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State-of-the-Art Upgrades to Existing Wet FGD Systems to Improve SO₂ Removal, Reduce Operating Costs and Improve Reliability

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ABSTRACT

European utilities are continuously looking for ways to reduce operating and maintenance costs of their wet flue gas desulfurization (FGD) systems while at the same time increasing sulfur dioxide (SO₂) removal efficiency. Upgrading an existing wet FGD system may be an effective way to improve SO₂ removal, allow the use of lower cost higher sulfur coals, reduce power consumption, eliminate high pressure drop packing, allow the conversion to a forced oxidized system, allow for the use of an alternate reagent, and improve the reliability of the system while reducing the operating and maintenance costs. By today's standards, older wet FGD systems were not designed to achieve high SO₂ removals and higher reliability while at the same time minimizing operating costs. New wet FGD systems are typically designed for SO₂ removal levels of 98% and reliability of 99%+. Fortunately, the technological improvements that have been incorporated into the newest wet FGD systems can be adapted for retrofit into older wet FGD systems. These technological improvements include the installation of improved gas-liquid contacting devices, wall rings, redesigned spray headers, state-of-the-art spray nozzles and upgraded mist eliminators, conversion from natural or inhibited oxidation to in situ forced oxidation, and improved limestone preparation systems and byproduct dewatering systems. This paper discusses how state of the art wet FGD technology can be used to upgrade the performance of existing wet FGD systems.

INTRODUCTION

SO₂ is an eye, nose and throat irritant. It is associated with respiratory illness. One of the major effects of SO₂ emissions is acid rain. A variety of SO₂ removal technologies are available. These include wet FGD, and dry FGD utilizing a spray dryer absorber (SDA), circulating dry scrubber (CDS), or dry sorbent injection (DSI). Wet FGD is the predominate technology used worldwide for the control of SO₂ from utility power plants. This technology was first introduced to electric utilities over 40 years ago.

Wet FGDs have been successfully used for a complete range of coal types including anthracite, bituminous, sub-bituminous, lignite and brown coals. Wet FGD is also installed on systems that use heavy oil and Orimulsion for fuel. Conventional wet FGD systems utilize a wet limestone process with in situ forced oxidation to remove SO₂ and produce a gypsum byproduct.

New state-of-the-art wet FGD systems are typically designed to achieve SO₂ removal levels of 98% and reliability levels of 99%+. The technology used in these modern wet FGD systems can be retrofitted into older systems. Upgrading an existing wet FGD system using current technology may be an effective approach to improve SO₂ removal, allow the use of lower cost higher sulfur coals, reduce power consumption, eliminate high pressure drop packing, allow conversion to a forced oxidized system, allow for the use of an alternate reagent, and improve the reliability of the system while reducing the operating and maintenance costs.

These modern day technologies include: the addition of an absorber tray for increased liquid to gas contact resulting in greater SO₂ removal; the use of wall rings, redesigned spray headers and spray nozzle patterns for improved slurry to flue gas contact within the absorber; redesigned mist eliminators and mist eliminator wash systems to handle higher velocities through the absorber; forced oxidation conversion to eliminate the need for disposal ponds, creating a saleable byproduct which will decrease disposal costs; and improved reagent preparation and dewatering equipment for greater system capacities and increased reliability. When upgrading an existing Wet FGD system, both capital and operating cost benefits are realized.

ABSORBER GAS-LIQUID CONTACT DEVICE

SO₂ removal in a limestone forced oxidized (LSFO) wet scrubber is controlled by how much SO₂ can be absorbed per unit volume of recirculated slurry (lb SO₂ per gallon, or kg per liter). This is referred to as absorption. SO₂ absorption is limited by the amount of solid and liquid phase alkalinity provided in each gallon of slurry. The absorption is also a function of the physical design of the absorber, which sets the gas-slurry contact area. Better contacting exposes more of the slurry to the gas and the increased exposure allows more of the alkalinity in each gallon of slurry to be utilized.

The most common type of wet FGD absorber is the spray tower. Many of these spray towers are open tower configurations where the flue gas enters the tower horizontally and turns 90 degrees into a vertical open cylindrical vessel with multiple levels of spray headers. The SO₂ removal process begins as hot flue gas enters the absorber tower where it is cooled and saturated by the slurry. The flue gas then flows upward through the absorber spray zone, where slurry is sprayed countercurrent to the flue gas flow, completing the SO₂ removal process. Maldistribution of flue gas across the cross section of the absorber is a common concern. This is caused by the high velocity of flue gas entering the absorber which causes a tendency of the flue gas to hug the walls of the absorber resulting in gas bypassing the spray headers. The SO₂ removal efficiency of an open spray tower can be upgraded by adding wall rings or an absorber tray. The structural aspects of adding wall rings or an absorber tray must be considered in any such retrofit.

Wall rings improve SO₂ efficiency by reducing the gas bypass in an open spray tower resulting from the tendency of the flue gas to hug the walls of the absorber. Also, wall rings push out the slurry that runs down from the walls back into the gas stream, making a better use of the liquid-to-gas ratio (L/G) from the spray headers. Figure 1 shows a typical wall ring retrofit in a wet FGD.



Figure 1 – Typical wall ring retrofit in a wet FGD

Retrofitting an absorber tray into an open spray tower is an effective way to maximize the contact between the flue gas and the slurry. The tray maximizes the contact between the gas and the slurry due to the vigorous frothing action that occurs on the tray. The absorber tray also evenly distributes the flue gas flow across the absorber cross-section, promoting optimum contact as the flue gas passes through the absorber spray levels. Figure 2 illustrates gas velocity profiles of the flue gas at the spray levels in an open spray tower compared to an absorber tower with a tray.

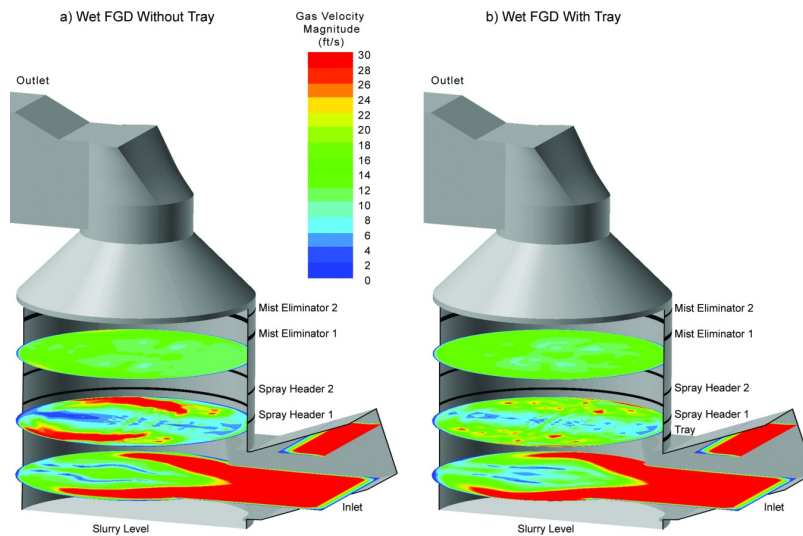


Figure 2 - Gas velocity profiles of the flue gas at the spray levels in an open spray tower (left) compared to an absorber tower with a tray (right).

The use of an absorber tray can eliminate the need for the addition of a spray level in the absorber. The additional fan power required from the increased gas-side system pressure drop of the tray is typically offset by a reduction in pumping power associated with the lower L/G required to achieve a given SO₂ removal efficiency. For moderate SO₂ removal improvements, the absorber tray retrofit can allow the plant to use one less spray level and spray pump per absorber. This results in decreased operating and maintenance costs.

Depending upon the target removal efficiency and configuration of the existing wet FGD module, installing two trays may also be considered as a means to achieve the most optimized upgrade to the system. Full-scale field tests have shown the benefit of adding an absorber tray to an open spray tower. Figure 3 illustrates the SO₂ removal efficiency increase in the same absorber tower with and without an absorber tray.

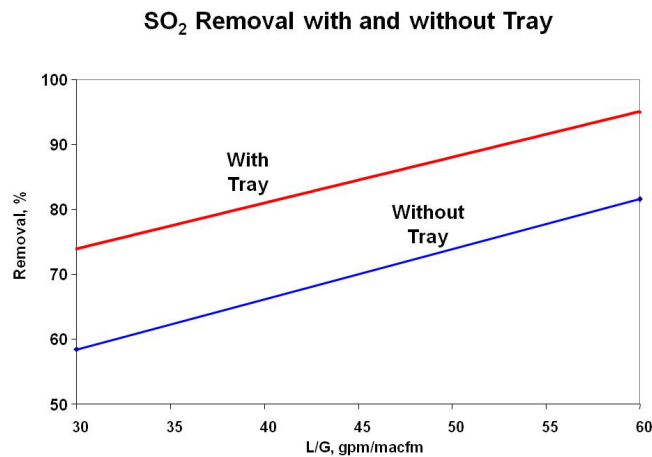


Figure 3- SO₂ removal efficiency increase in the same absorber tower with and without an absorber tray

ABSORBER SPRAY HEADERS

Older wet FGD absorber modules were designed with spray patterns which do not maximize contact of the flue gas with the slurry spray. Older designs have gaps or openings in the spray pattern that allow flue gas to bypass the spray zones without having contact with the slurry. Many of these gaps are seen on the outside of the absorber near the absorber walls.

These gaps provide a direct path for the flue gas to bypass the slurry spray. Figure 4 is an example of an original spray pattern compared to an upgraded spray pattern design in the same absorber. The modifications shown in Figure 4 involved replacement of the spray headers and nozzles. Modifications to the absorber pumps and absorber discharge pumping were not necessary to realize the benefit of the spray pattern redesign.

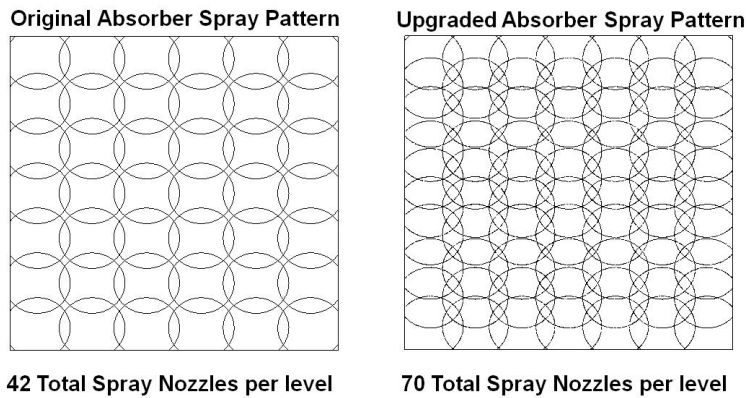


Figure 4 - Original spray pattern compared to an upgraded spray pattern design in the same absorber

Current wet FGD systems now use self-supporting spray headers with up to 60 ft (18.3 m) spans. The older generation spray header designs used a support system that was prone to breakage which causes the header sections to fail and fall to the bottom of the absorber. As a result, replacing the spray headers with a modern day self-supporting design can result in reduced maintenance costs and outage time. These new generation spray headers can be fabricated from either fiber-reinforced plastic (FRP) or alloy material.

CHEMICAL ADDITIVES

One method of increasing SO₂ removal is to improve gas-slurry contacting. This is accomplished by increasing the residence time on the tray or by adding a second tray as discussed above. Another means of increasing removal is to increase the L/G. The absorption per volume of liquid does not increase, there is just more slurry to provide more contacting. The third means of increasing removal is to increase the alkalinity in the slurry. This can be done by increasing the stoichiometry, but gypsum purity requirements usually limit the stoichiometry. Increasing the stoichiometry provides more liquid phase alkalinity and also more solid phase alkalinity. Both react in the absorption zone but dissolved alkalinity is much more effective.

Limestone-based systems can also use an organic acid additive to enhance SO₂ removal. (See Figure 5.) The dissolved (liquid phase) alkalinity can also be increased by a number of additives. The least expensive additives are organic acids that buffer the slurry liquor by acting as an acid or a base to help dissolve limestone or to directly neutralize the sulfurous acid formed by the absorption of SO₂. Dibasic acid (DBA) is the most economical acid which is a mixture of three acids: adipic, glutaric and succinic. This is produced as a byproduct in the manufacture of nylon.

The DBA is not consumed in the absorption reaction; it is involved in intermediate reactions but is regenerated when the overall reactions are complete. The same is true of other organic acids used to enhance performance, such as pure adipic acid or formic acid.

The capability of these organic acids to enhance removal has been known for over 40 years. Considerable testing of each of these has been performed in both pilot plants and field installations. A number of operating units use acid on a continual basis. Others use it to achieve removal when burning higher than design sulfur fuels. Acid has also been used for units in

which the design performance could not be achieved. In fact, this was the primary focus of acid use in the U.S. in the mid to late 1970s. Today the use of acid is a common method of reducing power consumption, limestone costs and earning emissions credits.

Using DBA allows flexibility in the design by allowing one or more of the following:

1. Reducing L/G and/or pressure drop to lower capital and operating costs.
2. Using DBA as a backup and allowing the absorber to be designed without a spare spray header and pump.
3. Designing the unit for the expected (design) sulfur concentration and using DBA at a range concentration or for future higher sulfur fuel.

The savings in capital and operating costs for the above have to be compared to the cost of the DBA and its storage and transfer system.

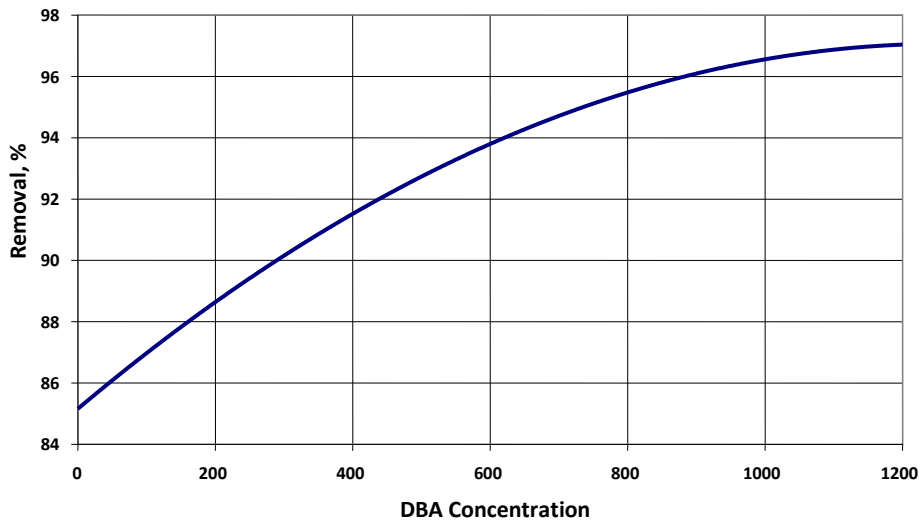


Figure 5 - Typical SO₂ Removal vs. DBA Concentration

MIST ELIMINATORS AND MIST ELIMINATOR WASH SYSTEM

Mist eliminators (ME) remove entrained scrubbing liquids to minimize fouling of downstream equipment before the flue gas enters the stack and to minimize fallout from the stack. The ME is a momentum separation device that separates the high momentum liquid droplets from the gas as it passes through the tortuous path of the mist eliminator chevrons. Mist from the absorber spray zone is collected by two stages of chevron type mist eliminators or a combination of chevron and tubular style mist eliminators. The first stage, which is closest to the spray headers, captures the larger particles while the second stage captures finer particles including the ME wash water

droplets. The mist eliminators require washing to prevent solids which are formed by evaporation and slurry particle deposits from accumulating on the blades. An array of wash headers and wash nozzles are provided. The top and bottom sides of the first stage are washed, but typically only the bottom side of the second stage is washed.

A variety of MEs and mist eliminator wash systems can be found on older generation wet FGD systems. Common old generation ME designs include a bulk entrainment separator followed by two levels of “teepee”-style mist eliminators or two levels of early generation flat chevron style MEs. Figure 6 compares an old generation ME system to a typical modern set of MEs.

Older generation ME wash system designs tended to not effectively wash all of the surfaces of the MEs when compared to modern day designs. Fixed grid ME wash headers can be retrofitted in place of retractable lance-style wash systems or fixed grids that were ineffective in washing the ME surfaces.

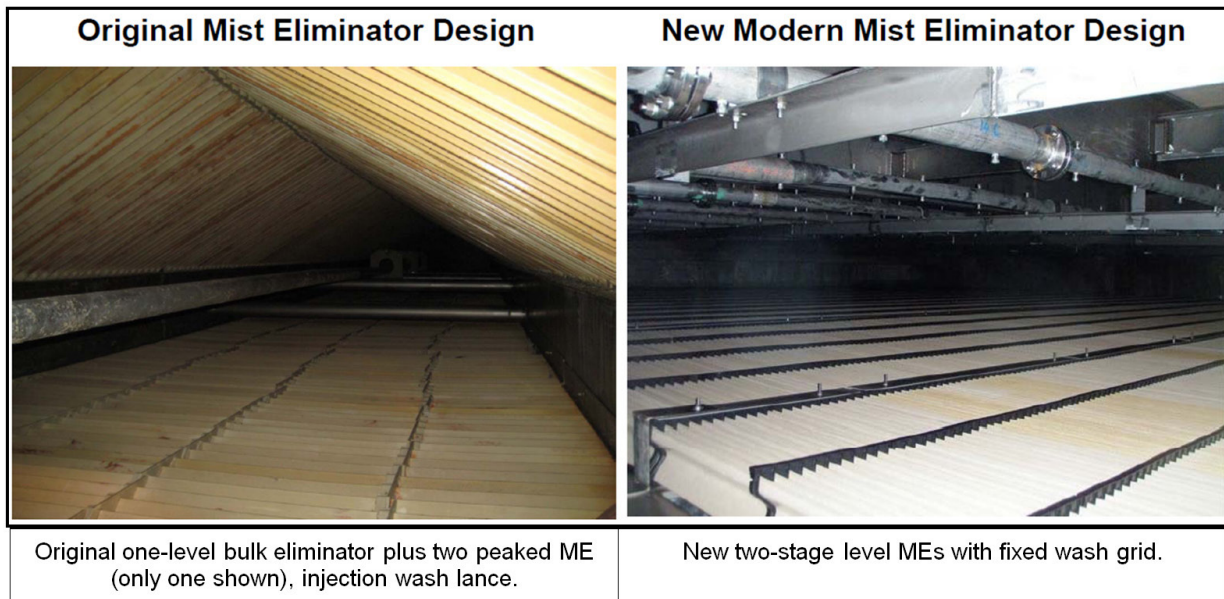


Figure 6 - Comparison of an old generation ME system to a typical modern set of MEs.

LIMESTONE FORCED OXIDIZED SYSTEM UPGRADES

The limestone forced oxidization (LSFO) system wet FGD is the most common system in use today. A stable gypsum byproduct is produced by the LSFO system which is typically sold for use in the manufacture of wallboard or to the cement industry. In some cases, a disposable gypsum product is produced for landfill if there are no wallboard or cement plants within a reasonable distance.

The differences between gypsum products depend on the amount of impurities or the degree of dewatering. In addition, the LSFO system is less prone to scaling compared to a natural oxidization system and as a result, requires less outage time. The LSFO wet FGD process incorporates air injection to ensure a fully oxidized gypsum product. The introduction of air into the absorber reaction tank creates calcium sulfate (gypsum) as a marketable byproduct.

The absorber reaction tank, sometimes referred to as the recirculation tank, serves several functions. It is a reservoir of slurry to supply the absorber recirculation pumps and the absorber bleed pumps. The reaction tank is where the oxidation of the calcium sulfite to gypsum takes place. It serves as a storage tank to allow the limestone to dissolve and to promote gypsum crystal growth.

A wet FGD can be converted to forced oxidation using the existing reaction tank, or in some cases, an external oxidation tank can be used. This conversion will minimize scaling from utilization of stable system chemistry and creating a saleable byproduct which will decrease disposal costs.

Air sparge grids and air lances with mechanical agitators are the two generally applied methods of injecting oxidation air into the process. The method to inject oxidation air has an impact on plant costs and system operating requirements.

The sparge grid is a multiple air header arrangement with evenly spaced bubble stations across the vessel plan area. The sparge grid is prone to nozzle plugging if the oxidation is not constantly passing through the absorber tank whenever it contains slurry. The lance system consists of air pipes directed to a region in the liquid jet created by side entry mixers. Figure 7 shows a typical air lance injection system.

The performance of the lance system is influenced by the energy of the fluid jet (mixer power) and the submergence depth (air blower power). The performance of the sparge grid is less dependent on the mixer power and is, to a much greater degree, influenced by submergence depth.

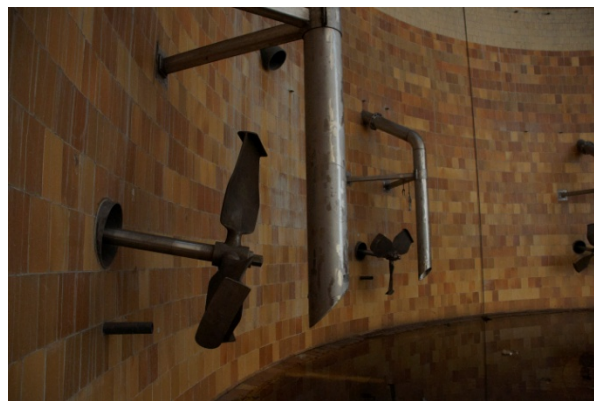


Figure 7 - The lance system consists of air pipes directed to a region in the liquid jet created by side entry mixers

When upgrading an existing wet FGD, a general review of the capacity available in the existing absorber recirculation tank is required. In some cases, a sparge grid or lance system can be retrofit into the existing tank. If there is not enough residence time available, an external oxidation air tank may be required.

REAGENT PREPARATION AND DEWATERING

When SO₂ removal is increased by equipment upgrades and/or when burning higher sulfur coals, the amount of wet FGD byproduct will increase. Wet FGD systems that use natural oxidation could be potentially impacted from this increased demand on the system. As a result, the disposal pond may reach its capacity. Additionally, the use of disposal ponds may not likely be allowed by future regulations.

If limestone consumption must be increased to improve SO₂ removal, the reagent preparation and dewatering systems may be undersized. In most cases, higher SO₂ removal requires a finer grind than what the older systems were originally designed to achieve. The standard grind on modern wet FGD systems is 95% passing through a 325 mesh.

The components of some existing milling systems can potentially be upgraded to handle the new quantity and grinding requirements. Optimizing the grind of the limestone milling system can have a significant positive impact on limestone utilization. However, it is typically not possible to vary the speed of the mill to increase/decrease its capacity.

Early generation wet FGD systems used thickeners for primary dewatering and rotary drum filters for secondary dewatering. Modern wet FGD systems have replaced thickeners with hydroclones which are able to achieve up to 55% solids, compared to 35 to 45% for thickeners which also require a substantial amount of plant real estate. Increased moisture removal from the hydroclones can reduce the required size of the vacuum filters.

Thickeners are prone to maintenance problems. The rakes tend to stick and the large mechanical equipment can be expensive to maintain or replace. Also, a conversion to forced oxidation can make thickeners difficult to operate because of the rapid settling of gypsum in the center well of the thickener.

Hydroclones require minimal maintenance with little downtime because of the use of spares. The use of hydroclones in forced oxidized system is a proven technology. Figure 8 shows a hydroclone cluster in a wet FGD application.



Figure 8 – Hydroclones require substantially less real estate compared to a thickener.

Many older wet FGD systems use rotary drum filters. (See Figure 9.) These filters may not have the capacity to handle increased SO₂ removal and the subsequently greater byproduct from the absorber. The existing rotary drum filters must be assessed to determine if it can handle the increased demand. One possible solution to handle this increased demand is to increase the amount of time per day that the rotary drum filter operates. Worn parts of the system may need replaced to ensure adequate reliability. In some case, replacement of the existing drum filters may be required. New generation rotary drum filter technology can also achieve levels of 10% moisture or better.



Figure 9 – Rotary drum filter

The majority of new wet FGD systems use vacuum belt filters (Figure 10) to reach moisture levels of less than 10%. Decreased gypsum moisture levels can allow for gypsum sales to wallboard and cement companies, or a decrease in landfill transportation costs.



Figure 10 –Vacuum belt filter

CONCLUSION

With the recent advancements in wet FGD technology, utilities have many ways to upgrade their existing systems. These upgrades can be effective for compliance with the latest environmental regulations, as well as reducing operating and maintenance costs, increasing the length of time between maintenance outages, and reducing forced outages.

These upgrade technologies include: retrofitting wall rings or an absorber tray for increased liquid to gas contact resulting in greater SO₂ removal; the use of organic acids to enhance SO₂ removal; redesigned spray headers for improved flue gas contact with the slurry within the absorber module; redesigned mist eliminators and wash systems to handle higher absorber velocities and improve mist elimination; conversion to forced oxidation for elimination of the need for disposal ponds and creating a saleable byproduct which will decrease disposal costs; and improved performance of the reagent preparation and dewatering system for greater capacities and reliability.

When upgrading a wet FGD system, the absorber, reagent preparation and dewatering equipment, and materials of construction must be reviewed to ensure compatibility with the new operating conditions.

European utilities are continuously looking for ways to reduce operating and maintenance costs of their wet FGD systems while at the same time increasing SO₂ removal efficiency. Upgrading an existing wet FGD may be the method of choice for applying proven technology to achieve this goal.

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