Evaporative Gas Conditioning Systems
State-of-the-Art Technology to the Rescue

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A competent consideration of the essential Evaporative Gas Conditioning system operational factors is required to achieve optimum performance under *all* operating conditions and process variations, not merely at the specified process conditions, and will avoid the necessity of revisiting the legalese of the contract documentation. Computational Fluid Dynamics is *the* tool that, when used properly at the hands of a competent technician, can cost-effectively analyze all the scenarios that are likely to cause problems and provide reliable performance.

Introduction

The cement industry is not unlike any other modern industrial sector, where the pressures to maintain a competitive position demand a careful analysis of all capital improvement purchases, and where those that are most likely to affect production receive the closest scrutiny. It is also precisely at this stage that an analysis emphasizing initial equipment price can at once defeat internal production goals and exceed operational costs, thus transforming this seemingly "smart-buy" into a "penny-wise and pound-foolish" loser.

In order to avoid this scenario, two things are normally generated prior to the purchase of a capital improvement project:

- Detailed specifications
- Total cost of ownership analysis

Unfortunately, during the budgeting stage of many fast-track projects (and most today seem to be blessed with this characteristic), many of the costs and schedules are under-estimated, only to be discovered during the execution stage that the project is over budget and behind schedule. It is here where desperate attempts will be made at rescuing it from these afflictions – and exactly why the lowest equipment price Kool-aid is so eagerly swallowed.

Standard vs. custom-engineered

In the case of *standard* equipment, it normally suffices to rely on the appropriate specification and good sense to ensure a satisfactory level of performance. In the case of *custom-engineered* equipment, however, the result in not that easily achieved. This is because most equipment suppliers modify a "standard" design, "customizing" it for the specified engineered application according to accepted traditional design practices. Due to the complexity of the process variations, however, a traditional approach is only capable of taking into account a few possible variations, limiting the operational flexibility of the equipment to the "normal" or "design" conditions rather to what is required by the full spectrum of the process, resulting in operation that is less than satisfactory at the plant level.

Evaporative gas conditioning

This is certainly the case with Evaporative Gas Conditioning (EGC) technology, a field that utilizes highly specialized equipment subjected to operational ranges that are difficult to thoroughly quantify and where individual companies with a complete spectrum of process experience are a rarity. EGC is a gas cooling technique wherein the heat present in a gas is itself used to evaporate finely atomized water injected into its flow field. Through the process of evaporation, heat energy in the gases is used up when the water droplets are converted to steam, resulting in a gas that is lower in temperature, but also higher in humidity. It is a cost-effective method of lowering the temperature of a hot gas that, for a defined period of time at least, recovery of its heat content is of little value, such as when the gases normally utilized for drying and fluidizing the limestone are not needed as the raw mill is down for weekly maintenance. During this period, the gases are bypassed around the raw mill, and cooled in a Gas Conditioning Tower (GCT) where the atomized water is injected.

New or used, it's all the same

It may appear a simple task to spray a few drops of water in a GCT, but in reality, if it were so easy, there wouldn't be so many poorly functioning GCTs. Designing a modern EGC system, as simple as it may seem, is a sophisticated process that must result in a system that is:

- Responsive to changing process conditions
- Maintenance friendly
- Energy efficient
- Cost-effective

and, most importantly,

- That works!

To make matters all the more difficult, poorly functioning GCTs that serve as evaporation chambers for existing high-pressure water EGC systems, although blessed with long theoretical gas residence times, end up working just as poorly after being retrofitted with new dual-fluid sprays and controls due to their poor gas distribution characteristics. Which leads us to the most important of all aspects of an EGC system – the gas flow distribution.

The role of modern analytical tools

The reality is that stringent emissions requirements of today, coupled with the need for energy-efficient and cost-effective designs, make it an increasingly complex task to meet performance requirements through experience and traditional methods of calculation alone. This is especially true for equipment that has a fixed geometry, but must provide a predictable level of performance under varying process conditions. In a cement environment, examples of such equipment are preheater cyclones, alkali bypass mixing chambers, main dust collectors, and GCTs. If not properly designed to handle the full range of operating conditions, operating too far beyond the specified design boundaries can have disastrous consequences. Computational Fluid Dynamics (CFD) is exactly the tool that has provided the means for surpassing the traditional methods of predicting performance in these cases.

CFD is a modern analytical modeling technique that utilizes advanced algorithms to predict the flow field in a given static or dynamic condition. The calculation process iterative, made up of millions of floating point calculations. In the past, technology was such that an expensive computing workstation capable of millions of floating point calculations per second was required in order to create a useful 3-dimensional model and to execute a run, thus generating a useful 3-D report. Thus, the implementation of CFD technology in many of the components used in air pollution control systems has traditionally been relegated to the simpler modeling tasks, such as spray tower or ESP flow distribution and cyclone collection efficiency. These exercises have traditionally been applied after installation when it is suspected that certain flow field conditions may be causing performance problems after the initial equipment design and installation. It is rare, with the exception of research and development efforts or the design of standard series equipment, that CFD be used habitually in the design of new, custom engineered electrostatic precipitators, fabric filters, spray towers, scrubbers, and other gas flow treatment apparatus used in air pollution control systems. Fortunately, advances in modern analytical tools have made it possible to achieve the desired high degree of operational performance without a major impact to the competitiveness of relatively low-cost and low-tech equipment, such as cyclones, ductwork and spray chambers. With the advent of more modern CFD programs now capable of running on a standard PC platform, models can be generated that are just as detailed and realistic as those that just a few years ago required the use of super-computers.

In the past, small-scale models have been used by fluid mechanics to optimize gas handling and separation equipment during the design stage, but this method is costly and time-consuming. Its great cost and time requirement can be justified when considering one single application unless the cost of the equipment is great, the design and production time allows it, and the consequences of a design flaw are great. Thus, air pollution control companies have used physical modeling for large electrostatic precipitator dust collectors, for example, especially when the pollution control apparatus has to be integrated into the network of ducting as specified by the engineer, and where the potential of liquidated damages is great, such as in a power plant application. It is difficult, however to justify it in those cases where the equipment cost is relatively low and the industry has already acquiesced as a whole and accepted the consequences of basic design flaws as problems that need to be lived with. Nowhere is this truer than in the case of a spray tower in a cement application. The universal acceptance of CFD as a technically valid prediction model however, has brought a much needed analytical tool within the reach of budget-conscious designers, and has begun to impact the expectation levels of the technically savvy cement manufacturer.

As a result of the many successful outcomes, not only in such high tech industries as aerospace and biomedical, but also in the basic industrial sectors of cement and steel, gas flow modeling houses that once only offered physical modeling, now offer CFD as an option. This general acceptance of CFD has made it the de-facto standard for modeling gas flows, and provides additional modeling parameters that are not available in simple mechanical models. These parameters include chemical reactions, capture efficiencies, temperature profiles, droplet evaporation and gas mixing, among others. Coupled with the ability to rapidly make changes to a model's input process conditions, CFD has become an essential design tool, thus providing a much more accurate predictive model that are easily modifiable, and at a lower cost and in a shorter time frame.

A unique philosophy

A few years ago, when it became clear that the technology was mature enough to be reliable and affordable, BoldEco Environment made the decision that it would acquire in-house CFD capabilities of its own. This decision was reached as a result of one particular customer's request for an in-depth study of several ESP to Fabric Filter conversions it was planning on carrying out. CFD was found to be such an invaluable tool in those projects and we discovered fallacies in many of the accepted fabric filter inlet design practices that we decided to apply it to all of our projects, including all of our Evaporative Gas Conditioning (EGC) systems. Prior to this, we were utilizing traditionally accepted design practices, an approach that was effective the majority of the time and was generally effective. CFD, however, in the hands of a team of skilled technicians, has been vital in convincing the end user exactly where the problems lie, thus resulting in a savings in both time and money. This capability as allowed us to advance the state-of-the-art of various air pollution control technologies, including EGC.

Already, it has resulted in the development of new and innovative technologies, such as the OptiVap nozzle, which is 30% more efficient than the best-known designs on the market and which is immune to over-driving (condition when water pressure supercedes the air pressure at the nozzle), a known cause of unevaporated water conditions in a GCT.

CFD-aided equipment design

BoldEco utilizes CFD to optimize the design of the main standard components for each custom-designed system at the initial stages of the engineering phase of a project. The systems that have been already designed utilizing CFD include Wet and Dry Scrubbers (particulate and SO_2), Pulse Jet Fabric Filters (low-pressure, medium-pressure and traditional high-pressure), ESP-to-FF Conversions, Gas Conditioning Towers and Air-to-Air Heat Exchangers. Various scenario models are generated and the flow fields analyzed in depth by our fluid mechanics. Each new finding is used to refine the base design of the system component. For each new project or to solve a particular problem with an existing system, CFD is employed to determine what the flow fields might look like at various operating conditions and if any flow or process-based correction is warranted.

Case Histories

BoldEco has carried out several CFDs for various end users and OEMs, spanning several industrial sectors. In all of these cases, an improperly functioning EGC system was analyzed and a solution presented. Some of the more recent cases of implementation of CFD to determine a solution to poor flow field distribution are listed below.

Case History 1 – New GCT

Against the recommendations of the supplier, a brand new GCT was designed with a slanted inlet duct and close-coupled to the GCT inlet. This inlet duct design resulted in a skewed flow field at the inlet cross section of the tower that was too poorly distributed for the standard inlet straight section design to accommodate. This resulted in wet material falling from the walls of the tower down into the hopper below, or in water running out from the hopper screw conveyor airlock. It thus became imperative to define the flow field in the GCT. Without knowledge of the gas distribution, it would be very difficult to devise an effective way of correcting any existing gas distribution problem upstream of the water injection location.

The CFD identified the cause of the difficulties. Analysis of the flow field in the GCT inlet showed the high-velocity gases to remain on one side of the tower instead of being distributed evenly across the entire cross-section of the GCT. This caused a region of gas recirculation in the inlet cone of the GCT, which caused the water injected in those locations to impinge on the walls of the GCT. The region that became wet with water also became a point of impact for the dust penetrating the top cyclones of the preheater tower, causing it to become a sort of mud that broke off intermittently and fell into the hopper below. Although this is a common occurrence in the operation of numerous GCTs around the world, this particular problem was not a usual case as it occurred under virtually all operating conditions rather than just during transitory periods of switching from bypass operation to direct operation (mill on to mill off) and vice versa just during mill off operation. In this case, the flow field exhibited the recirculation phenomenon under most operating conditions, resulting in incomplete or inconsistent cooling of the gases.

The preferred solution was to have a pipe grid that could be removed for cleaning, should the need arise. Several attempts were made to place the pipe grid in the CFD model directly above the spray elevation, but the energy of the gases was so high that the flow field was very unstable at various gas flow rates. The CFD models showed that, despite the pipe diameter, the pipe spacing or the pipe grid location, at different gas velocity conditions, the flow field either maintained its original impetus, or it was completely blocked by the pipe grid, thus rendering that solution impracticable. After various attempts, BoldEco devised a novel solution, placing a diagonal pipe grid in the high velocity section of the inlet duct that acted as a set of straightening vanes. A second set of pipes was installed directly beneath the diagonal pipe grid, this time in a horizontal arrangement, which acted as a secondary flow distribution device, thus providing a stable and predictable flow field at the inlet of the GCT. This solution was implemented and the GCT was found to perform according to design.

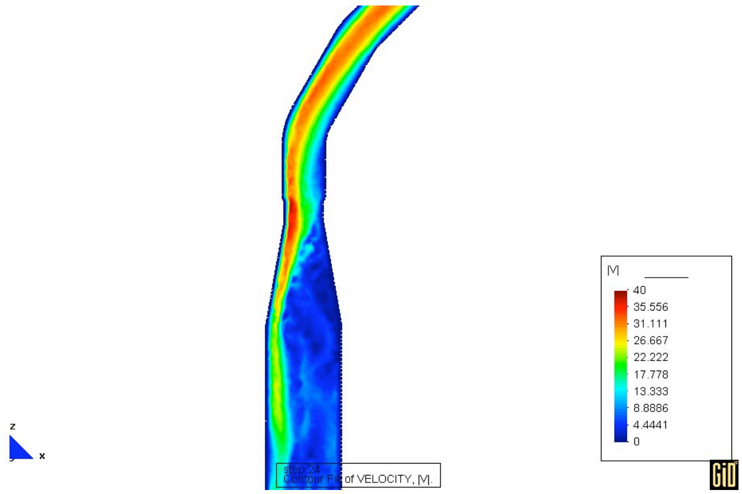

Figure CS1a –Original design generated poor flow field at GCT inlet

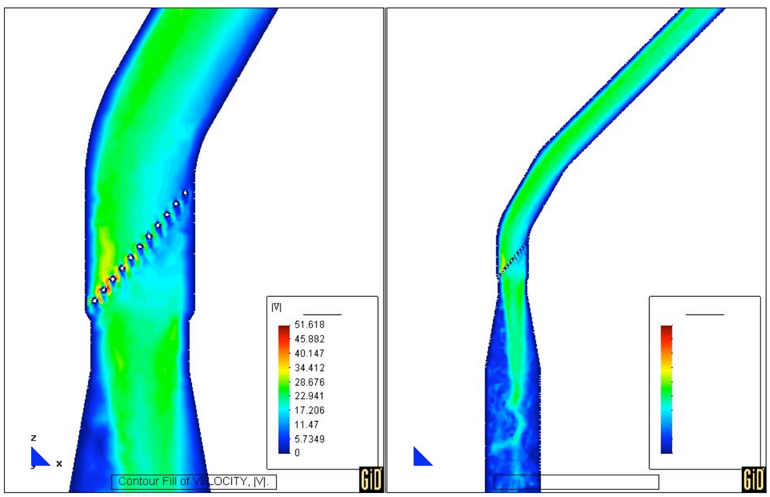

Figure CS1b – Initial modification with diagonal pipe grid shows improved gas flow distribution

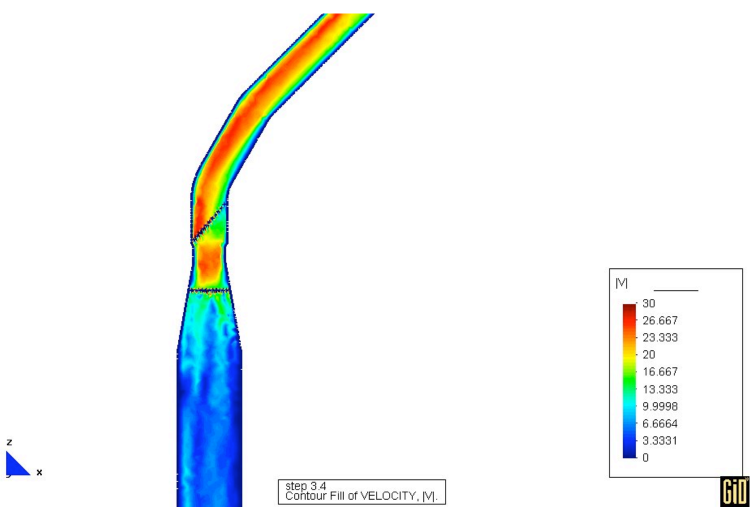

Figure CS1c – Final modified GCT inlet design shows much improved flow

Case History 2 – Old Design Cement GCT

A cement plant OEM wanted to utilize an old GCT design from the 1970's, originally designed to be used with high pressure water sprays, except fitted with a more modern air atomized spray system. The idea was to save on the engineering required for a new GCT design by simply installing the new system, but, despite its large dimensions and correspondingly long gas residence time, this particular design had notoriously poor gas distribution characteristics. Similarly designed GCTs had been retrofitted with air atomized systems before, and, although the installation of the replacement spray system provided much improved reliability over the original high-pressure design, the GCT was still plagued with unreliable operating service due to the poor inlet distribution. It thus was decided to install a gas distribution device at the inlet that would provide a high degree of re-distribution of the inlet flow field in order to make the operation of the GCT more dependable. Without the correct distribution characteristics, the resultant poor gas distribution would prevent the injected water to only partially evaporate, a condition that leads to problems with the hopper material transport system.

A series of CFD models were run and the unmodified flow field defined. Analysis of the flow characteristics at the GCT inlet showed the classic pattern of gas recirculation in the inlet cone of the GCT, and the resultant impingement on the walls of the GCT.

Another set of CFD models was created utilizing the original GCT design, this time with distribution devices with different open areas, one with 40% open area, one with 50% open area and another with 60% open area. The models generated showed that there was no distribution device that provided a perfect gas flow distribution at all flow rates, but it did allow us to find the open area that provided the best possible distribution characteristics at all flow conditions. This solution presented to the customer for approval. The GCT has been functioning as planned, showing no signs of gas-related operational difficulties.

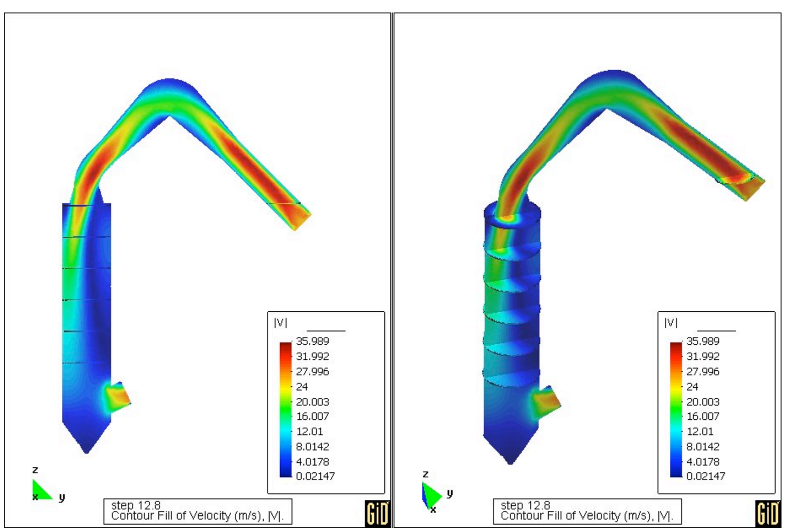

Figure CS2a –Original design generated poor flow field at GCT inlet

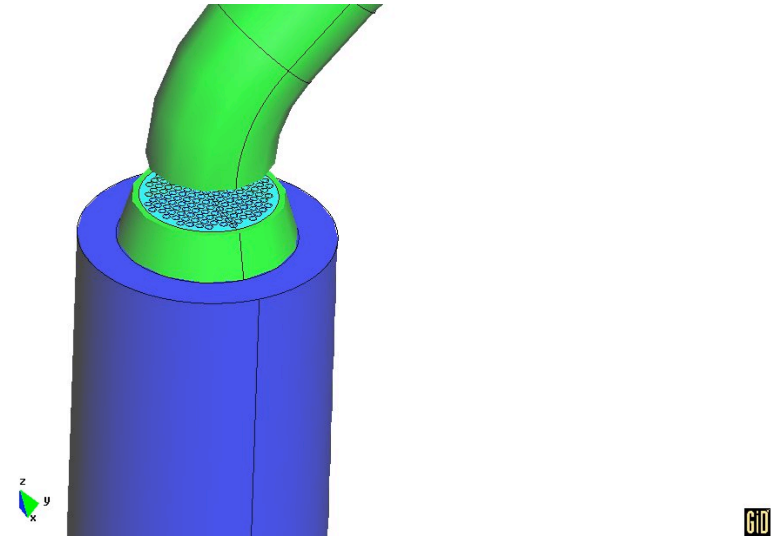

Figure CS2b – Detail of gas distribution device located in GCT inlet

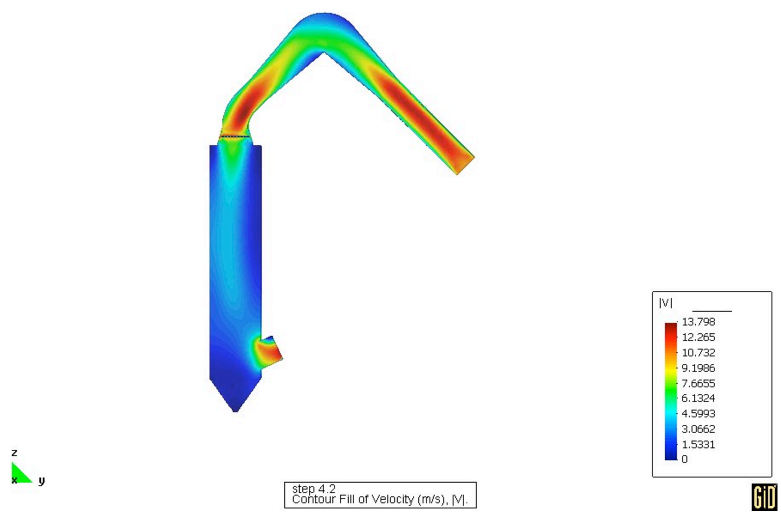

Figure CS2c – Modified GCT inlet design at maximum flow shows much improved flow

Conclusion

Implementation of modern analytical tools, such as CFD technology, not just in research and development or the design of production-run components, but as an integral part of the design phase at the beginning of a custom-engineered project, will result in the optimal operation and efficiency of custom engineered systems. Not only will the design of the system be much improved over previous, traditional methods, but its performance and limitations will be better understood by all involved with the project, thus allowing process designers and operators alike greater flexibility in defining production-oriented process parameters and operational limits for the entire plant.