Uncertainty Analysis of Stack Gas Flowrate Measurement with the S-Type Pitot Tube for Estimating Greenhouse Gases Emission

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Korea Greenhouse Gas Emission

- Top 10 countries of GHG Emissions in 2010, High proportion of GHGs emissions arising from the energy and industrial fields

- Korea Emission Trading Scheme have been implemented with allocation of emission cap for each company in 2015

- Continuous Emission Monitoring System (CEMS) measure GHG emissions by monitoring concentrations and volumetric flow rate at exhaust stack gas with higher quality tier

- First necessary to carry out accurate and reliable GHGs emission estimate with proper uncertainties
On-site measurement for CEMS

\[
E_{CEM} = \sum_{i=1}^{N} E_{5\text{min},i} = \sum_{i=1}^{N} (C_i \times Q_{5\text{min},i} \times \frac{MW_{\text{gas}}}{22.4 L})
\]

Flow Rate

\[
Q = V \times A \times \frac{T_{\text{std}}}{T_S} \times \frac{P_s}{P_{\text{std}}} \times \left(1 - X_w\right) \times 300
\]

S-type Pitot installation at the stack

Flow velocity distribution inside stack

Combined Heat and Power Plant, KOREA
S-Type Pitot tube

- S-type Pitot tube is mainly used in on-site measurements for GHGs in Korea emission (S-type Pitot: 56%, Thermal Flowmeter: 23%, Ultrasonic: 11%)
- Large pressure orifices (Φ=5~10mm) & Strong tubes for high dust environments like industry stack (ISO 10780, KS M9429, EPA method2)
- Measurement differential pressure between an impact (total pressure) and wake orifice (static pressure) based on Bernoulli equation

\[ V = C_{P,S} \sqrt{\frac{2\Delta P}{\rho}} \]

- \( V \): flow velocity in the stack gas (m/s)
- \( \Delta P \): differential pressure (Pa)
- \( \rho \): density of the stack gas (kg/m³)
- \( C_{P,S} \): S type Pitot tube coefficient
Uncertainty Evaluation

\[
\frac{u_c^2(Q)}{Q} = \frac{u^2(C_p)}{C_P^2} + \frac{1}{4} \frac{u^2(\Delta P)}{\Delta P^2} + \frac{1}{4} \frac{u^2(\rho)}{\rho^2} + 4 \frac{u^2(D)}{D^2} + \frac{u^2(P_s)}{P_s^2} + \frac{u^2(T_s)}{T_s^2} + \frac{u^2(1 - X_w)}{(1 - X_w)^2}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>unit</th>
<th>Uncertainty component</th>
<th>Sensitivity coefficient</th>
<th>Combined uncertainty contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Type A %</td>
<td>Type B %</td>
<td></td>
</tr>
<tr>
<td>(C_p)</td>
<td>0.826</td>
<td>-</td>
<td>-</td>
<td>0.55</td>
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<td>(\Delta P)</td>
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<td>Pa</td>
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<tr>
<td>(\rho)</td>
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<td>kg/m³</td>
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<td>1.05</td>
<td>0.5</td>
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<td>(D)</td>
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<td>(P_s)</td>
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<td>mmHg</td>
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<td>K</td>
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<td>1-(X_w)</td>
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<td>%</td>
<td>0.0016</td>
<td>0.30</td>
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<tr>
<td>(\Delta V_D)</td>
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<td>m/s</td>
<td>1.54</td>
<td>-</td>
<td>1</td>
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<tr>
<td>(Q)</td>
<td>12972.5</td>
<td>m³/min (5min)</td>
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</tr>
</tbody>
</table>

- 95 % confidence level, \(k=2\)

Expanded Uncertainty, \(U = 3.88 \%\)

- Uncertainty analysis of stack flow rate measurements with traceability to NMI
- Research for accurate average velocity measurements in the stack by used instruments (S-type Pitot tube, Ultrasonic meter, Thermal flowmeter)