A simulational and experimental attempt for a high temperature condensed nuclei magnifier based on long chained alkanes

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Introduction Condensation particle counters (CPC) are widely used in science and industry for measuring particle number concentrations. The condensation nuclei magnifier (CNM) is the part of the CPC where the actual particle growth happens. This work deals with an approach for a CNM operating at around 150 - 200 °C (HT-CNM) for engine exhaust.

On one hand this concept prevents formation of artefacts in the aerosol stream caused by dilution and heating and on the other hand the effort of aerosol preconditioning will be minimized. The main application field are defiled aerosols, in particular automotive exhaust gases, but such devices are also of interest for interference-free measurement of aerosols e.g. in highly humid environments.

Experimental Methods Lacking previous data or findings on how to design and operate an HT-CNM, the development started from scratch. The original approach described here is based on a standard “low temperature” CNM geometry in combination with paraffins, i.e. long-chain n-alkanes, as working fluid. Paraffins are non-toxic, thermally highly stable and chemically inert, i.e. they will not react with aerosol or gas components even at high concentrations and/or temperatures. Long chained alkanes proved useful, as they have sufficient vapour pressure at the intended temperatures.

To prove the fundamental feasibility of an HT-CNM, two embodiments were designed, built and characterised: an L-shaped (Fig. 1) and a T-shaped geometry. The two designs allow studying e.g. the influence of strictly laminar (T-type) vs. swirling flow conditions (L-type) and the impact of different (super)-saturation profiles on the activation of the growth on the nuclei. Furthermore testing of different materials and shapes for the gas saturator, including metal foams and porous ceramics was done.

The design was supported by extensive computational fluid dynamics (CFD) simulations of the flow and the (super-)saturation behaviour using Ansys Fluent and OpenFOAM. Both types of the HT-CNM were subsequently realised as functional models in an experimental setup. In order to prove sufficient activation of particle growth for different conditions (e.g. working fluids, temperature gradients) a static light scattering apparatus was realised allowing to characterise the process in detail.

Results The experimental material testing showed the chosen materials to be fully stable for more than 2 months at 250°C. This also applies in particular the chosen working fluid, which showed no signs of deterioration, even when in contact with water/steam. This is a vital difference to other working fluid candidates tested in this study, which decomposed thermally and/or corroded in particular the structural parts made of aluminium.

The detailed CFD simulation of the HT-CNM geometries under consideration provided important insights about the gas (super-)saturation of the studied HT-CNMs and the subsequent growth of droplets around the nm-sized nuclei. Besides aiding the design of the functional demonstrators, this simulation data (Fig. 1 for L-type) indicates very good gas saturation in the saturator and negligible aerosol particle losses due to wall contacts in both geometries. The cut-off size can be adapted by controlling the relative temperatures in the system; Fig. 1 shows a device designed for operation at 10 nm cut-off. This ability to discriminate between differently sized particles was found to be extremely sensitive for the L-type (which provides a low detection limit) and very stable for the T-type.

The functional demonstrators, each of which are easily modifiable, have been realised and tests are ongoing. First experimental results of the main objectives will be shown: 1) established practical feasibility of a functional HT-CNM using the chosen working fluid 2) characterisation of the heterogeneous nucleation for different operating conditions (e.g. flow rates, temperature gradients) 3) validation and optimisation of the CFD model (e.g. binary diffusion coefficients).

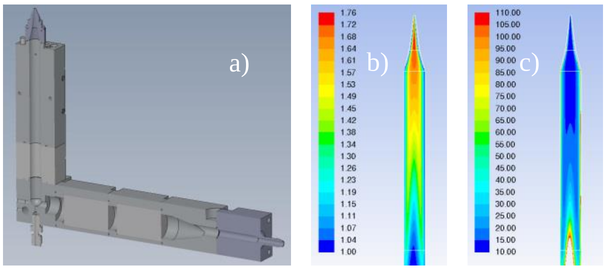

Fig. 1*: L-type CNM; a) Geometry of the L-type CNM; b) relative gas (super-)saturation and c)* d_K *(in nm), as predicted by Ansys Fluent simulations*