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Accuracy Improvement of PM Measuring Instruments

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ABSTRACT

The PM_{10} concentration in the underground areas should be monitored to protect the health of the commuters in the underground subway system. The purpose of this work is to study the reliability of the instruments using light scattering method to measure the PM_{10} concentrations continuously. A linear regression analysis method is used to improve the performance of the instruments using light scattering method. Some experimental results show that a linear regression technique would be very helpful for the performance improvement of light scattering instruments such as Air test PM2500 and HCT 4103.

KEYWORDS: *PM10, underground subway system, light scattering method, linear regression analysis*

I. INTRODUCTION

Particulate matter with an aerodynamic diameter less than 10 μm (PM10) is one of the major pollutants in subway environments. The PM_{10} concentration in the underground areas should be monitored to protect the health of the commuters in the underground subway system [1-9]. Seoul Metro and Seoul Metropolitan Rapid Transit Corporation measure several air pollutants regularly. As for the PM_{10} concentration, generally, measuring instruments based on β-ray absorption method are used.

In order to keep the PM_{10} concentration below a healthy limit, the air quality in the underground platform and tunnels should be monitored and controlled continuously. The PM_{10} instruments using light scattering method can measure the PM_{10} concentration every once in several seconds. However, the reliability of the instruments using light scattering method has still not been proven since they measure the particle number concentration rather than the mass concentration [10].

The purpose of this work is to study the reliability of the instruments using light scattering method to measure the PM_{10} concentrations continuously in the underground subway stations. A linear regression analysis method is used to improve the performance of the instruments using light scattering method. The data measured by these instruments have to be converted to actual PM_{10} concentrations using some factors. These findings propose that the instruments using light scattering method can be used to measure and control the PM_{10} concentrations of the underground subway stations.

II. Measurement of Particulate Matter

2.1 Airtest PM2500 laser particulate monitor:

Airtest PM2500 which is shown in Fig. 1 is a two-channel laser particulate meter that displays the average counter of particles of 1 to 5 micron each minute and larger than 5 micron. One can change several options with the front buttons. The characteristics of Airtest PM2500 laser particulate monitor is summarized as follows:

- Designed for use in homes or offices.
- A breakthrough in cost effective laser particle counting that makes this important measurements accessible to all.
- Professional laser particle counter performance in a personal monitor at less than 5% of the cost.
- The PM2500 counts particulates two critical size ranges
- Particles in the 1.0 to 5.0 micron size range are small enough to stay airborne for extended periods of time and can go deeper into the respiratory system.
- Particles in the 5 microns and greater range are larger and tend to settle out in still air. Pollen, insect and dust mite related particles are often in this range.
- Display indicates 100's of particles per cubic foot averaged over the past minute.
- Calculates and displays measurement history by minute, hour and day.
- Monitor mode wakes the unit every hour to sample particulate concentration.
- Horizontal bar graph indicates real time detection activity.

Fig.1. Airtest PM2500 laser particulate monitor

The general specifications of Airtest PM2500 laser particulate monitor is summarized as follows:

- Sampling method: Laser particle counter. This device is a Class 1 laser product and complies with 21 CFR 1040.10 and 1040.11.
- Particle channels: 1.0-5.0 um, 5.0+ um
- Flow rate: 0.06 cfm nominal
- Concentration limit: Coincidence loss less than 10% at 1,000,000 particles/cubic foot
- Display format: Particles/cubic foot (divided by 100) averaged over 1 minute
- Data storage 60 minutes of minute averages, 24 hours of hourly averages, 30 day of daily averages
- Dimensions:7.5 x 5.0 x 3.5 inches
- Weight approximately 12 oz
- Power: 9VDC, 400mA, 110VAC plug-in transformer provided.

2.2 HCT 4103 particle sensor: HCT 4103 particle sensor is shown in Fig. 2.

Fig.2. HCT 4103 particle sensor

A light scattering particle sensor provides an extremely sensitive tool for the measurement of aerosol concentration and particle size. HCT Particle Sensor model 4103 can provide instantaneous and continuous particle monitoring information. The characteristics of HCT 4103 particle sensor is summarized as follows:

- Compact, convenient, light weight
- Sizing sensibilities from 0.3 ~ 10 ㎛
- Easy to install in narrow space
- Smooth, durable exterior design
- Real time data display
- Easy system interface
- Compliant with JIS standards

The general specifications of HCT 4103 particle sensor is summarized as follows:

- Size range: 0.3 ~ 10 ㎛
- Flow rate: 0.1 CFM (2.83 L/min)
- Counting efficiency: 50% @ 0.3 ㎛, 100% for particles > 0.45 ㎛ (meets JIS)
- Laser source: Laser diode
- Zero count level: < 1 count / 5 minutes (meets JIS)
- Vacuum requirements: External vacuum
- Maximum particle concentration: 5,000,000 particles/ft^3
- Front panel display: LCD panel
- Output interface: RS422
- Dimensions(LWH): 84 X 105 X 60 mm
- Weight: 0.5 kg
- Power: 220 VAC, 60Hz

2.3 Linear regression analysis: Generally, a linear regression straight line is expressed as eq (1).

$$y = \hat{m}x + \hat{b} \tag{1}$$

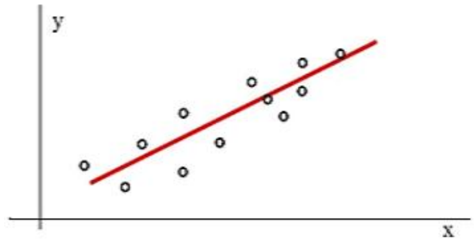

Fig.3. Approximation to a straight line

In Fig. 3, the data dotted in small circles can be approximated to a straight line using a linear regression analysis method. The error e can be expressed in eq (2)

$$e = \sum_{i=1}^{N} (y_i - (\hat{m}x_i + \hat{b}))^2 \tag{2}$$

In order to find the unknown variables $\hat{m}$ and $\hat{b}$ which minimize the error e, the partial differentiations are used as

$$\frac{\partial e}{\partial \hat{m}} = -2\sum_{i=1}^{N} x_i (y_i - (\hat{m}x_i + \hat{b})) = 0$$
$$\frac{\partial e}{\partial \hat{b}} = -2\sum_{i=1}^{N} (y_i - (\hat{m}x_i + \hat{b})) = 0 \tag{3}$$

From eq (3), we can get eq (4).

$$\hat{m}\sum_{i=1}^{N} x_i^2 + \hat{b}\sum_{i=1}^{N} x_i = \sum_{i=1}^{N} x_i y_i$$
$$\hat{m}\sum_{i=1}^{N} x_i + \hat{b}N = \sum_{i=1}^{N} y_i \tag{4}$$

Eq (5) can be obtained using eq (4).

$$\hat{m} = \frac{N\sum_{i=1}^{N} x_i y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{N\sum_{i=1}^{N} x_i^2 - (\sum_{i=1}^{N} x_i)^2}$$
$$\hat{b} = \frac{1}{N}(\sum_{i=1}^{N} y_i - \hat{m}\sum_{i=1}^{N} x_i) \tag{5}$$

2.4 Application of linear regression analysis:

The PM measuring instruments Airtest PM2500 and HCT 4103 were installed at a subway station for 480 minutes as shown in Fig. 4. The PM_{10} measurement data of Airtest PM2500 and HCT 4103 are shown in Fig. 5. Using the linear regression analysis technique, the measured PM_{10} concentration of Airtest PM2500 in Fig. 5 can be corrected as shown in Fig. 6. The $PM_{2.5}$ measurement data of Airtest PM2500 and HCT 4103 are shown in Fig. 7. Using the linear regression analysis technique, the measured $PM_{2.5}$ concentration of Airtest PM2500 in Fig. 7 can be corrected as shown in Fig. 8. It can also be seen in Fig. 6 and Fig. 8 that the measurement data of Airtest PM2500 was closely similar as those of HCT 4103 if they were corrected using a linear regression technique. So, it can be concluded that a linear regression technique would be very helpful for the performance improvement of light scattering instruments such as Airtest PM2500 and HCT 4103.

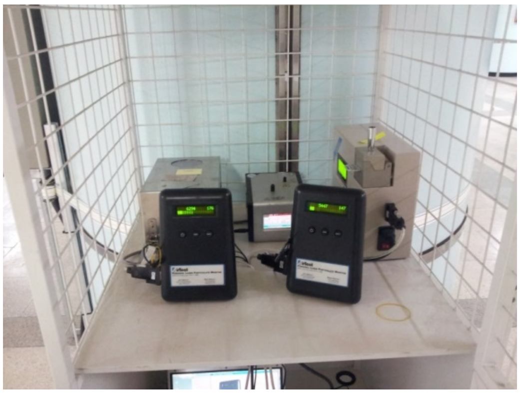

Fig.4. The PM measuring instruments Airtest PM2500 and HCT 4103 installed at a subway station

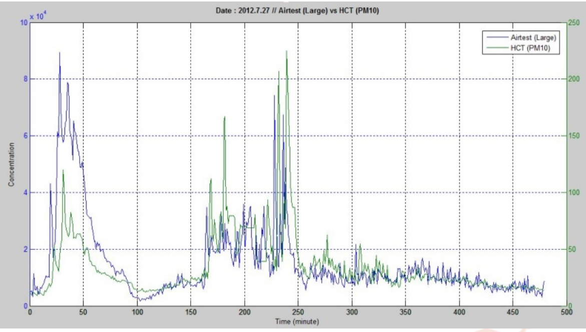

Fig.5. PM_{10} measurement data of Airtest PM2500 and HCT 4103 (Before correction)

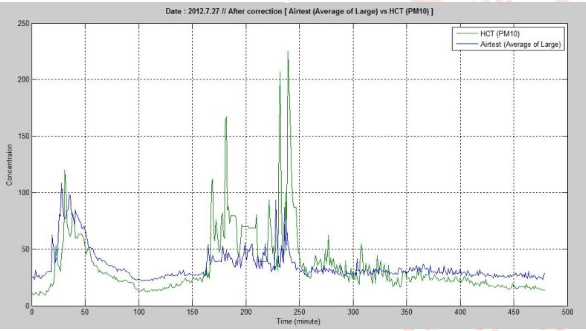

Fig.6. PM_{10} measurement data of Airtest PM2500 and HCT 4103 (After correction)

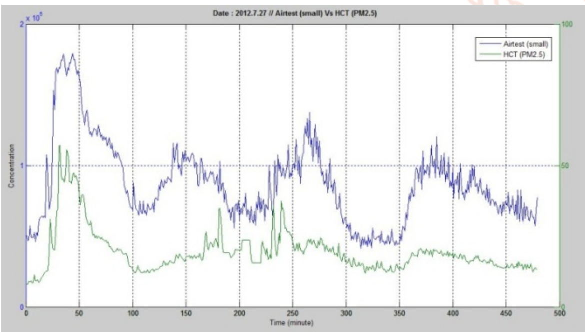

Fig.7. $PM_{2.5}$ measurement data of Airtest PM2500 and HCT 4103 (Before correction)

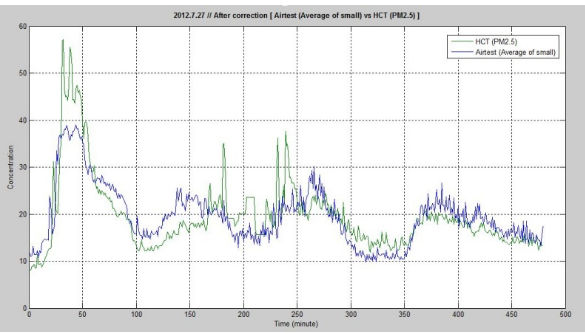

Fig.8. $PM_{2.5}$ measurement data of Airtest PM2500 and HCT 4103 (After correction)

III. Concluding Remarks

The metropolitan city of Seoul uses more energy than any other area in South Korea due to its high population density. It also has high emissions of air pollutants. Since an individual usually spends most of his/her working hours indoors, the ambient air quality refers to indoor air quality. In particular, PM_{10} concentration in the underground areas should be monitored to preserve the health of commuters in the subway system. Through some experimental studies, we found that a linear regression technique would be very helpful for the performance improvement of light scattering instruments such as Airtest PM2500 and HCT 4103. These findings propose that the instruments using light scattering method can be used to measure and control the PM_{10} concentrations of the underground subway stations.

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