Technologies for Measuring Particulates

Views and Conclusions from the FINE Particles – Technology, Environment and Health Technology Programme
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Part of a series of five reports that cover energy and industry, traffic and transport, measurement technology, indoor air, and health and the environment.

Tekes
The air we breathe exposes us to a growing number of airborne contaminants, including particulate matter invisible to the eye, as a result of ever-growing traffic volumes and ever-higher levels of energy generation, as well as other factors. Fine particulates are known to have major health implications, and result in the premature death of over 300,000 people in the EU annually alone. Advances in technology are allowing us to measure smaller and smaller sizes of particles and gain a better understanding of how they impact health and the environment, however.

The more we learn about the very real harm caused by these types of emissions, the more the benefits of introducing tougher air quality standards become clearer. Typical of the initiatives emerging in this area is the European Commission's Clean Air for Europe (CAFE) programme, the results of which will be used to enhance European air quality from 2010 onwards.

Tekes launched a four-year programme in 2002 known as the FINE Particles – Technology, Environment and Health Technology Programme – together with the Academy of Finland, the Ministry of Transport and Communications, and the Ministry of the Environment – to address some of these challenges. In particular, to generate new research data, leverage the existing broad range of Finnish expertise in fine particles and develop it further, and catalyse business opportunities in the field. The programme’s ultimate goal has been to improve our understanding of the impact emissions of this type have on health and the environment, identify the potential for new technological innovations, and encourage their commercialisation.

The FINE programme involved over 50 individual projects and close to 60 companies and 20 research institutions, and focused on emissions and technology in five main areas: energy and industry, traffic and transport, measurement, indoor air, and health and the environment. A summary report has been produced on each of these areas.

Drawing on the work of 11 projects carried out by teams from research institutions and the corporate sector, this report concentrates on measurement techniques and methods. Most of these projects were R&D projects aimed at generating new technology ideas or enhancing existing instruments, techniques, and services. The FINE projects in this area have made a valuable contribution to advancing our knowledge and technological understanding of measuring fine particulates – and deepening networking between researchers and their colleagues in industry.

The programme resulted in several new products and a body of new information that can be utilised for future innovations, thanks to a thorough examination of the fundamentals of the techniques concerned.

We would like to thank all the researchers and authors that have contributed to the Fine Programme, and whose work has made the publication of this report and the others in the series possible.
The need to measure aerosols has increased dramatically in recent years – mainly because of the undesirable effects they have on our health and the environment, particularly through the role aerosols and fine particulates play in atmospheric processes and climate change, and the fact that we still lack a precise understanding of how they interact with these processes. What is clear, however, is that measuring total particulate mass is insufficient in today’s world.

Legislation requires us to measure particle emissions and ambient and workplace particle concentrations and exposure, to ensure that limits are met and that the public is not exposed to undesirable concentrations of aerosols. Employees also need to be considered, as the number of manufacturing processes where materials pass through an aerosol phase is increasing rapidly, in areas from pigments, powders, and pharmaceuticals to optical fibres. The stringent environments required in manufacturing integrated circuits has also focused attention on the need to reduce contamination from fine particulates, and on how best to monitor particulate levels.

Given the wide variety in terms of the particle size, shape, density, chemical composition, and biological properties of the manufactured and naturally produced aerosols and particles found in ambient and industrial environments, there is no uniform measurement standard or technique available. Systems range from filter collection to sophisticated direct-reading instruments that report particulate levels in real time, including information on size distribution and composition. Most often, however, instruments provide only indirect measurement data.

Some aerosol measurements are already well defined and standardised, such as those related to measuring mass concentrations from emission sources and the ambient atmosphere. Size-resolved number concentration measurements in clean room environments are also well standardised.

To select the most appropriate measurement technique, it is important to establish which characteristics are of most interest, and be able to evaluate the meaning and usefulness of the data that is obtained. This generally means that those involved need to understand both the potential and the possible limitations of the underlying measurement principles employed.

**Particle size and size distribution**

Particle size varies from molecular clusters measuring approximately 1 nanometre to cloud droplets and dust particles measuring around 100 micrometers, five to six orders of magnitude larger. Size is an important particle property, because it largely determines particle behaviour in gas suspension.

Particles at the different ends of the size range behave in completely different ways and are even governed by different physical laws. As there is no single measurement technique capable of handling this range of sizes, the most appropriate method needs to be selected on a case-by-case basis. See Figure 1.

![Figure 1. Instruments used for determining particle size. TOF – time of flight; SEM – scanning electron microscope; TEM – transmission electron microscope.](image-url)

Particle shape is also an issue. Particle diameter is an unambiguous measure of particle size only for spherical liquid droplets; characteristic size, in contrast, is difficult to define for non-spherical particles, such as agglomerates, fibres, and crystals. See Figure 2.

As a result, particle size is usually defined by the chosen measurement method, and particle size given in equiva-
lent diameter, most commonly aerodynamic diameter, mobility equivalent diameter, and optical diameter.

Aerodynamic diameter is useful for characterising particle settling and inertial behaviour, and can be used to describe the behaviour of particles in the human respiratory tract, filters, cyclones, and impactors. The most common instruments used here are impactors and aerodynamic particle sizers.

Mobility equivalent diameter provides information on how particles respond to external forces, and is important when diffusion or electrical forces govern the behaviour of particles. Mobility equivalent diameter is usually measured using electrical mobility analysers, such as differential mobility analysers (DMA; Knutson and Whitby, 1975) and scanning mobility analysers (SMPS; Wang and Flagan, 1990).

Optical diameter, for its part, depends on the interaction of light with particles. In practice, data is reported in terms of an equivalent diameter for particles with the same refractive index as that of the calibration aerosol of the instrument employed.

Aerosols composed of particles of the same size are known as monodisperse aerosols, in contrast to polydisperse aerosols, which represent the majority of cases, where size distribution is the most important physical characteristic. Ideally, where particles are of known origin and material, size distributions can be converted to other quantities or moments. In practice, however, some approximations have to be assumed.

Aerosol concentration

The most commonly used concentrations are number concentration and mass concentration.

Number concentration is expressed as the number of particles per unit volume of air, and is important in many areas, such as atmospheric studies on cloud condensation nuclei, particle formation, and coagulation.

Number concentration is also used in industrial applications, including contamination control in clean rooms, where number concentrations can be very low, in the order of several thousands of particles (diameter larger than 0.1μm) per cubic meter. Classifying, verifying, and monitoring clean rooms is well standardised under the ISO 14644-1 standard and its companion standard, ISO 14644-2 (ISO 1999; ISO 2000).

Mass concentration is used as a standard for atmospheric concentrations and industrial emissions; and is traditionally measured by filtering a known amount of gas and weighing the collected particulate matter.

The current trend in concentration measurement methods is towards real-time instrumentation that can detect variations lost due to averaging in integral methods. Most methods used for number concentration measurements are of the real-time type, while traditional mass concentration measurement methods are of the integrating type, although there are some real-time ones available.

Aerosol composition

It is desirable in many cases to know the composition of an aerosol, to identify if particles contain unwanted or even toxic substances or biological material. Composition can also give an indication of how particles were formed and what processes they have gone through during their lifetime.

Chemical composition

Traditionally, aerosol composition has been determined by chemically analysing collected samples. Sample collection can be carried out using a filter or a cascade impactor.

A wide range of analytical techniques can be applied, including chromatography, fluorescence, Fourier transform infrared (FTIR), particle induced X-ray emission
or filtration, either with impactors (single-stage, cas-

or with similar chemical compositions. Chemical analysis
of integrated samples cannot provide exact information
on individual groups of particles, and various methods
have been developed to overcome this problem.

Individual particle analysis can be made using col-
lected particles or in real time. The methods for collected
samples need to meet two requirements: they must offer
sufficient spatial resolution to differentiate the particles
from the background and sufficient sensitivity to detect
compounds from particles. As the sensitivities required
are of the order of picograms for micrometer-sized par-
ticles, it is extremely difficult to measure the composition
of the smallest individual particles measuring less than
20 nanometres across. In addition to chemical analysis,
microscopy can also be used to determine the shape and
morphology of particles.

Shape and density

The shape of particles affects their motion and surface
area, and often gives some indication on their formation
and history. Particle shape can take the form of simple
spheres or rods that can described in one or two dimen-
sions. More complex shapes are often characterised by
assigning them a fractal dimension.

In most cases, the shape of a particle is determined us-
ing electron (or optical) microscopy. Because this is slow,
shape is usually measured in detail from only a few parti-
ticles and the assumption made that the rest of the aerosol
is similar. Light scattering can also be used. By carefully
controlling particle orientation, size and shape can be de-
termined from the spatial distribution of scattered light.

Particle density and the scaling of density as a func-
tion of particle size provide information on particle
composition and structure. The fractal dimension of
agglomerate particles can be determined from density
measurements. Density can be determined from particle
mass and size, or by connecting mobility measurement
to aerodynamic size classification.

Biological characteristics

A number of bioaerosols are of variable origin, such
as pollen, fungal spores, bacterial cells and spores, vi-
ruses, and residues from living organisms. The size and
concentration of biological particles varies widely, from
nanometres to hundreds of micrometers.

Traditionally, biological aerosols have been studied
by collecting them onto a substrate, such as a culture
medium or adhesive surface, using inertial impaction
or filtration, either with impactors (single-stage, cas-
cade or slit-sampler), liquid impingers, or filter samplers
(e.g. Reponen et al., 2001) – and analysing the resulting
samples, utilising the same principles as employed with
non-biological aerosols. However, the survival of bio-
logical activity has to be taken into account during and
after collection and during sample handling and stor-
age. Some bioaerosols, such as spores and pollen, are
very robust, while others, such as vegetative cells, are
very prone to damage.

Many general particle analysis methods can be used
with bioaerosols, although there are also dedicated meth-
ods available. The type of analysis to be used determines
the appropriate sampling method. Traditional methods
include cultivation analysis and microscopy.

The latter is labour-intensive and requires an experi-
enced microscopist. It also does not distinguish between
living or dead organisms, although some labelled anti-
body stains can be used to select micro-organisms. See
Morris (1995) for more details.

In culture methods, bacteria or fungi are collected
or transferred onto agar plates, where they grow into
colonies that can be visually counted and converted to
units of colony-forming units per cubic metre of air. The
growth medium and conditions have to chosen with the
organisms of interest in mind. A non-selective medium
is most often used for air sampling.

Newer analysis methods, such as biochemical, immu-
nological, and molecular biological assays, can be used
to determine specific biological molecules or target ant-
tigens (Reponen et al., 2001).

Sampling

While measurements can be carried out in situ in some
cases, sampling is often required due to the requirements
associated with the measurement principle being em-
ployed or the nature of the environment and parameters
such as temperature and concentration.

Sampling is a major factor affecting how representative
measurements are, because particle formation, chemical
composition, and size distribution are highly depend-
ent on the conditions surrounding the aerosol. Ideally,
a sampling system should quench all aerosol dynamics
(nucleation, coagulation, and condensation) and chem-
istry to obtain representative data.

Sampling is especially critical in the case of hot gases
containing many compounds that could condense, such
as stack gases or engine emissions. Care must be taken
to design a system to ensure that samples are taken in a
clear and controlled way. An example sampling set-up
is presented in Figure 3.

The two major aspects of sampling systems that need
to be considered are how best to optimise sample col-
lection and/or extraction and how to take account of
sampling losses.

It is good practice to try and achieve both isoaxial
and isokinetic flow through the extraction probe. Both
these requirements usually need to be met to avoid particle loss at the sampling point. As they are related to the inertial and viscous properties of particles and flow, they are considered significant only when sampling particles larger than 1 μm.

Particle loss is known to occur through inertial impaction, thermophoresis, diffusion, and electrostatic deposition on charged surfaces. These processes are understood relatively well and can be minimised in a well-designed sampling system. Losses are rarely uniform, and are typically strongly influenced by particle size, concentration, and environmental factors, such as temperature and pressure.

No single uniform sampling system exists for every application and measurement need. When studying automotive engine operation, for example, it can be advantageous to sample the hot exhaust and try to keep chemical and physical processes to a minimum. When studying emissions from the same source, however, sampling can be taken after the exhaust gases have cooled to atmospheric temperature.

**Dilution**

Diluting a sample lowers the concentration and temperature of an aerosol to enable it to be measured effectively. Depending on the measurement instrumentation, high dilution rates are often required, employing multi-stage dilution. Aerosol dynamics and changes in chemistry need to be quenched rapidly.

Dilution decreases the concentrations of both particles and gaseous components, and can effectively freeze particle size distribution against agglomeration at sufficiently low concentrations. Using colder air to reduce temperature is commonly employed for exhaust aerosol measurements. Mass transfer processes between the gas and aerosol phase can occur as the temperature drops.

Several chemical compounds can exist in both the gas and aerosol phases. Ambient outdoor air and exhaust gases have condensable compounds, such as water, nitric and sulphuric acid, and volatile organics. Dilution can lead to some condensable gas phase compounds entering a supersaturated state, which can then move towards equilibrium by condensation on existing particles or nucleation.

The ratio of these processes depends on the thermodynamic properties of the aerosol and gaseous components in question and on the environment, in terms of temperature, humidity, dilution ratio and rate, concentration of volatile compounds, and the size distribution and concentration of the aerosol. The end-result is usually a combination of different mechanisms.

There are two main approaches to dilution. One is to freeze the processes concerned, as is the practice in various EPA standards for mass concentration measurements, for example. The other aims at mimicking emissions to the atmosphere.

**Application areas**

Research uses a wide range of instruments, from simple monitoring instruments to highly sophisticated complex systems. Many of the instruments used widely today originated as spin-offs from equipment originally
developed in universities or research institutes. See, for example DMA; Knutson and Whitby, 1975 and ELPI; and Keskinen et al., 1992.

Ambient air quality regulations are based on standardised measurement of TSP (Total Suspended Particulate) or different classes of PM (Particle Mass, PM10, PM2.5). In addition to standard measurement equipment, many air quality stations are equipped with additional aerosol instrumentation to measure particle number concentrations, size distribution, and optical properties.

The simplest way to measure indoor air quality is to place a sampling device at a fixed location to provide a representative sample. An integrating sampler will provide an average concentration over the sample time. Alternatively, small, self-contained personal samplers can be used. These give a better estimation of an individual’s exposure than fixed-location samplers.

Both types of samplers are usually of the filter sampler or impactor type. The samples they collect are weighed to obtain aerosol concentrations, and can be further analysed for biological or chemical composition.

Historically, workplace aerosols have been measured using a number of different methods (Walton and Vincent, 1998). Number concentration was the original dominant parameter, and was usually determined using microscopy. Although exposure to fibres is still evaluated in this way, current sampling methods are dominated by mass-based methods, such as filter collection and inertial collection. In most cases, aerosol composition is known as a result of the processes in question. Concentrations can be significantly higher than in normal environments, and measurements are taken to check that exposure is within statutory or other agreed limits.

In the energy sector, aerosol measurements are used to monitor emissions and the performance of emission control systems. Regulations are usually based on particulate mass concentration, using standardised sampling and measurement methods and protocols. Many plants also use additional instrumentation to generate more comprehensive, real-time data.

Aerosol measurements have also become more common in the automotive and marine engine industries in recent years. Emission limits for diesel engines are becoming increasingly strict, and automotive manufacturers need to be able to monitor and quantify emissions both for their final product and during product development. Emissions are currently regulated on the basis of mass, but there are plans to introduce additional regulations based on particle number.

Aerosol measurements play an important role in the pharmaceutical industry and health care. Pharmaceutical aerosols are used in therapies and diagnostics procedures, for example. Exposure control issues are closely related to those linked to industrial hygiene, indoor and outdoor air quality, and radioactive aerosols.

There are many ways to deliver pharmaceutical aerosols, such as pumps, propellant-driven inhalers, dry powder inhalers, and nebulisers, all of which have their separate merits and uses. The most common way to characterise a drug aerosol is to collect samples in a filter or cascade impactor and then analyse the collected material, but this is slow, and industry today also uses optical and electrical methods to measure aerosols, and is looking for even faster and more reliable methods.

Radioactive aerosols are of particular interest to the nuclear industry, which uses both standard measurement methods as well as a number of specialised techniques that take advantage of the unique properties of radioactive materials. Radioactivity can be detected using photographic film or radiation detectors.

The main measurement objectives in this area can grouped into six areas: basic characterisation and toxicological testing, process control, health protection, environmental monitoring, emergency response, and demonstrating compliance (Hoover and Newton, 2001). Basic characterisation and toxicological testing should be performed before the use of radioactive materials is initialised. The list of measured properties is usually extensive: size, concentration, morphology, composition, and solubility. Off-line sampling and real-time monitoring are used to ensure that processes are operating correctly.

Particle contamination is a very common and important problem in the semiconductor and pharmaceutical industries. It is also becoming an issue in other areas, such as precision manufacturing, food manufacturing, and hospitals. Clean rooms or clean areas are becoming increasingly widely used.

Concentrations in these spaces are controlled on a number basis, and instruments used to verify operations need to be able to detect individual particles. Optical particle counters are the most widely used technique in this area. In some cases, sampling techniques and microscopic analysis provide more precise information about particles and their origin.

Commercial quantities of carbon black, fumed silica, titania, other powders, and optical fibres are produced using aerosol processes (Pratsinis et al., 2001). Common physical and chemical properties that are measured include size distribution, microstructure, phase composition, chemical composition, thermophysical and thermochemical properties, and surface properties.

Aerosol measurements are also used in military and security applications. Although numerous techniques have been developed or adapted for detecting biological particles, measuring and characterising these particles accurately, robustly, and in real time remains a challenging problem (Grinshpun and Clark, 2005). In addition to the threat of bioterrorism, the highly publicised outbreaks of diseases, such as SARS, have generated increased interest in investigating the aerosol transmis-
sion of infectious bacteria and viruses and developing new methods. Aerosol-related technologies could also be used to detect explosives and narcotics at airports, for example.

The focus of the FINE Programme

The FINE Programme included a total of 11 projects related to fine particulate measurement and measurement techniques and methods. Of these, six were research projects lead by university or research institutes and five were enterprise projects. See Table 1.

Subjects embraced both modelling and experimental work. Projects included instrument development, emission simulations, developing measurement networks and research services, and fundamental research on measurement techniques. See Figure 4, Figure 5 on Page 14, and Figure 6 on Page 16.

More than half of the projects focused on the development of measurement instruments and techniques, and most of these on new applications for existing instrumentation, such as the use of lidar for aerosol measurements. The possibility of using a triboelectric sensor for new applications was also studied.

Two projects developed new instrumentation for aerosol number concentration measurement and determining aerosol chemical composition; and one a measurement network for measuring urban particulates. Two projects developed single particle analysis modelling and measurement services for companies. Two projects addressed emission sample dilution and extraction. Both were research-oriented and aimed at understanding particle formation in the dilution process.
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<td>Triboelectronic applications, TRIBOS</td>
<td>Sintrol Ltd.</td>
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<td>Fundamental phenomena in particle measurements</td>
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<td>Development of research methods and the research service product</td>
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<td>Numeric modelling of small particles dynamics</td>
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<tr>
<td>Lidar in aerosol research, LATU</td>
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<td>University of Helsinki, Helsinki Metropolitan Area Council (YTV), National Public Health Institute, Ministry of the Environment</td>
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*Table 1. FINE Programme projects on aerosol measurement and measurement techniques.*
Several main trends can be identified in the development of measurement techniques and aerosol instrumentation in recent years. One of these is linked to determining the composition and morphology of individual fine particles. Establishing the chemical properties of particles is becoming increasingly important, above and beyond determining their physical properties, and there are a number of groups in the US, for example, developing real-time aerosol mass spectrometers. Although these instruments are still large and complicated, they are becoming available for a variety of applications.

Another trend is the need to measure number size distribution and concentration, rather than, or in addition to, mass concentration. Several new commercial mobility analysers and condensation particle counters have been introduced in this area. As the focus shifts to nanoparticles, the line between molecules, ions, and aerosol particles is beginning to disappear.

Parallel to the growing need for more sophisticated general-purpose instruments, there is also a requirement for simpler instruments for specialised monitoring purposes offering real-time response, small physical size, and low price.

**Number concentration and size distribution**

Several new commercial condensation particle counters (CPCs) for measuring number concentration have been launched in recent years.

One of these, the Dekati Condensation Particle Counter, produced by Finland’s Dekati Ltd., was studied and developed as part of the FINE Programme. This uses butanol as its working fluid, and detection efficiency is enhanced by employing a swirling flow in the mixing chamber. The unit is capable of measuring particles as small as 5 nanometres at 50% efficiency.

TSI Inc. has introduced several new CPCs, all of which are portable and lightweight, weighing less than 2 kg with batteries. Detection limits vary from 10 to 20 nanometres, with flow rates of approx. 0.1 l/min.

Breaking away from the traditional use of alcohol, usually butanol, as a working fluid, TSI has also introduced units that use water instead. The Model 3781 Water-based Condensation Particle Counter (WCPC), for example, can detect airborne particles down to 6 nm in diameter. Using single particle detection with live-time coincidence correction, the 3781 covers a particle concentration range up to 5×10^5 particles/cm^3. The Model 3786 Ultrafine Water-based Condensation Particle Counter (UWCPC) is designed primarily for researchers, and can detect particles down to 2.5 nm, using a sample flow rate of 0.3 l/min.

Most of the developments in measuring number size distribution have been in mobility analysers. A large amount of research has been produced in this area – Labowsky and de la Mora, 2006; Seol et al., 2002; Flagan 2004; Biskos et al., 2005; Shah and Cocker, 2005; Rosser and de la Mora, 2005 – and several new commercial units have also been introduced by companies such as Ioner and Grimm Aerosol Technik.

The need for faster instruments, preferably with real-time performance, has been pronounced. TSI has introduced two multi-electrode mobility analysers (Engine Exhaust Particle Sampler, EEPS, model 3090 and Fast Mobility Particle Sizer, FMPS, model 3091) employing the same basic principle originally developed in Estonia.

Cambustion Ltd. has introduced the DMS500 fast particulate spectrometer, which offers electrical mobility base size classification and has been designed for measuring engine emissions, employing built-in, two-stage dilution. The unit can measure an aerosol size spectrum from 5nm to 2.5 μm, with a frequency of 10 Hz.

Grimm Aerosol Technik’s Fast Automotive Particle Emission Spectrometer (FAPES) employs a unique particle sizing system, consisting of 10 Differential Mobility Analysers (DMAs) and 10 Faraday Cup Electrometers (FCEs). Each DMA concentrates on a particular size fraction and has a different fixed voltage, enabling 10 different fractions to be classified at the same time (up to 5 Hz), which can then be counted by the FCEs.

A new instrument from MSP Corporation combines a differential mobility analyser with an optical particle sizer. Known as a Wide-range Particle Spectrometer (WPS), this samples aerosol at a rate of 3.3 litres a minute. Three litres/m of this flow is directed through a laser particle counter for sizing and counting (200 nm - 10 μm diameter), while the remainder is directed through an ionizer to establish a Boltzmann equilibrium charge on the particles and fed through a miniature differential mobility system, or Scanning Mobility Spectrometer (SMS). This comprises a miniature high-resolution DMA and CPC to count and size aerosol particles in the 10 nm to 500 nm diameter range. Particles larger that 500 nm are sized using the laser particle counter.

Grimm Aerosol Technik’s Wide Range Aerosol Spectrometer (WRAS) – featuring a SMPS+C (Sequential Mobility Particle Sizer + Condensation Particle Counter) and an Optical Particle Counter (OPC) – is similar.
Measuring aerosol composition

This area of the measurement field has seen a lot of development in recent years, the most important related to single particle mass spectrometry. The advantages of mass spectrometry include high sensitivity, fast response, universal detection, and its ability to be deployed in the field.

Single particles are detected and sized, vaporised, and ionised, and the resulting compounds measured. The size of particles is usually measured using optical scattering or time of flight techniques. It is also possible to classify particles according to their size before passing them to the particle mass spectrometer.

To produce ions that can be detected, particles need to be vaporised and ionised. The simplest way of doing this is with laser desorption and ionisation in a single phase. In some cases, vaporisation is carried out first. The advantage of having separate ionization and vaporisation phases is that it makes mass easier to quantify. All of the spectrometers used in particle analysis are based on electrical forces; no instruments utilising magnetic forces have been employed as of yet.

The most popular method to date has been laser desorption and ionisation, and there are a number of research instruments of this type available, but only one commercial unit, the TSI 3800. The latter is based on the work of Professor Kim Prather and his colleagues at the University of California at San Diego (Gard et al., 1997).

Thermal ionisation is the second most popular ionisation method in use. The most notable of this type of instrument is the Aerodyne Mass Spectrometer (AMS), which was developed by Dr. Douglas Worsnop and his colleagues (e.g. Jayne et al. 2000) and uses electron impact ionization. The unit is commercially available.

Aerosol mass spectrometers could be very useful in a number of application areas, but are hampered by their complicated design, cost, and size. To gain wider acceptance, their price and size needs to be reduced.

For the finest nanoparticles (less than 10 nm), however, single particle analysis will be extremely difficult, and probably even impossible, unless techniques for nanoparticle collection and rapid transfer to a mass spectrometer can be developed.

Particle density and morphology

Particle composition is closely related to particle density. Particle density is not usually measured directly, and is

Figure 5. Power plant emissions were among those studied in the field as part of the FINE Programme, as here at Pyhäsalmi, where measurement equipment was installed temporarily next to the stack. Photograph: Harri Puustinen.
typically determined from the relationship between two or more different particle properties.

Particle effective density can be determined by combining mobility-based measurements, generated by differential mobility analyzers, for example, with aerodynamic size measurements taken with impactors or aerodynamic particle sizers.

De la Mora’s group has used hypersonic impactors, together with differential mobility analyzers, to measure the density of nanometre-sized particles (e.g. Ude and de la Mora, 2003, de la Mora et al. 2003). Ristimäki et al. (2002) have presented an on-line method to measure size distribution and size-dependent effective density from parallel measurements using DMA and ELPI technology. Virtanen et al. (2004) have further refined this method to identify particle effective density and fractal dimension.

Density can be determined from particle mass, if it is known. Aerosol particle mass analyzers (APM; Ehara 1995, Ehara et al., 1996) and Couette centrifugal particle mass analyzers (CPMA; Olfert and Collings, 2005, Olfert, 2005) are capable of measuring single particle mass, and can be used to determine particle density. See McMurry et al. (2002) and Park et al., (2004).

Optical methods can be used to infer information about the density and morphology of particles. Hand and Kredenweis (2002) used the data from an optical particle counter (OPC) and an aerodynamic particle sizer (APS) to determine the refractive index and effective density of particles. Murphy et al. (2004) combined an optical scattering signal and aerodynamic size to deduce the density of particles, and found the deduced densities to be consistent with composition inferred from the mass spectra taken from the particles in question.

A high-precision system for measuring the size, composition, and density of individual spherical particles has been presented by Zelenyuk et al. (2005), using a combination of DMA and single particle mass spectrometer to achieve a density measurement precision of 2.5% for spherical particles.

**Measuring biological properties**

Two developments have spurred interest in developing high-quality methods for biological aerosol detection, quantification, and identification: the increased threat from biological weapons and bioterrorism and the emergence of diseases, such as SARS, that can spread through aerosols. While numerous techniques have already been developed, accurate field-compatible methods are still needed.

Typical of the commercial biosamplers to have been introduced in recent years are InnovaTek’s BioGuardian Air Sampler, which collects particles into 10-15 ml of liquid at a flow rate from 100-1000 l/min; Specter Industries’ SpinCon air sampler, which collects samples into 10 ml of liquid at a flow rate of 450 l/min; and MesoSystems Technology’s BioCapture 650, which uses a flow rate of 200 l/min and 5 ml of liquid. However, these collectors can only operate for a few hours, and cannot detect or identify sampled aerosols.

The Autonomous Pathogen Detection System (APDS, e.g. Mainelis et al., 2005), developed at the Lawrence Livermore National Laboratory, is a continuous, fully autonomous monitoring instrument for multiple airborne threat organisms. The instrument consists of a sample collection system, a fluids module, and sample analysis using immunoassay detection. It has a high sampling flow rate of between 2100-3750 litres a minute, and concentrates collected particles into 4-7 ml of fluid. A fluids module handles the samples and transfers them into a rapid, sensitive immunoassay-based detection system. The system has already been used successfully to detect aerosolised Bacillus anthracis and Yersinia pestis (McBride et al. 2003; Hindson et al. 2005).

UV-fluorescence represents a promising method for detecting and identifying bioaerosols. Fluorescence information in itself is usually insufficient, however, and must be combined with other information related to size and shape before it can be used as a basis for biological aerosol detection. One new method developed by Biral, known as Verotect, combines measurement of the size and shape of particles with fluorescence characterisation. Spectral analysis of fluorescence from aerosol particles has been pioneered by Pinnick and Hill (e.g. Pinnick et al., 1995; Hill et al., 1995).

TSI’s UV-APS (Ultraviolet Aerodynamic Particle Sizer), also known as FLAPS (Fluorescent Aerodynamic Particle Sizer), combines particle sizing (aerodynamic or optical) with the detection of UV-fluorescence. This instrument can measure the particle size and intensity of UV-induced fluorescence from individual particles. Although it cannot be used to identify airborne micro-organisms, it can be very useful in studying the dispersion of bioaerosols, controlling the spread of bacterial diseases, and source identification.

Although recent interest has focused on the detection of threat bioaerosols, the future could see these types of instruments used to detect and identify biological particles in other environments, when monitoring air quality in hospital operating theatres, for example. As most fungal aerosols can cause allergic reactions and diseases, such as asthma, similar instruments could be used to monitor indoor air quality or to detect fungi originating from a building’s air conditioning system or its structure.

**Aerosol charging and charge measurement**

Charging aerosol particles, to measure and remove them, has also been the subject of increased interest,
probably because of the need to study and measure nanoparticles.

Charging particles becomes increasingly difficult as particles get smaller. Unipolar corona charging is one of the most widely used techniques (e.g. Hernandez-Sierra et al., 2003). Seto et al. (2005) and uses a positive helium ion beam to charge nanoparticles. Soft x-rays have been used by several groups (Lee et al., 2005; Hogan et al., 2004); Hogan and his colleagues have also used an electrostatic precipitator to remove charged viral nanoparticles.

Kwon et al. (2005) have developed a novel charger design based on the surface discharge on a dielectric barrier induced by DC pulses, and have used their surface microplasma aerosol charger (SMAC) as a stable bipolar ion source for neutralising particles. Ji et al. (2004) have studied the efficiency of radioactive neutralizers, and found that alpha sources are more resistant than beta ones to variations in flow rates. The efficiency of a beta source neutraliser drops as the flow rate increases. Corona chargers can also be used as neutralisers, and an AC-based neutraliser is described in Stommel and Riebel (2004).

Typical applications use either a radioactive source or high-voltage corona discharge as an ion source. These are neither convenient nor inexpensive, however, and there is still a need for a portable lightweight ion generator for charging and neutralising purposes that is both inexpensive and electrostatically hazard-free (Mazumder et al. 2006).

The net charge of an aerosol can be determined with an aerosol electrometer, and various new instruments have been introduced to measure the electrostatic charge on particles. A charge separator (Mountain and Mazumder, 2001), for example, separates particles with a different polarity of charge. Positive and negative particles are collected on different electrodes, and the accumulated charge measured with electrometers. The charge to mass (Q/M) ratio for positive and negative particles can be determined from the measured charge and the accumulated weight on the plates.

An ESPART analyser, employed in the toner industry for many years, can be used for measuring the charge distribution of particles, by measuring the motion of particles in real-time with Laser Doppler Vellocimetry (LDV).

There is still a need for instruments capable of measuring the charge of aerosol particles, featuring wide size range, the capability to handle nanometre-sized particles, accuracy, and compactness, however.
Optical methods and remote sensing

Traditional in-situ instruments using optical methods to detect and size individual particles are available at low cost. The current focus is on using optical methods for remote sensing to provide better spatial coverage and time resolution.

Absorption of light by aerosol particles is an important phenomenon, and has been studied by several groups recently. The photoacoustic method and cavity ring-down spectroscopy have been introduced. The latter is a very sensitive method that can be used to measure the optical extinction of an aerosol (Pettersson et al. 2004; Thompson et al. 2003; Moosmüller et al., 2005). Using the photoacoustic method, an aerosol is heated by absorbed light, which results in changes in air volume or pressure that can be detected with sensitive microphones in an acoustic resonator (e.g. Arnott et al., 1999; Arnott et al., 2005).

One trend here has been the attempt to differentiate soot and black carbon (BC) from other aerosols using aethalometers (e.g. Fialho et al., 2005; Weingartner et al., 2003; Bond and Bergstrom, 2006).

The use of lidar for aerosol measurements was studied by Vaisala Ltd. and the University of Helsinki as part of the FINE Programme, and has been studied by several other groups as well (e.g. Lagrosas et al., 2004; Lagrosas et al., 2005; Tiwari et al., 2003). Lidar would allow excellent spatial resolution and could be very useful for tracking aerosol variations in the atmosphere.

Monitoring methods

The tapered element microbalance technique (TEOM) has been used to measure mass concentration in real-time for a long time, and several new instrument specifically designed for measuring automotive emissions have emerged in recent years.

These include Dekati’s Dekati Mass Monitor (DMM), which provides second-by-second information not only on particle total mass but also the median diameter of particles. The advantage of mass monitors like this is that the information they generate is comparable with existing data and with emission regulations.

A Booker System-developed instrument, now part of Sensor Inc.’s portfolio, and based on quartz crystal microbalance (QCM) technique, collects particles by electrostatic precipitation and deposits them on an oscillating piezoelectric crystal. The natural oscillation frequency of the crystal is approximately 5 MHz, but this is reduced in proportion to the amount of material deposited on its surface. By measuring shifts in frequency, the mass of the particulate matter can be determined.

Several monitors based on measuring the charge of particles are available, including Matter Engineering’s PAS2000 and LQ 1-DC sensors. The PAS2000 charges an aerosol with UV-light and measures the result, and can be used to detect polyaromatic compounds. The LQ 1-DC is a diffusion charger sensor, producing a measured signal that is proportional to the surface area of the aerosol (e.g. Ntziachristos et al., 2004). Similar instruments are available from TSI.

Sampling and dilution

Several universal sampling systems are commercially available, one of which is the FPS 4000, a new unit from Dekati for measuring particles from all types of combustion or industrial processes. The system has adjustable dilution ratios, dilution temperatures, and residence times, which enables well-defined samples to be taken very flexibly from vehicle exhausts or power plant stacks at the appropriate concentrations and temperatures for measurement. Dilution takes place in two stages, using perforated tube technology in the first stage and an ejector diluter in the second stage, which acts as the sample pump and returns the sample to the ambient temperature.

Matter Engineering offers a rotating disk-based diluter (MD19-2E), which features variable dilution ratio and temperature, and can be used to sample directly from stacks and exhausts. A dilution system known as MPS (micro-proportional sampler), developed by Booker Systems and now owned by Sensor Inc., enables transient, in-use measurements to be taken of automotive emissions in cases where the use of a constant volume sampling (CVS) system would be impractical.
The FINE Programme included a total of 11 projects in the area of fine particulate measurements and measurement techniques and methods, which focused on:

- New applications for existing measurement methods
- New measurement instruments and methods
- Sampling and dilution, and
- Developing modelling and research services.

**New applications**

One of the existing technologies investigated for its potential was lidar (light radar). Designed for measuring cloud height and vertical visibility from aerosol backscatter profile, mainly for aviation purposes, the ceilometer is capable of measuring other interesting parameters, such as aerosol profiles, mixing layer height (backscatter signal from low altitudes), aerosol concentration (strong correlation with PM10), precipitation, wind profiles, and gas concentration profiles, such as humidity and ozone. See Figure 7.

Backscatter data from a ceilometer shows a high correlation with PM10 measurement figures under dry atmospheric conditions. The composition and shape of particles have a strong effect on the signal, however. The data from the FINE project suggests that ceilometers could be used to determine the height of the mixing layer, especially in foggy conditions. The aerosol and mixing layer information provided by a ceilometer makes it an attractive instrument for research purposes in particular.

The triboelectric method has been used to monitor industrial processes and the operation of filtration systems for over 20 years, and the sensor is small, low-cost, and virtually maintenance-free. See Figure 8. Experiments carried out as part of the FINE Programme concentrated on assessing the limitations of this type of measurement. A series of new ideas were applied with the aim of generating more accurate results more cost-effectively.

The new system that was developed directly digitises the input signal from solid particles without the need for several analogue amplifiers, reducing the component count and simplifying the control algorithm. The result is a system that can offer a very cost-competitive alternative to traditional systems that are seen as too expensive.

The results of the project will be used as the basis for future product development in areas such as real-time, on-line instrument for filter manufacturers and indoor, office, and workplace monitoring.

**New instruments, methods, and techniques**

In another FINE project, participants designed and built a new kind of aerosol time-of-flight mass spectrometer for use in real-time analyses of air samples. See Figure 9.

The objective was to develop a device that is portable and can analyse chemical compounds simultaneously from both aerosol and gas samples at very low concentrations. The aim was to offer an alternative to current commercially available instruments, which are both expensive and large. Cutting costs and the physical size of a system would open up a lot of new applications to aerosol mass spectrometry.

The operation of the system was verified using aerosols containing pure substances (see Figure 10), and the reproducibility of the system was found to be good. As the sample collection time for atmospheric samples proved too long, a new ionization chamber was designed to reduce the time needed for this stage.

New size-selective sampling and sample feeding systems were also designed and built. The sample feeding...
**Figure 8.** A triboelectric sensor. Courtesy of Sintrol Ltd.

**Figure 9.** Schematics of the GATOFMS system.
Figure 10. Measured spectrum of 2,5-dihydroxybenzoic acid.

The system can be used with other mass spectrometers or other analysers; and the overall sampling system can be used in other applications that require size-selective sampling.

A new type of condensation particle counter (CPC) was also developed, employing swirling flow in the mixing chamber to enhance detection efficiency. See Figure 11.

Operation of the CPC was studied using modelling techniques and experimentally. Data from the experiments showed good detection efficiency for particles above 10 nanometres, and a linear response to concentration. Work on the prototype has since led to a commercial instrument, the Dekati CPC.

Realising the benefits of in-situ automotive tailpipe measurements in eliminating the need for particulate sampling and dilution, Dekati has developed an Electrical Tailpipe PM Sensor (EtaPS).

Capable of detecting the amount of PM emitted from an engine, this is based on particle charging and electrical detection, as illustrated in Figure 12. When the flow passes through the inner charging chamber, a charge is attached to the particles passing through the chamber. When they exit the outer charging cage, this

Figure 11. Schematics of the new condensation particle counter.
signal, which is proportional to the amount of particles passing through, is measured.

Electrical detection technology offers a wide dynamic range and real-time operation, and possible applications include product development, quality control, and in-use testing.

Out in the field, participants in the FINE Programme constructed a network of measurement stations in Helsinki to study aerosol particle formation, sources, dispersion, and the relationship with urban air quality and possible health effects. Two new measurements systems were built: a Twin-TEOM ((Tapered Element Oscillating Microbalance) unit and a PILS-IC (Particles Into Liquid Sampler-Ion Chromatography) unit.

The first of these can measure small particles (PM2.5) and large particles (PM2.5-10) simultaneously, with samples being divided between the two TEOM units by virtual impactors. The TEOM units measure the mass concentration of both fractions. The semivolatile fraction of the particles can be determined using an additional FDMS (Filter Dynamics Measurement System) unit. See Figure 13.
The PILS-IC system can gather information on the chemical composition of particles with a time resolution of several minutes. An on-line method, PILS-IC (Particles Into Liquid Sampler-Ion Chromatography), determines atmospheric inorganic ions from fine particles, and combines particle growth by condensation, impaction sampling, and ion chromatography.

Figure 14 shows the PM1.3 mass concentration, measured with TEOM, and the ion composition of the fine particles, as measured in Helsinki (Kumpula) in summer 2005.

Work also addressed investigating the applicability of the EU’s PM10 method to Finnish conditions, which are characterised by occasionally very low and high concentrations in the spring, caused by traffic and road dust. A comparison between the European method and that use in the US is shown in Figure 15. Despite the higher flow rate and smaller inlet design of the European method, the correlation between the two is good, although the European method generally gives slightly lower mass concentrations. This is believed to be caused by higher losses of large particles and the volatility of the collected aerosol.

**Sampling and dilution**

Mass transfer between the gas phase and the aerosol phase can occur when hot flue gas emission samples are diluted. Different dilution techniques have a different effect. The properties of the dilution air – filtered/non-filtered, temperature, RH – are responsible for the bulk of the impact on the aerosol. Residence time, losses, and the mixing rate also have an effect.

The formation of a nucleation mode during the mixing of flue gases with colder ambient air can increase the number concentration of particles significantly. In addition to sulphur and nitrate species, organic vapours have been proposed as other nucleating agents. Nucleation mode formation has also been observed in on-road measurements, which indicates that nanoparticles are not only formed in the diluters used in combustion emission measurements but also during atmospheric dilution. Further modelling, simulation, and experimental work is needed here to extend our understanding of the complex processes involved.

Nucleation mode formation and condensation dynamics in respect of Dekati’s perforated tube diluter were studied by modelling and experiments using laboratory-generated condensable vapours and models. Turbulent mixing in the diluter mirrors what takes place during the release of exhaust gases into ambient air. The new data that was collected about the effect of turbulence on the behaviour of condensable vapours in exhaust emissions will be useful in determining emission factors, designing sampling equipment, and designing legislation to control emissions of fine particulates. This enhanced understanding of aerosol-turbulence interaction may also find application beyond emission issues.

**Research services**

The FINE Programme also saw the development of new methods for the single particle analysis of aerosols in research services. This work involved testing a number of aerosol sampling methods to identify the most suitable equipment. The substrate used, in particular, determines whether small particles can be analysed effectively. The result of a TEM/EDX analysis of a single particle is shown in Figure 16.
**Figure 15.** Correlation between European (EU PM10) and US method (US PM10) for PM10 measurement.

**Figure 16.** A TEM image of a particle is shown on the left, and an EDX-elemental analysis on the right. The particle contains mainly sulphur and some potassium. The carbon, oxygen, silicon, and copper present come from the substrate.
**Contribution of the FINE Programme**

The FINE Programme has advanced our understanding of aerosol measurement techniques and provided new information on the operational limits associated with various instruments and techniques, and helped identify new applications for existing systems. Information generated by the programme’s projects will also be valuable input for the companies involved in future product development.

Work on sampling and dilution has given us fundamental new information on the underlying processes affecting the mass transfer between the gas and particulate phase. Studies on the turbulent mixing processes occurring in diluters, combining modelling and experimental work, have contributed to our understanding of why particles are formed and how turbulence affects the behaviour of condensable vapours in exhaust emissions.

Prior to the FINE Programme, there were no particle mass spectrometers in Finland and insufficient knowledge of the fundamentals involved. Following the completion of the programme, the capabilities to build a portable aerosol mass spectrometer are now in place.

Although many of the projects related to measurement techniques were oriented towards product development, most also involved a thorough examination of the fundamentals involved, and generated new knowledge about the charging of aerosols and the optical properties of atmospheric and laboratory aerosols.

Extensive cooperation between the research institutes, universities, and companies that took part in the programme’s projects has enhanced future networking potential and already resulted in the launch of some new projects.

The programme’s R&D projects have resulted in new products, some of which are already commercially available and some still in development. These new products include not only instruments such as the CPC and EtaPS, but also new measurement services as well. In some cases, work carried out as part of the programme showed that existing instruments can be used in a new field with minor modifications, while in others more significant modifications will be needed, some of which may not be cost-effective to implement from a business standpoint.
Table 2. Future developments in aerosol measurement technologies.

<table>
<thead>
<tr>
<th>Application</th>
<th>Future developments</th>
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</thead>
<tbody>
<tr>
<td>Ambient air quality</td>
<td>Real-time monitoring, nanoparticles, particle origin</td>
</tr>
<tr>
<td>Industrial hygiene</td>
<td>Nanoparticles, real-time monitoring</td>
</tr>
<tr>
<td>Indoor air quality</td>
<td>Biological properties, real-time monitoring</td>
</tr>
<tr>
<td>Emission monitoring</td>
<td>Real-time monitoring, sampling harmonization</td>
</tr>
<tr>
<td>Process control</td>
<td>Real-time monitoring, new applications</td>
</tr>
<tr>
<td>Laboratory</td>
<td>Single particle analysis, nanoparticles</td>
</tr>
<tr>
<td>Mass</td>
<td>Real-time monitoring</td>
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<tr>
<td>Number</td>
<td>Cheaper counters, smaller particles, standardization</td>
</tr>
<tr>
<td>Biological</td>
<td>Identification, single particle analysis</td>
</tr>
<tr>
<td>Composition</td>
<td>Single particle analysis, nanoparticles</td>
</tr>
<tr>
<td>Sampling</td>
<td>Standardisation</td>
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</tbody>
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Figure 17. Automotive emissions were studied extensively as part of work on the FINE Programme’s various projects.
Given the growing interest in the health-related effects of fine particulates and their impact on climate, there is a clear need for research-scale instruments capable of providing wide-ranging particle characterisation data. It is particularly important to know the composition and structure of particles, as particle size and composition can help us understand the origin of particles. Methods must be size-selective and sufficiently sensitive to allow us to measure even the smallest particles. While it would be advantageous to be able to measure individual particles, sample collection and analysis are the priority for the smallest nanoparticles.

Our attention is moving to smaller and smaller sizes of particles, and in the cases of atmospheric studies, the size range of interest is already close to ion scale.

As emission limits and ambient maximum concentration values become stricter, emissions monitoring will become both more important and more difficult. Automotive emission limits, for example, are already becoming so low that current methods are incapable of providing reliable measurement data. New methods and techniques will be essential to meet new regulations. See Figure 17.

It is important in this context to remember that not only are the right measurement instruments needed, but also that the entire measurement and sampling system has to be characterised and standardised. Methods need to be more sensitive than current ones, and more reliable.

It is also possible that new limits restricting the amount of particles will be imposed in addition to mass-based limits. Number-based limits have been proposed in the Euro V standard for automotive emissions, for example. It is also very likely that emissions from sources not yet regulated will be limited in the future, as the discussion on imposing type approval emission limits on new small-scale combustion systems indicate.

Because of the low limits and emission levels that we are talking about, future sampling systems will need to be very well thought-out and consistent, and this will require extensive attention. Sampling systems will also need to be more closely tailored to measurement needs, in terms of parameters such as mass and number, as there is no universal way to sample and dilute material. Systems also need to be fully standardised, so that results are comparable and can be used for verification purposes.

Nanotechnology will play an increasing role in the future in respect of aerosols, for two reasons. The first of these is simple: the size of aerosol particles coincides with those common in nanotechnology. And the second is that aerosol routes are one very viable option for producing nanomaterials. Particle measurement instruments will be essential in the development of nanotechnology and monitoring nanomaterial processing, as a result. As the use of nanotechnology expands, the importance of exposure to nanoparticles from an occupational health standpoint will also increase, highlighting the need for new instruments and methods to measure nanoparticle exposure.

The use of industrial aerosol processes is increasing, and requires a growing amount of aerosol instrumentation to monitor processes and control the quality of products. This will see the need for low-cost monitoring instruments only increase.

Low cost – together with high reliability, ease of operation, low maintenance, and real-time operation – will also be a growing factor in work on the atmosphere and air quality. Large coverage is essential here, and means large numbers of instruments.

A growing amount of monitoring equipment is likely to be needed in the energy sector as well, with the spread of smaller decentralised units firing biomaterials. Monitoring emissions from these plants in a cost-efficient way represents a clear technological challenge.

In the traffic and automotive field, particle monitoring instruments will be become more common, as the requirement for measuring emissions and the performance of treatment devices on a vehicle-by-vehicle basis, and preferably in real-time, grows. If a cost-effective method and suitable instrumentation is developed, the number of users of these systems will be very high.

The research community is likely to remain a good customer for manufacturers of aerosol measurement equipment, and there will be a good market for new more advanced instruments. As research moves forward, it is probable that some of the sophisticated instruments currently restricted to research institutes and universities will enter more universal use.

All of these developments will increase both the need for new aerosol instrumentation and the volume of this equipment in the marketplace. This will undoubtedly see increased competition among suppliers and the possibility that larger companies will enter the business. It will also offer new opportunities for smaller companies developing and producing innovative new types of aerosol instrumentation.

Table 2 provides an overview of the most likely future developments in various areas and applications.
Particulates, and the challenge of how best to measure them, have been the subject of growing attention in recent years because of the harmful effect they have on people’s health and the environment, and the legislative measures that have been introduced in response to this.

Demands for lower particulate emissions call not only for technological advances to reduce emissions but also better technology for sampling, measuring, and monitoring particulates that are capable of meeting challenges such as new limits restricting the amount of particles that go above and beyond mass-based limits. This covers both automotive emissions and sources that are unregulated as yet, such as small-scale combustion.

Aerosol measurement is also becoming increasingly important in industry, to control processes, monitor product quality, and prevent particulate contamination. Progress in nanotechnology, for its part, has also triggered an increased interest in aerosol processes and helped leverage new methods. As nanomaterials can be produced using aerosol techniques, measurement and analysis needs will also grow here as well.

All of these developments will increase the need for new aerosol instrumentation and the volume of aerosol-related instrumentation – fuelling competition between suppliers in the field and creating new opportunities.

The FINE Programme included 11 projects devoted to measurement techniques and methods. Most of these were research and development projects aimed at producing new technology or enhancing existing instruments, techniques, and services. Despite this R&D focus, FINE projects have made a valuable contribution to advancing our knowledge and technological understanding of measuring fine particulates – and deepening networking between the research community and industry.

The programme resulted in several new products and a body of new information that can be utilised for new innovations in the future, thanks to a thorough examination of the fundamentals of the techniques concerned. This information includes data on the operational limits of existing instruments and techniques, and their potential for use in new applications.
References


Tekes, the Finnish Funding Agency for Technology and Innovation is the main publicly funded organisation for financing applied and industrial R&D in Finland.

Tekes’ primary objective is to promote the competitiveness of industry and the service sector in Finland by enhancing the country’s technological potential – through such areas as diversifying production structures, increasing production and exports, and creating a more solid foundation for prosperity today and into the future.

Tekes’ technology programmes are a key part of the Finnish innovation system, and have proved a highly efficient means of encouraging and stimulating cooperation and networking between companies, universities, and research institutes for developing innovative products, processes, and services.

Programmes focus on specific sectors of technology or industry, and are designed to give business access to the latest research results. Together with the Tekes network in Finland and overseas, they also provide an excellent framework for international R&D cooperation.
As a result of ever-growing traffic volumes and ever-higher levels of energy generation, the air we breathe exposes us to a growing number of airborne contaminants, including minute particulate matter. These particulates are known to have major health implications, and result in the premature death of over 300,000 people in the EU annually alone. Advances in technology are allowing us to measure smaller and smaller sizes of particles and gain a better understanding of how they impact our health and the environment, however.

Tekes launched a four-year technology programme in 2002, known as FINE, together with the Academy of Finland, the Ministry of Transport and Communications, and the Ministry of the Environment, to focus on particulate emissions. This concentrated on five main areas: energy and industry, traffic and transport, measurement technology, indoor air, and health and the environment. All in all, the FINE Programme involved over 50 projects and close to 60 companies and more than 20 research institutions.

A summary report has been produced on each of these areas. This report concentrates on particle measurement technology. Drawing on the work of 11 projects, it provides an overview of the current state of play, the challenges already being faced today – challenges that will only get tougher in the future – and a summary of work that has been carried out in developing new measurement approaches and applying existing technologies to new uses.

Tekes, the Finnish Funding Agency for Technology and Innovation is the main publicly funded organisation for financing applied and industrial R&D in Finland. For more information, see www.tekes.fi