Development of an Advanced Air Quality Control System

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ABSTRACT

Extensive work has been carried out to develop an advanced Air Quality Control Systems (AQCS) to meet the multi-pollutant control requirements for coal-fired power plants. Much of this work is being done at Babcock Hitachi's Environmental Research Center located in Akitsu, Japan, utilizing both laboratory scale apparatus and a 1 MW_{th} AQCS pilot plant. The pilot plant incorporates SCR, ESP, PJFF, wet FGD, and wet ESP. It can also be configured to test advanced features such as a gas-gas heater and new mercury oxidation SCR catalysts.

Since many U.S. power plants either have some of the above mentioned, conventional pollution control devices, or will need to install these in the near future, a goal of the R&D program is to maximize the co-benefits of the AQCS equipment to meet new emission requirements for not only SO_2, NOx, but also SO_3, mercury and other trace pollutants, thus minimizing combined capital and operating costs.

The paper presents an overview of this development effort with special focus on the findings in SO_3 and mercury control. A new SCR catalyst for medium to high sulfur applications has shown high mercury oxidation and low SO_2 to SO_3 conversion, while maintaining robust NOx reduction activity. For bituminous coals, pilot plant tests incorporating this new catalyst achieved over 95% Hg oxidation and 95% total mercury removal. Test data shown that mercury removal by both flyash and sorbent injection were inhibited by SO_3 in the flue gas and effective SO_3 removal was needed to enhance mercury removal. The combination of the new catalyst and other advanced features of the system including the gas-gas heater reduced the SO_3 emissions to levels well below 1 ppm. Development work for this new AQCS has entered the field testing phase, an update of which will also be included.

INTRODUCTION

Coal is the most abundant energy source in US. Clean and efficient utilization of coal for power generation is vital to the long term economic security and sustainability of our nation. Today, the coal power industry is facing unprecedented environmental challenges: in addition to SO_2, NOx, and particulate matter, we now must control mercury, SO_3, condensable PM, and other trace metals and acid gaseous. It is widely anticipated that power plant CO_2 emission will be regulated nationwide in the next few years.

To help the power industry meeting the above challenges while delivering reliable and affordable

electricity, Hitachi has carried out extensive R&D of an Advanced Air Quality Control System (AQCS). Much of this R&D work is being done at Babcock Hitachi's Environmental Research Center located in Akitsu, Japan. The research center is equipped with a full range of laboratory

scale and pilot scale test facilities for studying control devices such as selective catalytic reduction (SCR), dry electrostatic precipitator (ESP), flue-gas desulfurization (wet-FGD) and wet ESP.

It is has been well established that SCR catalysts can oxidize elemental mercury (Hg^0) to oxidized mercury (Hg^{2+})in coal combustion flue gas [1,2]. Hg^{2+}, which is mostly present as water-soluble mercuric chloride ($HgCl_2$), can be removed in downstream components such as DESP and WFGD [3,4]. Power plants burning bituminous coals, which generally contain relatively large amounts of chlorine (Cl), have shown high conversion of Hg^0 to Hg^{2+} across the SCR catalyst [5]. In fact, our field-scale test results at a power plant firing eastern bituminous coals with conventional SCR catalyst indicated Hg^0 oxidation between 78% and 93%. However, conventional SCR catalysts are typically designed with an SO_2 to SO_3 conversion of up to 1.5 % at SCR operating conditions (≥ 90 % NOx removal)[5]. This level of SO_2 conversion contributes significantly to the formation of SO_3, which can contribute to deposit and corrosion for downstream equipment as well as visible plumes at the stack. In order to address the new mercury and SO_3 requirements, Hitachi has developed a new, "triple action" catalyst that is designed to have high Hg^0 oxidation, low SO_2 to SO_3 conversion, and robust NOx reduction. Pilot-scale test data of this new catalyst have demonstrated over 95 % Hg^0 oxidation with SO_2 oxidation below 0.5 % [6].

In recent years, activated carbon injection (ACI) has been commercialized for power plant mercury capture. However, for high sulfur bituminous coal applications mercury capture by activated carbon is inhibited by the SO_3 in flue gas [7]. It is necessary to remove SO_3 upstream of ACI for the activated carbon to work effectively. In the advanced system a Gas-Gas Heater (GGH) is used. The GGH gas cooling section is located upstream of the DESP to reduce flue gas temperature and remove flue gas SO_3. This high dust GGH design has already been applied successfully by Hitachi to five large utility power plants in Japan[8]. It is being tested at the research center and in the field for application with medium to high sulfur US coals.

Based on pilot plant test data of several medium to high sulfur bituminous coals, this paper will discuss mercury and SO_3 behavior across the total AQCS which incorporates the new catalyst and the GGH.

EXPERIMENTAL

Three medium to high sulfur eastern bituminous coals and a PRB coal were evaluated in the pilot test facility, which is equipped with SCR, GGH, DESP, WFGD and WESP. A schematic diagram and a photo of the facility are presented in Figures 1 and 2.

The combustor is a vertical furnace with a burner installed on its top. Coal feed rate was 110-130kg/h (242-286 lb/hr) depending on coal type. Flue gas temperature at the inlet of DESP was controlled at a constant temperature ranging from 90 to 160 ^oC (194 to 320 ^oF) by the GGH. Gas samples were simultaneously taken at six points through the flue gas stream: SCR inlet and outlet, DESP inlet and outlet, FGD outlet, and the stack. Letters from A to F in Fig. 1 indicate each sampling point. Activated carbon when used was injected into the duct before the dry ESP.

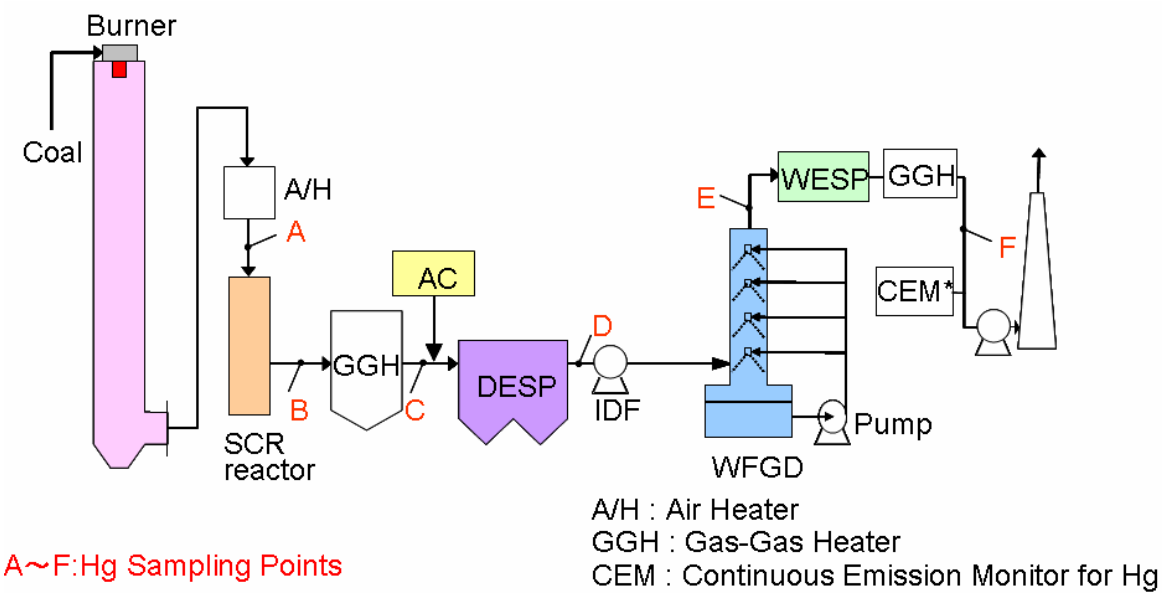

Fig.1 Schematic diagram of the pilot test plant

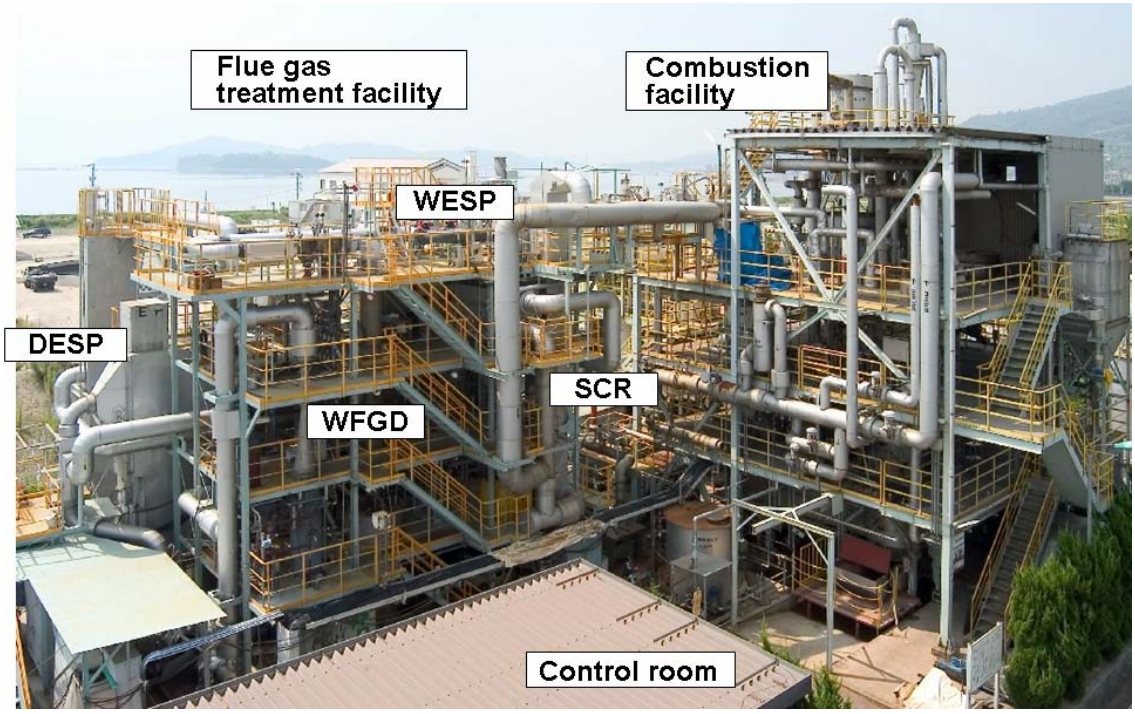

Fig. 2 Pilot-scale test facility

Coal analysis data are presented in Table 1. Mercury and chlorine concentrations in the bituminous coals vary from 0.06 to 0.12 ppmw and from 300 to 770 ppmw, respectively. Sulfur contents of the three bituminous coals are 1.6%, 2.9% and 3.6%. All tests were conducted under constant conditions of 90% NOx removal efficiency of SCR by controlling NH_3/NOx molar ratio at 0.9. The SCR nominal operating temperature was 380 ºC (716 ºF).

Table1. Proximate, elemental and trace element analysis results of test coals

Coal type	Eastern bituminous			PRB
Mine	A	B	C	D
Proximate Analysis, wt %				
Moisture	7.16	1.32	4.04	26.7
Volatiles	40.62	37.11	32.67	45.02
Fixed Carbon	48.70	55.68	38.98	49.35
Ash	10.68	7.21	28.35	5.63
HHV (MJ/kg, dry)	27.88	32.48	22.29	22.71
(Btu/lb,dry)	11,986	13,963	9,582	9,763
Elemental Analysis, dry, wt %				
Ash	10.68	7.21	28.35	5.63
C	71.32	78.48	54.47	70.76
H	5.14	5.03	3.93	4.73
O	8.38	6.33	8.70	17.65
N	1.58	1.35	0.92	0.99
S	2.90	1.60	3.63	0.24
Trace Elements, dry, mg/kg				
Hg	0.117	0.063	0.109	0.066
Cl	300	650	770	18

RESULTS AND DISCUSSIONS

Mercury Oxidation and Removal in AQCS with New and Conventional Catalyst: The new catalyst and the conventional catalyst were evaluated during pilot tests burning high sulfur bituminous coals. Table 2 shows the test results. The new catalyst demonstrated higher mercury oxidation rate as well as lower conversion rate of SO_2 to SO_3 than those of the conventional catalyst. The new catalyst achieved over 95% Hg^0 oxidation and low SO_2 to SO_3 conversion (0.4%) at 380 ºC (716 ºF). The mercury removal efficiency of the system with the new catalyst was 95% when the temperatures of the catalyst and the DESP were 380 and 160 ºC (716 F and 320 ºF), respectively.

Table 2. Test results of systems with new and conventional catalyst

System	Conventional catalyst	New catalyst
Hg^0 oxidation rate by catalyst (%)	82	96
Mercury removal in system (%)	84.7	95.2
SO_2 to SO_3 conversion rate by catalyst (%)	1.0	0.4
SO_3 removal in system (%)	>99%	>99%

Catalyst temperature: 380 ºC (716 ºF), DESP temperature: 160 ºC (320 ºF)

Figure 3 shows changes in mercury concentrations in the flue gas from the SCR inlet to the WESP outlet in the AQCS with the new and the conventional catalysts. The fuel used was coal C and the DESP inlet temperature was kept at 160 ºC (320 ºF). As expected, mercury concentration decreased dramatically in the WFGD for both cases. The system with new catalyst demonstrated very high mercury removal efficiency because of the high oxidation rate of elemental mercury.

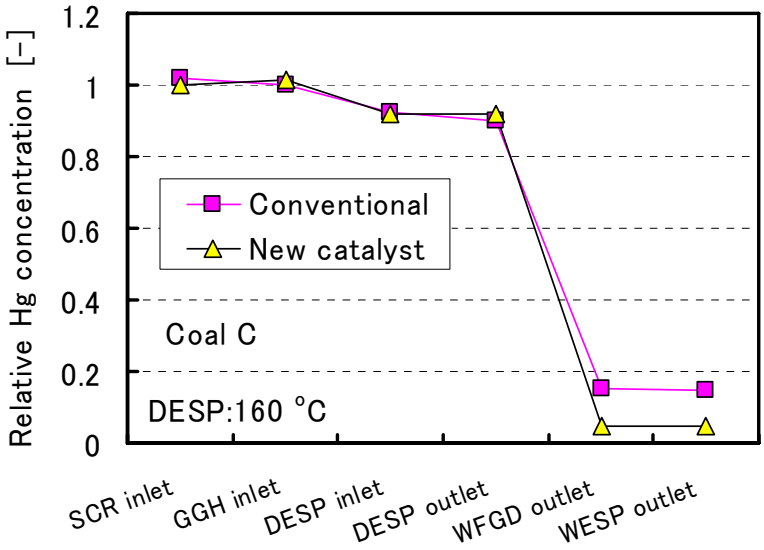

Fig.3 Behavior of mercury in AQCS

Effect of ACI on Mercury Removal across DESP: It has been confirmed that the presence of SO_3 has a negative impact on mercury capture by activated carbon[7]. ACI was tested when a low and a high sulfur coal were used and approximately 60mg/m3N (approximately 2.4 lb/MMacf)

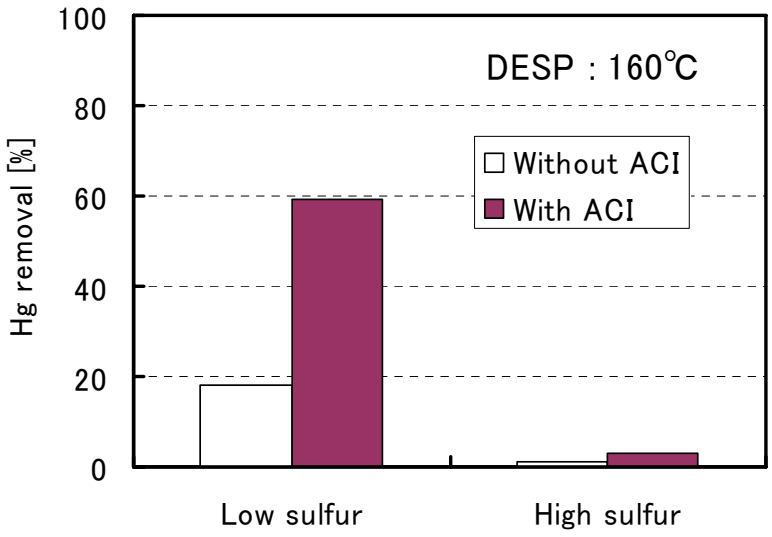

Fig.4 Effect of ACI on Hg removal across DESP for different coals

of AC was injected into the GGH outlet with the DESP inlet temperature kept at 160 ºC (320 ºF). Effect of ACI on mercury removal is shown in Figure 4. For the low sulfur coal (coal D), an increase in mercury removal from 18% to 59% occurred with activated carbon injection. On the other hand, mercury removal across DESP for the high sulfur coal (coal A) was very low (less than 5%), even when activated carbon was used.

SO_3 Removal across GGH - DESP in the Advanced System: The advanced system removes SO_3 in flue gas by reducing the DESP inlet flue gas temperature with a Gas-Gas Heater located upstream of the DESP. The GGH's gas cooling section is exposed to SO_3 and fly ash. With decreasing temperature, SO_3 in the flue gas condenses on the surface of ash and is neutralized by alkali in the fly ash. The fly ash keeps the GGH cooling surface dry, thereby avoiding deposition or plugging. The effectiveness of the GGH system has been verified for relatively low sulfur coals in several large utility power plants[8].

Medium to high sulfur coals have been tested with the advanced system at the pilot facility. Figure 5 shows flue gas SO_3 behavior from the SCR inlet to the WESP outlet for coal B tests. SO_3 concentrations decreased dramatically when DESP temperature was reduced from 160 ºC (320 ºF) to 90 ºC (194 ºF). In spite of high initial SO_3 concentrations, no deposition or plugging occurred on the cooling surfaces.

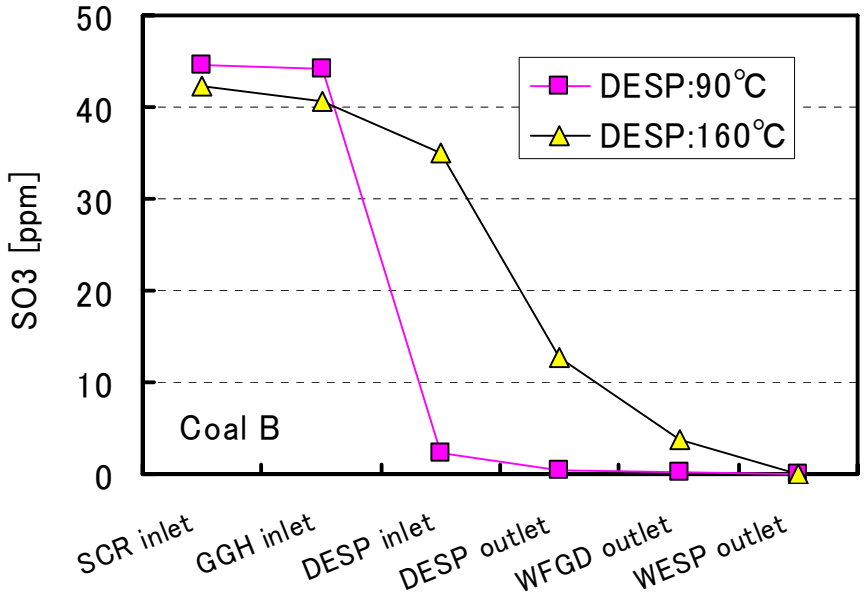

Fig. 5 Behavior of SO3 in AQCS at different DESP temperature

Effect of GGH on Mercury Removal: Mercury removal across DESP in the advanced system with activated carbon injection was investigated. For the three high sulfur coals, mercury removal across DESP increased sharply when gas temperature was reduced with the GGH . Since activated carbon is injected downstream of GGH, SO_3 removal by GGH (as shown in Figure 5) is believed to be the main reason for the improvement in mercury removal across the DESP.

The advanced system was tested with the GGH in operation and flue gas temperature controlled at 90 ºC (194 ºF) entering the DESP, with and without activated carbon injection. Mercury concentration did not change significantly from the SCR inlet to the DESP inlet. With ACI, the bulk of the mercury was removed across ACI / DESP (68% reduction), followed by further capture in the WFGD.

Without activated carbon injection, 17% of mercury was reduced across the DESP. However, due to the new catalysts, most of the mercury is in oxidized form and therefore is very effectively removed in the wet FGD. With or without ACI, mercury removal of the advanced system was about 95%.

Field Testing: After successful laboratory and pilot plant testing, a slipstream test plant of the advanced AQCS has been installed at Ameren's Duck Creek Power Station, in Fulton County, Illinois. The slipstream facility is currently undergoing extensive testing with the main plant firing a local bituminous coal. In the same plant, two full size modules of the new mercury oxidation SCR catalyst have been installed in the plant's main SCR reactor for long term exposure and testing.

CONCLUSIONS

1. The new catalyst oxidized over 95% Hg^0 and maintained low SO_2 to SO_3 conversion with SCR temperature at 380 ºC (716 ºF), and the pilot plant operated with high sulfur bituminous coals.

2. Mercury removal in the pilot AQCS with the new catalyst reached 95% when temperatures of the catalyst and the DESP were 380 ºC (716 ºF) and 160 ºC (320 ºF), respectively.

3. For high sulfur coals, with or without activated carbon injection, little mercury was removed in the DESP at 160 ºC (320 F) due to the inhibiting effect of SO_3 on mercury adsorption to fly ash and activated carbon particles.

4. The advanced AQCS effectively reduced SO_3 concentration in the flue gas with cooling by the Gas-Gas Heater. With activated carbon injection, most of the mercury was removed across ACI/ESP, followed by further capture in the WFGD. Without ACI, most of the mercury removal occurred in the WFGD, due to upstream oxidation by the new catalyst. In both cases, 95% mercury removal was achieved with the advanced AQCS.

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