

THEORY OF OPERATION

NANO ENHANCER

MODEL 3777

APPLICATION NOTE 3777-001 (A4)

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 δ_s , M , and ρ_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.

$$D_{\text{Kelvin}} = \frac{4\delta_s M}{\rho_L R T \log S} \quad (\text{Equation 1})$$

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 .

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

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 3777 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.

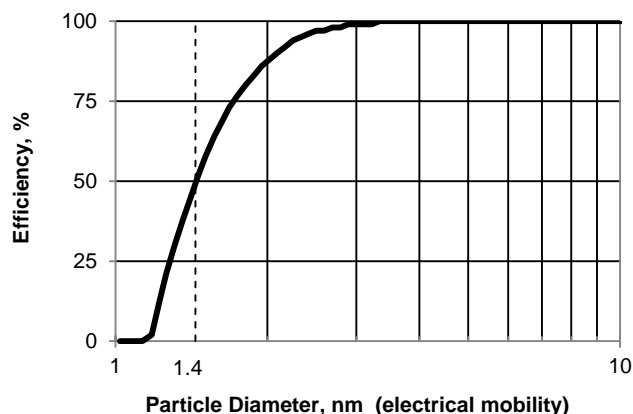


Figure 1: Model 3777 Nano Enhancer detection efficiency curve for negatively charged NaCl Particles (paired with 3772 CPC)

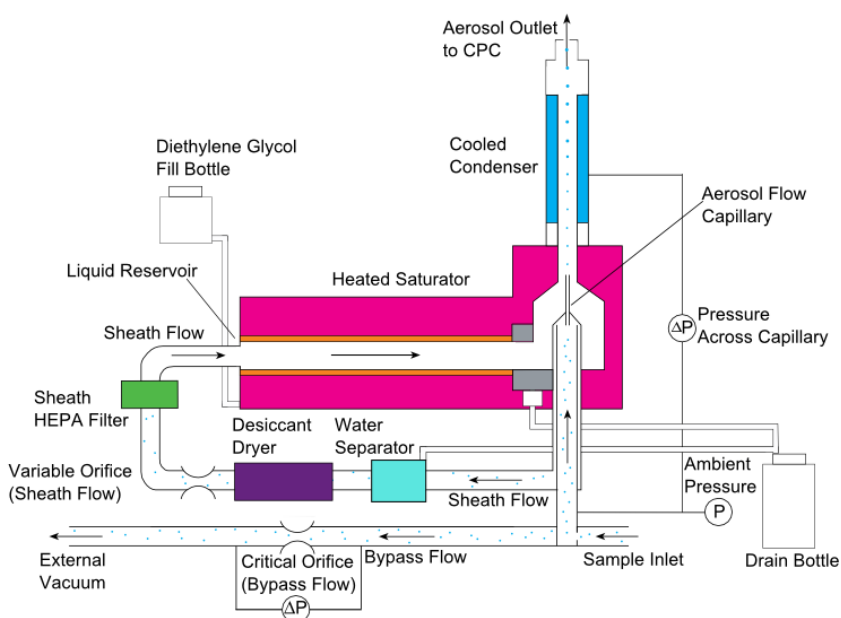


Figure 2: Model 3777 Nano Enhancer flow schematic

1nm CPC System

Coupling the Model 3777 Nano Enhancer to a conventional CPC creates a 1 nm 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 nm 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 μ m.

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

For complete specifications on the Model 3777 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 3777 Nano Enhancer coupled to a Model 3772 CPC

Key References

Iida, K., Stolzenburg, M. R., and McMurry, P. H., 2009, "Effect of Working Fluid on Sub-2 nm Particle Detection with a Laminar Flow Ultrafine Condensation Particle Counter," *Aerosol Science and Technology*, **43(1)**: 81–96

Jiang, J., Chen, M., Kuang, C., Attoui, M., and McMurry, P. H., 2011, "Electrical Mobility Spectrometer Using a Diethylene Glycol Condensation Particle Counter for Measurement of Aerosol Size Distributions Down to 1 nm," *Aerosol Science and Technology*, **45(4)**: 510–521

Jiang, J., Zhao, J., Chen, M., Eisele, F. L., Scheckman, J., Williams, B. J., Kuang, C., and McMurry, P. H., 2011, "First Measurements of Neutral Atmospheric Cluster and 1–2 nm Particle Number Size Distributions During Nucleation Events," *Aerosol Science and Technology*, **45(4)**: ii–v

Wimmer, D., Kreissl, F., Metzger, A., Kurten, A., Curtius, J., Kupc, A., Lehtipalo, K., Riccobono, F., and the CLOUD collaboration (2011) "Performance of an ultrafine Diethylene Glycol (DEG) based Condensation Particle Counter." *European Aerosol Conference*, Manchester, Great Britain, Sept. 4–9, 2011.

Wimmer, D., Lehtipalo, K., Franchin, A., Kangasluoma, J., Kreissl, F., Kurten, A., Kupc, A., Metzger, A., Mikkilä, J., Petaja, T., Riccobono, F., Vanhanen, J., Kulmala, M., and Curtius, J. (2013) "Performance of diethylene glycol based particle counters in the sub 3 nm size range," *Atmospheric Measurement Techniques Discussions*, **6**, 2151–2181.

Zhao, J., Han, H. S., Karn, A., & McMurry, P. H. (2015). "Design Refinements for a 1 nm DEG Ultrafine Condensation Particle Counter (UCPC)". *34th AAAR Annual Conference*, Minneapolis, Minnesota, USA. Paper number 2.IM.21.



UNDERSTANDING, ACCELERATED

TSI Incorporated – Visit our website www.tsi.com for more information.

USA Tel: +1 800 874 2811
UK Tel: +44 149 4 459200
France Tel: +33 1 41 19 21 99
Germany Tel: +49 241 523030

India Tel: +91 80 67877200
China Tel: +86 10 8219 7688
Singapore Tel: +65 6595 6388