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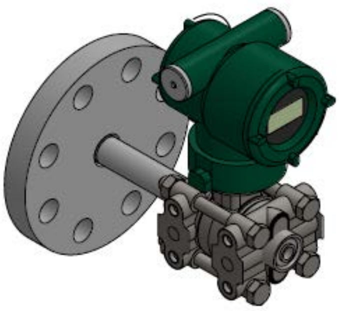
Points of Attention for Applying Pressure measurements with Diaphragm Seals in Urea Plants

Introduction

This document summarizes the points of attention when applying pressure measurements with pressure transmitter assembled with diaphragm seals in urea plants. Its content is based on evaluating several troubleshoot cases in the industry.

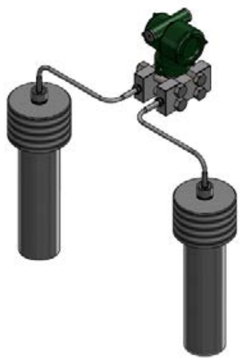
Pressure measurements with diaphragm seals is considered a very robust measurement solution to protect the pressure instrument from the often harsh process conditions. However, the diaphragm seal system needs to be engineered and installed properly. Firstly, this means selecting the best suitable diaphragm seal type and diaphragm size, suitable filling fluid to match temperature and withstand possible vacuum and the suitable material of the wetted parts of the diaphragm seal, which is best compatible / corrosion resistant with the process. Some transmitter manufacturers do offer sizing calculation reports. There is one company that provides online diaphragm seal sizing and selection tool, that helps you understand the impact of diaphragm seal type selection in combination with process conditions and installation and provides a total probably error of the total system. This software is available at www.basecal.com, power by Badotherm, one of the leading diaphragm seal manufactures in the world.

The operating principle of diaphragm seals is based on a hydraulic principle, typically consisting of a measuring instrument, 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 filling fluid.



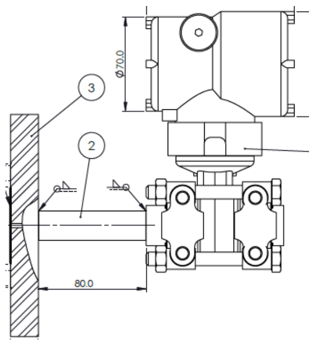
Example of direct mount

Example of pressure gauge (GP) with capillary mount



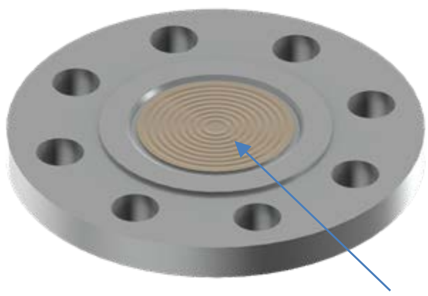
Example of delta-P with capillary mount

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 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 filling fluid behind the diaphragm. The transmission fluid is designed to withstand compression so the force is channeled proportionally and directly in to the measuring instrument to produce a resultant reading on the connected instrument.

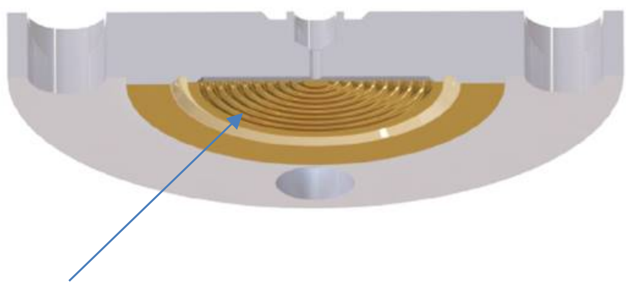


Schematic of a direct mount

The flexible diaphragm is a thin foil which is shaped in such a way that is very sensible to transmit the pressure as accurate as possible. The thickness can vary between 75 up to 150 micron, depending on the material. This is then also the weakest point of the diaphragm seal system. Corrosion rates have a strong effect on such a thin diaphragm.



Example of a blind flange seal with the diaphragm welded to the flange. Diaphragm has special convolution to transmit the pressure and has a thickness of 75-150 micron.



Example of a blind flange cut through to understand diaphragm thickness and diaphragm seal chamber for minimal filling fluid, tailored to the application and specifications. Both pictures relate to gold coating on diaphragm and seal.

Engineering – material selection recommendations

Best materials for diaphragm seals

The best material for the diaphragm seal in the high pressure synthesis section has proven to be zirconium. Best means here the lowest corrosion rates and proven to achieve the higher reliability / longest lifetime. One BADOTHERM zirconium reference is already nearly 4 years in operation (as per November 2018) under the most severe process conditions without any problems. Zirconium does not experience passive or active corrosion rates.
Second best material will be a super-duplex material like Safurex®, DP28W™ or Uremium29™, although one must realize that these materials experience still passive

corrosion rates. As a third best option 25-22-2 stainless steel is an option but this material shows passive and active corrosion due to for example condensation corrosion and thus proper tracing and insulation is important.
For the other sections than the high pressure synthesis section, the best material is 25-22-2 stainless steel. Alternatives are (super-)duplex materials. The passive corrosion rates under these temperatures are very low to assure long lifetime.
Tantalum in principle also is a good material with a low corrosion rate but the weld of the tantalum diaphragm to the body has proven to be a weak point.

Avoid dissimilar welds

Dissimilar welds are sensitive for higher corrosion rates when exposed to liquid ammonium carbamate. Best practice is to apply the same material for the diaphragm as well as for the body. Dissimilar welds are also related to the diaphragm seal type selection.

Extension length

The extension length should be less than the nozzle length so that the thin diaphragm is not exposed to the flow in the main pipe. The flow may contain small solids (i.e. chromium- and iron-oxides solids in liquid streams and liquid droplets with high velocities in gas streams), which may damage the diaphragm. A PTFE coating to protect the diaphragm is sometimes applied.

Flush streams

Flush streams should not be directed in the direction of the diaphragms to avoid any damage.

Take into account transmission / filling fluid specifications and characteristics

A bulged diaphragm can be caused by various factors, for example:

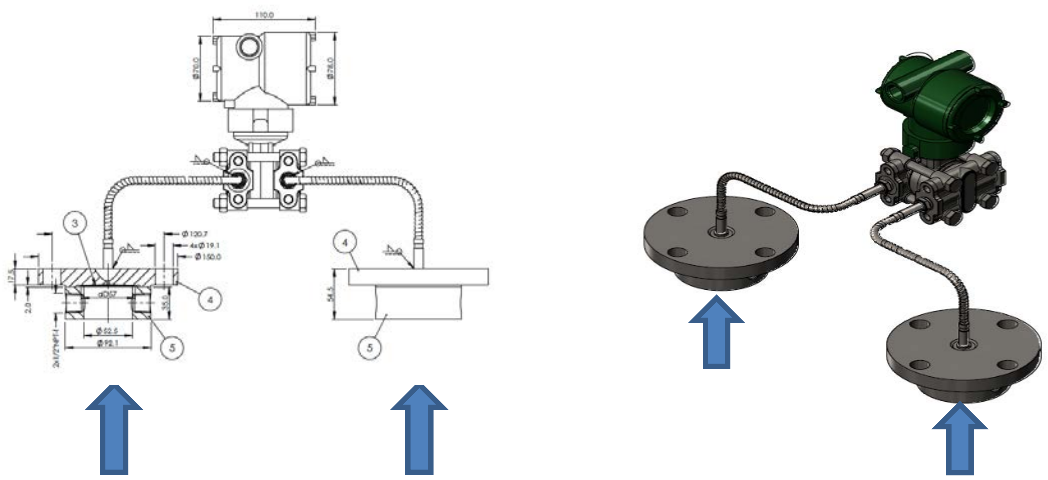
- No proper filling up the back side of diaphragm with filling fluid
- Overheating (cooking of filling fluid)
- Creating vacuum (close to vacuum) pressure at relatively high temperatures (i.e. flushing out conditions) leading to conditions below vapor pressure curve of the filling fluid. Apply / specify a filling fluid which does not evaporate / dissociate / vaporize at the maximum operating temperatures. Also take into account the possible temperatures during start-up (heating up with steam) and shut-down (flushing out) conditions
- Pressure fluctuations on process side during flushing out conditions
- During shutting down the urea plant the synthesis pressure will reduce from 140-150 bars to nearly atmospheric pressure. The synthesis will be filled up with a gaseous mixture of NH_3 and CO_2. When one applies a water flush the NH_3 will absorb in the water, which will result in a sudden pressure decrease together with a temperature rise. Under these conditions one can imagine that the diaphragm bulges and on the filling fluid side the

filling fluid experiences low pressure and high temperatures leading to a possible evaporation / dissociation / vaporization of the filling fluid.

Installation recommendations

General recommendations with regards to diaphragm seals are:

- Keep capillary lengths as short as possible
- Never mount seals and capillaries in direct sunlight
- Respect the bent-radius of capillary
- Leave diaphragm protect on the seal as long as possible and prevent any damage to the diaphragm
- Use capillaries of the same length on both taps when measuring differential pressure



An example of a delta-P measurement (note the same length capillaries)

- Keep diaphragm sizes equal to both sides
- Be sure that both capillaries experience the same temperature. For instance, avoid installing one capillary in a shady area and the other in the sun. This eliminates zero shifts that results from unequal thermal expansion and contraction of the fill fluid in the high and low legs

Specifically for urea plants to following additional recommendations are:

Clean diaphragms before installation

Avoid touching the thin diaphragms as much as possible and clean (degrease) the thin diaphragms before installation to avoid / reduce any corrosion issues. In case on the thin diaphragm fouling occurs, ammonium carbamate may be into contact with the metal

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diaphragm without the presence of any oxygen. In case the material is an austenitic stainless steel, active corrosion will occur with locally high corrosion rates (for example 50 mm per year). In case of zirconium hydrogen atoms, which form when no oxygen is present, will brittle the zirconium.

Be careful when installing the diaphragm

Install the diaphragm seals very carefully to avoid that the thin diaphragm touches any bolts or other piping parts.
Install the diaphragm with utmost care and let the job done only by specialists or people who are aware of the damage risks.

Trace and insulate diaphragm seals located in the gas phase

When gaseous ammonium carbamate (NH_3 and CO_2) are able to condense on cold spots, liquid ammonium carbamate will form with a low oxygen level. Ammonium carbamate with a low oxygen level shows high corrosion rates with most stainless steels and normal duplex steels. The temperature of the diaphragm seal should be higher than the condensation temperature of the ammonium carbamate vapors, which can be as high as 170-180 °C. Proper medium pressure steam or electrical heat tracing is thus required.

An example of proper tracing and insulation of a diaphragm

Inspection recommendations

When inspecting the diaphragm seal perform first a visual inspection by using a magnifying glass or microscope and inspect especially the weld area.
Visual inspection of diaphragm should include: no dents, deformation, scratches, discoloration, burrs or anything on the diaphragm or on the weld.

See above examples of a diaphragm with dents. Second picture is a typical example of a bulged diaphragm

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Check for no bulging, but flat diaphragm. A strong discoloration and stiff diaphragm (no longer flexible) could indicate the measurement is no longer reliable.
When visual inspection is positive, you could perform a dye penetrant test to test the weld and see any cavities.

Dye penetrant test of diaphragms

Colors in urea plants are typically a result of passive corrosion of ammonium carbamate: Blue color in the gas phase and brown / grey color in the liquid phase. These signs of passive corrosion does not harm the measurement.
Blueish color can also be a result of a welding or heating process when oxygen was present.

Blue colors as a result of passive corrosion

Finally perform a pressure test to assure a proper functioning of the pressure measurement.

This paper is prepared together with Mr. Azri B Arabi, Senior Engineer Instrumentation & Control of Petronas, Malaysia.