# The Most Advanced SCR Technologies for Contributing to Hydrogen-based Society and Other AQCS Products for Reducing Environmental Load

Air Quality Control Systems
Business Unit
Mitsubishi Power, Ltd.

*Mitsubishi Power, Ltd. (Mitsubishi Power) is the only manufacturer in the world that can provide the Air Quality Control Systems (AQCS), a comprehensive flue gas treatment system including Selective Catalytic Reduction System (SCR), De-SOx system, Electrostatic Precipitators, etc., in an integrated manner, thereby contributing to environmental conservation. As regulations on exhaust gas and wastewater become stricter around the world, further efforts for decarbonization are required. This report presents the latest status of promising technologies as measures to deal with this requirement: 1. high-efficiency SCR system that contributes to a hydrogen society, 2. zero liquid discharge equipment for De-SOx system as a measure to minimize wastewater from power plants and 3. SOx scrubber as a measure to comply with the relevant exhaust gas control system's regulation for marine engines.*

## 1. High-efficiency SCR system

Mitsubishi Power has achieved over 95% high-efficiency SCR system for gas turbine combined cycle (GTCC) plants. This achievement was realized by adopting (i) technology for reducing in NH3/NOx ratio distribution (high-performance ammonia injection nozzle and high-performance exhaust gas mixer) and (ii) exhaust gas seal structure compatible with high-efficiency SCR system. In addition, for the coming decarbonized society, we are planning (iii) application of the above high-efficiency SCR system technology to gas turbine power generation facilities that use hydrogen and ammonia as fuel. The details of these efforts are described in the following sections.

### 1.1 High-efficiency SCR technology

(i) Technology for reducing in NH3/NOx ratio distribution

SCR system is needed ammonia injection into the exhaust gas containing NOx generated in power generation facilities, etc. and converts into nitrogen and water with the following chemical reaction over the De-NOx catalyst.

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

Since NOx and ammonia react at a ratio of 1:1, in order to achieve high-efficiency SCR of 95% or more it is indispensable that injected ammonia is mixed with NOx in the exhaust gas as completely as possible to reduce the NH3/NOx ratio distribution. We have developed and adopted a high-performance ammonia injection nozzle and a mixer that utilizes a swirling flow, taking into consideration the NH3/NOx ratio distribution due to the temperature rise during ammonia injection to succeed in reducing the NH3/NOx ratio distribution and achieving high-efficiency SCR of 95% or more into practical use.

(ii) Exhaust gas seal structure compatible with high-efficiency SCR system

Since De-NOx system for GTCC is built into the Heat Recovery Steam Generator (HRSG), it is necessary to design the reactor (installed) with catalyst in consideration of the thermal expansion of the HRSG. However, due to this structure, exhaust gas that does not come into contact with the De-NOx catalyst and passes through clearance is generated. We have succeeded in reducing the gas leaks (gas blowing through) by changing the exhaust gas seal structure inside the HRSG.

(iii) Application of SCR technology to hydrogen and ammonia fired GTCC

In the future, when hydrogen and ammonia are used as fuel for hydrogen and ammonia-fired GTCC to reduce CO2, it is considered that NOx emitted from gas turbines will increase compared to that from the natural gas used at present and more efficient SCR system will be required. We are planning to realize such higher-efficiency SCR system by applying the catalytic technology to reduce the ammonia injection amount and the NH3/NOx ratio distribution , which increase as the NOx concentration at the inlet of the SCR system becomes higher than that of normal GTCC that uses natural gas as fuel.

### 1.2 Achievements of high-efficiency SCR system

We have already delivered SCR system with a De-NOx efficiency of over 95% to the combined cycle power plant demonstration facility at Takasago Works (T-point 2). This system has achieved a De-NOx efficiency of 95% or more by adopting an exhaust gas seal structure compatible with the NH3/NOX ratio distribution reduction technology and the high-efficiency SCR system (**Figure 1**).


**Figure 1 SCR system for combined cycle power plant demonstration facility at Takasago Works (T-point 2)**

## 2. WSD (Wastewater Spray Dryer) Zero Liquid Discharge equipment that contributes to reducing environmental load

In recent years, for protecting health and improving water quality around the world, regulations of wastewater from industrial facilities have been tightened including ELG's (Effluent Limitation Guidelines and Standards) in the United States, Action Plan for Prevention and Control of Water Pollution (Water Ten Plan) in China, Water Pollution Control Low in Japan , BREF (Best Available Techniques Reference) in Europe, etc.

Conventionally, in thermal power plants, waste water from the wet-FGD was fed to the wastewater treatment equipment and contained heavy metals and other harmful components were suppressed below the regulation standard values through multiple processes, and then discharged. However, as mentioned above, in response to the growing need for dry flue gas treatment and Zero Liquid Discharge (ZLD) technology, we have developed the Wastewater Spray Dryer (WSD), which efficiently and inexpensively eliminates wastewater from wet flue gas De-SOx equipment by contacting it with the heat source of exhaust gas, as an initiative that contributes to reduce environmental load.

**Figure 2** shows the flow of WSD. The WSD system draws part of the flue gas extracted from the Air Heater (AH) inlet into the WSD chamber body and at the same time, dropletizes and sprays the desulfurized filtrate wastewater to make it contact with the exhaust gas, evaporate and dry up. Then the system returns this exhaust gas to the AH outlet and removes the evaporated salt particles with a Dry Electrostatic Precipitator (ESP). The features of this WSD are as follows.

(i) Since ZLD can be efficiently realized by using the heat of the plant exhaust gas, utilities such as steam heat sources required by other ZLD methods are not required.

(ii) By installing a damper in the duct connecting the WSD chamber body and the main flue system and closing the damper to disconnect the WSD system when necessary, the inside of the WSD can be cleaned and maintained while the power plant is in operation. Therefore, stable operation of all the power plant is possible.

(iii) Exhaust gas can be drawn into the WSD chamber body by using the differential pressure of AH as a driving force and an air supply fan dedicated to the WSD system duct is not required, so the equipment configuration can be simplified.

By 2016, we completed the WSD basic research and development(prediction of delay in evaporation rate of saltwater droplets, suppression of deliquescency of evaporated salt and treatment method preventing elution of heavy metals) and pilot test demonstration(1) and made it possible to design the appropriate capacity of the actual equipment through a simulation method that simultaneously analyzes thermal hydraulics and saltwater droplet evaporation (**Figure 3**).

After this research, in 2017, in cooperation with Chinese EPC business company : Beijing Beike Ouyuan Technology Co., Ltd (OYST), we constructed the first WSD unit at Linfen Power Station (a 300MW coal-fired power plant ) in Shanxi Province, China and started its operation (with a desulfurization wastewater treatment rate of 5 t/h). As a result of appropriately adjusting the operation conditions and maintenance frequency based on operation data management in cooperation with OYST , which also handles O&M of the power plants, this WSD has been achieving long-term stable operation until now without causing any blockage in the outlet duct (**Figure 4**).

**Table 1** lists the reference project list of WSD. We have currently received orders for a total of 14 WSDs in China and the United States and we are in the bidding stage for multiple projects.

As the next initiative, we are examining the practical application of a technology that combines WSD with desulfurized wastewater-concentrating and volume-reducing equipment. For concentrating and volume-reducing desulfurized wastewater in the front stream of the ZLD equipment, either a method of increasing the amount of filtrate returned to the absorber after gypsum dewatering with desulfurization equipment or a method of passing the wastewater discharged from the desulfurization equipment through a Reverse Osmosis membrane (RO membrane) to extract a Brine Concentrate is used. In order to extend the life of the membrane and ensure stable operation, we are now selecting the RO membrane type and its osmosis pressure and optimizing the pretreatment method for preventing scaling and fouling and the backwash frequency.

**Figure 5** shows comparison for operation cost between the conventional type and WSD with RO membrane. It can be seen that WSD with RO has a total cost advantage over the conventional type. When WSD and RO are combined, the power cost (heat source) and equipment cost can be significantly reduced compared to when the WSD is used alone. This is the effect of the energy saving due to the reduction of the amount of wastewater, the amount of heat source required and the size reduction of the ZLD equipment. When WSD and RO are combined, the chemicals cost increases for pretreatment in the pretreatment system, but we are currently trying to find the ways of reducing it.

The WSD introduced in this report has the potential to be applied not only to thermal power plants, but also to other industry facilities, so we will strive for technological progress to contribute to the environment and energy saving in order to apply the WSD to ZLD.

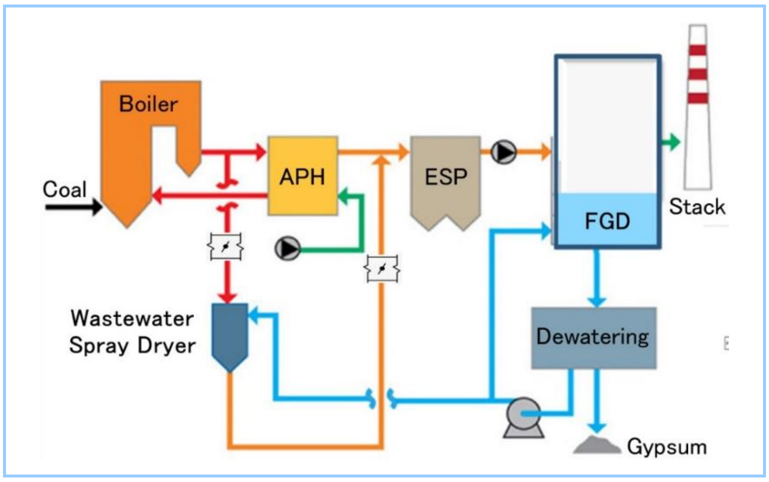


**Figure 2  Flow of WSD**

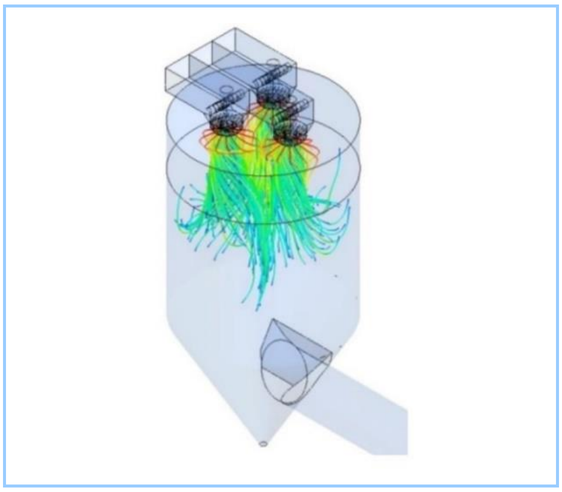

**Figure 3  Simulation analysis example of evaporation of wastewater droplets inside WSD Chamber  body**

**Figure 4  Photograph inside outlet duct at overhaul inspection of actual WSD equipment**

**Table 1  WSD reference list (by licensee*)  *WSD technology licensed company**

| Area | Delivery destination | Power plant capacity | Wastewater treatment amount | Number of WSD units | Plant state |
|---|---|---|---|---|---|
| Shanxi Province, China | Linfen Power Station | 1 × 300MW | 5t/h | 1 | In commercial operation |
| Shanxi Province, China | Houma Power Station | 2 × 300MW | 8t/h | 1 | In commercial operation |
| Hebei Province, China | Jingneng Qinhuangdao Power Station | 2 × 350MW | 12t/h | 2 | Under construction |
| Shanxi Province, China | Jinneng Xiaoyi Power Station | 2 × 350MW | 10t/h | 2 | Under construction |
| Guangdong Province, China | Guangdong Dapu Yudean Power Generation Co., Ltd. | 2 × 660MW | 20t/h | 4 | Under construction |
| Guangdong Province, China | Guangdong River Corp Power Station | 2 × 300MW<br>2 × 660MW | 8t/h<br>16t/h | 1 | Under construction |
| Jiangxi Province, China | Fuzhou Power Station of Datang International Power Generation | 2 × 1 000MW | 16t/h | 1 | Under construction |
| Minnesota, USA | Boswell Energy Center | 1 × 650MW | 24t/h | 1 | Under construction |
| Total | — | 8 190 MW | 119t/h | 14 | — |

As of June 2021

Received orders ： 13 units in China
1 unit in the United States

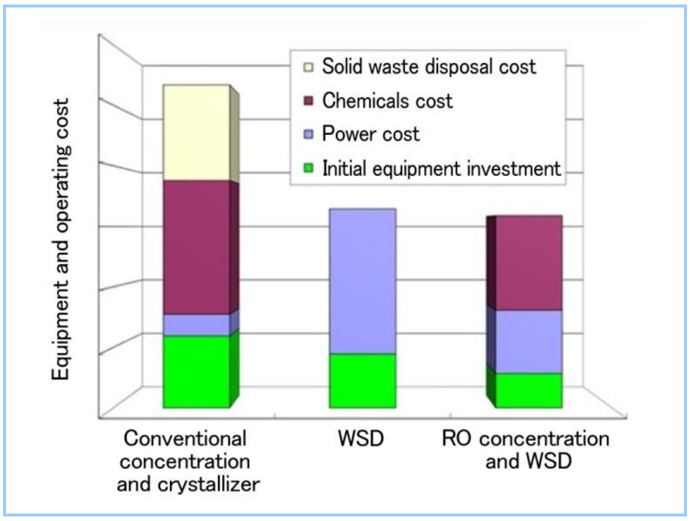


**Figure 5 Comparison of total equipment and operating cost (between conventional method, WSD and combination of RO concentration and WSD)**

## 3. Marine SOx scrubbers that comply with IMO regulations

From January 2020, the International Maritime Organization (IMO) implemented a stricter limit for sulfur in fuel oil of vessels operating in all sea areas based on their regulations. We developed marine SOx scrubbers by marinizing the rectangular flue gas desulfurization system for onshore boilers, which has been improved over the years, so they have advantages in terms of the installation layout, especially in large container vessels and can be installed without the cargo loss. In addition, these SOx scrubbers have a high sulfur removal efficiency and are compliant with the regulations of all sea areas including Emission Control Areas (ECAs), which are subject to the particularly strict emission regulations. We have received SOx scrubber orders for 45 vessels so far and have contributed to reducing the global environmental load in all sea areas around the world. This chapter introduces the latest situation surrounding this product.

### 3.1 Features of marine SOx scrubber

Marine SOx scrubbers use one of the following methods: open loop in which seawater is sent as absorbent liquid to the absorption tower in one-pass system , closed loop in which a circulating liquid containing chemicals such as caustic soda is used and hybrid in which the above two methods are used in combination. We produced open-loop systems that can comply with ECA regulation values and then received additional orders for hybrid systems that can be used even in areas where overboard discharge is prohibited (Non-Discharge Area) due to non-discharge operation mode. We have also designed and developed smaller-capacity range products compared to the existing models to expand our product lineup.

**Figure 6** is an external view of the marine SOx scrubber. As the height/width ratio of the rectangular scrubber tower can be changed relatively freely, the optimal layout in the limited space of a vessel becomes possible, achieving a higher volumetric efficiency than the existing cylindrical scrubbers. Especially for large container vessels, the scrubber can be installed without reducing the container loading capacity, which indicates that the rectangular shape offers a considerable layout advantage. **Figure 7** depicts an image of the layout of the scrubber on board a large container vessel. This is an example of a large container vessel with two-island design with living area separate from the engine casing in which the scrubber unit is accommodated, thus enabling the installation to be carried out without the cargo loss for container vessel.

In addition, the use of our scrubber can minimize the number of pieces of equipment by adopting a multi-stream method that handles gas from multiple engines in a single tower in consideration of easy maintenance. Considering the risk of work inside the tower, we selected and adopted a spray nozzle structure that is not likely to require maintenance inside the tower as a result of clogging.

**Figure 6  External view of marine SOx scrubber**

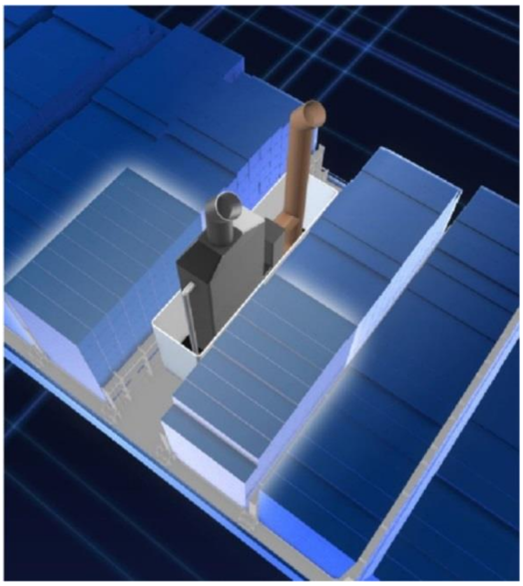

**Figure 7  Layout image of scrubber installed in large container vessel**

### 3.2 Engineering for installation

We can provide engineering service for installation SOx scrubber to vessel with Mitsubishi Shipbuilding Co., Ltd which is our partner company. Our service is provided to customers who want the SOx scrubber to be installed on board their planned vessels more quickly, easily and securely. We do our best to support our customers' plans combining the knowledge of Mitsubishi Power as a SOx scrubber manufacturer and of Mitsubishi Shipbuilding Co., Ltd., as a shipbuilding yard. While this service is also available to vessel owners who want to retrofit the SOx scrubber on their in-service vessels, the number of shipbuilders which are using this service for new built vessels are increasing. Mitsubishi Shipbuilding Co., Ltd. can propose an installation plan harmonious with any vessels whichever they are new built / retrofit, or vessel built by our company / vessel built by another company.

### 3.3 Post-installation support and after-sales service

As support for customers we are strengthening after-sales service for marine scrubbers, including periodical audit. We are promoting after sales support using our overseas network.

## 4. Future development

Reflecting the global decarbonization trend, the needs for next-generation products for environmental technology have been increasing. As a supplier of comprehensive Air Quality Control System (AQCS), Mitsubishi Power, Ltd. will continue to propose the optimum system according to the regulations of the country where the product is introduced and the situation of the plant and contribute to the reduction of environmental load.

## References

(1) Seiji Kagawa et. al, Development of Wastewater Spray Dryer (WSD) for Desulfurization Plants, Mitsubishi Heavy Industries Technical Review Vol. 52, No. 4 (2015)