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Estimation of Uncertainty in Aerosol Concentration Measured by Aerosol Sampling System

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1. INTRODUCTION

FNC Technology Co., Ltd has been developed test facilities for the aerosol generation, mixing, sampling and measurement under high pressure and high temperature conditions [1]. The aerosol generation system is connected to the aerosol mixing system which injects SiO_2/ethanol mixture. In the sampling system, glass fiber membrane filter has been used to measure average mass concentration [2]. Flow diagram for the aerosol generation, mixing and sampling system is shown in Figure 1.

Based on the experimental results using main carrier gas of steam and air mixture, the uncertainty estimation of the sampled aerosol concentration was performed by applying Gaussian error propagation law.

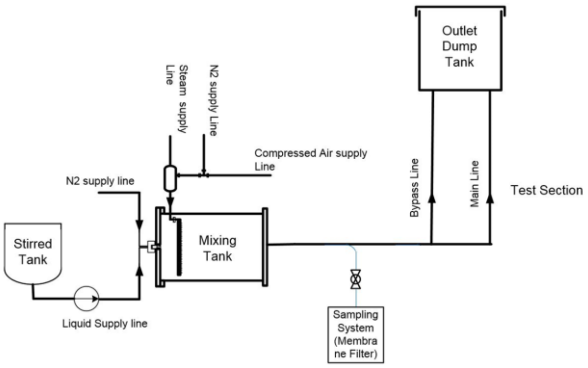

Fig.1: Flow Diagram for Aerosol Generation, Mixing and Sampling System

2. TEST PARAMETERS

The SiO_2 has been collected on membrane filter and weighted by micro balance. The SiO_2 concentrations of sampling line were calculated as below.

$$C_{SiO_2} = \frac{m_{SiO_2}}{t \cdot \dot{V}_{total}} \quad (2\text{-}1)$$

C_{SiO2} : Sampled Aerosol Concentration
m_{SiO2} : Aerosol Mass Collected on Membrane Filter
V_{total} : Volumetric Flow rates of Air and Steam
t : Sampling time

Test cases using the carrier gas of steam/air mixture were selected to evaluate the uncertainty of sampled aerosol concentration. The detail test data are not provided in this paper due to data security, but Table 1 shows summary of aerosol test conditions for uncertainty estimation.

Table 1. Summary of Aerosol Test Conditions for Uncertainty Estimation

	Pressure	Temperature	Sampling time	Sampled Mass	Total Flow rates
	kPa(g)	℃	s	g	m^3/s
Case 1	405	153	1800	0.26712	2.39E-04
Case 2	591	155	1286	0.11984	3.17E-04

3. UNCERTAINTY ESTIMATION

3.1 Propagation of Errors

A function of f(x, y, ⋯, z) is computed from the measured quantities x, y, ⋯, z with uncertainties △x, △y, ⋯, △z. The total uncertainty of a computed result, △ f is given by Gaussian error propagation law as [3]:

$$\Delta f = \sqrt{(\frac{\partial f}{\partial x}\Delta x)^2 + \cdots + (\frac{\partial f}{\partial z}\Delta z)^2} \quad (3\text{-}1)$$

3.2 Uncertainty Estimation of the SiO_2 Concentration

Flow rates of air were measured by mass flow meter and flow rates of steam were calculated by condensed steam mass in the sampling system. The air/steam mixture flow rates of sampling line were calculated as below.

$$V_{total} = V_{air} + V_{steam} \quad (3\text{-}2)$$

$$V_{steam} = \frac{1}{\rho_{steam}} \times \frac{m_{cw}}{t} \quad (3\text{-}3)$$

V_{air}, V_{steam} : Volumetric flow rates of air and steam
m_{cw} : Condensed steam mass collected in the condensation tank
t : Sampling time

The detailed uncertainty estimation for the flow rate of steam and air mixture is:

$$\Delta \dot{V}_{steam} = f(m_{cw}, t) \quad (3\text{-}4)$$

$$\Delta \dot{V}_{steam} = \sqrt{(\frac{\partial \dot{V}_{steam}}{\partial m_{cw}}\Delta m_{cw})^2 + (\frac{\partial \dot{V}_{steam}}{\partial t}\Delta t)^2} \quad (3\text{-}5)$$

The detailed partial derivatives for the flow rate are:

$$\frac{\partial}{\partial m_{cw}}\left(\frac{m_{cw}}{\rho_{steam} \cdot t}\right) = \frac{1}{\rho_{steam} \cdot t} \quad (3\text{-}6)$$

$$\frac{\partial}{\partial t}\left(\frac{m_{cw}}{\rho_{steam} \cdot t}\right) = -\frac{m_{cw}}{\rho_{steam} \cdot t^2} \quad (3\text{-}7)$$

$$\Delta \dot{V}_{total} = \sqrt{(\Delta V_{air})^2 + (\Delta V_{steam})^2} \quad (3\text{-}8)$$

The SiO_2 concentrations were calculated from equation (2-1). The detailed uncertainty calculations for the SiO_2 concentrations are:

$$\Delta C_{SiO_2} = \sqrt{\left(\frac{\partial C_{SiO_2}}{\partial m_{SiO_2}} \Delta m_{SiO_2}\right)^2 + \left(\frac{\partial C_{SiO_2}}{\partial t} \Delta t\right)^2 + \left(\frac{\partial C_{SiO_2}}{\partial \dot{V}_{total}} \Delta \dot{V}_{total}\right)^2} \quad (3\text{-}9)$$

The detailed partial derivatives for the SiO_2 concentration at sampling line are:

$$\frac{\partial}{\partial m_{SiO_2}}\left(\frac{m_{SiO_2}}{t \cdot \dot{V}_{total}}\right) = \frac{1}{t \cdot \dot{V}_{total}} \quad (3\text{-}10)$$

$$\frac{\partial}{\partial t}\left(\frac{m_{SiO_2}}{t \cdot \dot{V}_{total}}\right) = -\frac{m_{SiO_2}}{t^2 \cdot \dot{V}_{total,inlet}} \quad (3\text{-}11)$$

$$\frac{\partial}{\partial \dot{V}_{total}}\left(\frac{m_{SiO_2}}{t \cdot \dot{V}_{total}}\right) = -\frac{m_{SiO_2}}{t \cdot \dot{V}^2_{total}} \quad (3\text{-}12)$$

Table 2 shows results of uncertainty estimation for the aerosol concentration based on the test results.

Table 2. Uncertainty Estimation Results of Aerosol Concentration

	Concentration	Uncertainty	
	m^3/s	Absolute	Relative
Case 1	0.62090	±0.00609	±0.98%
Case 2	0.29410	±0.00219	±0.74%

4. CONCLUSIONS

FNC Technology Co., Ltd. has been developed the experimental facilities for the aerosol measurement under high pressure and high temperature. The purpose of the tests is to develop commercial test module for aerosol generation, mixing and sampling system applicable to environmental industry and safety related system in nuclear power plant.

For the uncertainty calculation of aerosol concentration, the value of the sampled aerosol concentration is not measured directly, but must be calculated from other quantities. The uncertainty of the sampled aerosol concentration is a function of flow rates of air and steam, sampled mass, sampling time, condensed steam mass and its absolute errors. These variables propagate to the combination of variables in the function.

Using operating parameters and its single errors from the aerosol test cases performed at FNC, the uncertainty of aerosol concentration evaluated by Gaussian error propagation law is less than 1%. The results of uncertainty estimation in the aerosol sampling system will be utilized for the system performance data.

REFERENCES

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