Integrated System to Control Primary PM 2.5 from Electric Power Plants

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LSR has completed Task 1, Advanced ElectroCore Electrode Evaluation, and has nearly completed the design of the ElectroCore separator part of Task 2. The conventional ElectroCore separator has been assembled in LSR's laboratory and modified to accept the Advanced ElectroCore's central electrode. Extensive flow testing has been completed to address changes in the flow geometry caused by the electrode and to accommodate achieving the highest possible electrical field strength in the separator.

A set of 19 design drawings were completed and sent to Merrick Environmental Technology, Inc. for review. Merrick has made a number of important design improvements which will be incorporated in the set of fabrication drawings. The ElectroCore fabrication is expected to begin in August 2000.

Advanced ElectroCore Electrode Evaluation

Task 1 involves fitting the conventional ElectroCore separator with a central electrode and evaluating the performance. The conventional ElectroCore, used in the field test at Plant Miller near Birmingham, Alabama, was shipped to the LSR laboratory where it was cleaned and inspected. The unit had been sitting unprotected outdoors and was badly rusted inside and out. After cleaning the unit to the best of our ability, the internal walls of the separator were still very rough compared to when the unit was new. Restoring the unit to its original condition was estimated to cost about $30,000 and take about 16 weeks, so it was decided to modify the test procedures to be able to use the unit in its existing condition. Repairing the unit would put the project over budget and behind schedule.

The rough walls would have little impact on the electrical characteristics or on the details of the flow geometry. It was believed that the rough walls would have a large impact on particle performance because the particles are expected to bounce along the wall before being extracted from the bleed flow outlet slot. The device is designed to prevent particles from adhering to the walls and it would be impossible to keep particles from adhering to the now roughened surface. The approach was to use the unit for evaluating the central electrode installation and to look at the gas flows within the unit but not to use it to measure particle separation efficiency.

The first task was to modify the unit to accept an 8-inch diameter central electrode. The conventional ElectroCore had two end plates. It was deemed very desirable to eliminate these end plates when installing the central electrode. The end plates reduced the gap between the central electrode and the grounded separating electrode and thereby reduced the maximum voltage that could be applied before spark-over occurred. Even if these end plates were made of a dielectric material, such as Teflon®, there was still concern that the plates might eventually become coated with an electrically conductive material, such as damp fly ash, and again reduce the maximum operating voltage.

The second undesirable feature of the end plates is they create horizontal surface area onto which fly ash may collect. By eliminating the endplates, the separators form an unobstructed vertical tube from top to bottom without any horizontal surfaces for fly ash

to accumulate. Eliminating the endplates would also make the separators easier to clean should tests show there is a material buildup on the vertical walls over time.
The conventional ElectroCore was installed with the end plates removed and the 8-inch diameter central electrode installed. The electrode was longer than the separators and extended into the upper and lower end caps. The ends of the electrode were fitted with corona shields made of ¾inch diameter tubing rolled into a torus. The electrode was bottom-supported and electrified from the top through a ceramic feed-through bushing that also acted as a positioner for the electrode. The supports and electrical connections were shielded so that the maximum field strength occurred at the wall of the central electrode within the separating section. Tests showed the maximum voltage obtainable was 110 kV at ambient temperature. No corona was detected prior to spark-over as was desired. This maximum voltage was an 80 percent increase over the maximum voltage obtained earlier when tested with Teflon endplates and without carefully designed corona shields.

Removing the endplates improved the electrical characteristics of the unit but created the opportunity for particles entering the separator near the extreme top or bottom of the inlet slot and proceed directly out with the clean flow without being given time to be separated from the clean gas. It was clear that the inlet slot would have to be modified to prevent this "short circuit" from occurring. The approach used was to block the inlet slot some distance from the end so that the gas and particles would make at least a 180-degree turn in the separator before being lost out the ends of the separator. If the gas was able to make a 180-degree turn then the particles would be able to exit through the bleed flow outlet slot with the bleed flow.

Flow visualization tests were conduced to determine what length of inlet slot would be required to insure that the flow made at least a 180-degree turn. The top of the separator's upper cap was replaced with a polycarbonate sheet so it was possible to see down into the separator. The view though this cap is shown in Figure 1. Flow visualization was accomplished by introducing white smoke though a probe placed in the inlet slot. The smoke generator generated white, non-toxic smoke with particles from 0.3 to 2.5 µm in diameter. In the first set of tests the probe position was moved up and down in the inlet slot and the rotation angle of the flow was observed. These tests were conducted without blocking the inlet slot. The results are shown in Figure 2. The results show, for example, that gas entering the separator 15 inches from the top of the separator makes a turn of 430 degrees (about 1.2 rotations) in the separator before exiting the end with the clean flow. This is essentially independent of the two bleed flow ratios tested. The bleed flow ratio, designated as ß, is the ratio of the flow rate of gas leaving through the bleed flow outlet slot to the gas inlet flow rate.

Figure 2 shows that gas entering closer than about 7 inches from the ends does not make at least a 180-degree turn so particles entering with this gas probably cannot be extracted with the bleed flow. This suggests that the length of inlet slot required to be blocked may be relatively small. In the second set of tests the inlet slot was blocked and the flow observations were repeated. The blocked inlet slot data are shown in Figure 3.

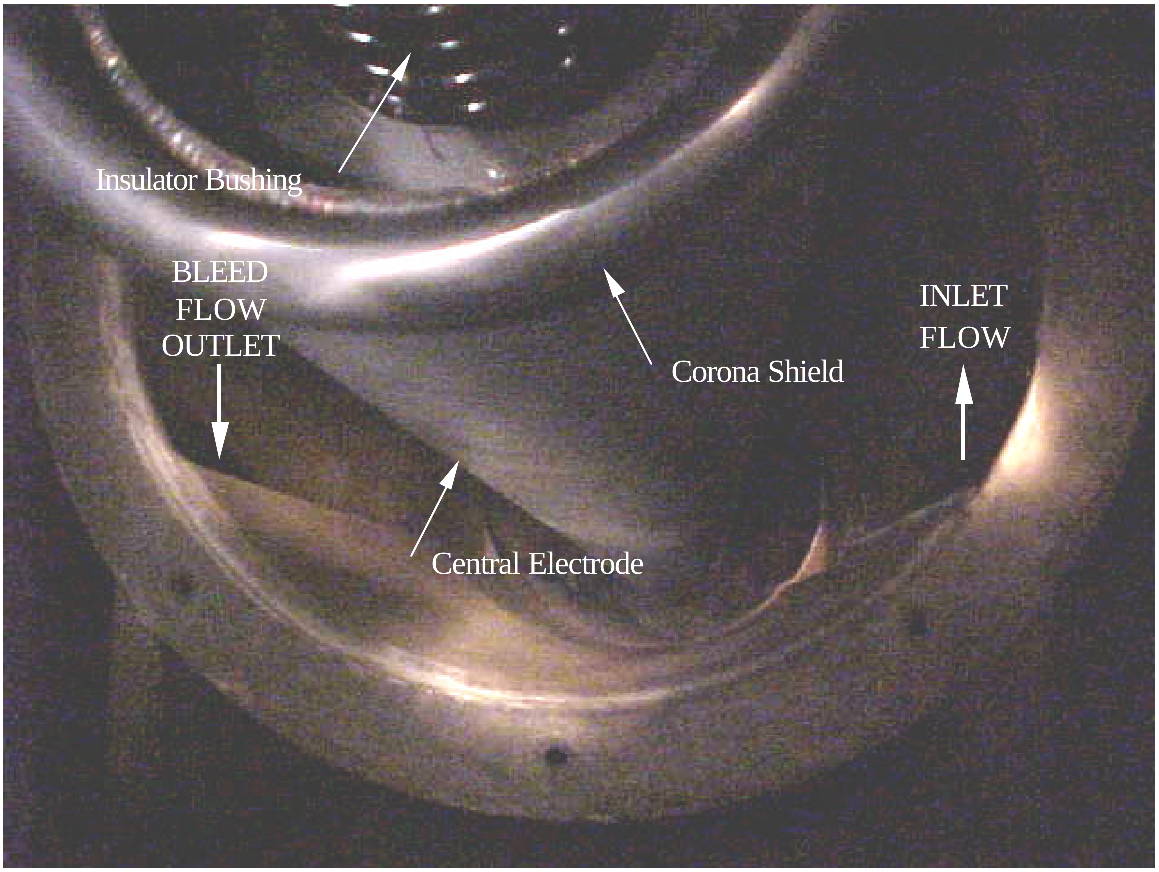

Figure 1: View Looking Down Into ElectroCore Separator Through Polycarbonate Top Cover

In Figure 3 the gas rotation angle indicates the number of rotations the incoming gas makes before leaving the end of the cylinder with the clean flow. If the gas is introduced at the end of the separators, it will leave immediately without making any rotations. As the distance from the end increases, the gas has more time in the separator and therefore makes more revolutions before exiting. The parameter "a" used in Figure 3 is the length of inlet slot that has been blanked off. The smoke test data show the gas rotates about 40 percent of the value predicted by simple theory. For example, if the top and bottom 16.4 inches of the inlet slot are blanked off and operating at a bleed flow ratio of 9.07 percent, theory predicts the incoming gas will rotate at least 575 degrees before leaving the end of the separator. The experimental data showed the rotation was only 230 degrees. At a bleed flow ratio of 15.51 percent theory predicts a minimum rotation of 620 degrees while the experimental data showed 250 degrees. The difference between theory and experimental data is due primarily to viscosity effects not considered by the theory.

The objective is to make sure the gas rotates at least 180 degrees, so a slot blanking distance of 16 inches was selected. In the field prototype the inlet slot length will be 32 inches shorter than the separator length. It will stop 16 inches from each end of the

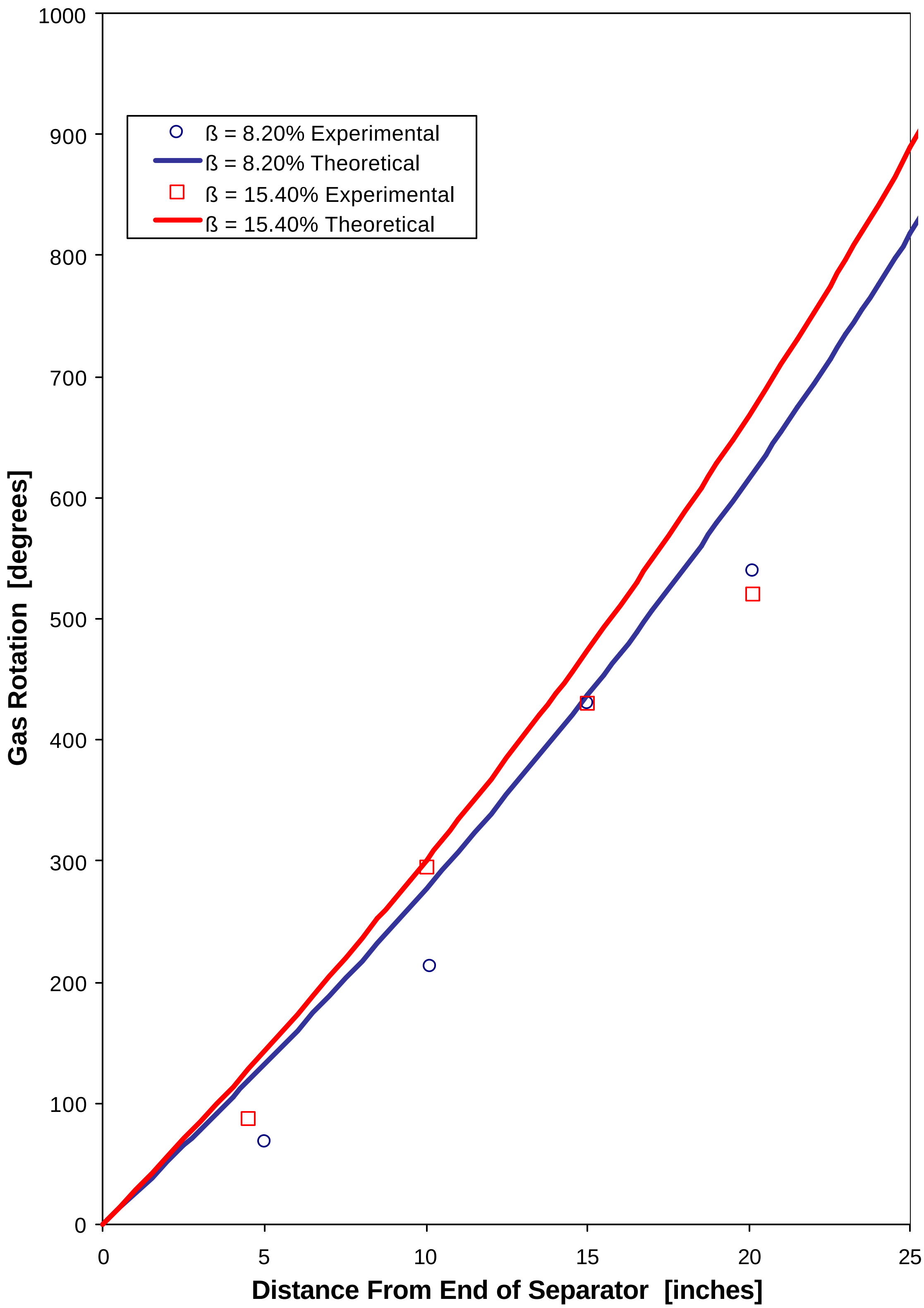

Figure 2: Gas Rotation Versus Distance Introduced From End of Separator – Unblocked Inlet

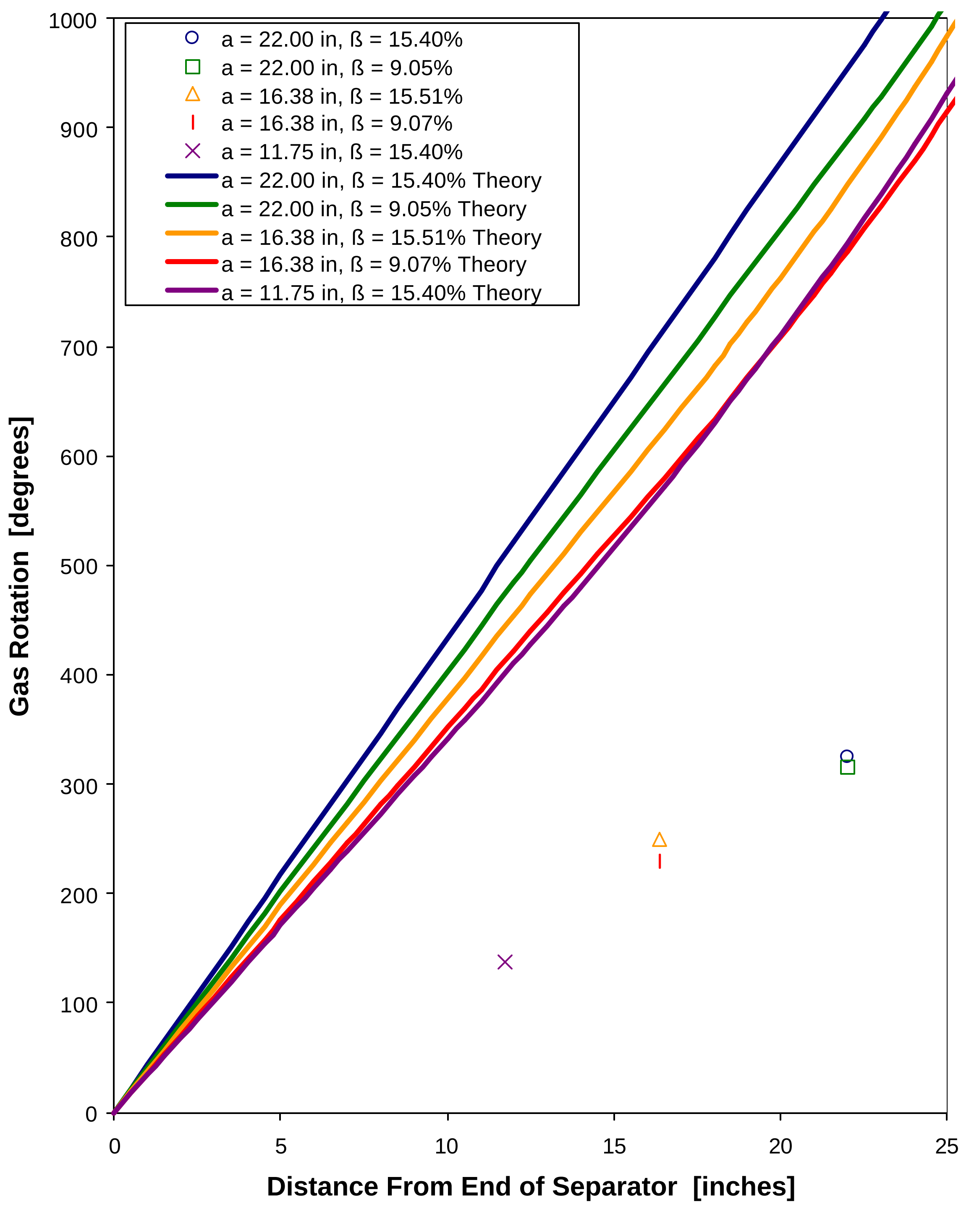

Figure 3: Gas Rotation Versus Distance Introduced From End of Separator – Blocked Inlet

separator. It is important to note that during these tests the flow rate of the clean gas remained constant as the inlet slot was shortened. In other words, the gas inlet velocity increased as the length of the inlet slot was shortened. Once the inlet slot geometry was determined our attention shifted to the bleed flow outlet slot.

It is apparent that, for a constant inlet gas velocity, as the length of ElectroCore separator increases the axial velocity of the gas leaving the end of the separator gets larger as well. This axial gas flow creates an axial pressure gradient. The static pressure is at its maximum at the symmetry plane half way between the two ends and decreases toward each end. Work with the computational fluid dynamics (CFD) computer model showed that if this pressure gradient gets too large, flow begins to recirculate from the bleed flow outlet slot. For large pressure gradients, flow comes back out of the bleed flow slot near the ends where the static pressure is a minimum. This returning bleed flow enters the separator just at the ends and then leaves axially with the clean flow. If, as expected, this flow contains particles then this recirculation zone acts as a pathway for particles to penetrate through the separator. Using both smoke and threads, the flow in the ends of the bleed flow slot was investigated.

The smoke tests were conducted by pushing the smoke probe upstream into the bleed flow outlet slot until it just entered the separator. A small recirculation zone was identified at the extreme top of the slot. The details of the zone were revealed by placing a 1 inch length of thin white tread on the end of a rod and inserting it into the separator through a small holed drilled in the polycarbonate the top cover. Although the zone was small it was decided to segregate this portion of the outlet slot and independently extract bleed flow to see if the recirculation could be stopped and what kind of flow would be required.

A divider that had been slipped into the bleed flow outlet slot segregated the top 4 inches of the slot. The flow in this 4" tall slot was termed secondary bleed flow. Tests were conducted by running at various bleed flow ratios and then determining how much secondary bleed flow was required to just eliminate the backflow. The results are shown in Figure 4.

The results are plotted versus bleed flow ratio. Bleed flow ratio is defined as the sum of the primary and secondary bleed flow divided by the separator inlet flow. What is plotted is the amount of secondary bleed flow just required to stop backflow, so this plot represents a bleed flow stability map. Operating points above the line will have no back flow in the bleed flow slot while points below the line can expect to have backflow occurring. The data have been plotted in two ways. On the left axis the average velocity in the secondary bleed flow slot has been divided by the average velocity in the primary bleed flow slot. On the right axis the results are expressed as the ratio of the secondary bleed flow rate to the primary bleed flow rate.

The data show that a minimum amount of secondary bleed flow is required when the ElectroCore is operated at a 45 percent bleed flow ratio. The maximum required secondary bleed flow occurs at a bleed flow ratio of about 32 percent and in this case the

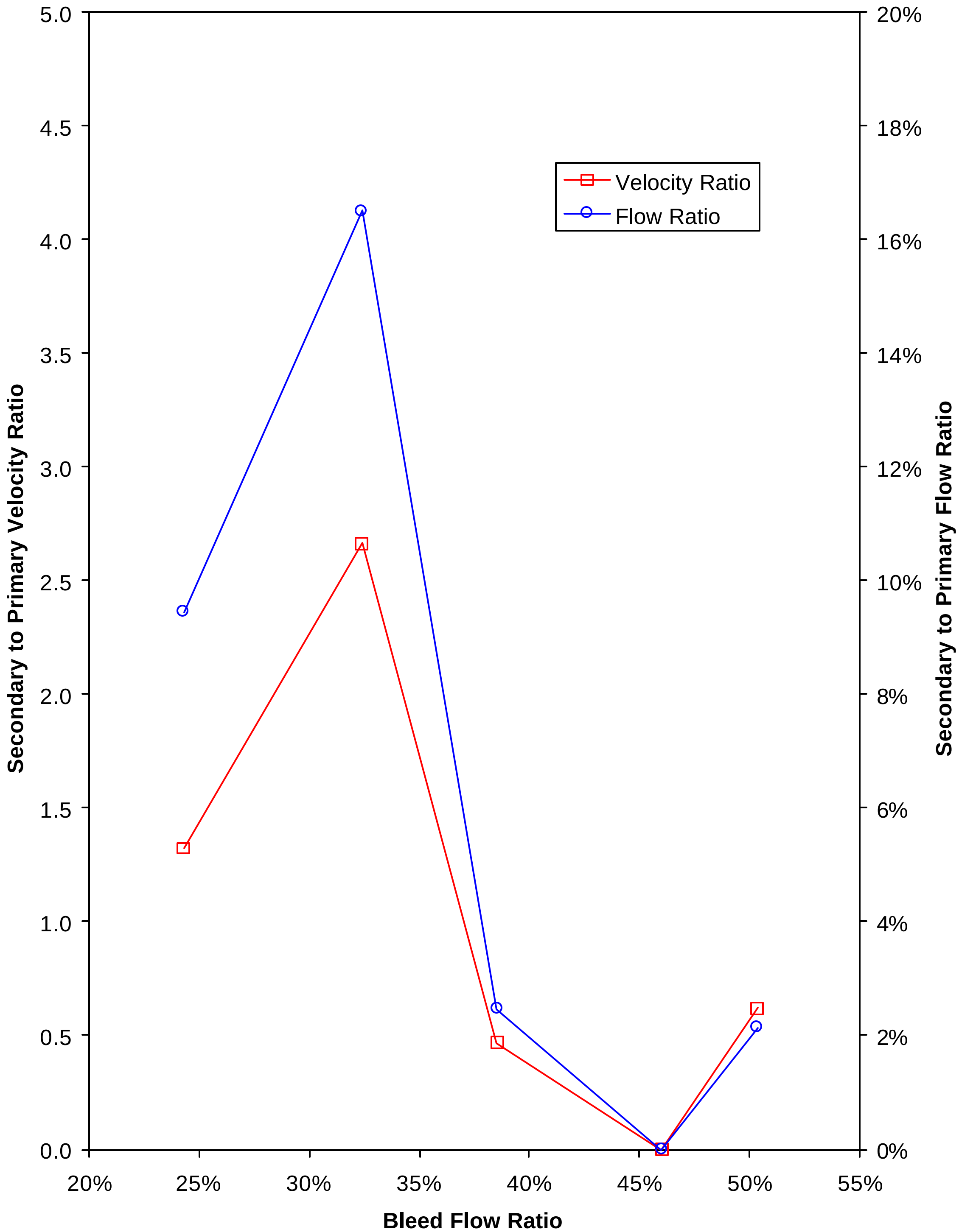

Figure 4: Secondary Bleed Flow Required to Stop Backflow

secondary bleed flow is about 16.5 percent of the primary bleed flow. At lower bleed flow ratios the required amount of secondary bleed flow decreases again.

Up to now, the discussion has been about flow geometry. The important issue however is particle separation efficiency. Backflow in the bleed flow slot is not important if the returning flow contains no particles. There is enough concern about backflow that LSR has decided to build the 5,000 acfm field prototype with the secondary bleed flow slots. They will be able to be "turned off" by connecting the primary bleed and secondary bleed flows together to measure the performance without secondary bleed flow. One of the important tasks in the field test is to determine how best to operate the secondary bleed flow.

Advanced ElectroCore Design

Task 2 in the project is to design the ElectroCore system components. The first component to be designed is the ElectroCore separator. LSR completed a set of 19 drawings of the separator and sent them to Merrick Environmental Technology, Inc. for review. The drawings showed the complete ElectroCore separator and an outline of the support structure. The drawings were a starting point from which Merrick could work to make the separator easier to build and install. All of the technical issues had been addressed in the drawings and therefore offered at least one solution to each of them. Issues included the electrical system supports and power feeds, accommodations for thermal expansion as well as structural strength and initial weight estimates. This set of drawings was also sent to Dr. Ralph Altman at the Electric Power Research Institute for his review. Merrick has made a number of practical improvements in the design to make it more compact, lighter and easier to fabricate. The final change from LSR has been on the details of the inlet and outlet slots. The latest information has been transmitted to Merrick and they will incorporate them into their fabrication drawings. The drawings will be used in bid packages that will go out to local manufacturers in August.

Conceptual design work has begun on the water-cooled particle precharger and the dry scrubber. It is expected that these components will be designed quickly as, unlike the ElectroCore, no technical issues need to be resolved based on the results of laboratory testing.

Work Planned For Next Period

In the next period the designs for the precharger and dry scrubber will be completed. The Advanced ElectroCore, precharger and dry scrubber construction should be nearly completed. Site preparation work will begin to ensure that when the unit arrives at Alabama Power Company's Gaston Station, it will be ready for installation. Prior experience has shown that it is very important to supervise and coordinate with the utility to ensure installation stays on schedule and on budget.