A Research of Acid Gas Condensation in Large-scale Coal-fired Power Plants

Anh Hoang, Tuyen Nguyen and Mao Nguyen

Abstract - ***Steam coil air heater (SCAH) are usually designed and used during oil and/or co-fuel firing conditions in order to prevent acid gas condensation which causes corrosion in a coal-fired power plant. However, a study of large-scale power plant units in Viet Nam has shown that the flue gas temperature is lower than acid dew point temperature even at stable high loads. To prevent gas acid dew point corrosion for 30 years life-cycle of new units in Viet Nam, SCAH is proposed to be operated at stable high loads and its design configured has been spared to achieve the requirement.***

Keywords: ***Coal-fired power plant, Sulfuric acid dew-point temperature, Steam coil air heater, Acid condensation, Flue gas.***

I. INTRODUCTION

The prediction of sulfuric acid dew-point has been extensively investigated in the last decade [1-2]. Much of the literature focuses on predicting the sulfuric acid dew-point in the flue gas [3–6]. Sulfur trioxide (SO_3) vapor in the flue gas stream is the component considered to be primarily responsible for combining with water vapor to form sulfuric acid (H_2SO_4). When condensing, the H_2SO_4 causes corrosion of metal it contacts [7-8]. In the normal combustion process, sulfur in the fuel is rapidly converted to sulfur dioxide (SO_2). In the absence of a catalyst, the conversion of SO_2 to SO_3 in the flue gas is relatively small. However, installation and operation of Selective Catalytic Reduction (SCR) will directly impact the flue gas acid dew point and necessitate raising the air heater flue gas outlet temperature to prevent condensation of acid in the flue gas. Platinum and vanadium which are present in the SCR catalyst, and rust in the form of Fe_2O_3, have been found to act as catalysts for the SO_2 to SO_3 conversion [9]. As such, addition of SCR will result in an increase in the conversion of SO_2 to SO_3 which will increase the amount of H_2SO_4 in the flue gas [10-11]. Otherwise, Babcock-Hitachi has also announced the new design with a gas cooler system to reduce SO_3 concentration to less than 1 ppm at Electrostatic Precipitator (ESP) inlet [12], but the slight fouling at the outlet of the first stage flue gas cooler and the serious fouling of the second stage was mainly caused by sulfuric acid condensation [13].

When a boiler is designed to fire a wide range of coals with varying sulfur content, the calculated acid dew point will vary as well. A wide range of coals can be accommodated in a particular boiler design. However, the design must be optimized for a particular coal. When choosing a particular coal to set the air heater design, the guarantee coal and boiler efficiency optimization are considered. Each 10 ^oC decrease in the flue gas temperature can cause about 0.6%–1.0% increase in the boiler efficiency [7-8]. Air heater design is not optimized to operate with an air heater exit gas temperature above the acid dew point and some will require the use of the Steam Coil Air Heater (SCAH) to maintain the air heater exit gas temperature at or above the acid dew point. SCAH are usually designed to be taken out of service after a complete shut-off of oil supply to the boiler burners in a coal-fired power plant. However, researches of large-scale units in Viet Nam have shown that the flue gas temperature is lower than acid dew point temperature even at stable high loads, which may cause corrosion of the components on flue gas stream.

II. MODELLING APROACH

This study includes units of sub-critical and super-critical larger-scale (+600MW) in Viet Nam, which fire domestic anthracite coal with sulfur 0.55% (arb) or mixed of 30% bitumen and 70% sub-bitumen import coal with sulfur 1.05% (daf). A sample configuration of balance draft system of the units is shown below (Fig. 1).

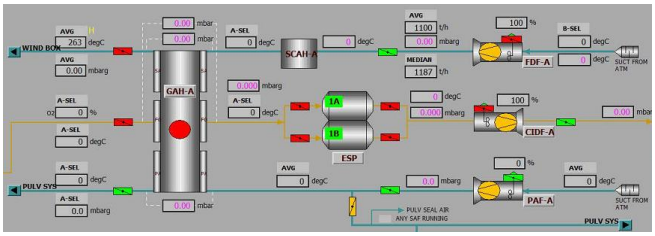


Figure 1. *A sample configuration of balance draft system*

The units were designed with SCAH which takes in during oil and/or co-fuel firing conditions and takes out of service after a complete shut-off of oil supply to the burners of the boiler.

III. METHODOLOGY OF RESEARCH

The location where acid corrosion is most likely to happen is at the Induced Fan (IDF) inlet, because the flue gas temperature there is at the lowest before the acid is removed. Therefore acid dew point should be calculated at the IDF inlet to ensure that acid corrosion is prevented in this area. Fig. 2 below describes a simple scheme of flue gas path showing the most affected areas for acid corrosion.

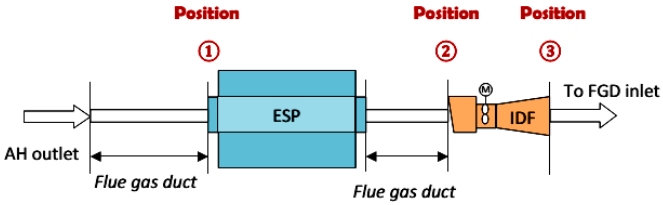


Figure 2. *The sample scheme of flue gas path*

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When flue gas leaves the Air Heater (AH), it passes through a section of duct, and enters the ESP (refer to Position ①). The flue gas temperature at ESP inlet may be slightly lowered (about 2°C, depends on the length of the ductwork) than that at the AH outlet, because air may leak into the duct due to lack of maintenances or occasional situations. When the flue gas passes through the ESP, the temperature may be lowered again due to ESP temperature drop (ESP vendors guarantee the maximum temperature drop is 7°C). When flue gas enters the ID fan, its temperature is considered to be the lowest point in the duct path (refer to Position ②). Because as the gas enters the IDF, the fan has done work on the gas, and this process will add amount of heat in the system, so there will be an increase in the flues gas temperature when passing through the IDF (about 8°C, depends on the pressure rise through IDF). After leaving the ID fan, the flue gas temperature will be increased before entering Flue Gas Desulphurization System (FGD) (refer to Position ③). The gaseous acid will be removed during FGD system. Therefore, if it is ensured the flue gas temperature at the worst location (Position ②) is above the acid dew point, the whole flue gas duct will be free of acid corrosion risk.

The acid dew point of a flue gas is the temperature, at a given pressure, at which any gaseous acid in the flue gas will start to condense into liquid acid. Among the many acid dew point calculation methods [6], the Verhoff - Banchero equation is a relatively accurate and widely used in the industry [14]. The equation is derived from experimental data, the formula considering the influence of SO_2/SO_3 and H_2O content in the flue gas on acid dew point temperature [15]:

$$\frac{1000}{T_{dp}} = 2.276 - 0.0294 \ln P_{H_2O} - 0.0858 \ln P_{H_2SO_4} + 0.0062 \ln P_{H_2O} \ln P_{H_2SO_4}$$

Where T_{dp} is flue gas acid dew point temperature, K; P_{H2O} is partial pressure of water vapor in flue gas, mmHg; P_{H2SO4} is partial pressure of sulfuric acid in flue gas, mmHg.

In this equation, the partial pressure of water vapor is determined by the water concentration in flue gas and the flue gas pressure:

$$P_{H_2O} = 760mmHg \times \frac{101325 + P_{fluegas}}{101325} \times H_2Ovol\%$$

The partial pressure of the sulfuric acid is determined by the SO2/SO3 concentration in flue gas and the flue gas pressure:

$$P_{H2SO4} = 760mmHg \times \frac{101325 + P_{fluegas}}{101325} \times SO_2vol\% \times \frac{64}{80} \times \frac{SO_3(wet)ppm}{SO_2(wet)ppm}$$

Both water concentration and SO_2/SO_3 concentration are derived directly from combustion coal data, flue gas pressure is derived from flue gas pressure at air heater outlet and pressure drop through the flue gas duct.

Flue gas acid dew points (Verhoff-Banchero) for various SO_3 and water vapor concentrations have been calculated and is presented in the following Fig.3:

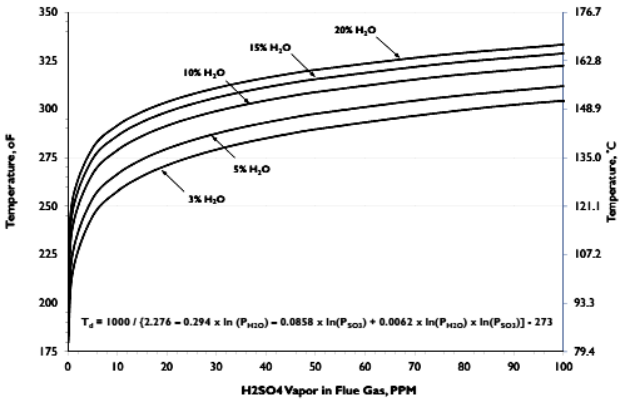


Figure 3. *The calculated flue gas acid dew points*

Methodology of this research includes the prediction of sulfuric acid dew-point and evaluated with existing flue gas temperature in the ID fan inlet and AH outlet for stable high loads of sub-critical and super-critical larger-scale (+600MW) units in Viet Nam. And it then proposes the solution to prevent acid gas condensation for new units in Viet Nam for 30 years life-cycle.

IV. RESULTS AND DISCUSSION

The AH outlet acid dew point temperature for the unit 622.5 MW sub-critical fired anthracite coal stable high loads are calculated and presented in table 1 with reference input data from boiler manufacturers [16].

TABLE 1. PREDICTION OF SULFURIC ACID DEW POINT TEMPERATURE FOR UNIT 622.5 MW SUB-CRITICAL FIRED ANTHRACITE COAL

Description	*Unit*	*BMCR*	*100% RO*	*75% RO*
AH outlet flue gas pressure	Pa	-3228	-3061	-3041
SO_2 concentration	% vol	0.0395	0.0350	0.0346
H_2O concentration	% vol	7.45	6.59	6.49
SO_3(wet)/SO_2 (wet)	-	0.0283	0.0283	0.0295
Partial pressure of H_2O	mmHg	54.83	48.57	47.85
Partial pressure of H_2SO_4	mmHg	0.0066	0.0058	0.0060
AH outlet acid dew point temperature	°C	132.6	130.2	130.3

The flue gas temperature exit the air heater at about 15°C below of the predicted acid dew point at stable high loads as illustrated in Fig. 4.

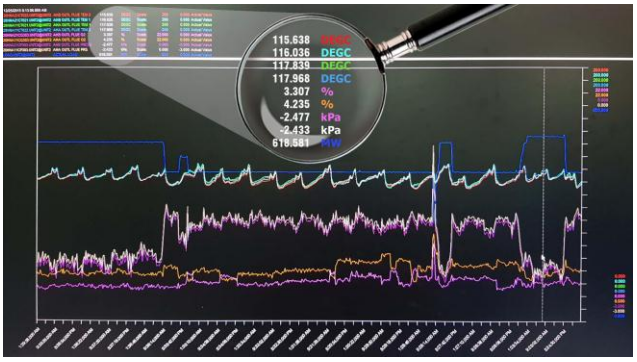


Figure 4. *Operated parameters at stable high loads of unit sub-critical fired anthracite coal*

Table 2 is presented the predicted acid dew point temperature at IDF inlet for the unit 622.5 MW sub-critical fired mixed import coals at stable high loads with input data derived from boiler manufacturers [17].

TABLE 2. PREDICTION OF SULFURIC ACID DEW POINT TEMPERATURE FOR UNIT 622.5 MW SUB-CRITICAL FIRED MIXED IMPORT COAL

Description	*Unit*	*BMCR*	*100% RO*	*75% RO*	*50% RO*
IDF inlet flue gas pressure	Pa	-4687	-4387	-3058	-2725
SO_2 concentration	% vol	0.0552	0.0551	0.0541	0.0533
H_2O concentration	% vol	10.258	10.249	10.128	9.935
SO_3(wet)/SO_2 (wet)	-	0.012	0.012	0.013	0.015
Partial pressure of H_2O	mm Hg	74.35	74.52	74.65	73.48
Partial pressure of H_2SO4	mm Hg	0.0039	0.0038	0.004	0.0048
IDF inlet acid dew point temperature	^oC	130.4	130.4	130.9	132.3

The IDF inlet flue gas temperature was at about 5^{o}C below of the predicted acid dew point temperature at stable high loads as illustrated in Fig. 5.



Figure 5. *Operated parameters at stable high loads of unit sub-critical fired mixed import coals*

A calculated result table of acid dew point temperature at IDF inlet for the unit 600 MW super-critical fired mixed import coals at stable high loads are presented in table 3 with reference input data from boiler manufacturers [18].

TABLE 3. PREDICTION OF SULFURIC ACID DEW POINT TEMPERATURE FOR UNIT 600 MW SUPER-CRITICAL FIRED MIXED IMPORT COAL

Description	*Unit*	*BMCR*	*100% RO*	*BMCR Worst (max ash&sulfur)*	*80% RO*	*60% RO*	*40% RO*
IDF inlet flue gas pressure	Pa	-4997	-4707	-5057	-3778	-3415	-2985
SO_2 concentration	% vol	0.069	0.069	0.085	0.069	0.068	0.06
H_2O concentration	% vol	13.01	13.00	14.31	12.89	12.75	11.68
SO_3(wet)/SO_2 (wet)	-	0.012	0.012	0.014	0.012	0.012	0.013
Partial pressure of H_2O	mm Hg	93.99	94.20	103.33	94.33	93.65	86.18
Partial pressure of H_2SO_4	mm Hg	0.005	0.005	0.007	0.005	0.005	0.005
IDF inlet acid dew point temperature	^oC	134.7	134.7	139.6	134.8	134.6	133.6

The IDF inlet flue gas temperature was at about 5^{o}C below of the predicted acid dew point at stable high loads as illustrated in Fig. 6.



Figure 6. *Operated parameters at stable high loads of unit super-critical fired mixed import coals*

The whole flue gas duct was under acid corrosion at stable high loads as mentions above. In addition, it also was observed that flue gas temperature steeply decreases whilst running soot-blowers.

The proposed solution, for new unit in Viet Nam with 30 years life-cycle, to prevent acid gas condensation is to operate the SCAH at stable high loads with the calculation and design configured has been spared to achieve the requirement as shown in table 4.

TABLE 4. THE CALCULATION RESULT FOR SCAH OPERATED AT STABLE HIGH LOADS[4]

Description	*Unit*	*Case 1 BMCR Perf. Coal*	*Case 2 BMCR Worst Coal*	*Case 3 RO Perf. Coal*	*Case 4 RO Worst Coal*
AH air inlet temperature	^oC	25.5	25.5	25.5	25.5
AH gas outlet temperature (without SCAH)	^oC	124.0	120.6	123.3	118.9
ID fan acid dew point	^oC	130.8	132.8	140.9	133.2
AH gas outlet temperature (with SCAH in service)	^oC	143.0	145.6	143.0	145.6
Margin above ID	^oC	>10	>10	>10	>10

Description	*Unit*	*Case 1 BMCR Perf. Coal*	*Case 2 BMCR Worst Coal*	*Case 3 RO Perf. Coal*	*Case 4 RO Worst Coal*
Fan Tdp (One coil out of service in each duct)					
Margin above ID Fan Tdp (Two coils out of service in each duct)	°C	>10	0≤Ma≤ 10	>10	0≤ Ma≤10
Margin above ID Fan Tdp (Three coils out of service in each duct)	°C	>10	0≤ Ma≤10	>10	0≤ Ma≤10
Margin above ID Fan Tdp (Four coils out of service in each duct)	°C	0≤ Ma≤10	0≤ Ma≤10	0≤Ma≤ 10	0≤ Ma≤10

4. Unit 688 MW super-critical fired mixed import coal [19]

Normally, the piping design for the steam coil air heater only considers an isolating valve at the inlet of each steam coil. A leak in one of the steam coils would require the shutdown of the entire steam coil heater because of the steam from the other coil may pass thru the leak. This design has been amended to add an isolating valve at the outlet of each steam coil as shown in Fig. 7. This modification would allow complete isolation of a faulty individual steam coil without interrupting or limiting boiler operation.

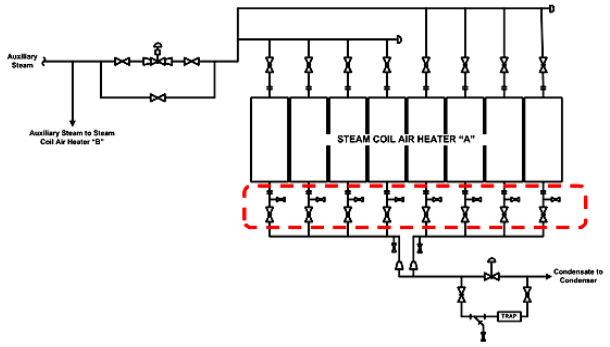


Figure 7. *The proposed new design configuration for SCAH*

V. CONCLUSIONS

The study result revealed that operating the flue gas temperature lower than acid dew point temperature even at stable high loads, may cause corrosion to the components of the flue gas stream in the coal-fired power plants. The new solution proposed to prevent acid gas condensation for new unit in Viet Nam guaranteed 30 years life-cycle, is to operate the SCAH at stable high loads and its design configured has been spared to achieve the requirement. Future research can be conducted concerning effect of operating SCAH at stable high loads, to performance guarantee and heat rate of unit.

ACKNOWLEDGMENT

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NOMENCLATURE

RO	Rate Output
SCAH	Steam coil air heater
FGD	Flue Gas Desulphurization System
IDF	Induced Fan
AH	Air heater
Ma	Margin above induced fan T_{dp}
T_{dp}	Flue gas acid dew point temperature
BMCR	Boiler Maximum Continuous Rating
ESP	Electrostatic precipitator
SCR	Selective Catalytic Reduction
$P_{fluegas}$	Flue gas pressure
P_{H2O}	Partial pressure of water vapor in flue gas (mmHg)
P_{H2SO4}	Partial pressure of sulfuric acid in flue gas (mmHg)
daf	Dry Ash Free Basis
arb	As Received Basis

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