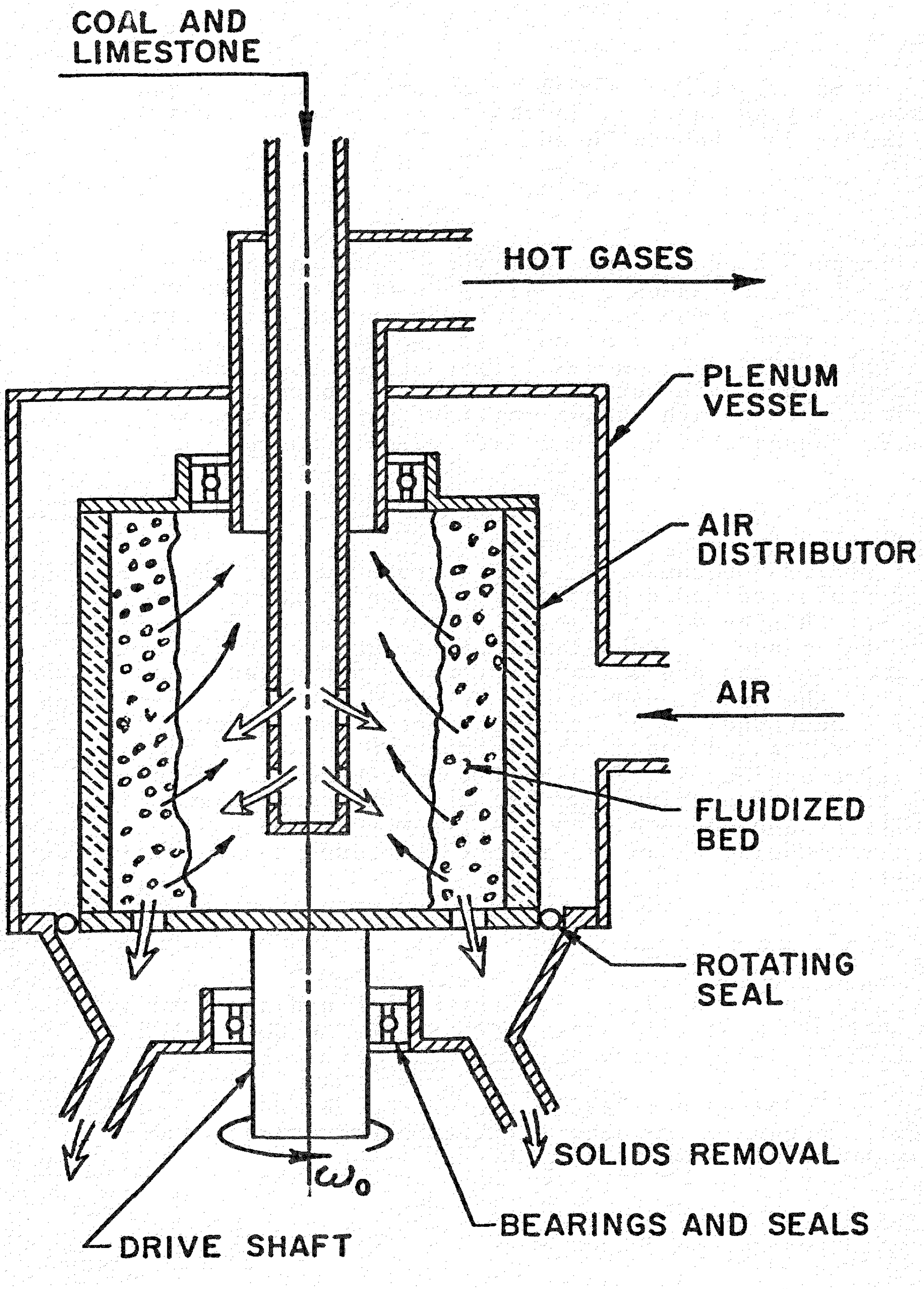

Fig. 1 Conceptual Drawing of Centrifugal Fluidized Bed Combustor

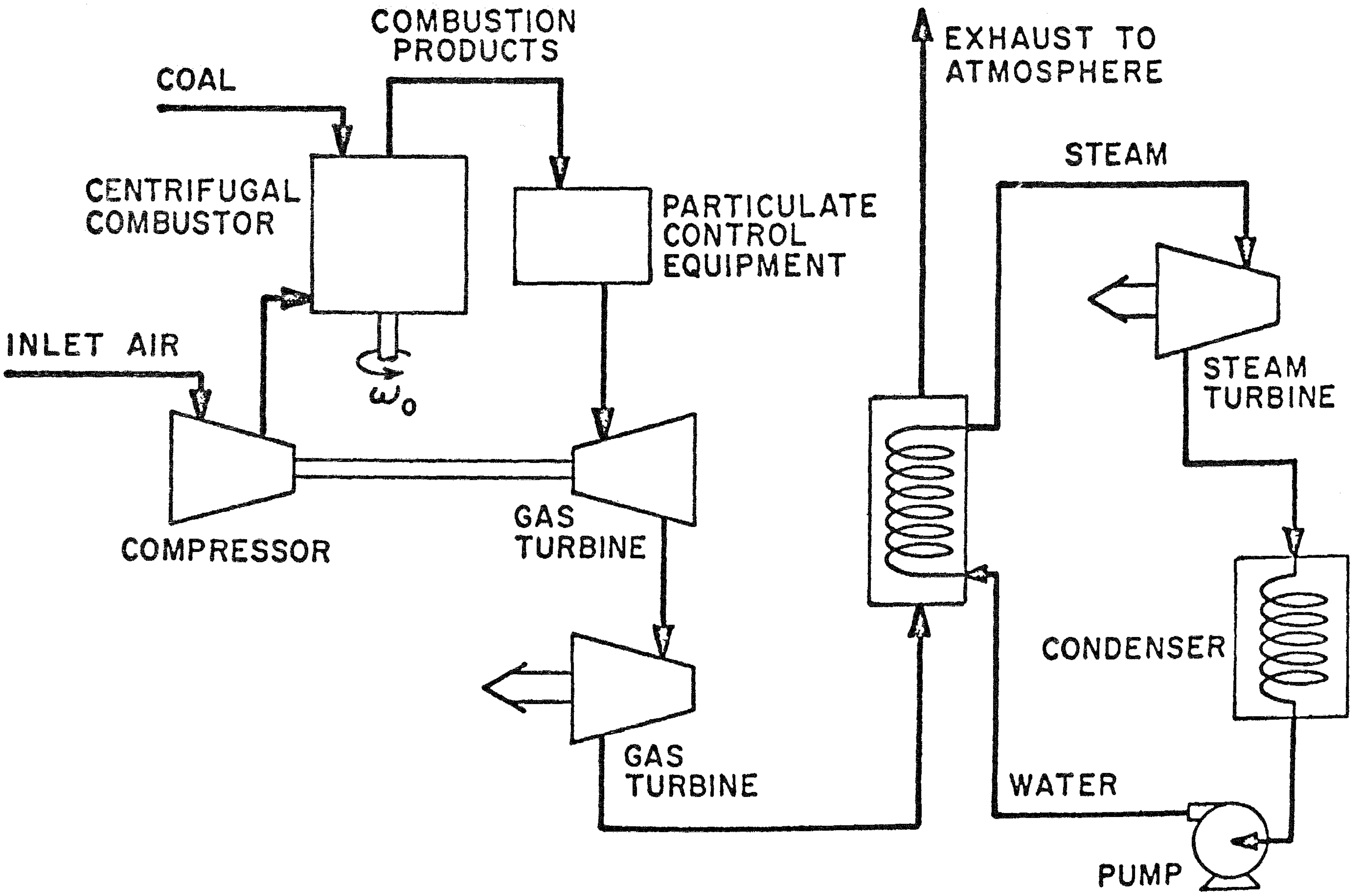

Fig. 2 Adiabatic Combined Cycle Power Plant

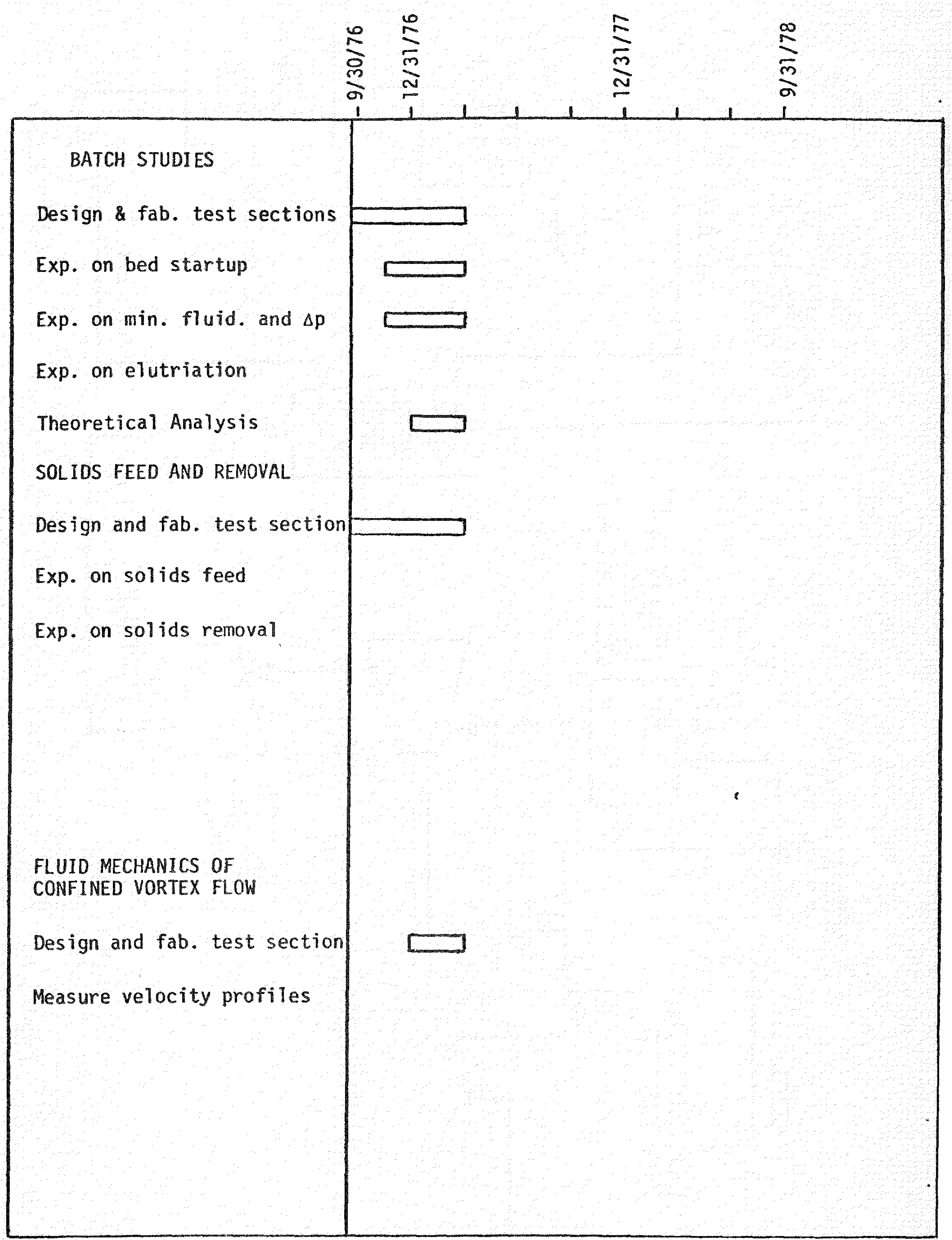

Fig. 3 Project Schedule

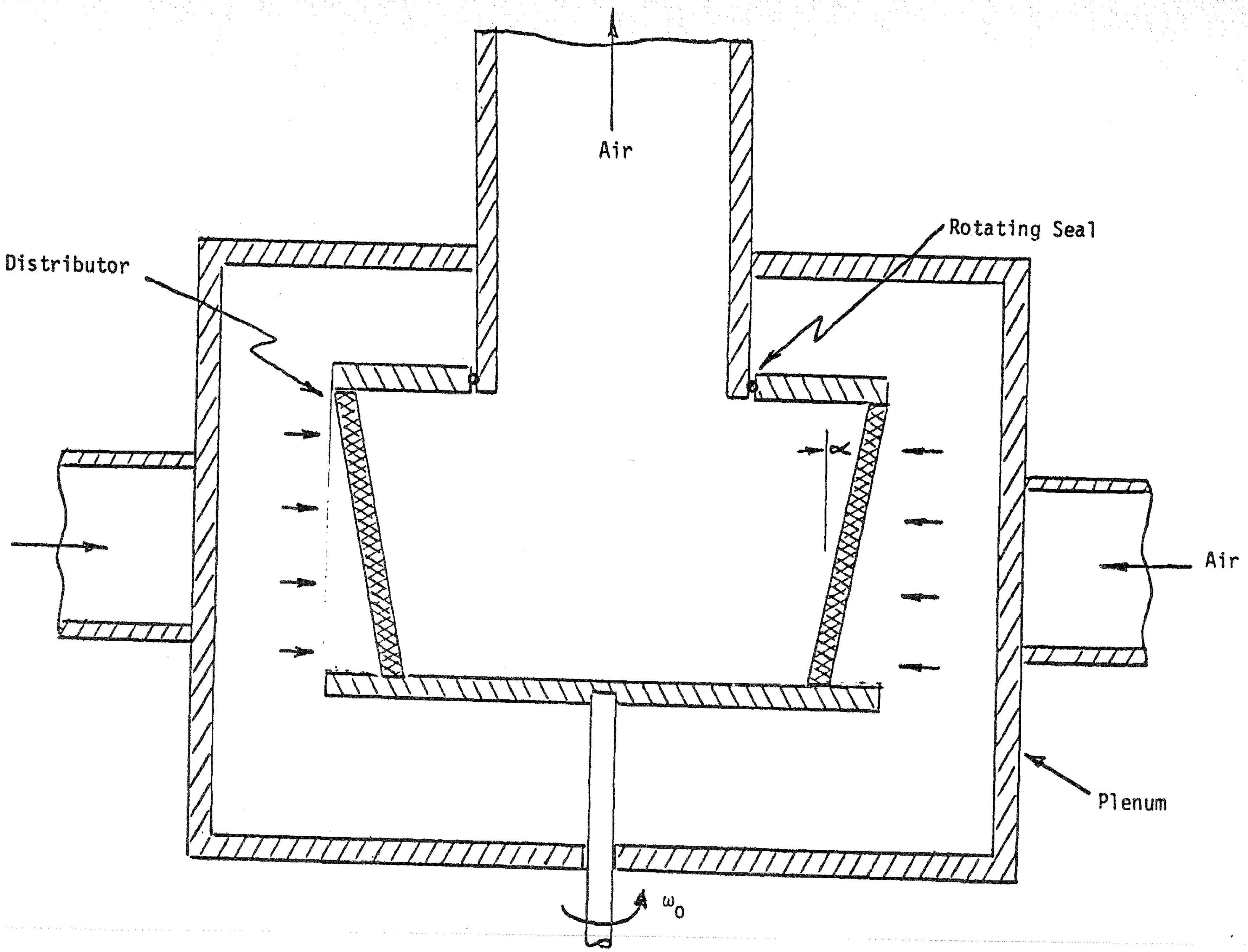

Fig. 4 Test Section with Conical Distributor

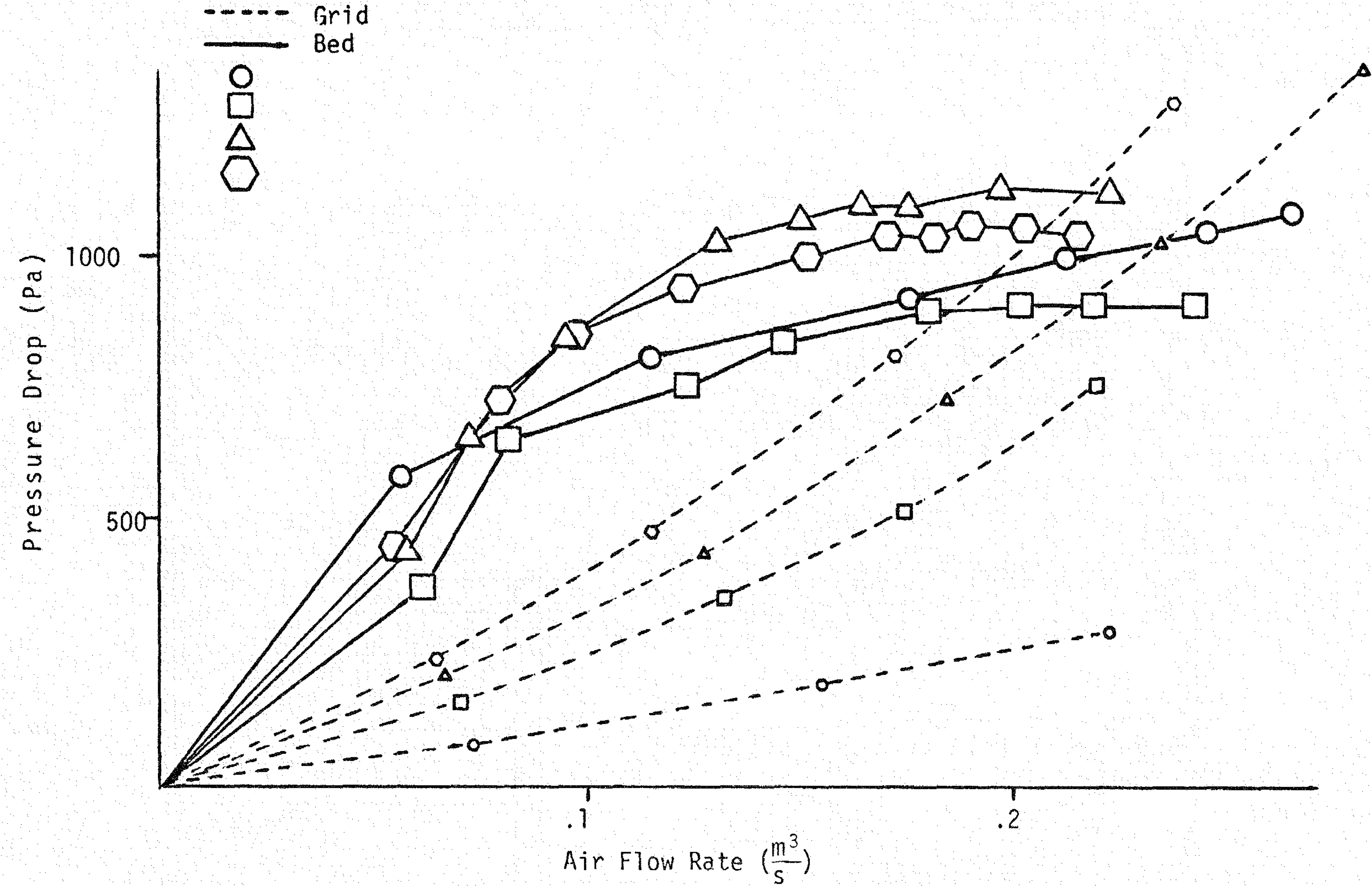

Fig. 5 Effect of Grid Pressure Drop on Fluidization

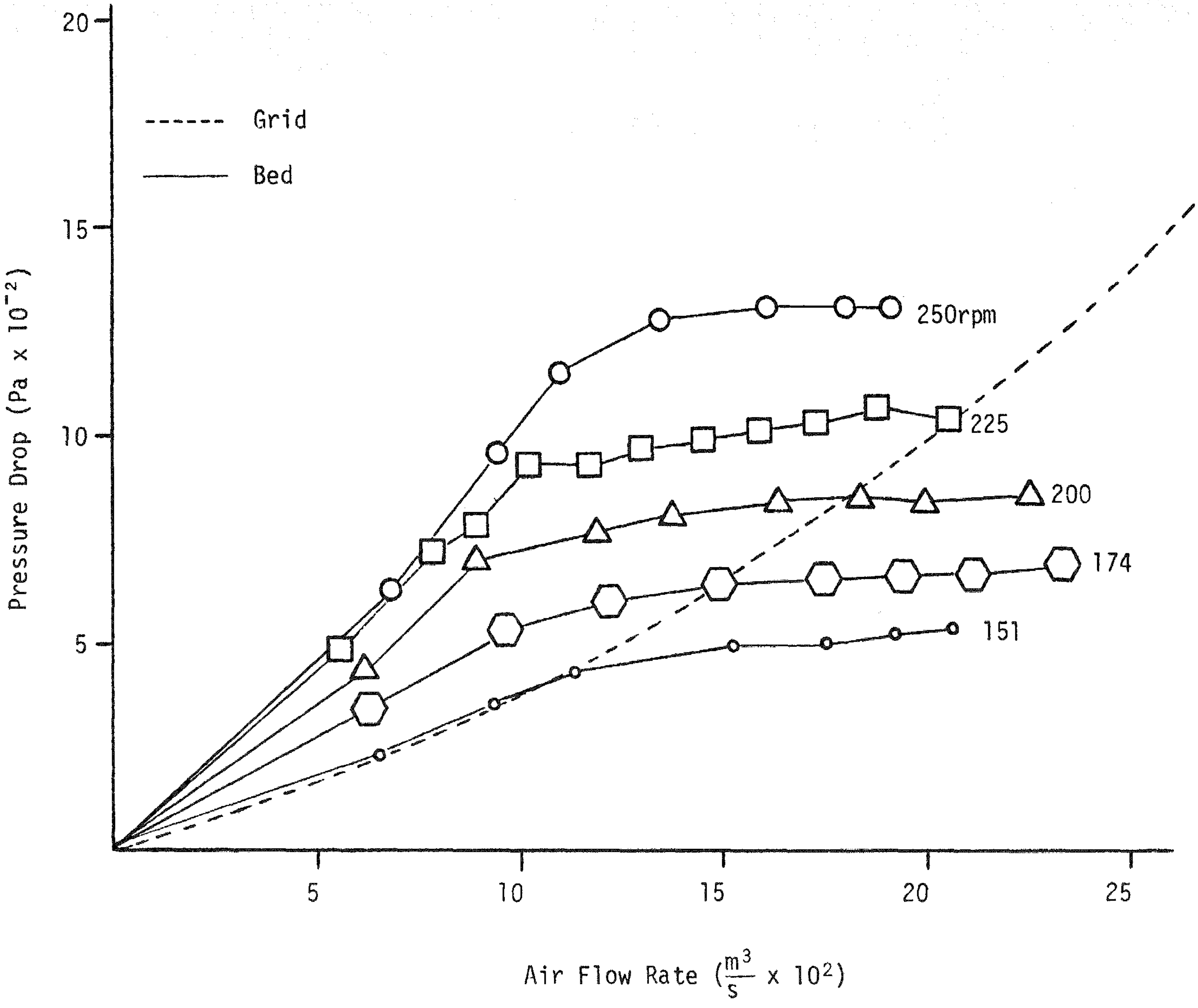

Fig. 6 Effect of Angular Velocity on Bed Pressure Drop

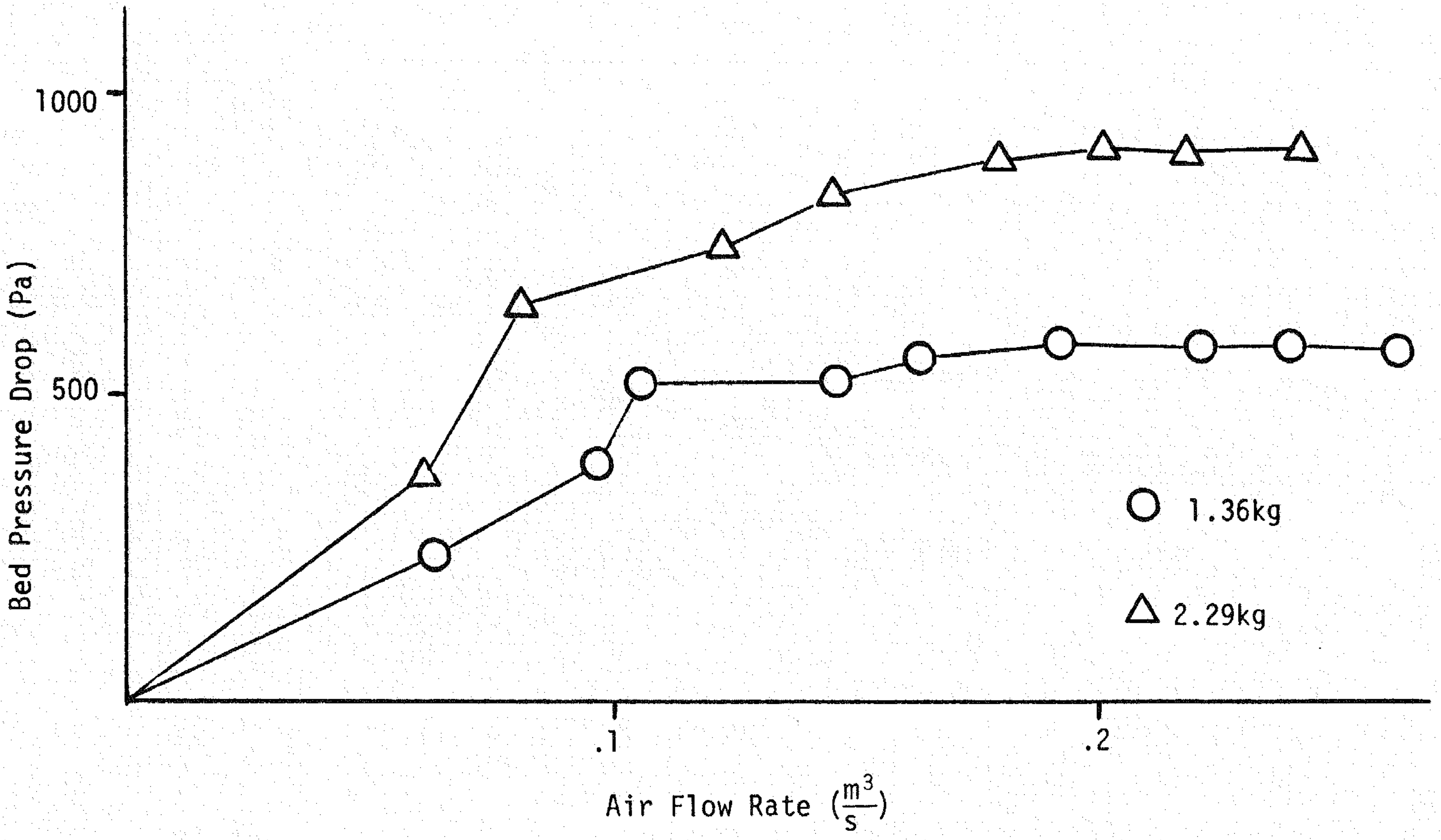

Fig. 7 Effect of Bed Mass on Bed Pressure Drop

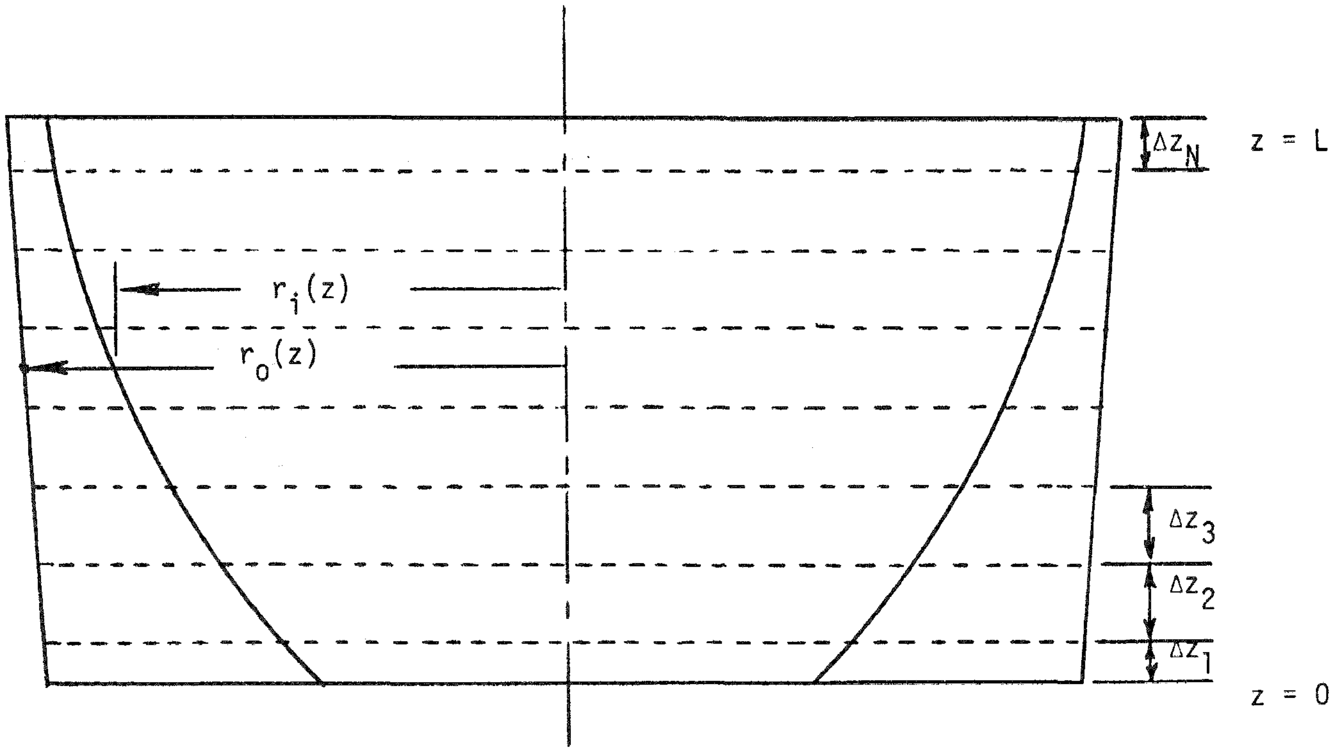

Fig. 8 Model of Bed for Analysis of Minimum Fluidization and Pressure Drop

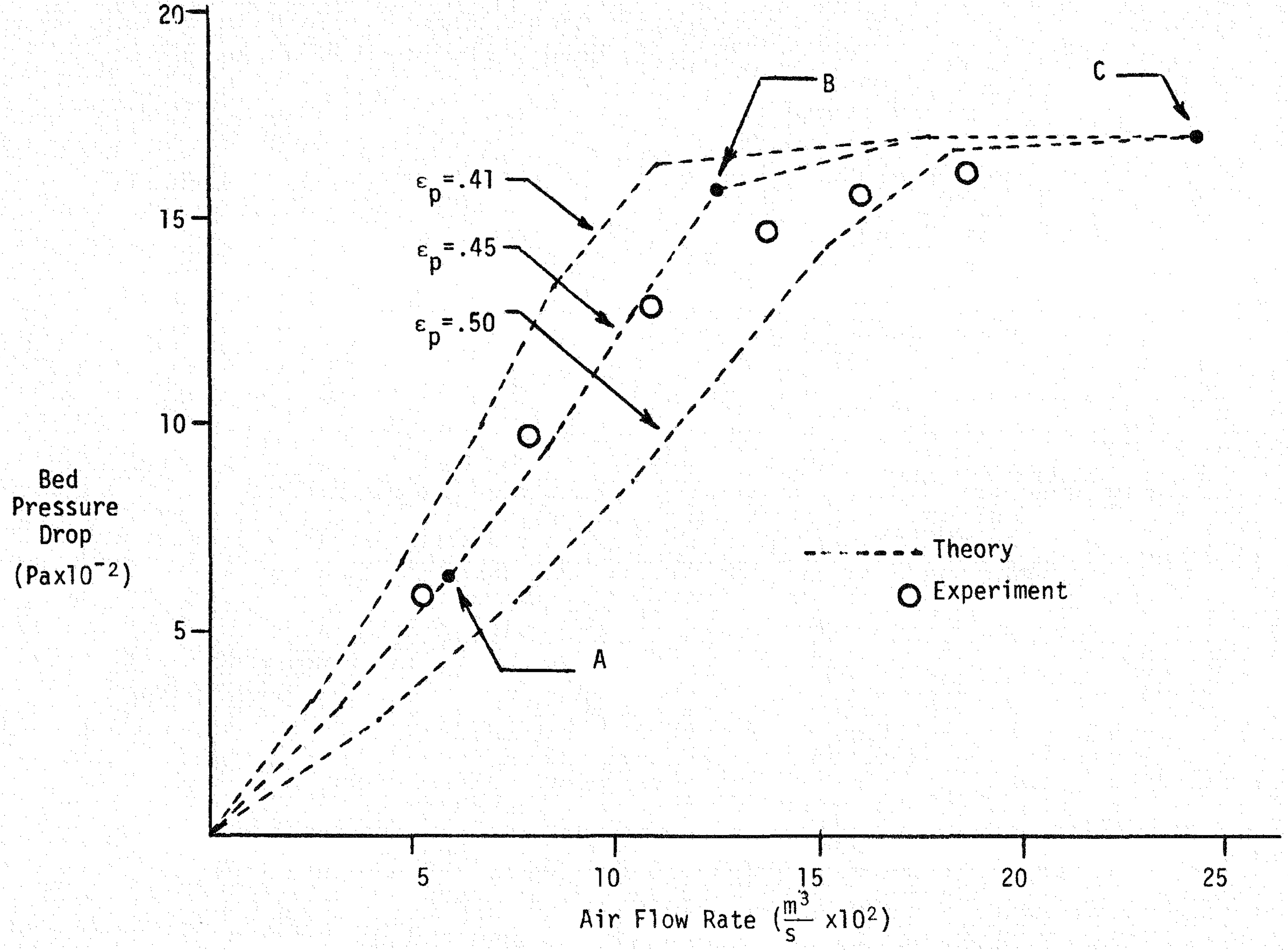

Fig. 9 Variation of Bed Pressure Drop with Air Flow Rate: Comparison of Theory and Experiment

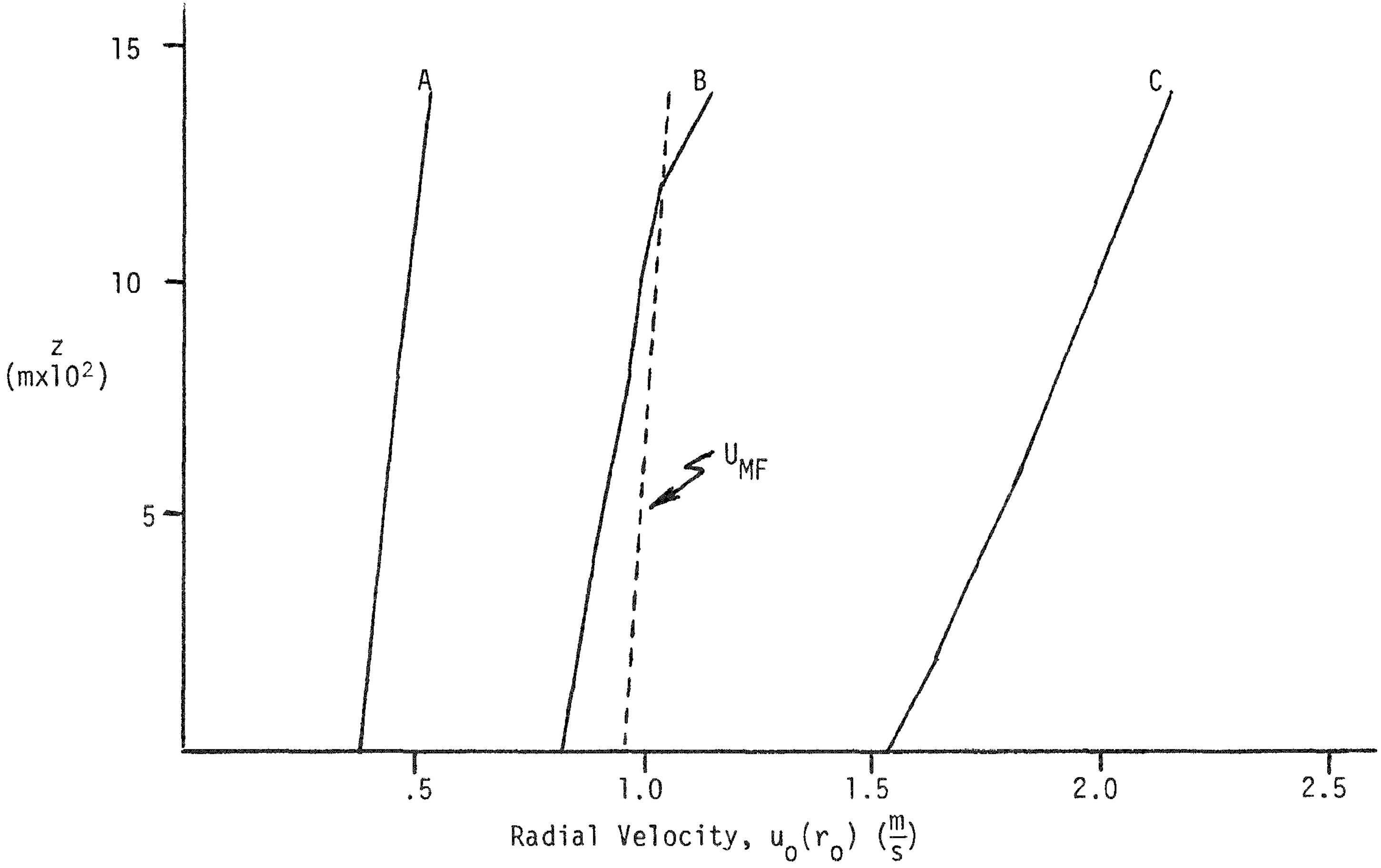

Fig. 10 Computed Variations of Velocity with Vertical Distance

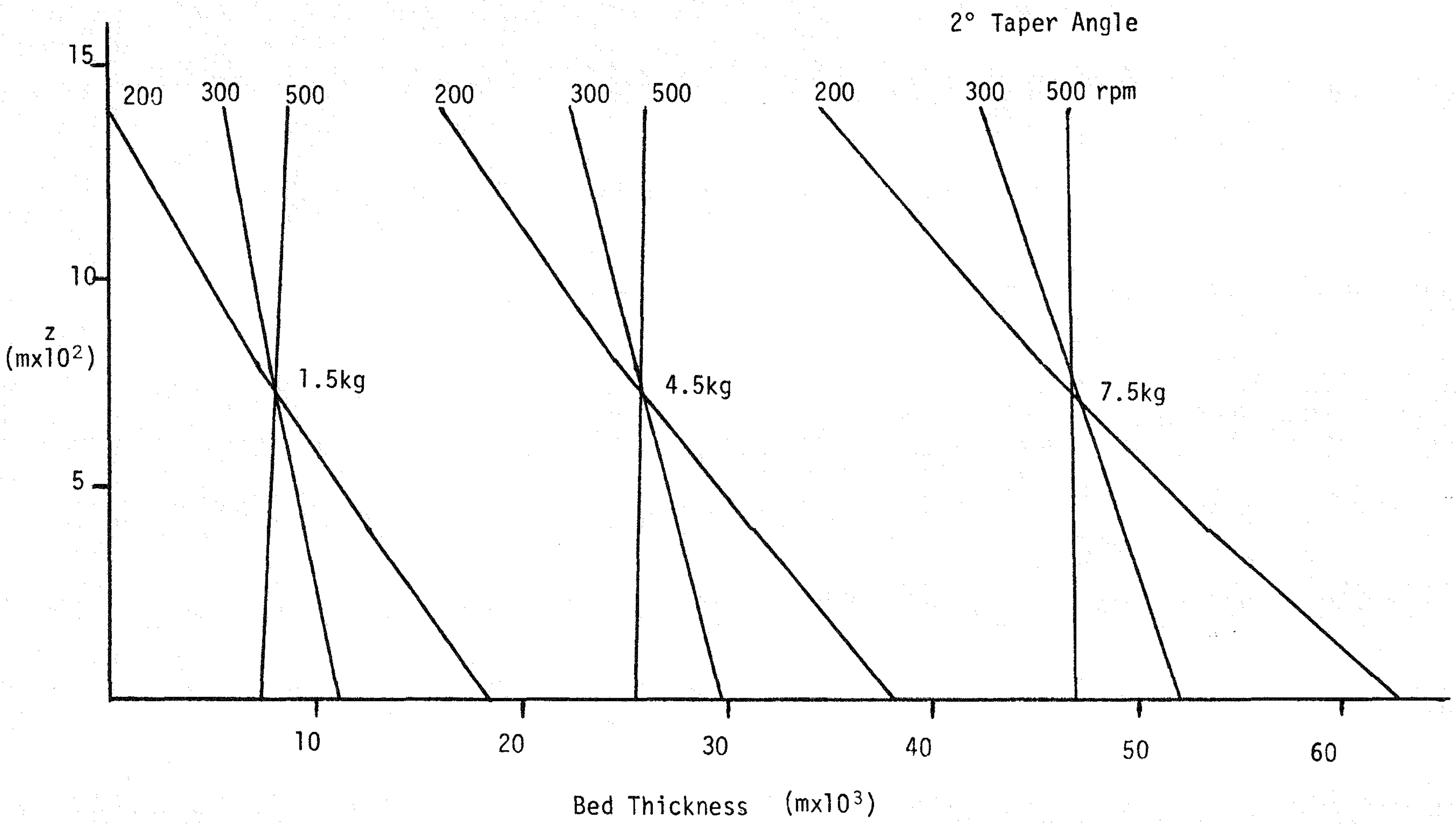

Fig. 11 Computed Variations of Bed Thickness

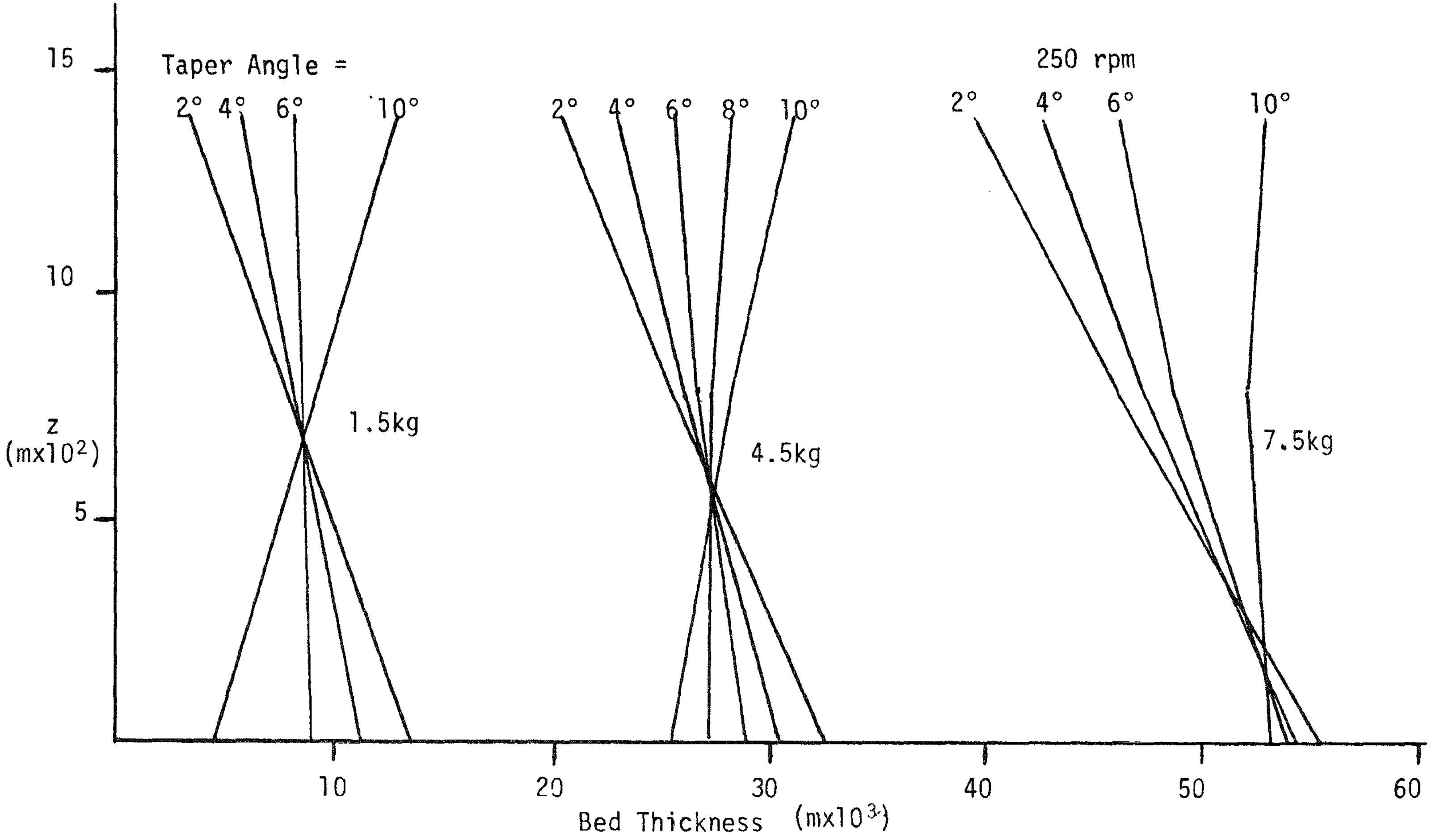

Fig. 12 Computed Variations of Bed Thickness

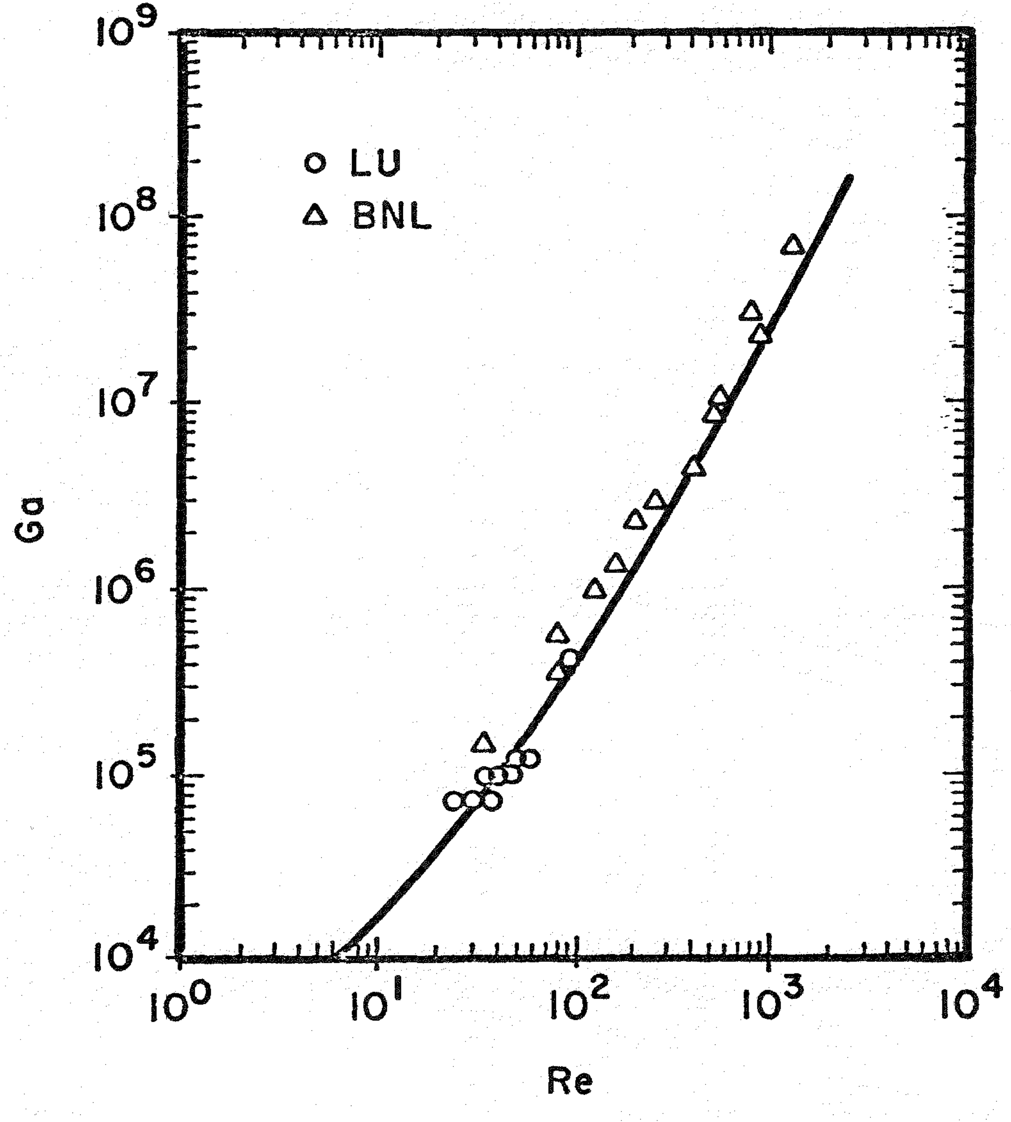

Fig. 13 Minimum Fluidization in Centrifugal Fluidized Beds

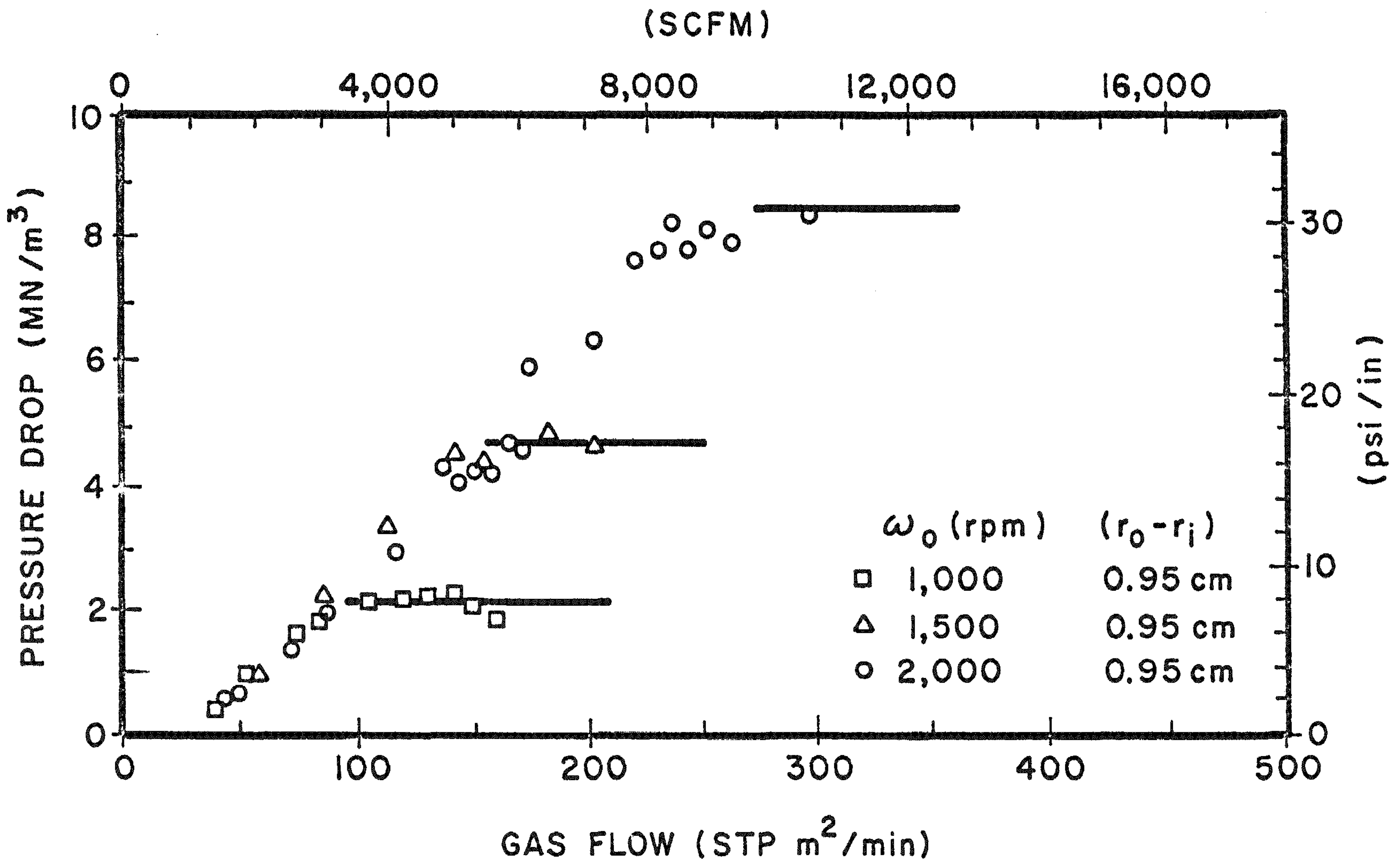

Fig. 14 Bed Pressure Drop; Comparison Between Data from Ref. 2 and Theory

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