Optimal RMS Sampling Location Selection Using CFD Analysis

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1. Introduction

In case that instrument is installed in duct or pipe system, it should be installed in the stable flow region for ensuring the reliable result. ANSI/HPS N13.1 defines criteria for particle sampling location of Radiation Monitoring System (RMS) in nuclear power plant [1]. In this viewpoint, this study is performed to look for the optimal RMS sampling location according to ANSI/HPS N13.1 criteria. One out of nuclear power plants being designed in domestic is selected. First of all, sampling location with duct geometry designed in initial stage is estimated using Computational Fluid Dynamics (CFD) analysis. In the next, some flow variables in sampling probe location are quantitatively investigated to compare with ANSI/HPS N13.1 criteria. Finally, the revised design to satisfy the criteria will be estimated.

2. Numerical Analysis

FLUENT code based on finite volume method is used for flow analysis. Reynolds Stress Model (RSM) is used as turbulent model. Validity on usage of this turbulent model is proved by sensitivity analysis on 180° and 270° curved ducts. Fig. 1 is one of the sensitivity analysis results on turbulent models in 180° curved duct. RSM turbulent model shows the satisfied results compared with experiment data [2] in curved duct as a whole.

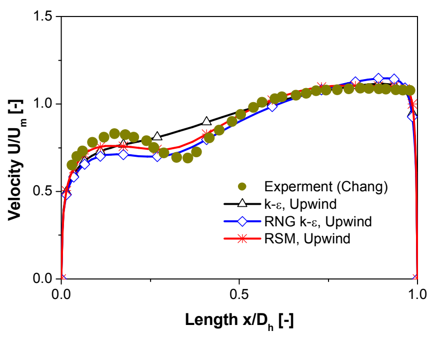


Fig. 1. Sensitivity analysis result on the turbulent models in 180° curved duct.

Fig. 2 is the schematic of duct that RMS sampling probe is installed. Air supplied through inlet A and B goes to atmosphere after passing the sampling probe. Aerosol particles can be supplied with air through inlet A and/or B.

Air flow rates through inlet A and B are 35,200 CFM and 47,000 CFM, respectively. Particle injection condition is assumed to be divided into 3 cases (only inlet A, only inlet B, or inlet A and B). Particles injected with air are assumed to be solids of which density is 1,000kg/m^3 illustrated in ANSI [1]. Particle flow rate is arbitrarily assumed to be 10% of inlet air flow rate because ANSI criteria demand just the deviation.

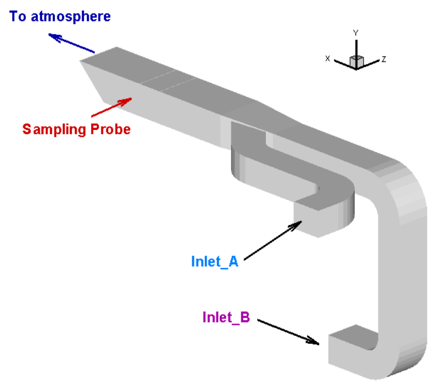


Fig. 2. Schematic of duct system for the RMS sampling designed in initial stage.

ANSI/HPS N13.1 demands the limited COV (Coefficient of Variation) on velocity, particle concentration and flow angle in sampling location. Average flow angle shall not exceed 20 degree (relative to the longitudinal axis of the stack or duct), and COV on gas velocity profile and aerosol particle concentration shall be within 20% across the area that encompasses at least the center two-thirds of the cross-sectional area of duct or stack.

3. Results and Discussion

Equation (1) and (2) are defined to derive the COV required in ANSI/HPS N13.1. Equation (1) is for flow angle and Equation (2) is for velocity or concentration.

$$\theta = \tan^{-1}\left(\sqrt{V_y^2 + V_x^2} / V_y^2\right) \times (180/\pi) \quad (1)$$

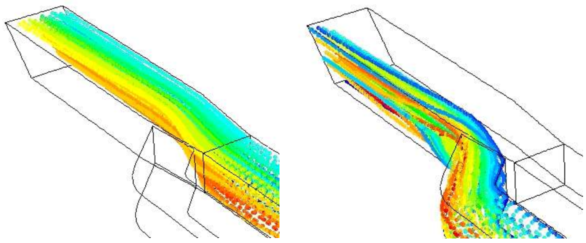
$$S_\phi = \sqrt{\frac{\int (\phi - \bar{\phi})^2 \, dA}{A}} / \bar{\phi} \times 100 \quad (2)$$

where, V is velocity component, ϕ is each variable values, $\bar{\phi}$ is average value and A is cross-sectional area.

Table. I shows the COV values on flow angle, velocity profile and aerosol particle concentration according to particle injection conditions. Case 1 is the condition that particles are injected through inlet A and B simultaneously. Case 2 is the condition injected through just inlet B. Case 3 is the condition injected through just inlet A. As shown in the results, flow angle and velocity profile satisfy ANSI/HPS N13.1 criteria but particle concentration doesn't satisfy the criterion in Case 2 and Case 3. As depicted in Fig. 3, this is because particles injected through each inlet are not fully mixed passing duct. It is recommended to extend the length of duct to be fully mixed in Case 2 or Case 3.

Table I: COV values on flow variables according to particle injection conditions

Characteristic	Case 1	Case 2	Case 3
Flow Angle	1.85 [deg]	1.85 [deg]	1.85 [deg]
Velocity Profile	18.15 [%]	18.1 [%]	18.0 [%]
Aerosol Particle Concentration	0.25 [%]	74.4 [%]	78.5 [%]



(a) Case 2 (b) Case 3

Fig. 3. Particle traces according to the particle injection conditions.

Fig. 4 illustrates the schematic and grid system of extended duct modified to meet ANSI/HPS N13.1 criteria. Considering space limitation, duct is extended as curved duct type. Particle injection condition is equal to that of Case 3.

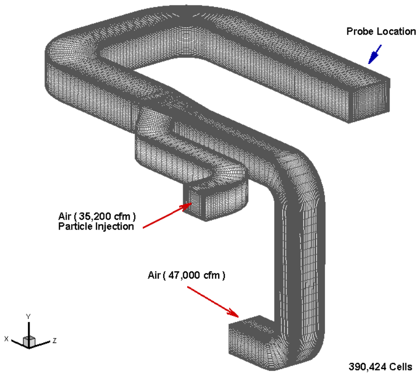


Fig. 4. Schematic and grid system of extended duct modified to satisfy ANSI/HPS N13.1 criteria.

Table II shows how much flow variables are revised in new sampling location. In velocity profile and particle concentration except flow angle, revised duct is better than previous duct. This is due to length extension and swirl as shown in Fig. 4 which shows particle traces in modified duct. Flow angle is increased due to swirl resulted from the curved geometry. But velocity and concentration fields are revised due to the increase of mixing effect by swirl. This shows that forced mixing as well as length extension should be considered when design modification is needed to meet the ANSI/HPS N13.1 criteria.

Table II: Comparison of COV values in previous duct and revised duct using shape change.

		Previous	Revised
Flow Angle	Total Area	1.85 [deg]	3.9 [deg]
Velocity Profile	Total Area	18.0 [%]	10.1 [%]
Aerosol Particle Concentration	Total Area	78.5 [%]	23.4 [%]
	2/3 Area	-	18.4 [%]

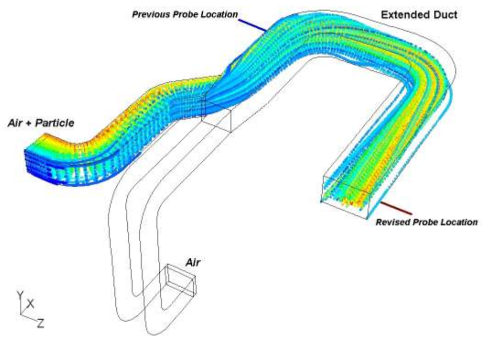


Fig. 5. Particle traces in the modified duct.

4. Conclusions

This study is performed to look for the optimal RMS sampling location to meet the ANSI/HPS N13.1 criteria. Estimation using CFD analysis is carried out and COV values on flow angle, velocity profile and aerosol particle concentration are investigated. In the multi-branched duct system, COV in sampling location may not be able to meet the ANSI/HPS N13.1 criteria. In this case, the length extension of duct geometry passing the connection part is demanded to assure the sufficient mixing. But when this extension is limited by site condition, forced mixing like swirl as well as length extension should be considered to meet the ANSI/HPS N13.1 criteria. This mixing effect increase due to swirl can be generated by the multi-curved duct extension or equipments.

REFERENCES

[1] American National Standards Institute, Sampling and Monitoring Release of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities, ANSI/HPS N13.1, 1999.

[2] Chang, S. M., Humphrey, J. A, C. and Modavi, A., Turbulent Flow in a Strongly Curved U-bend and Downstream Tangent of Square Cross Sections, Vol. 4, No. 3, pp. 243~260, 1983.