Semiconductor Products, Inc.



# Application Note
# AN 84/01

# Pressure Transducer Temperature Isolation Using Tubing (Steady State Condition)

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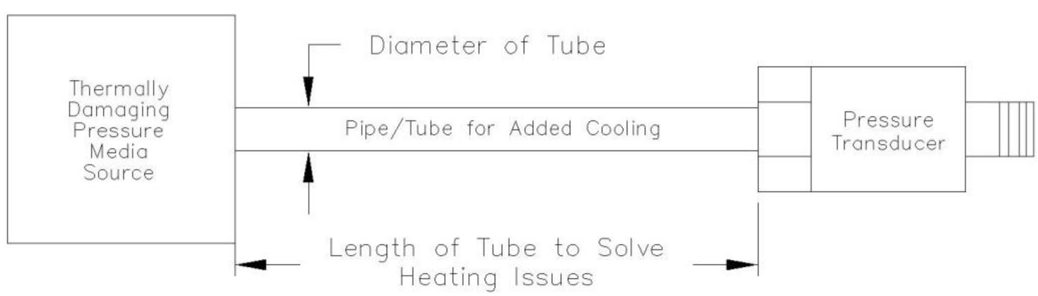
## 1. Introduction

In cases where it is desired to make pressure measurements, and the pressure media is at a temperature which exceeds the allowable thermal limits of an available transducer, tubing or pipe may be used to protect the transducer from out-of-specification media temperatures. It is the purpose of this paper to consider the variable involved, and for various steady state conditions, draw curves, which may be used for advising customers, who have encountered this problem, on possible solutions.



## 2. Analysis of the Problem

First, let us consider likely paths for heat to reach the transducer and logically decide the one most eligible for detailed examination.

1. Heat transfers by conduction, convection, and radiation. If the pressure source is contained within an insulated vessel, heat transfer by radiation is sufficiently small and can be neglected. We will now consider two paths for the transfer, by convection and conduction:

    a. Through the tube or pipe wall
    b. Through the pressure media

2. If the pressure media is a gas or liquid, it will have a coefficient of thermal conductivity on the order of 0.1 BTU/hr-ft-°F. Any metal will have a coefficient greater than 10 BTU/hr-ft-°F, which is a difference of two orders of magnitude. From this comparison, conduction through the tubing wall will contribute, to a much greater extent, to the transducer steady state temperature.

## 3. Derivation of Formula and Curves

The thin walled tube is modeled as a fin operating in conduction and convection, similar to a heat sink fin. The fin is of finite length, and loses heat by convection at its end.

The temperature profile is[1]:

$$\frac{T-T_e}{T_o-T_e} = \frac{\cosh n(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL+(h/mk)\sinh mL} \qquad (1)$$

Where

$T$ = Temperature of a point of interest on fin
$T_e$ = Temperature of environment, taken as 100°F for this analysis
$T_o$ = Temperature of pressure source of interest
$L$ = Length of tubing
$x$ = distance from pressure source

[1] Holman, J.P., *Heat Transfer*, McGraw Hill, 1986, pp. 43-45.

and

$m^2 = hp/kA$

where

h = heat transfer rate from tube to still air by natural convection, taken as 1.44 BTU/hr/ft$^2$/°F
k = coefficient of heat transfer, taken as 9.4 BTU/hr/ft/°F, for 316 stainless steel

and p is the perimeter of the fin, and A is the cross-sectional area of the fin,

$p = \pi D_1$
$A = \pi(D_2^2 - D_1^2)/4$

Where
$D_1$ = outside diameter
$D_2$ = inside diameter

The equation simplifies in two ways:

1. We are interested in the temperature at the transducer, at length L. The numerator will reduce to unity.

2. In the denominator, the cosh term is more significant, two orders of magnitude greater than the sinh term. The sinh term will be disregarded for simplicity.

Equation (1) then simplifies to:

$$\frac{T-T_e}{T_o-T_e} = \frac{1}{\cosh mL} \qquad (2)$$

Maintaining consistent units introduces a factor of 12, to convert the conduction and convection coefficients from feet to inches. The heat transfer coefficients are expressed in terms of feet, while diameters and tube length are expressed in inches. Equation 2, with diameters and coefficients inserted for direct use is:

$$\frac{T-T_e}{T_o-T_e} = \frac{1}{\cosh \left(L\sqrt{4hD_1/12k(D_1^2-D_2^2)}\right)} \qquad (3)$$

Where

T = Temperature of a point of interest on fin
$T_e$ = Temperature of environment, taken as 100°F for this analysis
$T_o$ = Temperature of pressure source of interest
L = Length of tubing, in inches
h = heat transfer rate from tube to still air by natural convection, in BTU/hr/ft$^2$/°F
k = coefficient of heat transfer, in BTU/hr/ft/°F
$D_1$ = outside diameter, in inches
$D_2$ = inside diameter, in inches

The unit conversion is taken care of by the factor of 12. The factor of 4 is a result of the area computation ($D_1^2$-$D_2^2$). The π's from area and perimeter cancel out. The L factor is not under the radical sign.

The coefficient of heat transfer is taken at 9.4 BTU/hr/ft/°F, for 316 stainless steel. For various materials, the coefficient of heat transfer is listed below[2]

**Coefficients of Heat Transfer**

| Material | BTU/ft-hr-°F |
|---|---|
| Inconel 625 | 5.6 |
| Inconel 718 | 6.5 |
| 15-5 PH | 10.3 |
| 316 SS | 9.4 |
| Nickel 200 (99Ni) | 40.4 |
| Monel 400 (63Ni 31Cu) | 12.5 |
| Monel 401 (42Ni 53 Cu) | 11 |
| Monel R405 (31 Ni 66Cu) | 12.5 |
| Monel 450 (31Ni 66Cu) | 17 |
| Monel K-500 (63Ni 30Cu) | 10.1 |
| Brass (70Cu 30 Zn) | 70 |
| Copper | 226 |
| Commercially Pure Titanium | 9.2 |
| Alpha Titanium | 4.4 |

Equation 3 is plotted, and displayed in Figure 1, for extreme temperature conditions of the pressure source ($T_o$), assuming an ambient temperature around the transducer ($T_e$) of 100°F and a heat transfer rate (h) from the tube to still air of 1.44 BTU/hr/ft$^2$/°F. To account for heat conductivity through the pressure media, and introduce a safety factor, the minimum allowable temperature limits for the transducer are assumed to be 200°F and 0°F, respectively.

[2] *Materials Handbook, Vol 1 Properties and Selection, Irons and Steels, and Vol 2 Properties and Selection, Nonferrous Alloys*, ASM, Materials Park, OH

## 4. Application of the Curves

From the curves, as shown in Figure 1, for a given length of tubing, better isolation is obtained with steel, rather than other materials, such as brass or copper. Where frequency response is a consideration, use steel tubing, to minimize the length, to reduce signal attenuation and distortion. At temperatures above 1000°F, brass and copper use is limited. Smaller diameter or thinner wall tubing requires shorter lengths, to isolate the transducer, for a given source temperature. A compromise must be made, between tubing diameter and length, and frequency response.

As a rule of thumb, one foot to steel tubing, any diameter, will isolate a transducer from any temperature.

## 5. Example

As an example, a reading must be taken on a pressure media with a steady state temperature of 500°F, and the allowable sensor operating temperature is 200°F. The available tubing is 316 stainless steel, .25 inch diameter x .035 inch wall thickness. We will determine the length of 316 steel tubing required to perform the reading, as

$$\frac{T-T_e}{T_o-T_e} = \frac{1}{\cosh\left(L\sqrt{4hD_1/12k(D_1^2-D_2^2)}\right)} \qquad (3)$$

Where

$T$ = Temperature at transducer = 200F
$T_e$ = Temperature of environment, 100°F
$T_o$ = Temperature of pressure source of interest, 500F
$L$ = Length of tubing, in inches, to be determined
$h$ = heat transfer rate from tube to still air by natural convection, 1.4 BTU/hr/ft$^2$/°F
$k$ = coefficient of heat transfer, 9.4 BTU/hr/ft/°F, for 316 steel
$D_1$ = outside diameter, .250 inches
$D_2$ = inside diameter, .18 inches

Note the inside diameter is OD- 2 times wall thickness, or .250- 2 x .035 = .18 inch

We have

$$\frac{200-100}{500-100} = \frac{1}{\cosh\left(L\sqrt{4(1.4)(.25)/12(9.4)(.25^2-.18^2)}\right)}$$

Or

$$\cosh(.642L) = 4$$

Solving for L, we have 3.21 inches.

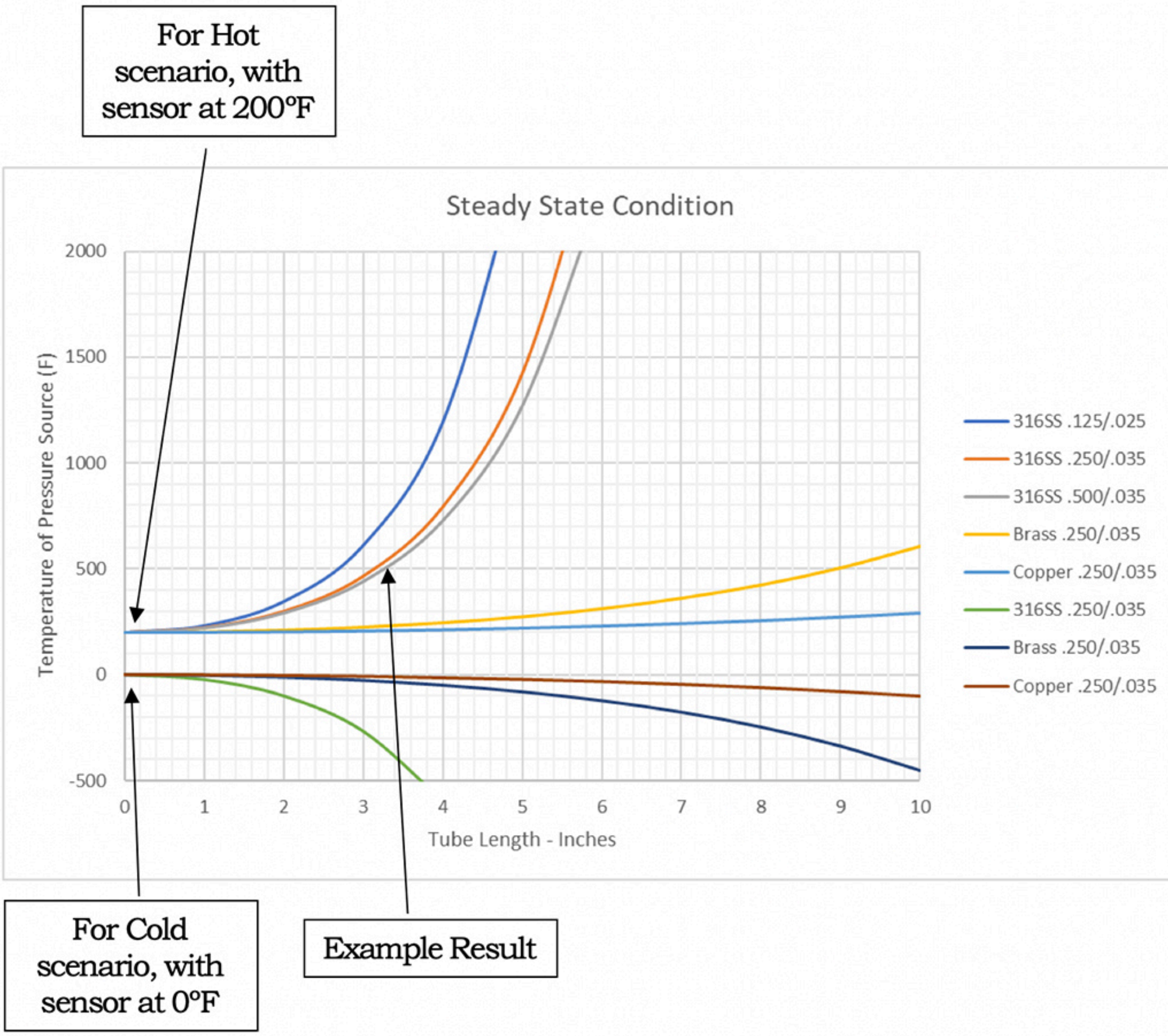



**Figure 1**

Curves for determining tubing length necessary to isolate transducers from thermally damaging pressure source. Ambient temperature at transducer location assumed to be 100°F. Maximum and minimum allowable transducer temperature assumed to be 200°F or 0°F, respectively. Dimensions are OD and wall thickness in inches.