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OPERATION

What is near forward light scatter?

In 1908, the German physicist G. Mie derived a theory to explain the behavior of light when normal Rayleigh scatter no longer applies. Many people have tried to explain the principles of Mie-Theory (forward light scatter) in layman's terms, but the science is hard to follow. The Mie scattering calculations are so complex that large computers are required, particularly if the complex refractive index must be used, as for metallic scattering particles. For non-spherical particles even more complex approaches are required, and workers such as R. Gans have solved special cases such as ellipsoids and rod-shaped particles; even more complex are mixtures of particles of different sizes. These solutions are important in the investigation of colloids, aerosols, smokes, smogs, and so on, where the particle sizes and shapes may be deduced from the light scattering behavior.

Figure 1 shows the principle of near forward light scatter. The light source on the left of the diagram represents an infrared beam of 880nm wavelength that is passed through a number of lenses to collimate it. In clean air conditions, the beam is stopped by the light stop represented in black. As the beam passes through the sensing volume, where particulate is introduced, the beam is scattered by the particles. This is picked up by the photo detector, which amplifies the signal and converts it to a mass concentration. The narrow angle of scatter is represented by the angle β and is around 12 to 20° depending upon configuration.

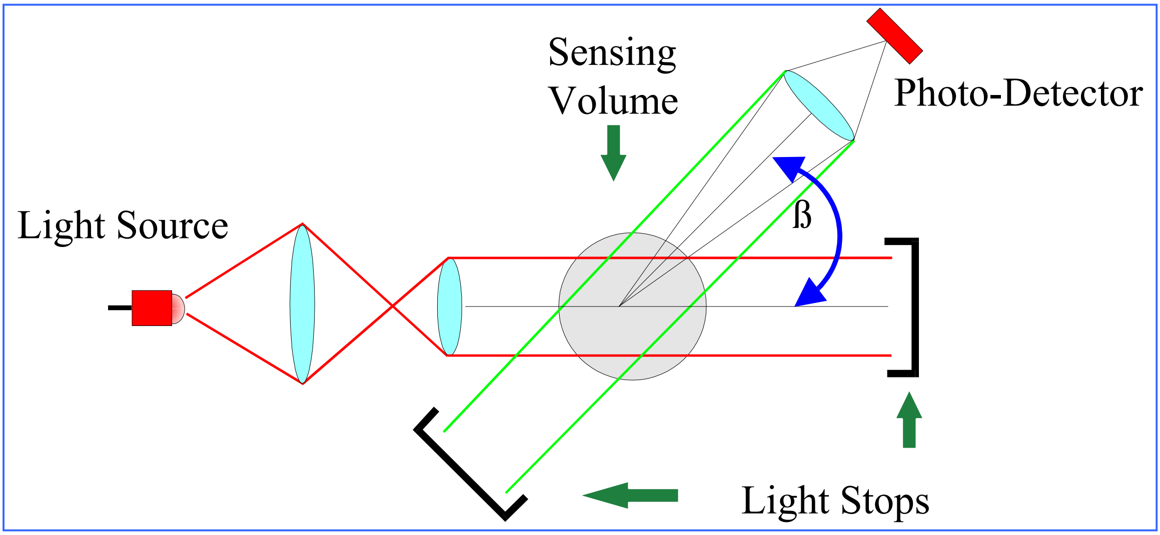
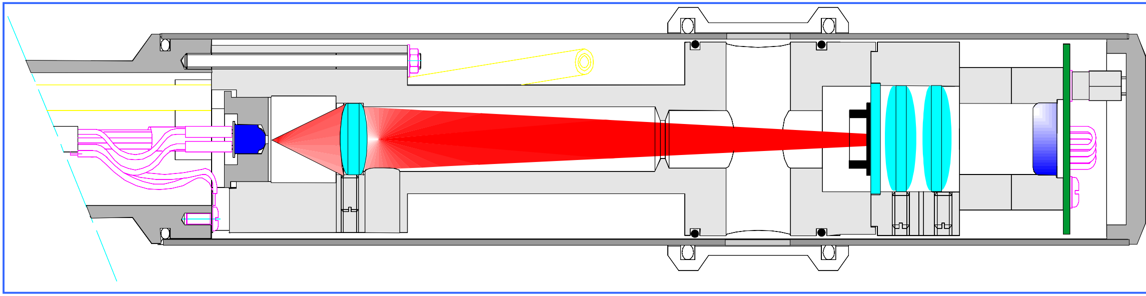


Figure 1: ***Schematic representations of near forward light scatter.***

This concept is better explained in figure 2, which shows the actual layout of the ***Microdust pro*** probe. Under clean air conditions, with the metal slider pulled over the sensing volume, the light comes to rest on the light stop. However, when the metal slider covering the sensing volume is drawn back, introducing the particulate, the beam is scattered around the light stop and onto the photo detector behind it. The amount of scattered light is directly proportional to the particulate concentration.

CLEAN AIR CONDITION



PARTICULATE INTRODUCED TO THE SENSING VOLUME

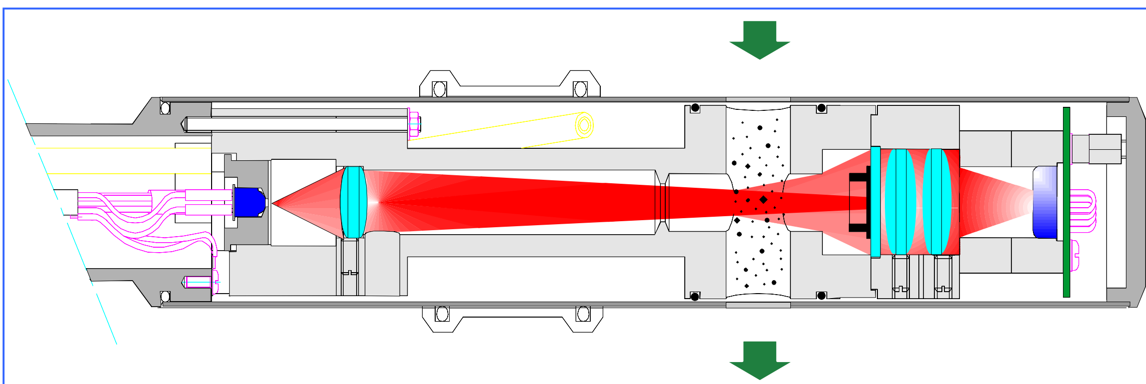


Figure 2: ***Schematic showing the arrangement of the Microdust pro Probe***

MEASURING PARAMETERS

What ranges of particle sizes will the pro monitor?

The **Microdust *pro*** will measure across a wide range of particle sizes, the smallest being around 0.1 μm to the largest, around 10 μm. However, as with all optical instruments, the particle size influences the instrument response. Optimum sensitivity is in the respirable size range.

Will it measure PM2.5 and PM10?

It is possible to measure both $PM_{2.5}$, PM_{10} and respirable particulate using Poly Urethane Foam filters (PUF's – figure 3). These have been developed by aerosol scientists and tested independently. Essentially the PUF's are small foam plugs fitted into cassettes, in turn fitted into an adapted version of the Conical Inhalable Sampling (CIS) Head. This head is now accepted for use and is ubiquitously used in the field of personal or occupational sampling in the UK.

Figure 3: Poly Urethane Foam (PUF) Filters

Work undertaken by the Health & Safety Laboratory (HSL) in Sheffield, UK tested the foam containing cassettes within the CIS sampler at a flow rate of 3.5 liters per minute. The techniques used in the tests were previously developed to measure the size selection characteristics of cyclones and impactors. Repeating tests with different plugs until suitable dimensions had been identified optimised the cassette designs and foam plug dimensions. Results indicated that with suitable preparation and analytical procedures, the modified CIS foam samplers developed could be used for monitoring of exposure to PM_{10} and $PM_{2.5}$, thoracic and respirable aerosol fractions (Kenny & Stancliffe, 1997).

A gravimetric adapter is necessary for monitoring PM_{10} or $PM_{2.5}$ with PUF's in the **Microdust *pro***. A personal sampling pump with a capacity of 3.5 $lmin^{-1}$ will also be required (such as a Casella Vortex or Apex pump).

If a size selective PUF is used, how can the instrument then be calibrated?

In the same way as the gravimetric comparison is performed, all the material which is size selected on the basis of the Poly Urethane Foam (PUF) filter passes through the sample volume of the **Microdust *pro*** probe and is collected on a standard filter behind the probe. We can then calibrate the instrument based upon the gravimetric filter results.

How often does the PUF need changing, and how will that need manifest itself or influence readings?

PUF's are generally only designed for fairly short sample durations, as they will suffer partial blockage over time. This will affect the size selectivity characteristics. Our advice to users is to change the PUF filter after every sample run, up to a full continuous 24-hour period. Little is presently known of how PUF loading affects the particle size selection characteristics, although tests have shown that the D50 (50^{th} percentile) of the PUF will gradually decrease as the particulate loading increases. We therefore recommend that the PUF foams are not reused and are transported carefully.

Is the Microdust pro a particle counter?

Definitely not. The principle of near forward light scatter and the use of this technique imply that mass concentrations of particulate are recorded. Essentially, this is a surrogate or derived measure based on a set of fundamental principles. Particle counting is only achievable by costly, generally static monitoring systems.

CALIBRATION & CLEANING

How is the Microdust pro calibrated?

There are several methods for calibrating the **Microdust *pro***:

1. The instrument is calibrated to a known reference dust standard before leaving the factory. This is covered below.
2. The instrument can be returned to this "factory" calibration setting at any time during its life by the use of a calibration insert and the appropriate software within the instrument. This is covered below.
3. It is also possible to "set" a calibration on the *pro* using a special technique of gravimetric calibration. This is covered in detail below.

How can the instrument be calibrated to a known dust type?

When faced with varying dust types, the response of the unit will differ slightly due to variations in particulate sizes, refractive indices and color. The relationship between these is described below. In order to correct for this difference, it is necessary to alter the response of the **Microdust *pro***. This involves the collection of a gravimetric (filtered) sample of the dust *after* it has passed through the probe optics. In this way, one collects two averages over the exposure period. One is from the filter, whilst the other is provided by the averaging function within the instrument. It is then possible to derive the difference in these two figures and correct accordingly (figure 4).

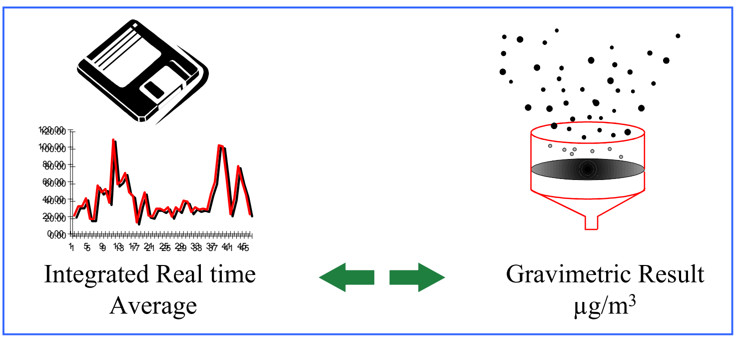


Figure 4: Comparing real time & gravimetric averages

For example, the instrument is run for 8 hours, yielding the following average concentrations:

Real time component:	=	35 mgm^{-3}
Gravimetric component	=	40 mgm^{-3}

Therefore the real time component is under-reading by 12.5% - we need to increase the gain of the photometer by this amount. The optical calibration insert is marked as "30", so we turn up the gain (span) until the display on the **Microdust *pro*** instrument is showing:

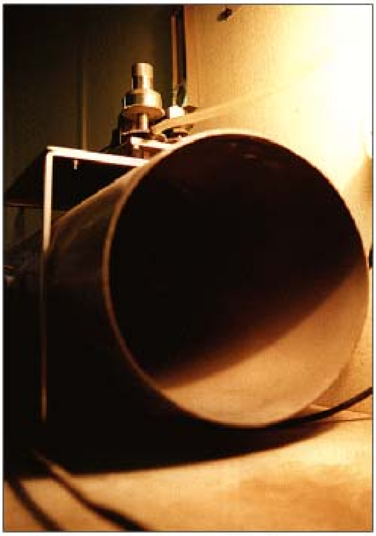
30 multiplied by 1.125 (12.5%)	=	33.75 (34)

Now the real time component equals the gravimetric component and the **Microdust *pro*** instrument is calibrated to that particular dust type. This is an extreme example to show how the procedure is performed.

Within the **Microdust *pro*** instrument operating software, it is possible to store 4 different calibration values and select these according to the situation. All these procedures are accessible through the easy menu structure.

What is meant by an iso-kinetic calibration system traceable to national standards?

This refers to the way in which the **Microdust *pro*** is calibrated. After manufacturing, there is a special calibration process using a wind tunnel. Fine reference dust is injected into the tunnel using a Wright Dust Feeder, which is pulled through the tunnel and through the Microdust probe (figure 5). After the airstream has passed through the probe, it is collected on a filter to establish a known and correct gravimetric result.



The term "iso-kinetic" refers to the matching of air velocities through the sampling volume. The instrumentation used for this is calibrated as part of the ISO9001 accreditation. The filter is weighed before and after the process and the difference is the collected mass of particulate. This value is then compared to the real time data collected by the **Microdust *pro*** instrument (specifically the average over the sampling period) and the instrument is adjusted so that the two values are the same. This implies that the unit is now calibrated to a known reference value. (Please see question below on reference standard).

Figure 5: Wind tunnel used in the calibration of the Microdust pro

What is the optical calibration insert and how can it not change or be degraded with time?

The calibration process provides a "reference" calibration. Once the **Microdust *pro*** instrument is correctly adjusted, a small insert is made, which consists of a piece of optical glass with particular physical characteristics. When this is inserted into the sampling volume, the infrared light is scattered and a value is displayed on the instrument. As the optical glass will not degrade with time (the only way to degrade it is to destroy it), the reference standard will always provide a calibration back to factory settings.

Are commercial standards of filtered samples available for calibration?

Due to the wide and diverse range of applications for the **Microdust *pro***, commercial standards have never been available – it is always up to the customer to establish a correct and qualitative sampling regime.

What is the purge for optical cleaning?

The purge refers to the nozzle or nipple on the lower end of the probe. This is provided as a cleaning mechanism and is connected to two separate tubes that pass up through the probe and terminate as air blowers at 90° across both the emitter and receiver lenses.

How often is cleaning required?

The cleaning regime depends upon how the instrument is used. For example in hand-held applications where an Industrial Hygienist for a walk-through survey is using it, it may require a 30 second clean on a daily basis. However, in a situation where the **Microdust *pro*** is continually being exposed to dust (for example in a dust chamber) there is a requirement to use the purge continuously. With this type of application it is necessary to connect up a clean, local air supply capable of supplying a small airflow (2-4 liters per minute) continuously.

ACCURACY

How accurate is the Microdust pro?

Any scientific measuring instrument is as accurate as the methodology employed by not only the instrument itself, but also the operator. The **Microdust *pro*** has been shown in independent tests to be a highly versatile particulate monitor with highly repeatable results and excellent linearity (see below).

Unlike many other hand-held particulate devices, the **Microdust *pro*** incorporates a unique post-sampling calibration facility that allows the user to calibrate the instrument to a specific dust type. This is explained in more detail in the ***calibration section***.

Is the Microdust pro sensitive to different particle sizes?

All optical sensors are suited to different sizes of particles, depending upon their source wavelength, focal distances and other optical parameters. By using an 880nm wavelength source, the **Microdust *pro*** instrument exhibits the highest response in the "respirable" dust size range. This has a D50 cut of around 3-4μm according to the ISO sampling convention curves.

However, the response shown to differing dust sizes can be shown in figure 6 in which the unit has been tested against various sizes and compositions. One important point to note is that all the responses are straight lines; so adjusting the gain of the photometer (gravimetric calibration – see ***calibration section***) will ensure the correct response in the **Microdust *pro***.

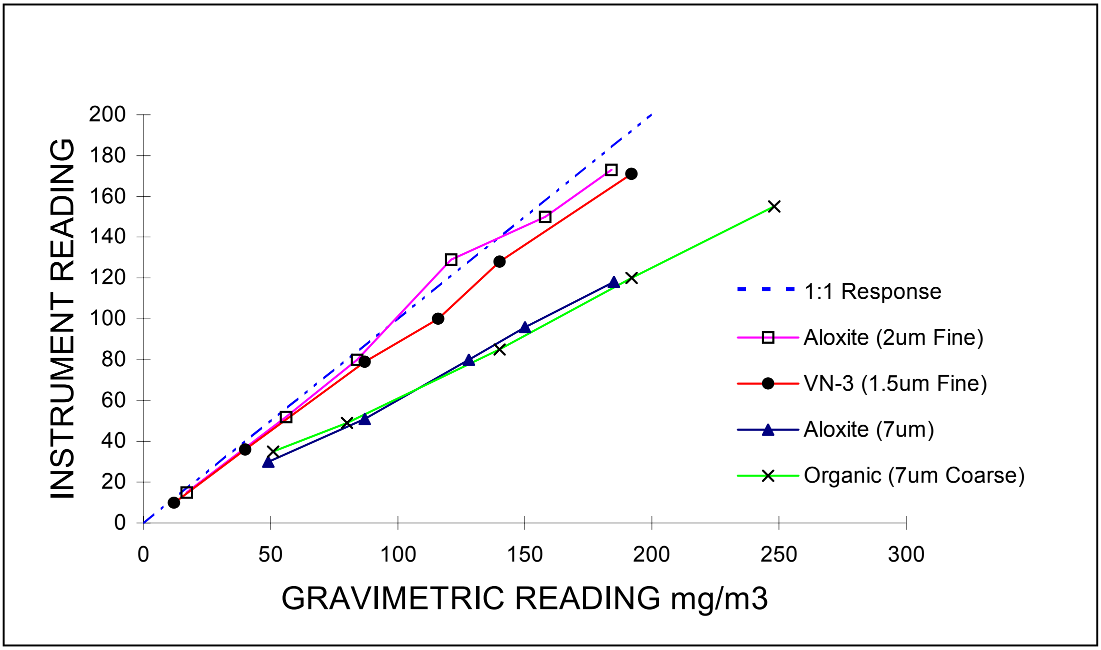


***Figure 6:* Photometer response to different particulate sizes**

How sensitive is the instrument to variations in particulate color and refractive index?

The **Microdust *pro*** uses a very narrow angle of scatter to deduce the particulate concentration (in the order of 12-20°). This reduces the amount of light scattered in the reflected component and instead concentrates on the diffracted and refracted components (see figure 7 below). The most important component is the diffracted light, which is the light "bending" around the object. Diffraction generally does not depend on particulate color or refractive index.

The use of a narrow angle eliminates most of the uncertainty involved with differences in color or refractive index. However, there is likely to be some deviation, but generally this is small. A good indication of this is when users gravimetrically calibrate instruments for two completely different types of dust (in terms of color). These may involve a recalibration factor of around 0.95 to 1.05.

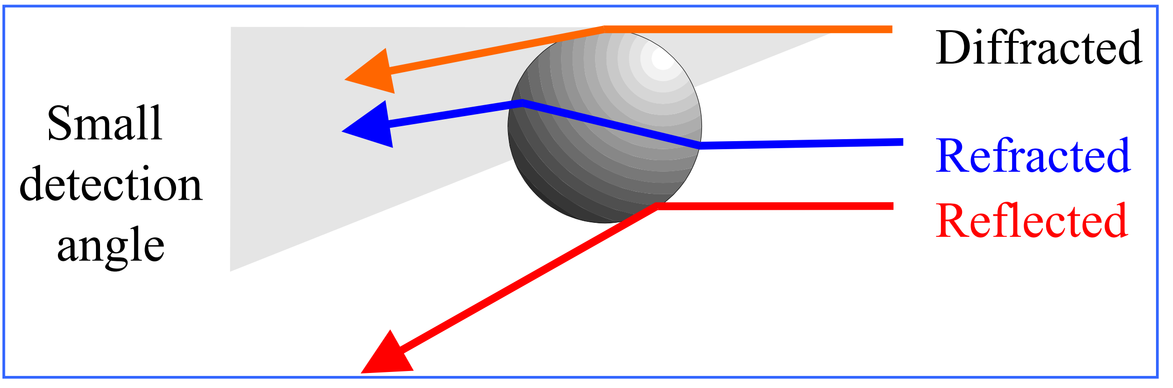


Figure 7: Simplified illustration of narrow angle forward light scatter

What is the linear response range if only zero and one calibration standard is used?

The linear response of the **Microdust *pro*** has been tested to concentrations up to around 30mgm^{-3} within our wind tunnel. The response is linear within this range (**R^2=0.9933** for 0 to 25mgm^{-3} – see figure 8 below).

Concentrations in excess of this amount are difficult to generate within a wind tunnel, so a separate high concentration dust "box" is used, in which we can generate dusts in concentrations up to around 2200mgm^{-3}. Linearity has been tested up to this level, producing excellent results (**R^2=0.9986**) – see figure 9 below.

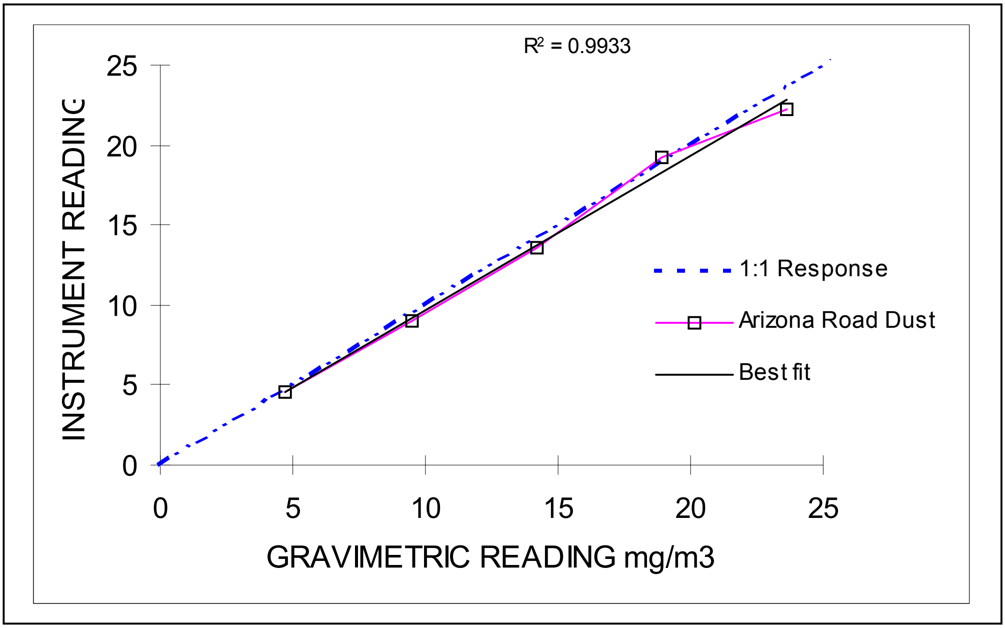


Figure 8: **Microdust *pro*** ***response to Arizona Road Dust (ARD) for low concentrations***

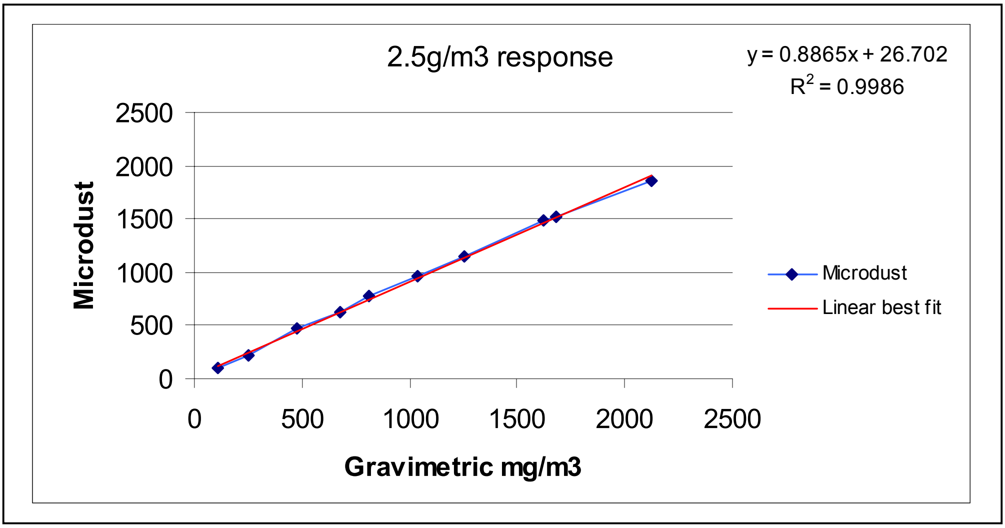


Figure 9: Microdust response to ARD for high concentrations

When are gravimetric samples required for calibration?

We generally suggest that all customers using the **Microdust *pro*** for anything other than general trend analysis (which is usually for process related activities) perform a gravimetric calibration. However, once this has been completed, you do not need to perform again, except when you change the monitoring application, for example changing from monitoring vehicle exhaust particulate to flour from a milling process.

Why are adapters required to ensure accurate measurements when used in static monitoring applications?

Optional adapters are required simply to yield a smooth and consistent flow of sample air through the instrument probe. Two general types are available.

The first is an ***aspirated adapter*** that uses a small fan (aspirator) to pull air through the probe at a given flow. This unit fits over the probe and is supplied with its own power supply.

The second type is a ***gravimetric adapter*** which generally uses a small personal sampling pump as the "pulling" device, with the added advantage of having a filter assembly located behind the sample volume (figure 10). Essentially, this is the same principle as the iso-kinetic calibration, where the sample is drawn through the probe at a known flow rate and captured on a filter. The weighed filter gives us a mass (in mg) and we can deduce the amount of air that has been drawn through (in m^3). We can then compare the instrument "average" concentration over the sample period with the gravimetric component and adjust accordingly.

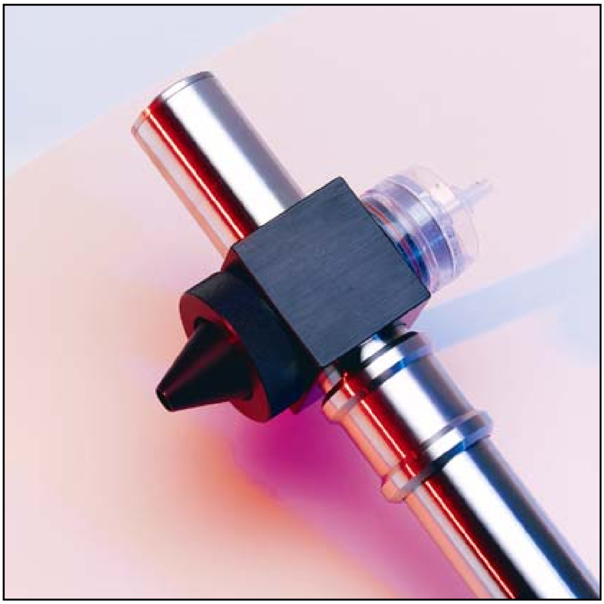


Figure 10: Gravimetric adapter for static monitoring & calibration

SOFTWARE & DATALOGGING

Can I use the "WinDust pro" PC software with Windows NT Operating Systems?

Yes, the software supplied is 32 bit, which runs on Windows 95, 98, 2000, ME, NT and XP.

What are the major features of the software?

The ***WinDust pro*** software offers the user the ability to perform the following functions:

- Create a "profile" for the instrument. This specifies which parameters are to be logged, the logging interval, and an "identifier" or name for the instrument. This is particularly useful when more than one instrument is owned.
- Transfer this control profile from the PC to the instrument.
- Recover data from the instrument
- Accumulation and processing of real time data for historical analysis and report generation
- Production of line graphs based upon historical data
- Tabular and report presentation of data files
- Real time presentation of prevailing conditions via the RS232 connection

What is the maximum logging duration?

The internal logger within the **Microdust *pro*** has a non-volatile 64Kb memory. This has the potential to store 32 separate runs. It is possible to set the logging interval from 2 seconds to 10 minutes. For example if the interval is set at 2 seconds, it is possible to record 8.75 hours of data. If the interval is every 5 minutes, this equates to a total logging time of 50 days. Up to 15,700 data records may be stored and downloaded.

What parameters are logged?

Recorded values are as follows:

- Average concentration over the logging interval (mgm^{-3})
- Maximum concentration over the logging interval (mgm^{-3})
- Date and time stamp

How do I transfer data from the instrument to the PC?

Each **Microdust *pro*** is supplied with an RS232 cable, which is connected to the instrument and the serial port of the PC. Upon running the software, the data transfer is facilitated by a "single click" of the mouse.

PRACTICAL CONSIDERATIONS

Which “concentration range” instrument do I need for my application?

Previous versions of the **Microdust *pro*** were sold as products with different ranges (eg 0-25 mgm^{-3} or 0-250 mgm^{-3}). The Microdust *pro* has the advantage that there is ***only one model which covers the entire measurement range*** (0 – 2500 mgm^{-3}). It is possible to “fix” the range of the instrument, or have it as an “auto-ranging” device.

How are the dust concentrations presented on the instrument?

The **Microdust *pro*** incorporates a 128 x 64 pixel graphical backlit display. Dust concentrations are presented in two ways:

- ***Numerical values*** – instantaneous concentrations are displayed on the screen in large numerals, as well as a value for the Time Weighted Average (TWA) that is calculated from the moment the instrument is switched on. This value can be reset at any time by a “one button” reset. Maximum concentrations are also displayed in this way.
- ***Graphical representation*** – the **Microdust *pro*** is the first real time particulate measuring instrument to have a scrolling graph of dust concentrations (figure 11). The graph is able to show a continuous trace over a number of time bases. These may be set on the X-axis at 100 seconds, 200 seconds, 15 minutes and 1 hour. The Y-axis range may be auto-ranging or fixed.

Figure 11: Real time scrolling graphical representation of dust levels

Will the probe get contaminated in a dirty environment?

The optics within the probe are susceptible to the build up of dust over time. For this reason, it is necessary to clean the optics at regular intervals. In normal operating environments, this is achieved by using the clean air “purge” facility. For environments subject to large concentrations of dust (e.g. process control), it may be necessary to connect a constant air supply to the purge to eliminate any dust from settling on the lenses. Both of these situations are described in the ***calibration*** section of this document.

Can I connect the output of the Microdust pro into other systems?

Yes – the **Microdust *pro*** has two possible outputs, an RS232 serial digital interface (up to 56k baud) or an analogue output (0 – 2.5Vdc full scale deflection). Both of these outputs have been used in different situations, for example monitoring processes, laboratory tests or controlling dust generation systems in the pharmaceutical industry.

Can I use the Microdust pro outside?

It is possible to use the **Microdust *pro*** outdoors, but this is generally restricted to short term monitoring, particularly in site boundary monitoring. However, the instrument is not designed to be used long term. For applications that require longer sampling periods, Casella CEL manufactures other specialist products such as the Environmental Enclosure or the APM950 (Ambient Particulate Monitor).

Does real time monitoring replace sampling with personal sampling pumps?

Real time dust monitoring is a very useful tool in many situations, but will not replace personal sampling pumps in occupational hygiene monitoring. This is because the methods used in gravimetric sampling are prescribed by the Health and Safety Executive in document MDHS 14/3 and must be adhered to if an employee's health is in question. However, real time monitoring is a useful tool in investigating the general concentrations of dust to see whether further sampling is needed. The high cost of equipment and analysis services for gravimetric sampling often makes the **Microdust *pro*** a cost effective survey tool.

For how long will the Microdust pro operate on its own batteries?

Two battery alternatives are offered with the **Microdust *pro***:

- ***Alkaline cells (4 x AA/ MN1500 cells)*** – these will provide around 2700 mAh which equates to around 20 hours operation (typically)
- ***Rechargeable Nickel Cadmium cells*** – these provide around 960 mAh that equates to around 10 hours operation (typically).

The advantage of using rechargeable cells is that they can be recharged ***in the instrument,*** from the internal fast charging circuit. However, it is very important that alkaline cells are not charged, as this will seriously damage the instrument and is potentially dangerous.

Can I use the Microdust pro to check concentrations within a "clean room"?

No, legislation usually states that clean rooms are checked with instrumentation capable of yielding an output of ***numbers*** of particles per cubic meter, rather than ***mass*** per cubic meter. This can only be achieved using a particle counter.

Can I use the probe in a hot exhaust stack?

Unfortunately the **Microdust *pro's*** probe is not designed to monitor particulate within hot exhaust stacks directly. However, it is possible to obtain a real time concentration by passing the hot sample through a number of cooling traps. The maximum temperature we would recommend the probe be subjected to is around 40°C (102°F).

What problems have been identified with this type of instrument?

It is hard to find fault with the **Microdust *pro***, but some comments we have received are as follows. It is interesting to note that most of these comments have arisen as a result of operator error / abuse:

- ***Contamination of the lenses.*** All optical instruments will suffer contamination of components exposed to dusts, fumes or gases. However, an effective and regular cleaning cycle will eliminate this problem.
- ***Optic misalignment.*** The lenses within the probe can be moved if the probe is dropped or hit hard on a surface. This requires a strip down and rebuild of the probe. This problem has been greatly reduced by the introduction of "screw-in" lenses, as opposed to "glued in".
- ***Battery abuse.*** The **Microdust *pro*** can use Nickel Cadmium batteries which can be seriously abused by poor charge management regimes. Instruments that are overcharged or left in a state of discharge for long periods of time will be subject to these problems.

How long does the infrared lamp last?

This is a difficult question to answer, as the infrared source is a solid-state photo diode that provides incredible performance. To try and put a value on the lifetime, we first started supplying the AMS (predecessor to the **Microdust *pro***) in 1989, which used the same diode and none of these have ever been returned due to lamp failure. We would estimate an MTBF of 15-20 years. Obviously the source strength of the diode will deteriorate over time, although periodic zero and span calibration, which effectively corrects the offset and multiplier values, correct this.

What are the terms of warranty, service, etc.?

All items are covered under the general Casella CEL warranty that is one-year duration.