MSA Gas Detection

Thermal Conditioning for Extracted Gas Samples

Gas detectors are sensitive devices that can be affected by environmental conditions. There are times when a gas sample to be analyzed exists within a hostile environment, with temperatures that are too extreme for direct sensor placement. The sensor might also be placed within a location that is too dusty or inconvenient to be monitored by a diffusion sensor. In these cases, extractive gas sampling is a better and more reliable method for the detection system.

In order to produce an accurate, reliable gas reading, conditions must be controlled at the sensor. Many times when doing extractive gas sampling, a sample must be tempered before it can be introduced to the gas detector. If a very hot or very cold sample is directly applied to sensitive electronics, detector instability may result. In addition, if the sample is very hot and must be cooled, condensing fluid may be an issue to be resolved before the sample enters the actual flow system. This paper specifically discusses gas sample temperature conditioning.

The heat of the sample must transfer to the surrounding atmosphere. The rate of transfer is determined by the temperature gradient from the inside of the tubing to the outside, tubing material and its heat transfer properties and wall thickness. The sample's temperature, heat capacity and sample flow rate determine how much heat must be transferred. These factors determine necessary sample tube length in order to reach the target temperature. In most cases, the sample line is long enough to cool a gas sample to sensor temperature, and no exotic methods need to be employed.

In the example below, a sample from a 190° F source was to be analyzed for toxic gases. The upper temperature limit of the sensor used in this case is 120° F, meaning that the sample had to be cooled to at least that level. To keep calculations simple, we assume that the heat transfer to the atmosphere is due to convection only. We also disregard the temperature gradient that exists along the tube as the sample cools, and assume a constant, stable temperature. Air is the background gas; the contribution of the ppm contaminant's contribution to the mass flow rate and the sample's heat capacity will be disregarded.

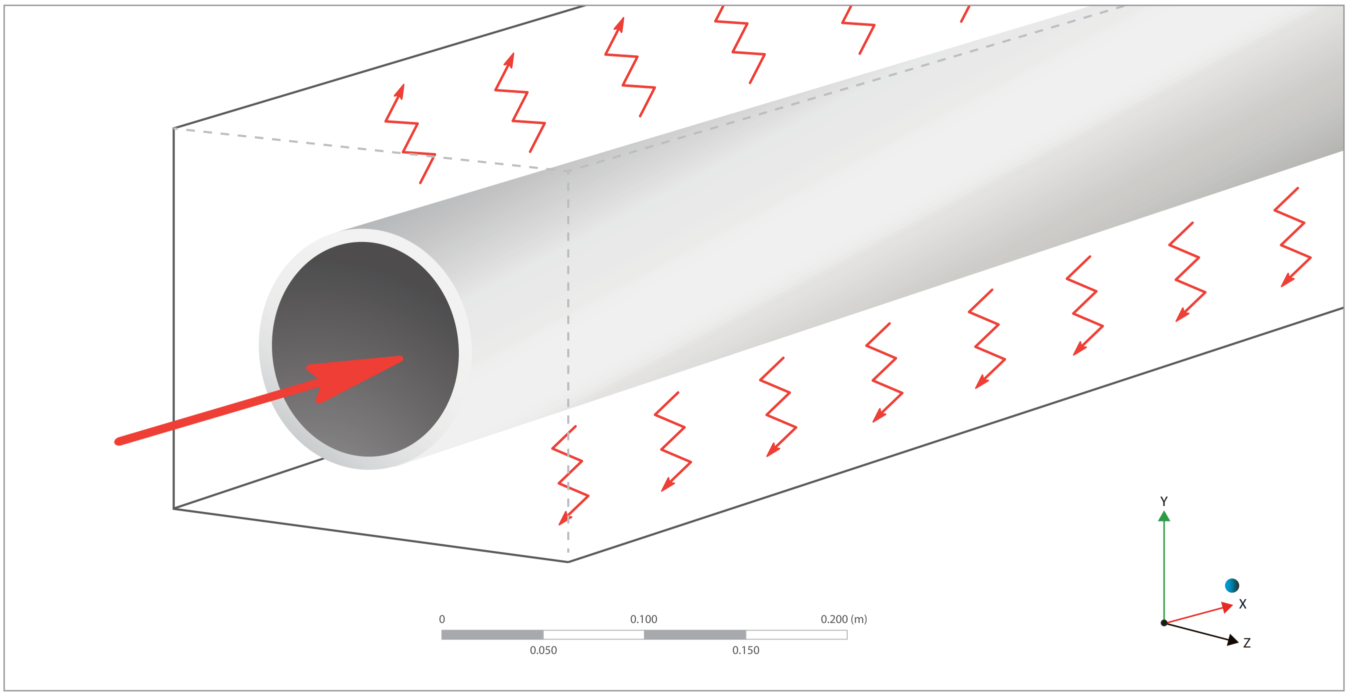

Figure 1. Heat radiating from tube

Thermal Calculations for Sample Stream (example)

316 stainless steel tubing, 1/4" OD, 3/16" ID
Inside diameter = 0.0047625 m

Tin = 190°F = 361K

Tout = 120°F = 322K

T∞ = external air temperature = 294K

Flow = v = 3 lpm = 0.003 m^3/min = 5 x 10-5 m^3 / s

Density ρ = (P·MW) / RT
ρ = ((961,129Pa) · (29 kg / Kmole)) / ((8314 J / Kmole ·K°) · (341K)) = 9.831 kg / m^3

Mass Flow Rate ṁ = Vm · ρ = (5 x 10-5 m^3 / s) · (9.831 kg / m^3) = 4.9 x 10^{-4} kg / s

Heat Capacity Cp = 1.008kJ/kg·K° (at 341.5K)

Thermal Conductivity K = 28.5 x 10^{-3} W/m·K° (for stainless steel)

Assumptions (to simplify calculations):
Tube temperature is uniform and constant
Tube temperature is equal to external air temperature
No effects due to radiation and conduction
Fluid properties are constant and evaluated at (Tin + Tout / 2)

Sample: assume air
Properties of air @ T = Tin + Tout / 2 = 155°F = 341.5K
Convection heat transfer coefficient then is: ɧ = 139.4 W / m^2·K°

Area of Tube Ac = π D^2/4 = 1.78 x 10 -5 m^2 (I.D. = 3/16" = 0.0047625 m)

Velocity V = 0.003 m^3/min ÷ 1.78 x 10 -5 m^2 · 1min/60sec = 2.81 m/s

Thermal Calculations (continued)
ln(Tout - T∞) / (Tin - T∞) = -Pɧx /ṁCp
Where P = tube inner circumference = π · ID
x = ln(Tout - T∞) / (Tin - T∞) · (ṁCp / -Pɧ)

x = ln((322-294) / (361-294)) · (4.9 x 10^{-4} kg / s)(1008 J/kg·K°) / -π(0.0047625m)(139.4 W/m^2·K°)

x = 0.207 m = 8.15 in. of sample line length to drop temperature to 120° F

(minimum length based upon assumptions listed above)

In the attached diagrams we can view a visual of the actual conditions within the sample tube. Because of friction between the gas sample and the tube wall, flow in the tube's center is faster and heat is carried further downstream within that section. This particular example has a relatively slow flow rate, small volume and a sample with low heat capacity; this effect is insignificant and can be disregarded.

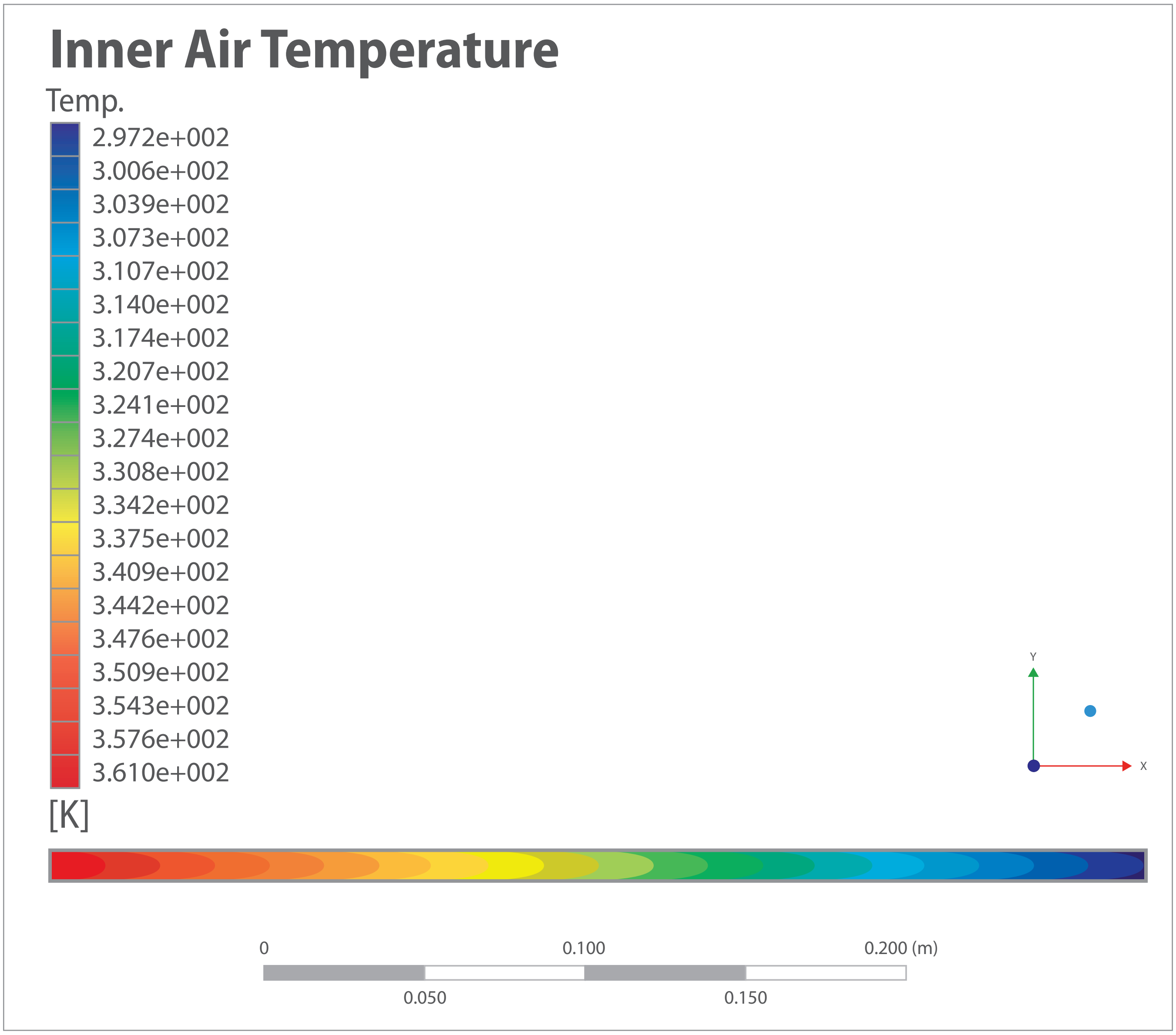

Figure 2. Fluid temperature along tubing length. Inlet is on left.

Based upon our calculations and generous assumptions made, the sample requires 8 in. of uninsulated tube to drop the temperature to the 120° F target within ambient 70° F. This minimum length is based upon many assumptions; in reality, a longer tube length is required, but will still be shorter than 5 feet, and is considered to be a short sample line.

A proper calculation also considers ambient air moving past the tube to carry off heat, requiring calculation of the Reynolds number (a concept used for predictions of fluid flow patterns) for air movement and resulting convection coefficient. Reynolds numbers should also be calculated for flow inside the tube; however, the final number would still be less than the 5-ft. length of sample line, resulting in valid assumptions.

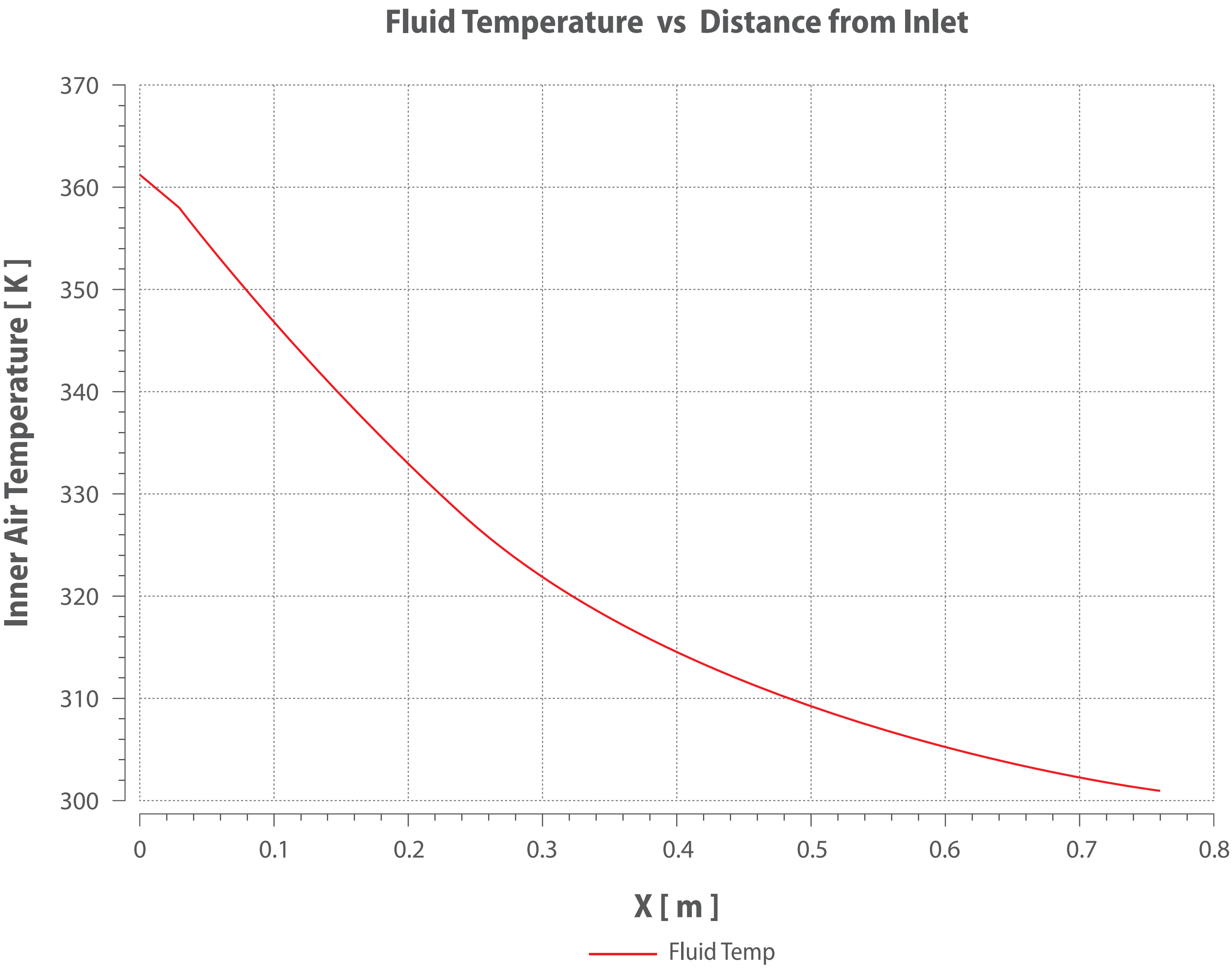

Figure 3.

MSA – The Safety Company
1000 Cranberry Woods Drive
Cranberry Township, PA 16066 USA
Phone 724-776-8600
www.MSAsafety.com

U.S. Customer Service Center
Phone 1-800-MSA-INST
Fax 1-800-967-0398

MSA Canada
Phone 1-800-MSA-INST
Fax 1-800-967-0398

MSA Mexico
Phone 01 800 672 7222
Fax 52-44 2227 3943

MSA International
Phone 724-776-8626
Toll Free 1-800-672-7777
Fax 724-741-1559
Email msa.international@msasafety.com

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