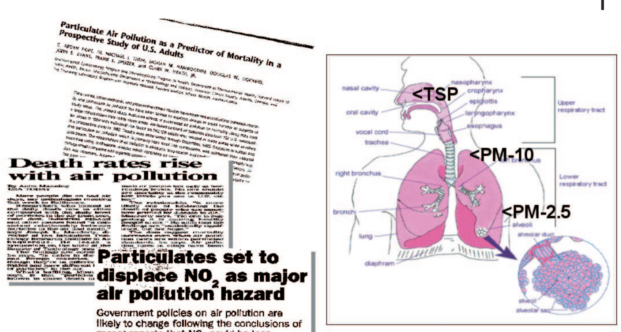
Issues in Airborne Particulate Monitoring

By Jim Mills

What's the Particulate Matter?

Airborne particles have been arguably the most talked about pollutant in recent times displacing such things as ozone, nitrogen dioxide and sulphur dioxide from the "most unwanted" list. This is understandable given the number of scientific studies published in the last few years implicating them to detrimental effects on human health. From the available evidence to date it is believed that they can exacerbate asthma and may cause other respiratory cardiovascular problems in certain vulnerable sections of the population and in the most severe cases can lead to early mortality.



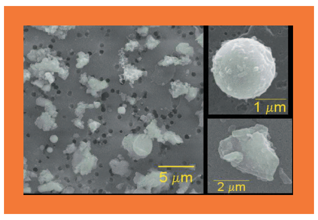
Health Effects of Airborne Particulate Matter

Old particles – New Particles

Today's particles are quite different particles than those responsible for the infamous London Smog's of yesteryear or the soot type particles that caused the grime of the early 1900's which were visibly evident in the air and on our buildings. The particulate matter (PM) in the 2000's is often something you can't see with the naked eye and it's made of quite different stuff than in the past. Due to the introduction of catalysts on petrol cars, cleaner diesel fuels, the introduction of diesel traps, improvements in industrial emission controls together with other measures, particulate levels have certainly fallen sharply over the years. However as the chemical nature of the particles has also changed, they often contain more volatile compounds, are on average smaller and much more complex to define and to measure.

Legislation

So, what is being done to try to control the airborne concentration of particulate matter? There are EC wide and national government controls on particles just as with pollutant gases but unlike gases, particulate matter cannot be defined by a molecular formula as it consists of a wide variety of different chemical compounds. PM can change between gas, liquid and solid phases in the atmosphere, can take up water vapour and adsorb gaseous and vaporous pollutants and can even change shape and size as it travels through the air. This, as you might imagine can make it very difficult to measure and arguably just as difficult to legislate for the control of its presence in the air we breathe.



Electron Microscopy of PM shape and Size

Monitoring Methods

In the 1950's we began measuring airborne PM by collecting onto a filter and either weighing or studying the "blackness" to try to determine concentration. In the last ten years legislation has been brought forward which defines the "worst offenders" as those particles with an average diameter of 10 microns or less (PM10) as these are thought to penetrate the human respiratory system and are most likely to be the cause of many of the health effects. Limit values for PM10 have been established and are usually expressed in micrograms per cubic meter (ug/m3) and monitoring methods have been developed attempting to define true airborne concentration.

Many of these monitoring methods involve pre and post weighing of filters onto which the PM is collected usually over a 24 hour period. This means that the results are often not available for several days after the monitoring has finished and therefore are of limited use in alerting the public to pollution episodes. Even though the European reference method for PM10 requires a minimum of 48 hours conditioning after sampling the commission also require member states to report daily PM10 concentrations to the public on at least a daily basis, clearly an impossibility using the "official" method. This provides a challenge for instrument manufacturers to come up with a way of delivering technology which can produce near - real time information for the public which is accurate, precise and can be used to fulfil the daily reporting requirements of the directive.

Contrasting old and new sampling technology

The Challenge

The problem in designing a monitor to measure airborne PM is, that PM can not be so easily defined as gaseous pollutants and PM's ability to change size and shape from solid to liquid to gas makes it almost impossible to measure true airborne concentration in near real time. However, in the late 1980's a technique born out of the space program in the USA promised the ability to "weigh" particles in real time and in a fundamental manner. The technique involves the relationship of frequency to mass and is based on a fundamental physical principal that when the mass of a body increases the natural frequency of oscillation decreases. This physical law is used to measure the mass of particles landing onto a filter and is able to match the weighing of a filter by gravimetric methods but to do so in near real time. The TEOM (Tapered Element Oscillating Microbalance) system as it is now known has become the most widely used system for determining the concentration of airborne PM across the world and it is used to provide real time data for use by regulatory authorities to better manage particulate airborne pollution However the "morphing" nature of airborne PM continues to present even this remarkable technique with further challenges.

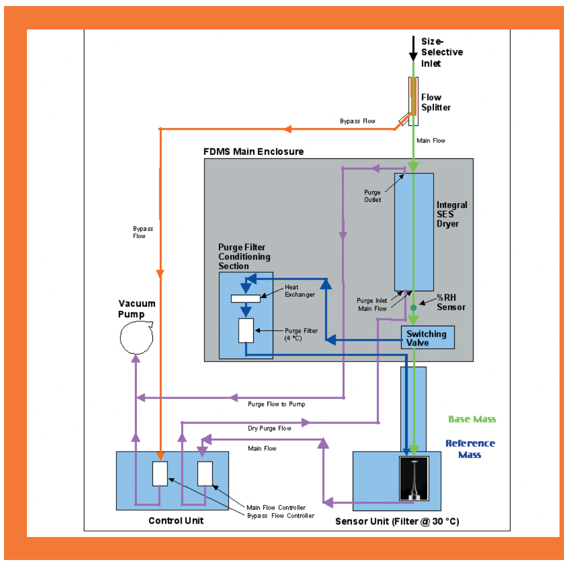
TEOM Mass Transducer

When is a particle not a particle?

What we really want to measure is the true airborne concentration of PM, however what most methods actually measure is the concentration of PM when sampled onto a filter, not necessarily the same thing. Filter based methods include the current EU "reference method" and many of the equivalent methods currently available, including the TEOM system. The problem arises when gases sampled onto the filter pass through PM previously collected and in doing so can adsorb onto the PM causing a mass change. The gases are by definition not PM when they were sampled but can add mass to the filter and collected PM and become part of the mass later determined. Water vapour can also cause a similar problem and under European reference conditions it is known that water vapour passing through the filter and PM during sampling will not all be lost at the post conditioning stage in the laboratory before weighing. This can cause the reference method to significantly over estimate the true airborne mass of PM. These filter based methods can also underestimate airborne PM. Consider that PM can contain semi volatile material and when sampled this can be present as particulate due to low ambient temperatures and / or high relative humidity present at the time of sampling. Some semi volatile materials such as ammonium nitrate or VOC's can subsequently be lost by volatilisation from the filter caused by later temperature increases and / or changes in humidity. The material which when sampled was particulate becomes gaseous and as it is lost from the filter will result in a lower mass measured on the filter.

This can be a real problem when one considers the diurnal variation in temperature and humidity that can occur during each sampling period, usually midnight to midnight.

One could of course take the view that the reference method is "correct" simply because it is the "reference method". However from a scientific stand point we surely must question if the current reference method actually provides a true and accurate representation of PM concentration in the air we breathe, which is of course what we really want to know, isn't it?



TEOM / FDMS Schematic

Correction Factors

Due to the differences observed at many monitoring sites between these different methods, caused mainly by filter artefacts, the European Commission and national governments have suggested applying "correction factors" to data sets produced by automated monitoring methods to bring them into line with the EC "reference method" However recent

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results have shown that these factors can vary site by site, day by day, and even hour by hour. As the nature and source of the PM changes the relationship between the methods also changes and this makes the use of factors less desirable in most cases.

Solving the Problem

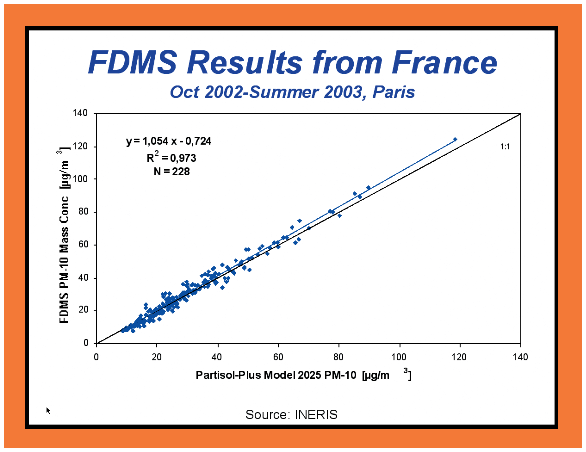
If the problem of measuring the true airborne concentration can compromised by the effects of sampling onto a filter then by measuring these effects and eliminating them from the mass measurement we can calculate the true airborne concentration. This is now achievable by using the high mass resolution and real time response of the TEOM as the basis of a system which can measure the mass of particles collected on the filter and to measure any artefacts caused by adsorption, volatilisation and other effects which might otherwise compromise the measurement. The Filter Dynamics Measurement System (FDMS) is able to make fast sequential measurements of airborne PM mass every few minutes in two distinct cycles. The first cycle measures the mass of particles sampled onto a filter together with any artefacts or interferences caused by chemical or physical "morphing" of the PM. During the second cycle the airborne particles are removed from the sample stream by a special technique which allows only the gases to continue onto the measurement filter of the TEOM. During this second cycle the TEOM measures the mass changes caused by any of the artefact processes and then subtracts these from the previously determined mass providing a measurement of the true airborne mass of PM. This self referencing approach is common to many other analytical techniques but until now it has not been possible to engineer into a PM monitor, however the fundamental measurement of mass and real time response provided by the TEOM system lends itself very well to the self referencing principle.

Filter Dynamics

The FDMS – TEOM system has now been on trial in the USA and Europe for over a year and is now commercially available as a stand alone system or as an update to earlier TEOM systems (those delivered post 1996). Early users of the FDMS systems are discovering its ability to provide both volatile and non volatile PM mass concentrations in near real time and to show excellent agreement with the European reference method for the measurement of PM10. Or at least when the reference method itself does not suffer from "filter dynamics" problems as is widely accepted to be the case when ambient temperatures during and after sampling are close to or above 20°C.

(The temperature at which it has been shown that semi-volatile material is lost in significant quantities from the filter)

The measurement of PM2.5 is also aided by the FDMS where it can be even more beneficial due to the higher levels of volatile materials normally found in the smaller size fraction.



TEOM / FDMS Data vs Reference Sampler Data from Paris, France.

The Future

As we learn more about the nature of PM in our air and we begin to focus on the "prime suspects" within the total PM mix, we will inevitably need to know more about the chemical nature, size distribution and total number of particles in order to identify the correct policies and actions to address the situation and improve air quality. There are now new monitoring tools being developed to assist in this task. Continuous monitors for particulate carbon (organic and elemental), particulate nitrate and sulphate monitors and a host of sampling systems for the more exotic species such as Polyaromatic Hydro-carbons (PAH's) such as benzo-a pyrene (a major suspected carcinogen) are becoming available.

Chemical Speciation Sampler

Like most other technologies in the 21st century particulate monitors and samplers are getting smaller and it is now possible to sample and measure total PM and chemically speciated PM indoors and on individuals. This is an important new field of measurement as most people spend the majority of their day indoors which raises questions about the validity of the information coming from fixed position outdoor sites to determine exposure.

Personal Air Quality Sampler

TEOM / FDMS System

R&P Europe are one of the leading innovators and manufacturers of PM monitoring technologies and together with their network of distributors across Europe will work with you in this challenging field of measurement to help you in the pursuit of the scientific truth and compliance with current practice and legislation.

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