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A pollution monitoring method for dilution tunnels toward low-concentration PM regulations

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Tightening vehicle exhaust regulations are driving particulate matter (PM) emissions toward extremely low levels. In particular, the U.S. EPA's upcoming Tier 4 standards are expected to require PM emission rates as low as 0.5 mg/mile for light-duty vehicles, placing stronger demands on measurement reliability in the low-concentration regime. Under such conditions, in full-flow dilution tunnel testing, not only vehicle-derived PM but also background PM (BG-PM) originating from dilution air and tunnel residues can contribute substantially to the measured result, becoming a major source of test uncertainty. Therefore, a practical operational method is needed to rapidly assess tunnel contamination before and during testing and to detect abnormalities early. However, while gravimetric filter weighing is the reference method, it requires time-consuming weighing procedures, and in the low-mass regime it tends to show increased relative variability due to handling-related effects.

In this study, without intending to replace gravimetric filter weighing, we investigated a method to support rapid operational monitoring of dilution-tunnel BG-PM by simultaneously acquiring a beta-attenuation mass indicator and an optical darkening indicator derived from images of the filter collection surface at the same collection spot. In the image-based method, darkening caused by reduced filter-surface reflectance due to particle deposition is utilized, and Luminance (a relative darkening index based on image pixel values) is calculated from the difference between images taken before and after sampling.

Using gravimetric filter weighing as the reference, we evaluated whether the proposed indicators follow PM level changes in the same direction. As a result, high consistency was obtained between the image indicator (Luminance) and filter PM (mg/mile) (R^2 = 0.979 in this study), demonstrating the feasibility of using the image indicator for BG-PM monitoring. The near-zero resolution (1σ equivalent), defined as the standard deviation of four blank points converted to mg/mile equivalent using the regression sensitivity, was approximately 0.015 mg/mile for the image indicator and 0.14 mg/mile for the beta indicator, indicating that the image indicator is advantageous for detecting small BG-PM fluctuations. In addition, 30-min interval continuous data including no-test periods suggested that baseline variation can be characterized and that the presence or absence of test events can be identified. Because the beta indicator may include negative values near zero, operational management based on deviations from a baseline updated during nighttime no-test windows is preferable to absolute thresholding.

Overall, the proposed method showed the potential to serve as an effective complementary tool to gravimetric filter weighing for operational monitoring and early abnormality detection of dilution-tunnel contamination.

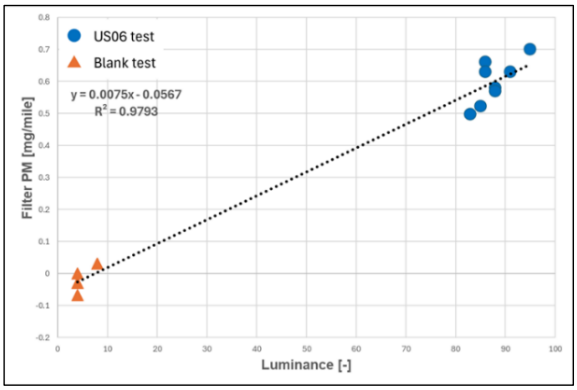

Fig.1 Correlation results between Luminance and Filter Mass

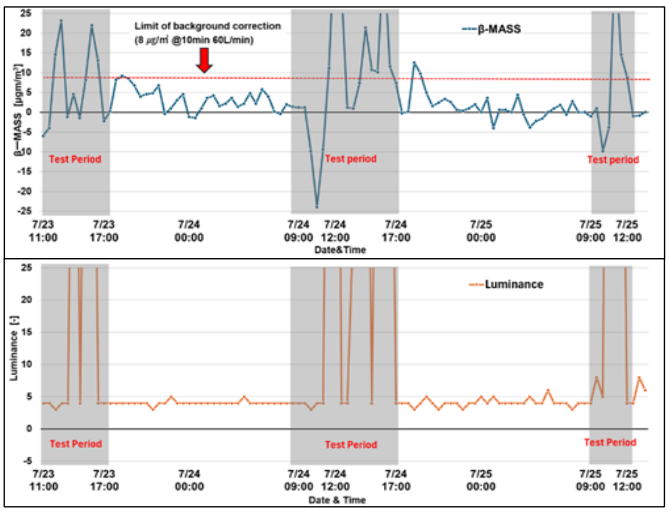

Fig.2 Continuous data of β-mass and Luminance