Computational Fluid Dynamics Eliminates Fires in Coal Classifiers

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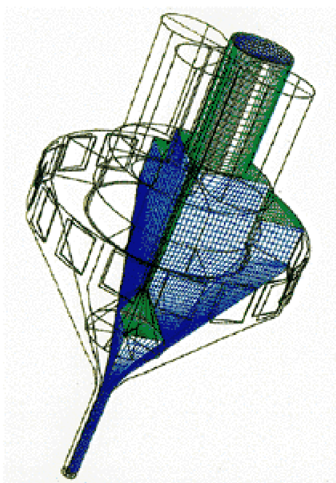


Computational fluid dynamics (CFD) helped to diagnose the cause of and eliminate fires in two ball mill cyclonic coal classifiers at Salt River Project's Coronado Generating Station Unit No. 1, St. Johns, Arizona. The mill had been experiencing a series of fires since the unit was returned to service after an outage in October 1993.

Computer modeling indicated that the fires were caused by the generation of an internal recirculating vortex on the underside face of the cone plug which provides a zone for maintaining and stabilizing a flame front. Consultants evaluated alternate designs for the cone, plug and shaft assembly and found one which eliminated the formation of internal recirculating vortexes. The new design was installed in the coal classifiers and has eliminated the problem.

The Coronado Station has 6 tubular ball mills with two cyclonic coal classifiers. Each classifier has a plug that looks like an inverted funnel which can be raised and lowered to control the mass flow through the apex. One ball mill has had several fires resulting in explosions that caused considerable damage to the ductwork and one side of the building.

There was no way to evaluate what was happening inside the mill using physical testing methods so the plant was not able to determine the cause of the fires or explosions .

RJM Corporation of Ridgefield, Connecticut, was asked to diagnose the problem using CFD. RJM is a consulting company specializing in the analysis and design of combustion systems. They routinely use CFD to predict and improve the performance of burners, furnaces, classifiers and transportation systems associated with coal and gas power generation systems. The key advantage of CFD is that it provides a comprehensive graphical description of what is happening inside the mill, including flows, pressures and temperatures. CFD can frequently provide insight into flow problems that can not be readily obtained by testing, particularly when taking a unit off-line or building a full scale prototype would be prohibitively expensive and time-consuming.

RJM's approach to this problem was to look at the overall process and determine the mechanisms that could combine to cause or sustain a fire. They then used CFD to confirm their hypothesis and better understand the underlying flow problems. Finally, they used the software to evaluate solutions and recommended changes to the design and operation of the mill to eliminate fires residing within the cyclonic classifiers.

Pulverizer coal system explosions are usually rare because pockets of fire which do occasionally occur are quickly blown through the pulverized coal transfer system into the furnace. Three factors must occur simultaneously for pulverizer coal system fires to be destructive: 1) a stable flame front zone must be sustained , 2) ignition particles must be present, and 3) a high volatilization rate must exist.

Empirical data suggests that a stable flame front zone cannot exist in a pulverized coal system unless there is a zone in the system in which velocities are less than the combustion flame speed, about 1.4 feet per second.

Coal pipes have a conveying velocity of 55-70 feet per second and the classifier velocities for the Coronado Unit No. 1 are 11 feet per second.Theoretically, then, a stable flame front should not exist in the Coronado Station units. Thus, the first step in the analysis was for RJM to identify operating conditions which could yield undesirably low velocities in the system.

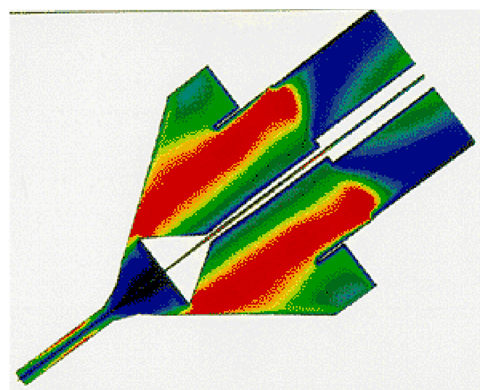
Coronado Station uses centrifugal classifiers to control the fineness of the coal which is delivered to the burners. At very high spin rates, internal recirculating vortices can be created within in the classifier as well as along the bottom of the cone plug. These internal recirculating regions have a unique boundary layer (called the adverse static pressure gradient boundary) in which the axial velocities equal zero. Immediately on either side of this boundary layer are zones where the velocities are less than the flame speed of the coal/air mixture.

As the classifier spin rate is increased, there is a corresponding increase in the size of the internal recirculation vortex and resultant sub-flame speed velocity zones. If these low velocity zones are large enough, a stable flame front can be established.

The potential for entraining coal particles below the plug also grows as the classifier spin rate increases. As the classifier rotating speed is increased, the internal vortex and the recirculation zone behind the plug both grow. As these zones begin to interact with each other under very high speed conditions, very fine coal particles within the classifier can become entrained in the recirculating flow behind the plug.

Finally, hot coal particles entrained within the classifier could sustain a high enough volatilization rate to produce a fire. This condition would not exist very frequently because there is a definite requirement for how much fuel must be in the air stream to sustain combustion. For coal the combustible volatiles must be greater than 4% and less than 15% by volume of the air/fuel mixture. The reason for this is that heating coal volatilizes combustible gases from the coal particle. The gases then mix with the oxygen in the air until a combustible mixture is reached. In the flammability range, hot sparks will initiate combustion.

Generally, above 600^{o}F the fuel volatilizes at a rate high enough to maintain the proper fuel/air mixtures, at which point the fuel is said to be at its fire point.In the C Mill classifier system, this volatilization rate can only occur if there are a large number of ignition particles in close proximity to each other, which would thereby sustain the volatilization rate needed for combustion. This could happen if the recirculation zones were strong enough to entrain a large number of fine coal particles.



CFD velocity magnitude profile for original coal plug

With this set of conditions which could yield an explosion identified, RJM Corporation developed a CFD model of the internal classifier zone of the coal classifier at Coronado Station. RJM used FLUENT Version 4.2.5 (from Fluent Inc., Lebanon, NH), a CFD code which has been adopted by the

International Flame Research Foundation and the American Flame Research Council as the benchmark code for combustion modeling. The model was composed of 91,676 computational cells in which pressure, mass flow rate, velocity, and turbulence quantities for both the gas and coal particle phases were calculated. Using field data provided by Salt River Project, operating conditions such as the classifier spin rate and the air and coal particle flow rates were specified. The actual coal particle size distribution was modeled using a Rosin-Rammler distribution. This enabled the varying trajectories and heating rates of different size particles to be accurately accounted for. With proper thermal boundary conditions, the model accurately represented the actual device and operating conditions under which explosions had occurred.

Because of the symmetry of the classifier, only a 90 degree cyclic section was needed to accurately model the entire flow field. Limiting model geometry to cyclic sections greatly enhanced computational efficiency, reducing the time required to converge a solution by 75%. Initial runs were converged on a Sun Sparcstation Model 10 in less than 100 CPU hours. Subsequent runs starting from a prior solution required only a fraction of that time. With the most recent release of the software and the faster workstations now available, initial solutions could now be obtained in less than a day.

The initial results of the analysis showed recirculation did not occur with the plug in its nominal position. The consultants were somewhat surprised, then they considered the possibility that the plug had moved to an incorrect position. Modifying the model to move the plug vertically one inch and re-running the analysis created a recirculation zone on the bottom side of the plug and three other internal recirculation patterns. There was a second internal recirculating vortex (as defined by a surface of zero axial velocity) on top of the cone plug, a third about the shaft of the cone plug and a fourth in the entrance of the outlet coal pipes. Mechanical examination of the mill showed the plug was one inch higher than the optimum setting. This resulted in the recirculation vortex being formed.

Simulations using FLUENT indicated that the most probable cause of classifier fires and subsequent mill explosions was a unique combination of the following events: 1) the vertical position of the cone plug in the classifier was instrumental to creating an internal recirculating vortex 2) a recirculating zone was also generated on the underside face of the cone plug, providing a location for a stable flame front to exist, 3) very fine coal particles became entrained first within the classifier vortex and then in the recirculating zone behind the plug, and (4) hot particles rejected by the cyclonic classifier ignited the air-fuel mixture behind the plug. This set up a flame front which traveled down the reject chute into the mill, explosively igniting it. Modeling data indicated that the vertical position of the plug is critical to generating the downstream-side internal recirculating vortex. At the optimum setting there is no recirculation vortex. As the plug is raised, a recirculation vortex is formed.

As the plug is raised even further, reverse-flow dynamics sweep the flat face of the plug and eliminate the vortex. However, raising the cone plug is not an acceptable solution as coal classifier dynamics decline with cone plug elevation. Interestingly, the flow simulations also showed that the vortices generated in the entrance sections of the coal outlet pipes unnecessarily raised system pressure drop requirements.

Thus, design modifications which would reduce the potential for fires would also improve the system operating efficiency. The consultants evaluated a range of plug geometries and finally settled on a configuration that eliminated the recirculation zones. They recommended adding a conic section to the end of the plug and thickening the shaft. They also recommended that the new cone plug major diameter be set to a two-inch radial distance from the classifier inner cone wall. Two-inch tabs were welded to existing support ribs to provide a mechanical "bottoming out" limit for the cone plug position in the classifier inner cone. These changes combined to eliminate the formation of internal recirculating vortices and the resultant continuous flame front. The fires residing within the cyclonic classifiers have been eliminated.