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Quantification of Uncertainty and Techniques for Improving Filter Mass Measurements

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ABSTRACT

The 2007 Diesel particulate matter (DPM) standard of 0.01 g/bhp-hr represents a 90% reduction of the previous standard and corresponds to roughly 100 micrograms (µg) gained on the filter sample used to determine compliance. The factors that influence the accuracy and precision by which this filter can be weighed are analyzed and quantified. These factors include weigh room environmental conditions, buoyancy, balance performance (resolution, precision, linearity, drift), off-center loading, drafts, electrostatic charge, and filter handling. Manual and automated filter weight schemes are compared and we show where large reductions in uncertainty are possible. Our analysis considers both filter types allowed for US DPM measurements: ringless glass fiber filters and PMP (polymethylpentene) or PFA (perfluoroalkoxy) ringed filters. To put the estimated errors into perspective, we compare the uncertainty contribution of filter mass error and flowrate measurement error with respect to determining compliance with the 2007 brake-specific (BS) PM standard.

We find that gravimetric measurements made on collected particulate samples at the 0.1 µg or even 1.0 µg level of sensitivity are complex measurements that have numerous sources of potential errors. With care and consideration of the environmental conditions, weighing processes and balance performance, electrostatic charges, and the intricacies of various filter medias, measurement uncertainties in the ±3 to ±10 µg (k=2, 95% confidence) range can be accomplished with manual weighing techniques. With automated weighing techniques measurement uncertainties can be reduced to ±1 µg (k=2, 95% confidence). In particular, care must be taken to reduce electrostatic charge induced forces and filter erosion, both of which can contribute errors greater than 10x these uncertainty levels. These uncertainties are used to compute the total uncertainty of the brake specific DPM emission calculation. This uncertainty also depends on flowrate uncertainty, face velocity, and secondary dilution ratio. For a typical case, the total fractional uncertainty is in the range of ~5 – 70% at 10% of the standard and ~1 – 10% at 90% of the standard.

The appropriateness of any measurement must be considered with respect to its uncertainty and the required quantity of interest. In the case at hand, this can be viewed as the fractional uncertainty contribution with respect to the BSPM standard. In typical measurement systems, a ratio of 1:20 is considered comfortable. If the optimum uncertainty is achieved at ±1 µg, the 1:20 ratio can be maintained while testing engines emitting at 10% of the BSPM standard for a dilution ratio of 2. The lowest measureable BSPM limit increases at higher dilution ratios due to the increased flowrate measurement error. Hence, the gravimetric method is useful in measuring the current metric (DPM – the mass collected on the filter) in even the most stringent cases. This comfortable ratio can, and probably will, be eroded as more stringent standards are required in the future and yet future advancements may need to be made.