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# AIRSTREAMS WITH HIGH MATERIAL LOADINGS

## INTRODUCTION

Suspended materials are a trace component in most Local exhaust Ventilation (LEV) Systems. Material loadings are normally in the range of 3 to 5 grains/cubic foot and rarely exceed 20 grains/cubic foot, or more than 5% of the air by mass. At loadings less than 20 gr/cu ft, the effects of material in the air are insignificant. At higher loadings, corrections to the volumetric flow rate, airstream density, mass flow rate, fan horsepower, duct velocity and duct friction losses should be considered.

The following guidelines are for systems or system segments operating in the intermediate range of material loadings found between typical LEV and pneumatic conveying systems. This intermediate range is defined by material loadings between 20 and 260 gr/cu ft, (material to air mass ratio up to 1:2). These guidelines can also be applied at material to air mass ratios up to 2:1 for short to medium distance, well designed systems.

### *Mass, Weight, and Density*

In everyday use, the terms mass and weight are often used interchangeably without any meaningful error. However, they have distinctly different meanings which should be clarified. *Mass* is the amount of matter in a substance, is constant (absent any external work), and cannot be either created or destroyed. *Weight* is expressed as the force exerted on the mass of a substance by gravity (heaviness). With mass being constant, weight then varies with the gravitational field in which the substance exists. For example, an astronaut (or any other substance) has the same mass on earth as on the moon, but the astronaut's weight differs on the earth and the moon due to the differences in gravitational forces. *Density* is simply the mass of a substance by volume. In LEV systems (and any other fan driven system), mass is used in lieu of weight as mass is constant and represents the true characteristics of any substance.

### *Materials Units of Measure*

Materials conveyed through LEV systems are noted by their concentration (loading) in the airstream and their material bulk density.

For material loadings, commonly used units of scale are the grain (gr), gram (g) and pound (lb), with 1 lb = 453.6 g and 1 g = 15.432 gr. The conversion between grains and pounds is 1 lb = 7,000 gr. For example, at a material loading of 120 gr/cu ft, the equivalent loading in pounds would be 0.017 lb/cu ft.

For material bulk density, the common unit is lbm/cu ft, with mass represented as pound-mass (lbm) and volume as one (1) cubic foot. For example, a material having a listed bulk density of 80 lbm/cu ft has a weight by mass of 80 lbs of substance for each cubic foot occupied by the substance.

### *Correction to Volumetric Flow Rate*

Theoretically, the volumetric flow rate should be corrected to include the volume of material in the air. This correction is made by adding the volumetric flow rate of the air and the volumetric flow rate of the material in the airstream. This requires knowing the volumetric airflow rate, the material loading and the material bulk density. In practice, the effect is quite small and can either be ignored or included, depending on the designer's preference. The corrected volumetric flow rate is calculated by:

$$Q_c = Q_a + Q_m$$

Where: $Q_c$ = Corrected volumetric flow rate, acfm
$Q_a$ = Volumetric airflow rate, acfm
$Q_m$ = Volumetric material flow rate, cfm

### *Correction to Static Pressure Loss*

High material loadings effect the static pressure loss in the duct segment(s) in which the material is transported. The friction coefficient for most materials is less than the friction coefficient of air, so correction using the ratio of the combined mass of air and material to the mass of air will normally overstate the actual friction loss. The static pressure loss for all segments transporting material should be calculated according to standard practice for air and then corrected for the material loading in the airstream by:

$$SP_c = (SP_a)\left[0.36\left(\frac{\dot{m}_m}{\dot{m}_a}\right) + 1\right]$$

Where: $SP_c$ = Corrected static pressure, in wg
$SP_a$ = Static pressure calculated based on airflow, in wg
$\dot{m}_m$ = Material, by mass, lbm/min
$\dot{m}_a$ = Air, by mass, lbm/min

*Correction to Fan Horsepower*

Correction to the air density at the fan inlet for material loadings is made to determine the fan horsepower required to transport the material through the system. Since fans are rated based on the air density at the fan inlet, this correction only applies when material is conveyed through the fan. If the material is removed from the airstream prior to entering the fan (such as at a cyclone or baghouse), correction to the fan horsepower is not made. When material is conveyed through the fan, the fan horsepower rating is corrected by the ratio of the combined density of the air and material to the density of the air by:

$$\mathrm{HP_c} = \mathrm{HP_a}\left(\frac{\rho_c}{\rho_a}\right)$$

Where: $HP_c$ = Corrected fan horsepower
$HP_a$ = Fan horsepower for air only
$\rho_c$ = Corrected airstream density (air + material), lbm/cu ft
$\rho_a$ = Airstream density, lbm/cu ft

*Minimum Duct Design Velocity*

Since the volumetric flow rate is predominately air, only the volumetric airflow rate is used to determine the duct velocity. The minimum duct velocity must be sufficient to keep the material in suspension throughout the system[1] and is often based on application specific data or laboratory testing. Absent of empirical or laboratory test data, minimum duct velocities between 4,000 and 5,600 fpm are often satisfactory.

*Wear Due to Material Loadings*

Wear such as erosion or abrasion to the system components (ducting, fittings, fan, etc.,) is largely independent of material loading and is instead due to the material characteristics. Variables such as velocity and material loadings are only factors influencing the *rate* of wear. Methods for protection against wear due to material in the airstream are the same for all systems, regardless of loading.

*Example 1: Known System Design – Determine the Corrections for Flow, Airstream Density, Pressure and Power*

A system is designed for 10,000 acfm of dry air at 12 "wg sp, sea level, 70F, and an airstream density of 0.075 lbm/cu ft. Dry materials having a standard bulk density of 100 lb/cu ft are introduced into the system and conveyed through the fan at a loading of 80 gr/cu ft. A material handling fan is selected based on airstream conditions of 10,000 acfm @ 12 "wg FSP, 0.075 lbm/cu ft inlet airstream density and 33 hp. Determine the corrections necessary to the fan capacity due to the material loading in the airstream.

*1) Correction to the Volumetric Flow Rate*

The corrected volumetric flow rate is,

$Q_c = Q_a + Q_m$

Where: $Q_c$ = Corrected volumetric flow rate, acfm
$Q_a$ = Volumetric airflow rate, acfm
$Q_m$ = Volumetric material flow rate, cfm

$Q_a$ = 10,000 acfm

$Q_m = \dot{m}_m \div \rho_m$

Where: $\dot{m}_m$ = Mass flow rate of material (lbm/min)
$\rho_m$ = Material bulk density (lbm/cu ft)
1 gr = 1/7,000 lb (conversion factor)

$$\dot{m}_m = \frac{(80 \text{ gr/cu ft x } 10{,}000 \text{ acfm})}{7{,}000 \text{ gr/lb}}$$

$\dot{m}_m$ = 114.3 lbm/min

$Q_m = \dot{m}_m \div \rho_m$

$$Q_m = \frac{114.3 \text{ lb/min}}{100 \text{ lb/cu ft}}$$

$Q_m$ = 1.14 cu ft of material/minute

$Q_c = Q_a + Q_m$

$Q_c$ = 10,000 + 1.14

$Q_c$ = 10,001 acfm

*2) Correction to the Mass Flow Rate*

Since material is conveyed through the fan, the mass flow rate is the sum of the mass flow rate of the air and the mass flow rate of the material,

$\dot{m}_c = \dot{m}_a + \dot{m}_m$

$\dot{m}_a$ = (10,000 acfm) (0.075 lbm/cu ft)

$\dot{m}_a$ = 750 lbm/min

$\dot{m}_m$ = 114.3 lbm/min

$\dot{m}_c$ = 750 + 114.3

$\dot{m}_c$ = 864.3 lbm/min

*3) Determine the Material to Air Mass Ratio*

The material to air mass ratio is simply the material mass flow rate divided by the air mass flow rate,

$\dot{m}_m \div \dot{m}_a = 114.3 \div 750 = 0.15{:}1$

*4) Correction to the Fan Inlet Air Density*

Since the volumetric flow rate is the mass flow rate divided by the air density, $Q = \dot{m} \div \rho$, then the corrected density at the fan inlet is,

$\rho_c = \dot{m}_c \div Q_c$

$\rho_c = 864.3 \div 10{,}001$

$\rho_c = 0.0864$ lbm/cu ft

*5) Correction to the Static Pressure Loss*

The FSP is 12 "wg and the material loading is 80 gr/cu ft. The corrected FSP is,

$$SP_c = (SP_a)\left[0.36\left(\frac{\dot{m}_m}{\dot{m}_a}\right) + 1\right]$$

$SP_c = (12)\,(1.055)$

$SP_c = 12.7$ "wg

*6) Correction to the Fan Horsepower*

Since horsepower varies directly with the change in density, the corrected horsepower is,

$$HP_c = HP_a\left(\frac{\rho_c}{\rho_a}\right)$$

$$HP_c = 33\left(\frac{0.0864}{0.075}\right)$$

$$HP_c = 38\ \text{HP}$$

*7) Correction to the Fan Capacity Rating*

The corrected fan capacity rating for the fan is 10,001 acfm @ 12.7 "wg FSP, 0.0864 lbm/cu ft inlet airstream density and 38 hp. The material loading is 80 gr/cu ft with a material to air mass ratio of 0.15:1.

*<u>Example 2: Known Volumetric Airflow Rate, Air Density, System Static Pressure, Material Loading and Bulk Density - Determine the Criteria for Fan Selection.</u>*

A system is designed for a volumetric airflow rate of 1,700 acfm at 0.075 lbm/cu ft airstream density and a system static pressure loss of 26 "wg. The design material flow rate is 2,220 pph (pounds/hour) with a material bulk density of 7 pcf (lbm/cu ft).

*1) Correction to the Volumetric Flow Rate*

The corrected volumetric flow rate is,

$Q_c = Q_a + Q_m$

Where: $Q_c$ = Corrected volumetric flow rate, acfm
$Q_a$ = Volumetric airflow rate, acfm
$Q_m$ = Volumetric material flow rate, cfm

$Q_a$ = 1,700 acfm

$Q_m = \dot{m}_m \div \rho_m$

Where: $\dot{m}_m$ = Mass flow rate of material (lbm/min)
$\rho_m$ = Material bulk density (lbm/cu ft)

$\dot{m}_m$ = 2,220 lb/hr ÷ 60 min/hr

$\dot{m}_m$ = 37 lbm/min

$Q_m = \dot{m}_m \div \rho_m$

$$Q_m = \frac{37\ \text{lb/min}}{7\ \text{lbm/cu ft}}$$

$Q_m$ = 5.3 cu ft of material/minute

$Q_c = Q_a + Q_m$

$Q_c = 1{,}700 + 5.3$

$Q_c$ = 1,705 acfm

*2) Correction to the Mass Flow Rate*

Since material is conveyed through the fan, the mass flow rate is the sum of the mass flow rate of the air and the mass flow rate of the material,

$\dot{m}_c = \dot{m}_a + \dot{m}_m$

$\dot{m}_a$ = (1,700 acfm) (0.075 lbm/cu ft)

$\dot{m}_a$ = 127.5 lbm/min

$\dot{m}_m$ = 37 lbm/min

$\dot{m}_c = 127.5 + 37$

$\dot{m}_c = 164.5$ lbm/min

*3) Determine the Material to Air Mass Ratio*

The material to air mass ratio is simply the material mass flow rate divided by the air mass flow rate,

$\dot{m}_m \div \dot{m}_a = 37 \div 127.5 = 0.29{:}1$

*4) Correction to the Airstream Density*

Since the volumetric flow rate is the mass flow rate divided by the air density, $Q = \dot{m} \div \rho$, then the corrected density at the fan inlet is,

$\rho_c = \dot{m}_c \div Q_c$

$\rho_c = 164.5 \div 1{,}705$

$\rho_c = 0.0965$ lbm/cu ft

*5) Correction to the Static Pressure Loss*

The static pressure loss of the air system is 26 "wg and the material loading is 37 lbm/min. The corrected static pressure is,

$$SP_c = (SP_a)\left[0.36\left(\frac{\dot{m}_m}{\dot{m}_a}\right) + 1\right]$$

$SP_c = (26)\,(1.1)$

$SP_c = 28.7$ "wg

*6) Correction Factor to the Fan Horsepower*

Since horsepower varies directly with the change in density, the correction factor for horsepower is,

$$HP_c = HP_a\left(\frac{\rho_c}{\rho_a}\right)$$

Where: $\rho_c = 0.0965$ lbm/cu ft
$\rho_a = 0.075$ lbm/cu ft

$$HP_c = HP_a(1.29)$$

*7) Criteria for Fan Selection*

The fan can be selected either on an air only basis with corrections applied for pressure and power, or on an air-material basis with the corrections made in the fan selection criteria.

On an air only basis, the fan would be selected for 1,700 acfm @ 26 "wg sp and 0.075 lbm/cu ft airstream density with applied correction factors of 1.1 for static pressure and 1.29 for horsepower.
On an air-material basis, the fan would be selected for 1,705 acfm @ 28.6 "wg sp and 0.0965 lbm/cu ft inlet airstream density (the horsepower will self-correct at fan selection due to the corrected airstream density).

## CONCLUSIONS

These guidelines are for systems or system segments having material loadings between 20 and 260 gr/gr/cu ft (material to air mass ratios to 1:2) operating in the intermediate range between LEV and pneumatic conveying systems.

Correction to the system volumetric flow rate for the material conveyed is normally slight and can be ignored.

The volumetric airflow rate is used to calculate design duct velocities.

The static pressure loss for all segments transporting material should be calculated according to standard practice and then corrected for the material loading.

Fan horsepower should be corrected only when material is conveyed through the fan.

Wear to system components is independent of material loadings and instead due to material characteristics. Loadings only effect the *rate* of wear.

## REFERENCES

[1] Howden Buffalo, Inc.; Fan Engineering, An Engineer's Handbook on Fans and Their Applications, 9th Edition, Chapter 24, "Floating and Relative Velocities".

## ACKNOWLEDGMENTS

James Friedman, PE, CIH, Senior Industrial Ventilation Consultant, Wood PLC, Minneapolis, Minnesota
David S. Maletich, Vice President, The New York Blower Company, Willowbrook, Illinois

## ABOUT THE AUTHOR

Dale Price is President of M&P Air Components, Inc., Huntington Beach, Ca, serving as a manufacturer's representative for industrial fans in Southern California. Dale has 38 years of experience in the design and application of dust collectors and industrial fan applications. Dale has over 30 years of tenure with the Michigan, Alabama and Las Vegas Industrial Ventilation Conferences and is the Director of the West Coast Industrial Ventilation Conference. Dale is a member of the ACGIH® Industrial Ventilation Committee.