David Anderson

is currently a Principal/Owner of Alden Research Laboratory, the oldest hydraulic testing laboratory in the United States. Along with his corporate responsibilities, David is responsible for Alden's Air & Gas Modeling group which performs physical and computational flow modeling of gas flow systems, primarily emissions control systems for fossil power plants. Prior to working at Alden, David spent over two decades at Combustion Engineering/ABB/Alstom's US Power Plant Laboratories in Windsor, CT where he was Manager of their Environmental Systems group. David is a registered Professional Engineer and holds 14 US patents.

Albert de Kreij

Albert de Kreij joined Hadek Protective Systems in 1989. He has been closely involved in a number of projects with the use of Borosilicate Glass Block Linings especially in wet stack operation conditions.

WetReady™ Guide Vane - A special guide vane for FGD Wet Stacks

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Most utility power plants strive to operate as efficiently as possible. As part of this process, a significant amount of effort is focused on reducing the pressure losses in the flue gas path. This is typically achieved through the addition of turning vanes or other type of flow control devices in the flue gas ductwork where the flue gas changes its direction and/or velocity. These devices reduce the pressure losses by minimizing the generation of turbulence and gas recirculation zones as well as maintaining a relatively constant gas velocity within the ductwork.

The most common technology for flue gas desulfurization at utility power generation stations around the world is Wet Flue Gas Desulfurization (WFGD). A significant and rapidly growing percentage of these plants utilize wet stacks in which the fully saturated flue gasses exiting the scrubber tower are sent directly into the stack liner for discharge to the atmosphere. The conventional wisdom for this type of system is to minimize the addition of any type of structure within the gas pass down stream of the WFGD absorber. This is because the flue gasses exiting the WFGD absorber are fully saturated and any structures exposed to these gases, such as turning vanes in the inlet to the liner, will collect liquid and become potential sources for the re-entrainment of droplets back into the gas flow, Figure 1.

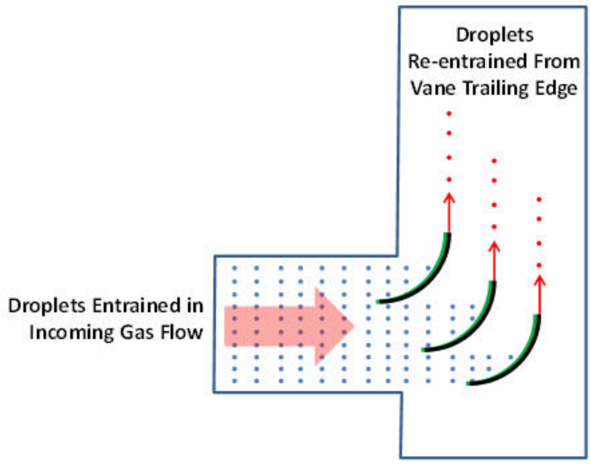

Figure 1: Droplets Passing Through Traditional Turning Vanes

Because the flow profile in the upper liner is relatively uniform, droplets re-entrained from turning vanes at the inlet to the liner will have little opportunity to migrate to and be collected on the liner wall significantly increasing the potential for stack liquid discharge, a phenomenon more commonly known as "rainout". For this reason, power plants typically do not use inlet turning vanes in wet stacks and as a result, are losing an opportunity to significantly reduce the plants total system pressure losses.

Seeing a lost opportunity for improved power plant efficiency, Alden Research Laboratory (Alden) and Hadek Protective Systems (Hadek) recently completed a joint research project to develop a stack inlet guide vane system called the WetReadyTM Guide Vane or WRGV which has been specifically designed to operate effectively in a wet environment and both optimizes pressure loss reduction and minimizes the potential for droplet re-entrainment back into the gas flow stream by effectively collecting and draining away any liquid which deposits or condenses on the vane surfaces.

Sources of Liquid on Liner Wall

There are three major sources of liquid contributing to the liquid film generated within a utility power plant stack liner, Figure 2. The first is carryover and direct impingement of droplets from the WFGD mist eliminator and any other liquid re-entrained back into the gas flow from surfaces in the absorber outlet/stack inlet ducting. This liquid can only be collected if it comes in direct contact with the internal surfaces of the absorber outlet duct, items located within the gas path such as internal duct supports, or on the liner wall. The second source of liquid is thermal condensation directly on the inside wall of the liner due to cooling of the fully saturated flue gasses in the liner. The third source is adiabatic condensation generated within the volume of the gas due to pressure drop within the liner. The ability of a gas to contain liquid in a vapour phase is a function of many variables including the static pressure of the gas. If the static pressure is reduced, the quantity of liquid that can remain in the vapour phase is reduced and a portion of the vapour condenses into very fine liquid droplets evenly dispersed throughout the gas volume. Only about 3-5% of the total liquid generated in the flue gas due to adiabatic condensation is actually deposited/collected on the liner wall due to turbulent diffusion and the remainder leaves the system as the ubiquitous white plume or cloud often seen exiting the top of the stack. If the velocity of the flue gas in the liner is within the range recommended by the EPRI/CICIND Revised Wet Stack Design Guide for the particular liner material being used, the liquid deposited and/or generated on the stack liner wall will form a downward flowing liquid film which can be easily collected by traditional wet stack liquid collection systems.

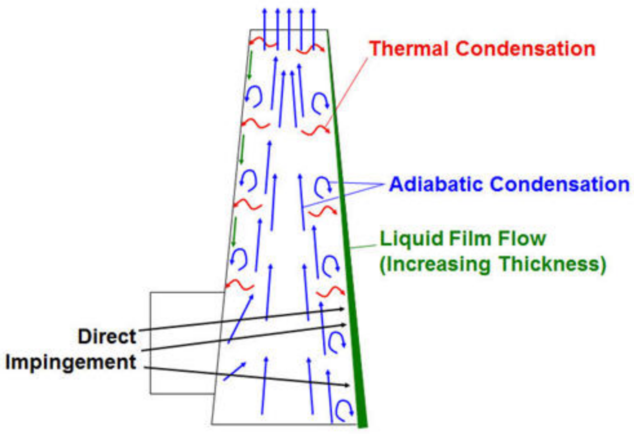

Figure 2: Sources of Liquid in Power Plant Stack Liner

Traditional liquid collection systems typically rely on inertial separation for the collection of direct carryover from the WFGD absorber and re-entrained droplets from the absorber outlet ducting. That is, as the gas containing the entrained droplets enters the stack and turns vertically up the liner, the entrained droplets want to continue in a straight path due to inertia and a significant portion will impact the rear wall of the liner before fully completing the turn. These deposited droplets form a liquid film which is then pushed by the internal gas flow patterns to locations where collection/drainage can be easily performed.

With the introduction of turning vanes in the lower liner for the purpose of reducing the pressure losses associated with the flue gas's turn into the liner, entrained drops will now deposit on the high pressure or upstream side of the vane instead of the rear wall of the liner and the resulting collected liquid film will be pushed up the vane until it reaches the trailing edge where it will be re-entrained back into the gas flow. Unfortunately, because of the trailing edges of the vanes are dispersed across the cross-section of the liner, these re-entrained droplets will also be dispersed throughout the gas volume and have little opportunity to be collected on the liner wall before exiting the top of the liner.

It is clear that to increase the overall plant efficiency, the pressure losses associated with the stack inlet must be reduced, and that turning vanes must be installed. It is also clear that traditional turning vanes while effective at reducing pressure losses will result in increased potential for stack rainout because they do not properly collect and drain the liquid deposited on their surfaces. What is needed is a turning vane specifically designed to both reduce pressure loss and efficiently drain away any liquid collected on it.

Wet ready Guide Vane Development

Alden has been involved in the physical and computational modelling of power plant systems for over 30 years and has designed turning vanes for hundreds if not thousands of installations. Alden has also been intimately involved with the design and optimization of wet stack liquid collection systems since performing the first fundamental liquid collection research and design studies for the Electric Power Research Institute (EPRI) ultimately leading to Alden's writing of the EPRI/ CICIND Revised Wet Stack Design Guide. Using this extensive background the WetReadyTM Guide Vane was developed at Alden's Gas Flow Systems Engineering Flow Laboratory located in Holden, Massachusetts, USA.

Development and testing was performed in a dedicated multiphase (gas/liquid) flow model of a typical side entry duct wet stack arrangement. The flow model, shown schematically in Figure 3 and photographically in Figure 4, consisted of a straight inlet duct fabricated from Plexiglas to allow observation of the vane during testing and a stack which was fabricated from a fiberboard tube with a specially prepared inner surface that properly simulates the "wetting" nature of actual stacks.

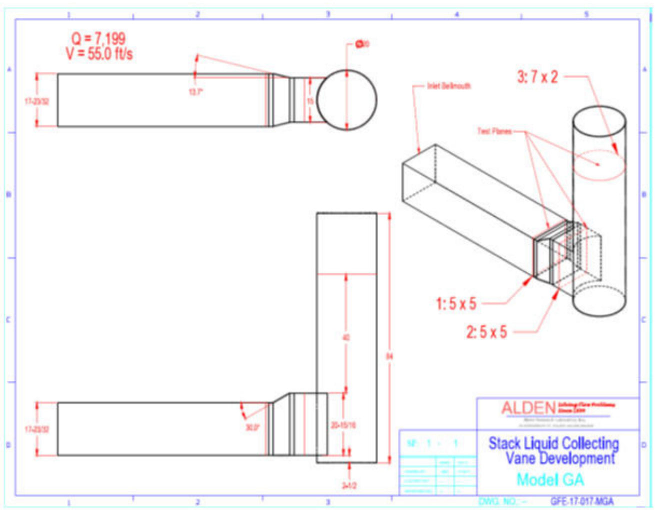

Figure 3: Schematic of WRGV Development Flow Model

Figure 4: Photograph of WRGV Develepment Flow Model

The cross-sectional areas of the model were constant and designed for the model to operate at a gas velocity of 16.77 m/s (55 ft/sec). The model operated with a uniform velocity profile (RMS = 4.9%) applied across the flow model inlet.

Testing was performed in two phases. The first phase focused on the design of the turning vane system with respect to reducing system pressure losses. The objective was to maximize the overall efficiency of the system and to minimize unfavorable gas flow patterns on both the high and low pressure sides of the vanes. Although more or less vanes may be needed for a particular installation, a system of three vanes was sufficient for this particular installation. To minimize the pressure losses associated with accelerating and deaccelerating the gas flow as it passes through the system, it was desired to maintain a constant area hence constant gas velocity through the system. This resulted in vanes with airfoil shapes, Figure 5. An additional

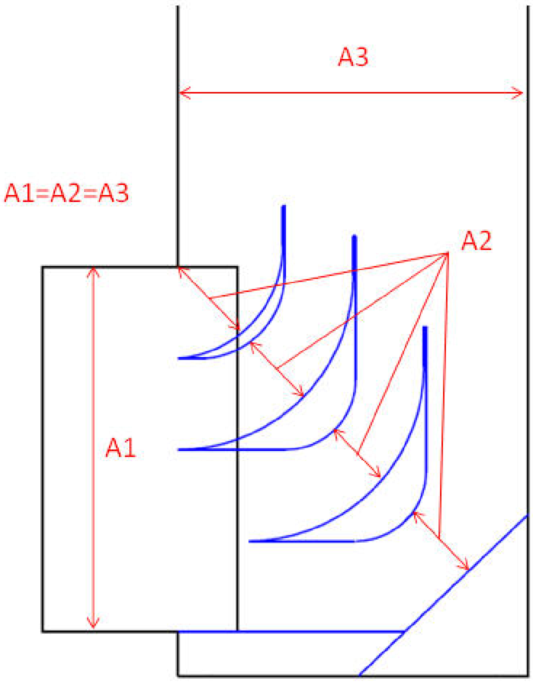

Figure 5: WRGV Airfoil Cross-Section

advantage of this shape is the ability to internally drain away liquid collected on the vane if desired.

Testing during the first phase of the study consisted primarily of qualitative flow visualizations to observe the gas flow patterns through the vanes and along the vane surfaces and detailed quantitative velocity and pressure traverses to determine the pressure loss coefficient of the vane arrangements.

The second phase of the project was for the development of the turning vane's integrated liquid collection system. This testing was performed on a single larger vane to eliminate any scaling issues specifically related to surface tension of the liquid films applied to the test vane.

Testing of each prototype liquid collector arrangement consisted of fogging the inlet to the model with a fine droplet mist to evaluate the trajectories of droplets carried over from the WFGD absorber and to observe where they impacted on the vane surfaces. Additional water was then carefully introduced at these locations to evaluate the motion of the resulting liquid film. Based on these observations a surface "V" collector was developed and optimized which both collects and guides the surface liquid film to drainage location on the vane surface. The general arrangement of the surface mounted "V" collector is detailed in Figures 6 and 7.

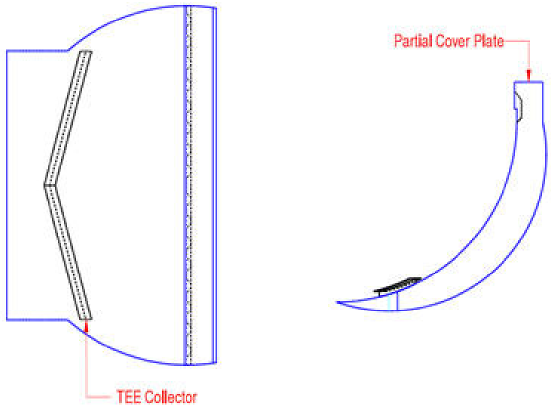

Figure 6: WRGV Surface „V" Collector

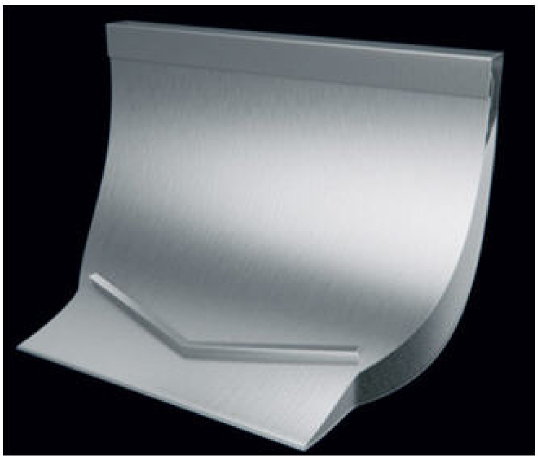

Figure 7: WetTeady™ Guide Vane

Most importantly, a trailing edge liquid collector was developed which allowed the liquid film moving vertically up the vane towards the vane's trailing edge to be collected from the surface without re-entraining back into the gas flow. This is accomplished through the addition of a slot along the entire length of the trailing edge incorporating a backward facing sharp edge which allows the liquid film to flip over into a collection gutter located within the vane without re-entraining back into the gas flow. Any gasses carried through the slot are deaccelerated and discharged through a partial cover back into the main gas stream. Liquid collected within the gutter is then drained from the system either internally through the vane or through the wall of the liner. Details of the trailing edge collector are shown in Figure 8.

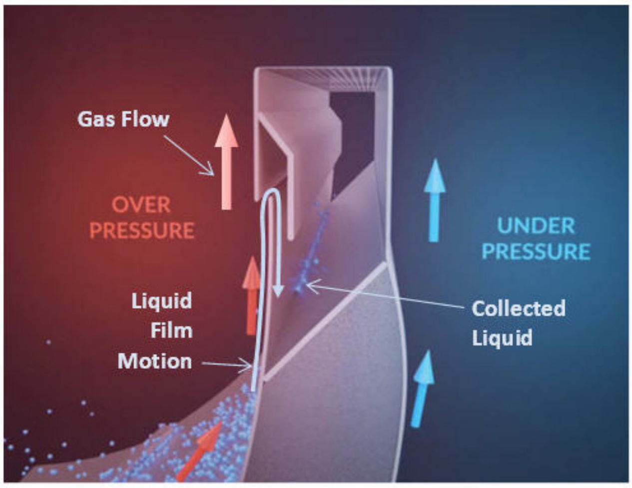

Figure 8: WRGV Vane Trailing Edge Liquid Collector

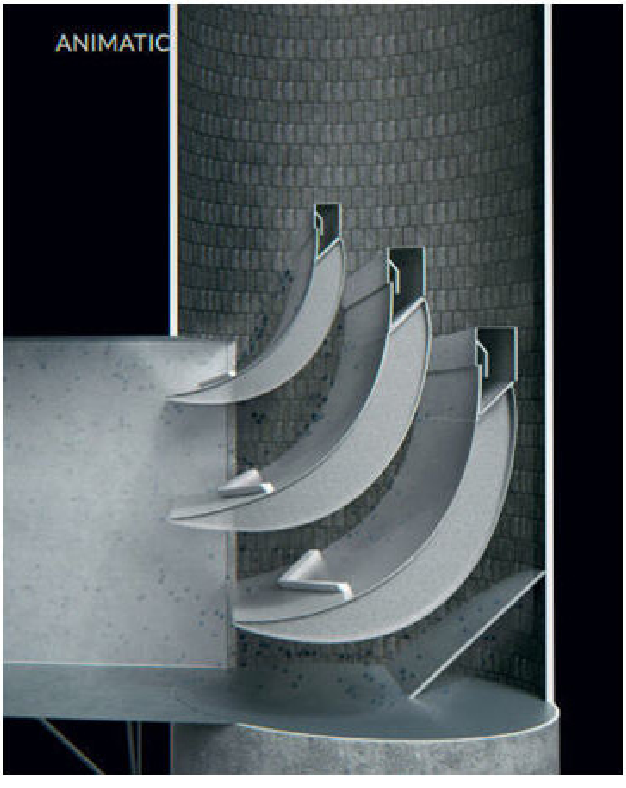

Figure 9: Typical WRGV Installation

Figure 9 presents a rendering of what a typical WetReadyTM Guide Vane installation would look like in a PennGuardTM lined utility power plant stack.

Pressure Loss Reduction

Pressure loss increases or decreases for different arrangements are evaluated through the comparison of their resulting pressure loss coefficients. The pressure loss coefficient "K" is a dimensionless number defined as:

$$K = \Delta P_{total} / P_{velocity}$$

Where:

$$\Delta P_{total} = Total\ Pressure\ Loss$$

$$P_{velocity} = Reference\ Gas\ Velocity\ Head$$

The WRGV development flow model without any vanes installed had a stack inlet pressure loss coefficient of 1.80. This is typical of modern side entry stack inlet design. With the three WetReady™ Guide Vane's installed, the resulting pressure loss coefficient was 0.46, a difference of 1.34 which equates to a 70% reduction in the resulting stack inlet pressure loss.

Conclusion

The Patent Pending WetReady™ Guide Vane was specifically designed to catch, retain and drain off droplets contained in the flue gas stream, reducing the risk of liquid droplet carryover into the environment while at the same time significantly reducing the stack inlet pressure losses. This will lead to increased plant efficiency and reduced operating costs.