

Selection Guide for Diaphragm Seals for Use with Gauges and Switches

Diaphragm Seals

Diaphragm seals are designed to separate a pressure instrument from the process while allowing pressure variations to be transmitted to the instrument's sensing element. Pressure is applied to the process side of a diaphragm. The gauge side of the diaphragm and the gauge, or transducer, is filled with a suitable fluid so that deflections of the diaphragm are transmitted through the hydraulic pressure of the fluid to the instrument.

Diaphragm seal upper housings, lower housings, and diaphragms are made from a wide selection of materials that are suitable to handle almost any exotic process. Diaphragm seals are designed to be used in combination with conventional pressure gauges as well as with transmitters or pressure switches. Pressure ranges from 5 in H₂O to 20,000 PSI can be handled with temperatures up to 750 °F.

Parameters which influence accuracy and performance of a diaphragm seal assembly can be very complex, requiring thorough consideration under all anticipated conditions of operation.

Typical Diaphragm Seal Users

Diaphragm seals are used most extensively in the process industry such as petrochemical, chemical and gas plants, oil refineries, pulp and paper mills, food and dairy processes, and water and sewage treatment plants. Special sanitary diaphragm seals are designed in compliance with the food and beverage market needs.

Applications Where a Diaphragm Seal May Be Considered

- The process is corrosive, as compatible diaphragm materials are more readily available than compatible bourdon tube materials.
- The process is highly viscous and cannot pass through a normal pressure entry port. A diaphragm seal will prevent clogging.
- The process is heterogeneous or contains suspended matter, which may obstruct the pressure entry or deposit inside the pressure element.
- The process tends to crystallize or polymerize.
- The system is used to process different batches and a diaphragm seal provides an easy way of cleaning to avoid contamination.
- The gauge needs to be isolated for safety reasons.
- The temperature of the process does not allow direct measurement. The temperature may be beyond the capability of existing pressure instruments or the effect of the temperature may cause

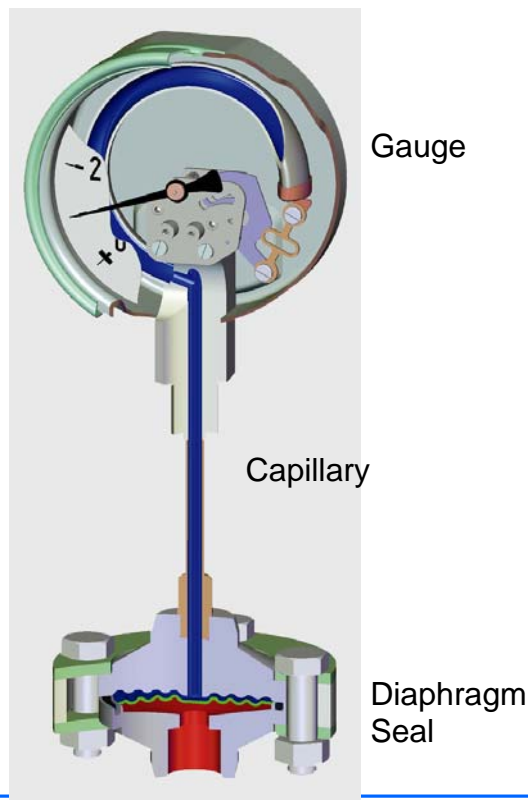
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unacceptable accuracies.

- The pressure tapping point does not allow direct installation of a pressure reading instrument. A diaphragm seal with capillary will facilitate relocation for easy observation of the instrument.
- Sanitary conditions must be maintained. A flush mounted diaphragm seal avoids cavities and dead volume. A seal can be easily be cleaned to avoid process contamination.
- The process is toxic or the medium may pollute the environment. A suitably designed diaphragm seal will provide protection.
- In applications where it is undesirable to have a dead end in the piping system where sludge or particles can accumulate a flush type, saddle or inline seal can be used for the pressure measurement.

Theory of Operation

The illustration below highlights operating principles of a diaphragm seal assembly. The instrument may be a conventional pressure gauge, as shown, as well as pressure transmitters, pressure switches, and pressure transducers. The diaphragm seal assembly is carefully filled with a suitable liquid. Any pressure applied to the diaphragm is hydraulically transmitted to the pressure sensitive element of the measuring instrument (in this case a bourdon tube).



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- Seal assembled with capillary

The pressure instrument may be either directly assembled or connected to the diaphragm seal by means of a capillary. The capillary isolates the instrument from hot processes. Effects of location, temperature, viscosity, and length of capillary on response time and accuracy must be considered. To improve response time the shortest possible capillary should be used. To limit the temperature effect the capillary I.D. is minimized to reduce the effect of volume expansion.

Once filled and calibrated, the hermetically sealed diaphragm seal assembly should not be disassembled. Where applicable, diaphragm seal parts (diaphragm, lower housing and gaskets) which are exposed to the process are made of materials which resist pressure, temperature and possible chemical corrosion. The diaphragm itself does not need to withstand the pressure as it is backed up by the hydraulic forces of the fill fluid.

The system fill fluid may leak if the diaphragm is damaged or subjected to abnormal wear; therefore, the fill fluid should be carefully selected to be compatible with the process. This is especially true when the diaphragm seal is used in food and beverage processing. A variety of fill fluids are available to handle almost any application.

An important consideration for the performance of the gauge is the displacement capability of the diaphragm and the spring rate of the diaphragm relative to the pressure gauge. Larger diameter diaphragms are used for both high displacement bourdon tubes and low pressure applications to minimize the effect of the added spring rate of the diaphragm.

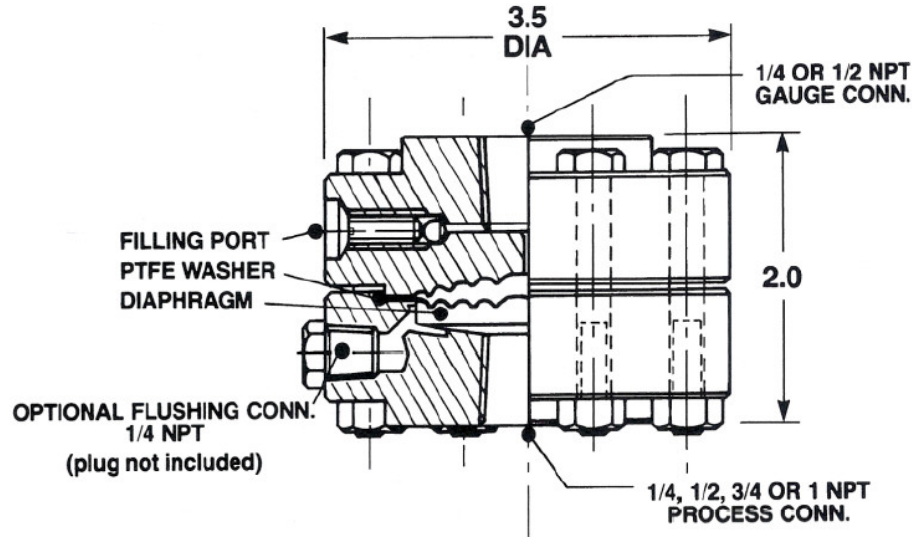
Types of Diaphragm Seals

Threaded Seals

Threaded seals provide lower housings with ¼” to 1 ½” NPT (female and male) sizes. The lower housing screws onto a pipe, and a mounting ring bolted to the lower housing holds the upper housing with diaphragm in place. Threaded seals are available in a large variety of materials with or without flushing connections, used to clean the process below the seal. Lower housings are available that meet all existing national and international standards. Generally the diaphragm is welded to the inside of the upper housing and may in some cases be coated with Teflon.

For low pressure, vacuum and compound ranges an elastomeric diaphragm, such as Viton® or Teflon® is often used, the diaphragm is clamped between the housings. The upper housing is bolted to the lower housing with a metal to metal, o-ring or gasket seal. The upper housing material is commonly made of 304 or 316 SS and includes a ¼” or ½” NPT for the gauge attachment and is also fitted with a fill port to introduce the fill fluid. Generally a stainless steel ball bearing provides the seal under the set screw that closes the filling port.

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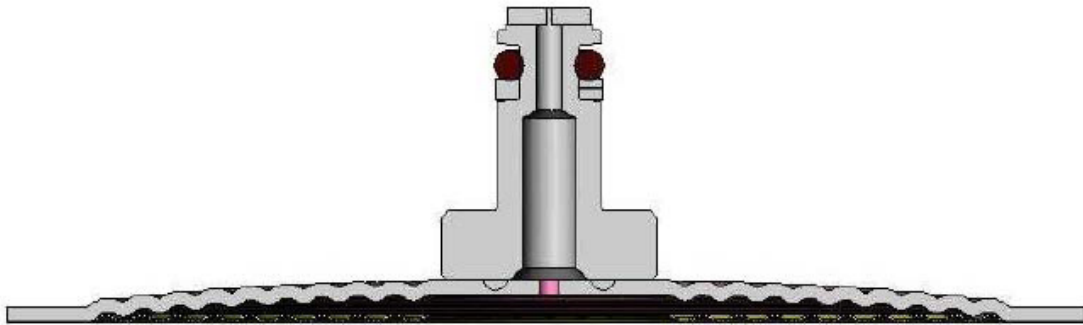
Diaphragm Capsule

Similar to the Threaded diaphragm seal the diaphragm capsule uses a separate upper and lower ring to clamp the upper and lower housing together. The diaphragm can be flat or in the form of a capsule welded at the edge and includes a fitting to locate and seal to the upper housing. The diaphragm capsule design allows the top housing and capsule to be removed without losing the fill fluid. The seal can be repaired by replacing the diaphragm capsule



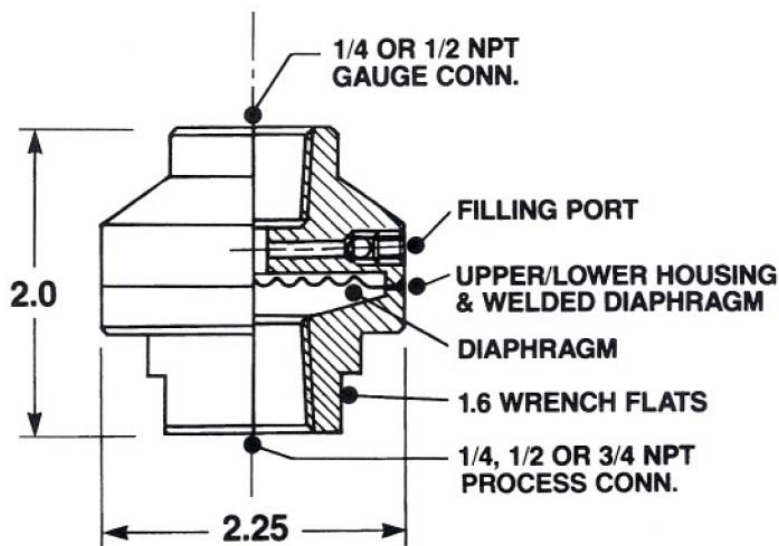
A metal diaphragm capsule is threaded into a nickel/ chrome plated carbon steel top housing. 316 stainless steel is an optional top housing material. The capsule construction assures positive sealing at all surfaces, preventing any leakage of the filling fluid from the system. The capsule design allows for the top housing and pressure instrument to be removed without losing the fill fluid. A Viton O-ring, compatible with all standard fill fluids, and a Teflon back-up ring provide a seal between the diaphragm capsule and the top housing. Since the diaphragm capsule is completely sealed upon being threaded into the top housing, tension of the clamping bolts has no effect on the sealing ability of the filled system. The diaphragm capsule can be replaced without replacing the entire top housing. The top housing and diaphragm capsule are interchangeable with all bottom housings.

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Welded diaphragm seal

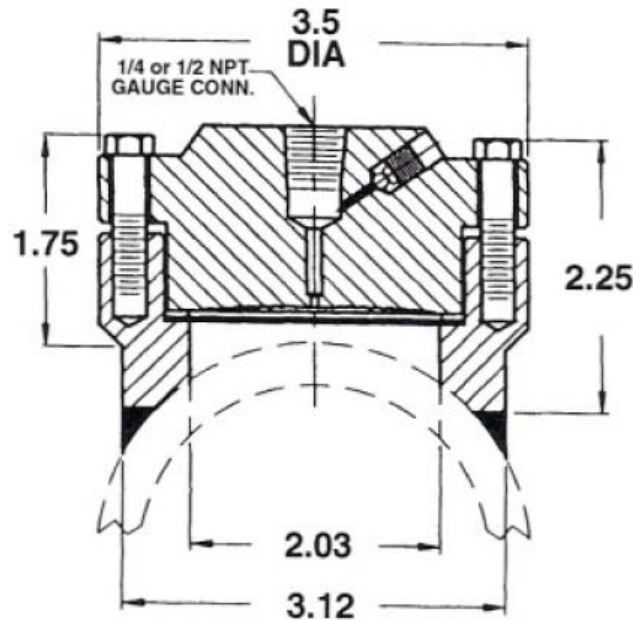
A compact construction with the sealing diaphragm sandwich welded between the upper and lower housings to form a one piece integral unit is suited for those applications where space and low cost are a factor. Used for operating pressures over 60 psi the seal is selected to include upper and lower NPT connections and is generally available in 316SS.



Saddle Weld Seals

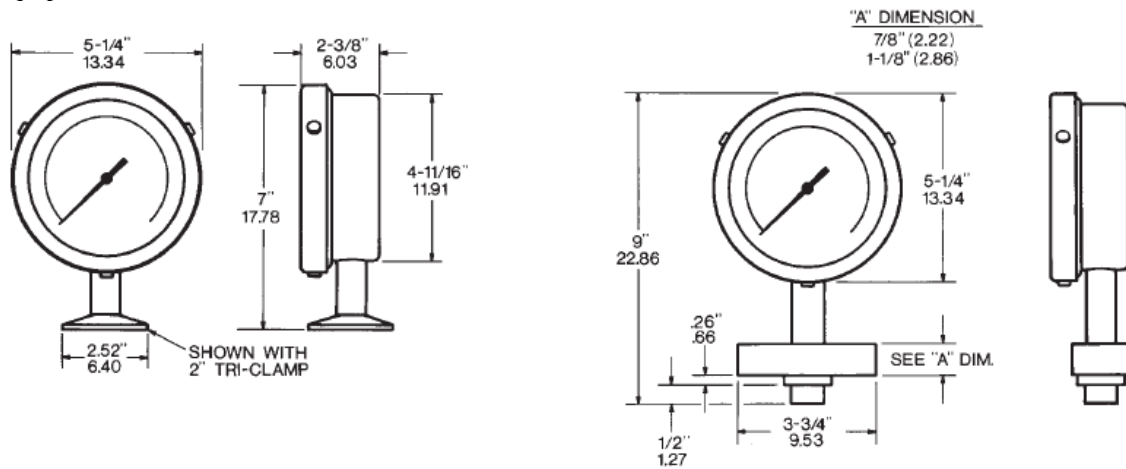
Saddle weld seals are recommended for applications that require a continuous process flow to ensure that the pressure sensing device is not inhibited by solids. The pipe size needs to be over 3” for this type of seal, the lower housing is welded to the pipe and then the upper housing, diaphragm and gauge are bolted on.

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Sanitary Seals

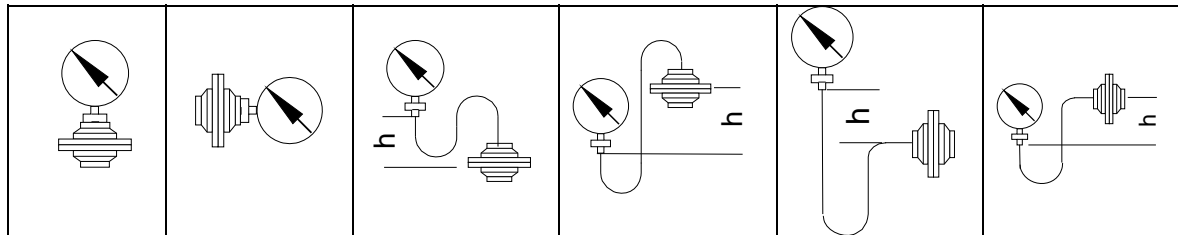
Pressure Gauges used for the food and pharmaceutical process industries are made to a high standard. 3A approval is required. The construction is void of crevices that may harbor contaminants such as bacteria,. The gauge is sold integral with a diaphragm seal and is made to quickly disconnect from a sanitary fitting for cleaning and service. The illustration below shows a typical sanitary gauge configuration with a Tri-Clamp® diaphragm seal, the gauge on the right is a homogenizer high pressure gauge that has a small diaphragm welded to the end of the gauge stem with a heavy duty flange that attaches directly to the equipment.



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Installation Considerations

Not all installations duplicate the position of the gauge and seal as it was when calibrated. The hydrostatic, or head, pressure of the fill fluid can effect the accuracy in the form of a zero shift. Position error, from the upright normal position, is also increased due to the weight of the fluid that solidly fills the gauge bourdon. These effects are especially important: vacuum range, compound range and low pressure ranges such as 0-15psi. The installation errors can be compensated for by zero shifting adjustment of a pointer or zero adjust of an electronic instrument. The following figure shows the various installation configurations, all except the first one will need to be zero adjusted if low pressure gauges are used.



OPERATING PRINCIPLE OF A DIAPHRAGM SEAL

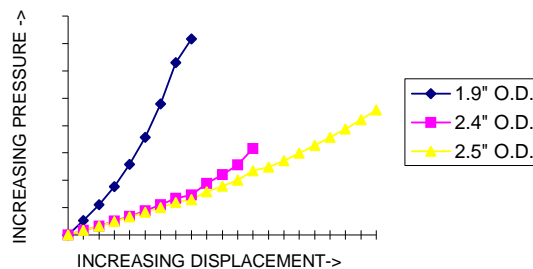
The pressure sensing instrument is isolated from the process fluid by means of a flexible diaphragm. The void between this diaphragm and the instrument's pressure element is filled with an incompressible fluid. This fluid transmits a pressure applied to the flexible diaphragm to the sensing element of the pressure instrument.

Volumetric displacement is the amount of fluid that a flexible diaphragm will displace when a pressure is applied. For proper function the diaphragm seal must have greater displacement capability than the sensing element requires for its full range actuation.

All fluids will expand and contract with a change in temperature. Fluids chosen for use with diaphragm seals will expand and contract in a linear fashion within certain temperature ranges. Choosing the appropriate fill fluid for an application is a key factor in the accuracy of a filled diaphragm seal pressure sensor assembly. This expansion and contraction creates a pressure change in the filled system as seen by the pressure sensor. The quantity of fill fluid within the filled system should be kept to a minimum to reduce errors related to fill fluid expansion and contraction.

Diaphragm spring rate is the term relative to a flexible diaphragm's resistance to movement. The higher the spring rate, the more the diaphragm is resistant to movement. As the temperature of the fill fluid increases and expands a high spring rate diaphragm will create greater internal pressures as seen by the pressure instrument than a low spring rate diaphragm. Large diameter diaphragms that have low spring rates will induce less error when subjected to temperature changes.

DIAPHRAGM DISPLACEMENT / SPRINGRATE



Diaphragm displacement curve is a term relative to the non-linearity of the relationship between pressure applied to a diaphragm and the amount of fluid it displaces. At ambient temperatures an instrument can be calibrated to perform in a linear fashion through its full displacement requirement. As the fill fluid increases in volume because of a rise in temperature, the operating range of the diaphragm has shifted to a less linear portion of the diaphragm's movement.

The result is that the instrument may be very accurate at ambient temperatures but very non-linear under elevated temperature conditions. Fill fluids used by diaphragm seal manufacturers are offered because of their low coefficient of expansion with changes in temperature. Care should be taken not to exceed the maximum operating temperature range of the fill fluid. If the fill fluid reaches its vaporization temperature, this filled system does not indicate accurately and typically exhibits irreparable damage to the sensing diaphragm.

The most important factor with regard to diaphragm seal performance is the integrity of the filled system. Regardless of the appropriate sizing of the diaphragm seal, and proper fill fluid selection, if the filled system contains entrapped gases or pockets of air, the performance will tend to be inaccurate and unpredictable. Remember, what works on the test bench and what works in the real world of process control can be two different things.

Operating Principle of the Instrument

Consideration for properly providing a diaphragm seal is understanding the requirements of the pressure sensing element of the instrument. A primary concern is the sensing element's displacement requirement. Diaphragm seal manufacturers will publish the displacement capability of a diaphragm seal. Instrument manufacturers of pressure instruments rarely publish the displacement requirement of the pressure sensor to actuate to its full range. Without knowing these values you can only derive the compatibility of these

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two devices by experimentation. After years of experience with pressure sensing devices we can summarize the following sensors:

- **Bourdon Tube** - Can usually be appropriately sized to a diaphragm seal. Typically, the higher the pressure, the lower the volumetric displacement requirement to drive the sensor it's full span. Inversely, low pressure Bourdon tubes may pose limitations on the smaller diameter sizes of the diaphragms that can be used.
- **Pressure helical** - Less displacement requirement than the equivalent pressure range Bourdon tube. Extremely low displacement requirement even in low pressure ranges.
- **Capsule or Diaphragm** - Contact the manufacturer for exact displacement requirements. The nature of this type of sensor is such that only the highest displacing diaphragm seals will work.
- **Bellows**- Contact the manufacturer for exact displacement requirements. If there is a diaphragm seal that has adequate displacement capability to drive the bellows it's full range, the large volume of fill fluid's head pressure usually shifts the bellows out of its operating range. Rarely compatible with diaphragm seals.

Lets look at a checklist of questions for choosing the appropriate diaphragm seal.

- **What is the displacement requirement of the instrument selected?** Regardless of the type of instrument, the displacement capability of the diaphragm seal must exceed the displacement requirement of the instrument. Vacuum applications or instruments that are to be in compound service (atmospheric and less than atmospheric pressure) should be reviewed by the diaphragm seal manufacturer.
- **What is the expected accuracy of this diaphragm seal and instrument?** Knowing what is expected from the instrument is essential in defining the specification. The accuracy is typically stated as the greatest inaccuracy allowable as a percentage of full scale indication. The addition of the diaphragm seal may have a compounding effect to the accuracy of the indication. Try to optimize the performance relative to the cost impact.
- **What is the range of process and ambient temperatures?** Choose a fill fluid that will be well within the operating temperature range to avoid vaporizing the fluid and minimize errors. The diaphragm seal manufacturer can provide the thermal coefficient of expansion for various fill fluids. Care should be taken in selecting compatible fill fluids when the process media is considered a strong oxidizer or is reactive with hydrocarbon based silicones. (i.e. oxygen, chlorine, fluorine)
- **What type of piping system is the diaphragm seal to be mounted?** Industrial piping systems can require flanged off-line, threaded off-line, and many styles of in-line process connections. Care should be taken in selecting a diaphragm seal assembly that will maintain or exceed the piping systems maximum working pressure. Sanitary piping systems require

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specialized flange configurations and surface finishes. There are also many non-standard or custom designed configurations available.

- **What is a compatible material of construction?** A wide variety of exotic metal alloys and non-metallics are available. Attention should be given to reduced pressure and temperature limitations of non-metallics. When in doubt, look at the material of the existing piping system or storage vessel. Like materials are usually available as diaphragm seal materials.
- **How is the instrument to be mounted to the Diaphragm Seal?** The diaphragm seal can be mounted directly to the instrument or utilize capillary lines to locate the instrument further away from the process containment. Long lengths (in excess of 20') of capillary line will contribute to inaccuracies and slow response.
- **How and who is going to fill the instrument and diaphragm seal?** Knowledge of high-vacuum technology and filling techniques is imperative to the successful application of a diaphragm seal. An assembly that is 99% filled will never provide acceptable performance.

ACCURACY OF A FILLED SYSTEM

The factors relative to the accuracy of a filled system are:

ΔT temperature change

E_t the volumetric change of the fill fluid relative to temperature

R_s diaphragm spring rate

V_t volume of fluid subjected to a temperature change

An equation for estimating performance of a filled diaphragm seal system:

Error (expressed in inches of H₂O) = $(\Delta T)(E_t)(R_s)(V_t)$

Let's look at a gauge, complete with 5' of capillary line, filled and attached to a diaphragm seal that utilizes a 1.9" diameter diaphragm. We will use the following example to realize the effect of varying the diaphragm diameter.

0-100" psi 4 1/2" process Gauge

5' capillary line attached to high side of transmitter

1.9" diameter diaphragm

200-10cs silicone filled

Ambient temperature 70°F

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Process temperature 240°F

When the diaphragm seal is installed on the process piping, we will assume that one foot from the diaphragm seal the heat from the process has dissipated; therefore, most of the capillary and instrument only sees ambient temperatures. Because the diaphragm seal was filled and calibrated at 70°F the fill fluid will expand and create an internal pressure.

$$\Delta T = (240-70) = 170$$

$$E_t = 0.0006 \text{ (coefficient of expansion of Sil. 200-10cs)}$$

$$R_s = 2600 \text{ (diaphragm spring rate)}$$

$$V_t = 0.187 + 0.053 = .24$$

(Diaphragm seal, 1/4" npt instrument conn. + 1' x 1/8" o.d. x 0.025" wall capillary)

Error (expressed in inches of H₂O) = $(\Delta T)(E_t)(R_s)(V_t)$

$$(170)(0.0006)(2600)(.24) = 63.65 \text{ inches of H}_2\text{O error or 2.3 psi.}$$

By changing to a diaphragm seal that utilizes a 2.4" diameter diaphragm the net result is:

$$(170)(0.0006)(800)(.232) = 18.93 \text{ inches of H}_2\text{O error or 0.68 psi.}$$

Let's assume that the gauge accuracy is $\pm 0.5\%$ of full scale. The filled system accuracy will be compounded by the effect of adding the diaphragm seal and the varying process temperature. These examples will yield an accuracy of $\pm 2.8\%$ and $\pm 1.18\%$ of full scale, respectively. Of course the larger diameter diaphragm is more costly. In this example the cost is 48% higher for the larger diameter diaphragm seal. This is why it is important to know the expected accuracy of the filled system. Either diaphragm seal sizes are considered correctly sized and fully functional in a controlled temperature environment. Economics play a role in determining the more appropriate diaphragm seal.

CONCLUSION

Selecting an appropriate diaphragm seal requires a working knowledge of several disciplines. These are

- An understanding of the operating principal of the pressure instrument
- Knowledge of the operating principal of the diaphragm seal
- Understanding the mechanics of a diaphragm foil
- Familiarity of fluid mechanics, or the hydraulic principals as applied to diaphragm seals
- Familiarity of the industry standard piping and connections
- Knowledge of material compatibility between process media and metal alloys or non-metals
- An understanding of the desired objective from the instrument

While you cannot be expected to be experts in all these disciplines, understanding the basic principles will help in properly applying diaphragm seals. Establishing a network of communication between instrument

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manufacturers, the diaphragm seal manufacturer, yourself, and the end-user will positively affect the success of any diaphragm seal application.

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