

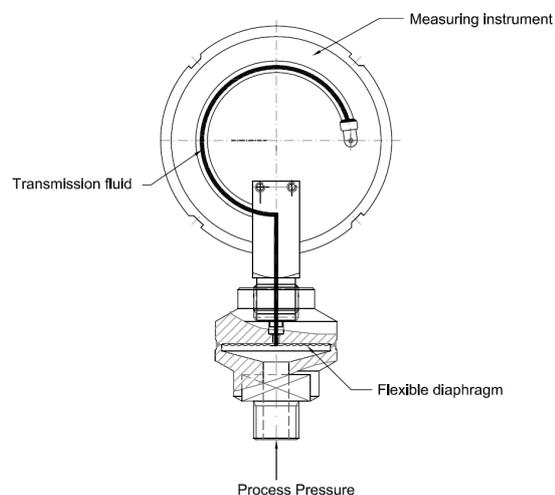
## INTRODUCTION

Modern chemical processing and process manufacturing procedures demand ever greater accuracy and reliability from their pressure, level and flow measuring instruments. This is important to minimise costs, and to keep production downtime and shut downs to an absolute minimum. In various situations it is necessary to isolate and therewith protect the pressure measuring instrument from the process medium in order to maintain the required accuracy and reliability objectives. This isolation or separation of the instrument and the process is typically done by means of Diaphragm Seals, to protect the vulnerable measuring instrument. This protection enhances the lifetime of the measuring instrument significantly.

Before the start of any project related to the pressure, level and flow applications one should understand the possibilities of Diaphragm Seals. Badotherm's expertise and experience are there to ensure that the right solutions are offered to meet the needs from the start and prevent any problems at a later stage. When Diaphragm Seals are needed the material characteristics, operating conditions for the instruments, and choice of mounting should be taken into account.

## OPERATING PRINCIPLE

A Diaphragm Seal System consists of a measuring instrument, typically a pressure transmitter or pressure gauge, with one or two Diaphragm Seals and either a direct mount construction or with capillary lines, filled with a fill fluid. A correctly prepared and filled Diaphragm Seal System will accurately transfer process pressure on the diaphragm to the sensing element of the measuring instrument. This is based on Pascal's principle which states that a pressure exerted on a fluid is transmitted undiminished through that fluid in every direction. The figures presents a schematic overview of this operating principle:



The process pressure exerts a force on the outside face of the seal, the flexible diaphragm. As the diaphragm flexes under this force it pushes inwards and attempts to compress the transmission or fill fluid behind the diaphragm. The transmission fluid is designed to withstand compression so the force is channelled proportionally and directly in to the measuring instrument to produce a resultant reading on the connected instrument.

## WHEN TO USE DIAPHRAGM SEALS

Diaphragm Seals are typically used to protect the measuring instrument. There are many different situations in which a Diaphragm Seal should be typically considered:

- **Corrosive medium:** When the process medium is corrosive it would chemically attack the wetted parts of a standard pressure measuring instrument.
- **Viscous medium:** When the process medium is highly viscous or contains solid particles, either of which could result in the instrument's pressure inlet getting blocked.
- **Solidification:** When the process medium is prone to solidification, crystallization and/or polymerization over time. The medium may freeze when the temperature drops, it may set as it dries, or it may be subject to polymerisation. In these situations the pressure inlet can get blocked.

- **High/low temperatures:** When the process medium temperature is very high or very low and exceeds the temperature limits of the pressure measuring instrument resulting in damaged measurement instruments.
- **Sanitary requirements:** When the process is easily affected by the formation of bacteria on or in the process connection. The presence of bacteria in the process medium can lead to rejection of production batches. These applications where hygiene is of paramount importance are often found in the pharmaceutical, food and beverage industry.
- **Specific process connections:** When the location of the pressure measurement is not suitable for a direct mounting of a pressure measuring instrument. A diaphragm with remote mounting, by means of capillary, ensures easy visual check of the instrument.
- **Replacing 'wet legs':** As a substitution for so-called 'wet legs' for liquid level measurements in pressure retaining tanks.
- **Hydrogen permeation:** Also Diaphragm Seals are used when in the process there is a chance of presence of hydrogen ions (H+) that can permeate the diaphragm. In those cases, a diaphragm seal with gold plating offers the required protection.
- **Mounting effect:** The mounting effect on a Diaphragm Seal System is the variation in the pressure represented by the vertical fill fluid column between the Diaphragm Seal and the instrument, due to the variation of the gravity of the fill fluid as a result of ambient temperature deviation.
- **Zero shift:** The most common application of Diaphragm Seals is a level measurement. Proper ranging of a transmitter for level service requires considering the specific gravity of both the fill fluid and the process fluid, and the transmitter range.
- **Temperature effect:** Changes in volume of the Diaphragm Seal System are referred to as temperature effects. They are caused by changes in volume and density of the fluid in the system and occur when the fill fluid expands or contracts caused by fluctuations of the process and/or ambient temperatures. This change in fill volume drives a change in the internal pressure of the Diaphragm Seal System.
- **Diaphragm characteristics:** The characteristics of the diaphragm itself are important for the performance. In general, a larger diaphragm diameter allows for more flexibility and is more sensible to changes in the volume due to temperature influences. Other diaphragm characteristics as the material, the thickness of the diaphragm as well as the convolution pattern, are an important factor as they all have an effect on the performance of the Diaphragm Seal System.
- **Fill fluid characteristics:** Each fill fluid has its own characteristics, such as density, viscosity, thermal expansion, and vapour pressure. These characteristics are influenced by the systems pressure and temperature and determine the performance of the Diaphragm Seal System. The selection of the fill fluid depends on factors such as temperature, pressure, volume to be displaced (response time) and process safety. Most used fill fluids are silicone oil, glycerin, or vegetable oils. Also special inert fill fluids, such as Halocarbon® for chloride and oxygen applications and other special filling fluids for high temperatures (up to 410 °C) are used.

## PERFORMANCE CONSIDERATIONS

Mounting a Diaphragm Seal to a pressure instrument changes the performance of the instrument. The Diaphragm Seal System will have additional temperature effects and response time depending on the system configuration. The performance of the entire Diaphragm Seal System needs to be evaluated when specifying a new application to ensure satisfactory performance when mounted in process.

- **System volume:** The fill volume in the Diaphragm Seal System needs to be minimized as much as possible. The more volume in the system, the higher the (potential) effect of temperature. For better performance always keep the system volume as small as possible, for instance by keeping capillaries as short as possible. Also it is advised not to use different capillary lengths at HP and LP of a DP measurement.

**BASECAL**

BaseCal is Badotherm's web-based Diaphragm Seal performance calculation software. BaseCal simplifies the proper selection of Diaphragm Seal transmitter combinations. Regardless the application (flow, pressure, level, etc), users can select the Diaphragm Seal System for the needs of the application. The software requests you to fill out the application parameters and will then calculate the correct calibration range. BaseCal considers the following application variables:

- Mounting style
- Differential, absolute or gauge application
- Ambient and process temperature
- Operating and design pressure
- Filling fluid volume, thermal expansion and vapour pressure characteristics
- Diaphragm seal type
- Diaphragm diameter and material
- Capillary length and inside diameter

In BaseCal the Badotherm Diaphragm Seal types can be selected together with the brand and type of transmitter required. BaseCal will calculate the total performance of the diaphragm seal/transmitter combination expressed as TPE (total probable error) and the response time of the system at several temperatures. An account can be obtained at [www.Basecal.com](http://www.Basecal.com).

**INTRODUCTION PRESSURE**

Diaphragm Seals on instruments are used to measure pressure. Pressure can be described as a force applied on a surface. There are different ways of expressing pressures. It can be expressed in kilogramforce per square centimetre (kgf/cm<sup>2</sup>), whereby kgf stands for a force and cm<sup>2</sup> for the surface the pressure is applied on. Same is valid for the commonly used Pounds per Square Inch (PSI). Pressure can also be expressed in various other units and most common are: bar, mbar, kPa and MPa, mmHG = Torr (vacuum measurement), mmH<sub>2</sub>O, inchH<sub>2</sub>O. The pressure that is present on a daily basis is the atmospheric pressure, which averages at 101,325 kPa.

In the industry pressure is typically used to create a chemical or physical reaction. By either raising or reducing the pressure a reaction takes place to obtain the desired result or product. This change to atmospheric pressure can be done by either heating or boiling a gas or fluid, by pumping a gas or fluid, by compressing a gas or by a chemical reaction as a result of mixing several substances. To control this process and to prevent that it runs out of control, these changes to atmospheric pressure need to be measured accurately.

**ABSOLUTE-, GAUGE-, AND DIFFERENTIAL PRESSURE**

Depending on what to measure, three sorts of pressures have been defined. They are differentiated by the zero reference used:

**ABSOLUTE PRESSURE:** is zero referenced against an absolute vacuum, so it is equal to gauge pressure minus atmospheric pressure. In order to make clear that it concerns absolute pressure an 'a' is added to the unit of measure, e.g.: mbara; PSla

**GAUGE PRESSURE:** is zero referenced against atmospheric pressure, so it is equal to absolute pressure plus atmospheric pressure. Negative signs are usually omitted. In order to make clear that it concerns gauge pressure 'g' is added to the unit of pressure, e.g.: mbarg; PSIg

**DIFFERENTIAL PRESSURE:** is the difference in pressure between two values

**DEFINITIONS OF PRESSURE IN PROCESS INDUSTRY**

Within the process industry different nominations of pressures are commonly used. The most relevant pressures for Diaphragm Seal Systems are the design pressure, the maximum working pressure, and the operating pressure.

**MAXIMUM WORKING PRESSURE (MWP):** is the highest pressure a device can withstand without bursting or failure in any way

The MWP is higher than any other pressure that can occur in process.

**DESIGN PRESSURE:** both the lowest and highest pressure that can occur in a given process specification

The minimum/maximum design pressure is reached when the process runs out of control and before the safety devices (e.g. pressure relief valves, rupture discs) come into service. Design pressures need to be taken into consideration during design phase to ensure mechanical integrity of the device when exposed to these design pressures. Proper functioning after exposure to the minimum/maximum design pressure is not required.

**OPERATING PRESSURE:**

- Minimum: the lowest pressure under which the process still runs stable
- Normal: the pressure under which the process runs optimally
- Maximum: the highest pressure under which the process still runs stable

Operating pressures need to be considered to ensure proper functioning of the device as such they are important for selecting the correct diaphragm seal design and fill fluid.

**STATIC PRESSURE:** the pressure at a nominated point in the process

Static pressure is commonly used to avoid ambiguity and to distinguish it from total pressure and dynamic pressure. Static pressure is identical to pressure and can be

either one of the above mentioned nominations of pressure. The static pressure is especially important in case of differential pressure measurement. E.g. pressure at high pressure (HP) side is 100,1 barg; pressure at low pressure (LP) side is 100 barg, then the differential pressure (dP) is 0,1 bar, and the value of the static pressure is 100 bar.

**HYDROSTATIC PRESSURE:** is the pressure exerted by a fluid column due to the force of gravity

With hydrostatic pressure measurement it is possible to measure level in vessels, tanks, reactors etc. This is one of the most common applications for Diaphragm Seals. Also the hydrostatic pressure can be used to measure changes in density.

A proper Diaphragm Seal selection is influenced by the above mentioned pressures of the process. Each diaphragm seal type has limitations according its construction or body material. For flanged connections an addendum is provided showing the maximum and minimum pressure/temperature ratings. Both flanged and threaded process connections have standard restrictions in withstanding pressure (EN1092-1, ASME B16.5, ANSI B1.20.1, ISO7005-1, ISO228-2, ISO10423, JIS B2220). The construction of the Diaphragm Seal however can also be a restrictive factor and is specified on the data sheets as the maximum working pressure of the specific Diaphragm Seal.

## VACUUM

Care should be taken when specifying a Diaphragm Seal System for measuring with process pressure under vacuum.

**FULL VACUUM:** the absence of matter

While the Diaphragm Seals perform normally for most standard vacuum applications, as the pressure moves closer to a full vacuum acceptable reliability becomes more difficult to achieve. This is due to the fact that most fill fluids contain microscopic amounts of air or trapped gases, which tend to expand significantly as a pressure of absolute zero is approached. This expansion undermines one of the most important component factors of a seal system, that of absolutely constant fill fluid volume at any pressure. In order to overcome this

potential problem, the Badotherm filling technology allows for a complete degassing of the fill fluid, at a pressure of  $< 1 \cdot 10^{-8}$  mbara in combination with the correct heating of the applied fill fluid.

Also, under vacuum process conditions, there is a potential risk that through a gasket or thread air is sucked in the system, with all possible consequences for the functioning of the Diaphragm Seal System. With Badotherm's full welded construction the measuring element has no gasket anymore to avoid any kind of leakage. Often vacuum occurs unintentionally for example during cleaning and fast cooling processes. To cover this often unknown and unaware presence of vacuum all Badotherm Diaphragm Seals are standard tested at 35 mbara even when no vacuum value is specified.

The presence of vacuum in process is a very important factor when selecting the Diaphragm Seal fill fluid and mounting the instrument. The relation between the vacuum value and the process temperature should be checked in the vapour pressure curves of the fill fluid to see if the fill fluid is suitable. When mounting the instrument for a vacuum application, the instrument should be placed below the (lowest) Diaphragm Seal to protect the instrument.

## DIAPHRAGM SEAL PRESSURE SPECIFICATIONS

The size of the diaphragm defines the minimum pressure range that the Diaphragm Seal can handle. Apart from the diameter, the flexibility of the diaphragm is also related to the shape and number of convolutions, the material, and its thickness. Badotherm diaphragms have standard thickness of 75  $\mu\text{m}$ . The dD dimensions mentioned are values for the active diameters of the diaphragms i.e. the outside diameter of the outer convolution. Badotherm Diaphragm Seals have a maximum static pressure effect of 0,25% of calibrated DP span on top of the standard differential pressure transmitter specifications with regard to static pressure effects. In general the total effect is  $< 0,5\%$  of calibrated DP span.

The following table presents an overview of the diaphragm size and the related pressure characteristics:

MINIMUM PRESSURE RANGE OR SPAN

	DP transmitter (mbar)			GP/AP transmitter (mbar)				Pressure gauge (bar)						BDT13 (mbar)
	1m	5m	15m	Direct	1m	5m	15m	63mm		100mm		160mm		
Diaphragm size								Direct	5m	Direct	5m	Direct	5m	
17mm	-	-	-	100 bar	-	-	-	100	-	-	-	-	-	-
20mm	-	-	-	50 bar	-	-	-	100	100	-	-	-	-	-
23mm	-	-	-	4 bar	5 bar	6 bar	10 bar	6	25	-	-	-	-	-
32mm	-	-	-	2 bar	2.5 bar	3 bar	4 bar	2.5	10	25	25	100	100	-
44mm	200	400	400	1200	1500	1800	2100	1.6	6	2.5	4	4	25	-
51mm	100	200	200	800	1000	1200	1400	1	1.6	1.6	2.5	2.5	4	-
57mm	50	100	100	600	750	900	1050	0.6	1	1	1.6	1.6	2.5	-
72mm	25	50	50	200	250	300	350	0.6	0.6	0.6	0.6	0.6	0.6	-
81mm	10	20	20	80	100	120	140	0.6	0.6	0.6	0.6	0.6	0.6	100

Notes:

- Minimum pressure ranges are only related to the diaphragm sizes. The pressure range of the transmitter or pressure gauge, and the capillary diameter should be adjusted accordingly.
- DP, GP & AP transmitter sensor diaphragm should be equal or smaller than seal diaphragm size.
- DP transmitter values applicable for double sided diaphragm seals.
- Pressure gauge dimensions refer to the internal size.

Testing variables:

- AISI 316(L) diaphragm material.
- Transmitter volume is average of various transmitters brands.
- Reference temperature 20°C.
- Capillary inside diameter 2mm (1mm for pressure gauges).
- Fill fluid BSO-22.

MAXIMUM PRESSURE

	DP transmitter (mbar)	GP/AP transmitter (mbar)	Pressure gauge (bar)						BDT13 (bar)
			63mm		100mm		160mm		
Diaphragm size			Direct	5m	Direct	5m	Direct	5m	
17mm	Limited to instrument or Diaphragm Seal pressure rating	Limited to instrument or Diaphragm Seal pressure rating	700	140	-	-	-	-	-
20mm			1000	250	-	-	-	-	-
23mm			1600	400	-	-	-	-	-
32mm			1600	1400	1400	540	1000	340	-
44mm			1600	1600	1600	1600	1400	1400	-
51mm			1600	1600	1600	1600	1600	1600	-
57mm			1600	1600	1600	1600	1600	1600	-
72mm			1600	1600	1600	1600	1600	1600	-
81mm			1600	1600	1600	1600	1600	1600	25

Notes:

- Maximum pressure ranges are only related to the diaphragm sizes. The pressure range of the transmitter or pressure gauge, flange rating and the capillary diameter should be adjusted accordingly.
- Pressure gauge dimensions refer to the internal size.

Testing variables:

- AISI 316(L) diaphragm material.
- Reference temperature 20°C.
- Capillary inside diameter 1mm.
- Fill fluid BSO-22.

**INTRODUCTION TEMPERATURE**

Temperature expresses the average energy of motion of particles in matter. A good explanation can be made with water: when water is solid (ice) the particles (H<sub>2</sub>O molecules) are not in motion and the temperature is thus low (cold). When fluid the H<sub>2</sub>O molecules move faster and the temperature becomes higher. When the H<sub>2</sub>O molecules move that fast that they release themselves from the fluid, steam is formed and the temperature is high. The motion of particles in matter is also influenced by the pressure exerted on the matter. In the example, water boils at 100°C at atmospheric pressure (101,325 kPa); at absolute vacuum it boils at 0°C. This combined effect of pressure and temperature exists for all fluids and is as such a predominant factor for the selection of the Diaphragm Seal fill fluid.

The common units of measure for temperature are: Kelvin, Celsius, and Fahrenheit. The relation between these units is presented in the table below:

	Celsius	Kelvin	Fahrenheit
Celsius	-	$K=C + 273.15$	$F=Cx1.8+32$
Kelvin	$C=K-273.15$	-	$F=Kx1.8-459.67$
Fahrenheit	$C=(F-32)/1.8$	$K=(F+459.67)/1.8$	-

**DEFINITIONS OF TEMPERATURE IN PROCESS**

**INDUSTRY**

Within the process industry, several temperatures are defined:

**AMBIENT TEMPERATURE:** is the temperature of the surroundings

When a Diaphragm Seal System is situated outdoors, the ambient temperature can become a very important factor for the functionality of the Diaphragm Seal System. Ambient temperatures can range from extremely high (>60°C e.g. in desert sun) to low (<-40°C, e.g. off-shore wind). Ambient temperatures should be specified with a minimum and maximum value, e.g. -10/+35°C would be a general specification for the Netherlands.

Similar to process pressures, process temperatures are specified with following denominations:

**DESIGN TEMPERATURE:** both the lowest and highest temperature that can occur in a given process specification

The design temperature is reached when the process runs out of control. Design temperatures need to be taken into consideration during design phase to ensure mechanical integrity of the device when exposed to these design temperatures. Proper functioning after this exposure is not required.

**OPERATING TEMPERATURE:**

- Minimum: the lowest temperature under which the process still runs stable
- Normal: the temperature under which the process runs optimally
- Maximum: the highest temperature under which the process still runs stable

Operating temperatures need to be considered to ensure proper functioning of the device and as such they are important to select the correct Diaphragm Seal design and fill fluid. The device will operate effectively within a specified operating temperature range which varies based on the device function and application context, and ranges from the minimum operating temperature to the maximum operating temperature (or peak operating temperature). Outside of this range, the device may fail. Each Diaphragm Seal has limitations according its construction or base material. For the flange connection a guide is provided, showing the maximum and minimum temperature ratings. This guide also details limitations on the flanges concerning at what pressure they can be used at specific temperatures. The maximum operating temperature is limited by the sealed system component with the lowest maximum temperature. The limiting component may be, but is not limited to, any one of the following: housing material, diaphragm material, gasket or o-ring material, or fill fluid.

**TEMPERATURE EFFECTS**

Changes in the volume of the Diaphragm Seal System can be caused by changes in volume and density of the fluid in the system and occur when the fill fluid expands or contracts due to fluctuations of the process and/or ambient temperatures. This change in fill volume drives

a change in the internal pressure of the Diaphragm Seal System. This is called the temperature effect.

There are 3 different influences that can be distinguished:

- **Process temperature:** the process temperature has effect on the Diaphragm Seal system and influences, in combination with the lowest process pressure, the selection of the fill fluid.
- **Ambient temperature:** Differences in ambient temperature have an effect on the viscosity and on the density of the fill fluid. The change in viscosity has a direct effect on the response time of the Diaphragm Seal System. The change in density creates a mounting effect in case of a vertical height difference which results in a zero-point deviation of the Diaphragm Seal System.
- **Delta T in DP measurement:** Temperature effects can cause a difference in density or viscosity between the HP side and LP side of the Diaphragm Seal System.

**CALCULATED TEMPERATURE EFFECTS**

The Diaphragm Seal System’s volume consists of three components: Diaphragm Seal chamber volume, capillary volume, and the pressure instrument volume. The table below presents the temperature effect in mbar for each of the components. The values for each component in the table need to be added to arrive at the total temperature effect for the Diaphragm Seal System.

**DP transmitter with two Diaphragm Seals**

Diaphragm Size	Transmitter (mbar)	Seal (mbar)	Capillary (mbar/mtr)
44mm	0.62	0.91	1.62
51mm	0.10	0.76	1.19
57mm	0.02	0.24	0.41
72mm	0.01	0.11	0.12
81mm	0.01	0.08	0.07

Temperature effect per 10°C

**GP/AP transmitter with Diaphragm Seal**

Diaphragm Size	Transmitter (mbar)	Seal (mbar)	Capillary (mbar/mtr)
17mm	300	300	1600
20mm	150	150	800
23mm	85	84	409
32mm	20	17	17
44mm	3.11	4.56	8.10
51mm	0.52	3.79	5.95
57mm	0.12	1.22	2.04
72mm	0.03	0.53	0.62
81mm	0.02	0.39	0.35
LGP	0.02	0.09	0.03

Temperature effect per 10°C

**Pressure Gauge with Diaphragm Seal below 60 bar**

Diaphragm size	Pressure Gauge (mbar)			Seal (mbar)	Capillary (mbar/mtr)
	63mm	100mm	160mm		
32mm	63	256	-	17	17
44mm	13	52	90	4.6	8.1
57mm	4.0	15	25	3.8	2.0
72mm	1.0	4.0	8.0	0.5	0.6
81mm	0.4	2.0	3.0	0.4	0.4

Temperature effect per 10°C

**Pressure Gauge with Diaphragm Seal above 60 bar**

Diaphragm size	Pressure Gauge (mbar)			Seal (mbar)	Capillary (mbar/mtr)
	63mm	100mm	160mm		
32mm	32	128	-	17	70
44mm	6.5	26	45	4.6	8.1
57mm	2.0	7.5	13	3.8	2.0
72mm	0.5	2.0	8.0	0.5	0.6
81mm	0.2	1.0	3.0	0.4	0.4

Temperature effect per 10°C

Testing variables:

- Reference temperature 20°C
- Inside capillary diameter 2mm
- Diaphragm stainless steel AISI 316(L)
- Filling fluid is BSO-22
- Transmitter volume is an average of various transmitters brands
- Diaphragm Seal and instrument are at same height

**EXAMPLE CALCULATION:**

DP transmitter with two 3” seals (81mm diaphragm) and 5 meter capillary.

- Transmitter: 0.01 mbar
- Seal: 0.08 mbar
- Capillary: 0.35 mbar (5x0.07)
- **Worst case effect: 0.44 mbar / 10°C**

**MINIMISING TEMPERATURE EFFECTS**

Temperature effects can be minimised by using the following techniques:

- **Reduce the volume of the application:** This can be done with reducing the capillary internal diameter (ID). However, reducing the capillary ID increases the response time for the application and in this a balance needs to be found. Badotherm standardly uses 2mm as inside diameter of the capillary. Switching to capillary with ID of 1 mm will increase the response time with a factor 16. Capillary with 1mm inside diameter is advised for gauge pressure applications with a range above 100 barg. It is also important to minimise the volume of fill fluid contained in the pressure instrument to a minimum. This can be done by replacing the standard process covers of a transmitter by special designed low volume covers, or to use pressure gauge with a reduced volume.
- **Specify the shortest possible capillary lengths for the application:** it is understandable that for interchangeable reasons the capillary lengths for all LT tags in a project are specified with the same length. It is advised that capillary lengths should be calculated on a tag by tag basis to define the shortest possible length for each tag. Too long capillaries will result in unacceptable response times and/or too high temperature influences with all consequences for the reliability of the measurement.
- **Cold temperature application:** there are processes where, due to a system of both low ambient and process temperatures, the contraction of fill fluid is as such that the diaphragm runs against the diaphragm chamber and transfer of pressure is no longer possible. A solution for these situations is a so-called 'supplementary fill' which allows for pressure transfer even when the fill fluid heavily contracts.
- **Insulation of Diaphragm Seal System:** in cases where both capillaries and Diaphragm Seals are exposed to severe outdoor conditions, insulating them will reduce ambient temperature effects considerably. Also in those cases where the capillary of one leg of a DP system is in the sun and the other leg in the shadow insulating them will result in the same or similar ambient temperature at both legs and minimises ambient temperature effects.
- **Tracing of capillaries:** this will reduce ambient temperature effects close to zero. Often tracing is considered expensive and requires intensive maintenance. However, a new development is that Badotherm is working together with O'Brien to include the product Tracepak around capillary lines already at the time of assembly of the Diaphragm Seal system.
- **High temperature process and temperature reducers:** in those processes with high temperatures (> 200°C) and where distant mounting by means of capillary is not possible, a temperature reducer (TR) can be foreseen between instrument and Diaphragm Seal. A temperature reducer reduces process temperatures to a value < 100°C at the instrument side.
- **Temperature compensator:** when the specifications of the process prescribe the use of a fill fluid with high viscosity this might result in unacceptable response times. A temperature compensator (TC) is developed to overcome this problem. By using the high viscous fill fluid in the part between seal diaphragm and TC, the fluid keeps a relative high temperature resulting in a low viscosity; after the TC a standard fill fluid with low viscosity is used resulting in an acceptable overall response time.
- **Process simulation:** Badotherm offers the possibility of a full process simulation. The Diaphragm Seal System is simultaneously subjected to: process temperature, ambient temperature, and static process pressure. Their respective influences on the calibrated (DP) span are recorded. This results in a fingerprint for this specific Diaphragm Seal System and the influences can be incorporated into the DCS to compensate for the effects. The result is a pressure (level) measurement with enhanced accuracy.
- **LGP solution:** is designed for Low Gauge Pressure measurement and eliminates temperature and mounting influences. Test results obtained by measuring low gauge pressures with a standard Diaphragm Seal and with the LGP, showed that the minimum range reduces from 80 mbar for a standard seal to only 10 mbar with the LGP. Similarly the ambient temperature effect reduces from 0.4 mbar per 10°C to 0.03 mbar, while the process temperature effect reduces from 0.39 to 0.09 mbar.

**INTRODUCTION MOUNTING**

Instruments with Diaphragm Seals can be mounted in various positions. In a differential pressure measurement the instrument can be mounted between the nozzles, but the instrument can also be mounted above the highest or below the lowest nozzle. Also in a gauge pressure measurement the instrument can be mounted in various positions compared to the Diaphragm Seal.

The mounting of the instrument is important to ensure the best possible measurement in the given circumstances. The specific gravity of the vertical fill fluid column between the instrument and the Diaphragm Seal is influenced by the ambient temperature deviation. These influences create a pressure variation within the Diaphragm Seal System. This is called the mounting effect.

**SHIFT IN ZERO POINT**

When the exact mounting details of the transmitter and the Diaphragm Seal are not known at calibration, the span is set from zero to the required value (e.g. 0-400 mbar). When mounting the Diaphragm Seal System in the field, the zero can shift depending on how it is mounted. This is caused by the gravity effect after installation. This shift can be zero suppression or zero elevation.

**ZERO SUPPRESSION:**  
the factory calibrated zero is shifted above zero after installation (e.g. 150 + 550 mbar)

**ZERO ELEVATION:**  
the factory calibrated zero is shifted below zero after installation (e.g. -390 + 10 mbar)

The shift in zero point can be calculated with the density of the Badotherm fill fluid, the height difference of the installed application, and the gravity. The shift in zero point is important to know prior to installation because the shift must remain within the limits of the transmitter range. If the zero shift is outside the limits of the transmitter range, the transmitter will fail to measure.

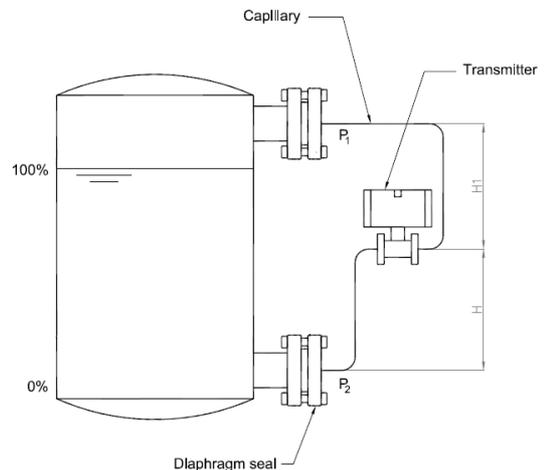
*Badotherm Diaphragm Seals have a minimum working pressure of 1 mbara, depending on the filling fluid. Please consider the minimum static or working pressure of the pressure instrument that is mentioned in the brand specific documentation.*

**DIFFERENTIAL PRESSURE APPLICATIONS**

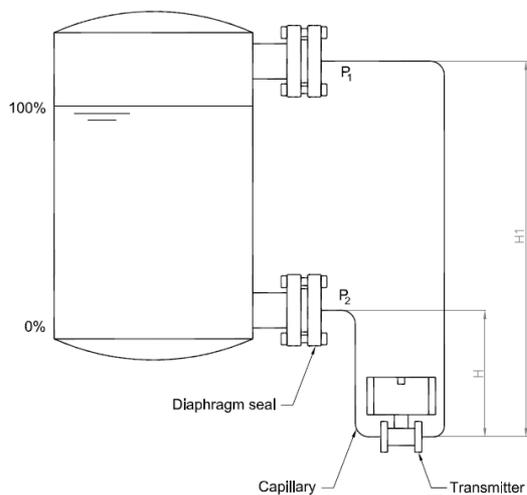
Differential pressure applications can be used for various purposes: differential pressure, level, flow, density, and interface measurements. There are three different mounting styles for level to be recognised, depending on the position of the instrument compared to the Diaphragm Seal.

- **DP STYLE 1:** instrument between the Diaphragm Seals
- **DP STYLE 2:** instrument below the Diaphragm Seals
- **DP STYLE 3:** instrument above the Diaphragm Seals

**DP Style 1: instrument between the Diaphragm Seals**



**DP Style 2: instrument below the Diaphragm Seals**

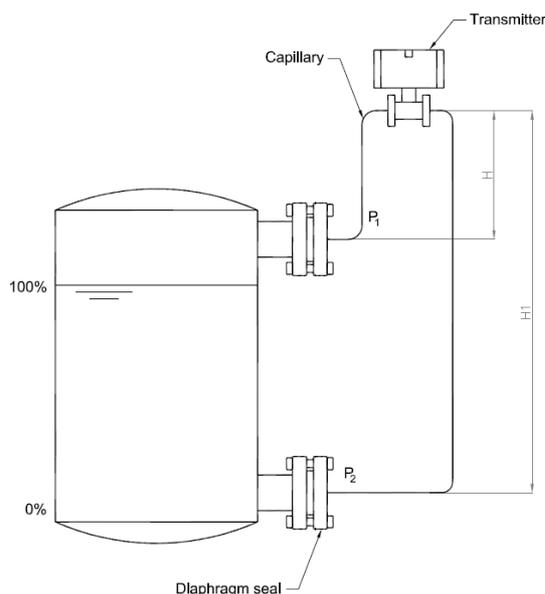


- Ease of installation
- Accessibility of the instrument: reading of local display and maintenance
- Obstacles that do not allow to place the instrument elsewhere

However, the process conditions should be considered first whilst selecting one of the mounting styles. The following example illustrates this.

Suppose DP Style 3 has been selected because the vessel is positioned below the walking grid ( $H_1=360\text{cm}$ ). The fill fluid (density  $1,020\text{ kg/m}^3$ ) column in the capillary that connects the lowest seal ( $P_2$ ) with the DP instrument, represents a pressure of ( $p=h*\rho*g$ ):  $0,360*1,020*9.81 = 360,2\text{ mbar}$ . This hydrostatic pressure is sensed at the DP instrument as a negative pressure,  $-360,2\text{ mbar}$ . When in this application the minimum operating pressure is as low as  $-800\text{ mbar}$  ( $200\text{ mbar}$ ), the selected mounting by style 3 will damage the Diaphragm Seal System:  $-360,2 - 800\text{ mbar} = -1160,2\text{ mbar}$ . This implies a pressure below absolute zero which is impossible. This will either damage the diaphragm of the seal or the diaphragm of the DP instrument. Also, the fill fluid can be damaged because it is pushed over the limits of its vapour pressure.

**DP Style 3: instrument above the Diaphragm Seals**



In this example DP Style 2 would have been the better option. The transmitter is then placed below the vessel ( $H=160\text{CM}$ ) and the hydrostatic pressure is then:  $0,160*1,020*9.81 = 160,1\text{ mbar}$ . This is sensed at the DP instrument as a positive pressure  $+160,1\text{ mbar}$ . With the minimum operating pressure of  $-800\text{ mbar}$ , it would result in a pressure at the instrument of  $-800 + 160,1 = -639,9\text{ mbar}$ . This is well above absolute zero, and thus the instrument and Diaphragm Seal System will function properly.

Each style has specific advantages, limitations, and considerations that should be taken into account. DP Styles 1 and 3 only allows limited vacuum and DP Style 2 allows for full vacuum ( $1\text{mbara}$ ), when 'H' is at least  $50\text{ cm}$ . The selection of one of the above indicated mounting styles is often driven by:

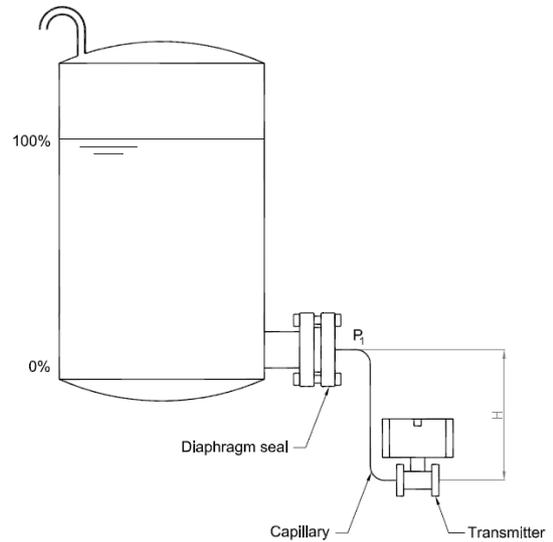
**GAUGE PRESSURE APPLICATIONS**

Gauge pressure applications can be used for pressure, level, and density measurement. Also for this application there are three different styles to be recognised depending on the position of the instrument compared to the Diaphragm Seal.

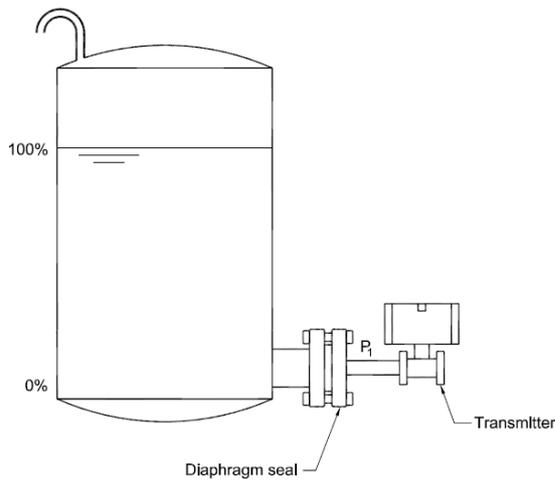
- **GP STYLE 1:** instrument equal to the Diaphragm Seal
- **GP STYLE 2:** instrument below the Diaphragm Seal
- **GP STYLE 3:** instrument above the Diaphragm Seal

The effect of the mounting on a GP instrument is similar as described for the DP instrument. When an instrument is placed above the seal, it will sense this as a negative pressure and that pressure, in combination with the minimum operating pressure, should not exceed a value below absolute zero. The Diaphragm Seal System would be damaged in a similar way as described for DP applications.

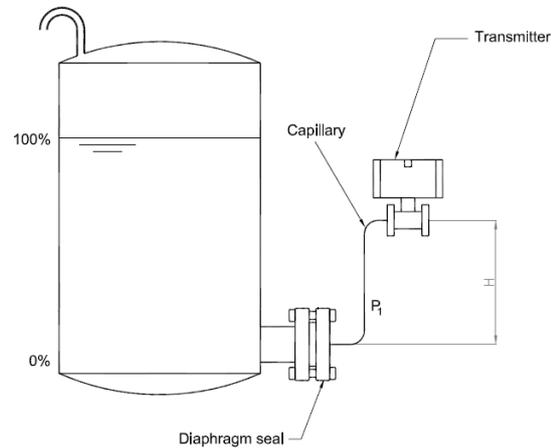
**GP Style 2: instrument below the Diaphragm Seal**



**GP Style 1: instrument equal to the Diaphragm Seal**



**GP Style 3: instrument above the Diaphragm Seal**



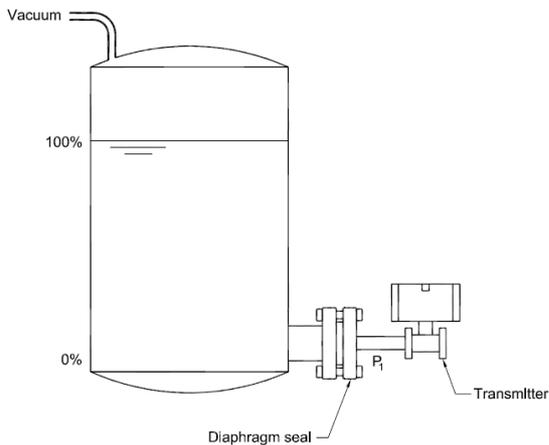
**ABSOLUTE PRESSURE APPLICATIONS**

Absolute pressure applications are only used to measure pressure. For this application there can be also three different styles recognised depending on the position of the instrument compared to the Diaphragm Seal.

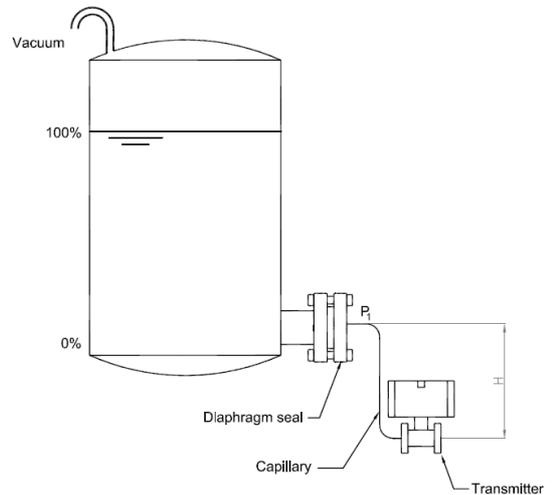
- **AP STYLE 1:** instrument equal to the Diaphragm Seal
- **AP STYLE 2:** instrument below the Diaphragm Seal
- **AP STYLE 3:** instrument above the Diaphragm Seal

For absolute pressure measurement the instrument should be mounted below the diaphragm seal in order to protect the instrument at all possible conditions. This is presented in AP Style 2. If for example  $H=50\text{cm}$  the pressure on the instrument is already above 50 mbar. With this mounting style the instrument has additional protection before it reaches absolute zero. AP Style 1 is also possible, but not preferred as there is no additional protection so it is possible to reach the absolute zero and damage the application.

**AP Style 1: instrument equal to the Diaphragm Seal**

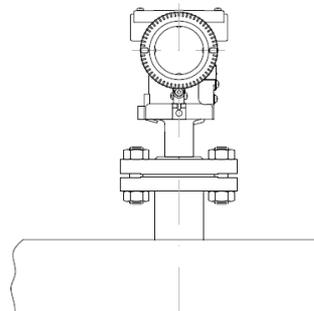


**AP Style 2: instrument below to the Diaphragm Seal**



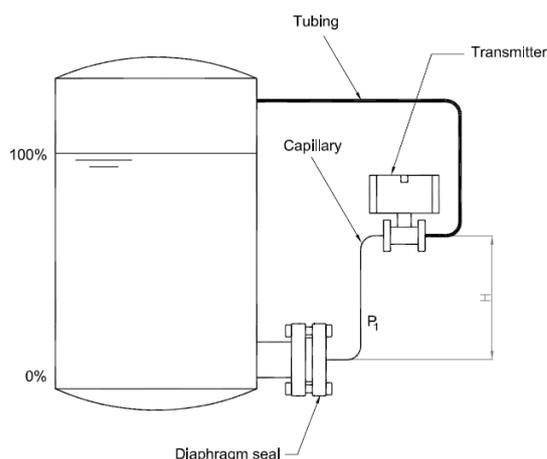
Mounting the instrument above the Diaphragm Seal (AP Style 3) will damage the Diaphragm Seal System in a similar way as described under DP applications. Care should also be taken, when an instrument is direct mounted on the Diaphragm Seal and installed as shown in AP Style 3. As a standard, Badotherm uses a distance tube of 80 mm. With a silicon BSO fill fluid, this will create a negative pressure of approximately 8 mbar at the pressure sensor. When the absolute pressure runs below 8 mbara, the Diaphragm Seal or instrument will be damaged.

**AP Style 3: instrument above to the Diaphragm Seal**



### DIAPHRAGM SEALS AND WET LEGS

A wet leg is made with tubing mounted directly to the transmitter and is filled with process medium. Diaphragm Seal Systems offer significant installation flexibility and maintenance advantages over wet leg systems. Diaphragm Seals make it easier to maintain the fluid between the tap and the transmitter, especially on the reference or low pressure side. In vacuum systems, a closed seal system, rather than an open wet leg, maintains a constant height for the low side reference. The Diaphragm Seal System does not need to be refilled or drained. They are also not vulnerable to plugging or freezing and they are easier to control than wet leg systems.



### BALANCED SYSTEM

A balanced system means that the volume of the Diaphragm Seal System is equal at the HP and LP side of the DP measurement. This can be obtained by ensuring that the fill volume in the Diaphragm Seal and the capillary lengths are similar at both sides. An unbalanced system can be equipped with two different sized diaphragms and/or with using two different lengths of capillary. This results in a larger volume of fill fluid on one side compared to the other side.

A balanced Diaphragm Seal System is preferred above an unbalanced system because it reduces or avoids the effect mentioned next:

- **Ambient temperature effects:** as a result of ambient temperature changes balanced systems will have equal expansion and/or contraction of fill fluid. As both sides are equal the effect on the DP transmitter will be zero or close to zero. Unbalanced systems have a different expansion and/or contraction of fill fluid on either side due to ambient temperature changes. This results in a different pressure build up (expansion) or drop (contraction) which negatively influences the accuracy of the overall measurement.
- **Process temperatures effects:** For applications with an elevated process temperature (>65°C) the effect of an unbalanced system can be considerable. For example there is an unbalanced system with a direct mounted Diaphragm Seal to the HP side and a capillary mounted to the LP side. The heat transfer from the process temperature to the direct mount on the HP side of the instrument will be higher than to capillary mount on the LP side of instrument. This results in a different pressure build up (expansion) which negatively influences the accuracy of the overall measurement.
- **Static pressure effects:** In case of fluctuating static pressures unbalanced systems can become unstable because the static pressure will be transferred faster to the side with the lowest volume.

### REDUCTION OF MEASUREMENT ERRORS

There are different ways to minimise the measurement errors of the Diaphragm Seal System:

- Keep capillary lengths as short as possible
- Use capillaries of the same length on both taps when measuring differential pressure
- Use diaphragms with the same diameter
- Never mount seals and capillaries in direct sunlight
- Ensure that both capillaries experience the same temperature. For instance, avoid installing one capillary in a shady area and the other in the sun



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