

Field Testing of Advanced Air Quality Control System for Multi-pollutant Control

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ABSTRACT

An advanced Air Quality Control System has been developed to help the power industry to meet the new environmental requirements by controlling SO₃, condensable particulate matter and mercury emissions. The new AQCS includes a) SCR with high mercury oxidation / low SO₂ to SO₃ conversion catalyst; b) a Clean Energy Recuperator (CER); c) pulse jet fabric filter or dry ESP; d) advanced wet FGD system.

Following extensive laboratory and pilot plant testing, the development work has entered the field testing phase. A slipstream AQCS test facility of 1 MW equivalent heat input has been installed at Ameren Energy Resources Generating's Duck Creek Plant. This paper describes the configuration of the advanced AQCS, the test facility arrangement, and slipstream test data firing an Illinois bituminous coal. Test data have shown that mercury removal by both fly ash and activated carbon injection was inhibited by SO₃ in the flue gas and effective SO₃ removal was needed to enhance mercury removal. The advanced air quality control system with CER reduced SO₃ concentration before the activated carbon injection, and enhanced mercury removal. The advanced venturi scrubber, which is a part of the advanced wet FGD system, was also tested and proved to be effective for removing mercury ahead of the wet FGD.

INTRODUCTION

The coal power industry today is facing unprecedented environmental challenges: in addition to the traditional SO₂, NO_x, CO, and particulate matter (PM), we now must control mercury, SO₃, condensable PM, and other trace metals and acid gaseous, as well as meeting stringent byproduct utilization and water conservation requirements.

Effective control of these pollutants requires careful consideration of their behavior across the whole Air Quality Control System (AQCS). In the case of mercury, it is necessary to evaluate how much elemental mercury (Hg⁰) can be converted to oxidized mercury (Hg²⁺) in the SCR reactor¹⁻³. Hg²⁺, which is mostly present as water-soluble mercuric chloride (HgCl₂), can be removed in downstream equipment such as the dry electrostatic precipitator (DESP) and the wet flue gas desulfurization (WFGD)^{4,5}. Flue gas temperature and chlorine concentration affect the oxidation and removal of mercury. Generally, coals containing high levels of chlorine, such as most eastern bituminous coals, produce high concentrations of Cl in flue gas and contribute to high oxidation and removal of mercury. Activated carbon injection (ACI) also can be effective to obtain further mercury removal. However, for high-sulfur bituminous coal applications mercury capture by activated carbon is inhibited by the SO₃ in flue gas⁶. It is necessary to remove SO₃ upstream of the activated carbon injection point for the carbon to work effectively.

To solve this problem, Hitachi's advanced AQCS uses a Clean Energy Recuperator (CER). The CER is a finned tube gas cooler located upstream of the DESP to reduce flue gas temperature and remove gas phase SO₃. The CER in the gas to gas heater (GGH) configuration has been applied successfully by Hitachi to five large coal-fired utility power plants in Japan⁷.

A slipstream AQCS test facility of 1 MW equivalent heat input was installed at Ameren Energy Resources Generating's Duck Creek Plant. This paper describes the configuration of the advanced AQCS, the test facility arrangement, and slipstream test data firing a high sulfur bituminous coal.

EXPERIMENTAL APPARATUS

Figure 1 shows the configuration of the test facility. The test plant mainly consisted of CER, DESP, Advanced Venturi Scrubber (AVS), WFGD and Wet ESP. A slipstream of the flue gas was extracted from the duct between the air heater (A/H) and the DESP of the 400 MWe power plant. The flue gas first went into an electric heater which maintained a flue gas temperature of 164 °C (327 °F) at the CER inlet. Hg⁰ was oxidized to Hg²⁺ in a mercury oxidation catalyst. Hg²⁺ and other pollutants were captured in the downstream DESP, AVS, WFGD and Wet ESP. Flue gas at the DESP inlet was controlled at a constant temperature ranging from 90 to 160 °C (194 to 320 °F) with the CER.

Table 1 shows the test condition. Flue gas flow rate was 2000 m³N/h (1270 scfm). The Transformer-Rectifier sets of DESP and WESP were rated at 45 kV and 70 kV, respectively. For the advanced WFGD system, the liquid to gas ratio for AVS was one order of magnitude lower than that of WFGD.

Coal analysis data are presented in Table 2. Mercury and chlorine concentrations in the coal were 0.070 mg/kg and 1000 mg/kg, respectively. Sulfur content was 2.79%. During the tests, the target of SO₂ removal efficiency by WFGD was over 99% to operate same condition as commercial plant.

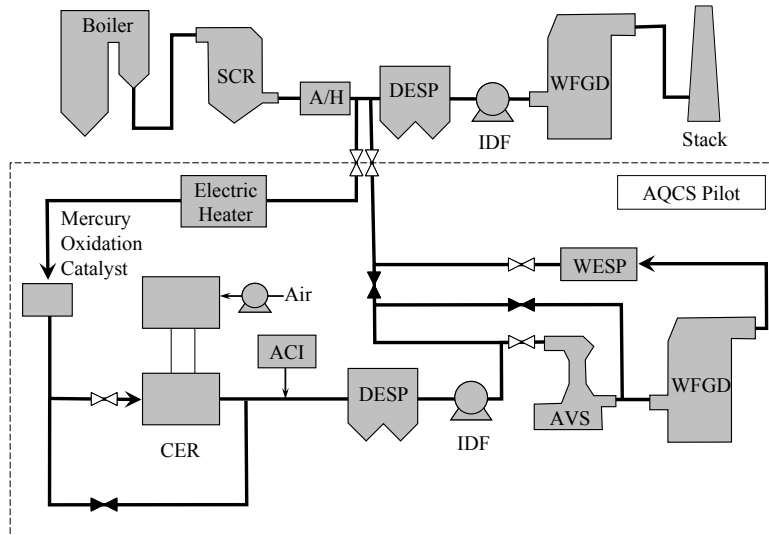


Fig.1 AQCS Pilot test configuration

Table 1 Test condition

Gas flow rate		SO ₂		Dust		Mercury	
[m ³ N/h]	[scfm]	[ppm]	[lb/MMBtu]	[g/m ³ N]	[lb/MMBtu]	[μg/m ³ N]	[lb/MMBtu]
2,000	1,270	2,100 ~ 2,200	4.9 ~ 5.1	6 ~ 7	4.9 ~ 5.7	5 ~ 7	4×10 ⁻⁶ ~ 6×10 ⁻⁶

Table 2 Coal property

	Item	Base	Unit	Test Coal : Gateway
Proximate Analysis	HHV	Dry	kJ/kg (Btu/lb)	29,974 (12,887)
	Moisture	As Received	Wt%	13.9
	Volatile	Dry	Wt%	39.96
	Fixed Carbon	Dry	Wt%	44.03
	Ash	Dry	Wt%	16.01
Ultimate Analysis	Carbon	Dry	Wt%	71.67
	Hydrogen	Dry	Wt%	4.59
	Oxygen	Dry	Wt%	3.45
	Nitrogen	Dry	Wt%	1.49
	Sulfur	Dry	Wt%	2.79
	Ash	Dry	Wt%	16.01
Trace Analysis	Chlorine	Dry	mg/kg	1,000
	Fluorine	Dry	mg/kg	70
	Mercury	Dry	mg/kg	0.070

RESULTS AND DISCUSSION

AQCS Configurations

Figure 2 shows the three AQCS configurations tested. For all three configurations, the inlet flue gas temperature was 164 °C (327 °F). In the conventional System without CER, flue gas temperature was 160 °C (320 °F) at the DESP inlet. In the advanced AQCS, the CER cooled the gas temperature to 90 °C (194 °F) at the DESP inlet. In the Advanced Venturi Scrubber (AVS) system, the flue gas temperature was almost the same as in the conventional System. The AVS was installed before WFGD.

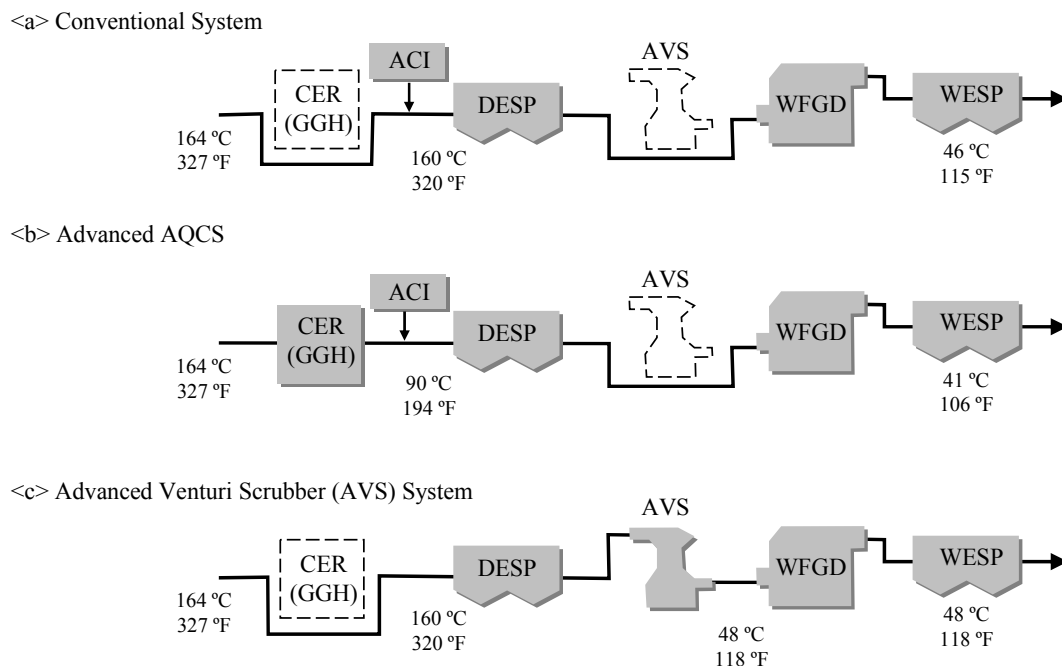


Fig.2 AQCS configurations tested

SO₃ Removal across CER to DESP in the Advanced AQCS

Low flue gas temperature due to the cooling by the CER contributes to the removal of SO₃. Figure 3 shows the concept of SO₃ removal. The dew point of SO₃ at the inlet concentration is around 160 °C (320 °F). As the gas temperature goes far below the dew point in the CER, SO₃ is condensed and adsorbed on to ash particles and neutralized. The ash along with captured SO₃ is removed by the DESP.

Figure 4 shows the gas phase SO₃ concentration from the CER inlet to the WESP outlet. In the conventional system, the SO₃ concentration decreased as the gas flowed through the system. The SO₃ concentration at the WFGD outlet was 11 ppm, a level higher than current U.S. AQCS requirements. A WESP is needed to reduce the SO₃ concentration further in the conventional system. On the other hand, in the advanced AQCS, most SO₃ removal was observed between the CER inlet and the DESP inlet. The SO₃ concentration was 1 ppm at the DESP inlet, and 0.9 at the WFGD outlet.

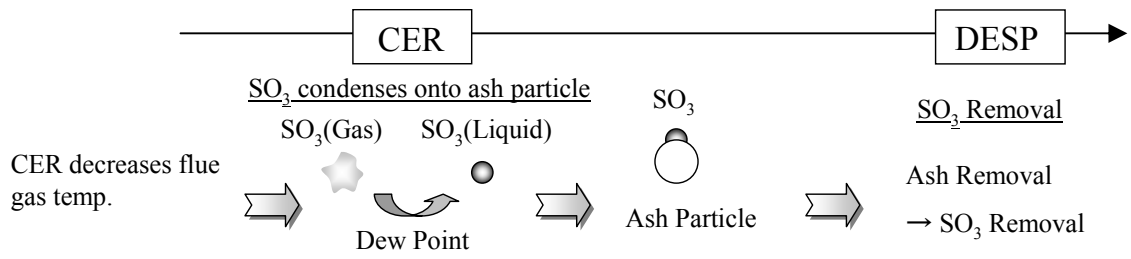


Fig.3 Concept of SO₃ removal in advanced AQCS

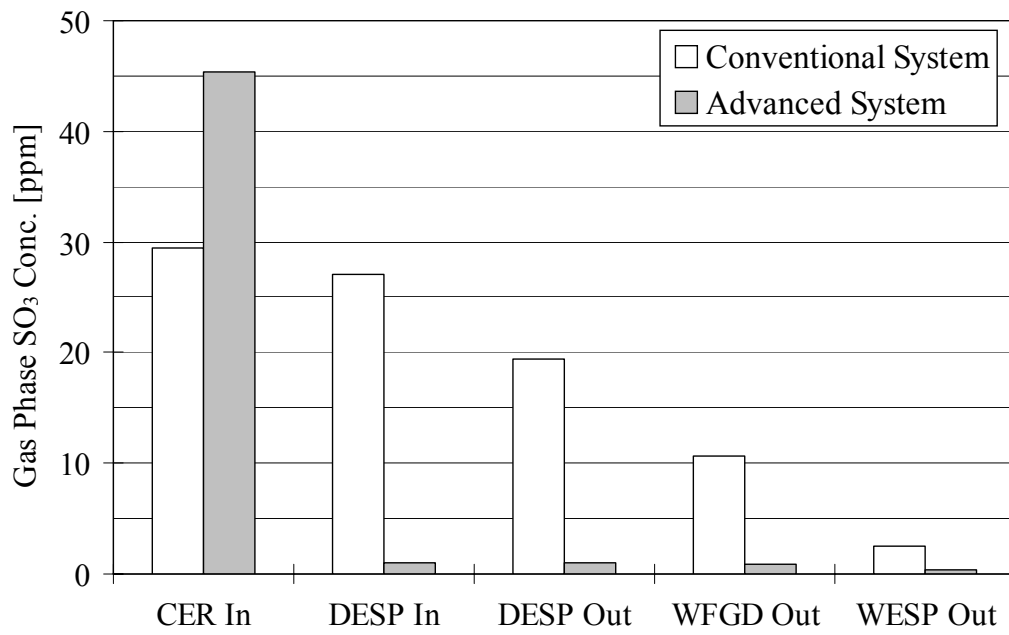


Fig.4 Behavior of SO₃ in AQCS

Effect of CER on Mercury Removal

The main object of the CER is to reduce SO_3 , but it also contributes to removal of Hg⁸. Fig. 5 shows the concentration of Hg in the flue gas from CER inlet to WESP outlet. In the conventional system, significant decrease of the mercury concentration was observed from the DESP outlet to the WFGD outlet. This suggests that Hg was absorbed mainly by the WFGD. On the other hand, there was no significant decrease between DESP inlet and outlet, even when activated carbon was injected. In the advanced AQCS, SO_3 is adsorbed almost completely by ash in the CER, upstream of the activated carbon injection point. This SO_3 removal is avoided the Hg inhibition factor. Therefore the activated carbon can effectively capture Hg. Significant reduction of Hg concentration was observed between the CER inlet and the DESP outlet in the advanced AQCS with ACI, as shown in Fig. 5. It is interesting to note that in the advanced system, with or without ACI, overall mercury removal of 95% was achieved.

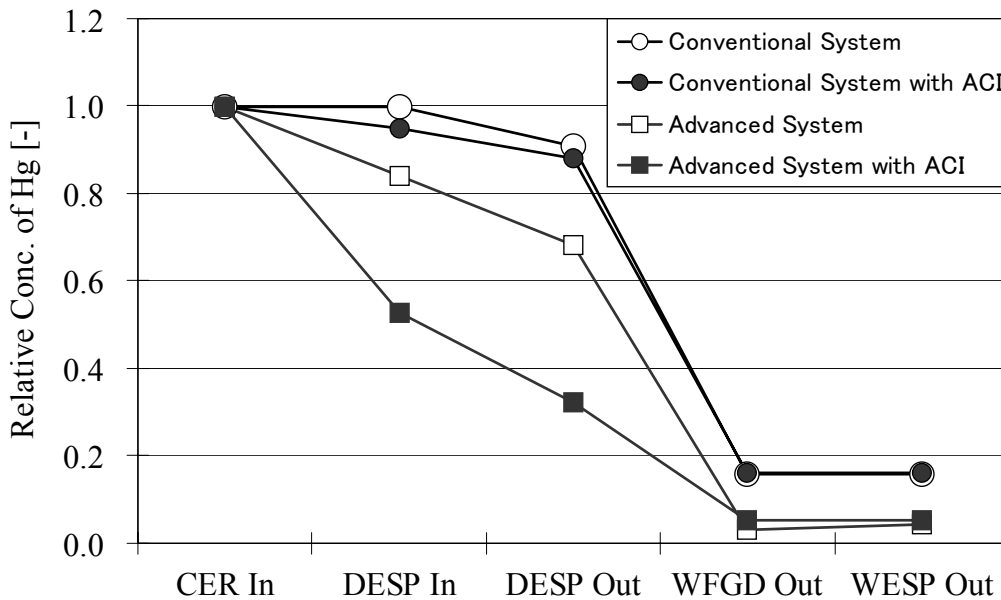


Fig.5 Behavior of Hg in AQCS

Role of AVS in WFGD system

Figure 6 shows the difference in Hg concentration between the conventional system and the AVS system. In AVS system, significant decrease of the concentration was observed from the AVS inlet to the WFGD inlet. Even though the liquid to gas flow ratio in AVS was small compared with the WFGD, Hg was absorbed mainly by the AVS. On the other hand, SO₂ was not absorbed by AVS because of its acidic absorbent. This shows that application of the AVS allows the segregated capture and export of Hg independent of the WFGD absorber.

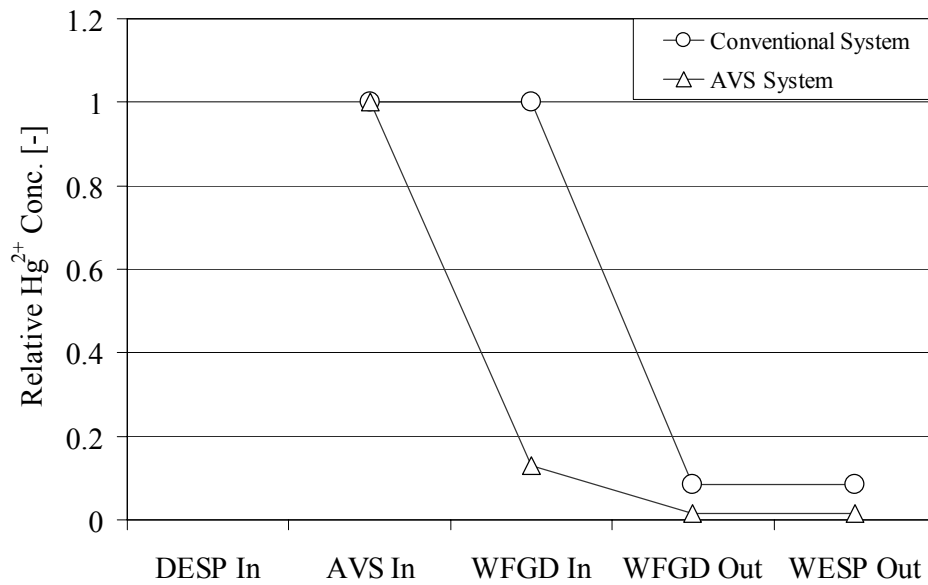


Fig.6 Behavior of Hg in AQCS

Effect of Activated Carbon Injection Rate on Mercury Removal

Figure 7 shows the effect of carbon injection rate on Hg concentration in the DESP ash. High concentration of Hg in fly ash corresponds to high removal of Hg from flue gas. As the injection rate increased, the Hg removal increased in advanced AQCS. On the other hand, no matter how much the activated carbon was injected, no significant increase of Hg removal was observed in conventional system. As mentioned above, SO₃ prevented the activated carbon from capturing Hg in the conventional system.

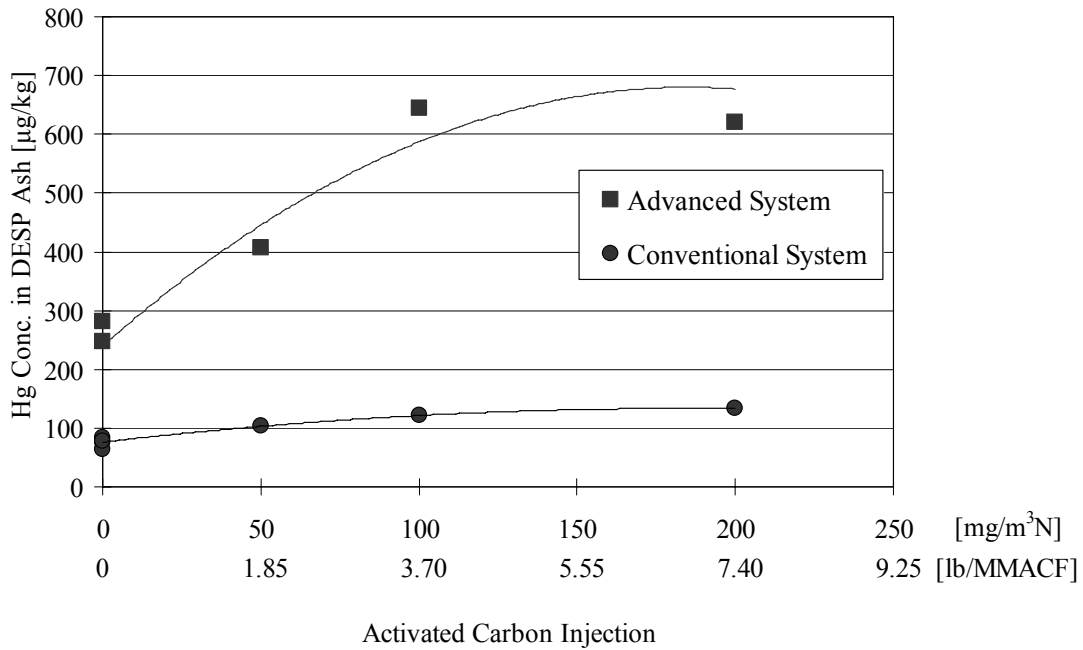
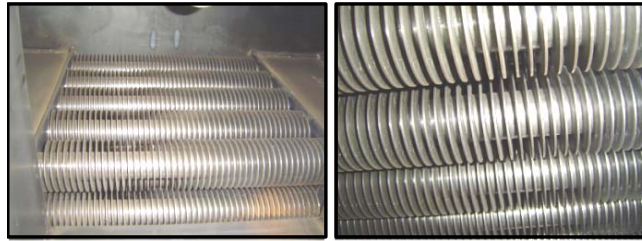


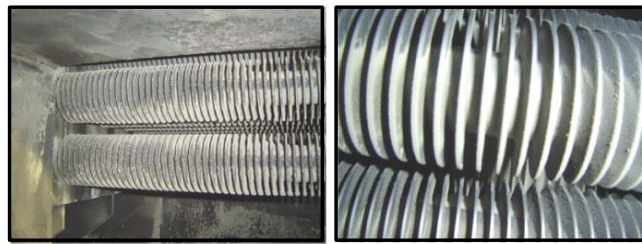
Fig.7 Effect of rate of ACI on Hg concentration

Study of CER Durability

Figure 8 shows photos of the finned, carbon steel tubes of the CER. A heat transfer medium flowed inside the tubes, and the tubes had been exposed to flue gas for more than one and a half months during this test period. A soot blower was operated periodically and it effectively removed the ash from the finned tubes. Similar to the commercial applications in Japan burning relatively low sulfur coals, no significant ash build-up was observed throughout the entire test period under such high inlet SO₃ concentrations. Figure 9 shows the trend of temperature of flue gas, heat medium temperature and differential pressure between CER inlet and outlet. Although the temperature at the CER inlet varied from 140 °C to 170 °C (284 °F to 338 °F), the temperature at the outlet remained around 90 °C (194 °F) throughout the test. The pressure drop remained between 2 to 3 inch H₂O which is favorable for steady operation.



Initial



After operation

Fig. 8 Pictures of finned-tube of CER

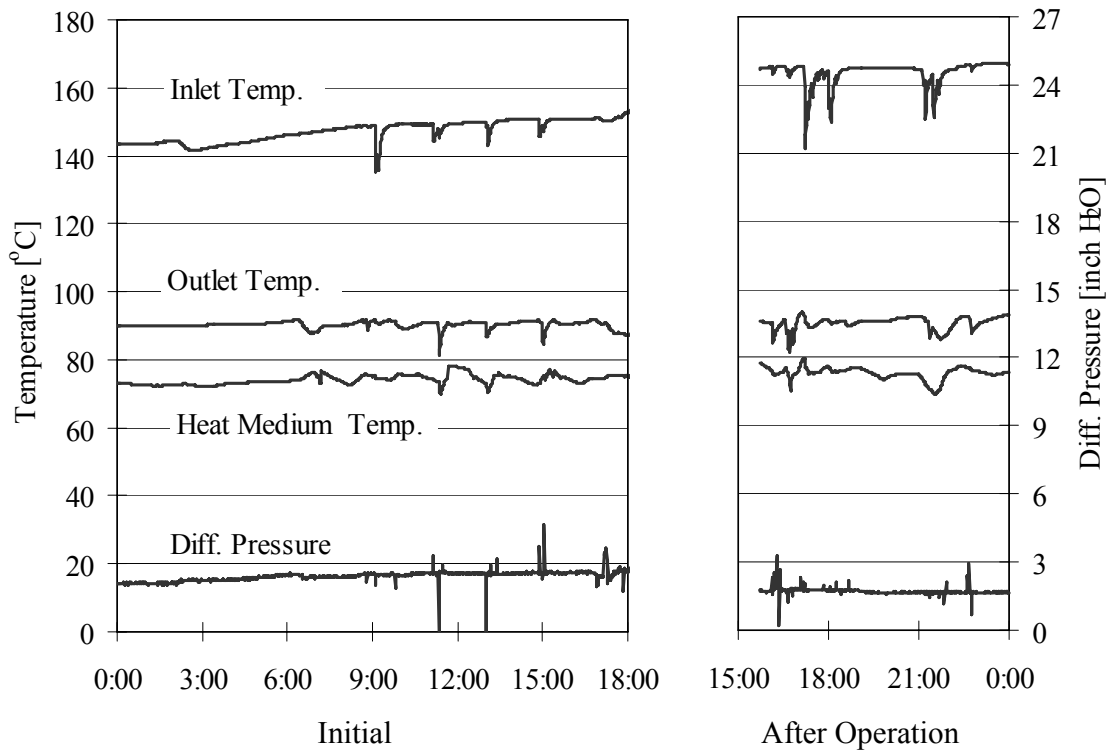


Fig. 9 Trends of temperature and differential pressure of CER

Following testing some of the finned tubes were removed from the CER. After an acid wash, the tube surfaces were examined. Even though this tube had been exposed to flue gas with a high SO₃ concentration, no corrosion was found. It is the same result as a commercial plant which has been in operation for 7 years in Japan.

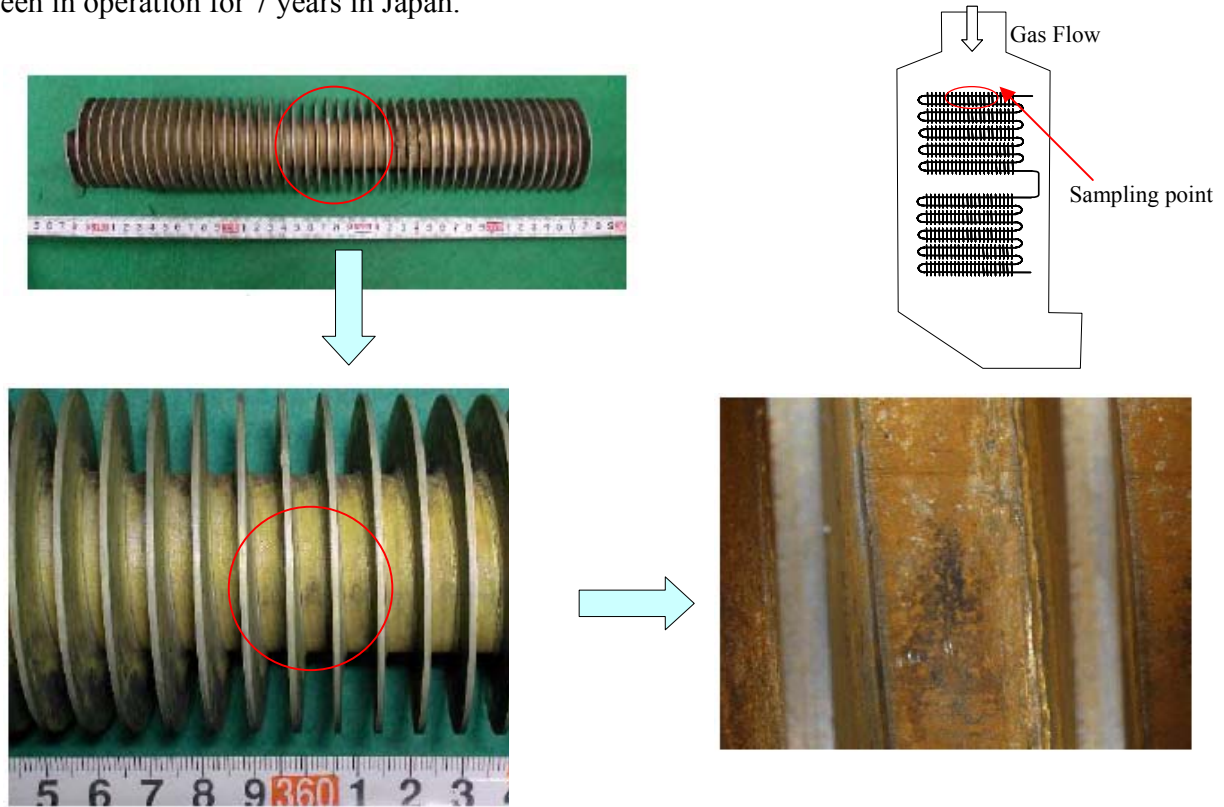


Fig.10 Pictures of sampled finned-tube

CONCLUSIONS

1. Stable and reliable operation of the slipstream advanced AQCS has been demonstrated at a U.S. power plant burning high sulfur bituminous coal.
2. In the conventional system, with or without activated carbon injection, little mercury was removed in the DESP at 160 °C (320 °F) due to the inhibiting effect of SO₃ on mercury adsorption to fly ash and activated carbon particles.
3. The advanced AQCS effectively reduced SO₃ concentration in the flue gas with cooling by the CER. With activated carbon injection, large amount of mercury was removed across ACI/DESP, followed by further capture in the WFGD. Without ACI, most of the mercury removal occurred in the WFGD. In both cases, mercury removal of 95% was achieved with the advanced AQCS.

4. The Advanced Venturi Scrubber (AVS) removed a majority of the mercury in the flue gas upstream of the main WFGD. The WFGD system with AVS can capture mercury and SO₂ separately and effectively prevent the re-emission of mercury. Removal of mercury ahead of the WFGD may also reduce potential concerns of mercury contamination in gypsum by-products.
5. During operation, pressure drop of the CER was stable (approx 2 – 3 inch H₂O). After testing, no corrosion was evident on the finned, carbon steel tubes. These test results are similar to the long term CER operating data at our commercial power plants in Japan, and support the commercial application of CER for US high sulfur bituminous coals.

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