

**PHYSICAL CHARACTERISTICS
OF PARTICULATE MATTER
AND HEALTH EFFECTS STANDARDS**

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Abstract

The workplace (industrial air hygiene) standards and community air pollution regulations implemented by OSHA and EPA, respectively, typically incorporate physical descriptions of the particulate matter (PM) that include particle size. Terms like “respirable”, “thoracic”, and “inhalable” are used to describe the concentration limits defined by the regulations or standards. More recently, EPA has promulgated new National Ambient Air Quality Standards (NAAQS) using terms such as “fine” (PM_{2.5}) and “coarse” (PM_{10-2.5}) for PM. Concentration limits defined by the OSHA and EPA standards and regulations are specified in terms of mass per “standard volume” rather than mass per “actual volume”. Specially designed samplers are used to measure the concentrations to determine compliance. These samplers generally consist of two stages. The first stage separates the PM larger than the size specified by the regulation or standard allowing the PM of interest to be measured on a filter in the second stage. The separating efficiency of the first stage is not 100%. As a consequence, a fraction of the PM larger than the particle size being regulated penetrates to the filter and a fraction of the PM smaller than the size being regulated is deposited in the first stage. When describing particle size, the term “aerodynamic equivalent diameter” (AED) is used. This paper includes discussions of engineering terms and descriptors and eliminate some confusion.

Introduction

The technical descriptions of particulate matter (PM) for regulatory purposes are confusing. They are difficult to decipher for many who are working in the field, much less, for agricultural processors, including cotton ginners, who are being regulated by State Air Pollution Regulatory Agencies (SAPRAs) and OSHA. The purpose of this paper is to help clarify the PM physical characteristics issues.

The regulation of airborne PM concentrations in the workplace is a responsibility of the Occupational Safety and Health Administration (OSHA) whereas regulating airborne PM in the ambient air (outside) is a responsibility of the Environmental Protection Agency (EPA). The expression used by OSHA for the regulation of PM concentrations in the work environment is “industrial air hygiene” whereas the term used by EPA for the regulation of PM concentrations is “air pollution”. Federal OSHA and EPA promulgate rules and regulations (standards). Some states have a state OSHA program and all states have SAPRAs who also formulate and enforce state rules and regulations. All state rules and regulations are required to be as effective (stringent) as the federal rules. The regulation of OSHA standards is performed primarily by industrial hygienists. Federal EPA are responsible for promulgating National Ambient Air Quality Standards (NAAQS) and are required to review these NAAQS every 5 years. Permitting and regulating of ambient air pollution is in large part performed by air pollution engineers. Typically, State Air Pollution Regulatory Agencies (SAPRAs) regulate air pollution and Federal OSHA regulate industrial air hygiene except in the 23 states which administer their own OSHA programs.

The NAAQS for PM₁₀ and PM_{2.5} require special samplers designed to remove PM larger than 10 and 2.5 micrometers (AED), respectively. The resulting measured “ambient” concentration represents the average exposure of the public to PM₁₀ and PM_{2.5} in an area, off the property of a facility that is a potential emitter. Determining accurate particle size distributions (PSDs) of the PM is becoming an essential component of the science of evaluating the health effects impacts of PM exposure. The “sharpness of cut” of the preseparator significantly impacts the accuracy of PM₁₀ and PM_{2.5} concentration measurements. Flat penetration curves allow larger particles to penetrate the preseparator and a fraction of the small particles that are supposed to penetrate by design are separated in the preseparator. The understanding of the engineering principles associated with the design of PM samplers which affect the accuracy of the concentration measurements and the interpretation of measured PM concentrations on anticipated health impacts by non-engineers is crucial to the appropriate regulation of industrial air hygiene and air pollution.

The NAAQS for PM (40CFR50.6) less than 10 micrometers or 2.5 micrometers aerodynamic equivalent diameter (AED), referred to as PM₁₀ and PM_{2.5} is a concentration limit set by EPA that should not be exceeded. The consequences of multiple exceedances of the NAAQS are having an area designated as nonattainment with a corresponding reduction in the permitted allowable emission rates for all sources of PM₁₀ in the area. The consequence of an exceedance of the NAAQS at the property line is the SAPRA denying an operating permit. It is a health based standard. A health based standard implies that if the ambient concentration exceeds the NAAQS, it is likely that there

will be adverse health effects on the public. For community air pollution, the most susceptible public are the elderly and infants who are exposed to ambient concentrations of air pollution for 24-hours per day. In contrast, OSHA standards apply to the work environments of healthy workers exposed for an 8-hour work day and 40-hour work week. The OSHA standard for inert or nuisance dust also referred to as particulate not otherwise regulated (PMOR) is 15 mg/m³ (total) and 5 mg/m³ (respirable) (29CFR1910.1000). The PM10 NAAQS 24-hour standard is 150 micrograms per dry standard cubic meter (µg/dscm). The NAAQS for PM10 of 150 micrograms per dry standard cubic meter (µg/dscm) is 1/100 of the OSHA standard for inert dust of 15 mg/m³. EPA's logic is that there needs to be a more restrictive standard to protect the elderly and infants exposed to air pollution 24-hours per day, 7 days per week than for healthy workers exposed to an OSHA concentration limit for an 8-hour exposure, 5 days per week. Toxicologists working for EPA and SAPRAs commonly determine Health Effects Screening Levels (HESLs) by dividing the Threshold Limit Values (TLVs) published by the American Conference of Governmental Hygienists (ACGIH) by 100 or 1000 depending upon whether the ACGIH TLV was established based upon human or animal exposure, respectively.

Health Effects - Respirable, Thoracic, or Inhalable and Course or Fine Dust

Both OSHA and EPA standards are based on health effects. Dust particles deposited anywhere in the respiratory tract when a normal person breathes are "inhaled". The health hazard of PM is dependent upon the chemical composition of the PM. The human respiratory tract has the ability to filter particles larger than 10 µm (AED) and prevent penetration of these larger particles to the air sacks in the lung referred to as alveoli. PM larger than 10 µm (AED) are considered "non-respirable". The prevention of PM deposition in the alveoli is the goal of all respirable standards. Table 1 shows the relationship of PM size and the percent respirable and the percent passing a ACGIH pre-selector. Note that no 10 µm particles reach the alveolar region, whereas 50% of the 3.5 µm particles reach the alveolar region.

Figure 1 illustrates the difference in the "ideal" preseparator collection efficiency as defined by the British Medical Research Council (BMRC) and ACGIH. The BMRC defined respirable dust reaching the alveoli as the particle diameter with the settling velocity twice the settling velocity of a 5 µm (AED) particle. The goal of the ACGIH was for the sampler to mimic the human respiratory system. In other words, 90% of the PM less than 2 µm (AED) would penetrate to the alveoli whereas only 25% of the 5 µm (AED) particles and none of the 10 µm (AED) particles would penetrate to the alveoli (table 1).

Inhaled PM, too large to penetrate to the alveoli, can also have a detrimental health effect. Soluble particles and systemic poisons adhering to PM larger than 10 µm (AED) can impact human health if these particles are inhaled and do not reach the alveoli region for toxic action. Hinds (1982) points out that aspiration of PM is dependent on aerodynamic particle size, air velocity, inhalation flow rate, whether nose or mouth breathing is used and whether facing into, perpendicular or away from the wind. According to ACGIH (1985) and the International Standards Organization (1981), approximately 50% of the PM 30-100 µm (AED) are inhaled. It would seem logical, therefore, to establish a particle size limit of 30 to 100 µm (AED) for inhalable particulate. The old high volume sampler (40CFR50, Appendix B) which is no longer being used by EPA or SAPRAs with a cut point of approximately 40 µm (AED) was a good measure of inhalable PM.

An ad hoc working of AIHA (1981) addressed the issues of defining PM size ranges for particle sampling. They state: "In measurement, particles are collected by a reference instrument which has the same efficiency $\xi(\phi)$ $\psi(\phi)$ as the respirable tract, i.e., which collects the same fraction F as the respirable tract." They include an equation for the "Inspirability" percent (ξ) as follows:

$$\xi = 100 - 15(\log_{10}[\phi + 1])^2 - 10 \log_{10}[\phi + 1] \text{ (Eq. 1)}$$

where ϕ = particle size, µm (AED). "The Extra-thoracic, Tracheobronchial and Alveolar fractions are subdivisions of this Inspirable fraction. --- These values are based on measurements of the average inspirability of a person equally exposed to all wind directions at windspeeds between 0 and 8 m/s.--- It was the opinion of the ad hoc working group that the tracheobronchial deposition is more often of health interest than the extrathoracic deposition, and that the bias toward overestimation of the Thoracic Fraction was reasonable and acceptable." In an addendum of this report, the working group redefined the tracheobronchial deposition cutpoint from 15 µm to 10 µm with geometric standard deviation of 1.5 which has the advantage of "compatibility with EPA practice." EPA refers to this fraction as "inhalable Particles" which is compatible with the Recommendations' definition of Thoracic Fraction or gives better agreement with measured values of extra-thoracic deposition.

Hinds (1982) points out that EPA "has tentatively defined 'inhalable particulates' as particles having aerodynamic diameters less than 10 µm (Miller et al., 1979). It is intended that samplers will have a cutoff size of 10 ± 1 µm and an 84%/50% cutoff size ratio of 1.4-1.6." This rather broad acceptance of preseparator performance of a cutpoint of 9 - 11 µm (AED) and a preseparator slope (84%/50% cutoff size ratio) ranging from 1.4 to 1.6 has the potential of allowing a rather wide range of PM to penetrate the PM10 preseparator and be deposited on the filter resulting in the larger particles being measured as PM10 and some

smaller PM being separated. The perception of the public is that a PM10 concentration is a measurement of the mass of PM in the ambient air less than 10 μm (AED) when in fact a portion of the mass of PM measured by an EPA Referenced Method (40CFR50, Appendix J) PM10 sampler is larger than 10 μm (AED) and a portion of the PM separated by the preseparator is less than 10 μm (AED) and not measured. Ideally, the mass of PM10 not measured is equal to the mass of PM larger than 10 μm (AED) measured. This is a source of significant error if these two masses are not equal.

Figure 2 illustrates the range of PM that would penetrate a preseparator with a fractional collection efficiency slope (σ_g)= 1.4 and a cutpoint of $10 \pm 1 \mu\text{m}$ (AED) {9-11 μm (AED)}. These plots were made assuming that the PM separated was log-normal $\{y = a \cdot \ln(x) + b\}$. The values of “a” and “b” were determined by solving two equations and two unknowns. Table 2 lists the values for “a” and “b” and the equations used to plot the curves in figures 2, 3 and 4. Figure 3 illustrates the range of PM that would penetrate a preseparator with a $\sigma_g = 1.6$ and a cutpoint of $10 \pm 1 \mu\text{m}$ (AED) {9-11 μm (AED)}. Figure 4 shows the total range of PM that could be viewed as acceptable for a $d_{50} = 9$ to 11 μm (AED) and a slope =1.4 to 1.6. Figures 2, 3 and 4 show the penetration curves for a virtual cut at 10 μm (AED) for comparison purposes. These analyses indicate that the range of PM captured on a sampler with a $\sigma_g = 1.4$ would be no larger than 18 μm (AED) and all PM smaller than 5.5 μm (AED) would penetrate and be captured on the filter. However, as Figure 3 illustrates, for a $\sigma_g = 1.6$ and a cutpoint of 11 μm (AED), PM as large as 21.9 μm (AED) can be captured and all PM less than 4.6 μm (AED) will penetrate the preseparator. In effect, a PM 10 sampler with performance characteristics of $d_{50} = 9$ to 11 μm (AED) and a slope =1.4 to 1.6. can have PM up to 22 μm (AED) on the filter. EPA recognized this problem and refined the requirements of an “EPA approved” sampler as having a $d_{50} = 9.5$ to 10.5 μm (AED). With this cutpoint limitation and allowable preseparator fractional efficiency slopes of 1.4 to 1.6, PM as large as 20 μm (AED) will theoretically be collected and measured. For PM present in ambient air having a mass median diameter of 14 μm (AED) and a geometric standard deviation of 1.6, the EPA approved PM10 sampler can result in a measurement of PM10 concentration that is in excess of 10% of the mass of PM less than 10 μm (AED). The public perception that only particles less than 10 μm (AED) are measured with an EPA approved PM10 sampler and that the preseparator performs a virtual cut at 10 μm (AED) is incorrect!

Hinds (1982) further states, “The term ‘inhalable’ is used by the EPA to distinguish this size classification from respirable dust and not to indicate whether or not the particles can be inhaled.” --- “They further recommend that the ‘inhalable particulates’ be separated into two size ranges, above and below 2.5 μm aerodynamic diameter. The latter is intended to define the particles deposited primarily

in the alveolar regions and the former to be those deposited in the airways. This seems arbitrary, because it ignores the significant mass contribution of particles between 2.5 and 10 μm that reach the alveolar region.” He goes on to describe the anomaly of inhalable/respirable definition for health hazards associated with worker exposure to cotton dust. OSHA’s cotton dust standard is referred to as both inhalable and respirable with a cutoff of 15 μm (AED) as measured by the vertical elutriator. EPA (1996) stated the following: “The selection of the most appropriate aerodynamic criteria for ambient aerosol sampling was only partially resolved by the 1987 EPA designation of a 10 μm (PM10) cutpoint.” ...Jensen and O’Brien (1993) illustrated the international conventions for cutpoints being categorized as Respirable, Thoracic, and Inhalable. “The British Standard describes size fractions for workplace aerosol sampling, and identifies inhalable “conventions” relative to thoracic, respirable, extra-thoracic and tracheobronchial penetration (but not necessarily deposition) in the respiratory system. They define a thoracic cumulative lognormal distribution with a median of 11.64 μm and a geometric standard deviation of 1.5, such that 50% of airborne particles with $D_a = 10 \mu\text{m}$ are in the thoracic region. The American Conference of Governmental and Industrial Hygienists (ACGIH, 1994) also adopted these convention definitions.”

EPA (1996) state: “The respirable conventions have had D_{50} values ranging from 3.5 to 5.0 μm , but a compromise convention has been accepted internationally by several organizations.---EPA’s emphasis on the 2.5 μm cutpoint was more closely associated with separating the fine and coarse atmospheric aerosol modes, rather than mimicking a respiratory convention.”

The difference between OSHA and EPA definitions for the size of PM classified as inhalable was not always the case. Miller et al (1979) states, “It is recommended that research to develop information for size-specific standard should focus on ‘inhalable’ particulate (IP) matter defined as airborne particles $\leq 15 \mu\text{m}$ aerodynamic equivalent diameter.”

Aerodynamic Equivalent Diameter

What is aerodynamic equivalent diameter? In theory, the aerodynamic equivalent diameter of a dust particle is the diameter of spherical water droplet that has the same settling velocity as the dust particle even though the dust particle may be non-spherical and may have a particle density other than 1. Dust particles (PM) present in the air when viewed under a microscope will be observed to have a number of physical sizes and shapes. Different PM will have varying weight per volume of a particle excluding air pockets (particle density). The definition of “aerodynamic diameter” (Cooper and Alley, 1994) is as follows: “The aerodynamic diameter is defined as the diameter of a unit

density sphere ($\rho_p = \rho_w = 1000 \text{ kg/m}^3$) that has the same settling velocity as the particle in question.” It can be calculated using equation 1:

$$d_a^2 = 18\mu v_t / C\rho_w g \quad (\text{Eq. 2})$$

where d_a = aerodynamic diameter, cm;
 μ = gas viscosity, poise;
 v_t = settling velocity, cm/s;
 ρ_w = density of water, g/cm³;
 g = gravitational acceleration, cm/s²; and
 C = Cunningham correction factor.

The equivalent spherical diameter of an irregular shaped particles can be determined using the stokes settling velocity equation as follows:

$$d_s^2 = 18\mu v_t / C\rho_p g \quad (\text{Eq. 3})$$

where d_s = stokes diameter, cm;
 μ = gas viscosity, poise;
 v_t = settling velocity, cm/s;
 ρ_p = particle density, g/cm³;
 g = gravitational acceleration, cm/s²; and
 C = Cunningham correction factor.

Davies (1979) published shape factors for different shapes and points out that shape does affect the settling velocity of particles. Irregular shaped particles settle at slower rates than do spherical particles. Some values of shape factors were 1.0 for a spherical particle, 1.32 for cylinders aligned horizontal to the direction of flow, and 1.07 for cylinders aligned vertical to direction of flow. He defined the equivalent volume diameter (d_e) utilizing the shape factor as follows:

$$d_e^2 = 18\mu v_t / C\rho_p g\chi \quad (\text{Eq. 4})$$

d_e = equivalent volume diameter, cm;
 μ = gas viscosity, poise;
 v_t = settling velocity, cm/s;
 ρ_p = particle density, g/cm³;
 C = Cunningham correction factor;
 g = gravitational acceleration, cm/s²; and
 χ = shape factor.

The Cunningham correction factor (C) is a measure of the slip associated with the particle drag. For particles larger than 2 μm (AED), $C = 1$. All of these equations hold for the Stokes regime which is for a particle Reynolds number less than 1. Equation 4 can be used to determine particle Reynolds number for standard air for a particle with diameter “d” centimeters and a velocity V cm/s.

$$R_e = 6.54 * V * d \quad (\text{Eq. 5})$$

Figure 5 illustrates how the particle density ($\rho_p = 4 \text{ g/cm}^3$) and shape factor ($\chi = 1.36$) impact the aerodynamic

equivalent diameter of an irregular shaped particle. The equivalent volume diameter (d_e) for particle #1 was 5.8 μm accounting for a shape factor of 1.36. This relationship plays an important role when performing microscopic sizing of PM. The diameter measured with a microscope is d_e .

The Stokes diameter for particle #2 (figure 5) was 5 μm which means that a 5 μm spherical particle with a density of 4 g/cm³ would settle at a velocity of 0.3 cm/s. The Stokes diameter (d_s) is the same diameter one would get if the irregular shaped particle were melted and formed into a sphere with no voids (air pockets). A spherical particle with $d_s = 5 \mu\text{m}$ and $\rho_p = 4 \text{ g/cm}^3$ would settle at 0.3 cm/s. By definition, the aerodynamic equivalent diameter would be the diameter of a spherical particle having a $\rho_p = 1 \text{ g/cm}^3$. Using Equation 1, we find that this particle would have a $d_a = 10 \mu\text{m}$. A special relationship between d_a and d_s can be developed by equating equation 1 and Equation 2. Equation 5 is a simple conversion from Stokes diameter to aerodynamic equivalent diameter.

$$d_a = (\rho_p)^{1/2} * d_s \quad (\text{Eq. 6})$$

The processing laboratory in the Department of Agricultural Engineering has been using a Coulter Counter particle sizing methodology to obtain particle size distributions (PSDs) of PM for a number of years. The unique principle of Coulter Counter sizing of PM is that the particles are sized by sensing particle volume and computing an equivalent spherical diameter (d_s). The results are in effect percent volume of PM versus d_s . By assuming that the particle density is constant over all particle sizes, the Coulter Counter results are percent mass versus d_s . Using Equation 5, the stokes diameters are converted to d_a and the resulting PSD is percent mass versus aerodynamic equivalent diameter. This is the only method that we have found that yields PSDs in units of mass versus aerodynamic equivalent diameter. It is repeatable in that subsequent PSDs of the same dust are the same. We believe that Coulter Counter PSDs are the most accurate method of obtaining PSDs. It also offers the advantage of determining PM10 and PM2.5 from one measurement of total suspended particulate (TSP) using the Coulter Counter PSD to determine the fraction less than 10 and 2.5 μm (AED). In effect, this method of determining PM10 and PM2.5 concentrations is a virtual cut (see figures 2, 3, and 4) in that this measurement is a measure of the mass of PM less than 10 and 2.5 μm (AED), respectively and does not depend upon the mass of larger PM penetrating to equal the mass of targeted PM pre-separated for an accurate measurement of PM10 and PM2.5 as does the current equipment used by the regulating agencies.

What is the aerodynamic diameter of cotton fibers? One SAPRA has attempted to regulate textile mills claiming that cotton fibers have an AED less than 100 μm . Using the procedure described above, the volume of a cotton fiber (cylinder) 15 μm in diameter and 0.3 inches (7620 μm) in

length would be $1.35 \cdot 10^6$ cubic microns. The equivalent diameter of an equal volume sphere (d_s) would be $136 \mu\text{m}$. Using equation 4 with a $\rho_p = 1.4 \text{ g/cm}^3$, $d_a = 162 \mu\text{m}$. For a cotton fiber with a length of 0.1 inches, $d_a = 112$. It is unlikely that fibers emitted by a cotton processing facility will be less than $100 \mu\text{m}$ (AED).

Concentrations in Units of Mass per Standard Volume

Another somewhat confusing issue is the determination of measured concentrations in mass per standard volume. When working with air, an engineering convention has been established that is referred to as “standard air”. In a way, it simplifies the reporting of data for fans and the design of pneumatic conveying systems. All of the OSHA and EPA standards are based on concentrations of mass per dry standard air volume. Standard air has a density of 0.075 lbs/ft^3 . This is the density of air at 70° F , $0\% \text{ RH}$, and 14.7 psia barometric pressure. As air becomes more humid, the relative humidity (RH) increases which in turn affects the air density. The magnitude of air density changes due to variations in RH are small compared to the impact of changes in barometric pressure. Barometric pressure significantly affects the air density and is determined by the height above sea level of the site. Equation 6 can be used to calculate air density.

$$\rho = (p_b - \phi p_s) / \{0.37(460 + t)\} + \phi p_s / \{0.596(460 + t)\} \quad (\text{Eq. 7})$$

where ρ = air density, lb/ft^3 ;
 p_b = barometric pressure, psia ;
 ϕ = $\text{RH}/100$;
 p_s = saturated water vapor pressure @ t , psia ; and
 t = dry bulb temperature, $^\circ\text{F}$.

Equation 7 can be used to estimate the barometric pressure that would exist at a site “z” meters above sea level.

$$\ln(1/p_b) = 3.42 * \ln\{298/(298-0.01z)\} \quad (\text{Eq. 8})$$

where p_b = barometric pressure, atm ; and
 z = height above sea level, m .

To illustrate the importance of these two factors, consider a measurement made of PM10 at College Station, TX (@ approx. sea level) and Denver, Colorado (5,000 ft above sea level). The samplers at both sites are operated at 40 actual cubic feet per minute (acfm) for 24 hours. A total of 57,600 acf or 1631 actual cubic meters (acm) is sampled and a mass of 0.24 grams (240,000 μg) is obtained on the filter. What is the concentration and do these measurements exceed the NAAQS of 150 micrograms per dry standard cubic meter ($\mu\text{g/dscm}$)? For case 1, lets assume that the $\text{RH} = 0$ (dry air at both sites).

Using Equation 7, we determine that $p_b = 1 \text{ atm} = 14.7 \text{ psia}$ for College Station and $0.835 \text{ atm} = 12.3 \text{ psia}$. Using

equation 6, we find that the air density is 0.075 lb/ft^3 and 0.063 lb/ft^3 at College Station and Denver, respectively. The concentration at both locations is determined to be $147 \mu\text{g/acm}$. Since the air is dry (no water vapor) and the density at College Station is the same as standard air, the concentration at College Station that will be compared to the NAAQS is $147 \mu\text{g/dscm}$. This site is in compliance (less than) the NAAQS. However, the Denver site has much lighter air. To convert the $147 \mu\text{g/acm}$ to units of $\mu\text{g/dscm}$ we must multiply this measurement by the ratio of standard air density over actual air density ($\rho_s/\rho_a = 0.075/0.063$) to obtain $175 \mu\text{g/dscm}$. Denver is not in compliance with the NAAQS.

To illustrate the effect of moisture on the concentration measurement at Denver, assume that the $\text{RH}=100\%$ and $t = 70^\circ \text{ F}$. The density calculations from Equation 5 are as follows:

$$\rho = \rho_{da} + \rho_m = 0.0609 + .0011 = 0.062 \text{ lb/ft}^3$$

where ρ_{da} = density of dry air component, lb/ft^3 ; and
 ρ_m = density of water vapor component, lb/ft^3 .

The total mass of air sample at Denver is $0.062 \text{ lb/ft}^3 * 57,600 \text{ acfm} = 3571 \text{ lbs}$. The mass of dry air sampled was $0.0609 \text{ lb/ft}^3 * 57,600 \text{ acfm} = 3508 \text{ lbs}$. Approximately, 63 lb of water vapor was sampled. This volume of water vapor must be excluded from the calculation of the concentration in order to calculate the concentration in units of mass per “dry” volume. In reality, the PM10 sampler sampled $3508/0.062 = 56,581$ cubic feet = 1602 cubic meters of dry air. The calculation of mass per “dry” actual cubic meters would be $240,000 \mu\text{g}/1602 = 149.8 \mu\text{g/dacm}$. The concentration to be compared to the NAAQS would be $184 \mu\text{g/dscm}$ ($149.8 * 0.075/0.0609$). The impact of the change in air density as a consequence of deleting water vapor in the calculation of mass per dry standard volume is not large ($175 \mu\text{g/scm}$ versus $184 \mu\text{g/dscm}$). The impact of accounting for air density variations as a consequence of changes in barometric pressure ($147 \mu\text{g/acm}$ versus $175 \mu\text{g/dscm}$) is quite large. This is a consequence of the relatively small impact that water vapor has on air density.

Summary

The purpose of this paper was to try to “shed some light” on issues that many do not understand. The understanding of calculation of AED is essential in the interpretations of standards and regulations. When a SAPRA attempts to require more costly controls be placed on a textile mill because they perceive that cotton fibers have an aerodynamic diameter less than $100 \mu\text{m}$ and should be considered airborne PM and subject to regulation and it can demonstrate that this perception is **wrong** using good science, then action should be taken (Wakelyn et al., 1995; Julien, 1997; Wakelyn, 1998). When air pollution sampling

is conducted, we must require that the consultant and/or regulator perform the correct calculations so that when the concentration is compared to the NAAQS, the units are in mass per dry standard cubic meter.

There is some merit in the argument that a PM₁₀ sampler will yield results that are not the true mass of PM less than 10 µm (AED) and that there is a standard error associated with each measurement. When a SAPRA attempts to prevent a cotton gin from obtaining a permit because modeling (40CFR51, Appendix W) results suggest that the concentration may be 151 µg/dscm at the property line, we must vigorously oppose this regulatory action and win.

We would like to see the Coulter Counter PSD being used with TSP measurements to measure/calculate PM₁₀ and PM_{2.5}. It would be less costly for the SAPRAs to measure TSP, PM₁₀ and PM_{2.5}. However there is a large bureaucratic hurdle to get this done.

The regulation of air pollution from agricultural sources is having a significant impact on agricultural operations and will continue to present problems that must be addressed. It is important that those of us faced with finding economical and effective methodologies to respond to SAPRA and EPA regulatory pressures insure that sound science is used and agricultural operations are treated fairly. Issues such as the definition of “respirable”, “thoracic”, and “inhalable” as well as PM_{2.5} (“fine”) and PM_{2.5}-PM₁₀ (“course”) will not likely be resolved by researchers but we must understand the arguments. There may be an opportunity to change policy at some point in the future. The policy we must strive for is one that results in the use of sound science based on credible data and in **fair** treatment of cotton processors and other agricultural clientele.

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Table 1. Criteria for respirable dust (Hinds, 1982)

Aerodynamic Diameter (μm)	Percent Respirable USAEC	Percent Passing Selector ACGIH
<2	100	90
2.5	75	75
3.5	50	50
5.0	25	25
10	0	0

Table 2. Equations for the log-normal preseparator efficiency curves, $y=a*\ln(x)+b$, where y = collection efficiency fraction, a = slope, b = y intercept, and x = particle size in microns. σ_g =slope of the preseparator fractional efficiency curve= the ratio of the particle size at the 84.1% and 50% or the ratio of the particle size at the 50% and 15.9%. d_{50} = the 50% cut-point of the penetration curve.

σ_g	d_{50}	a	b	equation
1.4	9	1.014	-1.73	$y= 1.014*\ln(x)-1.73$
1.4	10	1.014	-1.83	$y= 1.014*\ln(x)-1.83$
1.4	11	1.014	-1.93	$y= 1.014*\ln(x)-1.93$
1.6	9	0.726	-1.10	$y= 0.726*\ln(x)-1.10$
1.6	10	0.726	-1.17	$y= 0.726*\ln(x)-1.17$
1.6	11	0.726	-1.24	$y= 0.726*\ln(x)-1.24$

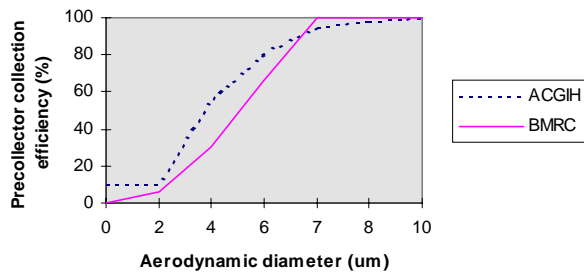


Figure 1. Pre-collector efficiency based on criteria for respirable dust (Hinds, 1982)

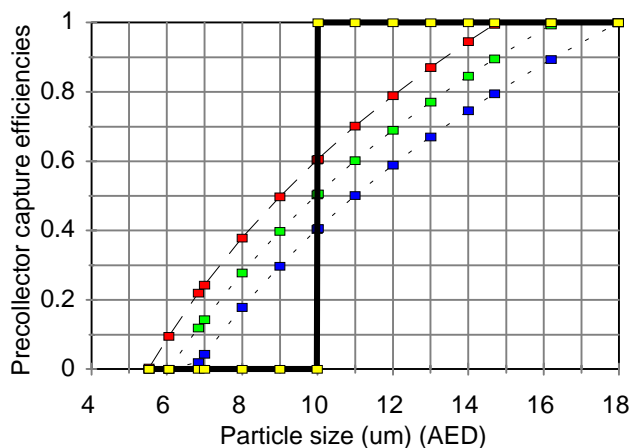


Figure 2. Range of particulate matter captured by a preseparator for a PM10 sampler for a cut point of $10 \pm 1 \mu\text{m}$ (9, 10 and 11 μm) with a fractional efficiency curve slope (σ_g) of 1.4. The virtual cut at 10 μm ($\sigma_g = 1.0$ and $d_{50} = 10 \mu\text{m}$) is illustrated for comparison purposes.

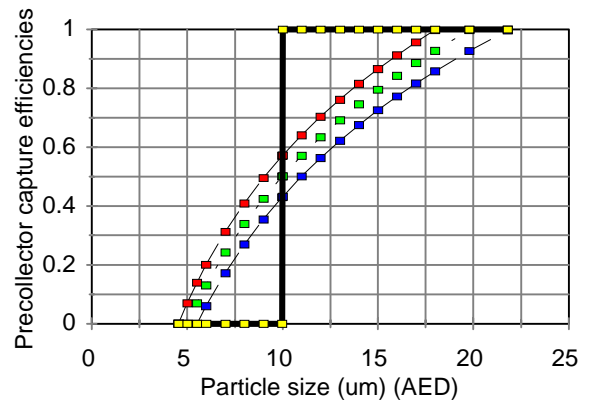


Figure 3. Range of particulate matter captured by a preseparator for a PM10 sampler for a cut point of $10 \pm 1 \mu\text{m}$ (9, 10 and 11 μm) with a fractional efficiency curve slope (σ_g) of 1.6 The virtual cut at 10 μm ($\sigma_g = 1.0$ and $d_{50} = 10 \mu\text{m}$) is illustrated for comparison purposes.

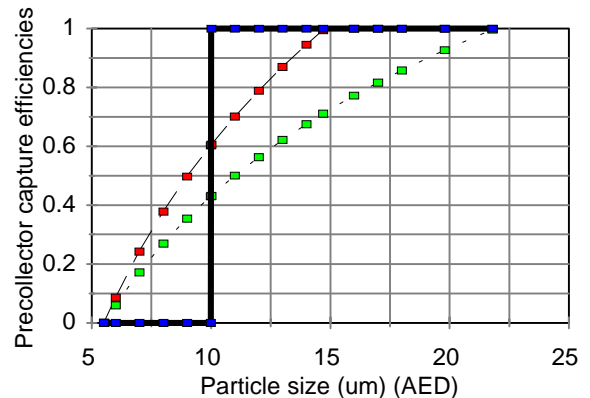


Figure 4. Range of particulate matter captured by a preseparator for a PM10 sampler for a cut point of 9 μm with a fractional efficiency curve slope (σ_g) of 1.4 and 11 μm with a fractional efficiency curve slope (σ_g) of 1.6. The virtual cut at 10 μm ($\sigma_g = 1.0$ and $d_{50} = 10 \mu\text{m}$) is illustrated for comparison purposes.

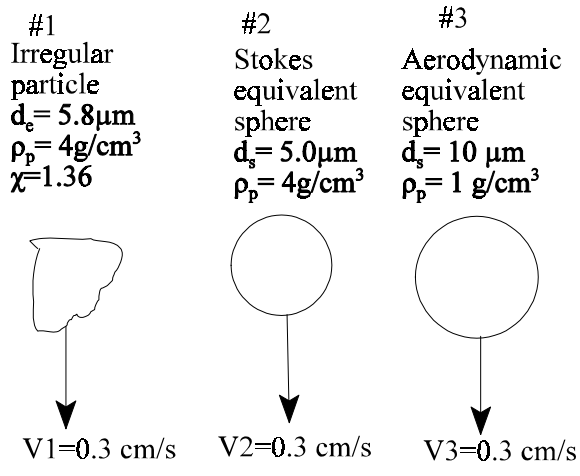


Figure 5. Illustration of the effect of particle density (ρ_p) and shape (χ) on the determination of aerodynamic equivalent diameter (Hinds, 1982). The irregular shape particle has an equivalent diameter of $5.8 \mu\text{m}$ using the Stokes settling velocity equation utilizing the shape factor of $\chi=1.36$. (See equation 3.) It would have a Stokes diameter (d_s) of $5 \mu\text{m}$ using the same Stokes equation disregarding the shape factor. This irregular particle would have aerodynamic equivalent diameter of $10 \mu\text{m}$.