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Technical note

Accelerated durability test of a condensation particle counter with high particle loading

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ABSTRACT

We investigated changes in particle detection performance of a condensation particle counter (CPC) for automobile exhausts (model 3790, TSI Inc.) during an accelerated durability test with high particle loading. The CPC was exposed to carbon particles for over 100 h with a mode diameter of 80 nm at a number concentration of 10^6 cm^{-3}, i.e., 100 times more than the maximum of the designed concentration range of the CPC specified by the manufacturer. This was equivalent to exposure at the designed maximum concentration (i.e., 10^4 cm^{-3}) for five years. The detection efficiencies of the CPC evaluated regularly at 23, 41, and 55 nm during the test remained unchanged, which indicated that the particle loading was less than the level at which the performance of the CPC would be degraded by contamination of the interior of the CPC. Based on this observation, it was concluded that the changes in the detection performance of our customers' CPCs, which we observed occasionally during annual maintenance and recalibration, were due to causes other than particle loading within the designed concentration range. The unchanged detection efficiencies in our test of exposure equivalent to five years suggest that yearly calibration should be sufficient for maintaining the measurement accuracy of a CPC if it is operated under normal conditions.

1. Introduction

A condensation particle counter (CPC) is an instrument that can measure the number concentration of aerosol particles with diameters ranging from a few nanometers to a few micrometers. CPC can measure with high accuracy and time resolution using condensational growth and light scattering detection techniques. This capability was recognized in Europe, where a decision was made to adopt the number concentration measurement method in which a CPC is used to regulate automobile particle emissions (UN/ECE, 2008).

The automobile particle emissions regulation in Europe, which came into effect in 2011, requires that CPCs used for regulation purposes be calibrated at least once a year. Tokyo Dylec Corporation, Japan, provides maintenance and calibration services in Japan for CPCs manufactured by TSI Incorporated. Since the launch of the calibration service in 2009, most of the calibrations performed have been on CPCs for regulating automobile exhaust emissions.

In Europe, detection efficiency of CPCs for regulating automobile emissions must be within the range of 50 ± 12% and greater than 90% for particle diameters of 23 and 41 nm, respectively. While these requirements appear to be quite broad

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and easy to meet, CPCs meet both requirements simultaneously only with small margins. That is, after tuning the settings of a CPC, the detection efficiency at 41 nm is close to 90%, which is the lower limit for that size, while the efficiency at 23 nm is close to 62%, which is the upper limit for that size. This means that a small drift in CPC performance may result in one of the detection efficiencies being out of tolerance, and this may happen within one year after the last calibration. While there have been a few studies on the detection efficiency of CPCs used to regulate automotive particle emissions, such as Giechaskiel et al. (2009) and Wang et al. (2010), there is limited knowledge on drifts in CPC performance over time, and such knowledge is needed to determine the appropriate interval of calibration. Furthermore, factors that may cause changes in detection efficiency are not well understood. The only investigation to date on performance drifts over time is a study by Giechaskiel & Bergmann (2011), in which they investigated performance changes of 14 CPCs for regulating automobile emissions. The CPC units had various histories and usage conditions, and the study included both brand new units and units that had not been calibrated for 1.5 or 2.5 years. Soot particles after heat treatment were used as calibration particles. Giechaskiel and Bergmann reported several observations of a reduction in detection efficiency. The reason for the reduced efficiencies was considered to be either a decrease in flow rate, which was caused by partial blocking of flow-controlling orifice, or contamination of saturator wick, which may have occurred while the CPCs were sampling particles from automobiles. It is, however, not possible to draw a clear conclusion from the above-mentioned study as to whether these factors really caused changes in detection efficiency because there were no detailed usage records of the CPCs.

In this paper, we report the results of our study in which a CPC was exposed to particles at an excessively high concentration for a short period of time while detection efficiencies were measured at planned intervals. An engine exhaust condensation particle counter model 3790, manufactured by TSI Incorporated, was used for this test.

2. Experimental methods

2.1. Accelerated durability test

A flow diagram for the test is shown in Fig. 1. A carbon particle generator, model GFG-1000, manufactured by Palas GmbH (Germany), was used to generate particles for the test. The flow rate of the carrier gas (argon) of the generator was set at 6 L min^{-1}. The spark frequency of the generator was set at its maximum in order to obtain the largest particles that the generator was able to produce, i.e., particles with a mode diameter of ~55 nm. The particles from the generator were then passed through a 0.7-m-long tube to increase their size by coagulation, which resulted in a mode diameter of about 80 nm (Fig. 2), which is approximately equivalent to the size of the accumulation mode particles emitted by automobiles. The particle sizes were measured with a scanning mobility particle sizer (SMPS, TSI Inc., USA). The particles were then diluted using a rotating disc diluter (model MD19-2E, Matter Aerosol, Switzerland) and delivered to the 3790 CPC for the test. The dilution was adjusted to ensure that the number concentration at the inlet of the test CPC was about 10^6 cm^{-3}, which was checked with a monitoring CPC that sampled the particles downstream of another diluter. The concentration of 10^6 cm^{-3} enabled the durability test to be accelerated by a factor of 10^2, assuming that the CPC is normally used at a concentration of ~10^4 cm^{-3}. For example, exposure at 10^4 cm^{-3} for five years, which we assumed to be 10,560 h (i.e., 8 h per day × 22 days per month × 12 months per year × 5 years), would be equivalent to exposure for 105.6 h at 10^6 cm^{-3}. Calibration of detection efficiencies was made at periods that were equivalent to 0.25, 0.5, 1, 2, 3, and 5 years during the course of the test. No adjustments were performed on the CPC during the experiment period.

Throughout the study, the environmental temperature and relative humidity were maintained at about 22–25 °C and about 40–65%, respectively.

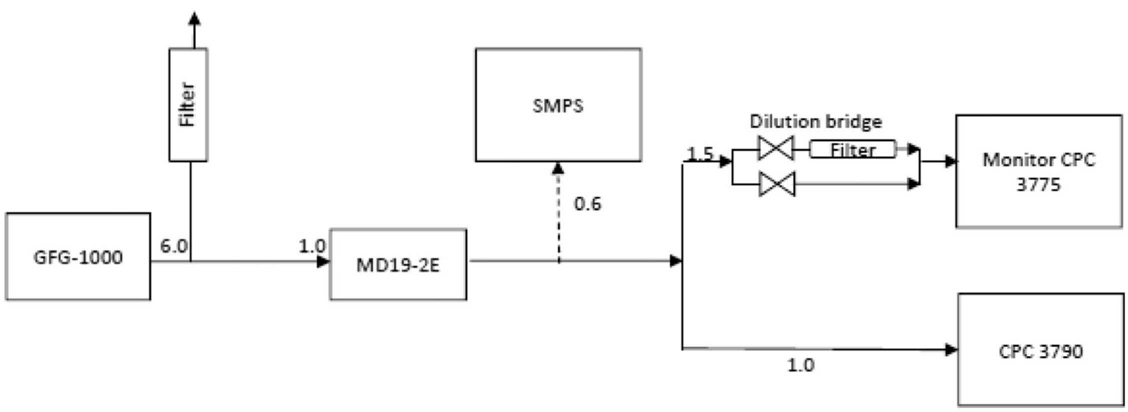

Fig. 1. Schematic diagram of the experimental setup for the accerelated durability test. The numbers indicate flow rates in L min^{-1}.