# The Largest and the Highest Performance Flue Gas Desulfurization Plant for Fossil Power Plants in the World

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*While sulfur oxides (SOx) and nitrogen oxides (NOx) emissions from coal-fired power plants are regulated drastically in the U.S., Mitsubishi Heavy Industries, Ltd. (MHI) established a joint corporation, Advatech LLC, with the URS Corporation, which is an American engineering company, in May 2002, and delivered on time a flue gas desulfurization (FGD) plant which was the first Advatech LLC plant, and started operation from the middle of October 2006. The FGD plant for Unit 3 of the Paradise Fossil Plant (unit gross generation capacity 1056 MW) that was ordered from Tennessee Valley Authority (TVA), which is the largest U.S. utility, is the largest in the world and the highest performance plant in which more than 98% of the sulfur dioxide ($SO_2$) can be removed in single module.*

## 1. Introduction

Taking the initiative with the rise of global environmental regulations in recent years, MHI has developed a desulfurization technology using a wet limestone-gypsum process, and has been building flue gas desulfurization (FGD) facilities for fossil power plants since 1972.

As of April, 2007, MHI has delivered the wet limestone-gypsum process to 191 FGD plants, and has a high share of the global market.

Although flue gas desulfurization facilities must have low capital, and operation and maintenance (O&M) costs with highly efficient performance, MHI has designed the double contact flow scrubber (DCFS), which is a fountain-like spray type absorption tower equipped with single stage upward DCFS spray as shown in **Fig. 1**, which has met these goals, and 76 units have already been installed, and received high evaluations from users.

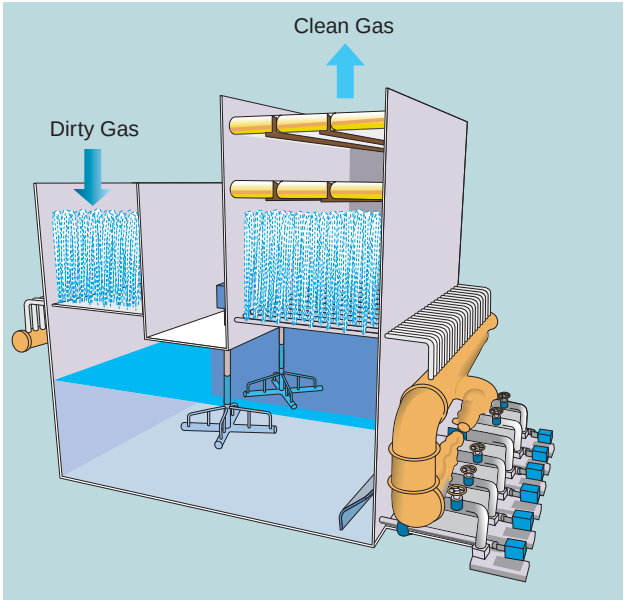


**Fig. 1 Twin tower of double-contact-flow-scrubber (DCFS)**

Because of the quickly increasing demand for desulfurization in the U.S., Advatech LLC was established in 2002 and was awarded the desulfurization facility by the TVA for Unit 3 of the Paradise Fossil Plant in the same year.

This paper presents an overview of the scrubber design for the TVA Paradise FGD system, and outlines its recent operating status.

## 2. Overview of Desulfurization Plant for Paradise Fossil Plant

### 2.1. Overview of Paradise Fossil Plant

The TVA is the nation's largest public power provider and has power stations in the states of Tennessee, Alabama, Georgia, and a part of Kentucky, with 33,000 megawatts of dependable generating capacity.

Paradise Fossil Plant[(1)] is located in western Kentucky on the Green River near the village of Paradise, and has three coal-fired boilers with a total of 2,273 megawatts of dependable generating capacity, and was built between 1963 and 1970.

Units 1 and 2 installed FGD scrubbers in 1983, and the amount of $SO_2$ emissions from the three-unit plant has been reduced by 93% by installing an FGD scrubber to Unit 3 when combined with the operation of the other two scrubbers.

Fig. 2 View of Paradise Fossil Plant

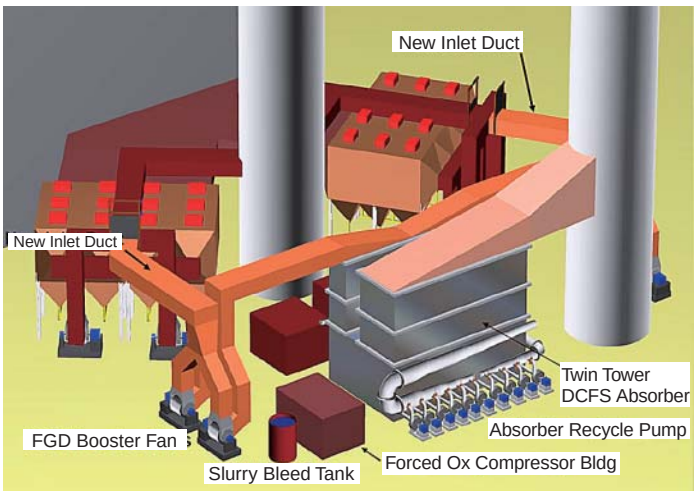


Fig. 3 Layout of the new FGD system at Paradise Unit 3

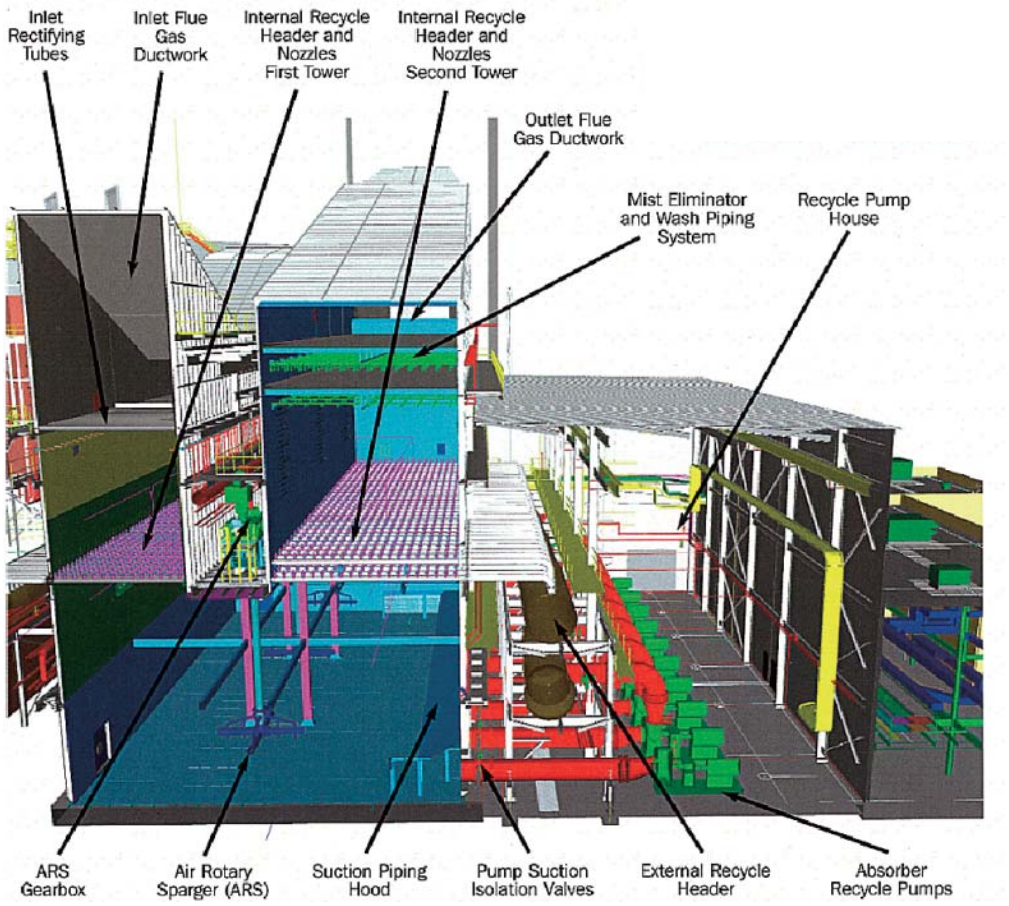


Fig. 4 Cross-section of the Unit 3 scrubber

A view of Paradise Fossil Plant is shown in **Fig. 2**, and the layout of the new FGD system at Paradise Unit 3 is shown in **Fig. 3**.

Paradise Fossil Plant Unit 3 also has a selective catalytic reduction system, the same as the two other units, which reduce NOx emissions from the plant. The boiler exhaust gas which has had the NOx removed is fed to four electrostatic precipitators to remove particulate matter via an air heater. The gas is then passed into a single scrubber DCFS module via four fans, and the gas with $SO_2$ removed is discharged from the new wet stack.

### 2.2. Outline of FGD System for the Paradise Unit 3

A cross-section of the Unit 3 scrubber is shown in **Fig. 4**. A co-current & counter-current DCFS (twin tower) is adopted, and upward single stage sprays are installed on a single spray header located in the lower sections of the first and second towers. The Unit 3 scrubber is the largest single scrubber module in the world with the highest performance and can treat 4 million acfm of flue gas, removing more than 98 percent of the $SO_2$. The key design system parameters of the scrubber are shown in **Table 1**.

**Table 1 Key design system parameters of the FGD system**

| Description | Units | Value |
|---|---|---|
| Unit Gross Generation Capacity | MW | 1 056 |
| Boiler Type | Balanced Draft Cyclone | |
| Inlet Flue Gas Flowrate | acfm | 4 028 000 |
| Inlet Flue Gas Flowrate | lb/hr | 12 020 000 |
| Inlet Flue Gas Temperature | F | 350 |
| Design Fuel Sulfur Content | %-dry basis | 3.4 |
| Design Inlet $SO_2$ Loading | lbs $SO_2$/MMBtu | 5.1 |
| Design Inlet $SO_2$ Loading | ppm-dry | 2 121 |
| FGD System $SO_2$ Removal Efficiency | % | 98 |
| Recycle Tank Volume | gallons | 1 371 000 |
| Fountain Nozzles | # | 2 346 |
| Recycle Slurry Solids | % by wt | 30 |
| Recycle Slurry Chloride Concentration | ppm-dry | 1 780 |
| Limestone Prep System Capacity | tph | 50 |
| Limestone Slurry Grind Size | %pass-325 mesh | 90 |
| Gypsum Solids Production Rate | tph | 75 |
| Limestone Consumption Rate | tph | 47 |
| Makeup Water Consumption Rate | gpm | 2 200 |
| Height of New Wet Stack | ft | 600 |
| Equipment Redundancy | | |
| Recycle Pumps | | 10+1 |
| Ball Mills | | 1+1 |
| Ox Air Blowers | | 2+1 |
| ARS | | 3+0 |
| Absorber Dimensions | | |
| Length | ft | 114 |
| Width | ft | 70 |
| Height | ft | 125 |
| Materials of Construction | Name | |
| | Common | UNS |
| Inlet-Wet/Dry Interface | C-276 | N10276 |
| 1st Tower Contact Zone | 2 550 | S32550 |
| 1st to 2nd Tower Crossover | 254 Smo | S31254 |
| 2nd Tower | 2 205 | S32205 |
| Recycle Tank | 2 205 | S32205 |
| Outlet Ductwork | 2 205 | S32205 |
| Stack Liner | Roll Bond C-276 | N10276 |
| Inlet Ductwork | Corten Steel | |
| Spray Header | 304 SS | |
| Mist Eliminator | 317 L | |

The first tower is called a co-current scrubber: flue gas is released from the top of first tower and contacts the recycle slurry that is sprayed upward from the spray nozzles, and goes down through the scrubber contacting falling droplets. The droplets of slurry fall into a reaction tank at the bottom of the scrubber. As the gas leaves the first tower, it traverses the top of slurry in the reaction tank before entering the second tower.

The second tower is called a counter-current scrubber: the gas enters the second tower and goes up through the scrubber contacting the recycle slurry sprayed upward, and the droplets fall into the reaction tank as in the first tower. After the flue gas exits from the spray zone of the second tower, it passes through a two-stage vertical flow mist eliminator to separate the mists and is discharged from the stack.

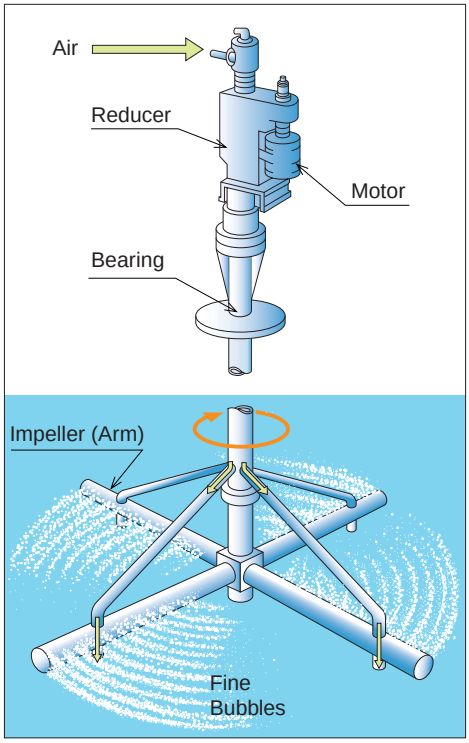


**Fig. 5 Air rotary sparger**

As mentioned above, the DCFS has no internal structure in the gas-liquid contact zone other than the single-stage spray pipes, so that maintenance is very easy on internal inspections. Since the spray pipes themselves are always washed by the slurry there is no gypsum scaling.

The recycle pump bay is located in front of the second tower. Recycle pumps discharge into two common external recycle headers which provide slurry for the first and second tower's spray pipes. By using a modular approach, the size of the absorber tower can be easily expanded by increasing the width of the absorber tower with the same length of spray pipes, and the number of pipes and pumps to accommodate the different volumes of flue gas.

In addition, the collected gypsum slurry is discharged into a pond in this plant.

### 2.3. Outline of the Other Equipment

The following latest equipment has been adopted in this FGD system which realizes even higher efficiency.

(1) Air Rotary Sparger (ARS)

Sulfite ions in the absorbent must be oxidized to sulfate ions in order to recover the gypsum from the absorbed $SO_2$. MHI has developed an arm rotary sparger (ARS) which provides oxidation air to the reaction tank and mixes with the slurry for commercial plants. As air is provided to four impellers (arms) through a shaft, it can be dispersed in fine bubbles by the shear of rotating arms as shown in **Fig. 5**.

**Table 2 Summary of Advatech projects in the US**

| Utility | Plant | Capacity | Description | Startup | Status |
|---|---|---|---|---|---|
| TVA | Widows Creek #8 | 550 MW | Retrofit FGD | Dec 2003 | Complete |
| TVA | Paradise #3 | 1 056 MW | New FGD | Oct 2006 | Complete |
| TVA | Bull Run #1 | 950 MW | New FGD | Oct 2008 | Under Construction |
| TVA | Kingston #6-9 | 200 MW × 4 | New FGD | Oct 2009 | Under Construction |
| TVA | Kingston #1-5 | 200 MW × 5 | New FGD | Apr 2010 | Under Construction |
| TVA | John Sevier #1-4 | 712 MW (188 MW × 4) | New FGD | Oct 2011 | Conceptual Design |
| Southern Company | Gorgas #8, 9 and 10 | Total 1 021 MW | New FGD | Dec 2007 | Under Construction |
| Southern Company | Hammond #1-4 | Total 800 MW | New FGD | Jul 2008 | Under Construction |
| Southern Company | Miller #3 & 4 | 750 MW × 2 | New FGD | 2009-2010 | Designing |
| Southern Company | Miller #1& 2 | 750 MW × 2 | New FGD | 2010-2011 | Designing |
| Southern Company | Scherer #1-4 | 923 MW × 4 | New FGD | 2011-2014 | Conceptual Design |
| Southern Company | Daniel #1&2 | 530 MW × 2 | New FGD | 2011 | Conceptual Design |
| IP&L-AES | Harding Street Station #7 | 465 MW | New FGD | Aug 2007 | Under Construction |

The ARS for the Paradise No. 3 scrubber was delivered by MHI. Three units are mounted on the top of the reaction tank between the first and second towers which agitate the whole reaction tank, and are the largest ARS units in the world.

(2) Limestone Reagent Preparation System

Limestone which is stored in a silo is fed to a ball mill with the process water and is crushed. The resulting slurry is sent to a holding tank, where it is pumped to a hydro cyclone classifier, where unacceptably large limestone particles are recycled to the ball mill. The grinding is accomplished by one or more additional ball mills.

## 3. Status of Operating the Unit 3 FGD System

Construction of the third Paradise scrubber was completed in October 2006. The Unit 3 FGD system started operation in October and is being prepared for performance testing currently scheduled for summer 2007.

## 4. Recent Future Work

The summary of Advatech's FGD projects in the U.S. is shown in **Table 2**. MHI has been already awarded five new FGD systems and one project to retrofit with DCFS from TVA, and will develop the further sales based on the success of this project.

Moreover, we think that we can contribute to the further sales promotion of desulfurization systems by applying MHI technology as a multi-emission control technology for the new regulations being enforced in the U.S.

**Reference**

(1) http://www.tva.gov/sites/paradise.htm