URBAN AIR QUALITY MONITORING: NUMBER- AND MASS-BASED SOLUTIONS FROM TSI

APPLICATION NOTE ENV-002 (A4)
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Contents

What are my options for monitoring ambient air?

The quality of ambient air impacts every member of society, and measuring air quality has been of interest to researchers and citizens alike for decades. As technology has advanced, techniques for measuring particulate pollution have become increasingly sophisticated, providing information that was simply inaccessible in years past.

With numerous measurement techniques available today, it can seem challenging to determine which technique is right for your goals. When considering what technique to choose, an important distinction must be made between mass-based and number-based techniques. While mass-based measurements are generally simpler (and thus have been made for a longer period of time), number-based measurements provide insights that traditional mass-based techniques cannot.

Mass-based measurements

Measurements based on the mass concentration of airborne particles have been made for decades, for two reasons: relative simplicity, and the correlation between high PM concentrations and negative public health outcomes (Heft-Neal et al 2018, Fann et al 2012, Pöschl 2005).

These measurements traditionally have been made by pulling ambient air through a filter to accumulate the airborne particulate matter on the filter, and then measuring the mass change of the filter. In order to collect enough particulate matter to obtain an accurate weight measurement, filter samples span multiple hours (often 24 hours), and sometimes multiple days. This means that one data point is obtained per day, or perhaps only 2-3 samples per week. This method is used widely in air quality monitoring efforts.

When the time-integrated nature of filter-based measurements does not provide enough resolution, a real-time mass-based measurement can be made with the TSI Model 140 QCM-MOUDI. This instrument provides real-time mass measurements, giving PM concentrations in six size channels. As a result, the user gains insight into short-term events that filter-based measurements cannot provide.[1]

Number-based measurements

While mass-based techniques account for all of the particle mass present in the air, number-based techniques are fundamentally different. A more technologically advanced approach, number-based techniques count each particle individually, almost regardless of size. A workhorse technology for number-based techniques is the Condensation Particle Counter, or CPC.

While each model of CPC has a cutpoint size below which it is not sensitive, CPCs will count every particle that enters them, from that cutpoint size all the way up into the super-micron range. Common CPC cutpoints are 2.5, 7, and 10 nm. Since the CPC's counting range covers the vast majority of the ultrafine and fine ranges, nearly all of the particles are counted.

Why use Particle Number as a metric for ambient air monitoring?

A number-based technique is valuable in that fine and ultrafine particles, while having very little mass, can exert an outsize influence on human health due to, among other properties, their ability to cross the blood-brain barrier. This has been observed in rats (Oberdörster et al 2004) and in humans (Maher et al 2016). By paying attention to number concentrations (PN), we can gain valuable insights to the quality of ambient air.

Insight #1: Measuring the influence of source control efforts on ultrafine particle concentrations: the Leipzig LEZ

Background

While ultrafine particles can come from many different sources, it is common for the ultrafine aerosol population in one location to be dominated by relatively few sources – perhaps only a single source. In such instances, instituting control measures on that emissions source can result in significant change in the ultrafine particle concentration. Collecting ultrafine concentration data before and after a control measure is begun can vividly illustrate the impact of the control effort.

One example of this is the designation of the city center of Leipzig, Germany as a Low Emissions zone (LEZ). Initiated in 2011, the LEZ designation required that only low-emission vehicles were allowed on the roads on large portions of the city of Leipzig. Some exceptions were made for public transit vehicles and in cases of social or economic hardship on the part of individual citizens up to and through 2016, but the majority of exceptions expired in 2014.

[1]http://tsi.com/QCM140/

Results

In order to best capture the impact of this new regulation on air quality, measurements of ultrafine particles, black carbon, and NOx from 2010 were used as a benchmark. Figure 1 shows the decrease – relative to the 2010 levels – of each of these pollutants from 2010 through 2016. The data shown in Figure 1 are taken from the original report from the German state of Saxony summarizing the outcome of the LEZ program (Löschau et al 2017).

Particle Number

By 2016, the concentration of particles between 30 – 200 nm had decreased by 74%, a very significant drop. Since vehicle emissions are dominated by ultrafine or near-ultrafine particles, the PN (30-200 nm) measurement is the most appropriate dataset to use when assessing the impact of the LEZ control effort.

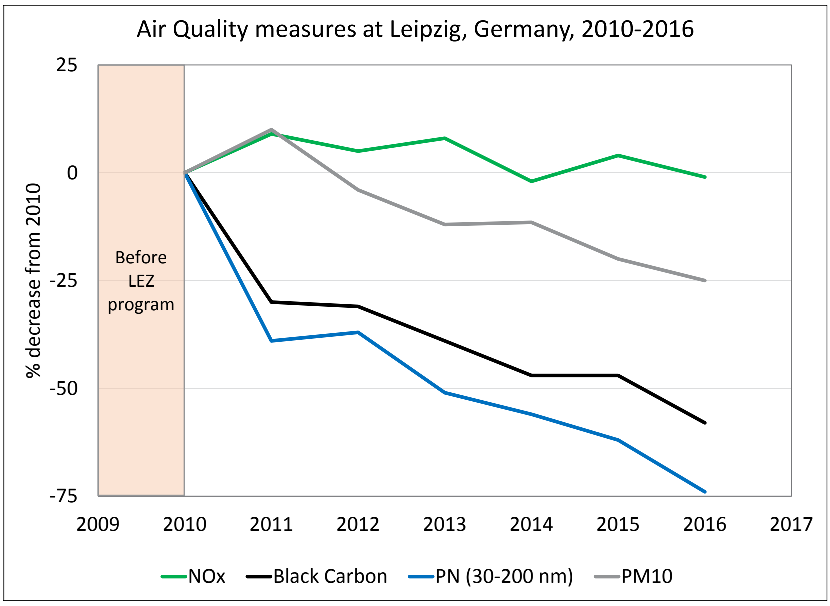

Figure 1: Air quality measures in Leipzig, Germany, as a result of the LEZ program. Relative to measurements conducted in 2010 (the year before the LEZ program started), concentrations of all pollutants but NO_x decreased.

NO_x

The other pollutants measured, however, did not experience such a substantial decrease. Concentrations of NO_x did not decrease appreciably during this period. Given, however, that vehicle manufacturers were frequently using software that manipulated emissions testing results during this time period (Krall & Peng 2015), the lack of change in the NO_x concentration may be attributed to that practice.

Black carbon

The ~60% decrease in black carbon from 2010 to 2016 may be attributed to the modernization of the vehicle fleet entering the restricted zone. Black carbon can also, however, be emitted from other non-exhaust sources such as tire wear.

PM10

As discussed above, PM measurements are dominated by a small number of larger particles. Since vehicle emissions (including diesel) are dominated by ultrafine or near-ultrafine particles, the influence of the LEZ program on PM10 measurements was more modest, showing a ~25% decrease. This modest decrease is evidence that for sources emitting small particles, PM measurements are not an effective tool for monitoring those emissions.

Insight #2: Capturing rapid fluctuations in ultrafine particle concentrations

Ultrafine particles often dominate the particle number count, but due to their small size, they do not appreciably influence the mass concentration. Thus by only looking at mass-based techniques, significant changes in particle number (PN) concentration can be missed.

Figure 2 illustrates the value of number-based measurements by showing data collected simultaneously by a mass-based technique and two number-based techniques. The figure shows data collected at TSI's global headquarters in Shoreview, MN, US, in January 2018. While the CPC and SMPS (middle and bottom plots, respectively) observe significant spikes in number concentration during the period t = 200-300 minutes, there is no significant change in mass concentration observed by the QCM MOUDI (top plot). This is because the particles making up the high number concentrations are ultrafine particles below 100 nm (as shown in the SMPS contour plot), and do not contribute appreciably to the mass concentration.

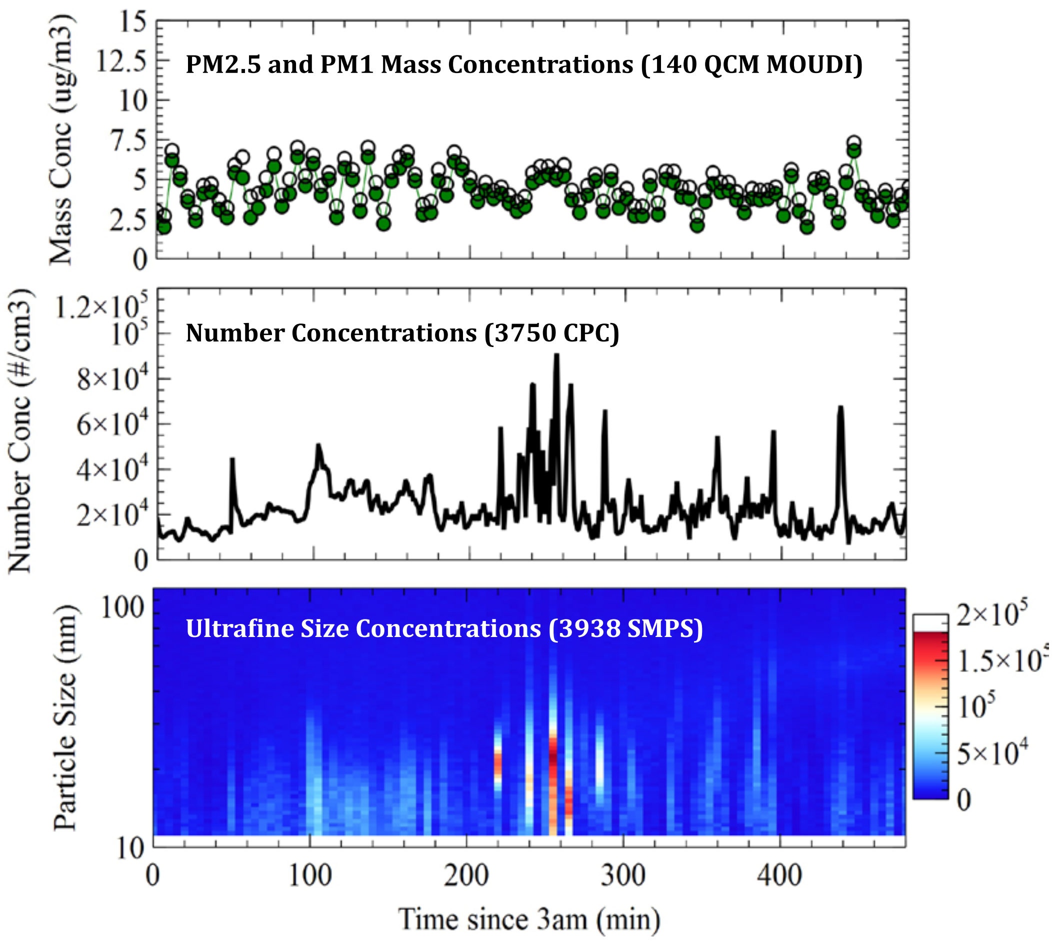

Figure 2: Three TSI instruments measured ambient air for an 8-hour period, 03:00 – 11:00 on 4th January 2018. Top: PM2.5 (open circle) and PM1 (green circle) mass concentration as measured by the Model 140 QCM-MOUDI. Middle: number concentration measurements by the Model 3750 CPC. Bottom: size distribution measurements – shown as a contour plot – by Model 3938N88 SMPS. Spikes in ultrafine particle concentrations can be seen using number-based techniques (i.e. CPC and SMPS), but are missed when using mass-based techniques. This is true even for fast-response mass-based techniques like the QCM-MOUDI.

Is PN a widely used metric?

While regulations around the world have been focused on mass for years, interest in monitoring number concentrations has increased in recent years. The interest is strong enough that multiple countries in Europe have established their own monitoring networks of CPCs. The National Air Pollution Monitoring Network (NABEL) in Switzerland and the German Ultrafine Aerosol Network (GUAN) are but two examples.

Going beyond national-level efforts, ACTRIS is an EU-level data center providing access to concentration measurements of dozens of atmospheric constituents, including particle number concentrations and size distributions. Number concentration datasets originating from five continents can be accessed through ACTRIS at http://actris.nilo.no. A map of available datasets for particle number concentrations is shown in Figure 3.

Figure 3: Map of datasets for particle number concentration measurements obtainable via the ACTRIS network.

The widespread interest in measuring particle number concentrations strongly suggest that while number may not yet be the basis of regulation, researchers around the world – whether in academia, government, or elsewhere – see significant value in PN measurements.

TSI solutions for PN measurements of ambient air Condensation Particle Counters (CPCs)

TSI offers many models of CPCs, any of which can be used with confidence for urban air quality monitoring. These models were either designed specifically for ambient monitoring, or have found very wide acceptance in this application:

3750 / 3750-CEN

Part of our newest generation of butanol-based CPCs, the 3750 is the successor to the very popular 3772. While the 3750 retains the full-flow design of the 3772, it has a lower cutpoint at 7 nm, and a higher upper concentration limit of 1×10^5 $\#/cm^3$. The software used with the 3750 allows the user to connect remotely to up to three CPC units and see number concentration measurements in real time.

As was true for the 3772, the 3750 is also available in a CEN/TS16976-compliant version, the 3750-CEN.

3783

While butanol-based CPCs are a standard presence in urban air quality monitoring, water-based CPCs are advantageous for this application due to having no volatile organic compound (VOC) emissions. The TSI 3783 can be mounted in standard 19” racks. The upper concentration limit is 1×10^6 $\#/cm^3$ and has a 7 nm cutpoint to match the 3750. While earlier versions of the 3750-CEN have been widely used in European CPC networks, the 3783 is more commonly used in the US for long-term monitoring.

SMPS

TSI SMPS systems are component-based, which allows users to mix and match the components that will best suit the application at hand. While some SMPS configurations are widely used in urban air quality monitoring, any configuration will give valuable data.

All modern TSI SMPS model numbers start with 3938. This four-digit model number is followed by a letter (L, N, or E) that signifies which differential mobility analyzer (DMA) is being used; DMA choice plays a large role in determining what sizes of particles can be measured. The digits following the letter indicate which CPC is being used.

3938L50

The 3938L50 SMPS – or L50, for short – is the modern version of an L10 system, which was a mainstay in air quality monitoring for years. The variable settings of this SMPS system enable the user to select a size range that suits their needs best, starting as small as 7 nm or going as large as 900 nm. This SMPS model is the preferred solution for monitoring urban air quality.

3938N56

Switching the CPC and the DMA opens up the possibility of measuring smaller particle sizes. The combination of the Nano DMA (Model 3085A) and the “high-flow mode” of the 3756 enables users to focus on the ultrafine, sub-100 nm fraction, going as small as 2.5 nm. For some urban air quality investigations, this size range is exactly what is needed. For those who want a little more flexibility in the field, an “NL56” system can be used, permitting measurement of both the smaller and the larger particles.

3938E57

For those who want to push their measurements to the limit, the 1 nm SMPS permits measurement of particles down to 1 nm. This system configuration utilizes the model 3086 1 nm DMA, the 3750 CPC discussed above, and the 3757 Nano Enhancer. The purpose of the 3757 Nano Enhancer is to pre-treat the incoming particles so that even the smallest particles – down to 1 nm – can be detected successfully. This opens the door to studying haze, nucleation, and new particle formation, all of which are active and impactful areas of research within atmospheric science.

Sampling inlet

Regardless of which instrument you choose, getting a representative sample to the instrument is critical to gathering high-quality data. It’s important to precede your CPC or SMPS with an appropriate sampling inlet to ensure comparability of results measured across the globe. The sampling system is tasked with removing large particles, reducing humidity, and (optionally) diluting high concentrations.

3772200

Sampling ambient air comes with complications: wind direction, precipitation, humidity, and supermicron particles can affect results when measuring particle number concentrations. In order to establish a standardized sampling method in the context of these complications, the standard CEN/TS 16976 was developed. TSI’s Sampling Inlet 3772200 meets the requirements of this standard and is widely used across the world, both for CPCs and for SMPS systems.

The sampling inlet dries and dilutes the incoming sample, and has < 30% diffusional losses for particles as small as 7 nm. It features a PM10 inlet within the omnidirectional sampling head.

The above instruments can offer significant insight into PN concentrations in a variety of ambient monitoring settings. For assistance in determining which instruments are best suited to your ambient monitoring application, please feel free to contact TSI using the contact information below. Alternatively, you may email particle@tsi.com, or contact your local sales representative.

References

Heft-Neal, S., Burney, J. Bendavid, E., Burke, M. (2018). "Robust relationship between air quality and infant mortality in Africa." *Nature*, 559 (7713): 254-258.

Fann, N., Lamson, A.D., Anenberg, S.C., Wesson, K., Risley, D., Hubbell, B.J. (2012). "Estimating the National Public Health Burden Associated with Exposure to Ambient PM2.5 and Ozone." *Risk Analysis*, 32: 81-95.

Krall, J.R., Peng, R.D. (2015). "The Volkswagen scandal: deception, driving and deaths." *Significance*, December 2015 issue, p12-15.

Löschau, G., Wiedensohler, A., Birmili, W., Rasch, F., Spindler, G., Müller, K., Hausmann, A., Wolf, U. Sommer, W., Anhalt, M., Dietz, V., Herrmann, H. Böhme, U., Kath, H.-G., Kühne, H. (2017). "Immissionssituation von 2010 bis 2016 und Wirkung der Umweltzone auf die straßennahe Luftqualität."

Maher, B.A., Ahmed, I.A.M., Karloukovski, V., MacLaren, D.A., Foulds, P.G., Allsop, D., Mann, D.M.A., Torres-Jardón, R., Calderon-Garciduenas, L. (2016). "Magnetite pollution nanoparticles in the human brain." *Proceedings of the National Academy of Sciences of the United States of America* (PNAS), 113: 10797-10801.

Oberdörster, G., Sharp, Z., Atudorei, V., Elder, A., Gelein, R., Kreyling, W., Cox, C. (2004). "Translocation of Inhaled Ultrafine Particles to the Brain." *Inhalation Toxicology*, 16: 437-445.

Pöschl, U. (2005). "Atmospheric Aerosols: Composition, Transformation, Climate, and Health Effects." *Atmospheric Chemistry*, Angew. Chem. Int. Ed.44: 7520-7540.

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