

# Application Data Sheet

## The Model ES-640 Laser Particulate Monitor – A Real-World Example of Ambient Monitoring

### Introduction

Particulate matter of diameter less than ten microns –  $PM_{10}$  and particulate matter of diameter less than 2.5 microns –  $PM_{2.5}$  are classified by the United States Environmental Protection Agency – US-EPA as criteria pollutants. As a result the US-EPA has developed primary and secondary standards for  $PM_{10}$  and  $PM_{2.5}$ . The current US-EPA regulations require that 24-hour and annual averages be monitored for each of these pollutants. The US-EPA has designated as Reference Methods for both  $PM_{10}$  and  $PM_{2.5}$  integration-style, manual sampling techniques. In these methods ambient air is sampled at a constant rate through a device that physically separates  $PM_{10}$  or  $PM_{2.5}$  components from the larger particulate matter and then deposits the  $PM_{10}$  or  $PM_{2.5}$  components onto a pre-weighed filter paper. After sampling for a 24-hour period, the filter paper is then re-weighed and then based upon the flow rate through the sampling device, the particulate concentration – usually in  $\mu\text{g}/\text{m}^3$ , is determined. Such manual sampling devices are simple to operate and ultimately produce a direct measurement of the air quality.

The principle disadvantage of manual sampling methods is that they are labor intensive, and do not yield results in real time. Therefore, it is frequently not known whether or not hazardous air quality conditions exist until many days after the fact. Met One Instruments, along with other manufacturers have developed and are offering Equivalent Method  $PM_{10}$  monitors which allow data to be generated and measured in near-real time. These continuous monitors may be adapted to monitor  $PM_{2.5}$  in real time as well, although none yet has achieved US-EPA designation as Equivalent Methods for  $PM_{2.5}$ . The advantage of these instruments over their non-automatic counterparts is that can operate continuously and unattended for long periods of time. They produce results that have been demonstrated to be equivalent, to the US-EPA's satisfaction, to the manual Federal Reference Method. The Met One Instruments Model BAM-1020 is designated by the US-EPA to be such an Equivalent Method (EQPM-0798-122). By attaining such designation, the US-EPA permits operation of the BAM-1020 as a substitute for any application in which the Federal Reference Method would be mandated.

Many applications however do not require the high accuracy or the expense associated with automatic Equivalent Method  $PM_{10}$  monitors. These include monitoring at remediation sites, general air quality surveys and other applications not requiring data required to be able to uphold the level of legal scrutiny that US-EPA Equivalent or Reference Method Equipment permit. For such applications, particulate monitoring based upon laser light scattering is suitable and appropriate.

Furthermore, automatic Equivalent Method PM<sub>10</sub> monitors or such monitors adapted to monitor PM<sub>2.5</sub> have operational power requirements mandating the availability of a source of external power, further limiting their attractiveness.

## **Laser Light Scattering Methods for Ambient Particulate Monitoring**

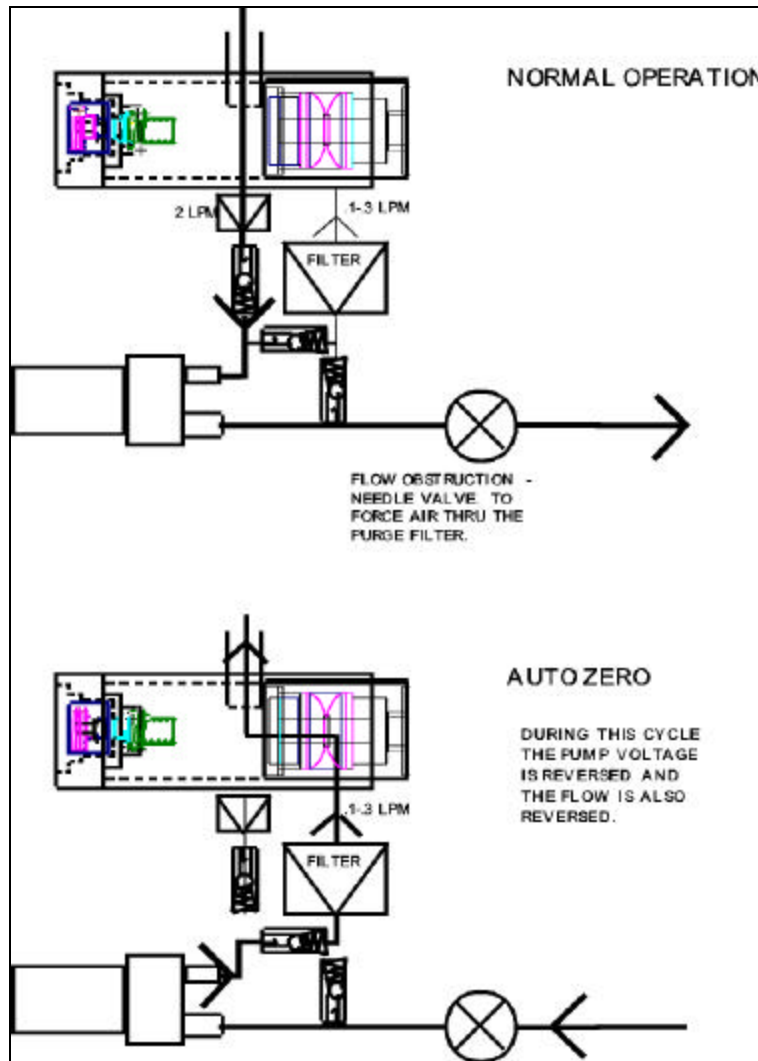
The Met One Instruments Model ES-640 was developed as a low-cost alternate to automatic Equivalent Method PM<sub>10</sub> monitors. It is also quite suitable for use in applications requiring the continuous monitoring of PM<sub>2.5</sub>. This device has the following desirable characteristics:

1. It is inexpensive. The typical Model ES-640 costs approximately 50-70 % less than a comparably equipped Model BAM-1020 – which is the least expensive US-EPA Equivalent Method mass monitor currently available.
2. It is truly portable. The Model ES-640 laser dust monitor does not require a permanent power source for operation, as do all other Equivalent Method mass monitors. Instead, it may be operated off of batteries or from a modest solar array.
3. It is lightweight. The Model ES-640 weighs approximately 15 pounds – only about 20 % as much as a comparably equipped Equivalent Method PM<sub>10</sub> monitor. It may easily be moved from one site to another.
4. It produces accurate reliable results as it was designed and built for ambient monitoring – not adapted from indoor air quality particle counters.

## **Principle of Operation of the ES-640**

A schematic diagram of the ES-640 is shown in Figure 1. Ambient air is sampled and then physically separated through the use of a sharp-cut cyclone device for either the PM<sub>10</sub> or the PM<sub>2.5</sub> fraction depending upon the cyclone device selected. The PM<sub>10</sub> or the PM<sub>2.5</sub> fraction entrained in ambient air at a sampling rate of two liters per minute is then passed through a chamber inside of the Model ES-640 in which a near infrared laser diode is continuously operating. Light emitted from the laser diode interacts with particulate matter entrained in the sample and is either absorbed, scattered or refracted. A silicon-PIN photodiode positioned directly in the path of the laser diode detects the light scattered off of the particulate matter passing through the chamber. Although the detector is directly in the path of the laser diode output, a beam stop prevents the detector from sensing the light coming directly from the laser. The chamber is large enough and the particulate concentration is high enough under most ambient conditions to preclude counting of the individual particles. Instead, a continuous signal is generated by the photodiode and then amplified.

Figure 1: Flow Schematic for ES-640



The magnitude of the signal produced from the silicon PIN photodiode detector depends upon the following factors based upon the constant illumination intensity from the laser diode:

1. Mass concentration of the particulate matter being sampled.
2. Chemical composition of the particulate matter being sampled.
3. Particle size distribution of the particulate matter being sampled.

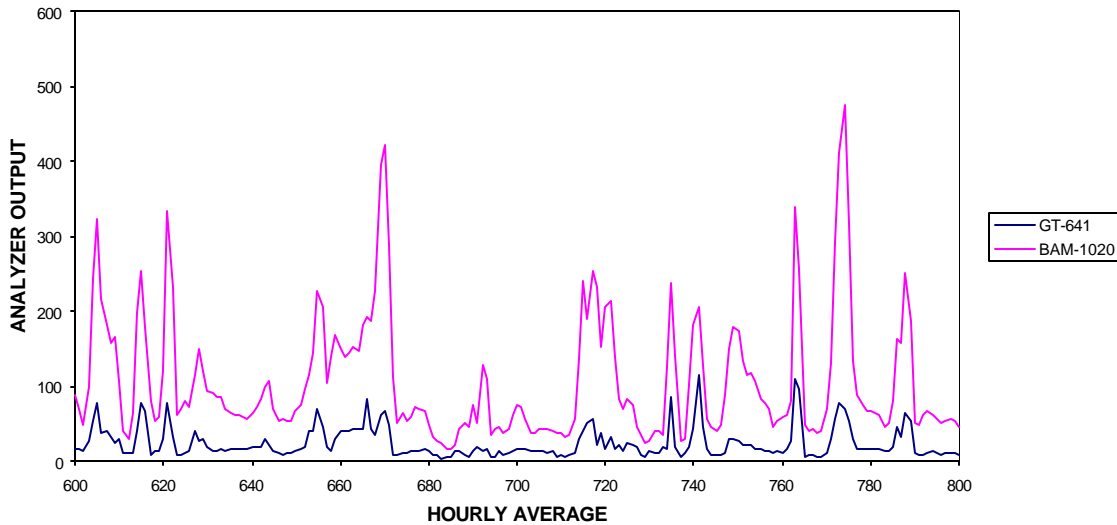
It is possible to generate an empirical relationship between the measured photodiode output ( $\mu\text{A}$ ) and true mass concentration ( $\mu\text{g m}^{-3}$ ) through the application of an empirically generated calibration coefficient – the “K” factor. The term “empirical” denotes the fact it is based upon field-generated observation and cannot be derived from first principles.

In practice, the “K” factor is determined by co-locating Model ES-640 unit in the field along side a reference standard, such as a Met One Instruments Model BAM-1020. We will show, in the following example, a step-by-step process of determining the “K” factor for a Model ES-640 followed by determination of mass concentration.

The data presented in the following example was taken over several months at a large mining operation in South America in which an air quality-monitoring network was designed, built and installed by Met One Instruments.

In the first figure, shown below we present 200 hours worth of hourly averages of a calibrated BAM-1020 against an un-calibrated ES-640. Notice that the BAM-1020 and the ES-640 are recording the same events, however the BAM-1020 reads consistently higher than the ES-640. The output of the BAM-1020 is in  $\mu\text{g}/\text{m}^3$ , the output of the ES-640 is in mV.

**BAM-1020 - ES-640 INTERCOMPARISON**



From this 100 hours worth of data we may develop a “K” factor that will be used to convert the raw output of the Model ES-640 into a predicted mass concentration. In order to do this, it is necessary to compare the integrated output of the Model BAM-1020 to the integrated output of the Model ES-640. If a continuous reference monitor, such as the BAM-1020 is being used, then we recommend at least 100 data points be used in order to ensure high accuracy. The “K” factor is determined by taking the ratio of the integrated outputs of the BAM-1020 to the ES-640. This is shown below:

$$I(BAM) = \int_0^t BAM(t) dt$$

$$I(ES) = \int_0^t ES(t) dt$$

The “K” factor may be found by taking the ratio of these two integrated outputs.

$$K \left( \frac{\mathbf{ng}}{m^3 \cdot \mathbf{mL}} \right) = \frac{I(BAM)}{I(ES)} = \frac{\int_0^t BAM(t) dt}{\int_0^t ES(t) dt}$$

In practice, we estimate the integrated output of each instrument to be simply the sum of the hourly averages. Therefore:

$$I(BAM) = \int_0^t BAM(t) dt \approx \sum_{i=1}^n B_i$$

$$I(ES) = \int_0^t ES(t) dt \approx \sum_{i=1}^n E_i$$

and

$$K \left( \frac{\mathbf{ng}}{m^3 \cdot \mathbf{mL}} \right) = \frac{\sum_{i=1}^n B_i}{\sum_{i=1}^n E_i}$$

where  $B_i$  and  $E_i$  are the hourly averages of the BAM-1020 and the ES-640 respectively. Applying this formula for the determination of K to the first 200 hours of co-located instruments, the “K” factor may be calculated:

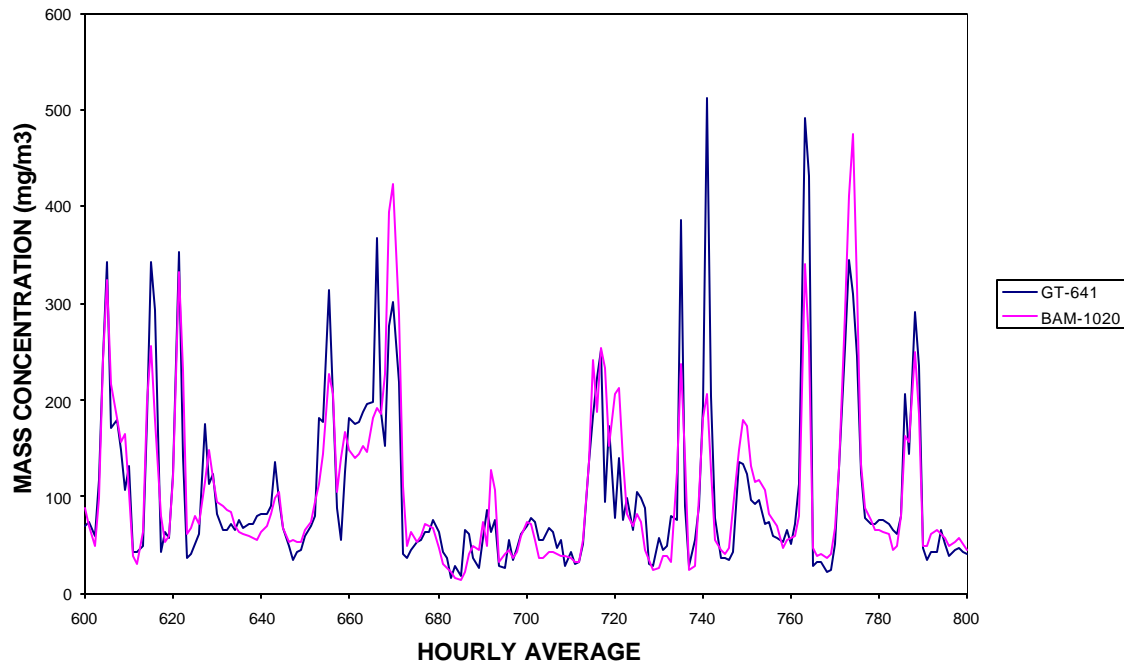
$$\sum_{i=1}^{200} B_i = 21,460$$

$$\sum_{i=1}^{200} E_i = 4,772$$

$$K = \frac{21,460}{4,772} = 4.497$$

Next, we multiply the ES-640 output by the “K” factor in order to convert its output into mass concentration. The results of this are demonstrated in the following graph.

## BAM-1020 - ES-640 INTERCOMPARISON

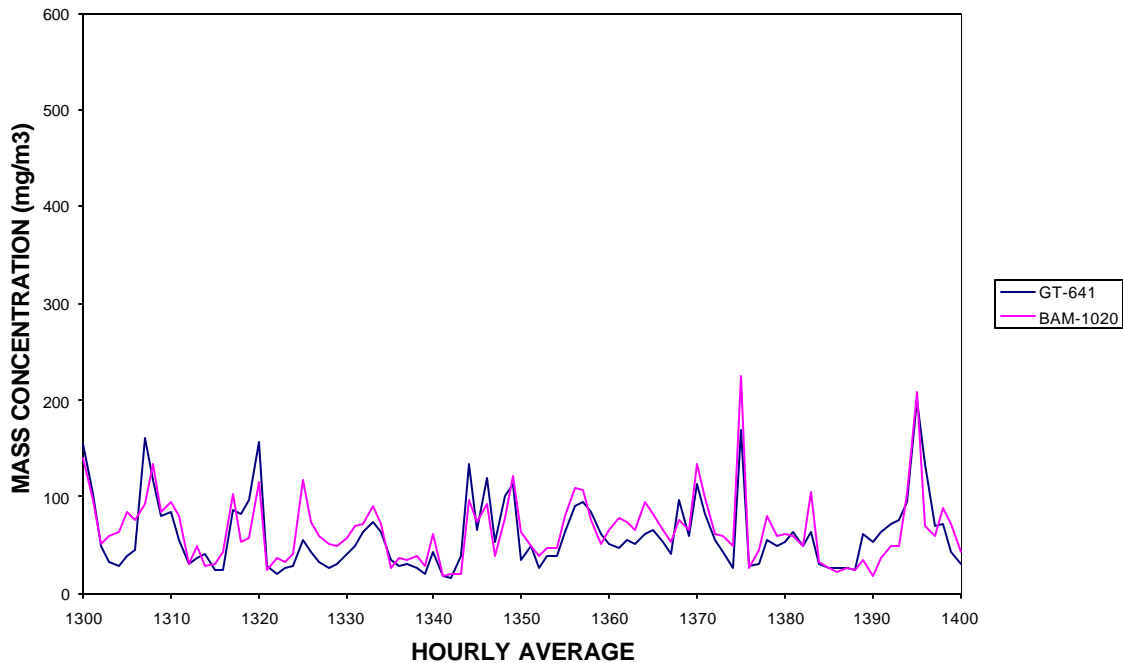


As one can clearly see, there is generally good agreement now between the BAM-1020 output – the reference, and the ES-640 output. Next, it's important to demonstrate that the same K factor, applied to data recorded many days later still demonstrates the good agreement between the BAM-1020 – reference method and the ES-640 output.

The following chart was recorded approximately one month after the calibration data was recorded. One can clearly see that there is still generally good agreement between the BAM-1020 and the ES-640.

The conditions under which this data was generated were exceptionally hostile. In addition to extraordinarily high concentrations of particulate matter, large temperature swings were recorded as were exceedingly high sulfur dioxide concentrations – frequently exceeding 2 ppm.

## BAM-1020 - ES-640 INTERCOMPARISON



### Conclusion

The Met One Instruments Model ES-640 has been demonstrated to be a low-cost alternative to more expensive, less portable US-EPA designated Equivalent Method monitors. It produces high-quality data for a number of applications where Equivalent Method automatic monitors are either unsuitable or unnecessary. These applications include but are not limited to:

- Applications where a permanent source of power is not available  
The Met One Instruments ES-640 can easily be operated off of batteries for several days between re-charging. With the incorporation of modestly sized solar panel arrays, the Model ES-640 can frequently operate unattended with no external power sources for several weeks.
- Ambient monitoring applications not requiring monitoring performed by US-EPA designated devices.  
The Met One Instruments Model ES-640 has been demonstrated to generate accurate data compared to both Equivalent Method and Reference Method PM<sub>10</sub> monitors as well as Reference Method PM<sub>2.5</sub> samplers when so equipped. For applications where law does not require the use of EPA designated equipment, the Model ES-640 is frequently an attractive alternative.
- Applications where true portability is a requirement.  
The Model ES-640 is lightweight, and may easily be mounted on a pole or a tripod. It is in a weatherproof enclosure.

- Applications where equipment and operational cost are overriding requirements. The price for the basic ES-640 is approximately \$5,000. This compares favorably to all Equivalent Method  $PM_{10}$  monitors.

It needs to be emphasized that the Model ES-640 is not meant to be a substitute for Equivalent Method automatic particulate monitors, such as the BAM-1020. However under many circumstances it provides a low cost, attractive alternative which produces high quality data.