Choosing the Right CPC for Your Application

Application Note CPC-002

Condensation Particle Counters (CPCs) enable real-time particle number (PN) concentration measurements of airborne particles down to 2.5 nanometers in diameter. These instruments measure discreetly nearly 100% of the particles in the sample flow, and as a result have a high degree of accuracy. TSI has been designing research quality CPCs for over 30 years, and has the engineering and manufacturing experience to deliver instrumentation which produces data that is accurate, precise and repeatable. The result is a comprehensive line of 10 newly developed state-of-the art CPCs. Each with a unique set of features, to ensure one is available to suit every application.

Table 1: CPC Specification Comparison

	8525	3007	3783	3772	3787	3775	3790	3776	3788
Specifications									
D_{50} Min. Size (nm)	20	10	7	10	5	4	20	2.5	2.5
Max. Concentration (particles/cm^3)	500,000	100,000	1,000,000	10,000	250,000	50,000 $<10^7$*	10,000	300,000	400,000
Concentration Accuracy (%)	N/A	±20	±10	±10	±10	±10 ±20*	±10	±10	±10
Response - T95 (s)	~3	<~3	<3	~3	~0.7	~4	~3	~0.8	~0.25
Sample Flow (LPM)	0.1	0.1	0.12	1.0	0.6	0.3	1.0	0.05	0.3
Total Inlet Flow	0.7	0.7	0.6/1.5	1.0	0.6/1.5	0.3/1.5	1.0	0.3/1.5	0.6/1.5
Flow Source	Internal	Internal	External	External	Internal	Internal	External	Internal	Internal
Working Fluid	Isopropanol	Isopropanol	Water	Butanol	Water	Butanol	Butanol	Butanol	Water
Weight	1.7 kg (3.8 lbs)	1.7 kg (3.8 lbs)	9.9 kg (22 lbs)	5.5 kg (12 lbs)	8.2 kg (18 lbs)	9.9 kg (22 lbs)	5.5 kg (12 lbs)	9.9 kg (22 lbs)	8.2 kg (18 lbs)
Display	Digital LCD	Digital LCD	Touch w/graph	Digital LCD	Touch w/graph	LCD w/graph	Digital LCD	LCD w/graph	Touch w/graph
Data Logging/ Storage	On-board	On-board	Flash drive	N/A	Flash drive	Memory Card	N/A	Memory Card	Flash drive
SMPS Compatibility	No	No	No	Yes	Yes	Yes	No	Yes	Yes
Price	$	$	$$	$$	$$	$$$	$$$$	$$$$	$$$$

* Above 50,000 particles/cm^3 the 3775 uses photometric mode which has concentration accuracy of ±20%

Condensation Particle Counter Theory

In a condensation particle counter, particles that are too small to scatter enough light to be detected by conventional optics are grown to a larger size by condensation. A vapor, which is produced by the instrument's "working fluid" is condensed onto the particles to make them larger. After achieving condensational growth, CPCs function similar to optical particle counters in that the individual droplets then pass through the focal point of a laser beam, producing a flash of light. Each light flash is counted as one particle. The science of condensation particle counters, and the complexity of the instrumentation, lies with the technique to condense vapor onto the particles. When the vapor surrounding the particles reaches a specific degree of supersaturation, the vapor begins to condense on the particles. The magnitude of supersaturation determines the minimum detectable particle of the CPC. In an ideal CPC, the supersaturation profile within the instrument is tightly controlled.

Continuous Flow CPCs

While there are several methods which can be used to create condensational growth, the most widely used technique is a continuous, laminar flow method. Continuous flow laminar CPCs have more precise temperature control than other types of CPCs, and they have fewer particle losses than instruments which use turbulent (mixing) flow. In a laminar flow CPC, a sample is drawn continuously through a conditioner region which is saturated with vapor and the sample is brought to thermal equilibrium. Next, the sample is pulled into a region where condensation occurs. In an alcohol based CPC (isopropanol or butanol), the conditioner region is at a warm temperature, and the condensation region (saturator) is cooler. Water has very high vapor diffusivity, so a laminar flow water-based CPC with a cool condensation region does not work thermodynamically. In a laminar flow water-based condensation particle counter (WCPC), the conditioner region is cool, and the condensation region is hot (growth tube). The condensational growth mechanism in a WCPC is similar to the situation which occurs when your glasses fog over when coming inside on a cold day.

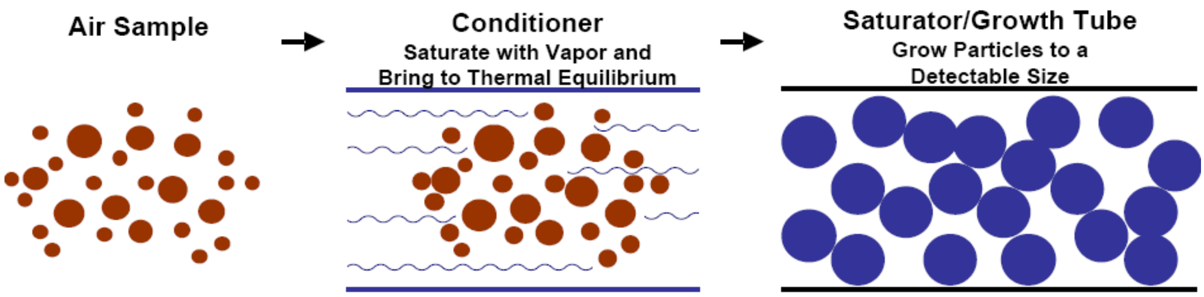

Figure 1: Continuous, laminar flow condensation particle counter (CPC) operation.

Condensation Particle Counter (CPC) Selection Criteria

There are several primary variables that should be considered when selecting the optimum CPC for various applications.

1. **Working Fluid**—TSI is unique in that we offer a choice in the working fluid used to create the condensational particle growth needed to detect the smallest nanoparticles. Some applications may require the use of one working fluid over the others, while the working fluid may not be a deciding factor for other applications.

   - **Isopropy alcohol (isopropanol)** is used in the Models 8525 P-TRAK® counter and 3007 Handheld CPC. Isopropanol (rubbing alcohol) provides excellent condensational growth, is easy to procure and is a relatively benign chemical. This is a convenient working fluid for hand-held instruments designed primarily for point source identification. Laminar flow CPCs designed to work with alcohols do not function when water is used as the working fluid. However, water readily diffuses into isopropanol (IPA). If too much water from the atmosphere dissolves into the IPA, the CPC will no longer accurately count particles. Therefore, isopropanol is not a good choice in instruments that are designed to run for long periods of time, or that have large liquid reservoirs.

   - **n-Butyl alcohol (butanol)** is the working fluid that has been used most in the history of commercial CPCs. Butanol is a large molecule that has low vapor diffusivity, so it stays in the vapor stream to provide reliable, repeatable condensation in CPCs. Additionally, water does not as readily diffuse into butanol as it does into isopropanol—making it a better choice for long term applications. Because of these two primary advantages, most of the historical aerosol science data has been taken using butanol CPCs. However, butanol also has a couple of disadvantages. Butanol vapor is a VOC (as is isopropanol alcohol vapor). This can be problematic if other gas analyzers are being used near butanol CPCs, or if human exposure is a concern. Butanol also needs to be procured from a chemical manufacturer, and a supply must be stocked for use in the CPC.

- **Distilled Water (<6ppm) or HPLC Water**—Water-based CPCs have a clear set of advantages. Water is non-toxic, environmentally friendly and easy to procure. Additionally, in the atmosphere, water vapor plays a significant role in the size of atmospheric particles, so in general it seems logical to mimic this occurrence to measure the concentration of sub-micron particles that may play a role in visibility and climate change issues. Water however, also has a few disadvantages. In general, the liquid purity is not as tightly controlled for water as for alcohols purchased from chemical supply houses. The impurities in the water will build up in the wick, and eventually cause the wick material to become ineffective. To counteract this, distilled or HPLC water needs to be used in the WCPCs, and the wicks needs to be replaced after approximately 4 weeks of continuous operation. Additionally, if particles of an extremely pure hydrophobic material (i.e. lab generated oil or other substance) are sampled with a WCPC, the minimum detectable particle diameter of the instrument may be increased. All working fluids have some type of slight 'material effect' to various degrees. In general, naturally occurring aerosols don't pose a counting efficiency problem for either alcohol based (butanol) or water based CPCs.

2. **Minimum Detectable Particle Size**—The minimum detectable particle diameter of a CPC can be described with a detection efficiency curve where the CPC counting efficiency versus a standard is plotted as a function of particle diameter (Figure 2). A steeper curve is generally preferred, so the counting range of the CPC can be more precisely defined. The minimum detectable particle size is commonly defined as the diameter at which 50% of the particles are detected by the counter (D_{50}). Typically, a lower detectable particle size is associated with a more complex instrument. The primary factors affecting the D_{50} are:

- The temperature differential between the conditioner and saturator/growth tube. The higher the temperature differential between the conditioner and saturator/growth tube, the lower the D_{50}.
- The aerosol sample flow scheme: if a sheath flow is used in the CPC, the D_{50} will be lower, and typically steeper.
- The physical design of the CPC engine (conditioner, saturator/growth tube, optics). The dimensions of the condensation region and the sensitivity of the optics & electronics also affect the minimum detectable particle size.

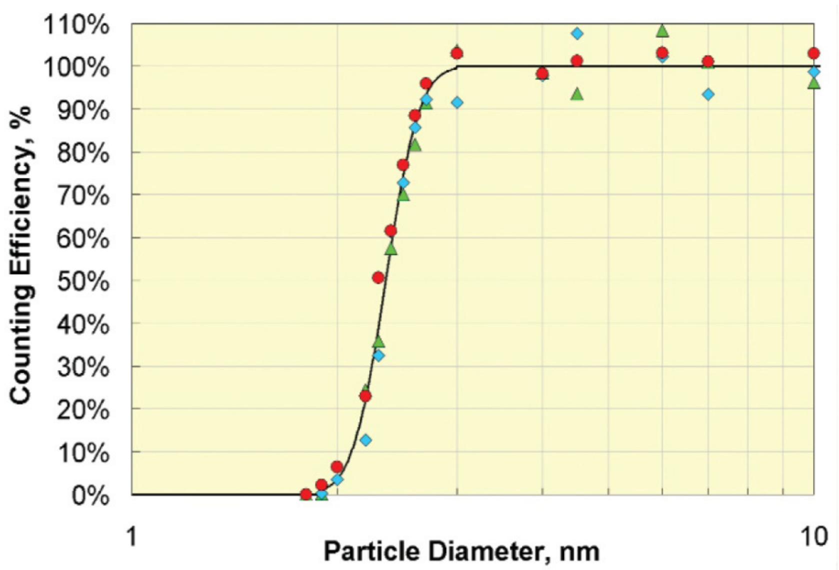

Figure 2: CPC Model 3776 counting efficiency curve using monodisperse sucrose aerosol as the challenge aerosol and an electrometer as the reference detector.

Note: CPCs are designed to effectively count the smallest of nanoparticles. The maximum detectable size of a CPC is generally anywhere from 1 to 3 µm. Particles larger than about 1 micron are very easily lost due to inertial impaction, (nanoparticles are essentially unaffected by this loss mechanism). These supermicron sized particles cannot penetrate through the CPC flow path to the detection region. If a sharp upper size limit is important for you application, it is best to consider using a low pressure drop inlet cyclone on your instrument.

Table 2: Calculated cut-point estimates for two inlet cyclones available from TSI

Inlet Cyclone (CPC) Part Number: 1031588	
Flow Rate (LPM)	**D_{50} cutpoint estimate (μm)**
0.3	5.9
0.6	3.3
1	2.1
1.5	1.5

Inlet Cyclone (3034) Part Number: 1031097	
Flow Rate (LPM)	**D_{50} cutpoint estimate (μm)**
0.3	2.2
0.6	1.2
1	0.8
1.5	0.6

3. **Concentration Range**—TSI CPCs have the widest single particle counting concentration range of any commercially available CPCs. This is achieved primarily by state-of-the-art electronics processing featuring live-time coincidence detection design, and by carefully designed optics which result in high signal to noise ratios. Additionally, in the WCPCs, the condensation region has been optimized to kinetically limit growth—thereby reducing final droplet size variation as a function of concentration. Another consideration regarding the concentration range of CPCs is that in general the sample flow rate has an inverse relationship with the maximum concentration specification. The higher the sample flow rate, the lower the maximum concentration value. Finally, it is important to note that the 3775 uses a photometric mode which enables it to measure particle concentrations up to 10^7 particles/cm^3. This technique is a departure from single particle counting and has been used widely to extend CPC concentration ranges.
4. **Concentration Accuracy**—Concentration accuracy in a single particle counting CPC is determined primarily by the flow control and the detection mode. Optical alignment can also affect concentration accuracy, but the optical alignment in TSI CPCs is very tightly controlled, and does not in general affect concentration accuracy. When the CPC is used in single particle counting mode, the concentration accuracy is primarily based on the flow control accuracy. For most instruments, the flow control will beat the standard ± 10% specification, so concentration accuracy will be less variable. The photometric mode used in the 3775 is fundamentally less accurate than single particle counting, with an accuracy specification of ±20%.
5. **SMPS Compatibility**—Whether or not the CPC can be used as a component of a Scanning Mobility Particle Sizer™ (SMPS™) Spectrometer sizing system is also an important consideration in the selection process of a CPC. The SMPS technique combines a size selecting device called a Differential Mobility Analyzer (DMA) with a CPC and scans the sample aerosol to get a high resolution size distribution in the from 2.5 to 1000 nm.
6. **Sample Flow**—For many applications, the sample flow is a useful selection criterion. Higher sample flow rates result in better counting statistics. It should be considered that sheathed instruments, while fundamentally having a lower sample flow, also have a lower D_{50} and steeper detection efficiency curve. Additionally, as mentioned above, CPCs with lower sample flow rates invariably have higher concentration ranges.
7. **Inlet Flow**—Higher flow rates result in less sampling diffusion losses. In general higher inlet flow rates are beneficial unless the application does not allow for it. Selectable flow rates are useful for SMPS component systems, where the flow rate of the CPC has some effect on the size range of the instrument.
8. **Flow Source**—For some applications, the convenience of an instrument with an internal vacuum pump is attractive. However, for other applications, the robustness of a large external pump may be preferred.
9. **Response Time**—TSI's laminar flow CPCs have extremely fast response times. The new 3788 Nano Water-based CPC (N-WCPC) is the fastest CPC in the world. Faster response times are useful for measuring particle nucleation/formation/transformation events or to measure short lived nanoparticle emission bursts. Fast CPCs also make fast SMPS sizing measurements possible.

The Right CPC for Your Application

The instrument application and desired measurement outcomes will factor largely into the decision of which CPC model to use. In general, some CPCs are more suited to particular applications than others. However, most users have specific practical needs within applications that should be identified and addressed. The best approach is to begin a conversation about your unique application with one of TSI's experienced sales managers. Visit www.tsi.com for more information on how to reach your TSI sales representative.

Table 3: CPC Application Selection Guide

For best results, contact a TSI representative for help with CPC model selection.

	8525	3007	3783	3772	3787	3775	3790	3776	3788
Indoor Air Quality	X	X	X		X				X
Industrial Hygiene	X	X							
Point Source Identification	X	X							
Outdoor Monitoring			X		X	X			X
Particle Nucleation Research								X	X
Combustion/Emission Research						X	X	X	X
Nanotechnology	X	X						X	X
Inhalation Toxicology					X	X		X	X
Instrument Verification/Calibration				X			X		
Filter Testing	X	X		X		X			
Controlled Environment**					X				X
Pressurized Gas Testing*				X	X				
Industrial Applications	X	X	X	X	X				
Basic Aerosol Research					X	X		X	X

**Requires custom pressure diffuser (matched to CPC flow rate), which TSI does not provide.*
***These instruments have moving parts which will likely generate particles—best to operate the CPCs in the equipment bay if possible and sample to the CPC.*

8525 P-Trak® Ultrafine Particle Counter (UPC)

A battery powered, portable instrument which features a convenient telescoping sample probe, the P-Trak counter is often used to locate pollutant point sources.

3007 Handheld Particle Counter

This counter is similar to the P-Trak counter without the sample probe. The 3007 measures down to 10 nm and has a flow control feedback loop for greater concentration accuracy.

3783 Environmental Particle Counter™ (EPC™) Monitor

This water-based CPC was designed specifically for long-term ultra-fine particle monitoring applications. The EPC™ Monitor is rack-mountable, has been tested extensively on outdoor air, and can measure concentrations up to 1,000,000 particles/cm^3 using exclusively single particle counting.

3772 Condensation Particle Counter

A compact, full featured butanol CPC that detects down to 10 nm with an inlet flow of 1 LPM. The 3772 is rugged and proven to be reliable in a variety of applications.

3787 General Purpose Water-based Condensation Particle Counter (GP-WCPC)

A fast, SMPS system compatible water-based CPC that detects down to 5 nm. The GP-WCPC offer a full set of features at an attractive price.

3775 Condensation Particle Counter

A general purposed CPC that detects particles down to 4 nm at concentrations up to 10^7 particles/cm^3. The 3775 is the instrument of choice for high concentration applications.

3790 Engine Exhaust Condensation Particle Counter (EECPC)

The 3790 is used to accurately measure PN concentration of exhaust emissions. The EECPC is fully compliant for light-duty vehicle certification in accordance with UN-ECE Regulation 83, and was used as the benchmark instrument for this regulation.

3776 Ultrafine Condensation Particle Counter (UCPC)

A favorite for researchers investigating the smallest nanoparticles, this state-of-the-art CPC detects particles down to 2.5 nm with single particle counting up to 300,000 particles/cm^3.

3788 Nano Water-based Condensation Particle Counter (N-WCPC)

This cutting edge counter can measure down to 2.5 nm, and is the world's fastest CPC with a response time constant of ~43 milliseconds.

Commonly Used Abbreviations

BCPC	Butanol-based Condensation Particle Counter
CPC	Condensation Particle Counter
DMA	Differential Mobility Analyzer
HPLC	High Performance Liquid Chromatography
IAQ	Indoor Air Quality
IPA	Isopropyl Alcohol (Isopropanol)
LCD	Liquid Crystal Display
LPM	Liter Per Minute
PN	Particle Number
SMPS	Scanning Mobility Particle Sizer™ Spectrometer
WCPC	Water-based Condensation Particle Counter

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