Dual Flow Tray Technology for Wet FGD Performance Upgrades

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Abstract

SO_2 emissions, as directed by the Industrial Emission Directive (IED) in 2011 and the Best Available Technologies Reference (BREF) in 2016 may require some utility and power producers to retrofit new Flue Gas Desulfurization (FGD) units to existing plant. Many other sites have existing Wet FGD systems that currently do not achieve the projected SO_2 emission according to BREF. For EU countries compliance is mandatory; however, non-EU countries such as Turkey may also follow IED guidelines pending government review.

Amec Foster Wheeler's Dual Flow Tray Technology can provide a cost effective solution for both new Wet FGD units and upgrades to existing WFGD plants to achieve the new emission standards as directed by IED and BREF. Dual Flow Trays (DFT's) consist of one or more levels of perforated plates in the absorption section of a wet FGD that enhance the gas to liquid mass transfer capabilities of the system. Flue gas, flowing upwards, contacts the falling absorber slurry on the tray causing a sustained froth layer to occur. The froth layer provides a substantial increase in flue gas / slurry contact time compared to traditional open spray towers, which enables comparable performance at lower Liquid to Gas (L/G) ratios. DFT's also improve flue gas distribution through the absorption section thus enhancing mass transfer opportunities. As an added benefit, DTFs are designed for maintenance loads and are routinely used during outages. The spray header system can be easily inspected without the use of costly and time consuming scaffolding or lift equipment.

Dual Flow Tray (DFTs) technology has been widely used in utility wet FGD applications in the US for over 30 years. For existing Wet FGD units, a Dual Flow Tray retrofit will improve the current performance. In many cases, the addition of a Dual Flow Tray will allow your existing system to achieve the new EU standard for SO_2 emissions in a very cost effective manner.

SO_2 Removal Basics and Theory

The removal of acidic gases (mainly SO_2 for this discussion) from the flue gas stream is governed by two processes; the absorption of SO_2 via gas / liquid contact and the ability to quickly neutralize the collected acids in the liquid phase. The ability to improve either of these will enhance SO_2 capture in a wet FGD absorber.

The first step in the SO_2 removal process is the absorption of SO_2 from the flue gas into the absorber liquor. The absorption is governed by the mass transfer coefficient, the surface area available for mass transfer, and the difference between the SO_2 partial pressure in the flue gas and the vapor pressure of SO_2 at the gas / liquid interface. Wet FGD system suppliers really have influence on only two of these variables, the surface area available for mass transfer and the dissolved alkalinity in the absorber slurry that affects interface vapor pressure.

The first variable, the surface area available for mass transfer, is controlled in open spray tower designs by the selected L/G ratio in conjunction with spray nozzle droplet size. The contact surface area is governed by the droplet size of the selected spray nozzles and the overall L/G ratio. Improving SO_2 performance for open tower designs is generally limited to increasing L/G ratio or creating smaller droplet sizes via higher pressure drop nozzles. In each instance, this results in higher pumping power requirements. Additionally, smaller spray droplet sizes are only marginally effective due to significant droplet coalescence within the spray zone of the tower.

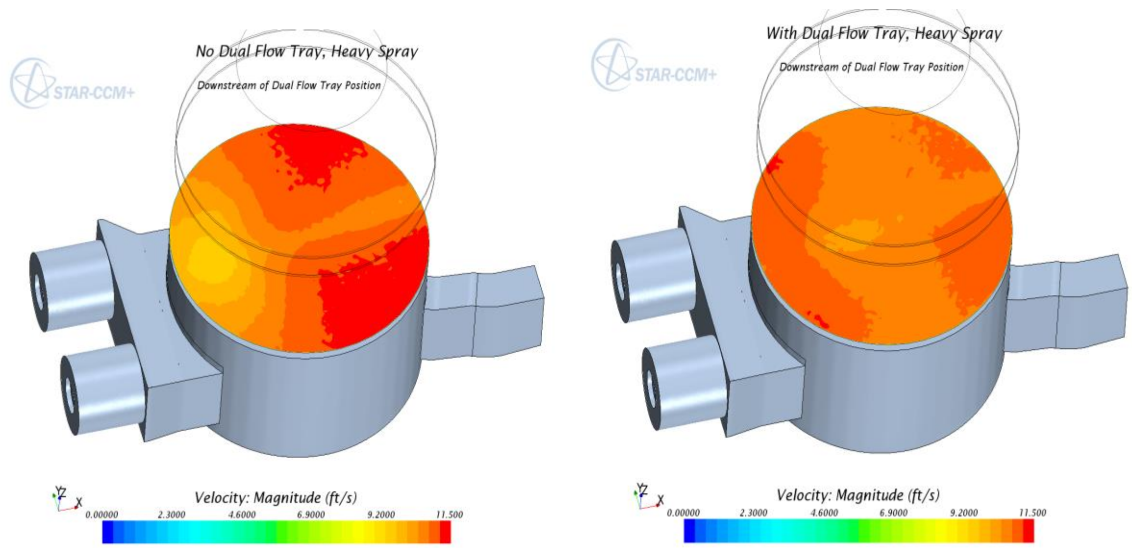
Figure 1
Dual Flow Tray after 24 month operation

Flue Gas / Slurry contact can be significantly enhanced with the use of internal contacting devices. In the past, packing material has been attempted for this application but has proven unreliable in Limestone based systems and is currently not acceptable to the US utility industry. This led to the development and acceptance of Dual Flow Tray (DFT) technology. DFT's are one (or more) levels of perforated plates that span the entire absorber cross section.   DFT's provide more effective gas to liquid contact than any open tower design relying on the surface area provided by the spray droplets. A typical DFT can be seen in Figure 1

Wet FGD performance improvements from the addition of DFT's can be explained by several factors. The DFT provides additional resistance to gas flow improving flue gas distribution at the ***beginning*** of the gas to liquid contact zone, which allows full use of the L/G provided by the slurry sprays. Many Wet FGD's have a side flue gas entry. The flue gas momentum pushes the gas to the far wall, where downstream resistance begins to redistribute the gas across the tower diameter. In open spray towers, the slurry sprays will redistribute the flue gas; however, this does not occur until the gas is well into the absorption zone. This does not provide optimum use of the available L/G and is a clear performance advantage for Dual Flow Tray absorbers.

A Computational Fluid Dynamics (CFD) flow model from an existing Amec Foster Wheeler DFT installation can be seen below in Figure 2. Flue gas entry is from the side which is typical of most absorber systems. The model was included as part of Amec Foster Wheeler's standard design package. For comparison, the same CFD model was run without the DFT included. The expected gas flow distribution for both cases is displayed in Figure 2.

Figure 2 – Flue Gas Distribution @ 1.5 m above inlet duct



Open Spray Tower
73% within 5% of average velocity
96% within 10% of average velocity

DFT Tower
97% within 5% of average velocity
100 % within 10% of average velocity

Dual Flow Trays also provide additional and very effective gas to liquid contact. Flue gas flowing upward is intimately mixed with the falling absorber slurry. The flue gas velocity travelling through the holes in the DFT causes a liquid resistance, thus forming a froth layer to occur on the tray. The froth layer, typically 150mm – 300mm deep, provides additional mass transfer surface area and contact time in the absorption zone. Amec Foster Wheeler estimates that each tray level provides an additional one to two seconds of contact time in the absorption zone. Full scale testing of absorber towers with and without DFT's confirm comparable performance for DFT absorbers at L/G ratios 15% – 30% below open tower designs.

In addition to effective gas to liquid contacting, absorber slurry liquid phase chemistry also plays a substantial role in the overall performance of the WFGD unit. The absorber slurry needs sufficient liquid phase alkalinity to quickly neutralize the absorbed acid to maintain the driving force necessary for SO_2 capture. In limestone based systems, the alkalinity is generated from dissolution of calcium carbonate. The operating pH is a general indicator of the alkalinity of the absorber liquor. The higher the pH, the more dissolved alkalinity is present.

As the absorber slurry falls through the absorber tower, the pH of the solution will fall as the acid is absorbed. For an absorber that is operating at a pH level of 5.7 in the reaction tank, the slurry pH falls to approximately 3.5 to 4.5 on the DFT. Since limestone dissolution rate is directly proportional to the hydrogen ion concentration (i.e. the solution pH), the lower pH on the DFT significantly increases limestone dissolution rates. The increased dissolution rate provides more alkalinity to be available for acid neutralization and maintains a high driving force for mass transfer. This chemistry advantage, in conjunction with the slurry holdup, is equivalent to additional recycle tank retention time and optimizes SO_2 removal performance.

DFT Tower vs Open Spray Tower for New Build Applications

To illustrate the typical differences between absorber types, Amec Foster Wheeler has provided a design comparison of our open spray tower design with an equivalent DFT design for a theoretical 500 MW boiler unit. In this example, the fuel sulfur level is 1.2% with a 98% SO_2 removal requirement. A side by side comparison of each design is shown in Table 1 below.

Table 1 – Design Comparison of a DFT Tower and an Open Spray Tower

	Open Spray Tower	DFT Tower
Absorber Diameter, meters	15.0	15.0
Recycle Tank Retention Time, mins	5.0	5.0
Recycle Tank Height, meters	10.1	7.4
Number of Recycle Pumps	*3+1*	*2+1*
Recycle Pump Flowrate, m^3/h	6,100	6,670
Number of Trays	Zero (0)	One (1)
Overall Tower Height, meters	30.3	26.1
Absorber Power Consumption, kw	1,800	1,310
Pressure Drop, kPa	1.0	1.4

The above example illustrates that a DFT tower will be smaller in size than a comparable open tower operating under identical inlet SO_2 values and equivalent emissions. The reason for this can be directly traced to the lower L/G necessary for the DFT absorber. In this instance, a DFT tower would achieve emissions with an overall liquid recirculation rate of 13,340 m^3/ h while an open tower would require 18,340 m^3 / h. Since limestone dissolution and gypsum crystallization require a minimum retention time in the recycle tank, a lower L/G results in a smaller recycle tank. The recycle tank, with a 5 minute retention time, is 7.4 m for a DFT absorber compared to 10.1 m for the open tower design.

Since a DFT tower requires less L/G, it is possible in many cases for a DFT tower to be designed with one less operating spray level and associated recycle pump. As a general design standard, Amec Foster Wheeler will not offer an open spray tower for SO_2 removal levels in excess of 95% with only two operating spray levels. The small absorption zone (2 spray levels) does not allow the flue gas to properly distribute and the L/G is not well utilized. This is not a concern for a DFT absorber due to optimal flue gas distribution, higher liquid holdup and contact time, and superior mass transfer capabilities for the DFT tower.

In this example, two operating spray levels are required for a DFT while three operating spray levels are needed for the open tower design. This decreases tower height by one spray level and reduces overall absorber height. For this example, an open spray absorber would be 30.3 m tall while the DFT absorber is 26.1 m. Absorber diameter is identical for either design, but absorber shell steel thickness may be able to reduced (depends on structural design) which could lead to additional cost benefit. Foundation requirements will also be lower for a DFT absorber as fewer recycle pumps are needed.

In addition to the lower capital cost for the DFT absorber tower itself, further project cost savings will be realized. The shorter absorber results in smaller quantities for recycle piping, auxiliary piping, electrical cable, electrical conduit, instrument cable, control cable, and plant air piping. Absorber access steel and structures will be smaller which results in further cost savings on both material supply and associated construction costs. The Dual Flow Tray Level can be used as a staging platform during initial construction (See Figure 3) and later as an inspection platform for the upper layers of the absorber.

Figure 3 – DFT used as Staging Platform during Construction

Improving Existing Wet FGD Unit Performance

There are several ways to improve the performance of an existing Wet FGD system. The easiest and most cost effective way to improve performance is to operate the system at a higher pH value. Many limestone based systems operate at controlled pH levels between 5.0 and 5.7. A higher operating pH will improve efficiency; however, this is not a proper solution for most applications due to system chemistry limitations and higher reagent costs. At pH levels greater than 6.0, reduced sulfite to sulfate oxidation rates and high limestone stoichiometry produce unacceptable gypsum quality. Poorer oxidation will also result in gypsum scaling conditions and is not acceptable for long term operation. These concerns limit chemistry modifications to only marginal increases in SO_2 removal efficiency.

An improved limestone reagent could also marginally increase SO_2 capture efficiency. Limestone for WFGD systems is either ground on-site or delivered to site at a usable size, typically 90 to 95% passing 44 µm. Higher reactivity of the limestone could also marginally improve performance. Both of these variables are difficult to modify. Additionally, these changes will only be effective if the system is liquid phase (i.e. alkalinity) mass transfer limited which may or may not be applicable the existing Wet FGD site.

This generally limits performance upgrades to physical changes of the existing system. For open spray towers this could mean any, or all of, the following modifications: addition of wall rings, improved flue gas or liquid spray distribution, smaller spray droplet spray nozzles, double spray nozzles, more L/G, or the addition of one or more Dual Flow Tray(s).

In a properly designed Wet FGD system, the addition of wall rings will only marginally improve efficiency. Higher pressure spray nozzles will produce smaller spray droplets that should help in theory; however, droplet coalescence minimizes the enhancement factor. Double spray cone nozzles will also improve performance, but droplet coalescence can also be a performance limiter. This means that additional L/G, in conjunction with spray header modification, is the most likely means of significantly improving performance of an existing open spray tower.

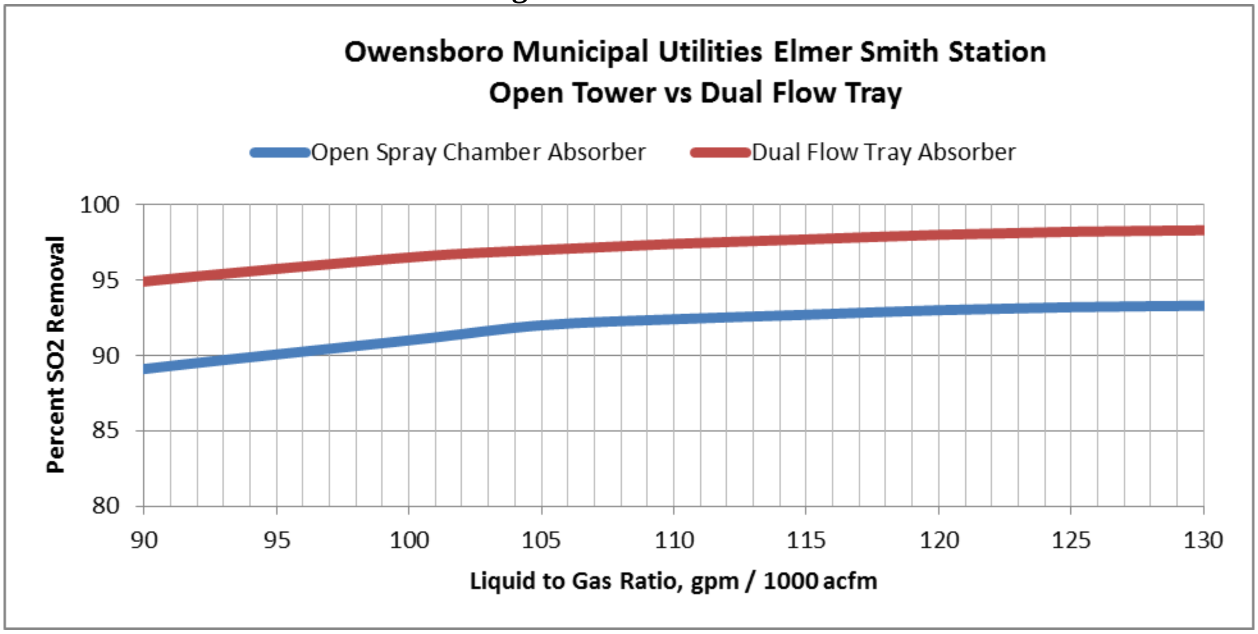
Unfortunately, increasing L/G in an existing absorber is typically a challenge. Most sites do not have adequate floor space for additional recycle pumps and not enough tower height for additional spray banks. Modifications to existing pumps are possible; however, recycle pump efficiency will likely be compromised and recycle pipe flow velocities could exceed proper design limits. Recycle tank retention times must also be considered when adding additional L/G. These solutions, although possible, generally require outages of several months and have high construction costs.

In many cases, Amec Foster Wheeler's solution is the addition of one or more Dual Flow Trays below the bottom spray bank. Many open towers have adequate space between the lowest spray bank and the inlet ductwork to allow installation of a Dual Flow Tray Level. Approximately 3.0 – 3.5 meters of vertical height is generally required for a DFT addition. An additional benefit to installing a Dual Flow Tray is that lower pressure drop nozzles can also be used (spray nozzle droplet size is less critical for a Tray Tower) to artificially increase L/G ***without*** modification to the existing recycle pump and recycle piping systems.

Owensboro Municipal Utilities DFT Upgrade

SO_2 removal performance improvement for a DFT addition into an existing open spray tower is seen at Owensboro Municipal Utilities (OMU), Elmer Smith Station, Kentucky, USA. Amec Foster Wheeler supplied two open spray chamber absorbers for this site that began operation in 1995. In 2008, the existing absorber towers were operating at 93% SO_2 removal at an operating pH level of 5.7. In order to meet an increased environmental standard, OMU requested a performance upgrade to increase SO_2 efficiency from 93% to 98%. This represented an increase in absorber mass transfer from 2.7 Number of Transfer Units (NTUs) @ 93% removal to 3.9 NTU's @ 98% removal. This was a 42% increase in NTU's over the existing design. Amec Foster Wheeler's operating data has suggested that the addition of one DFT level can increase the overall absorber NTU by approximately 50%. Therefore, it was determined that one level of DFT's could achieve the desired performance enhancement ***without*** any additional modification to the existing recycle pump or spray header system. Testing at the site confirmed the expected performance increase without changes to operating pH or limestone stoichiometry. Test data from this site can be seen in Figure 4.

Figure 4 – Site Test Data



Longview Power, Addition of 2nd DFT Level

Amec Foster Wheeler originally supplied a DFT absorber for Longview Power (West Virginia, USA) that began operation in 2011. Northern Appalachian bituminous coal for the 700 MW boiler is supplied by a local mine that conveys unwashed, medium sulfur fuel directly to the site. In July 2014, it was determined that future coal sulfur levels would be increasing by approximately 46% from original design values. As the allowable SO_2 emission limit was not modified, higher SO_2 removal was required by the existing absorber to maintain the compliance limit for SO_2. This required an increase in SO_2 removal efficiency from the original 97.9% up to 98.6% to meet this criterion.

Since floor space was not available for any additional recycle pumps, and the existing recycle pipe size was pushing allowable velocity limits, it was quickly determined that more L/G was not a cost effective option for this plant site. Instead, it was determined that the addition of a 2nd DFT level in conjunction with higher additive (Dibasic Acid) concentration would achieve the desired performance enhancement in the most cost effective manner.

Organic (Diabasic) acid is utilized as a buffer additive to enhance SO_2 gas/liquid mass transfer by reducing pH changes in the recycle slurry. The addition of an organic acid additive increases the diffusion of SO_2 as HSO_3^- within the recycle slurry by the following mechanism:

$$HA \leftrightarrow H^+ + A^-$$

$$A^- + SO_2\,(aq) + H_2O \leftrightarrow HA + HSO_3^-$$

The addition of dibasic acid reduces pH changes within the recycle slurry thereby increasing the SO_2 gas/liquid mass transfer.

An overview of the original Wet FGD absorber and the modified Wet FGD absorber can be seen in Table 2.

Table 2 - Longview Power Wet FGD Upgrade Data

Longview Power WFGD Design Data	Units	Original Design 2011	High Sulfur Design 2015
Mass Flowrate	kg/hr	2,965,600	3,283,200
Inlet SO_2	kg/hr	12,603	18,538
Outlet SO_2	kg/hr	259	259
SO_2 Removal Efficiency	%	97.9	98.6
Number of DFT's		One (1)	Two (s)
Absorber Recycle Pumps	# operating + spare	4+1	4+1
Total Recycle Pump Flow	m3/h	47,200	47,200
DiBasic Acid Concentration	ppm	750	1,000
SO2 Removal Performance Test Results	%	98.2	99.6
Absorber Pressure Drop	kPa	1.3	1.7

As can be seen from the above data table, the performance improvement for this absorber will be achieved with the addition of a second DFT level 0.6 meters above the existing DFT along with a small increase from current Dibasic Acid concentration values. No additional modifications to absorber geometry, recycle pump flow rate, recycle pipe size, spray nozzle style or spray nozzle pressure drop was required. A progress photo of the DFT installation can be seen in Figure 5.

Figure 5 – 2nd layer DFT addition

Conclusions

Amec Foster Wheeler's DFT absorbers have been successfully operating in the US for over 30 years and hold a significant market share of utility installations. Due to its superior mass transfer capabilities, DFT absorbers are more compact in size and offer a smaller footprint than comparable open spray tower offerings. In many instances, a DFT absorber will have one less recycle pumping system resulting in additional capital and construction cost savings for a new build Wet FGD system. DFT absorbers also provide a convenient maintenance platform for inspections for the upper half of your absorber vessel that result in shorter and more cost effective outage schedules.

For existing Wet FGD systems that require better SO_2 removal efficiency, the addition of a DFT has demonstrated that it will improve performance. Amec Foster Wheeler's predictive models indicate that a DFT can improve mass transfer capabilities by as much as 50% (1.5 times) from the current design. In many instances, the addition of DFT's alone can achieve desired performance objectives without any other modifications. For better performance, a DFT addition in conjunction with spray nozzle modification and pH adjustment will push the efficiency even higher. The liquid retention and low pH on the DFT allows higher operating pH levels without affecting limestone stoichiometry or gypsum quality.

Amec Foster Wheeler has provided more than 60 operating DFT absorbers over the past 30 years. Most of these absorbers are still operating today. During this period, full scale operating data from many of our units have been collected and is currently incorporated in our predictive model for performance. This experience base ensures high value solutions for any of your Wet FGD needs.