Computer Simulation Saves Time & Expense in Emissions Separator Design

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Computer simulation helped a manufacturer of a unique emissions control system to overcome a challenging problem in scaling up their product, making it possible to get the design right the first time. LSR Technologies, Inc. produces a unique centrifugal particulate emission control device that can often allow companies to meet federal and local emissions requirements without the cost and problems associated with using fabric filters and wet scrubbers. In scaling up their device, LSR engineers were concerned that the extra length of the separator might cause a reverse flow condition. To avoid the expense and lead-time involved in building and testing a prototype, they used computational fluid dynamics (CFD) to visualize the flow inside the separator. The simulation showed that simply scaling up their existing design would indeed create reverse flow, so they analyzed a number of alternative designs. The final design, which added a second cylinder to the main cylinder, worked perfectly at the larger size.

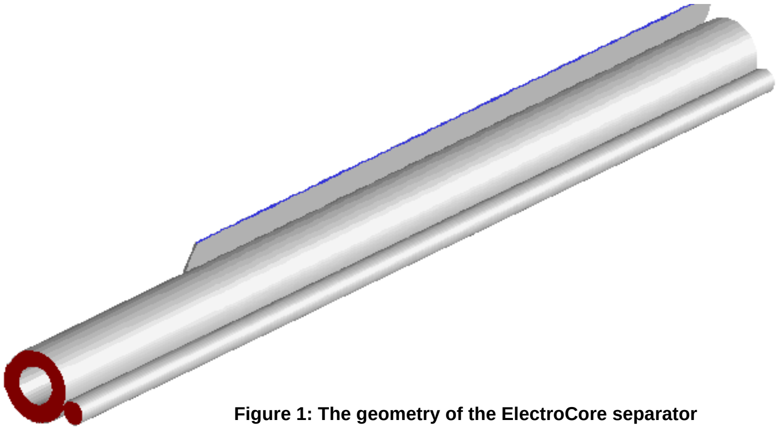

Figure 1: The geometry of the ElectroCore separator

LSR's Core Separator System

The LSR Core Separator is a high-performance particulate control system designed to remove micron and submicron particles entrained in gas streams using a unique recirculation method. The technology overcomes the performance limitations inherent in cyclones by performing the tasks of separation and collection in two separate components. Each unit has a single inlet for the stream to be treated and two outlets, one for the cleaned gas stream and the other containing a concentrated particulate recirculation stream. In operation, gas containing fine particulate matter is introduced through a tangential rectangular inlet. The particle-laden gas develops a rotating flow pattern through the main annular chamber. Because of the centrifugal force on the rotating particles, they tend to move toward the outer wall of the cylinder. The particles then leave the cylinder through a tangential exit on the side opposite the inlet along with a small amount of the gas, which becomes the recirculation stream. The recirculation stream is directed to a conventional collector for removal of the particles from the system while the gas flows to the separator inlet. The dust particles recirculate

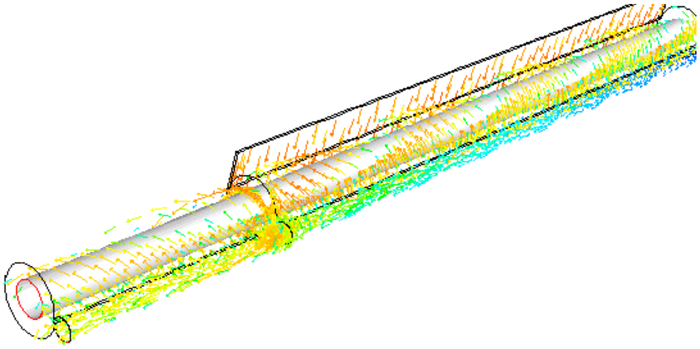

Figure 2: Velocity vectors throughout the device

repeatedly through the separator until they are collected. Clean gas leaves the cylinder through the "vortex finder" annular outlets at both ends of the cylinder.

Meeting emissions requirements at a lower cost

The performance of the LSR Core Separator is comparable to that of much more complicated, expensive, and difficult to maintain technologies. This is because particle entrainment is reduced by the fact that the device functions only as a separator, avoiding the need for a change in flow direction. In addition, its smooth, cylindrical shape helps to prevent vortex formation. The Core Separator provides an unusually high price to performance ratio with a typical 94% to 99% overall collection efficiency and a cost of less than $3 per cubic meter per hour. On the other hand, cyclones have a lower cost but their collection efficiency of only 75% to 85% generally means they can't meet most emissions requirements. Baghouses, the other primary alternative, offer only a slightly higher efficiency than the Core Separator, but at a significantly higher cost, sometimes up to three times as much. As a result, over sixty Core Separator systems have been placed in operation around the world.

LSR has recently developed a new version of its separator, called the ElectroCore, with electrostatic enhancement added to increase the separation efficiency of the device. The initial installations of this device were about 10 feet in length and performed very well. When the company began to investigate using a larger unit, about 30 feet long, LSR engineers were concerned that scaling problems might hurt its performance. The primary concern was that the longer cylinder could generate a significant pressure differential caused by friction losses as the flow moves through the cylinder. This pressure differential could in turn, in theory at least, cause a reverse flow condition that could reduce the separation efficiency of the device. The cost of building and testing a prototype device would have been very high because it would have had to be built to 100% scale in order to accurately measure the pressure differentials. Even if that step were taken, testing the prototype would provide relatively little of the information needed to improve the design because engineers could only measure flow conditions at the few points where they could position sensors.

Simulating flow on a computer

LSR engineers had previously used CFD to analyze and improve their basic separator designs and felt that it would provide the ideal tool for validating the ElectroCore. CFD simulation provides fluid velocity, and pressure and temperature values throughout the solution domain with complex geometries and boundary conditions. As part of the analysis, a designer may change the geometry of the system or the boundary conditions such as inlet velocity, flow rate, rotational speed, etc. and view the effect on fluid flow characteristics. CFD is an effective tool for generating detailed parametric studies, making it possible to evaluate far more design alternatives than the "build and test" method and thereby providing

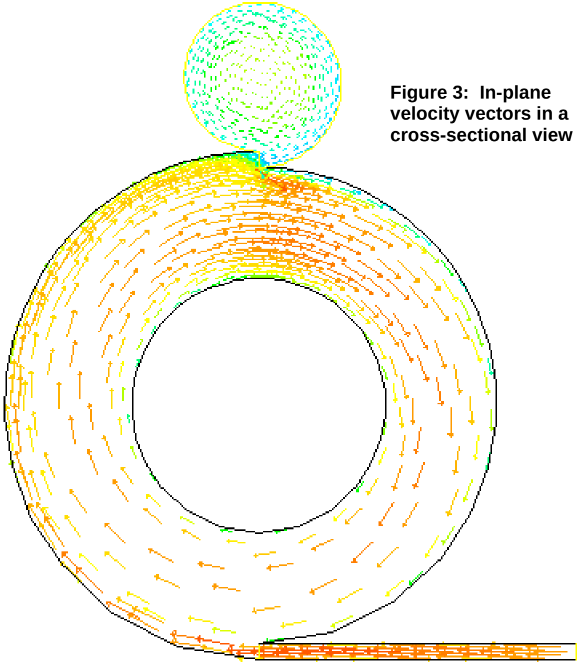

Figure 3: In-plane velocity vectors in a cross-sectional view

opportunities for optimization. Another advantage of CFD is that it provides more complete information than physical testing, including color-coded graphics that depict flow direction and velocity in all relevant locations. This helps designers gain more insight into the reasons why a design is performing as it is, which enables rapid design improvements.

LSR selected FLUENT software from Fluent Incorporated, Lebanon, New Hampshire, to perform the analysis for three basic reasons. First, LSR engineers have found that FLUENT provides exceptionally good results with the rapidly swirling flows that are a basic feature of any analysis of their devices. Another advantage of FLUENT is that it's easy to create user-defined subroutines. In this application, LSR calculated the strength of the electrostatic fields in the device and introduced a subroutine to apply an equivalent force as a function of the spatial coordinates. Finally, FLUENT provides the ability to easily introduce initial conditions, which in this case were calculated by a rough analytical solution.

Evaluating design alternatives

LSR engineers created a highly detailed geometry of the longer separator using the Gambit preprocessor and ran the simulation on a 450 MHz personal computer overnight. The analysis of the original design showed that reverse flow would have indeed been a serious problem if the larger separator had been built without analysis. LSR engineers modified the original design to evaluate a wide range of alternatives. The one that worked best was adding a second smaller cylinder that the particle-laden gas flows into after leaving the tangential exit of the main cylinder. The smaller cylinder has a circular outlet at one end that allows for removal of gas and particles. The flow in the smaller cylinder develops an axial pressure that counteracts the pressure differential in the main cylinder, eliminating reverse flow.

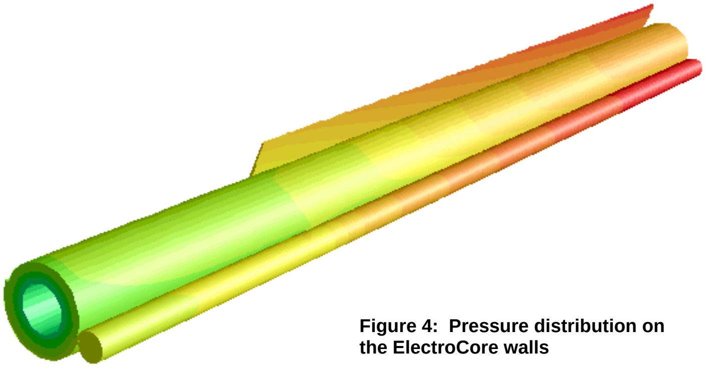

Figure 4: Pressure distribution on the ElectroCore walls

The accompanying illustrations show the detailed design information that was obtained from the CFD analysis. The flow enters through the narrow rectangular inlet and swirls around the solid central electrode before entering the smaller cylinder and moving axially toward the exit. The main gas stream flows around the electrode in the middle, and part of the flow passes into the second chamber. The flow that enters the smaller chamber has a high particle concentration, due in part to the centrifugal forces acting on the particles and in part to the radial electric field that results from the cylindrical anode at the core of the main cylinder and grounded cylinder walls. The passage between the two chambers is in a region where high fly ash/dust loading is expected. The effect of swirl on the flow field turbulence is included in the model.

Contours of static pressure on the walls of the separator show the axial pressure gradient that develops in the smaller cylinder as the particle-laden gas turns and flows towards the exit. This pressure gradient prevents the particle-laden gas from back-flowing into the main chamber. The particles illustrate both the swirling pattern in the main chamber as well as the axial pressure gradient in the smaller cylinder. By introducing the adjacent cylinder and studying the behavior of particle path lines for each of the candidate designs, engineers could optimize the design at relatively low cost. The resulting improvement in the system's particulate control was essential for the separator's success on the market. Without the benefit of the CFD simulations it would have been virtually impossible for the engineers at LSR to set up repeated experiments in order to get optimum particle separation.

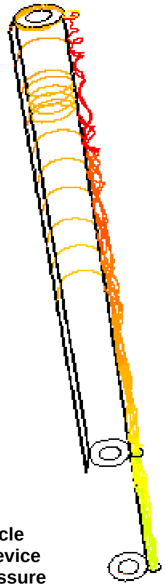

Figure 5: Particle tracks in the device colored by pressure