# The Use of TEOMs and Sampling Arrays to Quantify the Capture Efficiency of Fugitive Dust Emissions from Ready Mixed Concrete Loading

Edward Herbert, III
Environmental Director, National Ready Mixed Concrete Association
Silver Spring, Maryland
and
John Richards, Ph.D., P.E.
President, Air Control Techniques, P.C.
Cary, North Carolina

## ABSTRACT

The Ready Mixed Concrete Research Foundation ("RMC Foundation") and Air Control Techniques, P.C. have developed new sampling procedures to evaluate particulate matter emissions from ready mixed concrete sources. This paper summarizes the successful application of $PM_{10}$ TEOMs and Method 5D-type sampling arrays to continuously monitor fugitive dust emissions from ready mixed concrete truck mix and central mix loading operations. The fugitive mass emissions measured by the TEOM were compared with the mass inlet loadings to the fabric filter measured using the EPA Conditional Method 040 dual cyclone sampling train in order to determine the overall efficiency of the hoods on the loading operation at ready mixed concrete plants. This testing approach is a significant advancement over the previously available measurement technique that was limited to the qualitative estimates of fugitive capture efficiencies based on visible emission observations.

The RMC Research Foundation and Air Control Techniques, P.C. used a conventional TEOM system to measure the emissions from the fabric filter serving the loading operation. Due to the very low particulate mass loadings in this gas stream, the TEOM provided a significant improvement over conventional sampling techniques.

The new sampling procedures were used at six ready mixed concrete plants located in South Carolina, North Carolina, and Virginia. These tests were conducted in accordance with an emission testing protocol posted on the EPA ttn more than a month prior to the start of the tests. No significant problems were experienced in applying these new procedures to the six plants.

Ready mixed concrete loading operation capture efficiencies measured at three truck mix plants ranged from 93.1% to 99.5% and averaged 97.3%. The measured capture efficiencies at three central mix plants ranged from 97.2% to 99.3% and averaged 98.0%. These capture efficiencies are above those measured using qualitative visible emission observation procedures in the early 1990s.

Due primarily to the measured high capture efficiencies, the overall particulate matter emissions measured from truck mix loading operations were substantially lower than those measured previously and reported in AP42. The emissions from the central mix loading operations were slightly higher than those reported in AP42 based on the qualitative visible emission observation procedures.

## BACKGROUND INFORMATION

The presently available hood capture efficiency data applicable to ready mixed concrete plant loading operations were obtained during 1993 in tests sponsored by the U.S. EPA at two plants: one in Maryland and one in Virginia. In both test programs, EPA used qualitative visible emission evaluations to estimate capture efficiency. Observers arbitrarily assigned a capture efficiency value during the loading of each truck based on the opacity of the plume of dust observed during part of the loading cycle. These truck-by-truck fugitive dust capture efficiency estimates were averaged over a several hour period to determine a test-average capture efficiency.

Since the completion of these tests in 1993, tapered electrode oscillating microbalance ("TEOM") instrumentation has been developed by Rupprecht & Patashnick ("R&P"). These instruments provide a continuous, real time measurement of $PM_{10}$ concentrations and have been accepted as a U.S. EPA reference method (Ambient $PM_{10}$ Compendium Method IO-1.3). TEOMs are now used extensively in state and local agency air quality monitoring networks. Due to the availability of this advanced particulate matter monitoring technique, the subjective visible emission observation technique for hood capture efficiency evaluation is no longer necessary.

The RMC Research Foundation and Air Control Techniques, P.C. developed a testing program using the TEOMs. As part of this testing program, the $PM_{2.5}$, $PM_{10\text{-}2.5}$, $PM_{10}$, and total particulate matter emissions at the inlets and outlets of the fabric filters serving the loading operations were also measured. All of the testing procedures were described in a detailed testing protocol posted on the EPA ttn website one month before testing was started. Air Control Techniques, P.C. conducted tests at six ready mixed concrete plants during the period from December 2003 through May 2004. The plants tested are representative of ready mixed plants throughout the U.S.

## TEST PROCEDURES

### Capture Efficiency Test Procedures

The RMC Research Foundation and Air Control Techniques, P.C. designed and used a downwind sampling array to quantify the capture efficiency of the ready mixed concrete plant hood systems. This sampling array design was based on the sampling principles adopted by EPA in Method 5D (40 CFR Part 60, Appendix A, Method 5D) used for sampling open top fabric filter systems. This sampling array is also similar to the traversing hood system designed and used by Air Control Techniques, P.C. to measure fugitive particulate matter emissions[1] from sloped vibrating screens at stone crushing plants.

A set of downwind sampling arrays was mounted vertically on the side walls of the truck loading area and at the inlet of central mixing operations to measure the fugitive dust mass flux through a defined 140 to 200 square foot area[2]. The sampling arrays were mounted directly adjacent to the transfer operations. Due to the close positioning of the sampling arrays, all of the fugitive emissions passed through the area defined by the array. The arrays were designed to allow free

[1] The emission factors measured using the screening operation traversing hood system have been published in AP42 Section 11.19.2 (Fifth Edition, 1995).
[2] The array area for the inlet to the central mixer was limited to 140 square feet due to space constraints.

movement of ambient air past the loading operation. This was important to ensure that the array did not influence particle entrainment from the loading operations.

There were sixty sampling points in the set of two arrays. This number of points exceeds the requirements of thirty sampling points specified in EPA Method 5D. Air was drawn into all sixty nozzles simultaneously. The area monitored by the sampling arrays included all of the downwind area subject to dispersion of the fugitive particulate matter. The gas transport velocities through all sampling tubes and ductwork of the array were maintained at a minimum of 3,500 feet per minute to prevent settling of dust in the tubes and ductwork. Sampling arrays are shown in Figures 1, 2, and 3.

Figure 1. One of Two Sampling Arrays in Service at a Truck Mix Operation
(Array mounted on the downwind side of the truck being loaded)

Each of the sampling arrays was ducted together to yield a single sample gas stream. This gas stream was directed past an enlarged duct with the intake for an ambient TEOM monitor meeting the requirements of Method IO-1.3. The gas flow rate through this enclosure was maintained at less than 5 mph. The TEOM had a $PM_{10}$ sampling head and operated at a flow rate of 16.67 liters per minute. The TEOM was operated in accordance with U.S. EPA Reference Method IO-1.3. The instrument was calibrated in accordance with Section 12.1 of Method IO-1.3.

The TEOM is considered a primary standard for measuring particulate matter. The sample gas stream is acquired in an omni-directional head and passes through an inertial separator to remove particulate matter larger than 10 micrometers aerodynamic diameter. The $PM_{10}$ particulate matter in the sample gas stream is deposited on an oscillating electrode. The change in the frequency of oscillation is directly related to the increase in the mass of particulate matter.

Figure 2. Sampling Array at the Inlet of a Central Mix Operation

Figure 3.  Sampling Array at the Outlet of a Central Mix Operation

The TEOM instrument was mounted on a secure base and was protected from severe vibration. The TEOM was equilibrated prior to the start of the first test run on each test day.

The fugitive $PM_{10}$ emissions ($PM_{10}$ escaping the plant hood system) were measured by multiplying the TEOM measured $PM_{10}$ concentration in the array sample gas stream by the ambient airflow rate through the sampling array.  A Davis Instruments, Inc. meteorological monitoring station was located within 20 feet of the sampling arrays and at the same elevation as the sampling arrays to measure the wind direction and wind speed through the arrays.  Air Control Techniques, P.C. used multiple wind speed and direction monitoring stations on the plant site located in areas immediately adjacent to the sampling array to provide confirmation data.  Wind pennants were also mounted on the arrays to provide a direct indication of wind direction through the array.

All of the particulate matter measured by the TEOM during the time that the equipment being tested was operating was assumed to originate as fugitive emissions from the mixing operation. This approach introduced a bias to lower-than-true capture efficiency due to the presence of ambient $PM_{10}$ in the air upwind of the plant and due to other fugitive $PM_{10}$ sources in the plant area (i.e. roadways and truck exhaust).  There was no practical means to identify and correct for these other sources of $PM_{10}$ on a continuous basis.

The capture efficiency for the loading operation was calculated by comparing (1) the uncaptured $PM_{10}$ fugitive emissions measured using the TEOM and sampling arrays with (2) the captured $PM_{10}$ emissions at the inlet to the fabric filter.

### Process Operating Data and Meteorological Data

A number of variables potentially influence the particulate matter emission rates from the concrete mix operations.

- Raw material moisture levels
- Raw material silt contents
- Raw material size distribution
- Concrete raw material mix
- Production rates
- Wind speed
- Wind direction

All of these variables were monitored during the tests at each of the six plants.  These voluminous data are provided in the full test report that is available from the RMC Research Foundation.

### Captured Particulate Matter Emission Rates

U.S. EPA Conditional Method 040 tests were conducted at the inlets of the mixing operation fabric filter particulate matter control devices to simultaneously measure the concentrations of (1) total particulate matter, (2) $PM_{10}$ particulate matter, (3) $PM_{10-2.5}$ particulate matter, and (4) $PM_{2.5}$ particulate matter.  The $PM_{10}$, $PM_{10-2.5}$, and $PM_{2.5}$ emission concentrations were measured directly in this sampling train by partitioning the captured particulate matter into several size ranges.  $PM_{10}$ was measured as the sum of the $PM_{10-2.5}$ and $PM_{2.5}$ particulate matter.  Total particulate matter was measured as the sum of $PM_{10}$ particulate matter and all of the solids having a size greater than 10 micrometers that were captured in the cyclone and sampling train. The $PM_{10}$ emission rates were compared with the TEOM data to calculate the loading operation capture efficiency.

The Conditional Method 040 sampling train consists of a $PM_{10}$ cyclone followed by a $PM_{2.5}$ cyclone.  A 47 mm filter was mounted after the $PM_{2.5}$ cyclone.  This sampling train was identical to the EPA Method 201A (40 CFR Part 60, Appendix A, Method 201A) sampling train except that a $PM_{2.5}$ cyclone was inserted between the $PM_{10}$ cyclone and the filter.  Both cyclones and the filter were coupled closely together so that the entire sampling head shown in Figure 4 could be positioned entirely in the gas stream in large ducts. Due to the small size of the fabric filter inlet ducts at all of the plants tested[3], only a portion of the sampling head was inside the duct at some of the traverse points.

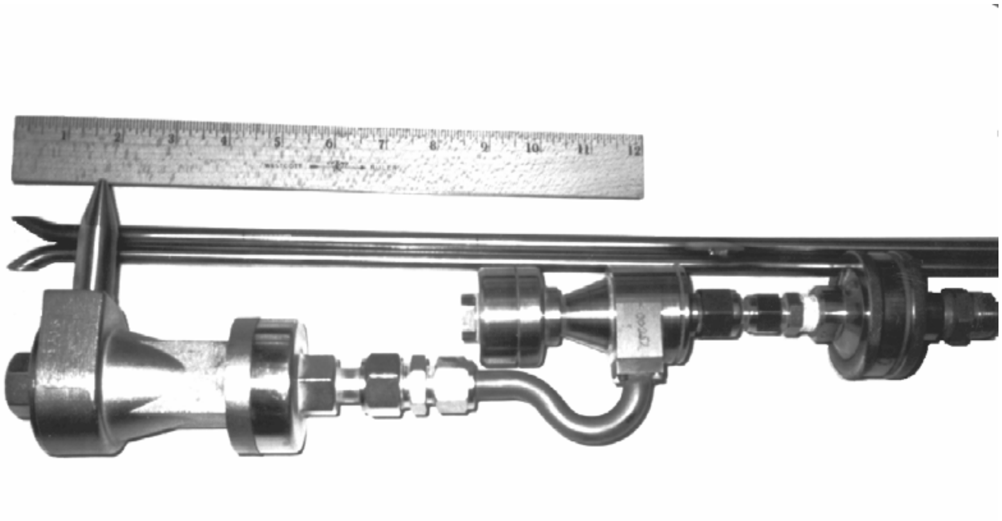

Figure 4. EPA Method 040 Sampling Head

As with Method 201A, the Conditional Method 040 sampling system is a constant sampling rate technique. It is important to maintain the actual sample gas flow rate in each of the cyclones at a rate that provides the desirable particle collection efficiencies. The $PM_{10}$ cyclone must collect particles that have a $D_{50}$ (particle size collected with 50% efficiency) between 9.0 and 11.0 micrometers in order to be consistent with Method 201A. The $PM_{2.5}$ cyclone (the cyclone on the right side in Figure 3) should optimally have a cut diameter between 2.25 and 2.75 micrometers. Using the cyclone performance curves, Air Control Techniques, P.C. calculated the sampling rates necessary to simultaneously satisfy the required $PM_{10}$ cyclone and cyclone $PM_{2.5}$ $D_{50}$ ranges.

Conditional Method 040 was conducted in accordance with all applicable EPA sampling and quality assurance requirements. Each test consisted of a set of three 1-hour test runs per test location. Particulate matter samples were withdrawn isokinetically (100% ± 20%) from the test locations.

During the initial set of tests at a truck mix plant, EPA Conditional Method 040 was also used at the fabric filter outlet; however, the total particulate matter catch weights in the sampling trains ranged from only 1.0 to 2.3 milligrams. These small catch weights were distributed in several different particle size fractions. Air Control Techniques, P.C. determined that tests sponsored by EPA[4] in 1993 also experienced low catch weights. To minimize data precision problems at these low catch weights, it was decided to use a TEOM continuous particulate matter monitor to measure the fabric filter effluent gas stream emissions. This instrument is sensitive down to particulate matter concentrations of less than 10 micrograms per cubic meter and is therefore

[3] The large majority of the fabric filter inlet and outlet ducts used at Ready Mixed Concrete plants in the U.S. are less than 24 inches, and most are less than 18 inches.
[4] EPA References 9 and 10 in AP42 Section 11.12.

very appropriate for testing low concentration particulate matter gas streams. During the subsequent tests, a $PM_{10}$ TEOM was used at the fabric filter outlet, and EPA Conditional Method 040 was used only at the fabric filter inlet.

## TEST RESULTS

### Capture Efficiencies and Emission Factors

The results of the RMC Research Foundation emission factor test program indicate that the hood capture efficiencies at ready mixed concrete plants are substantially higher than those specified in the 1995 edition of AP42 Section 11.12. Truck mix operations demonstrated hood capture efficiencies ranging from 93% to 99.5%, well above the 71% value estimated based on the 1993 tests and published in AP42. Central mix operations demonstrated hood capture efficiencies ranging from 97.2% to 99.3%, well above the 94% value published in AP42.

The total particulate matter and $PM_{10}$ particulate matter emissions measured at truck mix operations in this RMC Research Foundation study are substantially below the emissions reported in the 1995 edition of AP42 Section 11.12. The test results for central mix operations indicate that the particulate matter emissions are slightly higher than presently indicated in AP42 Section 11.12. The RMC Research Foundation and 1995 EPA emission factors are summarized in Figure 5.

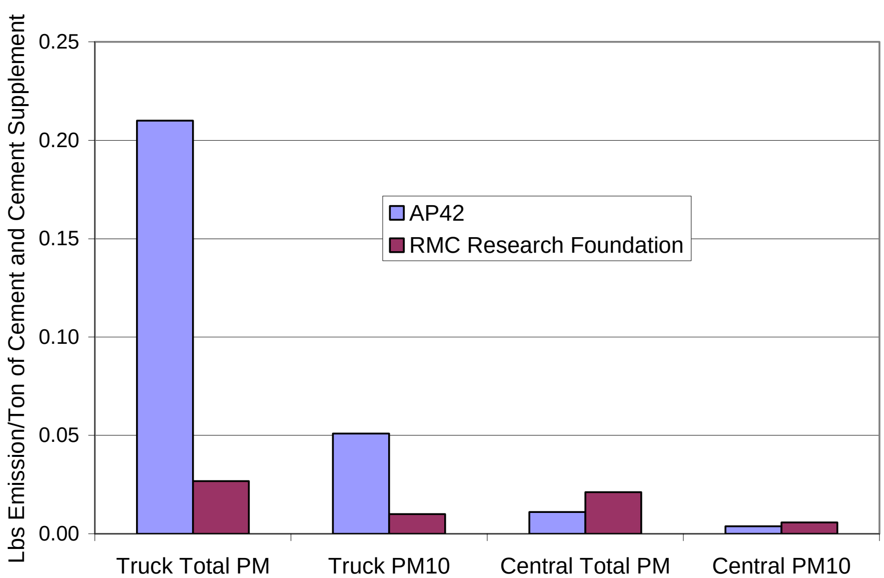


Figure 5. Comparison of AP42 and RMC Research Foundation Controlled Emission Factors

The results of the controlled[5] emission factor tests are summarized in Table 1 for the truck mix sources and Table 2 for the central mix sources. The RMC Research Foundation measured emission factors for filterable particulate matter and $PM_{10}$ particulate matter are compared with

[5] Controlled emissions are the total of emissions from the fabric filter used to control the mixing operation plus the fugitive emissions not captured by the hood.

previously published AP42 emission factors (controlled conditions). No emission factors were previously available for $PM_{10-2.5}$ (termed "coarse particulate matter") and $PM_{2.5}$ (termed "fine particulate matter").

| Table 1. Truck Mix Controlled Emission Factor Results[1] | | | | | | |
|---|---|---|---|---|---|---|
| Emission Factors | Plant 1 Truck Mix (Controlled) | Plant 2 Truck Mix (Controlled) | Plant 3 Truck Mix (Controlled) | RMC Research Foundation Truck Mix Average | AP42 Fifth Edition Truck Mix (Controlled) | Ratio, RMC Research Foundation compared to EPA |
| Emission Factors | Lbs./ton | Lbs./ton | Lbs./ton | Lbs./ton | Lbs./ton | Ratio |
| Total Particulate Matter | 0.0094 | 0.0512 | 0.0197 | 0.0268 | 0.2100 | 0.13 |
| $PM_{10}$ | 0.0039 | 0.0225 | 0.0035 | 0.0100 | 0.0510 | 0.20 |
| $PM_{10-2.5}$ | 0.0033 | 0.0195 | 0.0032 | 0.0086 | No Data | No Data |
| $PM_{2.5}$ | 0.0007 | 0.0031 | 0.0003 | 0.0013 | No Data | No Data |
| Collection Efficiency | | | | | | |
| Truck Hood, % | 99.5 | 93.1 | 99.3 | 97.3 | 71 | 0.093[2] |

1. All emission factors expressed as pounds of mass per ton of cement and cement supplement processed
2. Ratio calculated based on penetration; 100% - 97.3% for RMC Research Foundation tests, 100% - 1% for previous tests

| Table 2. Central Mix Controlled Emission Factor Results[1] | | | | | | |
|---|---|---|---|---|---|---|
| Emission Factors | Plant 1 Central Mix (Controlled) | Plant 2 Central Mix (Controlled) | Plant 3 Central Mix (Controlled) | RMC Research Foundation Central Mix Average | AP42 Fifth Edition Central Mix (Controlled) | Ratio, RMC Research Foundation compared to EPA |
| Emission Factors | Lbs./ton | Lbs./ton | Lbs./ton | Lbs./ton | Lbs./ton | Ratio |
| Total Particulate Matter | 0.0042 | 0.0402 | 0.0191 | 0.0212 | 0.0110 | 1.93 |
| $PM_{10}$ | 0.0028 | 0.0095 | 0.0049 | 0.0057 | 0.0038 | 1.50 |
| $PM_{10-2.5}$ | 0.0014 | 0.0087 | 0.0043 | 0.0048 | No Data | No Data |
| $PM_{2.5}$ | 0.0014 | 0.0007 | 0.0006 | 0.0009 | No Data | No Data |
| Collection Efficiency | | | | | | |
| Central Mix Hood, % | 99.3 | 97.5 | 97.2 | 98.0 | 94.0 | 0.33[2] |

1. All emission factors expressed as pounds of mass per ton of cement and cement supplement processed
2. Ratio calculated based on penetration; 100% - 98% for RMC Research Foundation tests, 100% - 94% for previous tests

The controlled particulate matter emission factors measured during the RMC Research Foundation tests for truck mix loading operations are substantially lower than those presently in

AP42, Section 11.12. To clarify the reasons for the differences, the conditions at the plants tested in Maryland and Virginia during the fall of 1993[6] were reviewed. The differences in the controlled emission factors measured in the RMC Research Foundation study and in the earlier EPA studies are believed to be due primarily to (1) underestimation of hood capture efficiencies by EPA using subjective visible emission observation techniques and (2) improved truck designs to minimize fugitive dust emissions and material spillage.

The authors believe that the previously reported EPA hood capture efficiencies are not representative of present practices in the Ready Mixed Concrete Industry.

### Evaluation of the Format of Loading Operation Emission Factors

All of the RMC Research Foundation and EPA emission factor data summarized in Table 1 and Table 2 are expressed n a format of pounds of emission per unit of production.[7] There are two major problems associated with this emission factor format.

(1) Plant operators can minimize emissions only by limiting production rate.

(2) There are no means available to tailor the emission factors to site-specific conditions that might affect particulate matter emissions.

To determine if this emission factor format is appropriates, the authors have reviewed the variability of both emission factors data sets: (1) the data from this study and (2) the previously available EPA data. As indicated in Figure 6, the use of emission factors expressed solely on production rate is <u>not</u> sufficient.

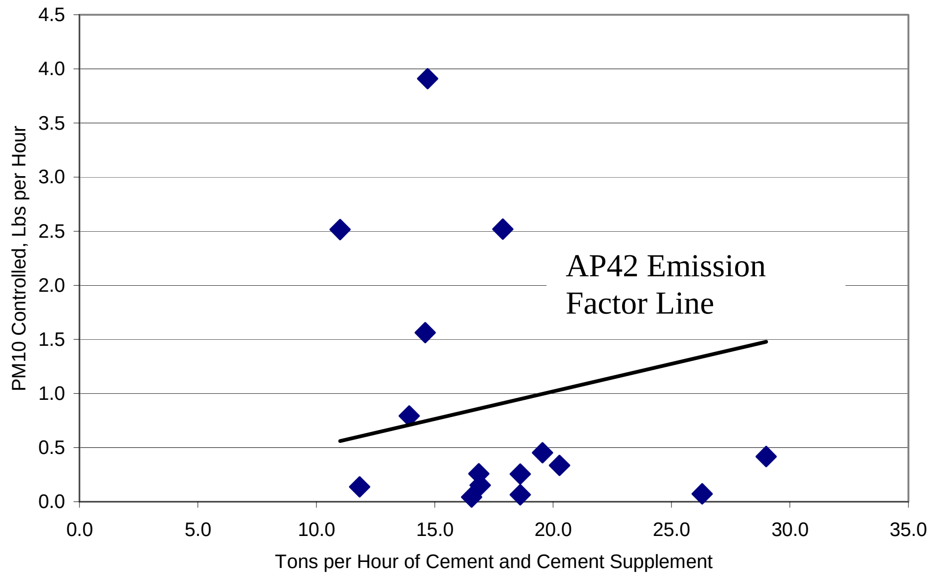


Figure 6. Truck Mix Emission Factor Data, EPA AP42 Section 11.12 References 9 and 10 (Note: Data should be on a line with a slope of 0.051 lbs $PM_{10}$/ton of cement.)

[6] The test reports concerning loading operations are references 9 and 10 of AP42 Section 11.12.
[7] Throughout this report, the term "production rate" will mean the throughput of cement and cement supplements such as "Newcem" in EPA reference 9 and flyash in the EPA and RMC Research Foundation test programs.

A similar plot can be prepared for the central mix data presently included in AP42. This graph demonstrates that the production rate alone is not a good predictor of emissions. An alternative emission factor format that includes additional variables is needed.

The EPA equation presented in AP42 Section 13.2 for loading mineral material on a storage pile was selected as a possible alternative format for the ready mixed loading operation emission factors. This EPA equation has an emission factor in a format expressed by Equation 1. Emission factor prediction equations were developed in this general format by the authors to predict the controlled emissions from the ready mix concrete plants tested as part of the RMC Research Foundation Study.

$$E = k(0.0032)\left[\frac{\left(\frac{U}{5}\right)^{a}}{\left(\frac{M}{2}\right)^{b}}\right] \qquad \text{[pound (Lb)/ton]} \qquad (1)$$

Where:

| | | |
|---|---|---|
| E | = | Emission factor in Lbs./ton of product |
| k | = | Particle size multiplier (dimensionless) |
| U | = | Wind speed, meters per second (m/s) or miles per hour (mph) |
| M | = | Moisture (% by weight) |
| a,b | | Exponents |

Analyses of the RMC Research Foundation test program data indicates that Equation 2 provides a good prediction of the measured emission factor data.

$$E = k(0.0032)\left[\frac{U^{a}}{M^{b}}\right] \qquad (2)$$

| | | |
|---|---|---|
| E | = | Emission factor in Lbs./ton of cement and cement supplement |
| k | = | Particle size multiplier (dimensionless) |
| U | = | Wind speed, meters per second (m/s) or miles per hour (mph) |
| M | = | Minimum moisture (% by weight) of cement and supplement |
| a,b | | Exponents |

The parameters for Equation 2 are summarized in Table 3. These parameters provide the best fit of the measured emission factor data for controlled particulate matter emissions.

Table 3. Emission Factor Predictive Equation Parameters

| Parameter | Parameter Category | Truck Mix Operations | Central Mix Operations |
|---|---|---|---|
| Particle size multiplier (k) | Total PM | 1.30 | 1.30 |
| | $PM_{10}$ | 0.35 | 0.35 |
| | $PM_{10-2.5}$ | 0.30 | 0.30 |
| | $PM_{2.5}$ | 0.05 | 0.05 |
| Exponents (a,b) | a | 2 | 0.3 |
| | b | 0.2 | 0.8 |

Figures 7 and 8 compare the measured $PM_{10}$ emission factors and the emission factors predicted by Equation 2 for truck mix and central mix operations.

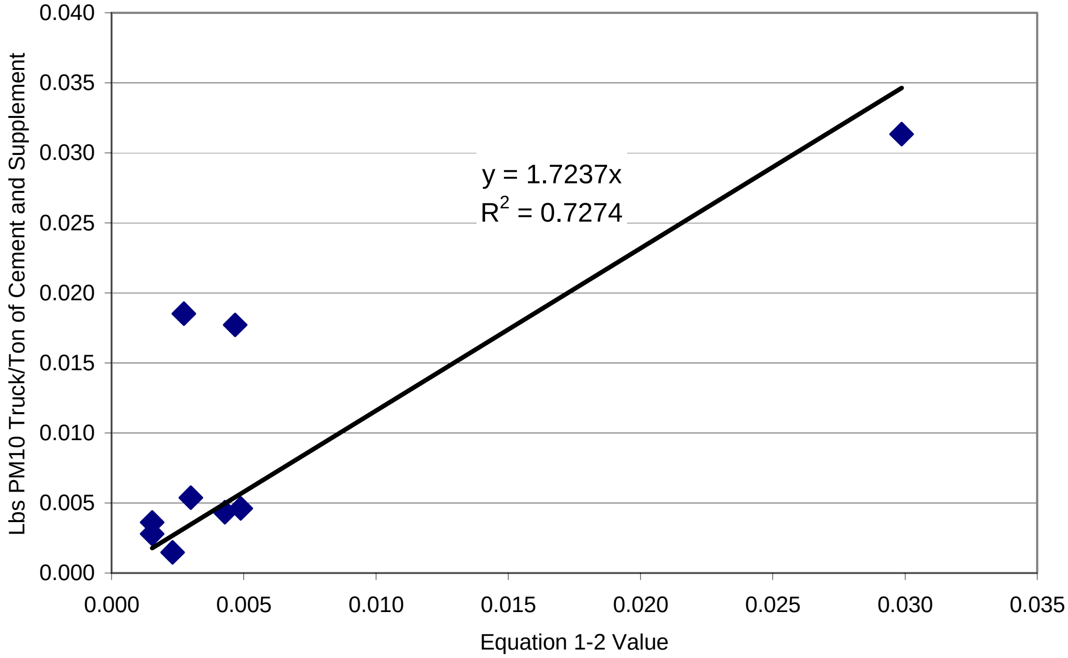


Figure 7. Truck Mix $PM_{10}$ Emission Factors Based on Equation 2

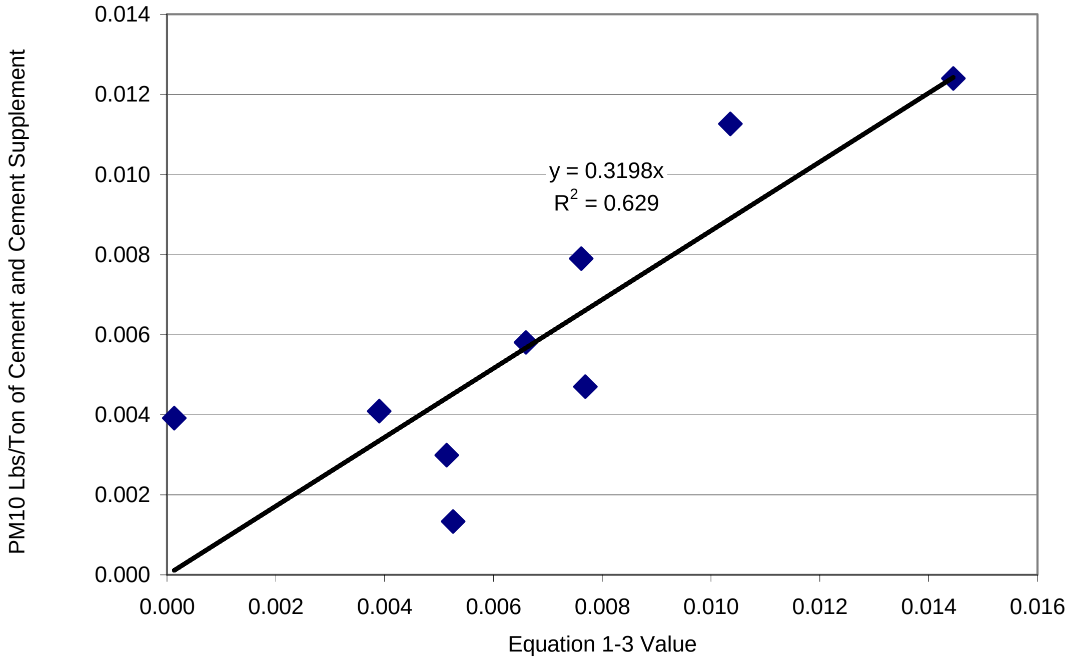


Figure 8. Central Mix $PM_{10}$ Emission Factors Based on Equation 2

Emission factors for truck mix and central operations based on Equation 2 minimize the variability associated with emission factors based solely on production rate. The inclusion of wind speed and moisture content parameters provides a means for ready mix plants to tailor the emission factors to their site-specific conditions.

Based on these analyses of the emission factor data, the authors recommend that the AP42 emission factors for truck mix and central mix operations be modified to be based on Equation 2. This equation increases the flexibility for ready mix plant operators to minimize emissions.

## SUMMARY

The Ready Mixed Concrete Research Foundation and Air Control Techniques, P.C. have developed an improved technique for measuring fugitive dust capture efficiency at ready mixed concrete loading operations. This technique includes the use of a Method 5D-type sampling array located extremely close to the loading area. Particulate matter concentrations are measured on a continuous basis using a $PM_{10}$ TEOM. The fugitive emission mass flux through the area defined by the sampling array is compared with the $PM_{10}$ particulate mass emissions in the inlet to the fabric control system in order to quantify the loading operation capture efficiency. This technique is a significant advancement over the qualitative visible emission-based techniques used in test programs conducted in the early 1990s.

The capture efficiency tests were conducted in conjunction with particulate matter emission rate tests at the outlet of the fabric filter. The particulate matter emissions in the $PM_{2.5}$, $PM_{10\text{-}2.5}$, $PM_{10}$, and total particulate size ranges were measured simultaneously. These data were used with the capture efficiency data to determine emission factors for the loading operations at truck mix and central mix operations.

The Ready Mixed Concrete Research Foundation sponsored emission factor test programs at six ready mixed concrete facilities located in North Carolina, Virginia, and South Carolina. The results of these tests indicate that the truck mix capture efficiencies are substantially higher, and, accordingly, the particulate matter emissions are substantially lower than those measured in the early 1990s. The capture efficiencies measured for central mix operations were also higher than those measured with the qualitative techniques; however, the particulate matter emissions from central mix operations were slightly higher than those previously reported in AP42.

In addition to measuring more accurate particulate matter emission factors, the RMC Research Foundation and Air Control Techniques, P.C. have evaluated the format used for emission factors in this source category. Based on this analysis, a revised format has been recommended that includes both the moisture content of the cement (or cement supplement) and the wind speed in the area immediately adjacent to the loading operation. The inclusion of these two variables provides for more accurate site-specific emission estimates.

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