Improving thermodenuders

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Introduction

Thermodenuders are used to separate the volatile from the solid fraction of an aerosol. The aerosol is first heated, and then the hot gas is passed through a cooled adsorption section containing activated charcoal.

The Problem

At the interface of the heating section to the adsorption section there is a rapid temperature decrease. This leads to large thermophoretic losses, and to recondensation of volatile material on the solid particles: The heat transfer is governed by the diffusion coefficient of the air molecules, while the volatile material removal is governed by the (smaller) diffusion coefficient of the volatile species – therefore, the gas always cools down faster than the volatile material is removed, and recondensation is inevitable, except if the gas temperature was much higher than the boiling point of the volatile species to begin with.

The Improvement

In contrast to previous designs, our new thermodenuder has a heated adsorption section (see Figure 1). With this, we avoid the problems outlined above, and by using multiple heating sections, we gain flexibility in choosing the temperature profile in the instrument. Temperature profiles in thermodenuders are often measured with thermocouples. In our opinion, this method does not lead to reliable results, and therefore we calculated the temperature profile instead. Figure 2 shows the calculated temperature profile in the instrument for different radial locations in the gas stream (calculated with Comsol multiphysics 3.3). It can be shown that the distance necessary for the gas to reach the wall temperature can be estimated by

$$L = \frac{Q}{\pi \cdot D} \quad or \quad L[cm] = 26.5 \cdot Q[lpm]$$

independent of tube diameter. For our thermodenuder with its 10 cm long heating section, this means that it should be operated at flows below ~0.4lpm, otherwise the setpoint temperature is not reached in the gas.

Results

Size resolved loss measurements were conducted for particle sizes from 10 to 100nm. The results are plotted along with the theoretical diffusion losses for a tube of the length of our thermodenuder in Figure 3. The losses are minimal, i.e. they are no larger than the predicted diffusion losses – no other thermodenuder that we know of achieves such low losses.

Figure 4 shows the removal of a DEHS coating from NaCl cores with two different temperature settings. The removal is nearly complete.

Figure 5 shows a practical application of the thermodenuder: Particles from wood combustion were sampled for analysis in the TEM with and without the thermodenuder. Without the thermodenuder, hazy shadows are visible on the TEM image.

Conclusions

Thermodenuders can be improved by heating the adsorption section. This design change leads to lower losses than in previous instruments, avoids recondensation on solid particles, and leads to a well-defined temperature profile in the adsorption section, which makes thermograms more meaningful.

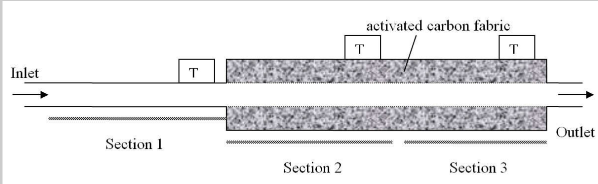

Fig 1: Instrument Setup

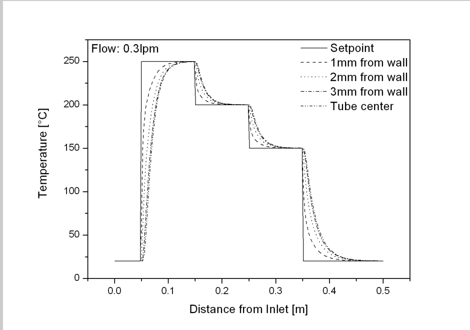

Fig 2: Calculated Temperature Profile

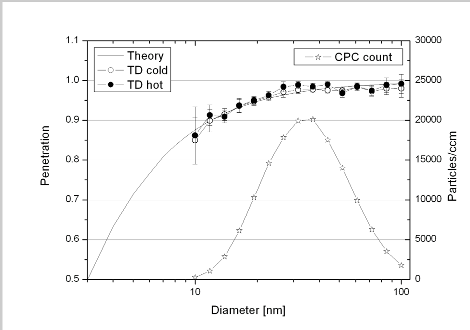

Fig 3: Loss measurements

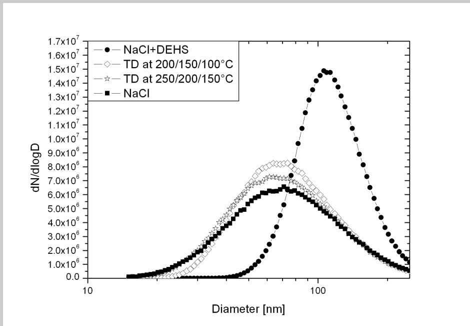

Fig 4: removal of DEHS from NaCl Particles

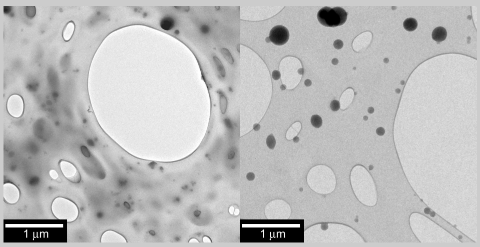

Fig 5: TEM images without (left) and with TD