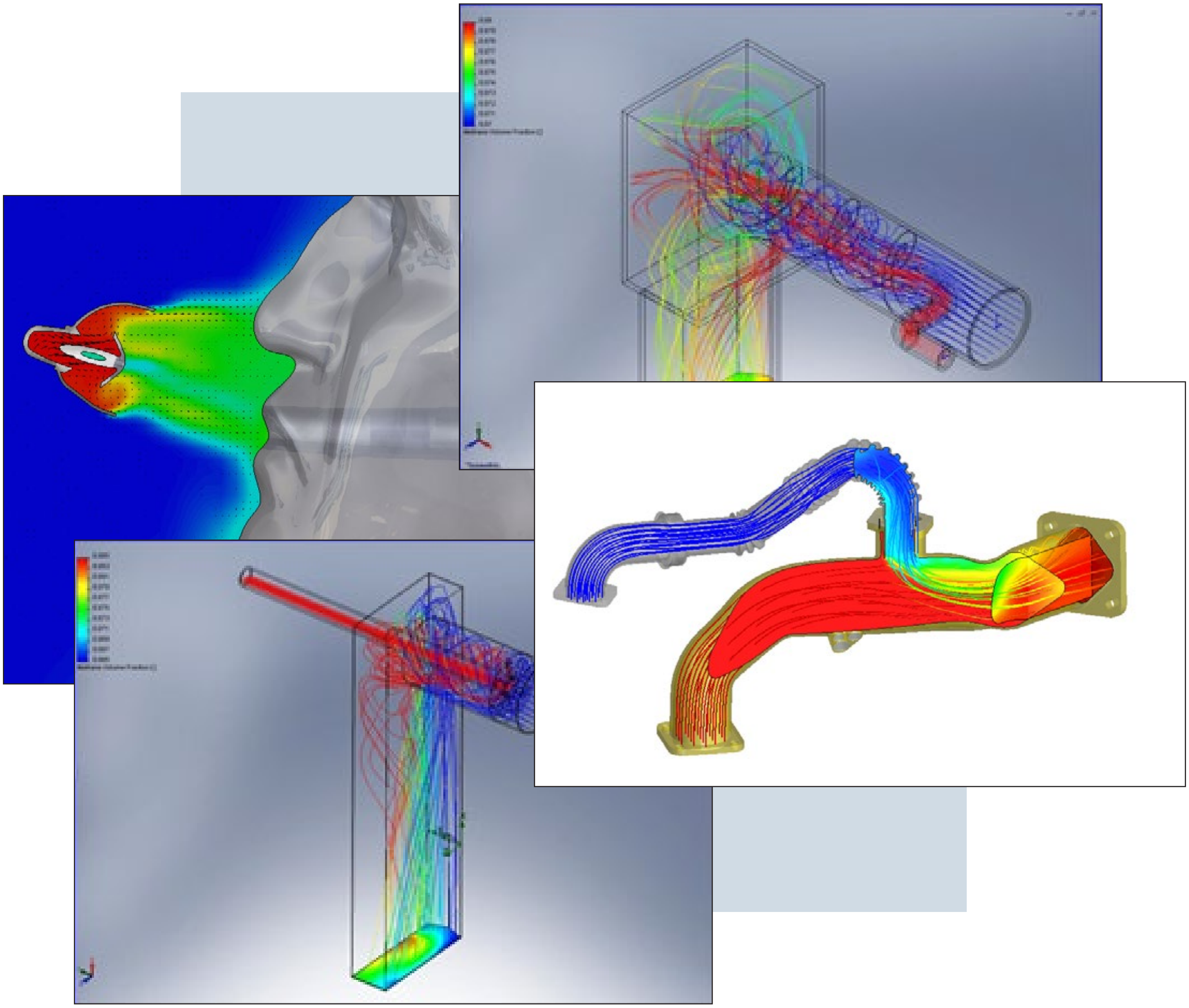
Optimizing Gas Mixing Processes with CAD-Embedded Engineering Fluid Dynamics Simulation

White Paper



BEST PRACTICES FOR CFD ANALYSIS IN GAS MIXING WITH SOLIDWORKS FLOW SIMULATION

The mixing of gases is important in a wide range of applications. For example, gas mixing in flues is often critical to the operation of emissions control systems. Gas mixing in packed columns and other types of chemical reactors affects throughput and variability of the process. Gas mixing has a major impact on the performance of rotary kiln incinerators used to treat hazardous wastes. Gas mixing in respiratory airways influences the performance of aerosolized medications. An improvement of just a few percent in mixing efficiency can substantially reduce the energy consumption and emissions of a low-NOx burner.

Optimizing gas and air mixing to meet the requirements of a specific application is a challenging process that normally involves a very expensive and time-consuming process of building and testing prototypes. Large companies have used computational fluid dynamics (CFD) to simulate gas mixing but its use up to now has been primarily limited to research or troubleshooting existing designs because of the considerable cost, time and expertise required to use CFD technology.

But in the past few years new CFD tools have become available that are fully embedded in the mainstream mechanical design environment so they are much easier, faster and less expensive to use. The new tools provide the ability to evaluate the performance of a large number of potential alternatives in the early stages of the design process. Early stage analysis makes it possible to improve the performance of the product and resolve design problems in less time at a low cost. This article provides guidelines for using CFD to improve gas mixing in the early stages of the design process.

Importance of gas and air mixing

Competitive and regulatory pressures are forcing manufacturers of combustion equipment to improve energy efficiency, reduce environment emissions, improve control and provide greater fuel flexibility. The key to this challenge is improving the performance of burners which are an integral part of all combustion systems. Even small improvements in performance can have a major impact on systems that operate continuously and consume large amounts of energy.

Fuel and air mixing plays a critical role in the design of nearly every burner. A major design challenge in many applications is injecting the gases so that near-ideal mixing is achieved. Mixing is important because uneven concentrations of air and fuel can substantially increase emissions levels and reduce combustion efficiency. The very thorough mixing of gas and air eliminates the hot and cold spots in the flame that are responsible for NOx emissions.

Change in gas and air mixing design methods

Until recently, designing for proper gas mixing was considered to be more of an art than a science. The traditional approach is to build a prototype or modify an existing product, test the product and then, based on the results, modify the prototype or product until desirable results are achieved. The problem with this approach is that the building, modifying and testing the prototype is often expensive and may take a considerable amount of time. Another concern is it may be expensive to shut down a product that is used in a continuously operating process such as power generation for modification and testing.

More recently, improvements in experimental and analytical tools have made it possible to replace hardware prototypes with software prototypes that accurately predict the performance of design alternatives. Engineers use CFD to simulate the operation of the product under conditions that are representative of its use in the field. A CFD simulation typically provides far more information than can be obtained from physical testing such as fluid velocity and direction, pressure, temperature, and species concentration values throughout the solution domain. As part of the analysis, a designer may change the geometry of the system or the boundary conditions and view the effect on fluid flow patterns. For these reasons, CFD enables the analyst to evaluate the performance of a wide range of different configurations in a shorter amount of time and at a lower cost.

Trend towards embedded CAD

The recent trend towards the use of CFD software that is embedded in the CAD system makes it possible to use simulation in the design phase in order to examine more design alternatives than would be practical with physical prototyping while reducing the number of prototypes required. CAD-embedded CFD's use of native 3D CAD data, automatic gridding of the flow space, and managing the flow parameters as object-based features eliminates the need for engineers to understand the computational part of CFD and instead enables them to focus on the fluid dynamics of the product which is already their responsibility to understand and master.

The newest generation of CFD software contains sophisticated automatic control functions that ensure convergence in almost every application without the need for manual tuning. Perhaps the most important function controls the quality of the mesh to avoid one of the biggest reasons for run divergence. As a result, the skills required to operate the CFD software are simply knowledge of the CAD system and the physics of the product, both of which the vast majority of design engineers already possess. Automating of these steps also greatly reduces the time required for analysis, making it possible to deliver results before the design has changed.

Simulation guidelines for gas mixing

Several best practices can help ensure the accuracy of CFD gas and air- mixing simulation. The utilization of native 3D data places a premium on the quality of the solid model. For an internal flow model with minimum mesh requirements the solids must form a sealed internal space with no leak paths outside the internal flow field. Minute details of the geometry should be eliminated wherever possible to keep the CFD model size to a minimum. After the geometry is imported, it should be checked for problems using the "check geometry" feature in the CFD software. Check for irregular cells, caused by holes in a thin solid, by performing a trial mesh generation and visualizing the irregular cells with the post-processor. Irregular cells can then be corrected by increasing the local mesh density.

Turbulence models are important in mixing simulation because most companies cannot afford computers that are powerful enough to capture the minute details of turbulent flow. The key factor in selecting the right turbulence model is matching the flow features likely to be present in the application with the models available in your solver. The K-epsilon model is a very popular two-equation turbulence model that includes two extra transport equations to represent the turbulent properties of the flow. Specialized versions of the k-epsilon model have been developed for specific flow configurations.

Design engineers need to be able to verify that their models accurately predict the chemistry and physics of the actual mixing process. One approach is to model the current generation of the product and confirm that the model predicts its performance. At this point the designer can modify the model with confidence that it will predict the performance of the new design. If it will be too costly to interrupt the operation of the current generation product, then it may make sense to build a small scale model of the product and compare its performance to a simulation model.

Real world example

Here's an example of how these methods were used to design the new generation Eclipse Linnox burner. This burner was designed to substantially reduce the energy consumption of the fans that push air into the natural gas burner while providing equal energy efficiency and emissions control relative to existing designs. To achieve this goal, engineers needed to streamline the design to remove features that helped achieve high levels of mixing on earlier designs but still maintain the proportion of gas to air at 7.5% +/- 0.5% throughout the entire mixture duct. Eclipse designers generated the initial burner designs in a 3D CAD system, then used SolidWorks Flow Simulation technology to simulate them.

The simulation results on the initial model showed the concentration of air and fuel throughout the mixture duct, highlighting the areas where mixing needed to be improved.

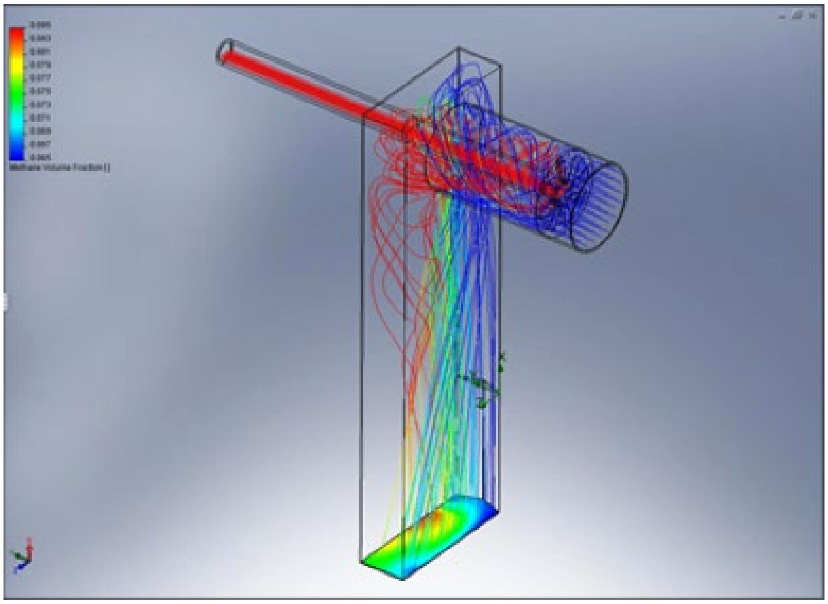


Figure 1: Simulation of the then-present design based upon medium pressure air swirl and gas injection creating a good quality mixture

Design engineers made a series of changes in the mixer design. After each change they re-ran the simulation to determine the impact of the change, paying particular attention to the species distribution throughout the chamber and the pressure drop. With each major variation, they also performed a series of parametric studies to evaluate the impact of changing key dimensions of the design.

Viewing the impact of these changes on the distribution of the two species, they gained an understanding of the design sensitivities than would have never been possible with physical testing. Engineers zeroed in on one of the designs and performed further optimizations. The simulation results showed the final design provides a pressure drop of only 300 pascals, a 900% (10 times smaller) reduction compared to existing design burners. Only at this stage of the process did Eclipse build the first prototype of the new design. The performance of the prototype was very close to that predicted by the simulation, which greatly reduced the time and cost required to obtain the new design.

In summary, CFD simulation with CAD embedded solution in the early stages in the design of products involving gas mixing can save time and money. Best practices tuned for the requirements of a particular industry can help design engineers avoid analysis mistakes. By following specific procedures, any engineer can optimize the design at a time when changes can be made at little or no cost.

COST OF NOT CONDUCTING ANALYSIS

The consequence of non-optimal gas and air-mixing would be significant for the performance of the Linnox burner. The harmful emissions from the burner and unequal heat distribution could have a negative impact in the applications, such as paper drying, gypsum board drying, food processing, catalytic air cleaning. A fair amount of research has been conducted on understanding the impact of engineering simulation on company profitability.

The Aberdeen Group has published several studies on the subject. Their latest report found that "best-in-class" companies tend to test virtual prototypes (see table) as opposed to physical prototype testing. In contrast, companies categorized as "laggards" spend far less time on virtual prototyping and go through more rounds of testing:

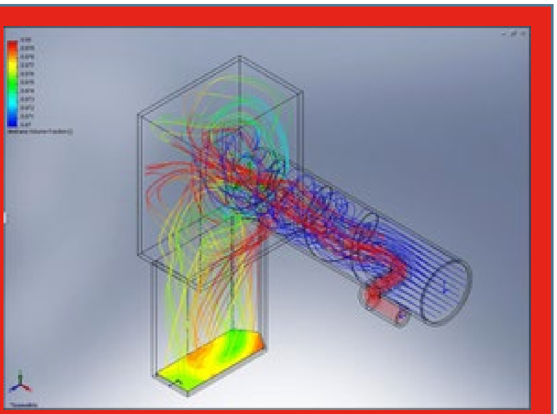


Figure 2: Simulation of the new design based upon low pressure air swirl and gas injection creating an even better quality mixture

Competitive Framework	Mean Number of Virtual Iterations	Mean Number of Physical Prototypes	Mean Rounds of Testing
Best-in-Class	7.3 iterations	2.7 prototypes	2.8 rounds
Average	9.4 iterations	3.1 prototypes	3.5 rounds
Laggard	4.5 iterations	3.8 prototypes	4.7 rounds

Source: Aberdeen Group

This impact can be significant. Depending on the complexity of the product designed, the development process can take anywhere between a week to 20 years. Most gas mixing related products are considered to have either "moderate" or "high" complexity levels and therefore can take anywhere between 1 and 20 years to develop:

Product Complexity	Number of Parts	Length of Development
Low	Less than 50	Between a week and a year
Moderate	Between 50 and 1000	Between a month and 5 years
High	Between 50 and 10,000	Between 1 and 5 years
Very High	Between 1,000 and 100,000	Between 1 and 20 years

Source: Aberdeen Group

Interestingly enough, at "moderate" or "high" complexity levels, the cost to build a physical prototype can be astronomical:

Product Complexity	Time to Build Prototype	Cost to Build Prototype
Low	13 days	$7,600
Moderate	24 days	$58,000
High	46 days	$130,000
Very High	99 days	$1,200,000

Source: Aberdeen Group

Therefore, to be able to build even one less prototype can have a significant impact on the company bottom-line:

Product Complexity	Time Saved by 1.1 fewer Prototypes	Cost Saved by 1.1 Fewer Prototypes
Low	14 days	$8,360
Moderate	26 days	$63,800
High	51 days	$143,000
Very High	109 days	$1,320,000

Source: Aberdeen Group

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