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# Air Quality Sensor Network for Philadelphia

*-Data Validation-*

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# Air Quality Sensor Network for Philadelphia

## *-Data Validation-*

This document is presented as a supplement to the Air Quality Sensor Network for Philadelphia senior design project at Drexel University. The purpose of this project is the development and use of a low-cost, low-profile, and easily maintainable network of sensor nodes. These sensor nodes are used to detect the presence of particulate matter (PM) in ambient air.

As stated by the Environmental Protection Agency (EPA), "The size of particles is directly linked to their potential for causing health problems" [1]. At this date, the EPA enforces regulations concerning two particle size categories, PM<sub>2.5</sub> and PM<sub>10</sub>, where the numerical designation refers to the size in micrometers (i.e. PM<sub>2.5</sub> refers to particles smaller than 2.5 micrometers in diameter).

This document will discuss the efforts made by this design team to validate the PM<sub>2.5</sub> measurements of the system against industrial grade monitors that are used at EPA facilities. PM<sub>10</sub> data was not available for comparisons and will need to be revisited at a later date.

## Theory

There are two well used methods for monitoring PM concentrations. The EPA Federal Reference Method uses filters to collect particulate matter over a period of time and then weighs the filters at a later date to determine the PM concentration [2]. The EPA Federal Equivalent Method is the practice of continuously monitoring particulate matter, which allows for more "real-time" results. The latter is not quite as accurate, but as the name implies, the method has been approved for use by the EPA as an equivalent method. Both methods yield results as units of micrograms per cubic meter.

This project uses Dylos DC1100 Pro laser particle counters to accomplish the task of monitoring PM concentration. These counters, however, do not yield a microgram per cubic meter concentration. Instead they output the number of particles per 0.01 cubic feet. These results can be converted to the proper units in order to compare them to the EPA standard.

It is important to note that this conversion is only a strong approximation; because it is impossible to quantify the exact properties of each of the thousands of microscopic particles

being counted, several assumptions are made in the calculation. These assumptions are noted as follows:

- All particles are spherical, with a density of  $1.65 \times 10^{12} \mu\text{g}/\text{m}^3$  [3]
- The radius of a particle in the PM<sub>2.5</sub> channel is  $0.44 \mu\text{m}$  [4]
- The radius of a particle in the PM<sub>10</sub> channel is  $2.60 \mu\text{m}$  [4]
- $0.01 \text{ ft}^3$  can be converted to  $\text{m}^3$  by multiplying by 3531.5

With the radius of both particle types known, it is possible to derive the volume and multiply by the particle density. This calculation results in the following approximations of mass for each particle type:

- The mass of a particle in the PM<sub>2.5</sub> channel is  $5.89 \times 10^{-7} \mu\text{g}$
- The mass of a particle in the PM<sub>10</sub> channel is  $1.21 \times 10^{-4} \mu\text{g}$

Finally, the following equation will convert the number particles per 0.01 cubic feet to the number of micrograms per cubic meter and the results can be directly compared with other EPA data:

$$PM \text{ Concentration } \left( \frac{\mu\text{g}}{\text{m}^3} \right) = \text{Number of Particles} \times 3531.5 \times \text{Particle Mass}$$

## Humidity

Consider how the action of mixing water with soil or wood affects each. In both cases, the water will be absorbed to some degree and the soil and wood will obtain a greater mass. This does not only occur when water is in liquid form, as is indicated by doors swelling and becoming hard to open and close during times of high humidity.

This absorption also takes place on the microscopic scale with particulate matter. "Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles" [1]. While not each of these components may be susceptible to the swelling effects of water, it has been observed that many of them are. In a paper by Lee et. al., it was concluded that in the presence of high humidity, particles take on water and gain mass [4]. It was also observed that there was a difference between rain conditions and dry conditions, as rain would "clean the air" by washing particles away [4].

This phenomenon would not be accounted for by a laser particle counter because it only counts the number of particles and does not make adjustments for mass. In order to make sure that this

is accounted for, adjustments need to be factored into the count-to-concentration conversion algorithm previously discussed.

## Correction Algorithm

After using this system to measure the particle count and convert to concentration, an additional step takes place in order to account for any additional mass that particles may have acquired due to weather conditions, such as humidity and rain. This step involves multiplying the concentration by a correction factor, which will now be discussed.



Figure 1 - Drexel monitor at AMS site

In order to define the correction factors it was essential to have a baseline to compare data against. This system was therefore deployed in a side-by-side arrangement with an industrial grade monitor at Air Management Services (AMS) in Philadelphia, PA. Figure 1 to the left shows our monitor placed upon an AMS monitor. The specific monitor was a Met-One Instruments BAM-1020, which is a FEM Monitor. Collecting data from the same location as an industrial monitor allowed for the direct comparison of results.

For 33 days, data was collected in this side-by-side deployment, resulting in a total of 3,177 usable data points. The concentration measured by our system was, on average,  $4.98 \mu\text{g}/\text{m}^3$  (95% CI 4.71 to 5.24) lower than measured by AMS. This substantiates the claim that weather conditions will result in increased mass for each particle counted by the system, as the average mass was too low.

In order to define the correction factor that should be used to correct this issue, it was necessary to separate the data points into humidity-level 'buckets'. For each bucket, the delta between our concentration and the AMS concentration was plotted against humidity in order to attempt a visual recognition of trends between humidity levels and the delta. We then incorporated a linear trend line with a y-intercept of 0.0. Doing so allowed us to adjust the correction factor until this trend line represented as small of a delta value as possible. This can be seen below in Figure 2. The correction algorithm which allows these results can be defined by the following relation,

$$F = O \times H \times C$$

where F is the final concentration, O is the concentration obtained after converting from particle

count, H is the relative humidity percentage, and C is the correction factor. Tables 1 below shows the correction factor values for each bucket. As mentioned previously, a different correction is used in the presence of rain.

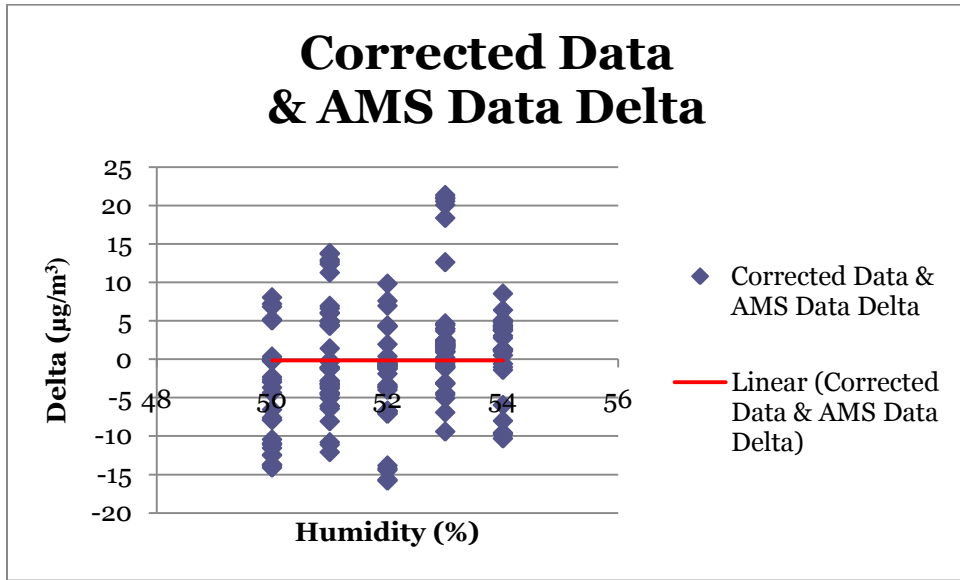


Figure 2 - Chart showing the result of process used for obtaining correction factor

Humidity (%)	Dry Correction	Rain Correction
0-19	10.1	6.4
20-24	8.75	6.4
25-29	8	6.4
30-34	8	6.4
35-39	8	6.4
40-44	7	6.3
45-49	6	6.3
50-54	5.75	5.7
55-59	5.5	5.5
60-64	5.5	4.2
65-69	3.5	4.1
70-74	3.5	3.2
75-79	3.75	3.2
80-84	2.25	2.1
85-89	1.5	2.1
90-94	0.825	0.8
95-100	0.525	0.5

Table 1 - Humidity Correction Factors

With the correction accounted for, the concentration measured by our system improved to an average of  $0.63 \mu\text{g}/\text{m}^3$  (95% CI 0.4 to 0.87) lower than measured by AMS. Figure 3 below shows the actual concentration measurements for a snapshot of the deployment. Both uncorrected and corrected concentration measurements are plotted along with the AMS concentrations. This figure shows that the data collected by this system now trends very nicely with the data collected by AMS.

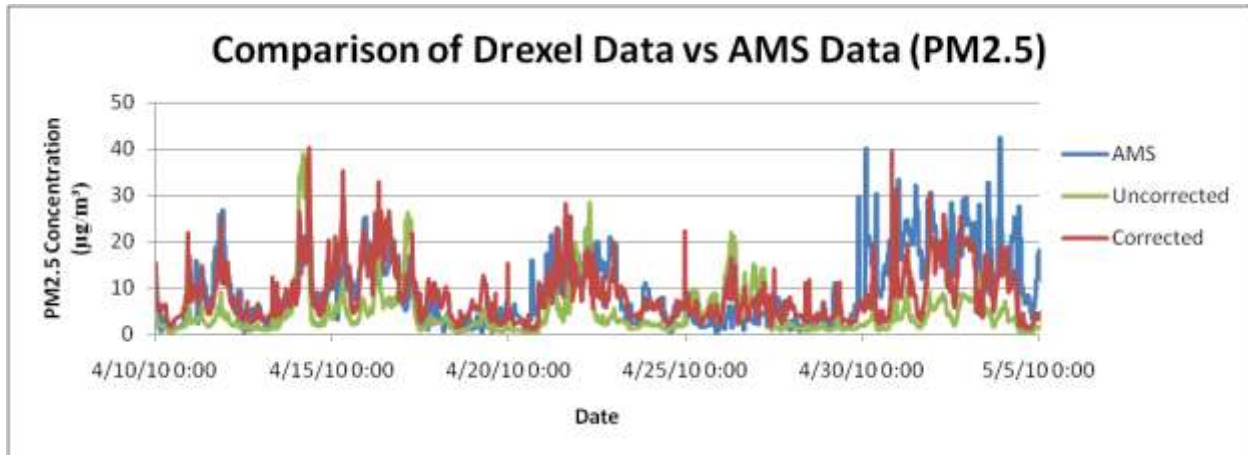


Figure 3 - Comparison of AMS data and both uncorrected and corrected Drexel data

## Conclusions

Particulate matter composition can be very diverse, but much of the composition is subject to swelling and fluctuations in mass due to humidity and rain. In order for this system to provide reliable results these fluctuations must be accounted for during the conversion from particle count to concentration.

In an effort to validate the results from this system, we have performed a side-by-side analysis with data obtained by an industrial grade monitor by a regulatory partner of the EPA. This analysis has shown that the correction algorithm discussed in this document will improve the average reading to be within  $0.63 \mu\text{g}/\text{m}^3$  (95% CI 0.4 to 0.87) of that obtained by the Met-One Instruments BAM-1020.

The calculations involved in this correction algorithm are based upon some assumptions that generalize the makeup of Particulate Matter. It is our concession that not all particles conform entirely to these assumptions, and as such, this correction algorithm yields only an approximation to actual measurements. However, as we have shown through this analysis, the

approximation does trend in the same fashion as seen with industrial-grade monitors and typically produces very near results.

As with any calibration technique, additional steps should be carried out in the future. Additional days of data should be obtained and compared, as well as comparing each monitor in the network against one another. Finally, because AMS is continuously updating their own algorithms to ensure accuracy, continued validation is an important aspect of this system[5].

## References

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