MASTER

Progress Report

Venturi Design for Metering Solids Flow
in
Gas-Solids Suspensions

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C. T. Crowe, Principal Investigator

Mechanical Engineering Department
Washington State University
Pullman, Washington 99164

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The objective of the contract is to investigate the possibility of extending the usefulness of the venturi as a gas-solids meter for larger particle sizes by modifying the inlet geometry. Also, the adaptability of the annular venturi to metering gas-solids flow is also under investigation. The venturi tests are to be performed with a laser-light attenuation system at the venturi throat to assess the adequacy of such measurements to provide an independent measure of solids loading.

The contract is subdivided into three tasks and the progress in each task is outlined below.

Task A The objective of this task is to investigate the influence of venturi approach angle on the meter's sensitivity to solids loading. Under this task, venturi meters with two approach angles (6° and 3° half angles) and two β -ratios (.5 and .7) are to be tested using pulverized coal and limestone over a range of Stokes numbers from .1 to 100.

These tests were the first to be carried out. Prior to the execution of these tests, a laser attenuation system had to be designed, fabricated and installed. The original system used one photovoltaic cell and it was found that the system was overly sensitive to temperature and extraneous light. The preliminary tests gave inconsistent and unreliable data. It was also discovered that the magnitude of the attenuation was such that the output signal was too small for accurate measurements. At this point, the testing program could not be continued until a viable attenuation system could be developed.

It was decided to use two photoresistive cells, one cell to serve as a reference cell. The photoresistive cells effect a change in resistance with incident light. A simple schematic of the system selected is shown in Fig. 1. The input voltage is adjusted to initially null the system. The two cells are also thermally connected to minimize thermal effects. This arrangement has been tested and works very satisfactorily. Calibration tests show a linear variation of voltage with light intensity and with voltage outputs of up to 10 volts and no apparent thermal effects.

The system was redesigned, constructed and mounted on the test rig as shown in the photograph in Fig. 2. One can easily distinguish the two photocells, laser and venturi section. This system has been tested with pulverized coal flowing in the venturi. There is a remarkable linearity between particle mass flow rate and light attenuation as detected by the system and shown in Fig. 3. The fact that the light intensity ratio, I/I_0 , does not extrapolate quite to unity at zero mass flow rate is owing to a small accumulation of coal dust on the surface. This measured

Fig. 1 Schematic of light-attenuation system.

Fig. 3 Light attenuation versus particle mass flow rate.

Fig. 2 Photograph of Light Attenuation System installed on test rig.

linearity and sensitivity is extremely encouraging for the development of a metering system which uses light attenuation and pressure drop data to yield, simultaneously, the mass flow rates of the solids and gas separately.

An example of the data now being obtained for pressure drop versus loading is shown in Fig. 4. These data were obtained for the 6°-half angle nozzle with a β -ratio of .7. The Stokes number is approximately 1.5 (awaiting an accurate measure of particle size). One notes a very linear response of pressure drop with loading which is consistent with data taken in this program and all previous programs. The reduced pressure ratio, $(\Delta P_{TP}/\Delta P_G - 1)/Z$ is .83 (unity being equilibrium flow) which is reasonable for this Stokes number range.

The execution of Task A was delayed because of the developmental problems with the laser attenuation system. These problems have been overcome and a reliable system is now in use. The testing program is now proceeding at an accelerated rate.

Task B The goal of Task B is to use the quasi one dimensional numerical model developed at WSU to determine the optimum inlet geometry for maximum sensitivity of the venturi to solids loading at high Stokes number representative of limestone transport to a fluidized bed. This venturi configuration is then to be fabricated and tested with limestone powder up to Stokes numbers of 200.

Pulverized coal
 $St \approx 1.5$
 Inlet half-angle = 6°

$$\frac{\Delta P_{TP}}{\Delta P_G}$$

Fig. 4 Measured Pressure Drop vs. Loading for 6° - approach angle.

The task was initiated by updating the numerical model to include wall friction effects and variable upstream geometry. Various geometries were put into the program and the resulting predicted sensitivities to solids loading were compared. It became evident that the optimum nozzle entrance contour in a given length is one in which the gas velocity is a maximum over the given length. The contour which would achieve this condition would be a sudden contraction section followed by a constant area duct in the given length. However, this configuration would lead to undesirable head loss of the conveying gas due to separation at the corner. Thus, the design which avoids the head loss due to separation but which provides the maximum gas velocity in a given length is the flow nozzle configuration. The converging section geometry is an ellipse which matches smoothly with a constant area duct corresponding to the β -ratio of the nozzle.

The result of a calculation to compare the pressure drop of an optimum entrance configuration with a 6°-half angle converging section of the same length is shown in Fig. 5. This calculation was performed for limestone powder with a Stokes number of 200. One notes a marked improvement in sensitivity (pressure drop vs. loading) of the optimum nozzle. This nozzle configuration will be fabricated now and tested later in the program.

This task is on schedule.

Task C The objective of this task is to investigate the adequacy of the annular venturi as a gas-solids flow meter. The advantage of the annular venturi is the fact that the calming length upstream can be shortened, allowing use in length-limited systems. The test will be done with the annular venturi five diameters and twenty diameters (conventional) downstream of an elbow in the system.

This task was begun by modifying the quasi one dimensional model for the annular geometry and to incorporate wall-friction effects. The predictions illustrated that, even though the surface area of fluid contact is higher for the annular venturi, the pressure drop due to wall friction is small compared to the pressure drop due to the area change.

Based on these numerical studies, an annular venturi has been designed and fabricated. A photograph of the completed venturi is shown in Fig. 6. The venturi is fabricated from plexiglas and the plug from aluminum. Pressure taps are located in the wall adjacent to the constant area annulus. The downstream section of the plug and pipe are designed to maintain a constant flow area as the flow proceeds toward and through a throat section where the laser attenuation measurements will be made. Because of wall curvature and the importance of maintaining a circular cross section for the plug, it was not feasible to carry out the attenuation measurements

Fig. 5 Comparison of pressure drop predicted for optimum and conventional venturi.

Fig.6 Photograph of Annular Venturi (with Plexiglas test plug)

in the vicinity of the pressure taps. The whole system can be easily assembled and adjusted.

This task is somewhat ahead of schedule.

Other Activities

An Alpine MZ100 particle size classifier is being used to obtain different particle sizes to test over a range of Stokes numbers. This is a new piece of equipment, purchased on another contract, and acquired last summer. The equipment is manufactured in Germany and it was found that a motor was incompatible (50 Hz) with our electrical power source. Some effort was spent in rectifying this problem and doing shake-down tests for equipment operation. The system is now working well and being used routinely.

An Alpine Mill was purchased on this contract and set up in the laboratory. This mill is now also being used routinely.

In December the principal investigator traveled East and consulted with the industrial and government resource personnel. Fruitful discussions were held with Dr. William Managan of Argonne National Laboratory. Some useful ideas were interchanged concerning the direction of the program and the operation of the respective

flow loops. Mr. C. Tom Carrol of Foster Wheeler Energy Corporation was ill the day of the visit, but discussions were held with Mr. W. McAllister and J. Starr. The pressing need for solids metering devices to operate under high pressure and temperature conditions was very evident.

Personnel

During the first semester, two graduate students were employed quarter-time on the contract. Mr. Alan Payne is conducting Task A. This work will constitute a portion of the experimental study for his doctoral dissertation. Mr. Matthew Werner is handling the annular venturi study and this will be the subject of his master's thesis. Professor D.E. Stock, Associate Investigator, has been assisting with the laser attenuation system. Professor C.T. Crowe, Principal Investigator, is responsible for Task B and overall management of the project.

Scheduling

All systems are now operative and testing is proceeding. Due to the difficulty with the laser attenuation system, the execution of Task A was delayed so the schedule has been revised as shown. Even with the delay, it is anticipated that all tasks will be completed by the end of the contract period. Activity during the summer months will be greater due to the fact that the graduate students will not be taking courses. Work on the final report will commence with completion of Task A.

Expenditures

The following expenditures have been made up to January 31.

DESCRIPTION	EXPENDITURE	TOTAL ALLOCATION
Salaries and Wages	\$4,100	\$ 19,184
Goods and Services	252	2,700
Travel	1,433	1,000
Computer	40	1,000
Equipment	3,000	5,100

The major salary expenditures will be during the summer months.

Revised schedule for completion of contract.

	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
Task A						
(Approach geometry)						
Task B						
(Optimum geometry)						
(Experimental)						
Task C						
Annular venturi						
FINAL REPORT						