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Exhaust Gas Velocity Distribution Analysis Method Using Temperature Distribution and Heat Transfer Characteristics of Catalytic Converters

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Catalytic converters reduce harmful exhaust emissions from engines, but their efficiency depends on uniform velocity and temperature distribution of exhaust gases. Non-uniform velocity distribution at the converter inlet causes uneven gas distribution, reducing reaction efficiency. Previous research used direct measurement equipment or CFD simulations, but these have limitations: direct methods modify converter geometry, cold flow rigs don't replicate real conditions, and CFD simulations lack verification accuracy. This study proposes a reliable measurement technique that works under real operating conditions without converter distortion.

The study proposes a heat transfer-based velocity distribution measurement method exploiting the large thermal mass of catalytic converters. The core principle is that temperature changes at the inlet are transmitted to the outlet with a time delay depending on exhaust gas velocity. Fast-flowing regions show shorter delays; slow-flowing regions show longer delays.

The relationship between time delay (τ) and velocity (u) is expressed as:

$$u = \frac{\rho c_{p,Subs} L}{\rho c_{p,Gas}} \ln\left(\frac{T_{in} - T_{c,0}}{T_{in} - T_{c,1}}\right)\frac{1}{\tau}$$

The measurement procedure consists of four steps:

1. **Inlet Temperature Control**
   : Modulate exhaust gas temperature using ignition timing adjustments
2. **Outlet Temperature Measurement**
   : Install 66 thermocouples at the converter outlet to record temperature changes
3. **Time Delay Analysis**
   : Calculate delay between inlet and outlet temperature responses
4. **Velocity Distribution Back-Calculation**
   : Estimate velocity distribution from measured delays

The technique was validated using a 1.6L T-GDI engine. Experimental results compared with three-dimensional CFD analysis showed high agreement, with accurate identification of high-flow and low-flow regions. Some minor quantitative errors were attributed to assumptions of negligible external heat loss, but differences were acceptable.

The technique can measure velocity uniformity under transient conditions (FTP-75, WLTC). Correlation analysis showed velocity uniformity has meaningful correlation with catalyst purification efficiency ($r = 0.31$, $p < 0.002$).

Key Advantages:

- Non-destructive measurement without converter modification
- Applicable under real engine operating conditions
- Can analyze transient operating conditions
- Validated against CFD with high accuracy

This study successfully demonstrated a practical technique for measuring exhaust gas velocity distribution by exploiting thermal characteristics, providing essential data for improving catalyst design and reducing emissions under actual operating conditions.

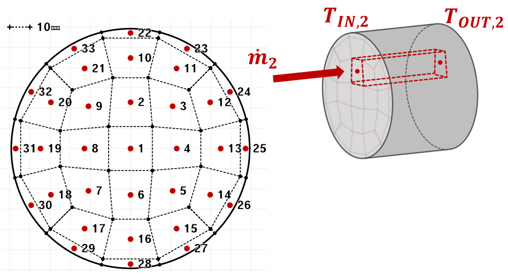

Fig.1 Temperature distribution measurement locations at catalyst inlet and outlet

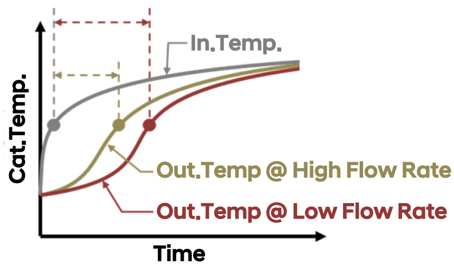

Fig.2 warm-up delay

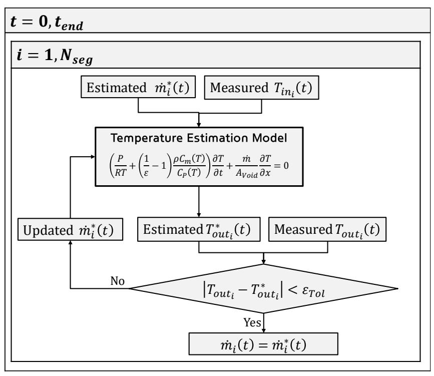

Fig.3 Flow Chart for Velocity Estimation