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Assembling and test of a system for determination on site of acid dew point of exhaust flue gas from power steam boilers

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Acid dew point occurs due to decreasing of the temperature of exhaust flue gas from steam boiler in thermal power plant. From other point of view the lower temperature is the main requirement for higher boiler efficiency. When the temperature of flue gasses up to the value of acid dew point, the part of streams are saturated consistent and the acidic gases form liquid acid. This temperature is the thin limit between efficiency and stable operation. Its determination is important to achieve best performance of thermal power plants. Theoretical prediction of acid due point is complicate and includes validation with additional laboratory test. Aim of this study it to assemble system for determination acid dew point, which can be used on site on different power steam boilers. After choosing the appropriate components and their assembling, the system was tested in laboratory condition. The achieved result of 56°C was compared to the data received from three different equations for theoretical prediction of acid dew point. The data comparison proved that the assembled system can operate reliable.

Key words: thermal power plants, performance test, flue gas, acid dew point

INTRODUCTION

As a result, from the combustion process in power steam boilers, are generated exhaust flue gas, which contain mainly carbon dioxide (CO_2), water vapor (H_2O), nitrogen (N_2) and excess oxygen (O_2) remaining from the combustion air. There are few additional gases compounds as carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2) and sulfur trioxide (SO_3), which has smaller concentrations but bigger environmental impact. At the saturation temperature of the exhaust gas, the acidic gases interact together with the oxygen and the condensed water vapor to compose liquid acids [1, 2] as shown below:

$$SO_2 + H_2O \leftrightarrow H_2SO_3 \quad (1)$$

$$H_2SO_3 + O_2 \rightarrow H_2SO_4 \quad (2)$$

$$2SO_2 + O_2 \rightarrow 2SO_3 \quad (3)$$

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad (4)$$

$$2NO + SO_2 \rightarrow N_2O + SO_3 \quad (5)$$

$$NO_2 + SO_2 \rightarrow NO + SO_3 \quad (6)$$

$$4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3 \quad (7)$$

$$NO_2 + SO_2 + H_2O \rightarrow H_2SO_4 + NO \quad (8)$$

All those reactions lead to a very complex gaseous system. From other point the particular composition of the flue gas depends on the organization of the combustion process, which is preconditioned by the combustion system and fuel properties.

There are a lot of studies for theoretical prediction of acid dew point of exhaust flue gas. The five equations below were developed from different authors with the aim to determine theoretically flue gas acid point:

According Ohtsuka [3]

$$t_D = 20 \lg V + A \quad (9)$$

A : constant depending on moisture content (°C) - 184 at 5 %, 194 at 10 %, 201 at 15 %.

Neubauer's equation [4]

$$t_D = t_S + (290.54 - 30.79 p_{H2O})\, p_{SO_2}^{\left(0.0959 + 0.143 p_{H2O} - 0.1669 p_{H2O}^2\right)} \quad (10)$$

According Mueller [5] / Pierce [6] / Okkes [7]:

$$t_D = 203.25 + 27.6 \lg(p_{H2O}) + 10.83 \lg(C\, p_{SO2}) + 1.06\{\lg(C\, p_{SO2}) + 8\}^{2.19} \quad (11)$$

Verhoff & Banchero [8] relation for acid dew point prediction:

$$T_D = 10000 / [15.13 - 0.2943 \ln(p_{H2O}) - 0.858 \ln(C\, p_{SO2}) + 0.062 \{6.633 - \ln(C\, p_{SO2})\} \{6.633 - \ln(p_{H2O})\}] \quad (12)$$

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Haase and Borgmann [9] equation for acid dew point:

$$t_D = [255 + 27.6 \lg(p_{H2O}) + 18.7 \lg(C\, p_{SO2})] \quad (13)$$

where:

- T_D : Dew-point temperature (K)
- t_D : Dew-point temperature (°C)
- t_S : Saturation temperature of water at total pressure of exhaust flue gas (°C)
- C : Conversion rate of SO_3 from SO_2 by volume
- p_{SO2} : mole fraction of SO_2, equivalent to partial pressure (in atm) with the mixture of gases at standard atmospheric pressure (101.325 kPa)
- p_{H2O} : mole fraction of water, equivalent to partial pressure (in atm) with the mixture of gases at standard atmospheric pressure (101.325 kPa)
- V : H_2SO_4 concentration (vol %)

According to above equations there are cases where the results for acid dew point evaluated by them have difference of 20° K [2]. This shows that theoretical determination of temperature of acid dew point depends on many factors as: exhaust flue gas content and conditions in the duct, even from fuel quality and combustion process organization. So the proved way to evaluate acid dew point of flue gas is to assembly a measuring system, which may be used on site at different boilers, independently of the fuel used and the combustion process organization.

EXPERIMENTAL

Assessment of acid dew point of flue gas requires measurement of the temperature of a cooled surface at the moment when a liquid aced appears over it. Measuring principle of the constructed sensor is demonstrated on Figure 1.

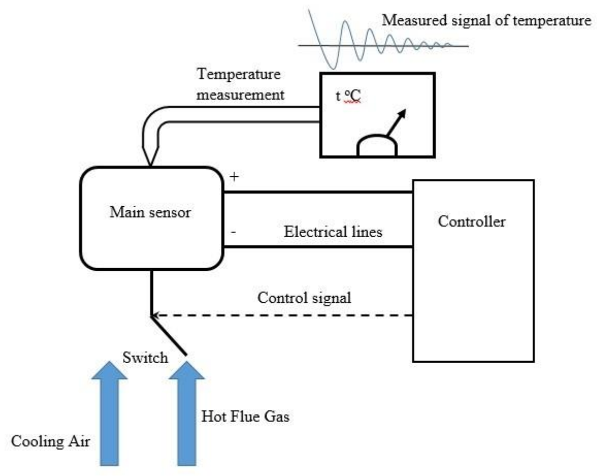

Fig. 1 Principle of measurement of acid dew point.

The main sensor gives two signals. The first is for the temperature measurement and the second is for existence of liquid acid. The signal of acid appearance is registered from a controller, which switch the main flow to hot flue gas pass over the sensor if it is necessary to increase temperature or switch to ambient air – to cool the sensor from the outside. The result of this regulatory process is temperature deviation around the acid dew point to the moment of achieving stable value.

Main elements of the acid dew point measuring system are presented on Figure 2. The operational principle of the system, is sampling exhaust flue gas from the duct and analyzing it to determine the acid dew point.

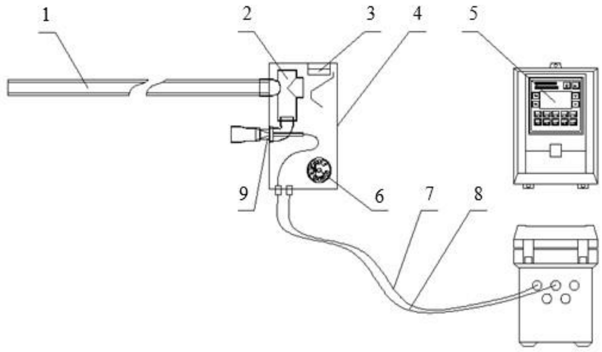

Fig. 2 Acid dew point measurement system: 1 – Ceramic sampling probe, 2 – Ceramic conductive sensor, 3 – Cooling fan,4 – Sensor's unit, 5 – Control unit, 6 – Transmitter TMT 181, 7 – Air supply line, 8 – Electrical line, 9 – Pneumatic ejector.

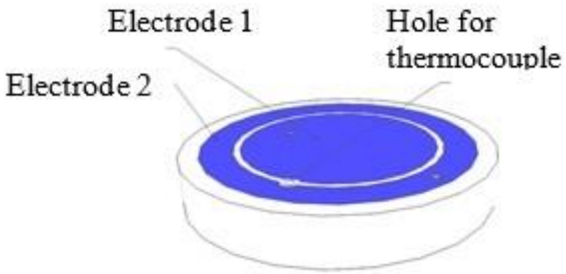

Fig. 3 Ceramic sensor.

The acid dew point measuring system includes a ceramic pad with metal overlay - Fig. 3, which forms two electrodes. Ceramic sensor (2) is attached tight to a metal tube with good seal to prevent leakage of ambient air. There is a small hole, 1mm in diameter, into the pad for mounting the thermocouple, and seal it with clay. Outer surface of the pipe is thermally isolated, except the back side of the sensor, because it has to be cooled by the cooling fan (3).

For the purpose of this system is used an FTW 325 electrical unit [10], which is very sensitive to condensate formation. It can detect condensation, which is not visible for the human eye. The electrical unit provides AC with frequency of 20 Hz, which prevents electrodes destruction.

Temperature measurement is assured by a J-type thermo-electrical thermometer. This thermocouple can measure temperature in the range -200…1200ºC. The thermocouple is connected to a TMT 181 temperature transmitter, produced by E&H [11]. Its role is to convert the raw signal from thermometer to a unified electrical signal of 4…20mA.

To increase the accuracy of the measuring system it is important to select a thermo-sensitive element with small inertia. In other case, there is a risk to read data different from the real temperature of the sensor.

In assembled system was used programmable logical controller – Vision 120-R1 [12]. It is responsible for reading both the temperature sensor and condensation detector, and manages the PID regulator, which controls the temperature of the ceramic pad, by switching on and off the cooling fan.

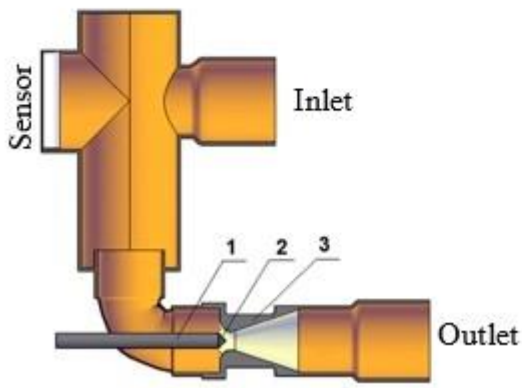

Fig. 4 Sampling unit.

One of the main components of the system is the sampling unit - Fig. 4. It contains an ejector, by which part of the exhaust flue gas is directed toward the ceramic sensor.

The ejector works with compressed air, provided by a compressor, external to the sampling unit. The air enters the pipe (1), through a nozzle (2) and is lead into a Laval nozzle (3). The high speed of the air flow expires within the Laval nozzle result to static pressure drop. Obtained by Laval nozzle dilution in necessary to compensate linear and local pressure loses through sampling system. The quantity of the collected flue gas depends on the compressed air flow rate. So compressor operation is managed by a Vision 120-R1 controller.

The assembled flue gas acid dew point measuring system gas was tested in the laboratory for Heat and Gas Supply - Fig.5 in department "Thermal and Nuclear Power Engineering" in Technical University of Sofia.

For the test was used RIELLO gas boiler with 24 kW thermal power. The combustion chamber and the burner, which are responsible for organization of the combustion process, are shown on Fig. 5b.

The acid dew point test is conducted ten times, at different setting for the hysteresis cycle of gas sampling and sample cooling, controlled by Vision 120-R1. Received data are statistically analyzed and an average value for acid dew point is estimated.

RESULTS AND DISCUSION

After conducting tests for determination of acid dew point of exhaust flue gas from laboratory boiler, achieved result was compared with data from equations 10, 12 and 13, for theoretical prediction of the same temperature. Other two equations 9 and 11 are not used, because they are appropriate for flue gas with high sulphur concentration. Comparison of the results from the test and the one calculated by the equations are shown above in Table 1.

Table 1. Comparison between laboratory test and theoretical equations.

Method	Lab. test	Haase&Borg.	Verh.&Banch.	Neubauer
Value	56ºC	41ºC	48ºC	68ºC

After the analysis of compared data from Table 1, the conclusion is that the assembled measurement system for determination of acid dew point of exhaust flue gas works properly. This fact proves that it can be used to provide determination on site of acid dew point.

Outlook

To achieve on site tests at different power steam boilers, with different fuels, respectively different combustion process conditions and flue gas content.

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АСЕМБЛИРАНЕ И ТЕСТВАНЕ НА СИСТЕМА ЗА ОПРЕДЕЛЯНЕ НА МЯСТО ТОЧКАТА НА РОСАТА НА ИЗХОДЯЩИ ДИМНИ ГАЗОВЕ ОТ ЕНЕРГИЙНИ ПАРОГЕНЕРАТОРИ

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(Резюме)

Кондензацията на водните пари и газообразните киселини резултат от горивния процес при енергийни парогенератори настъпва при понижаване на температурата на отпадните димни газове. Нуждата от по-ниски температури е продиктувана от стремежа за повишаване на ефективността на котлите. Точката на росата представя температурата, при която започва формирането на киселини в течна фаза. Тази температура представлява тънката граница между ефективност и надеждна експлоатация. Нейното определяне е необходимо за да се постигне оптимална работа, на една ТЕЦ. Определянето на точката на росата чрез теоретични зависимости е сложно и включва провеждане на допълнителни лабораторни тестове за доказване на получените резултати. Целта на настоящото изследване е да се асемблира система за определяне точката на росата, която да може да бъде използвана на място при различни енергийни парогенератори. След като бяха избрани подходящи елементи за асемблиране, системата беше тествана в лабораторни условия. Полученият резултат от 56°C беше съпоставен с данни от различни теоретични зависимости за определяне точката на росата. Сравнението на данните доказа, че асемблираната система може да работи надеждно.