

Increasing Catalytic Conversion Efficiency by Controlling Exhaust Pulsations

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During high-speed driving—such as the Ex-High phase of the Worldwide Harmonized Light Vehicles Test Cycle (WLTC)—the engine operates under high load and the exhaust gas is at elevated temperature, so the reaction rate constants are sufficiently large and the conversion process is limited not by the noble-metal surface reaction rate but by the rate of mass transfer from the bulk flow to the washcoat surface. Previous research on catalytic conversion performance under high engine-load conditions has predominantly employed steady-flow fluidic approaches rather than strategies that actively exploit the effects of pulsating flows. The exhaust system exhibits a pulsating flow field due to the opening and closing of the engine exhaust valves. In particular, strong pulsations arise when the pressure fluctuations generated by blowdown are coupled with the natural acoustic modes of the exhaust system. In the present study, exhaust pulsations are examined and conversion performance is sought to be improved by controlling those pulsations through changes to the exhaust flow-path geometry. Furthermore, whereas previous research has concentrated on modifying the flow path upstream of the catalyst, improvements in conversion performance afforded by modifications to the internal structure of the muffler installed downstream of the catalyst are examined.

Figure 1 shows the calculated time-averaged conversion as a function of pulsation when a pulsating flow enters a single catalyst cell.

$$U_{cc}(t) = U_{cco} + u_{cc}\sin\omega t \quad (1)$$

U_{cco} [m/s]: Steady flow velocity,

u_{cc} [m/s]: Velocity fluctuation amplitude,

ω [1/s]: Angler frequency, t [s]: Time

When the mean flow velocity inside the cell, U_{cco} , is below 30 m/s, increasing the pulsation amplitude is found to reduce the time-averaged conversion efficiency. Conversely, when U_{cco} exceeds 40 m/s, increasing the pulsation amplitude is found to enhance the time-averaged conversion efficiency. In other words, below a certain mean velocity, smaller pulsation amplitudes yield higher conversion efficiency.

Using the exhaust system shown in Figure 2, an investigation was conducted into how the internal geometry of a sub-muffler installed downstream of the catalyst can be modified to suppress standing waves in the exhaust, thereby reducing pulsations at the catalyst and improving conversion efficiency. The flow-velocity pulsation amplitude inside the catalyst was evaluated for different sub-muffler internal designs using one-dimensional simulation software. The results are presented in Figure 3. At the target engine speed of 2400 rpm, a case without a sub-muffler exhibits a peak in flow velocity due to longitudinal acoustic resonance of the exhaust system; this peak is reduced when an expansion chamber or a resonator is incorporated in the sub-muffler. Specifically, the pulsation amplitude decreases from 5.4 m/s (expansion structure) to 4.3 m/s (resonator structure), a reduction of 1.1 m/s. Using these pulsation amplitudes, the cycle-averaged conversion efficiency for the entire catalyst, $\bar{\eta}_{cyc}$, was calculated. The results are shown in Figure 4. After the sub-muffler was altered to reduce pulsations, an increase in conversion efficiency from 95.6% to 95.8% was observed, corresponding to a 0.2% improvement.

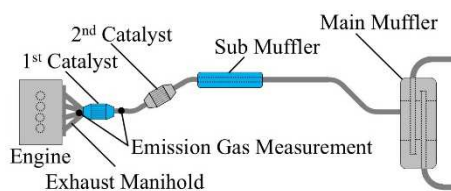


Fig.2 Test exhaust system

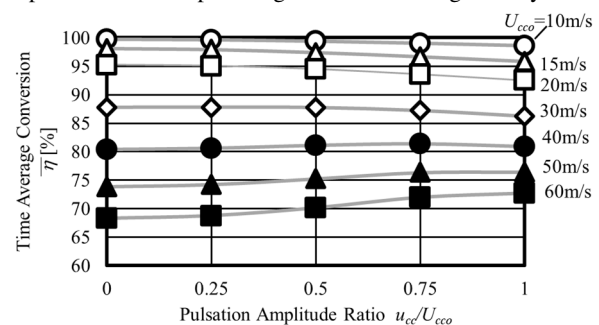


Fig.1 Effect of pulsation amplitude within a single channel on the Time-Averaged conversion

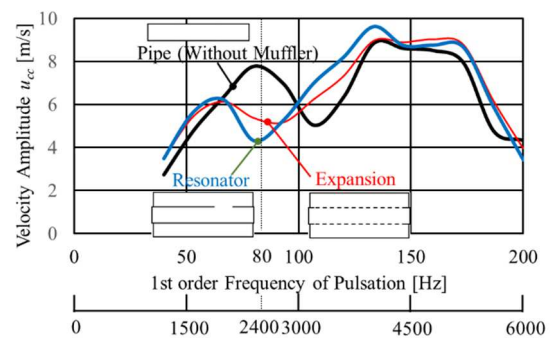


Fig.3 Velocity amplitude within a catalyst channel

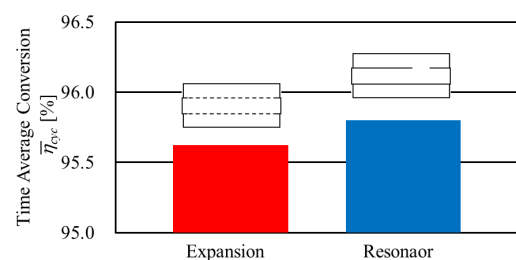


Fig.4 Conversion increase by sub muffler (2400rpm)