# Theory of Operation Nano Enhancer

## Model 3757

Application Note 3757-001 (US)

## Introduction to Condensation Particle Counters (CPC)

The number concentration of particles in an aerosol sample is often measured optically by sending the particles through a laser beam, and detecting the light scattered by each particle. By counting the pulses of scattered light and measuring the sample flow rate, the particle number concentration can be calculated. Particles with diameters on the order of micrometers are easily detected using this method; however, smaller particles scatter less light, making them more difficult to detect.

To measure particles in the nanometer size range, CPCs expose particles to a supersaturated vapor. This vapor condenses on the particles, typically growing them to a size of 1–10 µm where they are easily detected by light scattering.

The liquid used to generate supersaturated vapor within a CPC is known as the working fluid. The Kelvin Diameter, $D_{Kelvin}$, is the theoretical minimum diameter of a particle on which supersaturated vapor will condense. This diameter is dependent on the physical properties of the working fluid as shown in Equation 1, the Kelvin Equation. Equation 1 can be used to calculate $D_{Kelvin}$, where $\delta_S$, $M$, and $\rho_L$, are the surface tension, molecular weight, and density of the working fluid, respectively. $R$ is the universal gas constant, $T$ is the temperature and $S$ is the supersaturation ratio.

$$D_{Kelvin} = \frac{4\delta_S M}{\rho_L RT \log S} \qquad \text{(Equation 1)}$$

$D_{Kelvin}$ is controlled by the properties of the working fluid, as well as the temperature and supersaturation ratio. The supersaturation ratio is defined in Equation 2, where $P_v$ is the partial pressure of the working fluid vapor, and $P_s$ is the saturation pressure, which is a function of the temperature, $T$.

$$S = \frac{P_v}{P_s(T)} \qquad \text{(Equation 2)}$$

For a given working fluid, $D_{Kelvin}$ can be decreased by controlling saturator and condenser temperatures to increase the supersaturation ratio. However; a maximum super saturation ratio exists, above which, new particles will form due to homogeneous nucleation. As a result, $S$ must be kept below this threshold to avoid new particle formation, resulting in a minimum $D_{Kelvin}$.

As particle size increases above the minimum activation size, the fraction of particles on which the working fluid will condense, or the activation efficiency, will also increase. The diameter at which 50% of the particles are activated is defined as the $D_{50}$.

# Diethylene Glycol (DEG) as a Working Fluid

Conventional CPCs use water or butanol as a working fluid. Due to their physical properties, the $D_{50}$ of these CPCs is limited to around 2.5 nm. In an evaluation of other possible working fluids, Iida, et al. identified several potential working fluids that could push the $D_{50}$ to a size below 2 nm. Of the non-hazardous, moderate room temperature viscosity, readily available, and reasonably priced liquids, diethylene glycol (DEG) was shown to be the most practical working fluid (Iida, Stolzenburg and McMurry 2009).

By using DEG as the working fluid in the Model 3757 Nano Enhancer, the $D_{50}$ has been pushed down to 1.4 nm (electrical mobility diameter, 1.1 geometric diameter) as shown in Figure 1. While DEG allows for the activation of particles down to 1 nm, the lower vapor pressure of DEG limits the growth of droplets to less than 100 nm, whereas butanol or water droplets reach several µm in size.

This limit in maximum size for DEG droplets makes it difficult to detect the particle optically; therefore, a conventional CPC must be used on the outlet of the Nano Enhancer to continue the droplet growth to a size where they are easily detected and counted. The schematic of the Nano Enhancer is shown in Figure 2.

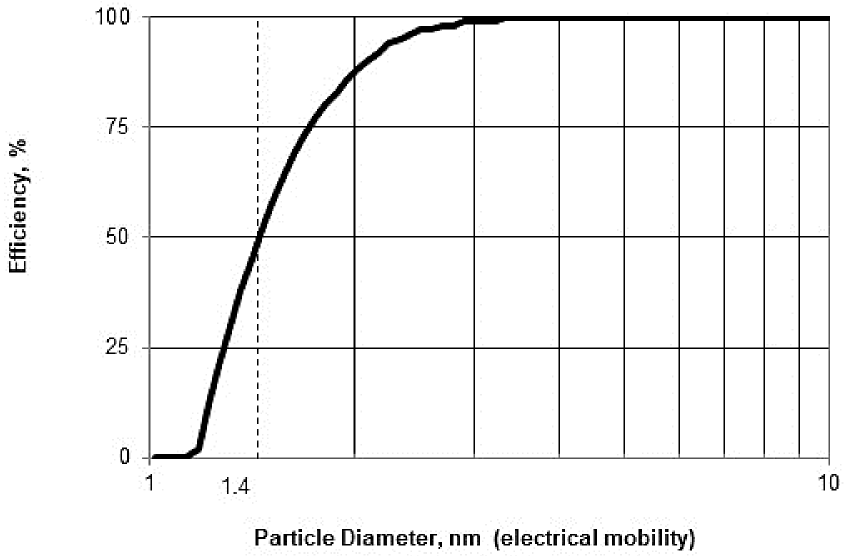

**Figure 1:** Model 3757 Nano Enhancer detection efficiency curve for negatively charged NaCl Particles (paired with 3750 CPC)

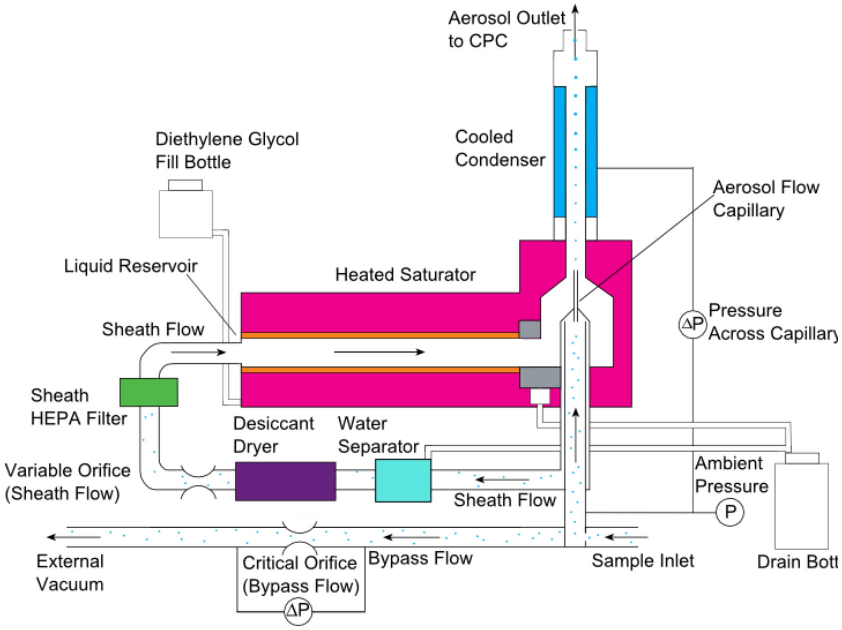

**Figure 2:** Model 3757 Nano Enhancer flow schematic

## 1nm CPC System

Coupling the Model 3757 Nano Enhancer to a conventional CPC creates a 1nm CPC system capable of counting total particle concentration down to 1 nm, as shown in Figure 3.

Additionally, the 1nm CPC system can be combined with a neutralizer, Model 3082 Electrostatic Classifier, and the Model 3086 1nm DMA, creating a Scanning Mobility Particle Sizer™ (SMPS™) spectrometer capable of measuring particle size and concentration from 1 to 50 nm. With the addition of the Model 3081A Long DMA, particle size and concentration can be measured over three decades from 1 nm to 1 µm.

For more information on CPC or SMPS™ technology see application note CPC-003 on www.tsi.com.

For complete specifications on the Model 3757 Nano Enhancer, 1nm DMA, and 1nm SMPS™ system see the 1nm specification sheet on www.tsi.com.

**Figure 3:** 1nm CPC system consisting of a Model 3757 Nano Enhancer coupled to a Model 3750 CPC

## Key References

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