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HOW TO CORRECT FOR DENSITY IN VENTILATION MEASUREMENTS

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HOW TO CORRECT FOR DENSITY IN VENTILATION MEASUREMENTS

1. PURPOSE. This guide is designed to provide *standard* methods for determining the correction factors for density in ventilation measurements. The industrial hygienist will find this guide helpful in the performance of his/her duties.

2. VENTILATION MEASUREMENT DEVICES.

a. Ventilation measurement devices [i.e., pitot tube and manometer, anemotherm (velometer)] are calibrated and designed to provide a visual numerical reading equivalent to the movement of air sampled at standard temperature and pressure. In ventilation work, this is considered dry air at 70°F and 29.92 inches of mercury (Hg) barometric pressure (at sea level, 1 atmosphere). This is equivalent to 0.075 lbs/cu ft. When altitude changes (usually over 4000 ft) and differences of temperature are encountered, the reading obtained from the particular measuring device must be corrected to indicate the actual flow (or volume) of air being handled by the system. The type of measuring device will dictate the formula used in determining the correction factor to be used.

b. Formulas (1) through (4) are common to ventilation.

$$Q = VA \qquad (1)$$

where: Q = volumetric flow in cubic feet per minute (cfm)
V = velocity in linear feet per minute (fpm)
A = area of opening in square feet (ft^2)

$$V = 4005 \sqrt{VP} \quad (2)$$

where: V = velocity, fpm
VP = velocity pressure in inches of water (H_2O)

3. PITOT TUBE AND INCLINED MANOMETER. These devices are used to measure *velocity pressure*. To correct for temperature and pressure (thus density), the ratio of the square roots of the density of standard air to measured air must be obtained. Several practical formulas exist to correct for the variables of altitude and temperature (density).

$$V = 1096.5 \sqrt{\frac{VP}{D}} \quad \text{(Velocity actual) (3)}$$

where: V = velocity, fpm
VP = velocity pressure
D = density [obtained from formula (4)]

$$D = 1.33 \frac{BP}{(T_{DB} + 460)} \quad (4)$$

where: D = density
BP = barometric pressure in inches of Hg
T_{DB} = temperature in degrees Fahrenheit (°F), dry bulb

Formula (3) above requires that each reading (VP) be adjusted before the readings are averaged. Altering formula (3) to shorten the mathematical mechanics of determining the actual velocity, while utilizing the velocity pressures and taking into consideration the effects of density gives,

$$V_c = 1096.5 \frac{\left(\frac{\Sigma_1^n \sqrt{VP_n}}{n}\right)}{\sqrt{D}} \quad (5)$$

where: V_c = velocity in fpm (corrected)
VP_n = velocity pressure in inches of H_2O of n reading
n = number of readings
D = density [from formula (4)]

The most convenient method involves multiplying either the volumetric flowrate (cfm) or linear flow (fpm) by the ratio of the square roots of the densities, Correction Factor (C).

$$C = \sqrt{D_s/D_D} \quad (6)$$

$$Q_c = Q\sqrt{D_s/D_D} = Q_c \text{ or } F_c = F\sqrt{D_s/D_D} = F_c \quad (7)$$

where: Q_c = volumetric flowrate, corrected
F_c = linear flow, corrected
Q = volumetric flowrate, uncorrected
F = linear flow, uncorrected
D_s = density of standard air (0.075 lbs/ft^3)
D_D = density of duct air (lbs/ft^3)

D_D can be computed from formula (4).

4. ANEMOTHERM. The anemotherm measures *mass flow*. The molecules of air rushing by the heated wires of the probe cools the wires, and changes the resistance of the electrical circuit. The Wheatstone Bridge circuit measures the change in resistance and the dial reading is the direct output of this resistance adjustment. The method of correction is a *straight* ratio.

$$\text{Average Meter Reading} \times \frac{14.7}{530} \times \frac{(T + 460)}{P} \quad (8)$$

where: T = F°
P = actual atmospheric pressure [pounds of force/square inch (in^2)]
460 = Temperature in degrees RANKINE (constant)
14.7 = Standard pressure of air at 0° F and sea level (lbs/in^2)

5. EXAMPLES.

a. Pitot Tube Traverse. The ventilation system evaluated consists of a 42-inch round duct having a duct air temperature of 100°F. A telephone call to the local weather bureau shows the barometric pressure to be 24.91 inches of Hg.

STEP 1. A 20-point traverse is performed using the pitot tube measuring points obtained from Tables 9-1 through 9-3, pages 9-6 and 9-7, Industrial Ventilation, A Manual of Recommended Practice, 17th edition, 1982, American Conference of Governmental Industrial Hygienist, Lansing, MI. The readings obtained from the inclined manometer are as follows:

Point #	Manometer Reading (VP)	Point #	Manometer Reading (VP)
1	0.13	11	0.14
2	0.18	12	0.19
3	0.20	13	0.22
4	0.24	14	0.26
5	0.27	15	0.30
6	0.37	16	0.34
7	0.38	17	0.35
8	0.38	18	0.32
9	0.33	19	0.30
10	0.26	20	0.25

STEP 2. Determine the corresponding velocity from the velocity pressures. Two methods are available.

NOTE: The examples are not of comparative measurements in a sample system, but of different systems and locations.

METHOD 1. Utilizing Formula (2)

$$V = 4005 \sqrt{VP}$$

For example, if VP = 0.13

$$V = 4005\sqrt{0.13}$$
$$= 4005 (0.36)$$
$$= 1444 \text{ fpm (velocity)}$$

METHOD 2. Utilizing Tables from the Industrial Ventilation Manual

Go to page 6-33, 17th edition of Industrial Ventilation and the corresponding velocity. For VP = 0.13, V = 1444.

For our example, the corresponding velocities are:

Point #	(VP)	(V)	Point #	(VP)	(V)
1	0.13	1444	11	0.14	1499
2	0.18	1699	12	0.19	1746
3	0.20	1791	13	0.22	1879
4	0.24	1962	14	0.26	2042
5	0.27	2081	15	0.30	2194
6	0.37	2436	16	0.34	2335
7	0.38	2469	17	0.35	2369
8	0.38	2469	18	0.32	2266
9	0.33	2301	19	0.30	2194
10	0.26	2042	20	0.25	2003
		20694			20527

STEP 3. Determine the average airflow for the readings obtained. This is accomplished by adding all the velocity measurements then dividing by the number of traverse points.

For this example: 20694 + 20527 = 41221 fpm
41221 ÷ 20 points = 2061 fpm average (uncorrected)

Remember - You cannot average the velocity pressures then convert to an average velocity. You can only average velocities.

STEP 4. Determine the volumetric flow rate.

From formula (1), Q = VA.

where: Q = cfm (volumetric flow rate)
V = velocity of the duct in fpm
A = area of the duct in ft^2

For our example the duct diameter is 42 inches. From page 6-35, Industrial Ventilation, the duct area or A of our formula is 9.621 ft^2. The velocity (V) is 2061 fpm (from Step 3). Therefore:

$$Q = VA = (2061 \text{ fpm})(9.621 \text{ ft}^2) = 19829 \text{ cfm}$$

This value is uncorrected. That is, we have *not* taken into account changes in the air density due to temperature and/or pressure.

STEP 5. Determine the actual or *corrected* airflow through the duct.

Several methods exist for doing this, however, if you understand the mechanics involved and the mathematical manipulations, the methods should be interchangeable and easily used.

METHOD 1. Velocity A

This method utilizes formula (3):

$$V = 1096.5\sqrt{\frac{VP}{D}}$$

As stated, formula (3) requires that each *reading* (VP, velocity pressure) be adjusted before totalling. We also must determine the D, or density from formula (4).

$$D = 1.33\frac{BP}{(T_{DB} + 460)}$$

where: D = density
BP = barometric pressure in inches of Hg
T_{DB} = temperature in degrees °F, dry bulb

From our example:

BP = 24.91 in (Hg)
T_{DB} = 100 °F

Therefore, $D = 1.33\frac{BP}{(T_{DB} + 460)}$

$$= 1.33\frac{24.91}{(100 + 460)}$$

$$= 1.33\ (0.044)$$

$$= 0.059$$

Returning to formula (3):

$$V = 1096.5 \sqrt{\frac{VP}{0.059}}$$

Take the first VP reading, 0.13:

$$V = 1096.5 \sqrt{\frac{0.13}{0.059}}$$

$$= 1096.5 \sqrt{2.20}$$

$$= 1096.5\ (1.48)$$

$$= 1622.8 \text{ fpm (corrected)}$$

The average corrected flowrate (fpm) of air through the duct can be obtained by averaging the corrected fpm values. Multiplying the average corrected flowrate (fpm) by the area of the duct (ft^2), provides the total corrected volumetric flowrate (cfm).

For our example:

Point #	VP	Corrected V	Point	VP	Corrected V
1	0.13	1627.6	11	0.14	1689.0
2	0.17	1861.3	12	0.20	2018.8
3	0.20	2018.8	13	0.22	2117.0
4	0.23	2164.9	14	0.25	2257.0
5	0.27	2345.7	15	0.29	2431.0
6	0.37	2745.9	16	0.36	2708.5
7	0.38	2782.8	17	0.35	2670.6
8	0.37	2745.9	18	0.32	2553.6
9	0.35	2670.6	19	0.30	2472.5
10	0.27	2345.7	20	0.22	2117.0
		23309.2			23035.0

23309.2 + 23035.0 = 46344.2

46344.2 - 20 points = 2317.2 corrected fpm

Formula (1), Q = VA

$$Q = 2317.2\ (9.621)$$

$$= 22294 \text{ corrected cfm}$$

METHOD 2. Velocity B

This method utilizes formula (5).

$$V_c = 1096.5 \frac{\frac{\Sigma_1^n \sqrt{VP_n}}{n}}{\sqrt{D}}$$

where: V_c = velocity in fpm (corrected)

VP_n = velocity pressure in inches of H_2O of n readings

n = number of readings

D = density [from formula (4)]

For our example:

Point	VP	$\sqrt{VP}$	Point	VP	$\sqrt{VP}$
1	0.13	0.36	11	0.14	0.37
2	0.17	0.41	12	0.20	0.45
3	0.20	0.45	13	0.22	0.47
4	0.23	0.48	14	0.25	0.50
5	0.27	0.52	15	0.29	0.54
6	0.37	0.61	16	0.36	0.60
7	0.38	0.62	17	0.35	0.59
8	0.37	0.61	18	0.32	0.57
9	0.35	0.59	19	0.30	0.55
10	0.27	0.52	20	0.22	0.47
		5.17			5.11

STEP 1. Sum the square roots of the velocity pressures

$$\Sigma_1^n \sqrt{VP_n} = 10.28$$

STEP 2. Divide by the number of readings

$$\frac{\Sigma_1^n \sqrt{VP_n}}{n} = \frac{10.28}{20} = 0.514$$

STEP 3. Divide by the square root of the density [from formula (4)], where D = 0.059

$$\frac{\frac{\Sigma_1^n \sqrt{VP_n}}{n}}{\sqrt{D}} = \frac{\frac{10.28}{20}}{\sqrt{0.059}} = \frac{0.514}{0.243} = 2.115$$

STEP 4. Multiply by the constant: 1096.5

$$\frac{\frac{\Sigma_1^n \sqrt{VP_n}}{n}}{\sqrt{D}} = (1096.5)(2.115) = 2319 \text{ fpm (corrected)}$$

NOTE: This equation requires the averaging of the square roots of the velocity pressures. Averaging the velocity pressures will cause an erroneous solution.

From formula (1), Q = VA where from our example,

V = 2319 fpm (corrected)

A = 9.621 ft^2

therefore,

Q = (2319) (9.621)
= 22311 cfm (corrected)

METHOD 3. Correction Factor (C)

This method is the easiest to use with the old USAEHA Form 70, Pitot Tube Traverse (16 Points - Rectangular Duct) and Form 71, Pitot Tube Traverse (20 Points - Round Duct); or renumbered new USAEHA Forms 15 and 16.

Utilizing formula (7),

$Q_C = Q_C$ or $F_C = F_C$

Where $C = \sqrt{D_S/D_D}$

Q = volumetric flowrate, uncorrected (fpm)

F = linear flow, uncorrected (fpm)

Q_C = volumetric flowrate, corrected (cfm)

F_C = linear flow, corrected (fpm)

D_S = density of standard air (lbs/ft^3)

D_D = density of duct air (lbs/ft^3)

For our example, substituting the values, where,

$Q = 19829$ cfm
$F = 2061$ fpm
$D_S = 0.075$ lbs/ft^3
$D_D = 0.059$ lbs/ft^3

we obtain, $C = \sqrt{\frac{0.075}{0.059}}$

$= \sqrt{1.27}$

$= 1.13$

Therefore, $Q_C = QC$ or $F_C = FC$ [formula (7)]

$Q_C = (19829)\ (1.13)$ or $F_C = (2061)\ (1.13)$

= 22407 cfm corrected or = 2329 fpm corrected

To obtain the volumetric flowrate (corrected) from the linear flow (corrected), we multiply, $F_C = 2329$ fpm by the area of the duct 9.621 ft^2

solving formula (1), $Q = VA$;

$Q = (2329)\ (9.621)$

= 22406.6 cfm corrected

NOTE: Three methods of correcting for the effects of temperature and/or pressure (density) in a ventilation duct have been shown. The total, corrected volumetric flowrates and corrected linear flows are not identical. For example:

	Corrected Volumetric Flowrate/	Corrected Linear Flow
Method 1	22294 cfm	2317 fpm
Method 2	22311 cfm	2319 fpm
Method 3	22407 cfm	2329 fpm

The factors contributing to these discrepancies include significant digits used in calculations and rounding off techniques, especially with the use of electronic calculators. There is nothing unusual with these discrepancies. Ventilation work is not an exact science nor technically advanced to eliminate measuring and calculation errors.

b. Anemotherm Traverse. The system evaluated is a 1 X 2 ft duct. The duct was of such dimension that a 21-point traverse was utilized. The duct temperature was 64°F and the weather station showed the barometric pressure at 24.97 inches Hg.

STEP 1. The duct traverse results are shown below.

Point #	V	Point #	V	Point #	V
1	1000	8	2100	15	1450
2	1200	9	2200	16	2500
3	1650	10	1950	17	2000
4	1300	11	2300	18	1800
5	1800	12	2450	19	2450
6	1800	13	2400	20	2200
7	1000	14	1900	21	1800
Total	9750		15300		14200

These readings are taken directly from the anemotherm meter scale and are uncorrected.

STEP 2. Averaging the readings obtained gives an average linear flow (V) of 39250 ÷ 21 = 1869.0 fpm (uncorrected)

STEP 3. The area of the duct A,
1 ft X 2 ft = 2 ft^2

STEP 4. Solving for Q = VA,

Q = (1869) (2)
= 3738 cfm (uncorrected)

STEP 5. To correct for altitude and temperature (density) utilizing formula (8), we need the temperature of the duct air in °F and P, atmospheric pressure in pounds per square inch.

$$\frac{14.7}{530} \times \frac{\left(T_{DB} + 460\right)}{P}$$

The temperature, T = 64°F, but there is nothing corresponding to the P value. However, barometric pressure (BP) is known, 24.97 inches Hg. One lb per square inch equals 2.036 inches Hg:

1 lb/in^2 = 2.036 in Hg

STEP 6. Converting 24.97 in Hg to lbs/in^2,

$$\frac{24.97 \text{ in Hg}}{2.036 \text{ in Hg}} = 12.26 \text{ lbs/in}^2$$

For our example,

$$\frac{14.7}{530} \times \frac{(64° + 460)}{12.26} = 1.185 \text{ density correction factor}$$

STEP 7. To complete the formula, the density correction factor (C) is multiplied by the average volumetric flowrate (uncorrected) to obtain the average volumetric flowrate (corrected).

$$Q_C = Q_{Average} \times C$$

where: Q_C = volumetric flowrate corrected (cfm)

$Q_{Average}$ = volumetric flowrate uncorrected (cfm)

C = correction factor or $\frac{14.7}{530} \frac{(T_{DB} + 460)}{P}$

For our example,

$$Q_C = Q_{Average} \times C$$

= 3738 cfm X 1.185

= 4430 corrected cfm

The correction factor (C), can also be used to correct the linear flow and then compute the corrected volumetric flowrate.

$$F_C = F_{Average} \times C$$

where F_C = linear flowrate, corrected (fpm)

$F_{Average}$ = linear flowrate, uncorrected (fpm)

For our example,

$$F_C = F_{Average} \times C$$

= 1869 fpm X 1.185

= 2215.6 corrected fpm.

To determine the corrected cfm we simply take

$$Q_C = F_C \times A$$

where A = area of the duct in ft^2

$$= 2215.6 \times 2 \text{ ft}^2$$

$$= 4431.2 \text{ actual cfm}$$

The slight differences in corrected cfm and corrected fpm for the different calculation methods are caused by the same factors mentioned in paragraph 5a.