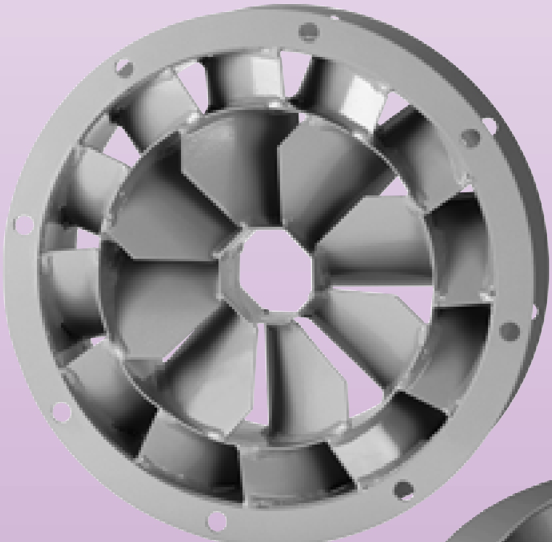
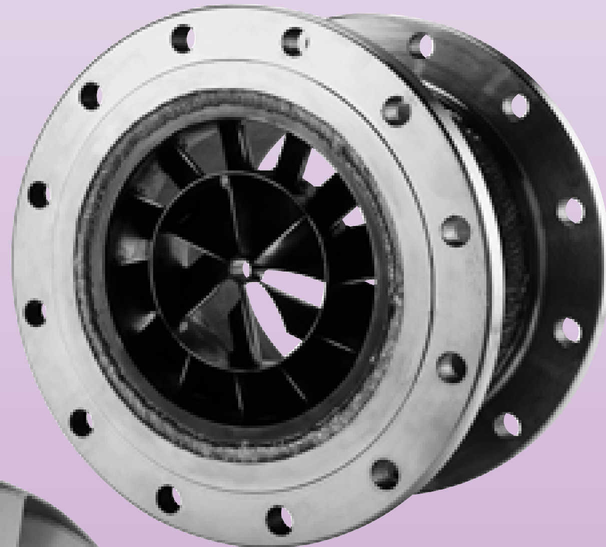
Rev 00

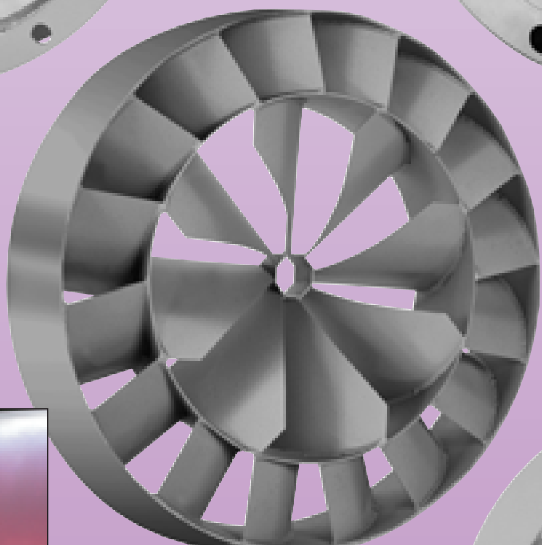
GAS BLENDER™ ENGINEERING MANUAL

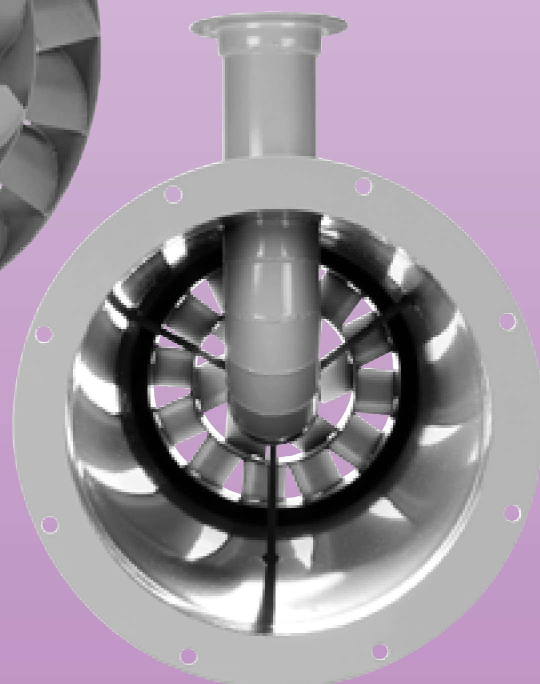
PROCESS MIXING

High Performance Mixing for Process Applications







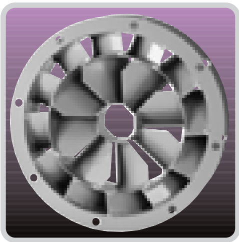


Blender Products, Inc.

Engineered Air Mixing Systems and Equipment

5010 Cook Street • Denver, Colorado 80216
Phone: 303.295.6111 • Fax: 303.296.1520
Toll-free: 800-523-5705
E-mail: INFO@airblender.com
Internet: www.airblender.com

GB-EM 01/03



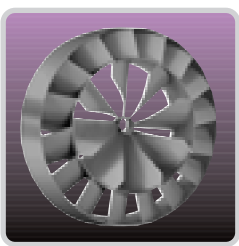



Table of Contents

Introduction 1

PART I:
Glossary of Terms for Evaluating
Process Mixing Applications

Static Mixers 1

Ideal Gas Law 2
- Gas Pressure
- Absolute Temperature
- Universal Gas Constant
- Gas Density

Determining Properties of Mixtures. . 3

Reynolds Number. 4

Simplified Pressure Loss. 5

Mixing Performance Rating 5
- Coefficient of Variation
- Blend Number
- Range Mixing Effectiveness

PART II:
Procedures for Analyzing
Process Mixing Applications 6

Case 1:
Same Gas, Different Temperature,
Same Pressure 6

Case 2:
Same Gas, Different Temperature,
Different Pressure. 7

Case 3:
Different Gas, Same Temperature,
Same Pressure 8

Case 4:
Different Gas, Same Temperature,
Different Pressure. 9

Case 5:
Different Gas, Different Temperature,
Same Pressure 10

Case 6:
Different Gas, Different Temperature,
Different Pressure. 12

References. 14

PART I: Glossary of Terms for Evaluating Process Mixing Applications

Introduction

The mixing of air streams is found in many processes that exist today. The mixing process can take the form of mixing temperatures, mixing particles, or mixing different species of gases. Almost invariably, if the mixing of the different streams is incomplete or inadequate, the efficiency of the process suffers. This inefficiency takes the form of increased operating costs or increased emissions or in decreased output or quality. As a result, providing complete mixing within a process can have dramatic impacts upon the profitability of a process or system.

The goal of this manual is to provide some engineering background material that will enable the reader to understand the role of mixing and apply the correct mixing equipment to a process system. This manual is not intended to be a comprehensive scientific textbook on the subject of mixing. Instead it is intended to provide useful information that can be used by a practicing engineer.

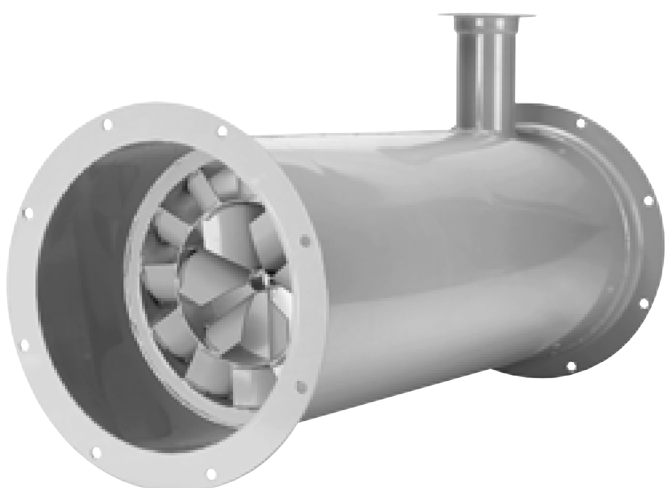
Part I of this manual is aimed at defining and qualifying terms used in evaluating process mixing application of non-condensing gases. Part II of this manual provides a step by step procedure for analyzing various applications and properly applying a Gas Blender static mixing device. For assistance or additional information on a given application, please contact Blender Products, Inc. or a local company representative.

Part I

Static Mixers

Some degree of mixing exists within every fluid flow. In many cases the time it takes for complete mixing to take place is far longer than the time that a fluid is within a system. In a flowing fluid, this required mixing time takes the form of many pipe or duct diameters. Static mixers are fixed devices that have been designed to create additional turbulence in a fluid stream in order to enhance the mixing that is naturally present within the fluid stream. By using static mixers, the time and, as result, the distance, required for mixing is decreased substantially.

There are many different designs of static mixers and each has a different performance in terms of mixing and pressure loss. The information here can be used to design the mixing system for a wide variety of process systems.



Example of static mixer in a duct.

Ideal Gas Law

The Ideal Gas Law can be used to approximate the behavior of gases. The ideal gas equation is:

$$P \cdot V = n \cdot \mathfrak{R} \cdot T$$

There are many cases in which this equation includes considerable error. This error can be reduced by introducing the compressibility factor (Z) into the equation. This is defined as:

$$Z = \frac{P \cdot V}{n \cdot \mathfrak{R} \cdot T}$$

Typically the error is greatest when the temperature is near the critical temperature of a gas. In many cases, Z can safely be ignored. For example, with mixtures that are predominantly air, Z is between 0.05 and 1.05 with temperatures above -35°F with pressures up to 547 psia. For the most accuracy, the actual Z factor should be found using a compressibility chart from a thermodynamic textbook or handbook.

Gas Pressure

The quantity P in the ideal gas equation is the absolute pressure of the gas. It is important that the pressure is stated in the correct units. For English units, the pressure should be in terms of pounds per square foot. Since it is more common for the pressure to be stated in terms of pounds per square inch (psi), the equation can be modified to allow psi to be used in the equation instead.

$$(P \cdot 144) \cdot V = \mathfrak{R} \cdot T \qquad \text{(IP Units)}$$

In SI or metric units, the pressure needs to be stated in terms of Pascals.

Absolute Temperature

The temperature in the Ideal Gas law is the absolute temperature of the gas. The absolute temperature is stated in degrees Kelvin for the SI or metric system and degrees Rankine for the English system. Usually the "°" symbol is not used with absolute temperatures so the symbol for degrees Rankine is "R" and "K" for degrees Kelvin. In addition, an uppercase "T" is used to denote absolute temperature and a lower case "t" is used to denote Fahrenheit or Celsius in equations.

It is possible to restate the ideal gas equation in terms of the more common Fahrenheit or Celsius temperature scales. The conversion from °F to R and from °C to K are:

$$T = t + 459.69 \qquad \text{(IP Units)}$$

$$T = t + 273.16 \qquad \text{(SI Units)}$$

Substituting these conversions into the ideal gas law results in the following equations:

$$(P \cdot 144) \cdot V = \mathfrak{R} \cdot (t + 459.69) \qquad \text{(IP Units)}$$

$$P \cdot V = \mathfrak{R} \cdot (t + 273.16) \qquad \text{(SI Units)}$$

Universal Gas Constant

The value $\mathfrak{R}$ in the ideal gas law is the universal gas constant. The value of this constant depends upon what units system is being used. Table 1 shows some of the more common units systems that are used.

Table 1: Universal Gas Constant ($\mathfrak{R}$)

Value	Units
1545.33	ft • lbf/(lbmole • R)
8.3143	J/(gmole • K)
8314.3	J/(kgmole • K)
1.9858	BTU/(lbmole • R)
1.9858	Cal/(gmole • K)

Gas Density

Dividing the universal gas constant by the molecular weight of the gas gives a constant specific to the gas. Table 2 gives the molecular weights for several common gasses.

When this new gas constant is substituted into the ideal gas equation, the equation can be used to determine the density of a gas. The density from this equation is stated in terms of pounds per cubic foot or kilograms per cubic meter.

$$P = \rho \cdot R \cdot T$$

where

$$R = \frac{1545.33}{\hat{M}} \qquad \text{(IP Units)}$$

$$R = \frac{8.314}{\hat{M}} \qquad \text{(SI Units)}$$

ρ = Density of specific gas
R = Gas Constant for the specific gas ($R/\hat{M}$)
$\hat{M}$ = Molecular weight of the gas

Table 2: Gas Constants for Common Gasses

Gas	Symbol	Molecular Weight	R [ft lbf/(lbm R)]	R [J/(kg K)]
Air		29	53.29	0.2867
Ammonia	NH_3	17.031	90.74	0.4882
Butane	C_4H_{10}	58.123	26.59	0.1430
Carbon Dioxide	CO_2	44.01	35.11	0.1889
Carbon Monoxide	CO	28.01	55.17	0.2968
Chlorine	Cl_2	70.905	21.79	0.1173
Ethane	C_2H_6	30.07	51.39	0.2765
Helium	He	4.003	386.04	2.0769
Hydrogen	H_2	2.016	766.53	4.1240
Methane	CH_4	16.043	96.32	0.5182
Nitrogen	N_2	28.014	55.16	0.2968
Oxygen	O_2	31.999	48.29	0.2598
Propane	C_3H_8	44.097	35.04	0.1885
Sulfur Dioxide	SO_2	64.065	24.12	0.1298
Water	H_2O	18.015	85.78	0.4615

Determining Properties of Mixtures

When dealing with a mixture of non-reacting fluids, it is possible to treat the mixture as an equivalent fluid. The properties of this equivalent fluid can be determined using Dalton's law as a starting point. This law states that the total pressure of a mixture is equal to the sum of the partial pressures of the constituents of the mixture. In equation form this is written as:

$$P_{Mix} = p_1 + p_2 + \ldots + p_n = \sum_{i=1}^{n} p_i$$

where p_i is the pressure of each constituent. Similarly, the total mass of the mixture is found by adding the mass of each constituent:

$$m_{Mix} = m_1 + m_2 + \ldots + m_n = \sum_{i=1}^{n} m_i$$

These equations can be combined with the ideal gas equation:

$$P_{Mix} = \frac{m_1 \cdot R_1 \cdot T_l}{V} + \frac{m_2 \cdot R_2 \cdot T_2}{V} + \ldots + \frac{m_n \cdot R_n \cdot T_n}{V}$$

This last equation can be also be stated as:

$$P_{Mix} = \rho_{Mix} \cdot R_{Mix} \cdot T_{Mix} \qquad \text{where} \qquad R_{Mix} = \frac{\sum_{i=1}^{n} m_i \cdot R_i}{\sum_{i=1}^{n} m_i}$$

This equation can be used to approximate other properties of the gas stream such as specific heat (cp) and viscosity (μ) :

$$cp_{Mix} = \frac{\sum_{i=1}^{n} m_i \cdot cp_i}{\sum_{i=1}^{n} m_i}$$

$$\mu_{Mix} = \frac{\sum_{i=1}^{n} m_i \cdot \mu_i}{\sum_{i=1}^{n} m_i}$$

When mixing gases with different temperatures, the same equation can be used to determine the mixed air temperature:

$$T_{Mix} = \frac{\sum_{i=1}^{n} m_i \cdot T_i}{\sum_{i=1}^{n} m_i}$$

However, the use of this equation is limited to case when the specific heats of the fluids being mixed are the same. When the specific heats of the fluids are significantly different, the equation should be modified to include the specific heats of the fluids being mixed:

$$T_{Mix} = \frac{\sum_{i=1}^{n} m_i \cdot cp_i \cdot T_i}{\sum_{i=1}^{n} m_i \cdot cp_i}$$

Reynolds Number

In fluid flows, there are three different flow regimes: Laminar flow, Transitional flow, and Fully Turbulent flow. The Reynolds Number is a dimensionless number used to determine the flow regime for a particular fluid flow. It is calculated using the equation:

$$\mathrm{Re} = \frac{\rho \cdot V \cdot D}{\mu}$$

Laminar flow, which occurs when Re ≤ 2000, is a smooth flow in which little mixing takes place. This is because the viscous forces are greater than the velocity forces. In transitional flow, which occurs when 2000 < Re ≤ 10000, the velocity forces begin to be stronger than the viscous forces and eddies begin to form in the fluid. These eddies are the start of the turbulence in the flow. This turbulence begins to increase the mixing that takes place in the fluid. Fully turbulent flow, which occurs when Re >10000, is when the entire flow is filled with eddies.

In the equation for Reynolds number, Re is the Reynolds number, ρ is the density of the fluid (lbm/ft^3 or kg/m^3), V is the velocity of the fluid (ft/s or m/s), D is the hydraulic diameter of the duct or pipe (ft or m), and μ is the viscosity of the fluid (lbm/(ft•s)) or (N•s/m^2). The density of the gas is calculated using the ideal gas law for a pure fluid or for mixtures. The velocity is the volumetric flow rate divided by the cross-sectional area of the pipe or duct. The hydraulic diameter is calculated using the equation:

$$D_h = \frac{4 \cdot A}{P}$$

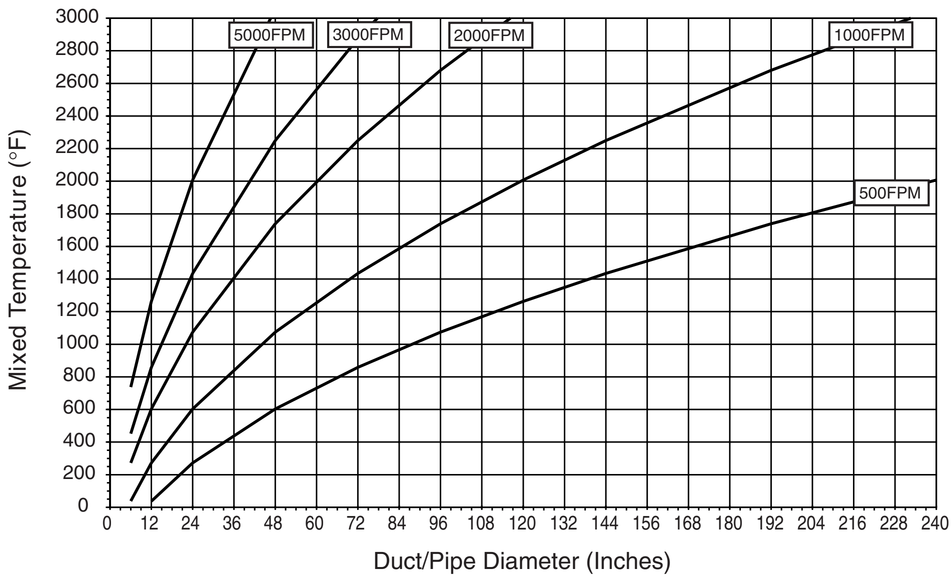
where D_h is the hydraulic diameter (ft or m), A is the cross-sectional area of the pipe or duct (ft^2 of m^2), and P is the wetted perimeter of the pipe or duct (ft or m). For circular ducts, the hydraulic diameter is equal to the diameter of the pipe. For square ducts the hydraulic diameter is equal to the length of one side of the duct. Like the density, the viscosity of the fluid is determined using the mixture equations.

When using the Gas Blender static mixer, is it necessary for the mixer Reynolds number to be in the transitional or the turbulent regime for mixing to take place (Re ≥ 2000). If the mixer Reynolds number (Re_{Mixer}) is greater than 10000, then the flow is fully turbulent and the maximum mixing will take place. The equation for the mixer Reynolds number is:

$$\mathrm{Re} = \frac{0.16 \cdot \rho \cdot V \cdot D}{\mu}$$

If the primary gas stream is air, Figure 1 can be used to determine whether or not the flow is suitable for the use of a Gas Blender static mixer.

Gas Blender™ Mixer Reynolds Number Chart



Instructions for use: Find the point of intersection between the duct diameter and temperature of the gas stream. If the point of intersection lies to the right of the appropriate velocity line (pipe or duct velocity) then the Gas Blender mixer can be used. If the point lies to the left of the velocity line then contact the factory for application assistance.

Simplified Pressure Loss

Placing a static mixer in a fluid stream results in a pressure loss in the flow. This pressure loss increases the amount of energy required by a pump or fan. In fully turbulent flows, the pressure loss across a static mixer is related to the velocity pressure in the duct or pipe. The general form for this pressure loss is:

$$\Delta P = C \cdot P_{velocity}$$

where ΔP = pressure loss across the device (in inches of water or Pa), C is a pressure loss coefficient (dimensionless), and $P_{Velocity}$ is the velocity pressure of the flow (inches of water or Pa). The form of the equation changes depending upon the unit system that is used during the calculation. The two basic forms are:

$$\Delta P = C \cdot \rho \cdot \left(\frac{V}{1097}\right)^2 \quad \text{(IP Units)}$$

$$\Delta P = C \cdot \frac{\rho \cdot V^2}{2} \quad \text{(SI Units)}$$

In these equations, the density is calculated using the ideal gas law and is stated in terms of lbm/ft^3 or kg/m^3. The velocity is stated in terms of feet per minute for the IP equation and meters per second for the SI equation.

The value for C depends upon the design of a static mixer and how it is applied. The appropriate value for C is given in the product catalog for each particular mixer.

Mixing Performance Ratings

There are several ways that can be used to state the performance of a mixing device. The method that is used depends upon the process and the requirements of that process. Some of the more common methods are the Coefficient of Variation (COV), the Blend Number (B), the Range Mixing Effectiveness (E_{Range}), and the Absolute Range.

Coefficient of Variation

One of the most common ways used to rate the performance of a static mixer is the Coefficient of Variation (COV). This rating is the ratio of the standard deviation in the concentration measurements to the average concentration. In equation form this is written as:

$$COV = \frac{\sigma}{\bar{x}}$$

where σ = the standard deviation of the measured concentration readings and $\bar{x}$ is the average concentration. The standard deviation is calculated using the equation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

The COV can also be applied to velocities ($\bar{V}$ = average velocity) and temperatures ($\bar{T}$ = average temperature) by altering the equation:

$$COV = \frac{\sigma}{\bar{V}} \qquad COV = \frac{\sigma}{\bar{T}}$$

The one difficulty in using the COV with temperatures is determining what system of units the average temperature should be stated in. For example, if the average temperature of a fluid mixture is 560 R (100°F), and the standard deviation is 10 R (which is also 10°F), then the COV can take on two different values:

$$COV = \frac{10}{560} = .018 \quad \text{or} \quad COV = \frac{10}{100} = .10$$

Because of this discrepancy, it is easier to use the desired final temperature range or range mixing effectiveness when mixing gases of different temperatures.

In most cases a COV ≤ 0.05 is considered perfect mixing. However, in some cases a COV ≤ 0.10 or a COV ≤ 0.20 represents adequate mixing. Since the distance required increases as the COV decreases, it may be unpractical to design a system with an unrealistically low value for the design COV.

Blend Number

As an alternative to the COV concept, the Blend Number is also used. The Blend Number is defined as:

$$B = 1 - \frac{\sigma_{Out}}{\sigma_{In}}$$

where B is the Blend Number, σ_{In} is the standard deviation of the properties entering the mixing device, and σ_{Out} is the standard deviation of the properties at some point after the mixing device.

Range Mixing Effectiveness

The Range Mixing Effectiveness is another convenient way to express the mixing of a mixing device. The Range Mixing Effectiveness is defined as:

$$E_{Range} = 1 - \frac{Range_{Out}}{Range_{In}}$$

This is especially useful when some limit on the properties exists. For example, if the performance of a catalyst bed drops significantly when the gas temperature is above a certain temperature, the Range Mixing Effectiveness provides a better way of determining the required performance than a statistical based rating system.

Part II

Part II of this brochure serves two purposes. The first is to define procedures for dealing with the six possible combinations of non-condensing mixtures between two streams in which different gases, temperatures, and pressures are possible. Table 2.1 defines each of these possible combinations. The second purpose is to provide examples of how these procedures are executed in each of these six different combinations.

Table 2.1 Non-Condensing Mixtures of Two Air Streams

Case	Gas	Temperature	Pressure
1	Same	Different	Same
2	Same	Different	Different
3	Different	Same	Same
4	Different	Same	Different
5	Different	Different	Same
6	Different	Different	Different

Case 1: Same Gas, Different Temperature, Same Pressure

	Gas T_1	+	Gas T_2	=	Mixed Gas T_{Mix}
Pressure:	**P**		**P**		**P**

$$m_{Mix} = m_1 + m_2 + \ldots + m_n = \sum_{i=1}^{n} m_i$$

Procedures:

1. Determine density of gas streams.
2. Determine mass flow rate of gas streams.
3. Determine temperature of mixed gas stream.
4. Determine density of mixed gas stream.
5. Determine volumetric flow rate of mixed gas stream.
6. Determine volume fraction of additive.
7. Determine required mixing.
8. Determine required distance using a Gas Blender mixer.

Example:

Mix 2000 acfm of air at 1000°F with 5000 acfm of air at 70°F. Final temperature range is to be 100°F.

Solution:

Step 1. Determine density of gas streams.

$$\rho_1 = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 1000)} = 0.0272$$

$$\rho_2 = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 70)} = 0.0749$$

Step 2. Determine mass flow rate of gas streams.

$$m_1 = \rho \cdot Q = 0.0272 \cdot 2000 = 54.4\ lbm/min$$

$$m_2 = 0.0749 \cdot 5000 = 374.5\ lbm/min$$

$$m_{Mixed} = m_1 + m_2 = 54.4 + 374.5 = 428.9\ lbm/min$$

Step 3. Determine temperature of mixed gas stream.

Step 3a. Determine temperature of mixed stream assuming constant specific heat.

$$T_{Mix} = \frac{\Sigma\, m_i \cdot T_i}{\Sigma\, m_i} = \frac{54.4 \cdot 1000 + 374.5 \cdot 70}{428.9} = 187.9°F$$

Step 3b. Determine average temperature for stream 1 and stream 2.

$$T_{Average_{Stream\ 1}} = \frac{1000 + 188}{2} = 594$$

$$T_{Average_{Stream\ 2}} = \frac{70 + 188}{2} = 129$$

Step 3c. Determine specific heat at each average temperature for stream 1 and stream 2.

$$cp_{594°F} = 0.251 \qquad cp_{129°F} = 0.243$$

Step 3d. Determine temperature of mixture.

$$T_{Mix} = \frac{\Sigma\, m_i \cdot c_p \cdot T_i}{\Sigma\, m_i \cdot c_p} = \frac{54.4 \cdot 0.251 \cdot 1000 + 374.5 \cdot 0.243 \cdot 70}{54.4 \cdot 0.251 + 374.5 \cdot 0.243} = 191.3°F$$

Step 4. Determine density of mixed gas stream.

$$\rho_1 = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 191.3)} = 0.0609$$

Step 5. Determine volumetric flow rate of mixed gas stream.

$$Q_{Mix} = \frac{428.9}{0.0609} = 7042.69 \approx 7043$$

Step 6. Determine volume fraction of additive.

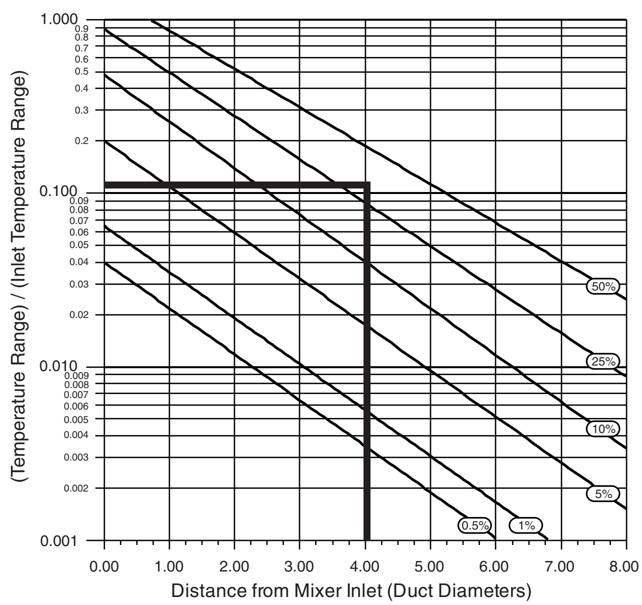
$$Q_1 = 5000 \qquad Q_2 = 2000$$

$$n = \frac{2000}{5000 + 2000} = 0.286 \approx 0.29$$

Step 7. Determine required mixing.
Desired Temperature Range: 100°F
Inlet Temperature Difference: 930°F (1000-70)

$$\frac{Range_{Out}}{Range_{In}} = \frac{100}{930} = 0.108 \approx 0.11$$

Step 8. Determine required mixing distance using a Gas Blender Mixer.
Distance required: 4 mixer diameters.



Case 2: Same Gas, Different Temperature, Different Pressure

Gas $T_1\ P_1$	+	Gas $T_2\ P_2$	=	Mixed Gas $T_{Mix}\ P_{Mix}$

$$m_{Mix} = m_1 + m_2 + \ldots + m_n = \sum_{i=1}^{n} m_i$$

Procedures:

1. Determine density of gas streams.
2. Determine mass flow rate of gas streams.
3. Determine temperature of mixed gas stream.
4. Determine density of mixed gas stream.
5. Determine volumetric flow rate of mixed gas stream.
6. Determine volume fraction of additive.
7. Determine required mixing.
8. Determine required distance using a Gas Blender mixer.

Example:

Mix 5000 cfm of air at 300°F, 14.7 psi, with 100 cfm of air at 70°F, 150 psig. Final temperature range is to be 50°F.

Solution:

Step 1. Determine density of gas streams.

Since stream 2 is at a much higher pressure than stream 1, stream 2 must expand until it is equal to the pressure of stream 1. (This is a simplified assumption.) When stream 2 expands, its temperature and its density will fall. It is necessary to determine the density of stream 2 in its compressed state (in order to calculate the mass flow rate) and in its expanded state (to determine the volumetric rate that is to be mixed).

$$\rho_1 = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 300)} = 0.522$$

$$\rho_{2150psig} = \frac{P}{R \cdot T} = \frac{(150 + 14.7) \cdot 144}{53.35 \cdot (459.59 + 70)} = 0.8515$$

In order to determine the density of stream 2 in its expanded state it is necessary to determine the temperature of the stream after it expands using the following equation:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

where k = 1.4

$$T_2 = 70 \cdot \left(\frac{14.7}{164.7}\right)^{0.2857} = 35.10°F$$

$$\rho_2 = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 35.1)} = 0.0802$$

Step 2. Determine mass flow rate of gas streams.

$$m_1 = \rho \cdot Q = 0.5224 \cdot 5000 = 261.2 \ lbm/min$$

$$m_2 = 0.8515 \cdot 150 = 85.15 \ lbm/min$$

$$m_{Mixed} = m_1 + m_2 = 261.2 + 85.15 = 346.4 \ lbm/min$$

Step 3. Determine temperature of mixed gas stream.

Step 3a: Determine temperature of mixed stream assuming constant specific heat.

$$T_{Mix} = \frac{\Sigma m_i \cdot T_i}{\Sigma m_i} = \frac{261.2 \cdot 300 + 85.15 \cdot 35.1}{346.4} = 234.8°F$$

Step 3b: Determine average temperature for stream 1 and stream 2.

$$T_{Average_{Stream\ 1}} = \frac{300 + 234.8}{2} = 267.4$$

$$T_{Average_{Stream\ 2}} = \frac{35.1 + 234.8}{2} = 152.5$$

Step 3c: Determine specific heat at each average temperature for stream 1 and stream 2.

$$cp_{267°F} = 0.245 \qquad cp_{153°F} = 0.243$$

Step 3d: Determine temperature of mixture.

$$T_{Mix} = \frac{\Sigma m_i \cdot c_p \cdot T_i}{\Sigma m_i \cdot c_p} = \frac{261.2 \cdot 0.245 \cdot 300 + 85.15 \cdot 0.243 \cdot 35.1}{261.2 \cdot 0.245 + 85.15 \cdot 0.243} = 253.3°F$$

Step 4. Determine density of mixed gas stream.

$$\rho_1 = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 235.3)} = 0.0571$$

Step 5. Determine volumetric flow rate of mixed gas stream.

$$Q_{Mix} = \frac{346.35}{0.0571} = 6065.7 \approx 6066$$

Step 6. Determine volume fraction of additive.

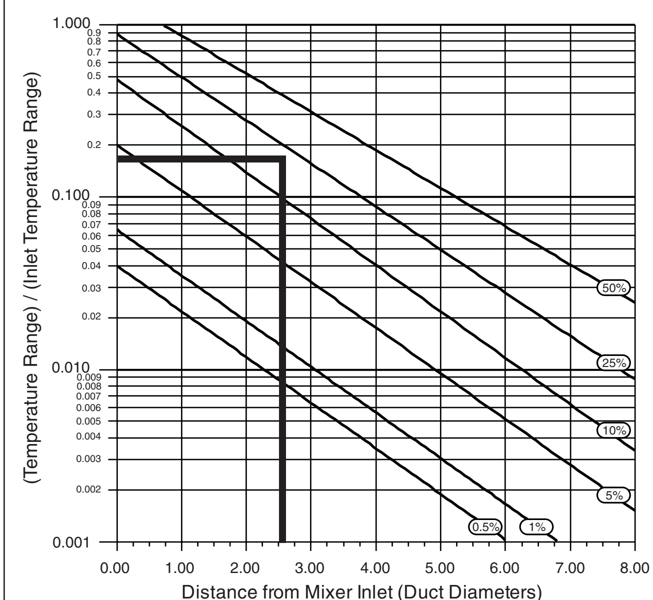
$$Q_1 = 5000 \qquad Q_2 = \frac{85.15}{0.0802} = 1061.7 \approx 1062$$

$$n = \frac{1062}{5000 + 1062} = 0.175 \approx 0.18$$

Step 7. Determine required mixing.
Desired Temperature Range: 50°F
Inlet Temperature Difference: 265°F (300-35)

$$\frac{Range_{Out}}{Range_{In}} = \frac{50}{265} = 0.188 \approx 0.19$$

Step 8. Determine required mixing distance using a Gas Blender Mixer.
Distance required: 3 mixer diameters.



Case 3: Different Gas, Same Temperature, Same Pressure

	Gas A V_A	+	Gas B V_B	+	Gas B V_B	=	Gases A+B+C Volume V
Temperature:	**T**		**T**		**T**		**T**
Pressure:	**P**		**P**		**P**		**P**

$$V_{Mix} = V_1 + V_2 + \ldots + V_n = \sum_{i=1}^{n} V_i$$

$$m_{Mix} = m_1 + m_2 + \ldots + m_n = \sum_{i=1}^{n} m_i$$

Procedures:

1. Determine density of gas streams.
2. Determine mass flow rate of gas streams.
3. Determine gas constant (R) for mixed gas stream.
4. Determine density of mixed gas stream.
5. Determine volumetric flow rate of mixed gas stream.
6. Determine volume fraction of additive.
7. Determine required mixing.
8. Determine required distance using a Gas Blender mixer.

Example:

Mix 1500 cfm of air at 70°F, 14.7 psi, with 100 cfm of Methane (CH_4) at 70°F, 14.7 psi. Mixing requirement is COV ≤ 0.10.

Solution:

Step 1. Determine density of gas streams.

$$R_{Air} = 53.35 \qquad R_{CH_4} = 96.32$$

$$\rho_{Air} = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 70)} = .0749$$

$$\rho_{CH_4} = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{96.32 \cdot (459.59 + 70)} = 0.0415$$

Step 2. Determine mass flow rate of gas streams.

$$m_1 = \rho \cdot Q = 0.0749 \cdot 1500 = 112.35 \ lbm/min$$

$$m_2 = 0.0415 \cdot 100 = 4.15 \ lbm/min$$

$$m_{Mixed} = m_1 + m_2 = 112.35 + 4.15 = 116.5 \ lbm/min$$

Step 3. Determine gas constant (R) for mixed gas stream.

Component	Mass Flow	% Mass	R	% Mass x R
Air	112.35	0.9644	53.35	51.45
Methane	4.15	0.0356	96.32	3.43
Mixture	116.5	1.0		54.88

Step 4. Determine density of mixed gas stream.

$$\rho = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{54.88 \cdot (459.59 + 70)} = .0728$$

Step 5. Determine volumetric flow rate of mixed gas stream.

$$Q_{Mix} = \frac{116.5}{0.0728} = 1599.56 \approx 1600$$

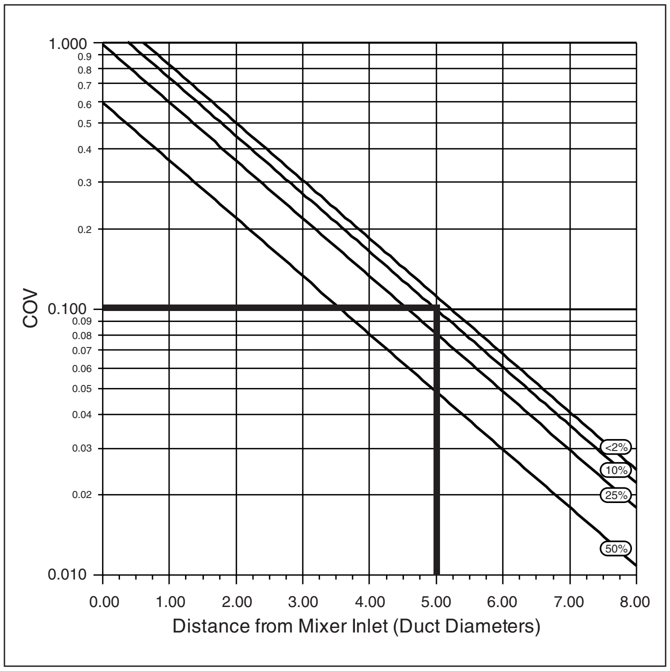
Step 6. Determine volume fraction of additive.

$$Q_1 = 1500 \qquad Q_2 = 100$$

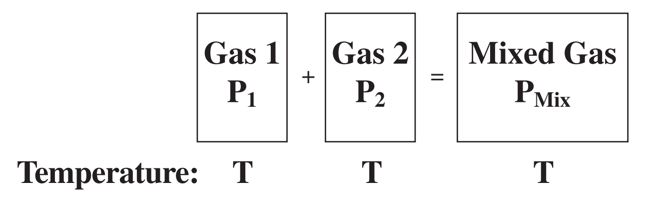
$$n = \frac{100}{1500 + 100} = 0.0625$$

Step 7. Determine required mixing.
Mixing Requirement (Given): COV ≤ 0.10

Step 8. Determine required mixing distance using a Gas Blender Mixer.
Distance required: 5 mixer diameters.



Case 4: Different Gas, Same Temperature, Different Pressure



$$m_{Mix} = m_1 + m_2 + \ldots + m_n = \sum_{i=1}^{n} m_i$$

Procedures:

1. Determine density of gas streams.
2. Determine mass flow rate of gas streams.
3. Determine gas constant (R) for mixed gas stream.
4. Determine density of mixed gas stream.
5. Determine volumetric flow rate of mixed gas stream.
6. Determine volume fraction of additive.
7. Determine required mixing.
8. Determine required distance using a Gas Blender mixer.

Example:

Mix 250 lbm/hour of methane (CH_4) at 25 psig 70°F with 6750 lbm/hr of air at 5" w.g. and 70°F. Desired COV = 0.10.

Solution:

Step 1. Determine density of gas streams.

$$\mathrm{R}_{CH_4} = 96.32 \qquad \mathrm{R}_{Air} = 53.35$$

$$\rho_{CH_4} = \frac{(14.7 + 0.18)\cdot(144)}{96.32 \cdot (459.59 + 70)} = 0.0420$$

$$\rho_{Air} = \frac{(14.7 + 0.18)\cdot(144)}{53.35 \cdot (459.59 + 70)} = 0.0758$$

Step 2. Determine mass flow rate of gas streams.

$$m_{CH_4} = \frac{250}{60} = 4.2\ lbm/m$$

$$m_{Air} = \frac{6750}{60} = 112.5\ lbm/m$$

$$m_{Total} = m_{CH_4} + m_{Air} = 116.7\ lbm/min$$

Step 3: Determine gas constant (R) for mixed gas stream.

$$R_{Mix} = \frac{\sum_{i=1}^{n} m_i \cdot R_i}{\sum_{i=1}^{n} m_i} = \frac{4.2 \cdot 96.32 + 112.5 \cdot 35.5}{4.2 + 112.5} = 54.897$$

Step 4. Determine density of mixed gas stream.

$$\rho_{Mix} = \frac{(14.7 + 0.18)\cdot(144)}{54.897 \cdot (459.59 + 70)} = 0.07379$$

Step 5. Determine volumetric flow rate of mixed gas stream.

$$Q_{Mix} = \frac{(4.2 + 112.5)}{0.07369} = 1583.7\ ft^3/min$$

Step 6. Determine volume fraction of additive.

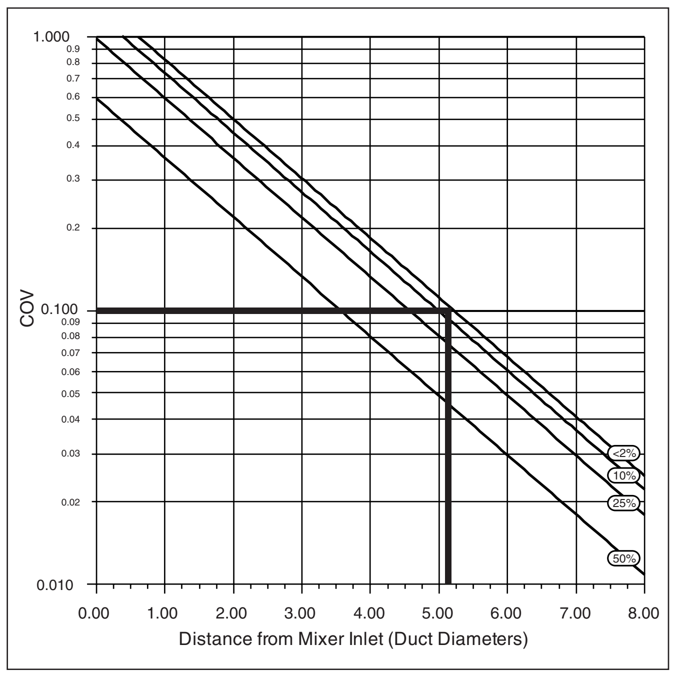
$$Q_{CH_4} = \frac{4.2}{0.0420} = 100\ ft^3/min$$

$$Q_{Total} = Q_{CH_4} + Q_{Air} = 1584\ ft^3/min$$

$$n = \frac{100}{1584} = 0.063$$

Step 7. Determine required mixing.
Mixing Requirement (Given): COV ≤ 0.10

Step 8. Determine required mixing distance using a Gas Blender Mixer.



Case 5: Different Gas, Different Temperature, Same Pressure

	Gas 1 T_1	+	Gas 2 T_2	=	Mixed Gas T_{Mix}
Pressure:	**P**		**P**		**P**

$$m_{Mix} = m_1 + m_2 + \ldots + m_n = \sum_{i=1}^{n} m_i$$

Procedures:

1. Determine density of gas streams.
2. Determine mass flow rate of gas streams.
3. Determine gas constant (R) for mixed gas stream.
4. Determine temperature of mixed gas stream.
5. Determine density of mixed gas stream.
6. Determine volumetric flow rate of mixed gas stream.
7. Determine volume fraction of additive.
8. Determine required mixing.
9. Determine required distance using a Gas Blender mixer.

Example:

Mix 1000 lbm/hr of air at 400°F, 14.7 psi, with 15 lbm/hr of Ammonia (NH_3) at 250°F, 14.7 psi. Mixing requirement is COV ≤ 0.10, with a temperature range ≤ 10°F.

Solution:

Step 1. Determine density of gas streams.

$$R_{Air} = 53.35 \qquad R_{NH_3} = 90.74$$

$$\rho_{Air} = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 400)} = 0.0462$$

$$\rho_{NH_3} = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{90.74 \cdot (459.59 + 250)} = 0.0329$$

Step 2. Determine mass flow rate of gas streams.

$$m_{Air} = 1000\ lbm/hr = 16.67\ lbm/min$$

$$m_{NH_3} = 15\ lbm/hr = 0.25\ lbm/min$$

$$m_{Mixed} = m_1 + m_2 = 1000 + 15 = 1015\ lbm/hr = 16.92\ lbm/min$$

Step 3. Determine gas constant (R) for mixed gas stream.

Component	Mass Flow	% Mass	R	% Mass x R
Air	1000	0.9852	53.35	52.56
Ammonia	15	0.0148	90.74	1.34
Mixture	1015	1.0		53.90

Step 4. Determine temperature of mixed gas stream.

Step 4a. Determine temperature of mixed stream assuming constant specific heat.

$$t_{Mix} = \frac{\Sigma m_i \cdot t_i}{\Sigma m_i} = \frac{1000 \cdot 400 + 15 \cdot 250}{1015} = 397.8°F$$

Step 4b. Determine average temperature for each stream.

$$t_{Average_{Air}} = \frac{400 + 397.8}{2} = 398.9°F$$

$$t_{Average_{NH_3}} = \frac{250 + 397.8}{2} = 323.9°F = 435K$$

Step 4c. Determine specific heat for each component.

$$cp_{Air} = 0.247$$

$$cp_{NH_3} = \left(4.238 - 4.215 \cdot 10^{-3} \cdot 435 + 2.041 \cdot 10^{-5} \cdot 435^{2}\right) \cdot \frac{1.986}{17.031} = 0.7307$$

Step 4d. Determine temperature of mixed air stream.

$$t_{Mix} = \frac{\Sigma m_i \cdot c_p \cdot t_i}{\Sigma m_i \cdot c_p} = \frac{1000 \cdot 0.247 \cdot 400 + 15 \cdot 0.731 \cdot 250}{1000 \cdot 0.247 + 15 \cdot 0.731} = 393.6°F$$

Step 5. Determine density of mixed gas stream.

$$\rho = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.90 \cdot (459.59 + 393.6)} = 0.0460$$

Step 6. Determine volumetric flow rate of mixed gas stream.

$$Q_{Mix} = \frac{1015}{0.0460} = 22065\ ft^3/hr = 367.75\ cfm \approx 368\ cfm$$

Step 7. Determine volume fraction of additive.

$$Q_{Air} = \frac{1000}{0.0462} = 21645\ \frac{ft^3}{hr} = 361\ cfm$$

$$Q_{NH_3} = \frac{15}{0.0329} = 456\ \frac{ft^3}{hr} = 8\ cfm$$

$$n = \frac{8}{368} = 0.022$$

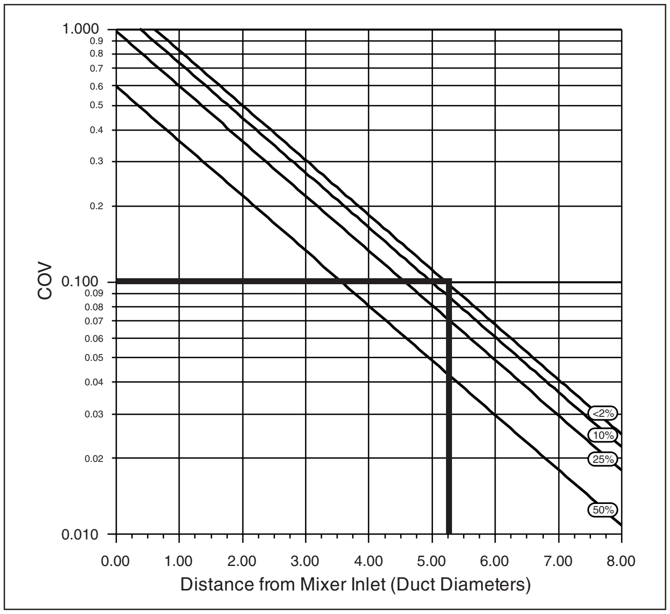
Step 8. Determine required mixing.

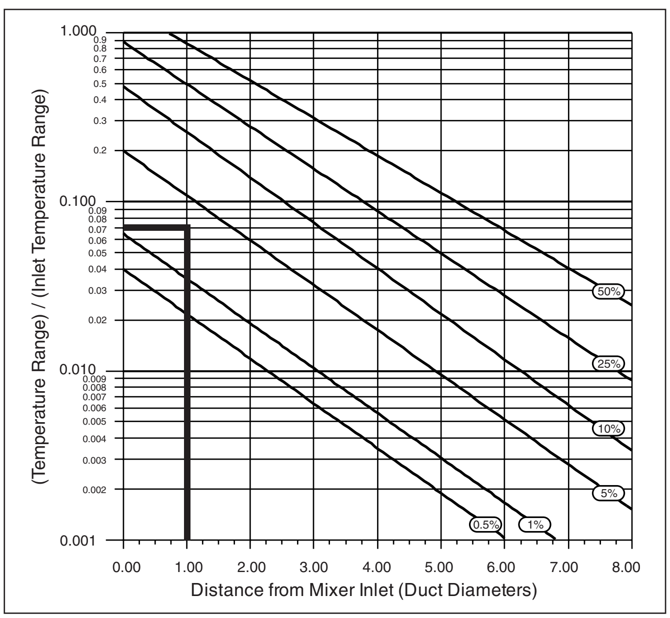
COV ≤ 0.10
Temperature Range ≤ 10°F

$$\frac{Range_{Out}}{Range_{In}} = \frac{10}{400 - 250} = 0.07$$

Step 9. Determine required mixing distance using a Gas Blender Mixer. (See charts below.)

Distance required for COV: 5.25 mixer diameters.
Distance required for temperature range: < 1 mixer diameter.





Case 6: Different Gas, Different Temperature, Different Pressure

Gas 1 $T_1 P_1$	+	Gas 2 $T_2 P_2$	=	Mixed Gas $T_{Mix} P_{Mix}$

$$m_{Mix} = m_1 + m_2 + \ldots + m_n = \sum_{i=1}^{n} m_i$$

Procedures:

1. Determine density of gas streams.
2. Determine mass flow rate of gas streams.
3. Determine gas constant (R) for mixed gas stream.
4. Determine temperature of mixed gas stream.
5. Determine density of mixed gas stream.
6. Determine volumetric flow rate of mixed gas stream.
7. Determine volume fraction of additive.
8. Determine required mixing.
9. Determine required distance using a Gas Blender mixer.

Example:

Mix 1000 lbm/hr of air at 400°F, 14.7 psi, with 20 ft^3/hr of Ammonia (NH_3) at 70°F, 250 psig. Mixing requirement is COV ≤ 0.10, with a temperature range ≤ 10°F.

Solution:

Step 1. Determine density of gas streams.

$$R_{Air} = 53.35 \qquad R_{NH_3} = 90.74$$

$$\rho_{Air} = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.35 \cdot (459.59 + 400)} = 0.0462$$

$$\rho_{NH_3} = \frac{P}{R \cdot T} = \frac{(250 + 14.7) \cdot 144}{90.74 \cdot (459.59 + 70)} = 0.793$$

In order to determine the density of stream 2 in its expanded state it is necessary to determine the temperature of the stream after it expands using the following equation:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

where k=1.27

$$T_2 = 70 \cdot \left(\frac{14.7}{264.7}\right)^{0.2126} = 37.9°F$$

$$\rho_{NH_3} = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{90.74 \cdot (459.59 + 37.9)} = 0.0469$$

Step 2. Determine mass flow rate of gas streams.

$$m_{Air} = 1000\ lbm/hr = 16.67\ lbm/min$$

$$m_{NH_3} = 20 \cdot 0.793 = 15.6\ lbm/hr = 0.26\ lbm/min$$

$$m_{Mixed} = m_1 + m_2 = 1000 + 16 = 1016\ lbm/hr = 16.93\ lbm/min$$

Step 3. Determine gas constant (R) for mixed gas stream.

Component	Mass Flow	% Mass	R	% Mass x R
Air	1000	0.9843	53.35	52.512
Ammonia	16	0.0157	90.74	1.429
Mixture	1016	1.0		53.94

Step 4. Determine temperature of mixed gas stream.

Step 4a. Determine temperature of mixed stream assuming constant specific heat.

$$t_{Mix} = \frac{\Sigma m_i \cdot t_i}{\Sigma m_i} = \frac{1000 \cdot 400 + 16 \cdot 30.6}{1016} = 394.2°F$$

Step 4b. Determine average temperature for each stream.

$$t_{Average_{Air}} = \frac{400 + 394.2}{2} = 397.1°F$$

$$t_{Average_{NH_3}} = \frac{31 + 394.2}{2} = 212.6°F = 373\text{K}$$

Step 4c. Determine specific heat for each component.

$$cp_{Air} = 0.247$$

$$cp_{NH_3} = \left(4.238 - 4.215 \cdot 10^{-3} \cdot 373 + 2.041 \cdot 10^{-5} \cdot 373^2\right) \cdot \frac{1.986}{17.031} = 0.642$$

Step 4d. Determine temperature of mixed air stream.

$$t_{Mix} = \frac{\Sigma m_i \cdot c_p \cdot t_i}{\Sigma m_i \cdot c_p} = \frac{1000 \cdot 0.247 \cdot 400 + 16 \cdot 0.642 \cdot 31}{1000 \cdot 0.247 + 16 \cdot 0.642} = 385.3°F$$

Step 5. Determine density of mixed gas stream.

$$\rho = \frac{P}{R \cdot T} = \frac{14.7 \cdot 144}{53.94 \cdot (459.59 + 385.6)} = 0.0464$$

Step 6. Determine volumetric flow rate of mixed gas stream.

$$Q_{Mix} = \frac{1016}{0.0464} = 21882\ ft^3/hr = 364.7\ cfm \approx 365\ cfm$$

Step 7. Determine volume fraction of additive.

$$Q_{Air} = \frac{1000}{0.0469} = 21322\ \frac{ft^3}{hr} = 355\ cfm$$

$$Q_{NH_3} = \frac{15.6}{0.0476} = 328\ \frac{ft^3}{hr} = 5\ cfm$$

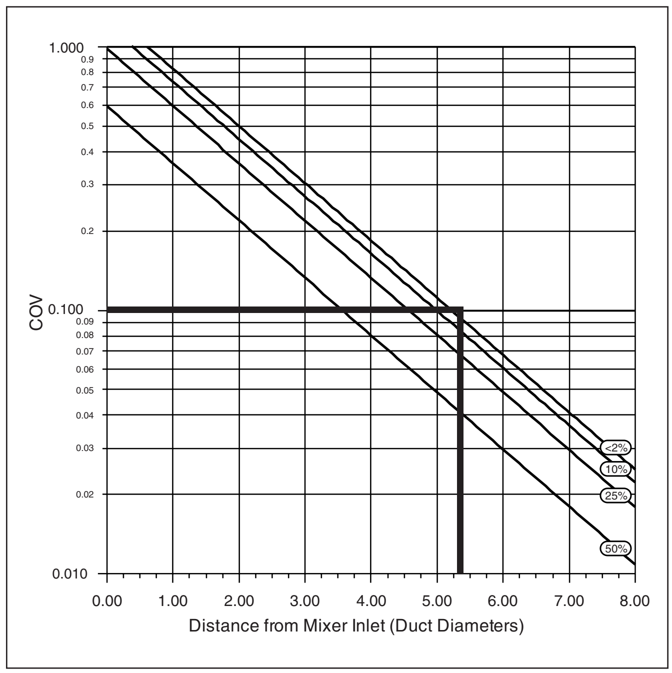
$$n = \frac{5}{360} = 0.014$$

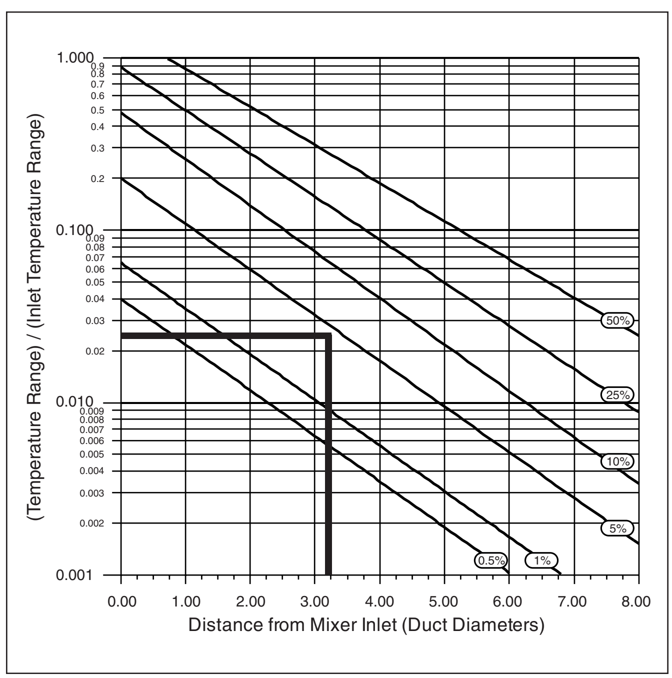
Step 8. Determine required mixing.
COV ≤ 0.10
Temperature Range ≤ 10°F

$$\frac{Range_{Out}}{Range_{In}} = \frac{10}{400-31} = 0.027$$

Step 9. Determine required mixing distance using a Gas Blender Mixer. (See charts below.)

Distance required for COV: 5.25 mixer diameters.
Distance required for temperature range: 2 mixer diameter.





References

The information in this manual has come from a wide variety of sources. The major sources and some related sources are listed below.

Poling B.E., Prausnitz J.M., and O'Connell J.P.: *The Properties of Gases and Liquids*, 5th Edition, New York, McGraw-Hill, 2001.

Reynolds, W. C. and Perkins H.C.: *Engineering Thermodynamics*, 2nd Edition, McGraw-Hill, 1977.

Olson, R. M.: *Essentials of Engineering Fluid Mechanics*, 4th Edition, New York, Harper & Row, 1980.

Kreith, F. and Black W.Z.: *Basic Heat Transfer*, New York, Harper & Row, 1980.

American Society of Heating, Refrigeration and Air-Conditioning Engineers: *1993 ASHRAE Handbook Fundamentals, I-P Edition*, ASHRAE, Atlanta, 1993.

American Society of Heating, Refrigeration and Air-Conditioning Engineers: *1997 ASHRAE Handbook Fundamentals, SI Edition*, ASHRAE, Atlanta, 1997.

American Conference of Governmental Industrial Hygienists: *Industrial Ventialation – A Manual of Recommended Practice*, 22nd Edition, ACGIH, Cincinnati, 1995.

Avallone, E.A. and Baumeister, T.: *Mark's Standard Handbook for Mechanical Engineers*, 9th Edition, New York, McGraw-Hill, 1987.

Health Physics Society: *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities*, ANSI/HPS N13.1-1999.

Blender Products, Inc.

Engineered Air Mixing Systems and Equipment

5010 Cook Street • Denver, Colorado 80216
Phone: 303.295.6111 • Fax: 303.296.1520
Toll-free: 800-523-5705
E-mail: INFO@airblender.com
Internet: www.airblender.com