Redesign of a Thermodesorber and Assessment of its Performance

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Abstract
This report describes the development, construction and application of a thermodesorber (TD). Such an instrument enables near real-time measurements of total volatile and non-volatile particle concentrations in engine exhausts by conditioning emission samples in the ultrapure particle regime. The TD is designed to strip-off the volatile and semi-volatile fraction (short-chain hydrocarbons) attached to the surface of particles by thermal desorption (Abdul-Khalek & Kittelson, 1995). In general, a TD is suitable for use with instruments such as SMPS (Scanning Mobility Particle Sizer) and is essential for the determination of dry and wet aerosol fractions originating from such combustion processes.

Methods
The development and application of the QUT-TD is based on the concept proposed by Wehner et al. (2002). This redesigned instrument (fig. 1 & 2), includes easy parameter control, better accessibility to key elements of the instrument, a direct heating system based on a galvanically separated AC-power unit, and the direct detection of the aerosol (gas) temperature. These features keep the temperature gradient stable and, at the same time, prevent unexpected sample transformations within the desorber stage (due to uncontrollable condensation and nucleation under supersaturated conditions). The QUT-TD was then tested and compared under laboratory conditions with the commercially available TSI-TD (TSI Model 3065 – see figure 3, left instrument).

Results
Even with a preset heater temperature of 400°C, the design of the TSI-TD’s heater stage makes it very difficult to keep the gas temperature at the junction of the desorber/adsorter stage above the required threshold temperature of 250°C. Temperature profiles of the TSI-TD revealed that the design of the heater stage favours temperature fluctuations and are most likely due to the different thermal properties of steel and glass, especially at its interface (especially at higher flow rates). Already Wehner et al. (2002) pointed out that the small dimensions of the desorber stage of this instrument, resulting in short residence times, is the main reason for the incomplete desorptive properties. The QUT-TD on the other hand, meets this criterion already with a desorber stage set temperature of 350°C (figure 5).

Conclusion
This study has shown that the aerosol temperature of the TSI-TD (upon entering the desorber stage) hardly reaches the required desorption aerosol temperature of 250°C, resulting in a partial removal of the volatile fraction. Consequently, recondensation of the desorbed volatile fraction onto the die particles must have occurred still within the desorber stage. An increase in flow (1 - 1.5 L/min) may significantly compensate for this short-residence-time effect, allowing a more reproducible “dry” particle size spectrum for the diesel exhaust.

The stripping mechanism is achieved by first heating it to a preset temperature – typically to 250°C (Abdul-Khalek, 1995; Mikkanen, 2001). This will cause the volatile fraction to desorb and evaporate from the solid particle fraction. Then the heated gas and particle load is pushed along into a cooler section where the heated volatile fractions adsorb onto the cooler surface and thus are trapped by the charcoal pellets.

Regarding the stripping efficiency of the wet fraction from the solid fraction both instruments have been tested with a DEHS-NaCl aerosol. Thereby, the TSI-TD with the desorber stage set to 400°C reveals a M-shaped pattern (shown in figure 6). This a strong indicator for the recondensation of the desorbed volatile fraction onto the solid particle fraction while within the desorber stage (Burtscher et al., 2001). In comparison, the QUT-TD managed to reduce a complete peak shift (stripping off the DEHS from the solid fraction) already at temperatures around 350°C (inset of figure 6). For temperatures above 350°C the obtained size distribution after the stripping process of the QUT-TD corresponds to that one when using pure NaCl aerosol only.

The M-shaped pattern in the aerosol concentration observed by the particle size-distribution of the TSI-TD confirmed the limited performance of this instrument (fig. 4). Obviously, there is only a partial shift from the larger to the smaller diameter spectrum, even when the instrument is operated at the maximal desorption temperature of 400°C (diameter shift highlighted as #2 and #2 minus #1 and peak increase as a result of cluster-defragmentation denoted as #3 and #4 in figure 6). On the other hand, the QUT-TD set to 350°C retained a distinct peak shift from the larger heterogeneously nucleated peak to the smaller core having a slightly higher surface area than the desorbed pellet.

References