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Diaphragm Seals

PIP #: DS/PI-14

Applicable to:
All Diaphragm Seals
1279's

DIAPHRAGM SEAL TEMPERATURE ERROR

Diaphragm seals can be used to protect pressure instruments from high temperature process media, cold ambient environments and corrosive process chemicals. Errors in instrument readings result from expansion or contraction of the fill due to process and ambient temperature changes. The effect of this error on the accuracy of the assembly is a function of the coefficient of expansion of the fill, the volumetric spring rate of the diaphragm, the total volume of fill subject to a temperature change and the pressure range of the instrument. If a diaphragm seal/gauge assembly is properly filled, a theoretical approximation of the temperature error is a relatively straight-forward calculation.

The total volume of fill will be the internal volume of the pressure instrument, i.e. Bourdon tube, bellows, etc., plus that of the diaphragm seal. Table I lists the approximate internal volumes of commonly used 4½ inch Ashcoft® pressure gauges. Table II lists the internal volumes of Ashcroft® diaphragm seals.

The temperature we are interested in is really the difference in temperatures between filling and use. It is assumed that all the assemblies are filled at 70°F (21°C).

The following is a sample calculation of temperature error:

Gauge – 4½ Inch 100 psi Duragauge
Diaphragm Seal – Type 100 AISI 316L Stainless Steel
Ambient Temperature – 120°F
Filling Fluid – Silicone

From Table I, the internal volume (V1) of the Gauge is 24 ml. From Table II, the internal volume (VD) of the diaphragm seal is 1.7 ml.

On a direct connected assembly (gauge is attached direct to seal), the temperature increase that expands the fill inside the gauge/diaphragm seal assembly is the ambient temperature minus the room temperature where the unit was assembled. As mentioned above, all assemblies are assumed to have been filled at 70°F.

120°F-70°F = 50°F
to convert to °C, divide by 1.8
50°F/1.8 = 27.7°C

The change in temperature, multiplied by the total fill volume, multiplied by the coefficient of expansion of the fill gives the total volumetric expansion inside the assembly.

The coefficients of expansion of various can be found in Table III.

27.7°C x (24 ml + 1.7 ml) x 9.6 x 10^{-4} ml/ml/°C = .69 ml

From the Type 100 volumetric spring rate graph on drawing 96A148, this volume change (.69 ml) corresponds to a pressure increase of approximately 1.25 psi. Therefore, our sample Gauge, would have an indicating error of 1.25 psi or 1¼%.

This calculation was based on a direct connected Gauge/Diaphragm Seal assembly. Assemblies used on extremely high or low process temperature applications with flexible line assemblies will be treated slightly differently. The fill in the capsule will be approximately at the process temperature. The fill inside the instrument and line will remain at ambient temperature.

Gauge – 4½ Inch 100 psi Duragauge
Diaphragm Seal – Type 100 AISI 316L Stainless Steel
Ambient Temperature – 130°F
Process Temperature – 250°F
Filling Fluid – Silicone
130°F-70°F = 60°F (33.3°C) at Gauge and capillary
250°F-70°F = 180°F (100°C) at Seal

Volumetric expansion inside the Gauge equals:
33.3°C x 24 ml x 9.6 x 10^{-4} ml/ml/°C = .774 ml

Volumetric expansion inside capillary:
33.3°C x 5 ft. x .8 ml/ft. x 9.6 x 10^{-4}ml/ml/°C = .128 ml

Volumetric expansion near the Diaphragm equals:
100°C x 1.7 ml x 9.6 x 10-4ml/ml/°C = .163 ml

The total expansion is then:
.774 ml + .128 ml + .163 ml = 1.1 ml

From the same graph on drawing 96A148, we see that the pressure increase is then 2 psi or 2%.

The above calculation predicts the temperatures error for a properly filled assembly. It does not accurately predict errors for overfill, underfill, aeration, or assemblies contaminated with foreign liquids or particles. The calculation of such errors is a complicated in-exact process which does not easily lend itself to useful solutions. It is worthwhile though to discuss the effects on accuracy of improperly filled assemblies.

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Overfilling – Overfilling an assembly distorts the diaphragm outward. By distorting outward, the diaphragm starts in a stiffer position, causing high errors for elevated temperatures and a lack of span for vacuum applications. Overfilling does not reduce span in pressure applications and is sometimes wrongly used as a technique to increase the internal volume beyond the design capacity.

Underfilling – Underfilling the assembly leaves the diaphragm in a concave condition. This reduces the ability of the diaphragm to provide enough displacement for the proper operation of the attached instrument. An underfilled diaphragm not only effects linearity, but often prevents the gauge or instrument from seeing full range pressure. In extreme cases, the instrument will not function at all in low temperature applications.

Aerated Fills – As stated earlier, any displacement the instrument sees is transmitted from the diaphragm through an incompressible fluid. The key word here is incompressible. Air and other gasses are compressible. The gas by compressing, increases the volume which must be displaced by the diaphragm. This affects the span by making the diaphragm travel farther to transmit the same pressure.

A more subtle problem is related to gas being absorbed into solution with the fill. The absorbed gas remains in solution for pressure applications, but bubbles out under vacuum, again reducing span. An example of this is a vacuum gauge/seal assembly which initially might read 26 inches mercury full scale. After a few minutes, the pointer will begin to move back down scale toward zero. This is evidence that dissolved gas in the liquid is bubbling out.

Summary – Temperature errors result from an expansion or contraction of the filling fluid. These errors can be predicted by knowing specifics of the fill (i.e. total internal volume and coefficients of expansion), the seal/instrument assembly (i.e. volumetric spring rate and pressure range) and temperature influences (i.e. ambient and process temperatures). The change in the internal volume of the fill in the assembly is not a function of the instrument pressure range, but the final percent error does depend on the range. Therefore, low pressure range gauges will have higher errors than a high pressure range gauge. Teflon and Viton Diaphragm Seals, because of their low volumetric spring rates, extend the use of seals to low pressure applications. Accordingly, assemblies with non-metallic diaphragms have low temperature errors.

Most abnormalities in the operation of a filled assembly can be explained by one or more of the three types of improperly filled assemblies. After the problem is corrected, a prediction of temperature errors can be made using the calculations techniques sampled above.

TABLE I – GAUGE INTERNAL VOLUME (V1)

GAUGE RANGE	ml	in.3
12	25	1.5
15	25	1.5
30	25	1.5
60	24	1.5
100	24	1.5
160	22	1.4
200	21	1.3
Bellows Gauges (All Ranges)	36	2.2

Note: The temperature error for all 2½ inch and 3½ inch Gauges and for 4½ inch Gauges with pressure ranges above 200 psi will be relatively small and need not be considered.

TABLE II – SEAL INTERNAL VOLUME (VD)

	DIAPHRAGM MATERIAL	INTERNAL VOLUME – ml
100, 200, 300	Metal	1.15
300T	Teflon	2.3
300Y	Viton	8.2
300K	Kalrez	8.2
310	Metal	.41
311, 312	Metal	.52
320 (1½˝ Process)	Metal	.41
320 (2˝ Process)	Metal	1.14
330	Metal	.41
400	Metal	1.14
500	Metal	1.14
702, 703	Metal	7
740/741	Metal	7

Internal Volume of Flexible Line Assembly = 0.8 ml/ft

TABLE III – FILLING FLUID – EXPANSION COEFFICIENT

FILLING FLUID	COEFFICIENT OF EXPANSION ml/ml/°C
Silicone	9.6×10^{-4}
Glycerin	6.2×10^{-4}
Fluorolube/Halocarbon	8.0×10^{-4}

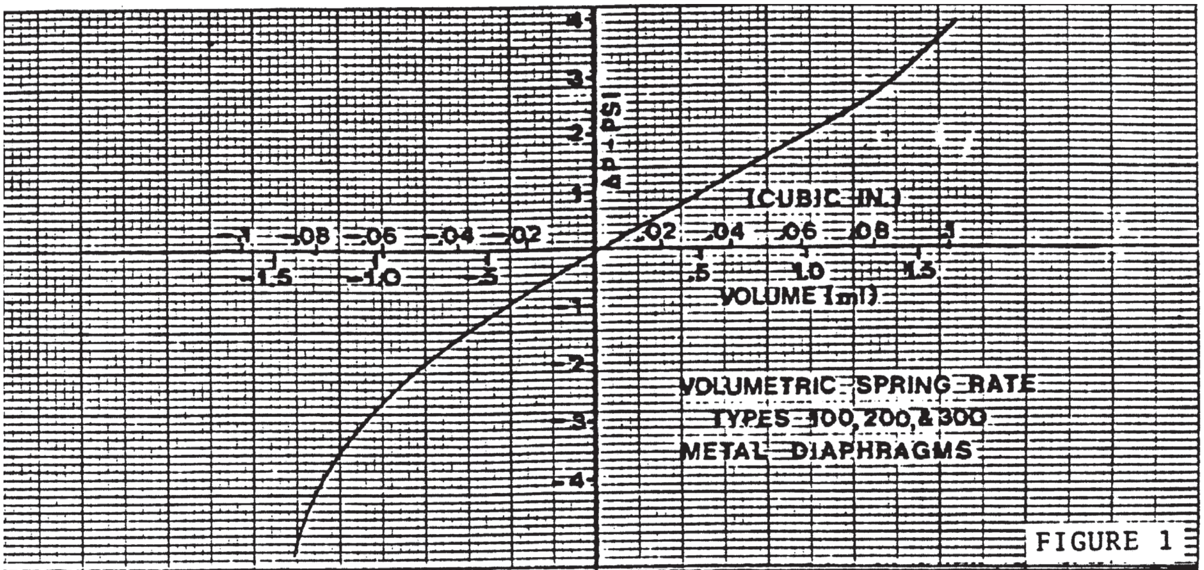

FIGURE 1

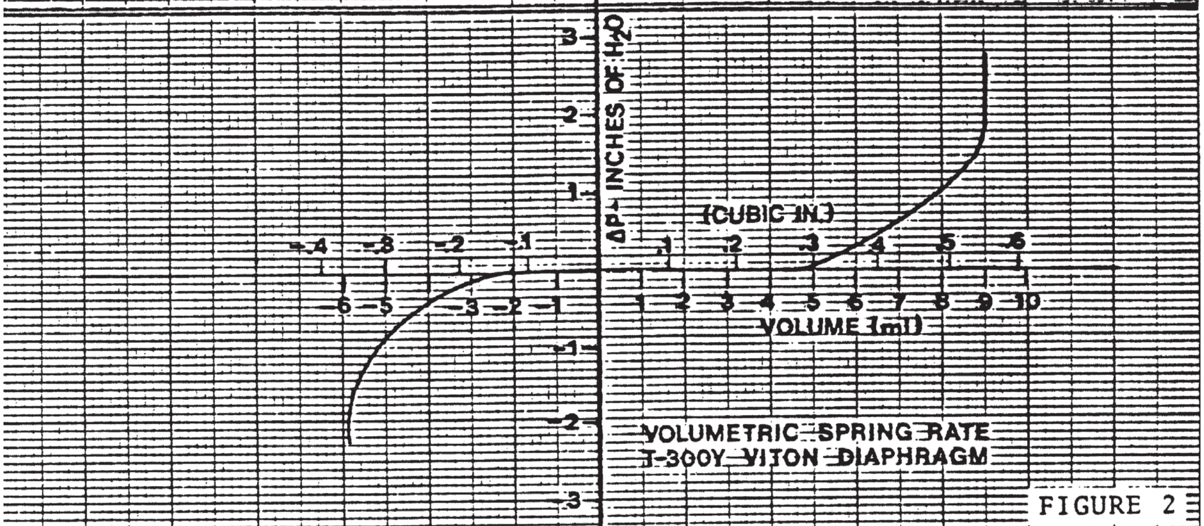

FIGURE 2

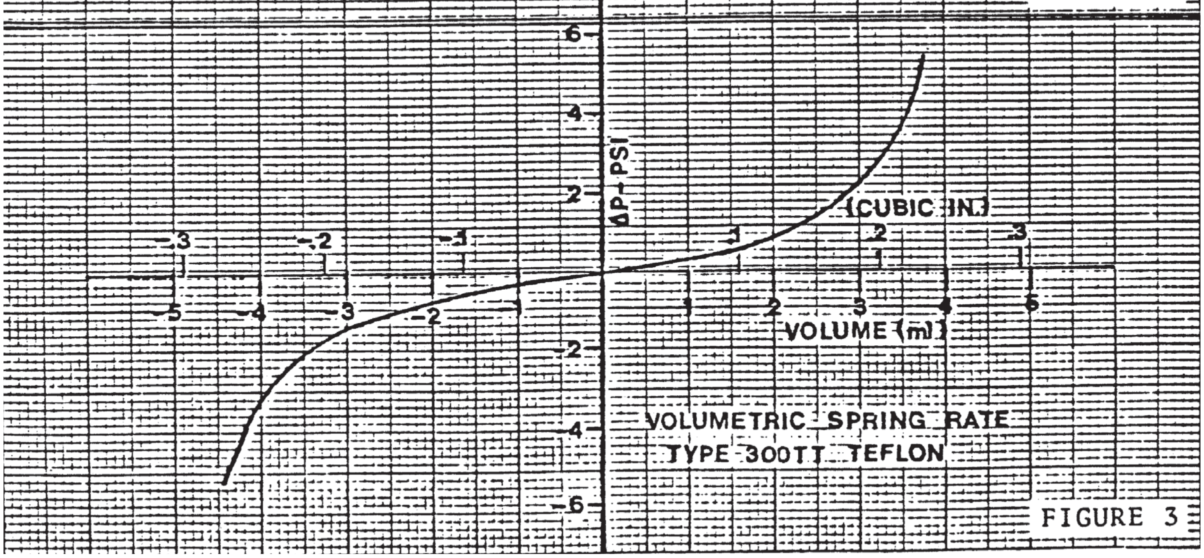

FIGURE 3