AIRTEC™ TECHNOLOGY

TECHNICAL NOTES

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Technology

Existing instrumentation for real-time air particulate measurement is often expensive, power-hungry, and bulky (such as condensation particle counters and many light-scattering devices). Even with these compromises many instruments are still unable to detect the most hazardous particles (less than 100 nm diameter in the case of most light-scattering devices) and are subject to serious interference from non-carbon particles often found in mine air such as oil mist, water droplets, dust, and pollen. As a result, most particulate air pollution studies use air samplers that trap particles on a filter that must then be sent to an analytical laboratory for subsequent analysis.

MSHA uses the NIOSH 5040 method for diesel particulate (DPM) measurement in mines. This method employs a pump to draw air through a particle size selector and a quartz filter. After a specified period of sampling (typically eight hours) the filter is sent to an analytical laboratory for thermo-optical analysis which yields total, elemental, and organic carbon (TC, EC, and OC) values.

The NIOSH 5040 method is accurate and reliable, but has serious drawbacks. The cost of generating a single number from this analysis is ~$100, discouraging frequent testing. Test results are an average over an entire shift, so there is no way to know where in the mine (if the sampler was carried by a miner or placed on a vehicle) or when in time various levels of DPM were encountered. Most seriously, results of the analysis are not available until (typically) weeks after the sample is taken which doesn't allow for on the spot remedial measures to be taken in the event of overexposure.

This prevents any real-time adjustment to the mine's ventilation, personnel, or equipment use to modify DPM exposures. Overexposure to DPM can thus be detected using this analysis method but not prevented. NIOSH 5040 sampler methods cannot be used for active control of combustion particle generation or site ventilation to reduce human exposures to hazardous levels of particulates.

The ICx Airtec real-time DPM monitor is based on a technique developed by Respiratory Hazards Control Branch at the National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Research Laboratory (Noll et al., 2007; Noll & Janisko, 2007), and subsequently licensed to ICx.

As shown in Figure 1, mine air is drawn by a flow controlled diaphragm pump through a particle size selector which only permits the passage of submicron particles.
These particles are collected on a filter. A laser illuminates the filter and the transmittance of the laser beam is measured in real-time by the instrument. As DPM particles accumulate on the filter, the light transmittance decreases. The instrument converts this decrease in transmittance into a real-time concentration of elemental carbon in the air using calibration data obtained by the NIOSH laboratory using the NIOSH 5040 Method.

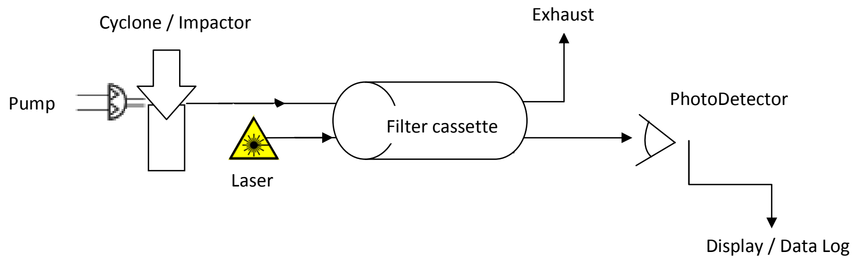


Figure 1
Principal components of the Airtec monitor.

The filter on which the particulates are captured is manually replaced (which takes only a few seconds) when it is fully loaded with black carbon. Its capacity is sufficient to operate for at least a full (12 hour) shift even in a highly contaminated environment. In the event of overloading, a filter saturation alert is given by the instrument. However the low cost of the filter cassette allows its replacement after every shift.

Airtec preferentially collects and analyzes DPM particles by two methods. First, many potential interferents are removed by the particle size selector. Second, the use of light absorbance for the analysis focuses on the detection of highly absorbing materials such as black carbon rather than on less absorbing materials such as silicates or condensed water.
The instrument operates for up to 12 hours on a built in rechargeable lithium-ion battery. The unit has a real-time limit of detection equivalent to 15 µg/m3 EC when using 5-minute averaging at a flow rate of 1.7 liters per minute (lpm). The dynamic range is equivalent to 9 – 300 µg/m3 at 1.7 lpm and 18 – 600 µg/m3 at 0.85 lpm expressed as an 8-hour time weighted average.

The sensitivity and dynamic range of the instrument may be adjusted for the operating conditions in three ways. First, the averaging time of the instrument may be adjusted to a period of 1 to 60 minutes (values of one or five minutes are typically used in mine environments).

Second, the pump flow rate may be set to a low (0.85 lpm) or high (1.7 lpm) value. Third, the photodiode has both high and low gain settings.

The laser transmittance measurement method for black carbon is a technique that has been used for decades and is used in commercial instruments sold by several companies. However, none of these instruments have the combination of portability, ruggedness, sensitivity, dynamic range, and particle selectivity for effectively measuring personal exposure to DPM in a mine environment in real time.

Highly reflective targets will return more energy back to the radar and will be more easily detected. The reflectivity or scattering from an object depends on factors such as the material the object is made of, its dimension, its shape and the angle at which the signal hits the object. This is defined as the Radar Cross Section or RCS. The RCS is a measure of the target's ability to reflect radar signals back in the direction of the radar receiver. In a surveillance context, a potential target or intruder could be a pedestrian. A pedestrian is often characterized in literature as having a RCS of 1.0 m^2. This does not mean that the pedestrian is physically 1 m^2 in cross section, it means that its apparent size as observed by the radar is equivalent to 1 m^2. The table below provides examples of RCS for various targets that may be encountered in a security or surveillance environment.

Output
The unit, shown in Figure 2, displays real-time EC levels on an LCD display, and can also display TC levels (converted from the EC data using a user-supplied, mine-specific conversion factor as described in MSHA publications). EC can also be displayed as an eight hour time-weighted average. In addition to the real time display, EC data is logged internally and can be downloaded to a personal computer via a USB connection.

A nearly linear calibration curve showing the filter absorbance as a function of the EC level measured by the NIOSH 5040 method is shown in Figure 3. The downloaded data from EC in an underground mine is shown in Figure 4. The peaks in EC level are correlated with the passage of diesel vehicles near the monitor.

Figure 2

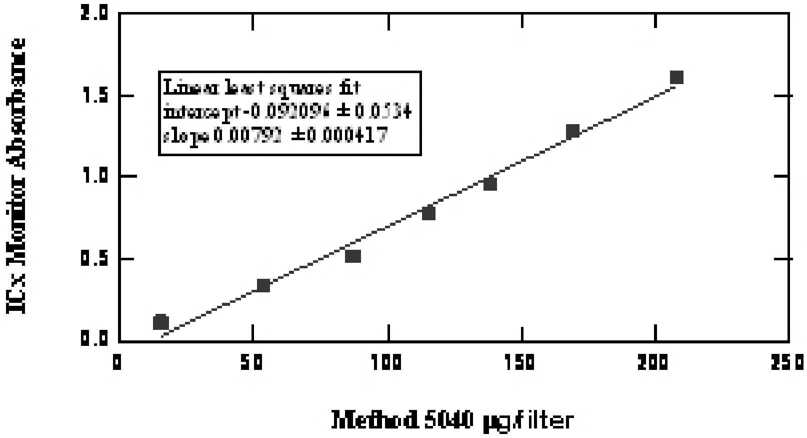


Figure 3
Optical response of an Airtec monitor, compared to the standard laboratory method for EC measurement (Method 5040).

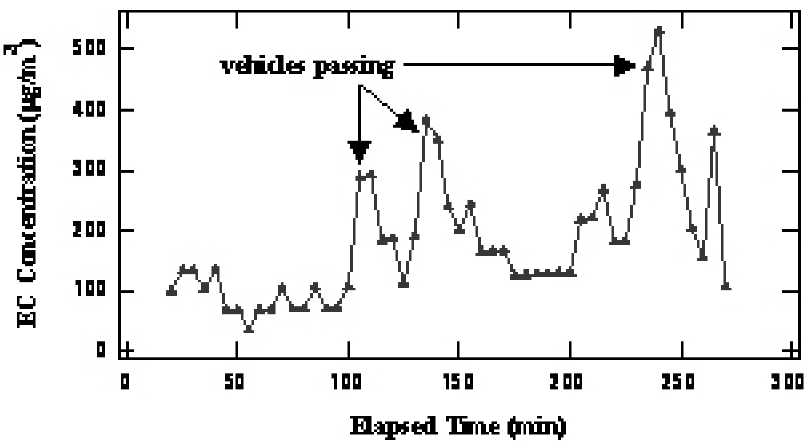


Figure 4
Example of the data from an ICx Airtec real-time DPM monitor. Data was taken in a commercial mine; peaks in the EC data reflect passing diesel vehicles.

Use of the Monitor in Underground Mines
A detailed discussion of how the monitor can be used to facilitate DPM exposure analysis and reduction in underground mines is given in the paper by Janisko and Noll (Janisko & Noll, 2010). Briefly, the monitor may be worn on a miner's belt, placed in or on a vehicle, or placed on a wall or table in an area where EC monitoring is desired. The intake and size selector may be attached via a lapel clip near a miner's breathing zone. When activated, the unit will display and log the EC concentration until either the battery is exhausted or the filter is saturated. Usually, the battery is limiting, and the operating time of the instrument is determined by the battery life though AC power may also be used.

The exposure limit alarm on the Airtec can be turned on or off to alert the user when a set level of EC exposure has been reached. More commonly, the instrument will be collected by a ventilation engineer or hygienist at the end of a shift or work period. The integrated exposure may be simply recorded at that time to yield an instant analog to a NIOSH 5040 test, without the need for outside lab analysis and a wait. Alternatively, some engineers will download the monitor's data (EC concentration as a function of time) to a personal computer, where they can correlate EC levels to the location of the miner, vehicles, or activity near the monitor's location. The locations in the mine or mine activities contributing to the greatest EC levels can be determined. If necessary, changes to personnel, vehicle use, or ventilation may be implemented to reduce EC concentrations. The monitor may then be used to instantly determine if such changes are having the desired effect on EC levels. The Airtec monitor may also be purchased with an optional 4-20 mA output, enabling the instrument to be connected to a mine's data network and monitored remotely.

Effect of Real-time Monitoring on Data Collection

The Airtec DPM monitor generates dozens, hundreds, or more values for a fraction of the cost of the NIOSH 5040 method, depending on how the mine engineer chooses to use the unit. By any measure, the cost of DPM monitoring is drastically reduced. This cost reduction should allow a corresponding increase in EC sampling.

Real-time sampling allows ventilation engineers and hygienists to develop comprehensive knowledge of the DPM levels in their mine. This information can be used to institute more responsive and effective DPM control strategies. For the mine operator, the reduction in DPM sampling and analysis costs go right to the bottom line and a finer control of ventilation rates may be feasible, resulting in reduced energy usage and cost. The greater frequency of sampling enabled by the real-time monitor will also allow the operator to reduce the likelihood of being found out of compliance with DPM regulations and having to suffer the costs of noncompliance. For the miners, the knowledge that a health threat is being monitored in real-time should be more assuring than only having the chance that this condition could be discovered weeks after it has taken place.

Examples of DPM monitoring in mines show how the real-time data can be more useful than time-averaged results. As shown in Figure 5, samplers for DPM were placed onto a vehicle to determine the concentration of DPM at the working face of the mine where the vehicle was operating. The average concentration (130 µg/m3) included the time the vehicle was outside of the mine to refuel. The real time data showed that the concentration at the face was actually slightly above the average concentration, and the concentration of DPM when the vehicle was at the face was 200 µg/m3 though the time weighted average was below the regulatory limit. The periods when the vehicle left the mine are also readily apparent. This information can be important to determine the ventilation rates needed to lower the DPM concentration in this area to below a certain value. In Figure 6, real-time EC data obtained from a monitor prototype is shown for a monitor mounted on a vehicle periodically working near a crusher. While the average concentration was 52 µg/m3, during the period when the vehicle was located near the crusher (where miners were present), EC values between 80 and 140 µg/m3 were recorded.

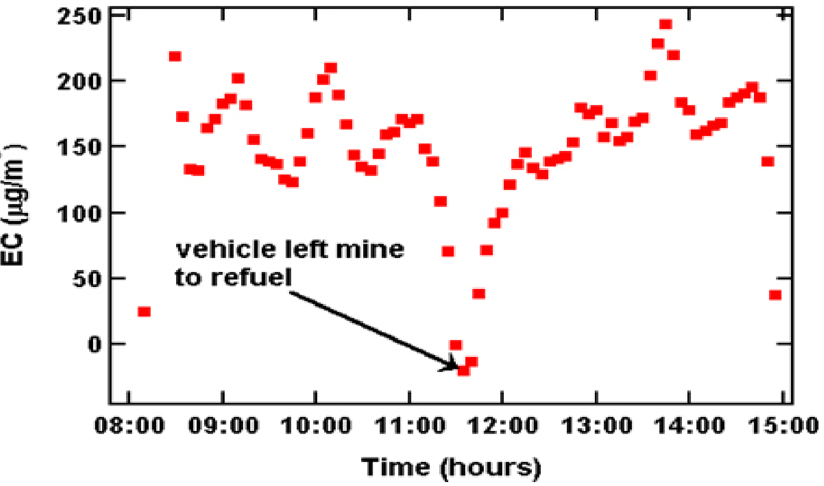


Figure 5

EC data recorded by the ICx Airtec DPM monitor operating on a vehicle in an underground mine.

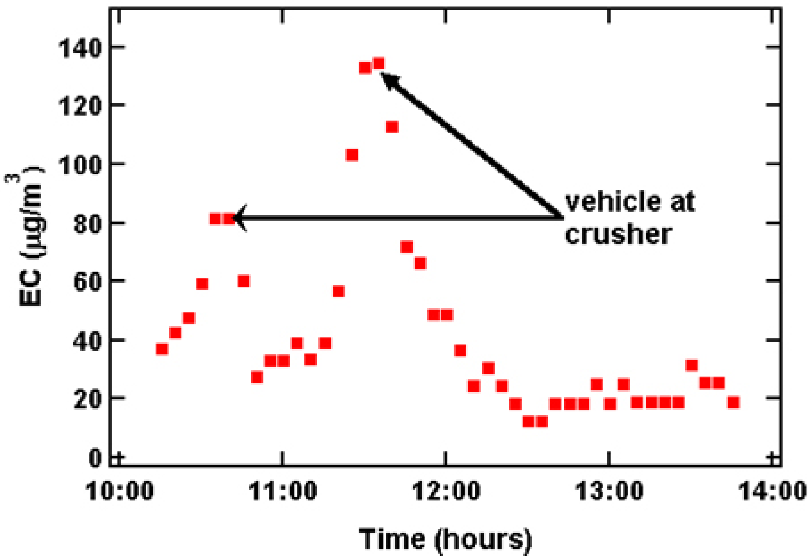
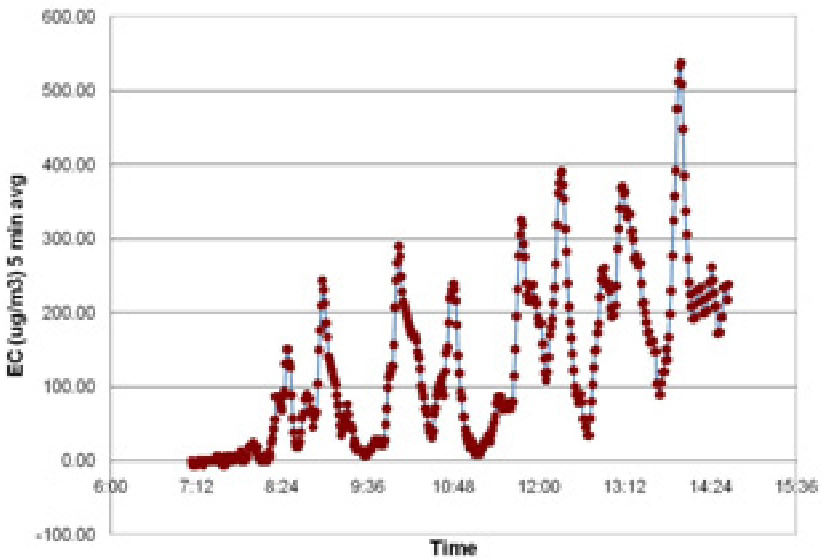


Figure 6
EC data obtained from an Airtec DPM monitor mounted on a vehicle in an underground mine operating in the vicinity of a crusher.



NIOSH 5040	real time	% bias
150	154	-2.7

Figure 7
Example of the correlation between Airtec real time measurement and NIOSH 5040 results

The real-time ICx Airtec DPM monitor described here accurately replicates the results of the NIOSH 5040 technique used for EC and TC measurements in underground mines. The monitor does so without the delay in obtaining results associated with a laboratory analysis method. The Airtec monitor provides a large amount of real-time data at a much lower cost and promises to be a useful tool for mine ventilation engineers and hygienists to allow active reductions in DPM concentrations.

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