



# Density Calculations: Calculating Density For Use In Fan Systems

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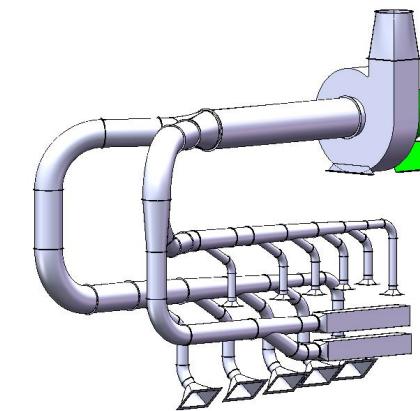
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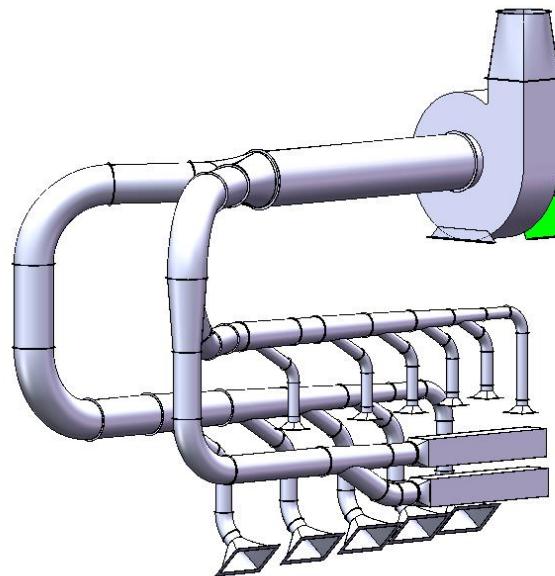


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# **Density Calculations: Calculating Density For Use In Fan Systems**

## **Purpose and Learning Objectives**

The purpose of this presentation is to educate engineers, system designers, and fan application specialists on the calculations required to determine air or gas density.

At the end of this presentation you will be able to:

1. Describe the makeup of standard air.
2. Identify factors that determine gas density.
3. Calculate gas density for temperature, elevation, or pressure change.
4. Calculate gas density for gas other than air.
5. Combine multiple factors to calculate gas density.
6. Explain the impact of gas density of fan and system performance.

# Density Calculation Topics

- Standard Air
- Temperature Change Calculations
- Pressure & Altitude Change Calculations
- Molecular Weight Calculations
- Humidity and Water Vapor
- Combining Multiple Density Calculations
- Density Effects On Fan and System Performance
- ACFM and SCFM Calculations

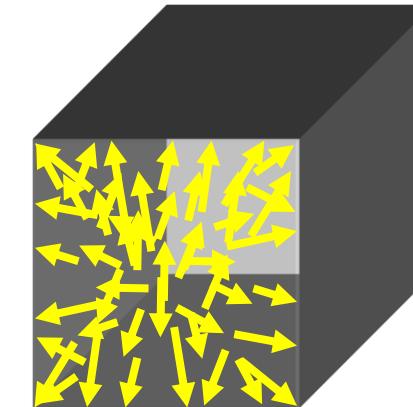
# Standard Air Recipe (Ingredients)

- Gas make up (by volume)
  - 78% Nitrogen (N<sub>2</sub>)
  - 21% Oxygen (O<sub>2</sub>)
  - 0.9% Argon (Ar)
  - 0.04% Carbon Dioxide (CO<sub>2</sub>)
  - Pinch of other trace gases
- Gasses have different molecular weights and the percentages determine overall gas weight
- Molecular weight of standard air
  - 28.965 grams/mole

	<u>Gas</u>	<u>Cst %</u>	<u>Mole Weight</u>	<u>MW %</u>	<u>Cst Wt.</u>
	N <sub>2</sub>	78.08%	28.014	75.52%	21.87
	O <sub>2</sub>	20.94%	31.998	23.14%	6.70
	Ar	0.93%	39.948	1.29%	0.37
	CO <sub>2</sub>	0.04%	44.01	0.06%	0.02
	Ne	0.002%	20.18	0.001%	0.00
		100.00%		100.00%	28.96
			Mole Weight air	~28.965	

# Standard Air Recipe (Pressurize and Heat)

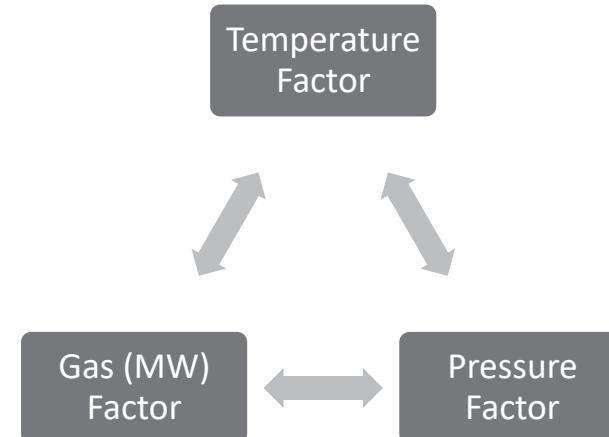
- Gas make up (by volume)
  - 78% N<sub>2</sub>, 21% O<sub>2</sub>, 0.9% Ar, 0.04% CO<sub>2</sub>, and trace gases
- Pressure (atmospheric or system)
  - 29.921 in Hg, 14.696 psi, 101.325 kPa, 760mm Hg
- Temperature basis for standard air
  - 70°F, 21°C, 530R, 294K  
(Dry air or 68°F 20°C with 50% Relative Humidity)



- Density is mass/unit volume
- Add gases to one cubic foot
- Weight will be 0.075 pounds
- 0.075 pounds mass/cubic foot
- Standard Air Density:  
 $0.075 \text{ lb}_m/\text{ft}^3, 1.2 \text{ kg/m}^3$

# Standard Air Uses and Changes

- Standard Air → standard density
    - Reference gas for:
      - Fan Catalogs
      - Performance test results
      - Rating tables
      - Data sets
    - STP - Standard Temperature and Pressure
  - Standard air in nature is rare
  - Fans handle actual air or gas
- Change the recipe → change the density → Change the Factor
    - Temperature
    - Pressure
    - Ingredient gas mix

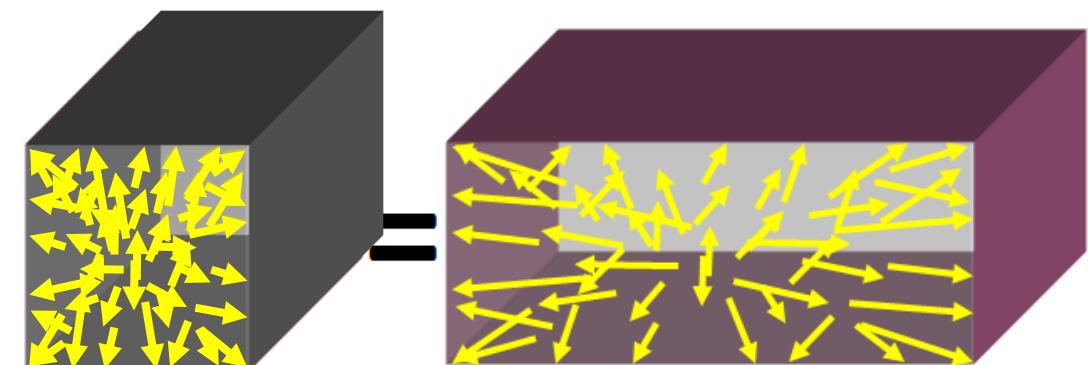


# Density Standards and Calculations

- 0.075 lb<sub>m</sub>/ft<sup>3</sup> is standard density IP units  $\rho_{std} = 0.075lb_m/ft^3$
- 1.20 kg/m<sup>3</sup> is the standard density for SI units  $\rho_{std} = 1.20kg/m^3$
- $\rho$  (rho) is the symbol for density  $\rho_{act} = \text{actual density}$
- Standard density is multiplied by a series of calculations to calculate actual density at the fan inlet.
- The calculations are for changes of temperature, pressure, and gas mixture.

# Temperature Changes

- Pressure is constant in most systems.
- Causes of temperature changes:
  - Heat being added to system
  - Recirculating system
  - Intake over hot process
  - Hot or cold location
  - Other...
- Temperature changes cause the density and volume to change when pressure is constant.
- Density is based on the cubic foot (or cubic meter)



# Density Calculation for Temperature Change

- Density change is inversely proportional to absolute temperature change
- Calculate density with temperature factor based on absolute temperature
- Calculate density for 430°F (221°C)

$$\rho_{act} = \rho_{std} \frac{\text{Absolute temp}_{std(R \text{ or } K)}}{\text{Absolute temp}_{act(R \text{ or } K)}}$$

Absolute Temperature IP or SI units correction

- IP Units Rankine Scale 459.67°F=0°F
- SI Units Kelvin Scale 273.15°K=0°C

In both cases the degree size is same as base unit.

$$\rho_{act} = \rho_{std} \frac{\text{absolute zero}_{correction(R \text{ or } K)} + \text{temp}_{std(F \text{ or } C)}}{\text{absolute zero}_{correction(R \text{ or } K)} + \text{temp}_{act(F \text{ or } C)}}$$

# Pressure Changes

- Density change is proportional to absolute pressure change
- Sources of pressure changes:
  - Elevation
  - Pressurized System
  - Suction or compression from blower
  - Other
- Multiple pressure factors can combine to change density



# Elevation Changes Pressure and Density

- Elevation changes density by reducing the atmospheric pressure. (News service pressure is corrected to 0 elevation.)
- Density and factor are calculated based on elevation above sea level:

$$\rho_{act} = \rho_{std} * (1 - ((6.8754 * 10^{-6}) * feet))^{5.2561}$$

$$\rho_{act} = \rho_{std} * (1 - ((22.08 * 10^{-6}) * meters))^{5.2561}$$

# Density Calculation for Elevation

- Calculate density for elevation of 3,937 feet, (1,200 meters) ASL:

IP units (feet)     $\rho_{act} = \rho_{std} * (1 - ((6.8754 * 10^{-6}) * feet))^{5.2561}$

$$\rho_{act} = 0.075 \frac{lb_m}{ft^3} * (1 - ((6.8754 * 10^{-6}) * 3,937))^{5.2561}$$

$$\rho_{act} = 0.075 \frac{lb_m}{ft^3} * 0.866 \quad \rho_{act} = 0.065 \frac{lb_m}{ft^3}$$

SI units (meters)  $\rho_{act} = \rho_{std} * (1 - ((22.08 * 10^{-6}) * meters))^{5.2561}$

$$\rho_{act} = 1.20 \frac{kg}{m^3} * (1 - ((22.08 * 10^{-6}) * 1,200))^{5.2561}$$

$$\rho_{act} = 1.20 \frac{kg}{m^3} * 0.866 \quad \rho_{act} = 1.04 \frac{kg}{m^3}$$

# Local Atmospheric Pressure Calculation for Elevation

- Calculate local Barometric Pressure for elevation of 3,937 feet, (1,200 meters) ASL:

IP units (Feet & PSI)

$$P_{b(act)} = P_{b(std)} * (1 - ((6.8754 * 10^{-6}) * feet))^{5.2561}$$

$$P_{b(act)} = 14.696 \text{ PSI} * (1 - ((6.8754 * 10^{-6}) * 3,937))^{5.2561}$$

$$P_{b(act)} = 14.696 \text{ PSI} * 0.866 \quad P_{b(act)} = 12.72 \text{ PSI}$$

SI units (meters & kPa)

$$P_{b(act)} = P_{b(std)} * (1 - ((22.08 * 10^{-6}) * meters))^{5.2561}$$

$$P_{b(act)} = 101.32 \text{ kPa} * (1 - ((22.08 * 10^{-6}) * 1,200))^{5.2561}$$

$$P_{b(act)} = 101.32 \text{ kPa} * 0.866 \quad P_{b(act)} = 87.99 \text{ kPa}$$

# Pressurized System Changes Density

- A closed system changes density by increasing, or decreasing, the pressure within the process loop relative to local atmospheric pressure.
- Calculated the same with IP or SI units with constant units, i.e. system psi/atmospheric pressure psi or system kPa/local kPa
- Pressures listed may be gauge or absolute. (Bar is absolute typically)
- Density and factor are calculated based on absolute system pressure to standard pressure ratio:

$$\rho_{act} = \rho_{std} * \frac{System\ Pressure + Local\ Pressure}{Standard\ Atmospheric\ Pressure}$$

Use 0.075 lb<sub>m</sub>/ft<sup>3</sup> (IP) or 1.20 kg/m<sup>3</sup> (SI) standard density  $\rho$  units

## Density Calculation for System Pressure (IP)

- Calculate density for system at 34.65 PSIG, (238.9 kPa(g))
- Use local atmospheric pressure from earlier local atmospheric pressure calculation (12.72 PSI, 87.99 kPa)

$$\rho_{act} = \rho_{std} * \frac{System\ Pressure + Local\ Pressure}{Standard\ Atmospheric\ Pressure}$$

$$\rho_{act} = 0.075 \frac{lb_m}{ft^3} * \frac{34.64\ PSI + 12.72\ PSI}{14.696\ PSI}$$

$$\rho_{act} = 0.075 \frac{lb_m}{ft^3} * 3.22 \quad \rho_{act} = 0.242 \frac{lb_m}{ft^3}$$

## Density Calculation for System Pressure (SI)

- Calculate density for system at 34.65 PSIG, (238.9 kPa(g))
- Use local atmospheric pressure from earlier local atmospheric pressure calculation (12.72 PSI, 87.99 kPa)

$$\rho_{act} = \rho_{std} * \frac{\text{System Pressure} + \text{Local Pressure}}{\text{Standard Atmospheric Pressure}}$$

$$\rho_{act} = 1.20 \frac{kg}{m^3} * \frac{238.9 \text{ kPa} + 87.99 \text{ kPa}}{101.3 \text{ kPa}}$$

$$\rho_{act} = 1.20 \frac{kg}{m^3} * 3.23 \quad \rho_{act} = 3.87 \frac{kg}{m^3}$$

# Suction on Inlet Changes Density

- Suction in the inlet of the blower changes density by decreasing the pressure at the inlet of the blower relative to local atmospheric pressure, (rarefaction).
- Calculated the same with IP or SI units with constant units, i.e. suction pressure inches H<sub>2</sub>O/atmospheric pressure inches H<sub>2</sub>O or system mm H<sub>2</sub>O /local mm H<sub>2</sub>O
- Density and factor are calculated based on absolute system pressure to standard pressure ratio:

$$\rho_{act} = \rho_{std} * \frac{Local\ Pressure - abs(Suction\ Pressure)}{Standard\ Atmospheric\ Pressure}$$

Use 0.075 lb<sub>m</sub>/ft<sup>3</sup> (IP) or 1.20 kg/m<sup>3</sup> (SI) standard density  $\rho$  units

# Density Calculation for Suction on Inlet (IP)

- Calculate density for suction on inlet of -30in H<sub>2</sub>O, (762mm H<sub>2</sub>O)
- Use local atmospheric pressure from earlier local atmospheric pressure calculation (12.72 PSI, 87.99 kPa)

$$\rho_{act} = \rho_{std} * \frac{\text{Local Pressure} - \text{abs}(\text{Suction Pressure})}{\text{Standard Atmospheric Pressure}}$$

$$\rho_{act} = 0.075 \frac{lb_m}{ft^3} * \frac{(12.72 \text{ PSI} * 27.7 \text{ in H}_2\text{O/PSI}) - \text{abs}(-30 \text{ in H}_2\text{O})}{(14.696 \text{ PSI} * 27.7 \text{ in H}_2\text{O/PSI})}$$

$$\rho_{act} = 0.075 \frac{lb_m}{ft^3} * \frac{322.1 \text{ in H}_2\text{O}}{406.8 \text{ in H}_2\text{O}} = 0.075 \frac{lb_m}{ft^3} * 0.792 = 0.059 \frac{lb_m}{ft^3}$$

# Density Calculation for Suction on Inlet (SI)

- Calculate density for suction on inlet of -30in H<sub>2</sub>O, (762mm H<sub>2</sub>O)
- Use local atmospheric pressure from earlier local atmospheric pressure calculation (12.72 PSI, 87.99 kPa)

$$\rho_{act} = \rho_{std} * \frac{\text{Local Pressure} - \text{abs(Suction Pressure)}}{\text{Standard Atmospheric Pressure}}$$

$$\rho_{act} = 1.20 \frac{kg}{m^3} * \frac{(87.99 \text{ kPa} * 102 \text{ mm H}_2\text{O/kPa}) - \text{abs}(-762 \text{ mm H}_2\text{O})}{(101.3 \text{ kPa} * 102 \text{ mm H}_2\text{O/kPa})}$$

$$\rho_{act} = 1.20 \frac{kg}{m^3} * \frac{8,210 \text{ mm H}_2\text{O}}{10,332 \text{ mm H}_2\text{O}} = 1.20 \frac{kg}{m^3} * 0.795 = 0.954 \frac{kg}{m^3}$$

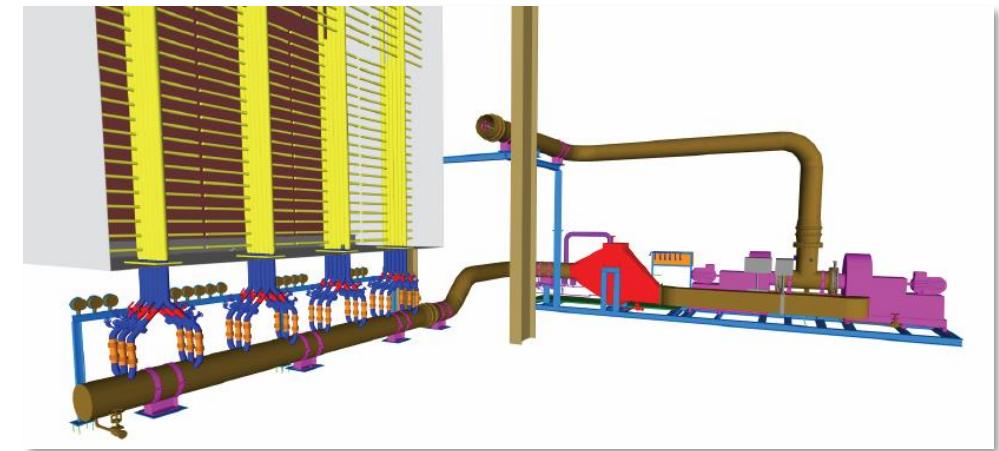
# Standard Versus Local (Actual)

- Calculating factors requires use of:
  - Standard Density
  - Actual Local Density
  - Standard Atmospheric Pressure
  - Local Atmospheric Pressure
- Local or standard unit in denominator should be consistent with the reference value

$$\rho_{act} = \rho_{std} * \frac{Local\ Pressure - abs(Suction\ Pressure)}{Standard\ Atmospheric\ Pressure}$$

# Gas Make Up Changes Density

- Some systems handle gases that are not air
- Common Systems using other gases:
  - Refinery and Nitrogen Blowers
  - High Temperature Ammonia Injection Blower
  - Mechanical Vapor Recompression Steam System
  - Other
- The molecular weight of the gas combined with temperature and pressure determines the density



# Calculating the Gas Molecular Weight

- The molecular weight of air was calculated 28.965 kg/mole
- Gas mixture is provided by specifier
- Calculation is based on the constituent gases and their percentage volume in the mix and individual molecular weight

Name	Gas	Cst %	Mole Wt.	MW %	Cst Wt.
Carbon Dioxide	CO <sub>2</sub>	15.700%	44.01	6.91	23.39%
Chloride	Cl	0.001%	35.45	0.00	0.00%
Hydrogen Chloride	HCl	0.206%	36.46	0.08	0.25%
Water	H <sub>2</sub> O	10.300%	18.016	1.86	6.28%
Nitrogen	N <sub>2</sub>	73.100%	28.014	20.48	69.32%
Oxygen	O <sub>2</sub>	0.700%	31.998	0.22	0.76%
		100.0%		-----	100.0%
Gas Combination Mole Weight:				29.54	-----

# Density Calculation for Molecular Weight

- Density change for molecular weight is proportional to specified gas molecular weight ratio to standard air molecular weight.
- Factor calculated the same with IP or SI units
- Use 0.075 lbm/ft<sup>3</sup> (IP) or 1.20 kg/m<sup>3</sup> (SI) Standard density  $\rho$  units for basis

- IP Units:  $\rho_{std} = 0.075 \frac{lb_m}{ft^3}$   
$$\rho_{act} = \rho_{std} * \frac{Actual\ Mole\ Wt}{Standard\ Mole\ Wt}$$
- SI Units:  $\rho_{std} = 1.20 \frac{kg}{m^3}$   
$$\rho_{act} = \rho_{std} * \frac{Actual\ Mole\ Wt}{Standard\ Mole\ Wt}$$

# Density Calculation for Molecular Weight

- Calculate density for the actual Refinery gas stream at standard temperature and pressure
- Gas stream molecular weight calculated 29.54 kg/m

$$\rho_{act} = 0.075 \frac{lb_m}{ft^3} * \frac{29.54 \text{ kg}/m}{28.965 \text{ kg}/m}$$

$$\rho_{act} = 1.20 \frac{kg}{m^3} * \frac{29.54 \text{ kg}/m}{28.965 \text{ kg}/m}$$

$$\rho_{act} = 0.075 \frac{lb_m}{ft^3} * 1.020$$

$$\rho_{act} = 1.20 \frac{kg}{m^3} * 1.020$$

$$\rho_{act} = 0.0765 \frac{lb_m}{ft^3}$$

$$\rho_{act} = 1.224 \frac{kg}{m^3}$$

# Air and Water Vapor Mixtures

- Humidity (water vapor in the air) is lighter than standard air.
  - Mole Weight Standard Air 28.965
  - Mole Weight H<sub>2</sub>O 18.016
- Water vapor displaces some of the air in mixture and density is lower.
- Humidity calculations also use the barometric pressure.
- Psychrometrics, calculating the density of gas-vapor mixtures (humidity) is complex.



**IP    (Source AMCA 210)    SI**

$$p_e = (2.96 \times 10^{-4})t_{w0}^2 - (1.59 \times 10^{-2})t_{w0} + 0.41 \quad | \quad p_e = 3.25t_{w0}^2 + 18.6t_{w0} + 692$$

$$p_p = p_e - p_b \left( \frac{t_{d0} - t_{w0}}{2700} \right)$$

$$\rho_0 = \frac{70.73(p_b - 0.378p_p)}{R(t_{d0} + 459.67)}$$

$$p_p = p_e - p_b \left( \frac{t_{d0} - t_{w0}}{1500} \right)$$

$$\rho_0 = \frac{p_b - 0.378p_p}{R(t_{d0} + 273.15)}$$

# Air and Water Vapor Mixtures

- AMCA Calculation requires:
  - Local barometric pressure
  - Dry bulb temperature
  - Wet bulb temperature
- Often temperature and relative humidity are available
- When precise density is required with humidity it must be calculated in detail
- Density can be approximated for temperature and relative humidity...

Temp. °F (°C)	Temp. (°C)	Density Per Cubic Foot (Lb./Ft. <sup>3</sup> ) of Air at Relative Humidity and 0 Feet Elevation										
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
32	(0)	0.0808	0.0808	0.0808	0.0807	0.0807	0.0807	0.0807	0.0807	0.0806	0.0806	0.0806
36	(2)	0.0801	0.0801	0.0801	0.0801	0.0801	0.0800	0.0800	0.0800	0.0800	0.0799	0.0799
40	(4)	0.0795	0.0795	0.0795	0.0794	0.0794	0.0794	0.0794	0.0793	0.0793	0.0793	0.0793
60	(16)	0.0764	0.0764	0.0763	0.0763	0.0762	0.0762	0.0761	0.0761	0.0760	0.0760	0.0759
68	(20)	0.0753	0.0752	0.0752	0.0751	0.0750	0.0750	0.0749	0.0748	0.0748	0.0747	0.0746
70	(21)	0.0750	0.0749	0.0749	0.0748	0.0747	0.0746	0.0746	0.0745	0.0744	0.0744	0.0743
72	(22)	0.0747	0.0746	0.0746	0.0745	0.0744	0.0743	0.0743	0.0742	0.0741	0.0740	0.0740
76	(24)	0.0742	0.0741	0.0740	0.0739	0.0738	0.0737	0.0737	0.0736	0.0735	0.0734	0.0733
80	(27)	0.0736	0.0735	0.0734	0.0733	0.0732	0.0731	0.0730	0.0729	0.0728	0.0727	0.0727
84	(29)	0.0731	0.0730	0.0729	0.0727	0.0726	0.0725	0.0724	0.0723	0.0722	0.0721	0.0720
88	(31)	0.0725	0.0724	0.0723	0.0722	0.0720	0.0719	0.0718	0.0717	0.0716	0.0714	0.0713
92	(33)	0.0720	0.0719	0.0717	0.0716	0.0715	0.0713	0.0712	0.0710	0.0709	0.0708	0.0706
96	(36)	0.0715	0.0713	0.0712	0.0710	0.0709	0.0707	0.0706	0.0704	0.0703	0.0701	0.0699
100	(38)	0.0710	0.0708	0.0706	0.0705	0.0703	0.0701	0.0699	0.0698	0.0696	0.0694	0.0693
110	(43)	0.0697	0.0695	0.0693	0.0691	0.0688	0.0686	0.0684	0.0681	0.0679	0.0677	0.0675
120	(49)	0.0685	0.0682	0.0679	0.0676	0.0673	0.0670	0.0667	0.0665	0.0662	0.0659	0.0656
130	(54)	0.0674	0.0670	0.0666	0.0662	0.0658	0.0655	0.0651	0.0647	0.0643	0.0639	0.0635
140	(60)	0.0663	0.0658	0.0653	0.0648	0.0643	0.0638	0.0633	0.0628	0.0623	0.0618	0.0614
150	(66)	0.0652	0.0645	0.0639	0.0633	0.0627	0.0621	0.0614	0.0608	0.0602	0.0596	0.0590
160	(71)	0.0641	0.0633	0.0626	0.0618	0.0610	0.0602	0.0595	0.0587	0.0579	0.0571	0.0564
170	(77)	0.0631	0.0621	0.0612	0.0602	0.0592	0.0583	0.0573	0.0564	0.0554	0.0544	0.0535
180	(82)	0.0621	0.0609	0.0597	0.0586	0.0574	0.0562	0.0550	0.0538	0.0526	0.0514	0.0503
190	(88)	0.0612	0.0595	0.0579	0.0562	0.0546	0.0529	0.0513	0.0496	0.0480	0.0463	0.0447
200	(93)	0.0602	0.0585	0.0567	0.0550	0.0532	0.0515	0.0497	0.0480	0.0462	0.0444	0.0427

To convert values to kg/m<sup>3</sup> multiply value by 16.0185

# Density with Relative Humidity Table

Density Per Cubic Foot (Lb./Ft. <sup>3</sup> ) of Air at Relative Humidity and 0 Feet Elevation												
Temp. °F (°C)	Temp. °F (°C)	Relative Humidity %										
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
32	(0)	0.0808	0.0808	0.0808	0.0807	0.0807	0.0807	0.0807	0.0807	0.0806	0.0806	0.0806
36	(2)	0.0801	0.0801	0.0801	0.0801	0.0801	0.0800	0.0800	0.0800	0.0800	0.0799	0.0799
40	(4)	0.0795	0.0795	0.0795	0.0794	0.0794	0.0794	0.0794	0.0793	0.0793	0.0793	0.0793
60	(16)	0.0764	0.0764	0.0763	0.0763	0.0762	0.0762	0.0761	0.0761	0.0760	0.0760	0.0759
68	(20)	0.0753	0.0752	0.0752	0.0751	0.0750	0.0750	0.0749	0.0748	0.0748	0.0747	0.0746
70	(21)	0.0750	0.0749	0.0749	0.0748	0.0747	0.0746	0.0746	0.0745	0.0744	0.0744	0.0743
72	(22)	0.0747	0.0746	0.0746	0.0745	0.0744	0.0743	0.0743	0.0742	0.0741	0.0740	0.0740
76	(24)	0.0742	0.0741	0.0740	0.0739	0.0738	0.0737	0.0737	0.0736	0.0735	0.0734	0.0733
80	(27)	0.0736	0.0735	0.0734	0.0733	0.0732	0.0731	0.0730	0.0729	0.0728	0.0727	0.0727
84	(29)	0.0731	0.0730	0.0729	0.0727	0.0726	0.0725	0.0724	0.0723	0.0722	0.0721	0.0720
88	(31)	0.0725	0.0724	0.0723	0.0722	0.0720	0.0719	0.0718	0.0717	0.0716	0.0714	0.0713
92	(33)	0.0720	0.0719	0.0717	0.0716	0.0715	0.0713	0.0712	0.0710	0.0709	0.0708	0.0706
96	(36)	0.0715	0.0713	0.0712	0.0710	0.0709	0.0707	0.0706	0.0704	0.0703	0.0701	0.0699
100	(38)	0.0710	0.0708	0.0706	0.0705	0.0703	0.0701	0.0699	0.0698	0.0696	0.0694	0.0693
110	(43)	0.0697	0.0695	0.0693	0.0691	0.0688	0.0686	0.0684	0.0681	0.0679	0.0677	0.0675
120	(49)	0.0685	0.0682	0.0679	0.0676	0.0673	0.0670	0.0667	0.0665	0.0662	0.0659	0.0656
130	(54)	0.0674	0.0670	0.0666	0.0662	0.0658	0.0655	0.0651	0.0647	0.0643	0.0639	0.0635
140	(60)	0.0663	0.0658	0.0653	0.0648	0.0643	0.0638	0.0633	0.0628	0.0623	0.0618	0.0614
150	(66)	0.0652	0.0645	0.0639	0.0633	0.0627	0.0621	0.0614	0.0608	0.0602	0.0596	0.0590
160	(71)	0.0641	0.0633	0.0626	0.0618	0.0610	0.0602	0.0595	0.0587	0.0579	0.0571	0.0564
170	(77)	0.0631	0.0621	0.0612	0.0602	0.0592	0.0583	0.0573	0.0564	0.0554	0.0544	0.0535
180	(82)	0.0621	0.0609	0.0597	0.0586	0.0574	0.0562	0.0550	0.0538	0.0526	0.0514	0.0503
190	(88)	0.0612	0.0595	0.0579	0.0562	0.0546	0.0529	0.0513	0.0496	0.0480	0.0463	0.0447
200	(93)	0.0602	0.0585	0.0567	0.0550	0.0532	0.0515	0.0497	0.0480	0.0462	0.0444	0.0427

To convert values to kg/m<sup>3</sup> multiply value by 16.0185

# Elevation Temperature and Humidity

- When Elevation, Temperature, and Humidity must all be considered together use Density with Relative Humidity Table value with factor below
- To adjust for humidity and elevation multiply density at 0 elevation by the adjustment factor in the table
- Do not apply additional separate factors

Density Per Cubic Foot (Lb./Ft. <sup>3</sup> ) of Air at Relative Humidity and 0 Feet Elevation											
Temp.	Temp.	Relative Humidity %									
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%
32	(0)	0.0808	0.0808	0.0808	0.0807	0.0807	0.0807	0.0807	0.0807	0.0806	0.0806
36	(2)	0.0801	0.0801	0.0801	0.0801	0.0801	0.0800	0.0800	0.0800	0.0800	0.0799
40	(4)	0.0795	0.0795	0.0795	0.0794	0.0794	0.0794	0.0793	0.0793	0.0793	0.0793
60	(16)	0.0764	0.0764	0.0763	0.0763	0.0762	0.0761	0.0761	0.0760	0.0760	0.0759
68	(20)	0.0753	0.0752	0.0752	0.0751	0.0750	0.0750	0.0749	0.0748	0.0747	0.0746
70	(21)	0.0750	0.0749	0.0748	0.0748	0.0747	0.0746	0.0746	0.0745	0.0744	0.0743
75	(22)	0.0747	0.0746	0.0746	0.0745	0.0744	0.0743	0.0743	0.0742	0.0741	0.0740
76	(24)	0.0742	0.0741	0.0741	0.0739	0.0738	0.0737	0.0735	0.0735	0.0734	0.0733
80	(27)	0.0735	0.0734	0.0734	0.0732	0.0732	0.0730	0.0729	0.0728	0.0727	0.0727
84	(28)	0.0731	0.0730	0.0729	0.0727	0.0726	0.0725	0.0724	0.0723	0.0722	0.0721
88	(31)	0.0725	0.0724	0.0723	0.0722	0.0720	0.0719	0.0718	0.0717	0.0716	0.0714
92	(33)	0.0720	0.0719	0.0717	0.0716	0.0713	0.0712	0.0710	0.0709	0.0708	0.0706
96	(36)	0.0715	0.0713	0.0712	0.0710	0.0709	0.0707	0.0707	0.0704	0.0703	0.0701
100	(38)	0.0710	0.0709	0.0708	0.0705	0.0703	0.0701	0.0699	0.0696	0.0694	0.0693
110	(43)	0.0697	0.0695	0.0693	0.0691	0.0688	0.0686	0.0684	0.0681	0.0679	0.0677
120	(49)	0.0685	0.0682	0.0679	0.0676	0.0673	0.0670	0.0667	0.0665	0.0662	0.0659
130	(54)	0.0674	0.0670	0.0666	0.0662	0.0659	0.0655	0.0651	0.0647	0.0643	0.0639
140	(60)	0.0663	0.0659	0.0653	0.0648	0.0643	0.0638	0.0633	0.0628	0.0623	0.0618
150	(66)	0.0652	0.0645	0.0639	0.0633	0.0627	0.0621	0.0614	0.0606	0.0602	0.0596
160	(71)	0.0641	0.0633	0.0626	0.0618	0.0610	0.0602	0.0593	0.0587	0.0579	0.0571
170	(77)	0.0631	0.0621	0.0612	0.0602	0.0592	0.0583	0.0573	0.0564	0.0554	0.0544
180	(82)	0.0621	0.0609	0.0597	0.0586	0.0574	0.0562	0.0550	0.0538	0.0526	0.0514
190	(88)	0.0612	0.0595	0.0579	0.0562	0.0546	0.0529	0.0513	0.0496	0.0480	0.0463
200	(93)	0.0602	0.0585	0.0567	0.0550	0.0532	0.0515	0.0497	0.0480	0.0462	0.0444

To convert values to kg/m<sup>3</sup> multiply value by 16.0185

Humidity and Elevation Adjustment Factors												
Temp. °F	Temp. °C	Elevation, Feet (Meters)										
		0 (0)	500 (152)	1000 (305)	1500 (457)	2000 (610)	2500 (762)	3000 (914)	3500 (1,067)	4000 (1,219)	5000 (1,524)	6000 (1,829)
40	(4)	1.0000	0.9835	0.9669	0.9504	0.9338	0.9173	0.9007	0.8842	0.8677	0.8346	0.8015
70	(21)	1.0000	0.9834	0.9667	0.9501	0.9334	0.9168	0.9001	0.8835	0.8669	0.8336	0.8003
100	(38)	1.0000	0.9831	0.9662	0.9493	0.9324	0.9155	0.8985	0.8816	0.8647	0.8309	0.7971
120	(49)	1.0000	0.9827	0.9655	0.9482	0.9310	0.9137	0.8964	0.8792	0.8619	0.8274	0.7929
150	(66)	1.0000	0.9817	0.9634	0.9451	0.9268	0.9085	0.8902	0.8719	0.8536	0.8170	0.7803

To adjust for humidity and elevation multiply density at 0 elevation by the adjustment factor in the above table.

# Humidity Above 200°F (93°C)

- Water Vapor above 200°F is steam and density should be calculated based on mixture molecular weight
- In boiler and steam process units there is typically little air compared to the water vapor
- Water, H<sub>2</sub>O, mole weight is 18.0 compared to standard air at 28.965
- Water vapor and steam are less dense than standard air
- Density of known water vapor air mixtures or all water vapor can be calculated

Gas	Cst	Mole Wei	MW	Cst V
Air	10.00%	28.965	2.90	15.156%
H <sub>2</sub> O	90.00%	18.016	16.21	84.844%
	100.00%		19.11	Mole Weig

$$\rho_{act} = \rho_{std} * \frac{19.11 \text{ kg/m}}{28.965 \text{ kg/m}}$$

$$\rho_{act} = \rho_{std} \frac{\text{Absolute temp}_{std(R \text{ or } K)}}{\text{Absolute temp}_{act(R \text{ or } K)}}$$

# Density Calculation Steam 200°F (93°C)

- Calculate density for 10% air 90% water vapor at 212°F and standard pressure
- The condensate side of a steam system pressure may be below atmospheric pressure due to condensation of the vapor

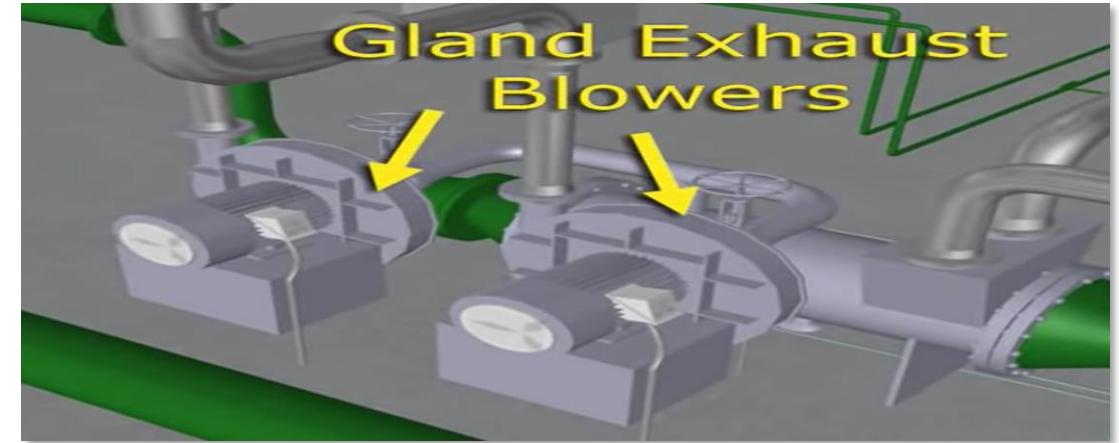
$$\rho_{act} = \rho_{std} * \frac{\text{Actual Mole Wt}}{\text{Standard Mole Wt}} * \frac{\text{absolute zero}_{\text{correction}(R \text{ or } K)} + \text{temp}_{\text{std}(F \text{ or } C)}}{\text{absolute zero}_{\text{correction}(R \text{ or } K)} + \text{temp}_{\text{act}(F \text{ or } C)}}$$

$$\rho_{act} = 0.075 \frac{\text{lb}_m}{\text{ft}^3} * \frac{19.11 \text{kg}/\text{m}}{28.965 \text{ kg}/\text{m}} * \frac{460_{\text{correction}(R)} + 70^\circ\text{F}}{460_{\text{correction}(R)} + 212^\circ\text{F}}$$

$$\rho_{act} = 0.075 \frac{\text{lb}_m}{\text{ft}^3} * \frac{19.11 \text{kg}/\text{m}}{28.965 \text{ kg}/\text{m}} * \frac{530^\circ\text{F}}{672^\circ\text{F}} = 0.075 \frac{\text{lb}_m}{\text{ft}^3} * 0.660 * 0.789 = 0.075 \frac{\text{lb}_m}{\text{ft}^3} * 0.520 = 0.039 \frac{\text{lb}_m}{\text{ft}^3}$$

# Combining Multiple Density Changes

- Many systems will have multiple factors effecting density
- Specifications often have density miscalculated. Check the density if possible
- Steam Gland Exhaust Blowers
  - Gas Constituents (MW)
  - Suction on inlet
  - System Pressure
  - Elevation



- Previous calculations all multiplied to standard density

$$\rho_{std} = 0.075 \frac{lb_m}{ft^3} = 1.20 \frac{kg}{m^3}$$

# Density Calculation Using Factors

- The calculations are ratios to apply to standard density
- 0.075 lbm/ft<sup>3</sup> is standard density IP units
- 1.20 kg/m<sup>3</sup> is the standard density for SI units
- Calculate factors:
  - $df_T$  = Temperature Factor
  - $df_e$  = Elevation Factor
  - $df_p$  = Pressure Factor
  - $df_{mw}$  = Mole Weight Factor

$$\rho_{act} = \rho_{std} * df_T * df_e * df_p * df_{mw}$$

# Calculating Density Factors

$$df_T = \text{Temperature Factor} = \frac{\text{absolute zero}_{\text{correction}(R \text{ or } K)} + \text{temp}_{\text{std}(F \text{ or } C)}}{\text{absolute zero}_{\text{correction}(R \text{ or } K)} + \text{temp}_{\text{act}(F \text{ or } C)}}$$

$$df_e = \text{Elevation Factor (IP)} = (1 - ((6.8754 * 10^{-6}) * \text{feet}))^{5.2561}$$

$$df_e = \text{Elevation Factor (SI)} = (1 - ((22.08 * 10^{-6}) * \text{feet}))^{5.2561}$$

$$df_p = \text{Pressure Factor} = \frac{\text{System Pressure} + \text{Local Pressure}}{\text{Standard Atmospheric Pressure}}$$

$$df_{mw} = \text{Mole Weight Factor} = \frac{\text{Actual Mole Wt}}{\text{Standard Mole Wt}}$$

$$\rho_{\text{act}} = \rho_{\text{std}} * df_T * df_e * df_p * df_{mw}$$

# Standard Tables for Density Factors

- Tables for density factors for temperature and elevation combined provide quick factor for use with standard air
- Values can be used with IP or SI units

$$\rho_{act} = \rho_{std} * df_T * df_e$$

$$\rho_{std} = 0.075 \frac{lb_m}{ft^3} = 1.20 \frac{kg}{m^3}$$

- Table does not include humidity

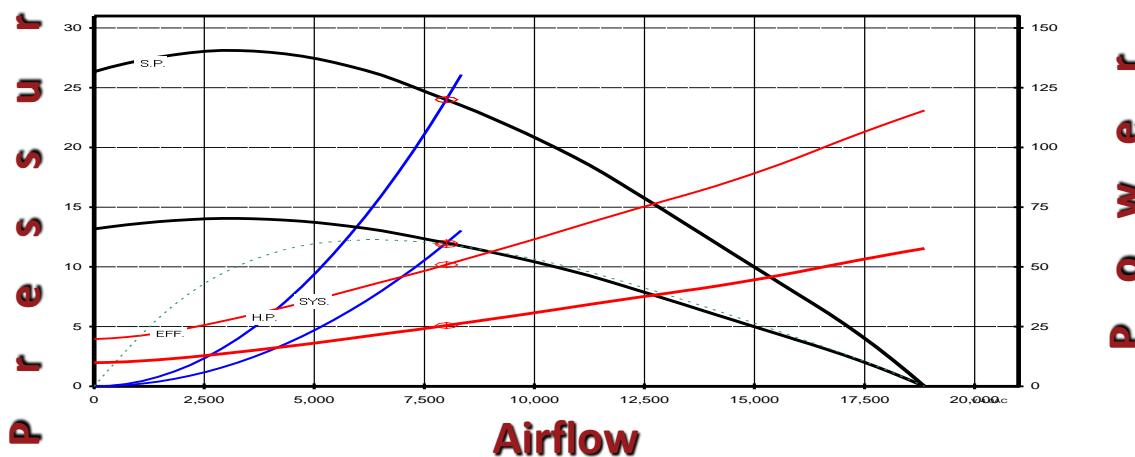
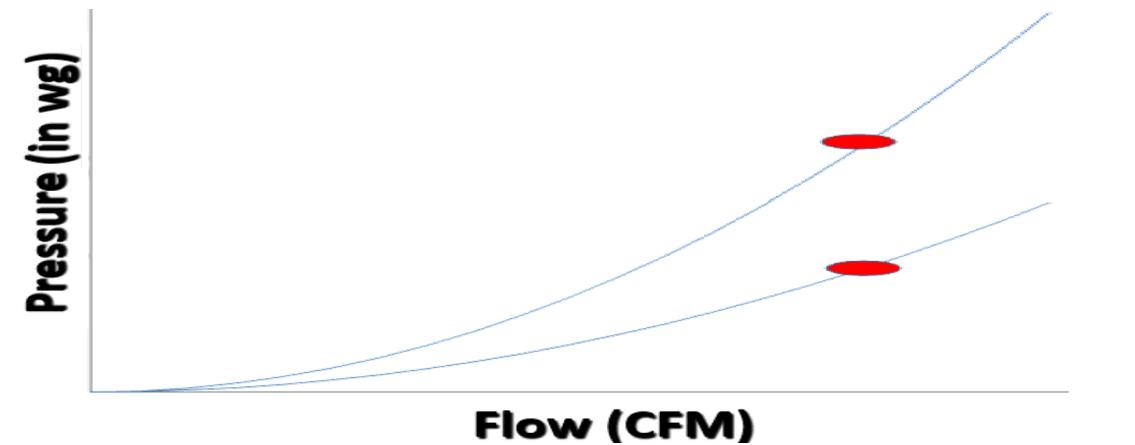
Temp. °F (-40)	Temp. °C (-40)	Elevation, Feet (Meters)									
		0 (0)	300 (91)	600 (183)	1,000 (305)	1,500 (457)	2,000 (610)	2,500 (762)	3,000 (914)	4,000 (1,219)	6,000 (1,829)
-40	(-40)	1.26	1.25	1.24	1.22	1.20	1.18	1.15	1.13	1.09	1.02
0	(-18)	1.15	1.14	1.13	1.11	1.09	1.07	1.05	1.04	1.00	0.93
16	(-9)	1.11	1.10	1.09	1.07	1.06	1.04	1.02	1.00	0.96	0.90
32	(0)	1.08	1.07	1.05	1.04	1.02	1.00	0.99	0.97	0.93	0.87
50	(10)	1.04	1.03	1.02	1.00	0.99	0.97	0.95	0.93	0.90	0.84
70	(21)	1.00	0.99	0.98	0.97	0.95	0.93	0.91	0.90	0.87	0.81
86	(30)	0.97	0.96	0.95	0.94	0.92	0.90	0.89	0.87	0.84	0.78
100	(38)	0.95	0.94	0.93	0.91	0.90	0.88	0.87	0.85	0.82	0.76
125	(52)	0.91	0.90	0.89	0.87	0.86	0.84	0.83	0.81	0.78	0.73
150	(66)	0.87	0.86	0.85	0.84	0.82	0.81	0.79	0.78	0.75	0.70
212	(100)	0.79	0.78	0.77	0.76	0.75	0.73	0.72	0.71	0.68	0.64
300	(149)	0.70	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.60	0.56
400	(204)	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.53	0.50
500	(260)	0.55	0.55	0.54	0.53	0.52	0.51	0.50	0.50	0.48	0.44
600	(316)	0.50	0.49	0.49	0.48	0.47	0.47	0.46	0.45	0.43	0.40
700	(371)	0.46	0.45	0.45	0.44	0.43	0.43	0.42	0.41	0.40	0.37
800	(427)	0.42	0.42	0.41	0.41	0.40	0.39	0.38	0.38	0.36	0.34
900	(482)	0.39	0.39	0.38	0.38	0.37	0.36	0.36	0.35	0.34	0.31
1,000	(538)	0.36	0.36	0.36	0.35	0.34	0.34	0.33	0.33	0.31	0.29

0.075 lbm/ft<sup>3</sup> (1.2 kg/m<sup>3</sup>) standard air density at 68°F (20°C), 50% relative humidity, and 29.92 in. Hg (101.325 kPa).

Adapted from ASHRAE Handbook—2009 Fundamentals

# Density Impact Through The Fan And System

- What happens as density changes:
  - Mass changes through system
    - Resistance through system changes proportionally to mass change
    - Volume through the system remains constant
  - Mass through fan changes
    - Performance of fan changes proportionally to mass change in two ways:
      - Volume through fan remains constant
      - Pressure developed by the fan
      - Power consumed by the fan
- Pressure is constant in most systems.



# ACFM and SCFM

- ACFM – Actual Cubic Feet Per Minute (m<sup>3</sup>/hr)
- SCFM – Standard Cubic Feet Per Minute (nm<sup>3</sup>/hr)

*ACFM ≠ SCFM*

- Conversion of SCFM is based on temperature elevation, and pressure factors
  - Some SCFM temperature conversions are based on 60°F or 0°C
  - Divide SCFM by Density factors for temperature, elevation, and pressure

$$Flow_{Act} = \frac{Flow_{Std\ Basis}}{df_T * df_e * df_p}$$

# SCFM Conversion System Effects

- When converting SCFM to ACFM The System resistance must be:
  - Corrected to resistance at actual density
  - Calculated for new flow value of Actual Volume
  - Confirmed with the specifier
- The resistance of the system will vary directly with the density
- The resistance will vary as the square of the change in volume
- Combine changes to develop actual system point

$$Press_{Act} = Press_{Std\ Basis} * \left( \frac{Density_{Act}}{Density_{Std}} \right) * \left( \frac{Flow_{Act}}{Flow_{Std\ Basis}} \right)^2$$

# Resources

- **AMCA International:** [www.amca.org](http://www.amca.org)
- **AMCA Publications:** [www.amca.org/store](http://www.amca.org/store) (available for purchase)
  - > 201-02 (R2011) – Fans and Systems
- **ANSI/AMCA Standards:** [www.amca.org/store](http://www.amca.org/store) (available for purchase)
  - > 210-16 / ASHRAE 51-16: Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating
  - > 803-02 (R2008): Industrial Process/Power Generation Fans: Site Performance Test Standard
- **American Conference of Governmental Industrial Hygienists:** [www.acgih.org](http://www.acgih.org)
  - > Industrial ventilation: A manual of recommended practice for design (30th ed.; 2019)

# AMCA SPEAKERS NETWORK

- Related presentations available on:
  - Fans, fan testing, field testing, and fan efficiency
  - AMCA certification and Fan Energy Index
  - System effect and field work
  - Ventilation-system design and commissioning
  - Fan, blower, and system troubleshooting
- Many more topics available!

To request an on-location or online presentation by Bill or any other AMCA Speakers Network presenter for your organization, go to [amca.org/educate](http://amca.org/educate) and click on “Outreach Activities.”

# Thank you for your time!

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*If you viewed the webinar as a group and only one person registered for the webinar link, please email Lisa Cherney ([lcherney@amca.org](mailto:lcherney@amca.org)) for a group sign-in sheet today. Completed sheets must be returned to Lisa by tomorrow, July 15.*

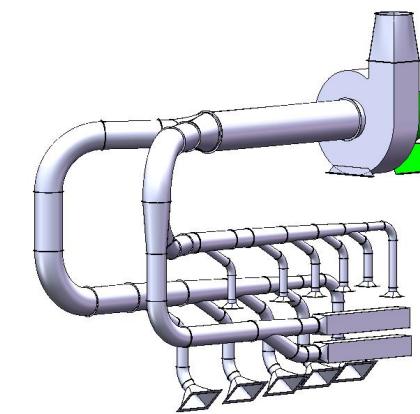
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# Questions?

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## NEXT PROGRAM

Join us for our next AMCA *insite* Pop-Up Webinar:

- Wednesday, July 29
- 2:00-3:00pm CDT
- ***TOPIC: 2019 California Building Code (Life Safety Damper Requirements)***
- Presenter: Daniel Benton, Regional Sales Manager, AMCA Member Company

**>> For additional webinar dates go to: [www.amca.org/webinar](http://www.amca.org/webinar)**