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Engineering Diaphragm seals for The Industrial World

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Introduction

Story 1: The cursed diaphragm seal system

It all started with a call from my friend on site. He said there is magic curse cast on this diaphragm seal system by a witch. It works when tested in laboratory and even on site but as soon as you install in vacuum column it stops responding.

He felt it could be a coincidence so he did the same with another diaphragm seal system and to his surprise he found the same error happening. He called me asking solution to this curse cast on his diaphragm seal system, he felt it was his mistake during commissioning.

However, it was a simple engineering mistake of not checking the vapor pressure curve by the engineering team and the poor commissioning fellow was blamed.

Had the engineering team checked the “Vapor pressure curve the loss of time, money, stress could have been avoided”

You can know more about this in chapter 5 of the book and prevent such engineering flaws.

Story 2: 7$ Billion Dollars lost in 7 Seconds

An incorrect selection of a simple piece of plastic (polymer) costing a few dollars could lead to such a tremendous loss to one of the top notch engineering companies in the world (NASA).

It was a simple gasket selection concept called “glass transition temperature” that was not given due attention due to stringent schedule deadline that had to be met.

The same gasket that was used by NASA is also used in lot of our oil and gas, renewable energy, chemical project and thus it seems gasket selection is very critical and must be given paramount importance.

You can know more about this in chapter 3 of the book.

Story 3: I&C engineer copying piping engineer incorrectly

This reminds me of a story during our college time, We had Gopal Sir a smart and passionate teacher for programming subject. Instead of given text book programming questions he would have his own programming questions

The trend was as follows, one student usually would solve his question as the rest of the class would follow.

This time everything changed.

The program was neatly copied by everyone but Sir within a fraction of second would inform us that this student has copied, but the surprising thing was as soon the original copy came sir could identify it and say this student has not copied. The copy cats were shocked they tried to copy again with the perfection of full stop and commas yet sir would identify in a second that this kid has copied.

Finally the students went to sir accepting their defeat and asked him how is he able to identify? He said politely “On the 18 line of program I have asked to print your name the number of times your roll number is”. “How can you all have the same roll number as that of Paras?”

I thought this happens only in college but when I entered into corporate world I found out that still some engineers do the same.

This happened for Flange rating and I&C engineer copied the same flange rating as that of piping engineer and when asked by client what is ASME B16.5 standard the poor guy had no answer.

Since instrument and piping engineer have different material so the rating could differ.

You can know more about this in chapter 6 of the book.

Similarly every chapter has its own story.

Hope you find it valuable and useful.

The Flow of Book

The main theme of the book is practical aspects of diaphragm seal and it assumes reader has basic understanding and knowledge of diaphragm seals like working principle, application etc.

This book gives a head start after it has been decided by sound engineering judgment to use diaphragm seal system.

Hence in order to keep the book rich in practical industrial content the theoretical parts are not included since they are readily available on the internet just a few clicks away.

Wetted parts: The most critical aspect

So the first aspect is the wetted part selection of diaphragm seal that has been a major cause of failure and contributed to various accidents especially the material selection since even the vendors can provide limited assistance since it's the end user that is well equipped with the knowledge of the process.

Non-Wetted parts: The potential to cause great damage

Non-wetted parts don't come in contact with the fluid hence sometimes engineers ignore the due importance it deserves.

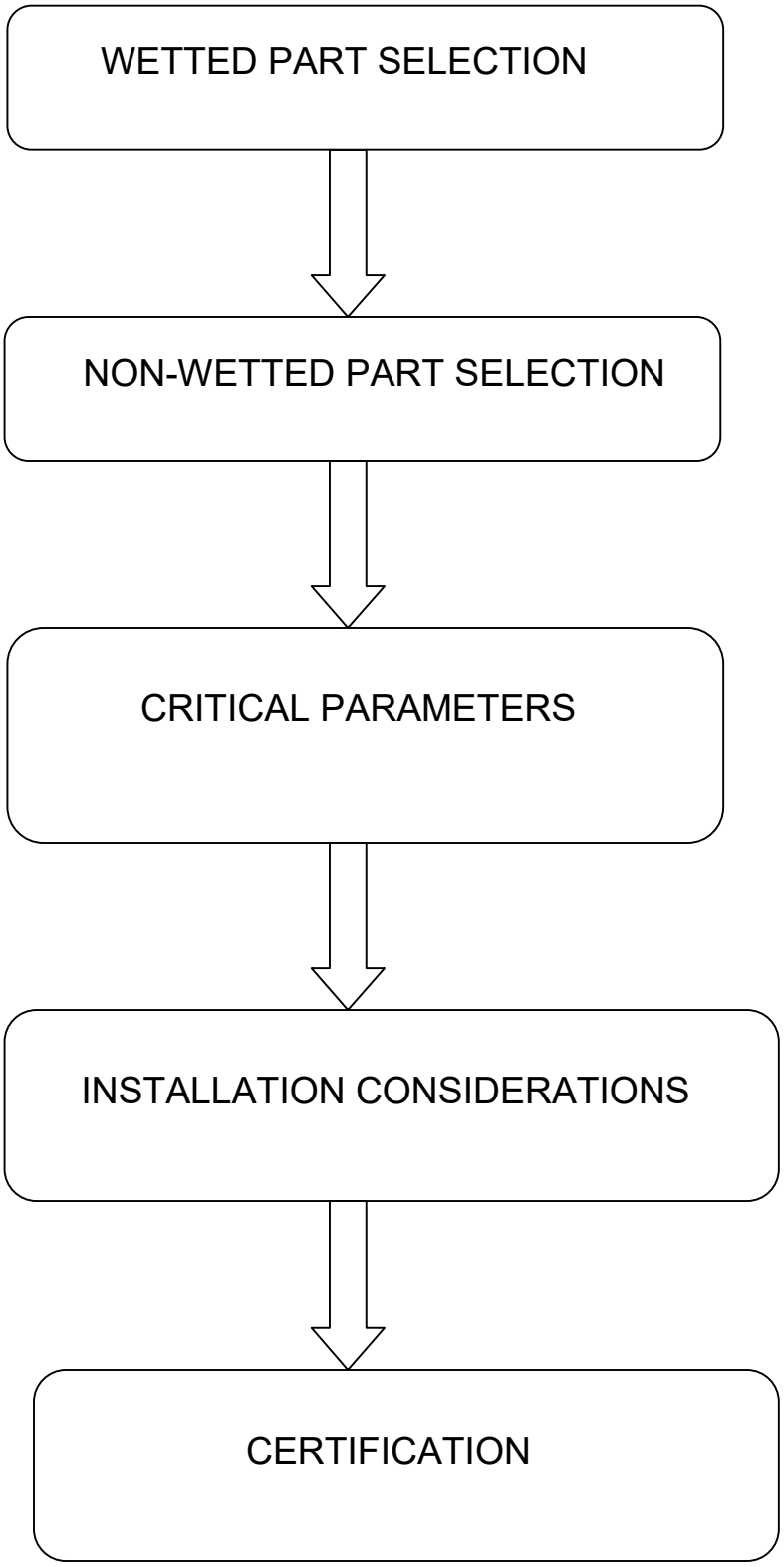
There have been cases where the diaphragm seal membrane failed and the fill fluid mixed with the process and it lead to a violent reaction since the compatibility of fill fluid with process fluid was not evaluated.

You can know more about this in chapter 4 of the book.

Finally considerations

Now the focus shifts to response parameters, Installation recommendation and certification, these are not critical to safety however without proper response and installation guideline it would be difficult to have our diaphragm seal system work as designed. Thus this sums up the book.

The flow of the book is simple and can be summarized as follows



Part -1

Wetted Part selection of diaphragm seal system

Diaphragm membrane material selection

Usually for Material selection of instruments our basis is Pipe material specs.

It is logical to assume that if our instrument sits on the pipe, we can blindly choose the material that pipe is made up of.

However, This is not the cases always.

Before we dive into a story that highlights the importance of material selection of diaphragm membrane, let us understand the basics of corrosion allowance.

Basics concept of Corrosion Allowance

In simple words it is the extra thickness that is added to pipe where corrosion or erosion can occur so that pipe's required thickness is not affected by corrosion.

Let's take a hypothetical Example:-

If a Pipe corrodes at a Rate of 0.02 inches per year you will provide corrosion allowance of maybe 0.5 inch.

That means if in one year the Pipe gets corroded 0.02 inches then in 25 Years it will get corroded up to 0.5 inches.

0.02(Corrosion rate/year) * 25 (Years) = 0.5 inches of layer eroded

So if the pipe required is of 1 inch thickness we will specify 1.5 inches for the above example. (The 0.5 inches compensates for the corrosion during the pipe's lifetime)

A practical story

Now let's explore a project scenario which would make this concept simple to understand

Diaphragm seal material specified in a Diaphragm seal Datasheet was "**Duplex 2205"**

And the pipe material spec for that line stated Duplex 2205 but did not mention trim material.

So as the pipe material (Duplex) is compatible with the fluid so the Diaphragm seal material was also selected as Duplex 2205 by requisition engineer

Here's the catch!

Piping guys have pipe with good thickness (also referred to as Pipe schedule) so that it could compensate for corrosion but we don't have that provision in diaphragm seal membrane.

Most metal diaphragm membrane thickness are in the range of 0.002″ or 0.004" and maximum up to 0.006" (inches) for design reasons.

And the pipe class had a **CORROSION & EROSION RATE of 0.03 inch/yr** this value looks insignificant but compare this to diaphragm seal's membrane thickness.

I.e. in 6 months 0.015 inches would be corroded & eroded and in 3 month 0.0075 inches.

In short so your diaphragm would last for up till maybe a month or more ONLY!!!! (Depending on its thickness)

And imagine this, in one of Hydrocracker unit, the corrosion allowance was 0.125inches/year so much that ½ inch pipe were not recommended.

Imagine our small and innocent diaphragm seal is being exposed to such harsh fluid. It is obvious that in a very short span of time it will corrode and erode.

Conclusion:-

Usually the above being one of the governing factors why we use the **TRIM MATERIAL** mentioned in pipe spec for diaphragm seal membrane selection.

Also when the corrosion & erosion rate is very high like 0.125 inches/year and above better to be safe and consult with material specialist that whether the trim material is sufficient for diaphragm seal membrane or some other higher/extra thick exotic material must be specified.

Hence choose wisely!!

Note:-

Usually We encounter the pipe material as Carbon steel and we as instrumentation engineer take stainless steel as diaphragm seal membrane material which has high corrosion resistance Hence we are safe.

However when pipe is made of exotic material, it is of paramount importance to be sure of the corrosion and erosion rate and thus select the trim material or higher as our diaphragm seal membrane as explained in this chapter.

Gold Plating on Diaphragm Seal membrane

When do diaphragm seal membranes require Gold plating?

API RP 551 recommends for the following scenarios:-

1. For a transmitter with temperature ≥43 °C (110 °F) when any hydrogen is present.

2. Wet hydrogen service

3.Hydrogen Service with pressure greater than 90 PSIA (5 BARG)

Why to go for gold plating of diaphragm seal?

This is due to phenomenon of Hydrogen permeation.

In simple words hydrogen is very miniscule in size, thus it tends to permeate through the Diaphragm seal membrane.

Hence hydrogen embrittlement weakens it and also enters the fill fluid of diaphragm seal causing errors.

Why do we have this criterion of 5 Barg of Pressure?

Hydrogen in environmental condition exists as H2 molecule, but at high pressure this bond breaks and high pressure causes them to temporarily split.

These small H+ atoms now being so minuscule in size, permeate through the diaphragm membrane.

Once they permeate through other side of the diaphragm seal there isn't such high pressure so these molecules combine and thus remain trapped inside the assembly.

Note:-There is no rule fix value of 5 BARG, Project have been executed with gold plating done for Hydrogen service above 6 BARG. Thus it also depends of client preference however if no guideline is available, it is recommended to stick to 5 BARG pressure limit. Since API recommends it and also majority of well renowned clients have recommended this criteria.

Gold plating thickness?

As a rule of thumb 40µm thickness is preferred for Diaphragm seal membrane.

Thickness for gold coating of transmitter's membrane in hydrogen service (without diaphragm seal) is usually preferred as 25µm.

Note that there is "no fixed guide" to stick with a particular thickness, for Instance API 551 RP emphasizes more on the quality of coating than just the thickness, sometimes client design preference dictate the thickness of gold plating.(reference API 551 Section 3.6.6 page 16)

Base membrane material for Gold coating?

Stainless Steel is usually the least affected material and is the most preferred with regards to base material.

API explicitly states that tantalum is very prone to Hydrogen embrittlement and recommends that it should not be used as base material.

It is said that Hastelloy C276 material is not be used as base material for gold coating of diaphragm seal but unfortunately such a statement was not found in the few major standards of diaphragm seal like ASME B40.2 or API 551 RP etc.

Personally, there was a project done with a reputed vendor, who had provided Gold plating on Hastelloy Base material.

But regardless, I would suggest if such a situation arises then it is advisable to consult with material engineer before deriving to a conclusion.

Also beware that in worst case scenario if the Gold plating fails, the membrane material will come in contact with process hence it must be given due consideration that it should also be compatible with process fluid.

Miscellaneous precautions

In a diaphragm seal assembly besides diaphragm membrane there are also other parts that come in contact with process (Wetted parts).Like Flushing ring, Flushing Flange, Plugs, Isolation valves, gaskets etc.
Due care must be taken during their selection as well.

The most preferred choice of material for these wetted parts is stainless steel as it is one of the least affected material with regards to hydrogen embrittlement and is highly recommended in by API RP (refinery practices) 511 standard as well.

How Simple O-Ring led to loss of billons to NASA: Gasket selection

A question was asked that gasket is simply as piece of plastic costing a few dollars. Why are you paying so much attention to it?

What possible harm can it cause? Is it having any real importance?

The below story answers this question

NASA one of the top engineering companies in the world had their space shuttle launch. The space shuttle was named challenger.

A strange thing happened this time. After 17 secs in air the space shuttle worth billions of dollars was into pieces.

You might thing the cause of this accident could be something very complex. However scientist Feynman discovered and showed to the team of investigators that it was a simple gasket that caused the accident.

He dipped the gasket in Ice cold water for some time and then stretched the gasket; He showed that the gasket once stretched took a long time to regain back to its original shape.

When the gasket was cooled further, it broke into pieces when stretched.

How can this happen?

It is a simple concept called glass transition temperature (Tg)

When we cool a plastic below its glass transition temperature it starts to behave similar to brittle substance like glass.

Hence the name given to this phenomenon is glass transition temperature.

What had happened?

When the rocket was launched the atmospheric temperature was very low and snow had accumulated on the rocket but due to stringent deadlines it was decided to launch the rocket.

As the rocket was launched the temperature inside the engine was very high and caused the metal parts to expand. This phenomenon is also referred to as ballooning or by contractor Morton-Thiokol as extrusion.

Thus the gases could leak between these gaps created. However in the previous launches the gasket would come out of its place and seal the groove and thus prevent these combustible gases to leak out.

However this time since the rocket was launched during a very cold weather the gasket was near it glass transition temperature thus when the ballooning/extrusion phenomenon happened the compressed gasket took time to seal the grove and thus these gases escaped quickly thought the groove.

Thus it was inevitable for the explosion to be prevented when such combustible gases are leaked and the temperature is around 1000 Deg Celsius, within few seconds the space shuttle, billions of dollars were destroyed and the most unfortunate thing was that the crew died.

Why is this incident very important to us in gasket selection?

Since the gasket they used in space shuttle engine was FKM Vitton and the same gasket is used in a lot of places in our industries as well.

This is a widely used O-ring in our Petroleum & chemical industry.

Also Hydrocarbons that we handle are one of the most dangerous things every handled by mankind. Hence a small negligence on our part can lead to a catastrophic accident.

With Little more Engineering Knowledge we can save lives of people at plant and Billions of dollars!

So what are the Technical lessons we can learn?

Check: The upper as well as the lower temperature limit the gasket can sustain

We usually only check the Upper Temperature limit of O-Rings and Gaskets

Like for example PTFE has the upper temperature as 260 °C.

But there is also the Lower temperature that must be checked.

This is sometimes called “Glass Transition temperature” or “Brittleness Temperature” or “Lower Temperature limit”

Below is a screen shot from ISO 23936-1:2009

Table 5 gives the characteristic properties of the unfilled polymers, together with the related standards.

Table 5 — Characteristic properties of selected unfilled polymers

Type	Property				
	Melting point (DSC) °C	Vicat B softening temperature (50 K/h) °C	Maximum operating temperature °C	Brittleness temperature °C	Impact strength at −30 °C (Charpy) MPa
	Standard				
	ISO 11357-1 to ISO 11357-6	ISO 306	—	ASTM D746	ISO 179-1
PPS	280	220	200	−50	No break
PEEK	335	259	250	−65	No break
PTFE	325	300	260	−200	No break
PAI	275	260	200	−65	No break

Yellow highlighted is “Brittleness Temperature” for PTFE

Yes PTFE has a very low brittleness temperature but all materials do not have such a low glass transition or brittleness temperature!

Avoid selecting gaskets near upper or lower temperature limit

Also as we learn from this accident is don't keep lingering around this glass transition temperature.

When an O-ring is cooled near, but not beyond, it's Tg(Glass transition temperature), the cold O-ring, once compressed, will take longer than normal to return to its original shape and in the mean time gases can leak out,

Checking Chemical Compatibility of Gasket/ O-ring

Few Examples of materials that must not be used for a particular service

Polyether-etherketones (PEEK)

Hydrogen sulfide can attack PEEK, specifically in the presence of amines and elemental sulfur and at high partial pressures and temperatures in the range of 200 °C

Limited chemical resistance exists also against halogenated hydrocarbons (Reference: O-Ring selection standard ISO 23936-1:2009 Page 10)

Now, My Personal Favorite the O-Ring used above in NASA's Shuttle Motor FKM Vitton

FKM Vitton

This is an amazing O-ring material acceptable to many services but still there are few services where it is not compatible

FKM is not acceptable for Amines or hot water and steam.

(Reference API RP 551…..Page 15)

And STEAM is used in majority of plants.

We cannot predict how an Elastomer will fail some swell, some dissolve, and some take a compression set.

Explosive Decompression (ED) can occur when an elastomer absorbs process vapor and the pressure is abruptly released.

A seal can become damaged as a result and will be unable to hold pressure afterwards

Polytetrafluoro-ethylene (PTFE)

The temperature limit is 260 °C. At this temperature, the mechanical properties are very poor due to creep. Stress corrosion cracking has not been observed with PTFE.

No media used in oil and gas production, including functional chemicals (detergents, surfactants, emulsifiers, demulsifies and corrosion inhibitors), have been reported to attack PTFE up to the temperature limit.

(Reference O-Ring selection standard ISO 23936-1:2009 Page 11)

But please note the standard does not hold any responsibility of compatibility but it gives us a good guideline in selection.

Hence stay safe and refer Standards :-

1) ISO 23936, Non-metallic Elastomers for Oil and Gas Production

2) EN 682, Non-metallic Elastomers for Oil and Gas Production,

Also consult with manufacture and material engineer in case you find something that needs further clarification!

Avoid startup of a plant at extreme weather conditions

Also, during initial start up of plant it is better to not start activity at extreme conditions since the probability of such accidents increases like unaccounted thermal expansion at high temperature or glass transition temperature is unchecked etc.

In conclusion check the following 3 aspects of gaskets:-

1. Check the Chemical compatibility with the process.
2. Check maximum temperature and then maintain a safety margin.
3. Check minimum temperature and then maintain a safety margin .

Part-2

Non-Wetted part Selection in Diaphragm seal systems

Fill Fluid Compatibility in diaphragm seal assembly

We presume that diaphragm seals provide complete isolation from process so the only wetted part that needs to be considered for compatibility with process is diaphragm seal membrane.

Such an engineering judgment can lead to a catastrophic accident especially when dealing with hazardous and flammable substance like hydrocarbons or where the environment is highly explosive.

The diaphragm membrane seems invincible but due to incorrect material selection or improper understanding of corrosion rate and a variety of other factors, the diaphragm could get eroded, corroded etc.

Thus in extreme cases it has been reported in various pharma plants that the fill fluid inside diaphragm seal came in contact with the process fluid.

Hence the fill fluid inside diaphragm seal should be compatible with the process.

It is recommended that glycerin or silicone oil (which is a common choice for majority of our application) should not be used with strong oxidizing agents such as oxygen, chlorine, nitric acid or hydrogen-peroxide.

(Reference ASME B40.100-2013 (B40.2) Section 2.8.4)

In the presence of such oxidizing agents, potential hazard could result from chemical reaction, ignition, or explosion.

Thus glycerin or silicone oil would not be suitable for such services.

Completely fluorinated or chlorinated fluids, or both, may be more suitable for such applications

(Reference ASME B40.100-2013 (B40.2) Section 2.8.4)

Also for instance, fill fluids that use hydrocarbon compounds should not be used in oxygen or chlorine service.

(Reference API RP 551 Section 9.2.4 page 199).

For diaphragm seals to be used on pharmaceutical or food processing application care should be taken that in worst case scenario if the diaphragm membrane fails, the fill fluid should not contaminate the entire batch or product making it hazardous.

Various standards apply for pharmaceutical or food processing application and must be adhered to by instrument engineer and vendor.
Example: - 3A Sanitary standard

(Reference ASME B40.100-2013 (B40.2) section 2.8.5)

Special fill fluids are available by vendor for such application like inert oil etc.

Also the fill fluid must be evaluated for it pressure, temperature compatibility which is discussed in the coming chapter.

Conclusively, The Fill fluid of diaphragm seal assembly must be give due importance that it deservers by checking its compatibility with process fluid, environmental conditions, compatibility with pressure and temperature of process.

Otherwise it would be a like a “Time bomb” waiting to react with process fluid or environment and cause significant harm to personal and equipment.

Concept of Fill Fluid Vaporization

In school it was taught that water boils at 100°C.

Do you still believe it is true?

Well this statements needs rectification water boils at 100°C at Atmospheric pressure.

A whitepaper published by badotherm a well know vendor and an expert in diaphragm seal systems, stated that water can boil at even ~0°C when pressure reduces to full vacuum (I.e zero absolute pressure).

It is a mandatory requirement to have the fill fluid in liquid state under all process conditions if the fill fluid turns to vapor state then the diaphragm seal system will cease to work correctly.

This is because the diaphragm seal system works on the principle that liquids are incompressible and thus transfer pressure from process side to transmitter.

However gases are compressible and would absorb some pressure thus transmitter would show incorrect reading.

Practical Example from the Industrial World

Let's take Emerson (Rosemount) Diaphragm seal systems.

They have a variety of Diaphragm seal Fill Fluid to select as per our requirement.

Let us select Silicone 200 since it is one of the most common fill fluid used in the Industry.

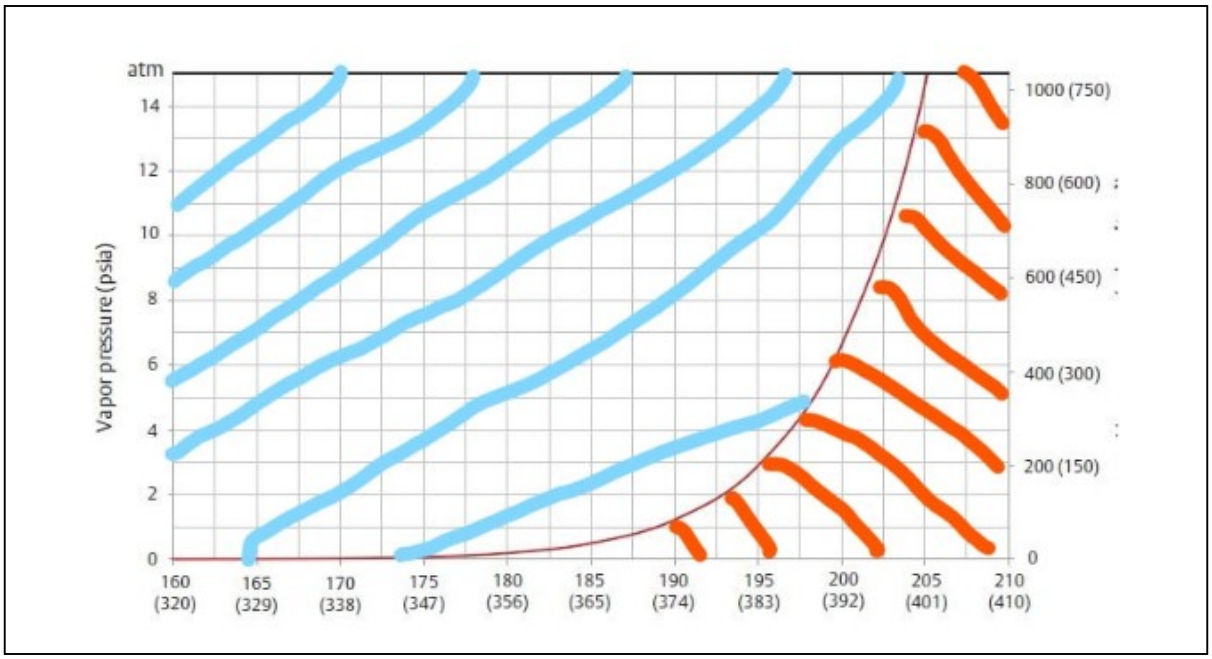
How to read Pressure Temperature Graphs

The following graph is taken from Vendor Emerson (Rosemount-1199-fill-fluid-specifications-en-74338)

The Blue Region shaded is where the Fill fluid stays in Liquid state.

The Red region denotes the region where the fill fluid is in vapor state.

Our aim is to have the full fluid in the blue range for accurate working of diaphragm seals.



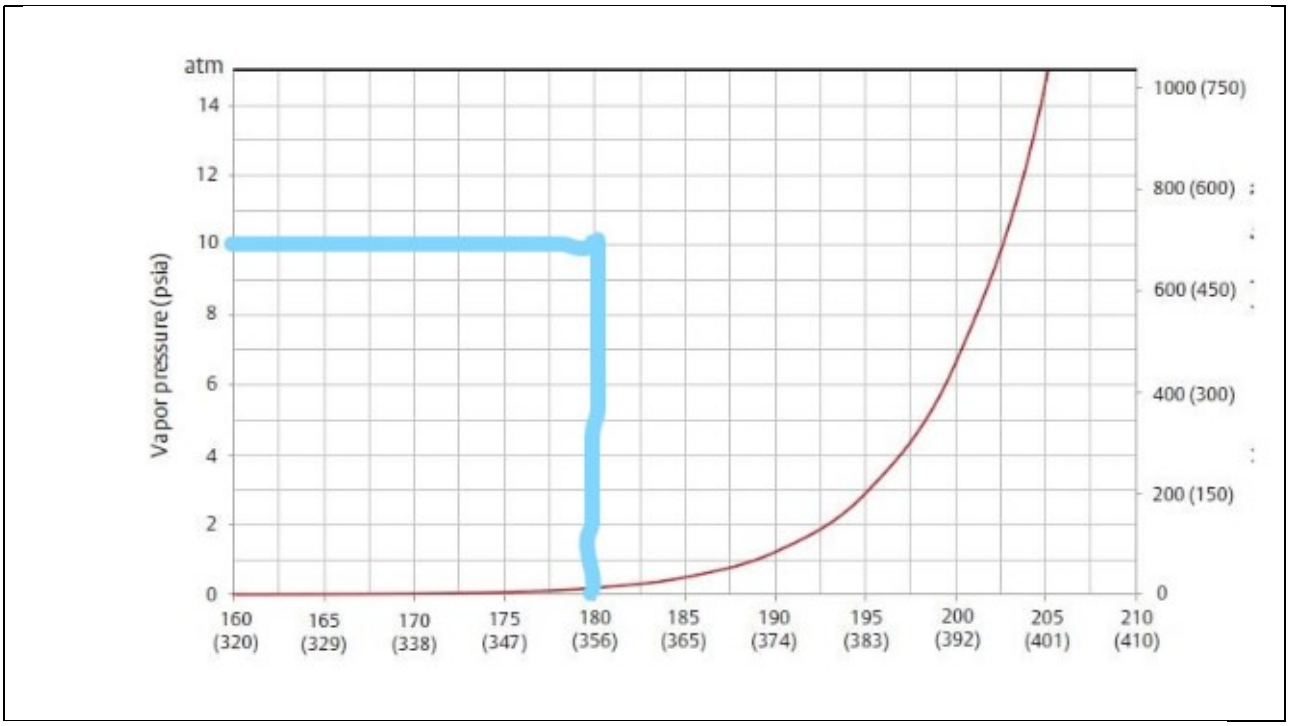
Let us have 2 cases:-

Case 1: The fill Fluid is suitable for the process pressure and temperature parameters

The Lower Design Pressure of the process is 10 Psia

And the Design Temperature is 180 Deg C

Thus we get the following point of intersection



This states that Fill fluid will remain in Liquid state during the extreme design conditions of the process.

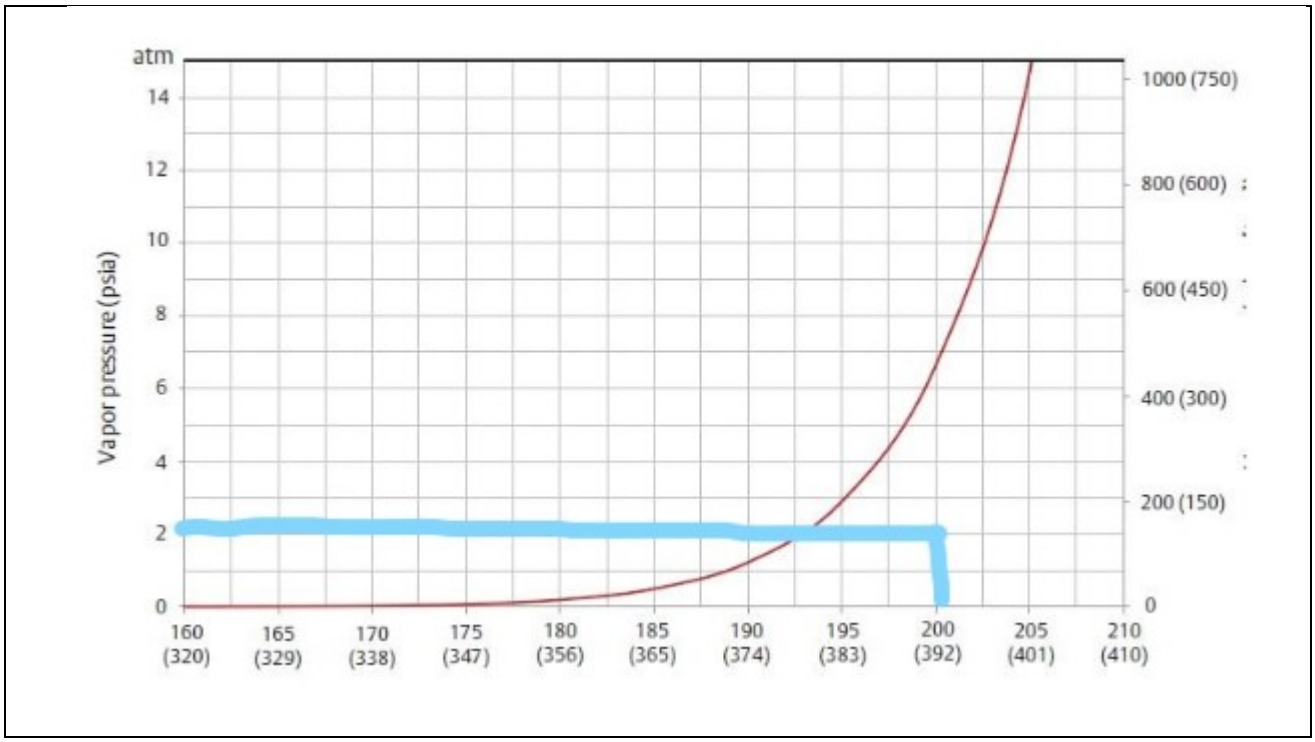
Hence the fill fluid is suitable for our process condition.

Case 2: The Fill fluid is unsuitable for the process pressure and temperature parameters

The Lower Design Pressure of the process is 2 Psia

And the Design Temperature is 200 Deg C

Thus we get the following point of intersection



This states that Fill fluid will not remain in Liquid state, It would turn to gaseous state and thus diaphragm seal would not be able to translate the process pressure since gases are compressible in nature.

Hence the fill fluid is not suitable for our process condition.

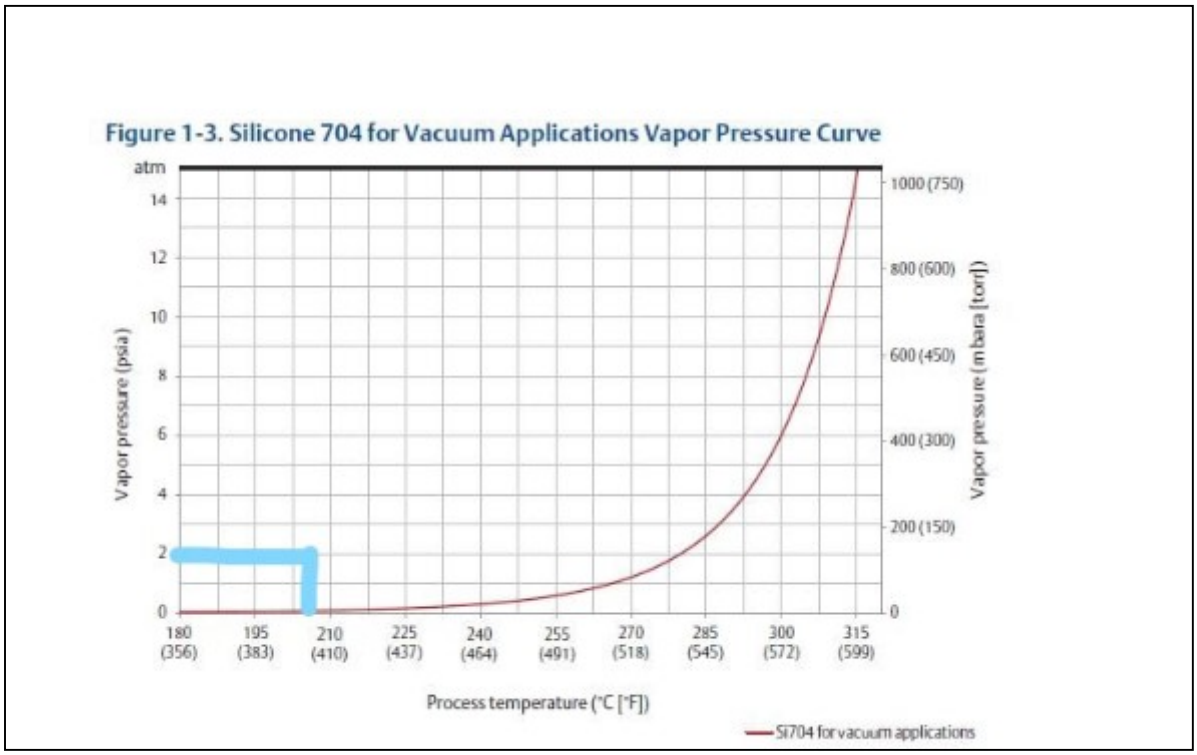
Solution 1:-The Fill fluid must be changed and then the intersection point must be checked for the fill fluid staying in liquid state for all the conditions.

Solution 2:- Change the installation condition to provide positive head pressure. This technique is covered in chapter 11 of this book.

Practical example of implementing solution 1:-

Hence let's select silicone 704 as our fill fluid.

Here it is observed in the below graph that for our design conditions the fill fluid will stay in liquid state and thus can be selected for our process conditions.



Note: Silicone 200 oil itself has various grades so always confirm from your respective vendor and use their PT Graphs.

Example: The Silicone 200 Grade of Emerson and Endress+Hauser had slight differences in operating temperature limit. Hence it is recommended to refer technical graphs of respective vendors or request the vendor to provide graphs if they have not published the same online.

Flange Rating selection as per ASME standard

Usually Instrumentation engineers' copy the Piping department i.e. pipe flange rating when it comes to instrument flange rating

However when it comes to material selection of flange we generally use Stainless steel material when piping flange material is carbon steel.

Note copying without understanding can lead to catastrophic safety hazard since flange ratings differ with material as well.

Basics of flange rating: Where do flange ratings come from?

Well this rating come from the following ASME standards*

1.ASME B16.5 (if pipe size is less than 24 inches)

2.ASME B16.47 (if pipe size is greater than 24 inches)

Every material has a certain limit of pressure and temperature it can withstand so we have the Pressure Temperature tables in this standard

In simple words:-They describe at a particular rating how much Pressure and Temperature it can withstand.

The Higher the rating the more pressure & temperature the flange can withstand.

Enough of theory let's take a practical Example

How to practically use ASME B16.5 standard

Let's take a Carbon Steel (A106) flange with rating 300#

It is derived from this standard that 300# carbon steel flange can withstand 37.6 Bar of pressure at 350 Deg C.

How to use this Standard?

Refer a partial Snippet below from the Standard for A105 Material

Table 2-1.1 Pressure–Temperature Ratings for Group 1.1 Ma

Nominal Designation	Forgings	Castings
C–Si	A105 (1)	A216 Gr. WCB (1)
C–Mn–Si	A350 Gr. LF2 (1)	...
C–Mn–Si–V	A350 Gr. LF6 Cl. 1 (3)	...

Material name

Flange Rating

Max Temp.

Max.Pressure

	Working Pressures by Classes, bar				
	Class				
Temp., °C	150	300	400	600	900
−29 to 38	19.6	51.1	68.1	102.1	153.2
50	19.2	50.1	66.8	100.2	150.4
100	17.7	46.6	62.1	93.2	139.8
150	15.8	45.1	60.1	90.2	135.2
200	13.8	43.8	58.4	87.6	131.4
250	12.1	41.9	55.9	83.9	125.8
300	10.2	39.8	53.1	79.6	119.5
325	9.3	38.7	51.6	77.4	116.1
350	8.4	37.6	50.1	75.1	112.7
375	7.4	36.4	48.5	72.7	109.1

Here's the Catch!!!!

For same 300 Class of flange rating the material stainless Steel (SS316L) can withstand 25.1 Bar of pressure at 350 Deg C.

Refer a partial Snippet below from the Standard for SS 316 Material

Table 2-2.3 Pressure–Temperature Ratings for Group 2.3 M

Nominal Designation	Forgings	Castings
18Cr–8Ni	A182 Gr. F304L (1)	...
16Cr–12Ni–2Mo	A182 Gr. F316L	...
18Cr–13Ni–3Mo	A182 Gr. F317L	...

Material

Flange Rating

Max Temp.

	Working Pressures by Classes, bar				
	Class				
Temp., °C	150	300	400	600	900
−29 to 38	15.9	41.4	55.2	82.7	124.1
50	15.3	40.0	53.4	80.0	120.1
100	13.3	34.8	46.4	69.6	104.4
150	12.0	31.4	41.9	62.8	94.2
200	11.2	29.2	38.9	58.3	87.5
250	10.5	27.5	36.6	54.9	82.4
300	10.0	26.1	34.8	52.1	78.2
325	9.3	25.5	34.0	51.0	76.4
350	8.4	25.1	33.4	50.1	75.2

Max.Pressure

Do you see the difference

For same class 300# flange at 350 Deg C, SS316L can only withstand 25.1 Bar while CS A105 can withstand 37.6 Bar.

But if you compare the corrosion resistance Yes, SS316L is more corrosion resistant than CS A105 since it has very low carbon content.

In one of our Hydrocracker unit which had very high pressure & temperature majority of SS flanges did not fit in the PT rating.

Hence higher Flange rating had to be used and the same had to be informed to piping that even they have to do the same!!
(So that both flanges are of same dimensions)

In conclusion

keep you plant safe and always check PT ratings in ASME B16.5/16.47 standard and if you find that SS flange requires higher flange rating then inform piping department as well since both flanges must be of the same rating to fit correctly.

(* Note: There is also DIN piping standard called 1092-1. In this the flange ratings are mentioned as PN rating. And it follows the same concept as explained above)

The Difference between flushing flange and flushing ring

Introduction: - Flushing flange/ring is fitted below diaphragm seal flange. Its' major purpose is to easily clean the diaphragm seal when viscous fluid could clog near diaphragm membrane

Some other words used for it are calibration ring, flushing ring, drip ring etc

There is a key design difference between flushing flange and flushing ring that gets overlooked. A lot of times it is noticed that these terms are used interchangeably but they have a subtle difference that needs to be considered.

Flushing ring:-

It is like a cumber that gets sandwiched between two bread slice.

It gets sandwiched between diaphragm seal flange and process flange

Refer the below pic:

No stud and bolts assembly can go through the flushing ring

Flushing flange:-

It is also sits between diaphragm seal flange and process flange but the bolts and stud assembly can go “through” the flange.

As the bolts can go through the flushing flange so there is better stability etc.

Refer the below pic:

Stud and bolts assembly can go through the flushing flange

Obviously there is trade of between choosing flushing flange or flushing ring like cost, stability etc.

Or sometimes client design bases/preference dictates when to use flushing flange or ring.

Credits: - The flushing flange pic is from Badotherm.

What is "Axial" and "radial" diaphragm seal connection?

Back to basics:-

What is the difference between Axial and Radial movement mean?

Axial movement
Imagine a circle an you are in the middle of the circle.
Now you start jumping, this is axial movement.

Radial movement
From the center of circle you move to the end of circle.
This is radial movement.
In other words movement along the radius of the circle is called radial movement.

A Practical example:-

Let's take a case study of the vendor Badotherm

This vendor has a separate model number code to choose whether we want an axial or radial entry.(Reference :- GS 06P01Y01-E-E 7th Edition)

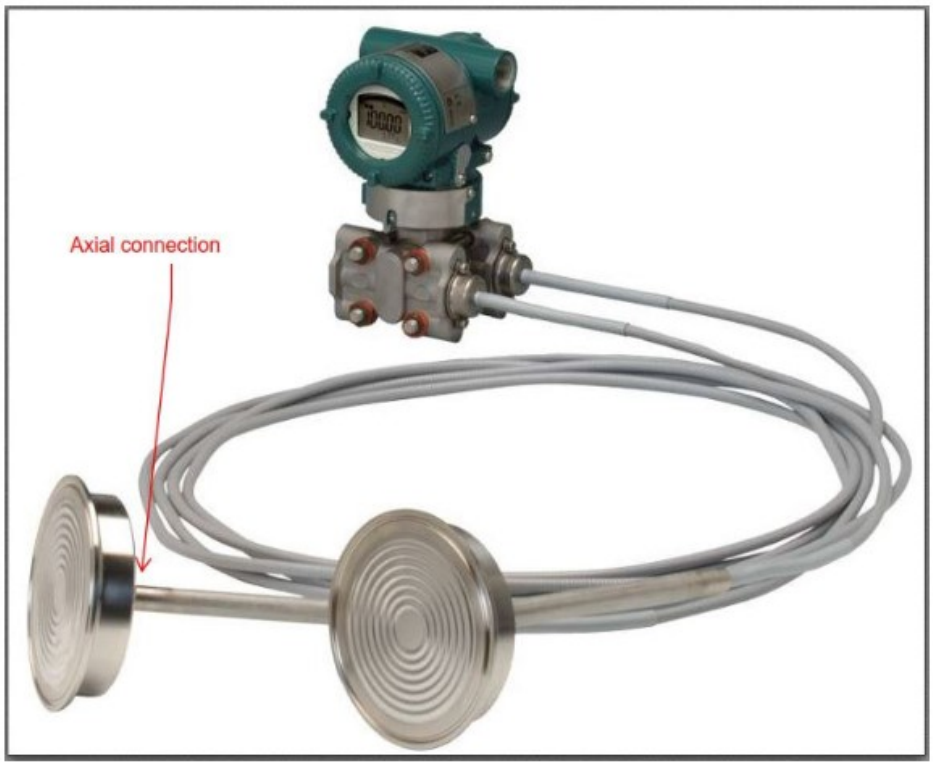
Model code C1/C2

8. Capillary Size / Type (AISI 316 Stainless Steel Armoured)		
NN	Direct coupled / Welded (No Capillary)	
C1	Capillary (2mm ID)	axial
C2	Capillary (2mm ID)	radial

<u>Note: - A majority of vendors by default provide Radial capillary entry.</u>

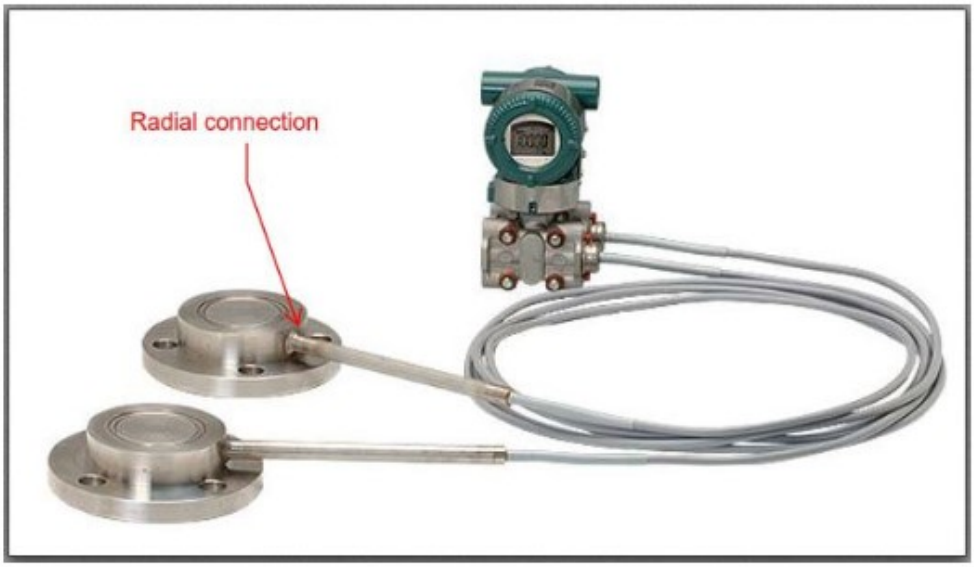
The difference between the 2 connections can be seen below.

Axial Connection



Courtesy:-Yokogawa

Radial connection



Courtesy:-Yokogawa

How is this useful?

Clearance space requirement

If we mount the diaphragm seal flange in vertical position, like in case of vacuum column or other such equipment. The clearance space required for the capillary coming out of the flange would vary.

Note that rule of thumb for the bending radius for diaphragm seal capillary is at least 150 mm.

Axial diaphragm seal requires clearance space in the X-Y plane.

While the Radial diaphragm seal clearance space in the Y-Z plane.

Type of diaphragm seal

The type of diaphragm seal also dictates the connection type.

Example “Pancake” diaphragm seal requires a radial entry diaphragm seal only. Since a pancake diaphragm seal sits between two flanges axial entry is not feasible.

Refer picture of pancake diaphragm seal in the following page

Here we do not have the liberty to select as per our convenience since only one connection is suitable.

Wafer (Pan-cake) diaphragm seal connection

Thus depending on space consideration and type of diaphragm seal etc appropriate diaphragm seal connection must be used.

Conclusion:

The freedom of selecting radial and axial diaphragm seal connection depends on the available options with vendor, type of diaphragm seal (Pancake type supports only radial connection), Space considerations in plant etc.

Part 3

Critical concept of Response time in diaphragm seal system

Is the Diaphragm seal Lazy to react?

The diaphragm seal must have a response time within PST of the process.

But what is PST (**Process Safety Time)**

The IEC 61508:2010 standard defines **Process Safety Time** as the "**Period of time"** between a failure, that has the potential to give rise to a hazardous event, occurring in the EUC [equipment under control] or EUC control system and the **time** by which action has to be completed in the EUC to prevent the hazardous event from occurring"

Let us simplify the definition.

In simple words the PST of a given process is the fault-tolerant time of that process, prior to becoming a dangerous condition.

I.e. Within this PST the safety system has the opportunity to take necessary action to prevent an accident.

Eg:-Closing a valve to prevent overfill or spillage in Tanks.

Why is PST important?

Within PST the safety system has the opportunity to take the necessary action to mitigate the hazard and prevent and accident.

Example: - Pressure transmitter senses very high pressure inside tower and opens the valve connected on the vent line to release the excess pressure.

Why PST is is a concern for diaphragm seal assembly?

There is always some delay between the time when diaphragm seal membrane senses pressure and when this is transmitter to the Transmitter.

A variety of factors that affect diaphragm seal response time are:-

1.Size of Flange

2.Capillary length and diameter of capillary tube

3.Fill fluid of diaphragm seal assembly

4.Process temperature and ambient temperature

5.Vacuum condition in process

Hence if your transmitter is responsible to detect safety critical issue (SIL Transmitter) and if the overall response time of transmitter and the entire diaphragm seal assembly is greater that the PST then accident is bound to occur.

Even if the issue is detected it will still be of very little use as the process has already reached a dangerous condition.

How to mitigate this issue?

Evaluate the response time of your diaphragm seal assembly during engineering phase.

All major suppliers have their software that replicates the real time conditions and the response of their diaphragm seal assembly under these conditions.

Note that even though fill fluids having similar names like “Silicone oil”.

They are divided into various grades and thus the vendors must be consulted for accurate response time and other characteristics for critical applications.

Vendor calculation tools come handy to give a baseline idea whether the diaphragm seal system's response time is within the PST or not.

A practical example.

Let's us take case study of the Client SHELL and Vendor Badotherm.

Shell Pernis had been using diaphragm seal pressure transmitter for their safety function.

A typical situation that the diaphragm seal has to encounter when used on critical equipments (like vacuum column, reactors etc) is when temperature in reactor reaches 300-400°C and at this point the fill fluid will boil because of low vapor pressure (Refer chapter 5 for more details on fill fluid vaporization) and on top of it the outside temperature is -20°C which would make the viscosity high.

In this situation it is difficult to ascertain what could be the response time of the system. (Incase the fluid is completely in vapor state then obviously an incorrect reading would be shown).

Hence badotherm came up with a tool called **"Base cal"** to simulate conditions and assure the response of diaphragm seal system.

A whitepaper published by badotherm explains this concept in detail.

Here's the link to it.
http://www.badotherm.com/downloads.html

When to check this response time?

This should be carried out for critical systems like Diaphragm seal connected to Safety systems with long capillary lengths or challenging environmental conditions.

What if response time is not satisfactory?

If the response time is not satisfactory we can figure solutions to improve the same.

If the ambient temperature is very low and causes the viscosity to increase then heat tracing should solve the issue.

If the process temperature is very high then changing the fill fluid could solve the issue.

Personal recommendation is to discuss with vendor since they have done in-depth studies for their product and can come up with innovative solutions, one such innovative solution is Thermal ranger diaphragm seal system by Emerson.

In conclusion:

It is important to ascertain the response time of the entire diaphragm seal assembly the response time of transmitter is not sufficient to ensure the reliability of diaphragm seal system.

The entire assembly's response time is critical and must be calculated and discussed with vendor when such systems are used for critical applications and especially where the process or environmental conditions are challenging.

Part 4

Installation of Diaphragm seal System

Installation Concerns for Diaphragm seals

Space consideration for bending radius of capillary in Axial and Radial diaphragm seal systems

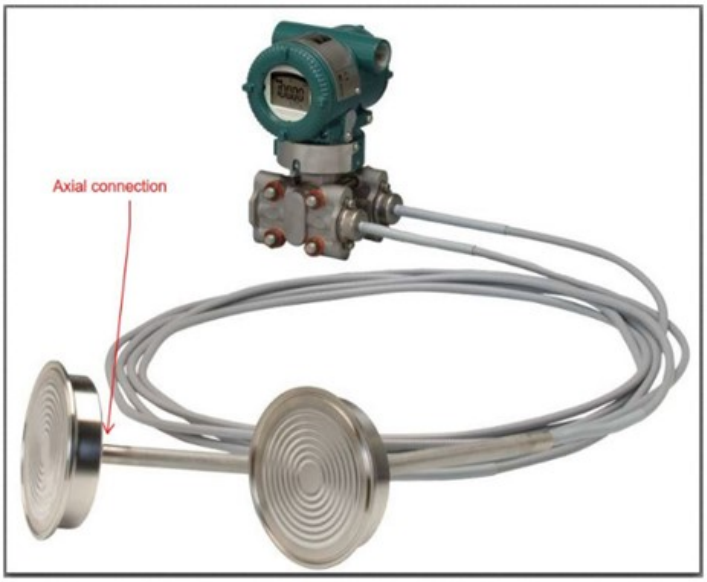
The capillary connecting to the diaphragm seal would require clearance in the X-Y or Y-Z plane depending on its connection to diaphragm flange (Axial or radial)

As a rule of thumb the bending radius of 150mm should be provided.

For axial connection (flange mounted on horizontal surface) it should be provided in vertical plane and for radial it should be provided in horizontal plane.

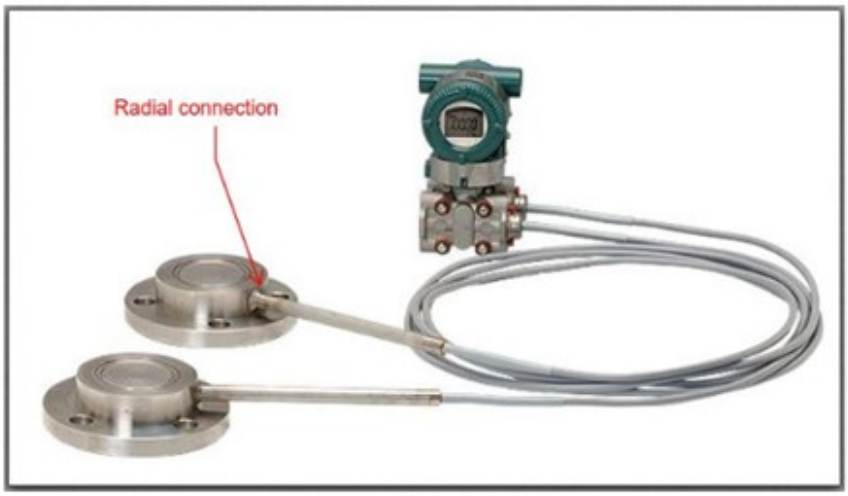
This is critical when there is a cluster of pipes in close proximity and a diaphragm seal has to be tapped into one those pipes.

Axial Connection



Courtesy:-Yokogawa

Radial connection



Courtesy:-Yokogawa

Armored Capillary :-

The Capillary tubes are sensitive and hence it is prefer to have them armored.

The most widely used choice of material selection is SS316 Armored.

Sometimes, PVC coated capillaries are also used. However for such cases it must be known that PCV has temperature limitation and the fill fluid must not get heated beyond PVC's sustainable temperature else it would melt.

Calculation of capillary length:-

It is advisable to have a safety margin while calculating the length of capillary due to the following reasons.

1. Capillaries are hard and require a bending radius of approximately 150mm.
2. Site conditions would require a different path of capillary connection between transmitter and diaphragm seal than the one estimated in design phase.
(Safe practice is to consider longest path between diaphragm seal and transmitter the extra length of capillary can be coiled up)

3. If the length of capillary falls short on site then it is not possible to add an extra meter of length, a new assembly would be required.

Extra Capillary length:- It is advisable to coil the extra capillary and not let it run lose causing people to trip or cause errors.

Strut connections on Vessel :- This is a important consideration that gets overlooked.

The Diaphragm seal assembly is also used for level measurement and we know the distance between the two tapping of DP LT measurement could be large.

For such long distances the capillary cannot be hanging in air, The Clients who are very particular in safety aspect usually have it mentioned in their design basis that such capillary should run via a 50 mm tray across the vessel.

The real concern is that in order to mount the 50 mm tray we need strut support on the vessel.

Note that after the equipment is fabricated and shipped to site it is usually not allowed to drill anything on the equipment since it could affect the integrity of the equipment.(sometimes such drilling requires lot of approvals and are often referred to as hot permission)

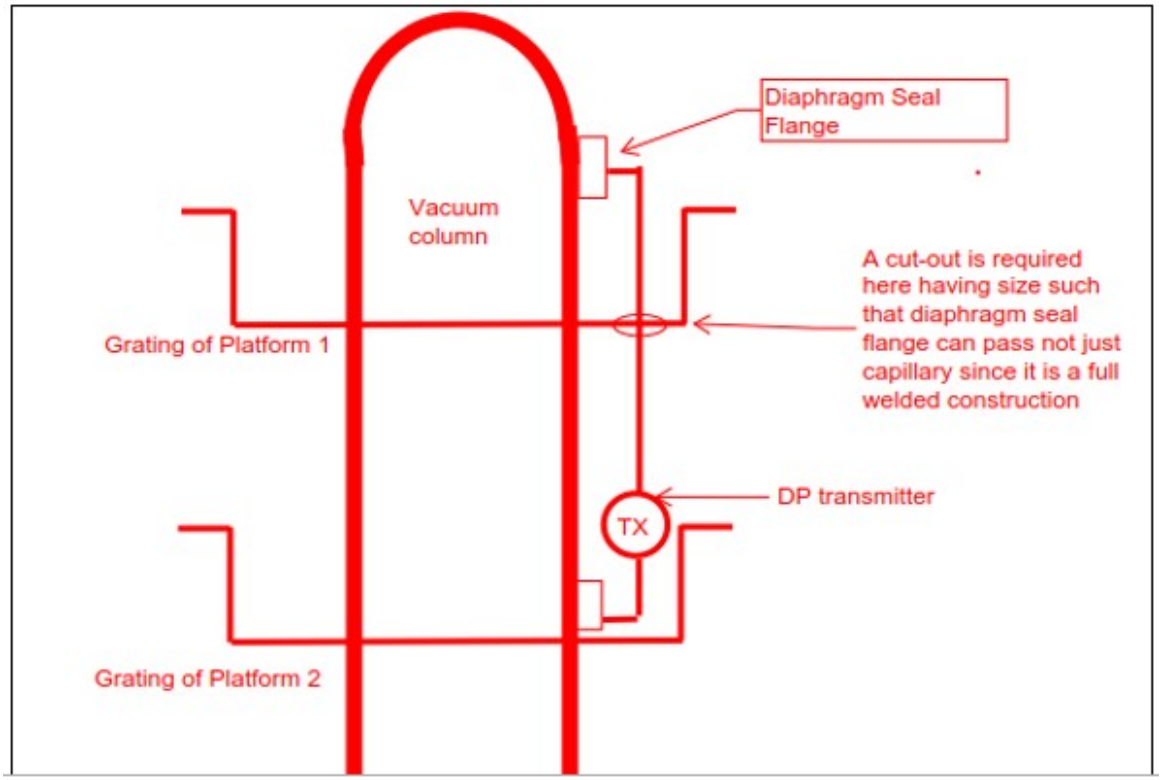
Cut out between platform:-

When we mount diaphragm seal on a tank there is high probability that we need provide cut out between gratings on various platforms.

These cut out size are sometimes mistaken by design team and the cutout length of capillary are considered.

However diaphragm seal capillary tubes are usually full welded to Diaphragm flange on one end and transmitter on the other end.

Hence the cutout must be given between grating/Platform keeping Diaphragm seal flange's length in mind.
(Refer following diagram indicating a typical case)



Venting of Flushing ring or flushing flange ports:-

Diaphragm seal are usually used when the tradition differential pressure transmitter with Impulse lines cannot be used. Usually these services are Toxic, Corrosive, erosive or highly viscous.

The flushing ring/flange as discussed in previous chapter are used to periodically clean the diaphragm seal membrane. For certain toxic services it is a mandatory requirement that the residue after cleaning the diaphragm seal membrane should not be let out in the atmosphere rather it must be collected.

So for such cases an impulse tube is connected to the outlet of flushing ring which further connects to common collection sump. If this is the case then the Impulse tube, Connectors must be identified and procured accordingly and must be indicated or mentioned in installation drawing of the same.

Installation in Full vacuum

A bold statement was made that "In full vacuum always mount the diaphragm seal transmitter below the lower diaphragm seal taping"

However engineers know that diaphragm seals can be mounted at any position and there is not limitation on its position.

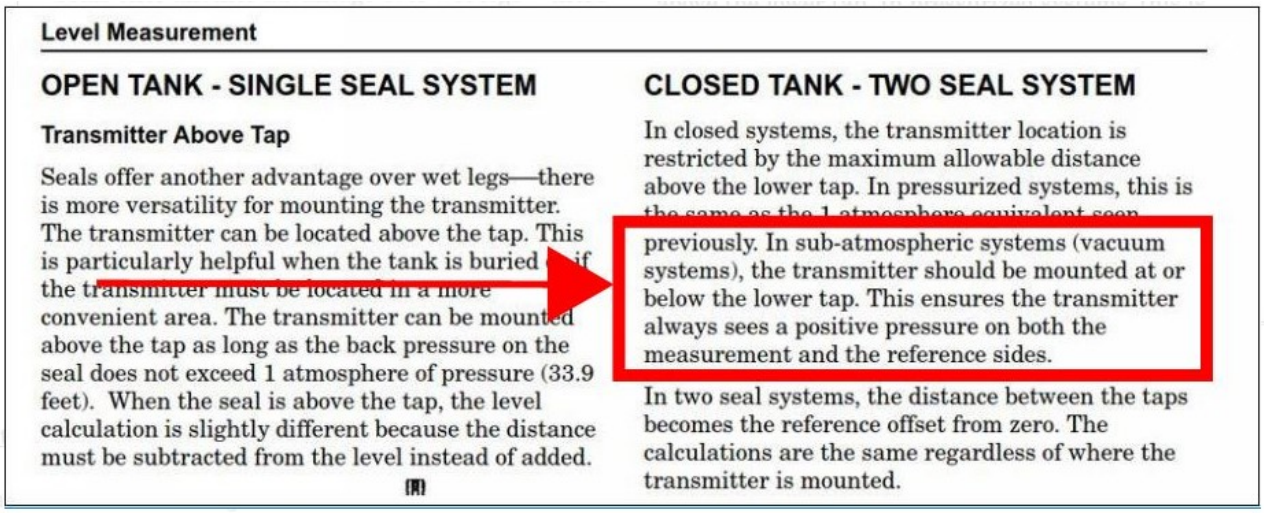
Before we explore the reasons as to why should we follow such an installation in vacuum condition. It's important to first provide proof to strengthen its importance and then we can explore the interesting part as to why should we go for such an installation.

The below recommendations are from some world renowned vendors for Full vacuum service.

1.**Vendor :- EMERSON**

Reference document :-
https://www.emerson.com/documents/automation/technical-data-sheet-level-measurement-pressure-rosemount-en-74346.pdf

Below is a extract from above document with regards to vacuum service.



Level Measurement

OPEN TANK - SINGLE SEAL SYSTEM

Transmitter Above Tap

Seals offer another advantage over wet legs—there is more versatility for mounting the transmitter. The transmitter can be located above the tap. This is particularly helpful when the tank is buried or if the transmitter must be located in a more convenient area. The transmitter can be mounted above the tap as long as the back pressure on the seal does not exceed 1 atmosphere of pressure (33.9 feet). When the seal is above the tap, the level calculation is slightly different because the distance must be subtracted from the level instead of added.

CLOSED TANK - TWO SEAL SYSTEM

In closed systems, the transmitter location is restricted by the maximum allowable distance above the lower tap. In pressurized systems, this is the same as the 1 atmosphere equivalent seen previously. In sub-atmospheric systems (vacuum systems), the transmitter should be mounted at or below the lower tap. This ensures the transmitter always sees a positive pressure on both the measurement and the reference sides.

In two seal systems, the distance between the taps becomes the reference offset from zero. The calculations are the same regardless of where the transmitter is mounted.

2.Vendor:- Badotherm

Reference document :- **http://www.badotherm.com/downloads.html**

Below is a extract from above document with regards to vacuum service.

> 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.

3.Vendor:- E&H

Reference document :- Deltabar S PMD75, FMD77, FMD78 catalog, Page 106

Below is a extract from above document with regards to vacuum service.

> **Mounting instructions**
>
> For applications under vacuum, Endress+Hauser recommends mounting the pressure transmitter below the lower diaphragm seal. This prevents a vacuum load of the diaphragm seal caused by the presence of filling oil in the capillaries.

4. Even Standards like **API 551** recommend mounting the transmitter 1 m (3 ft) or lower below the tap.

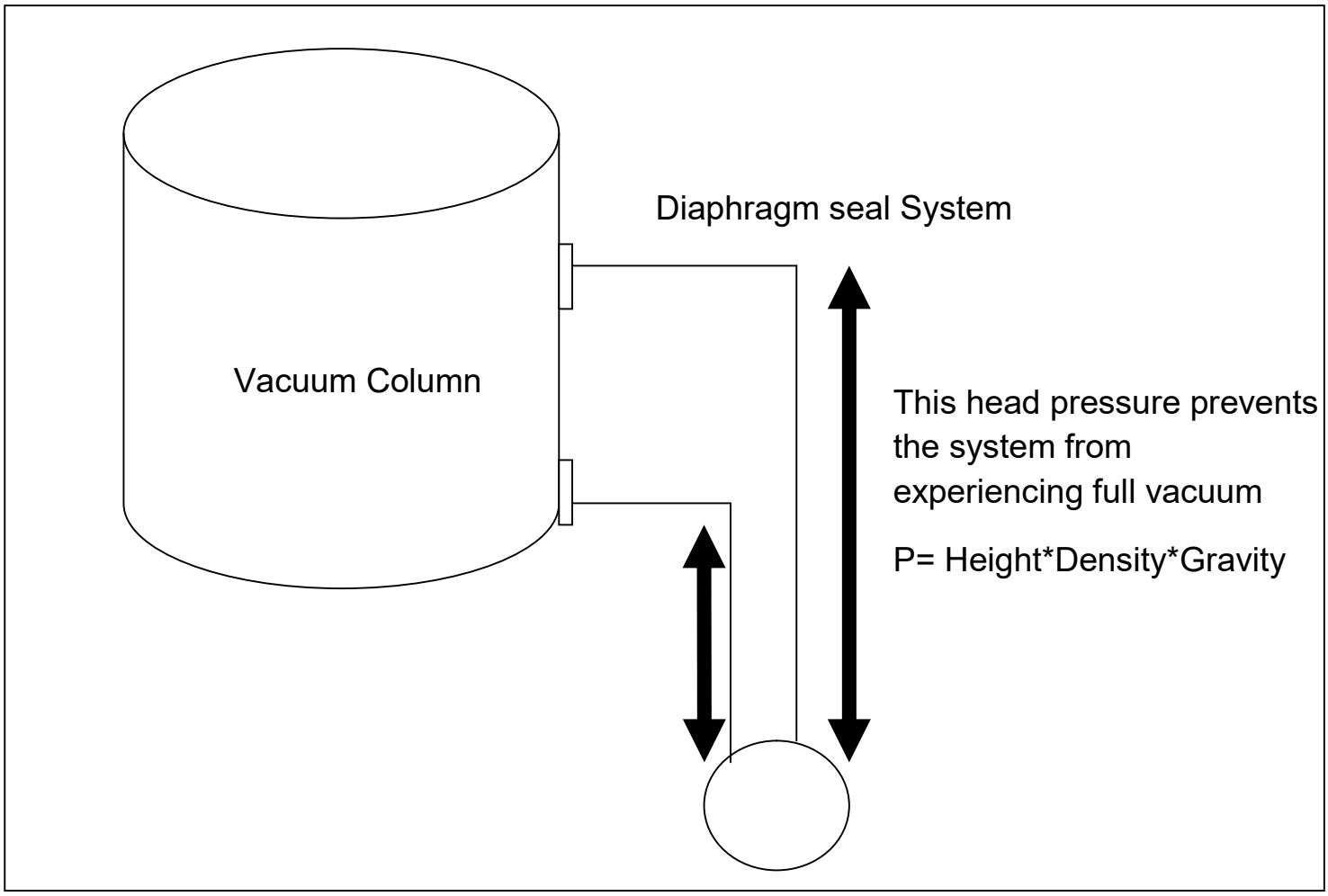
(Reference:-API 551 Section 9.2.6 page no 200)

Now the best part, why so?

When we mount the transmitter below the lower tapping there is gravity's head acting on the fill fluid. Thus even if the instrument is exposed to full vacuum, due to gravity's head the diaphragm seal system experiences some positive pressure.

This prevents the fill fluid from vaporization and form bubbles as discussed in chapter 5.Since bubbles formed inside the diaphragm seal fluid will cause error. Also the pressure measurement capsules could get damaged.

So it is better to follow this recommendation provided in vendor literature and in various instrumentation standards to mount transmitter below lower tapping for full vacuum condition.



Part 5

Certification Concepts and examples

Relation between NACE MR0103 & MR0175

When there is Sour Service we opt for NACE.

But what standard of NACE is applicable?

Usually these are the two standards that we instrumentation engineers widely used in upstream and downstream sector.

1.NACE MR0175 is for Petroleum and natural gas industries — Materials for use in H2S-containing environments in oil and gas Production

In short this standard serves the UPSTREAM Oil and Gas sector

2.NACE MR0103 is for --Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments (In short Downstream)

In short this standard serves the DOWNSTREAM Oil and Gas sector

The Origin :-

Initially there was only NACE MR0175 standard. Then gradually there was a need in the market to have a standard that specifically serves the need of downstream sector.

And thus a new standard was born. Named NACE MR0103 to especially serve the needs of the downstream industry.

Certain new thing like sulphide stress cracking were emphasized that especially trouble the downstream industry

The challenge:-

Vendor Catalogs sometime mention compliance to NACE MR0103 or NACE MR0175 only.

So when to accept what?

The Technical paper Number 04649 2004 NACE International has a detailed study done on differences between the 2 standards.

As per my understanding I have inferred the following:-

Case 1:-Requirement is of NACE MR0103 and vendor provides NACE MR0175

It seems that MR0175 has stringent requirements as compared to MR0103, and it is also somewhat apparent since offshore/upstream has harsher and tougher conditions to deal with as compared to downstream sector.

So for non-critical factors like Paint system for relief valves if vendor states compliance to NACE MR0175 and we are doing a refinery project, we can accept it even if our requirement is MR0103.

For critical factors like material section it is recommended to discuss with a Corrosion specialist whether it could be accepted depending on your typical project conditions.

Example:-While I was doing a Refinery project, for Orifice plate the vendor compiled to NACE MR0175 so after discussing with specialist we inferred that this can be accepted.

For critical parameters it is advised to accept only after consultation with a specialist.

Case 2:-Requirement is of NACE MR0175 and vendor provides NACE MR0103

This is a risky proposition to accept, since offshore/upstream environment generally has harsher conditions.

Here it advised to stick to our requirement of NACE MR0175 and not accept NACE MR0103.

In conclusion:-

NACE MR0175 deals with offshore environment and NACE MR 0103 deals with downstream environment .NACE MR0175 has more stringent requirements as compared to NACE MR0103 however NACE MR 0103 has special additions for issues especially troubling the downstream industry like sulphide stress cracking etc.

Material Certification: - CMTR VS PMI with a practical example

PMI means positive material identification, Material certificate (CMTR) is also used to identify the material used in instrument so what is the difference between the two?

Mr. Wedding planner example

Imagine you are a wedding planner and you need to get 1000 liters of high quality milkshake from a vendor. You need to ensure that for making the milkshake sweet and tasty, vendor puts Grade A sugar.

In order to be sure that the milkshake vendor uses Grade A sugar and not the cheap sugar you do two things

STEP 1 :- You ask the Vendor to submit the Detailed bill of sugar purchased from wholesaler (D-MART etc) to ensure vendor has bought Grade A sugar. (Concept of material certificate)

Now When you receive 1000 liters of milkshake there could be a chance that vendor bought the Grade A sugar from D-MART but did not use it in your milkshake and used some cheap quality sugar.

STEP 2 :- So you run a test (like PMI) in milkshake sample or entire lot to know whether grade A sugar was put in it or not .(Concept of PMI)

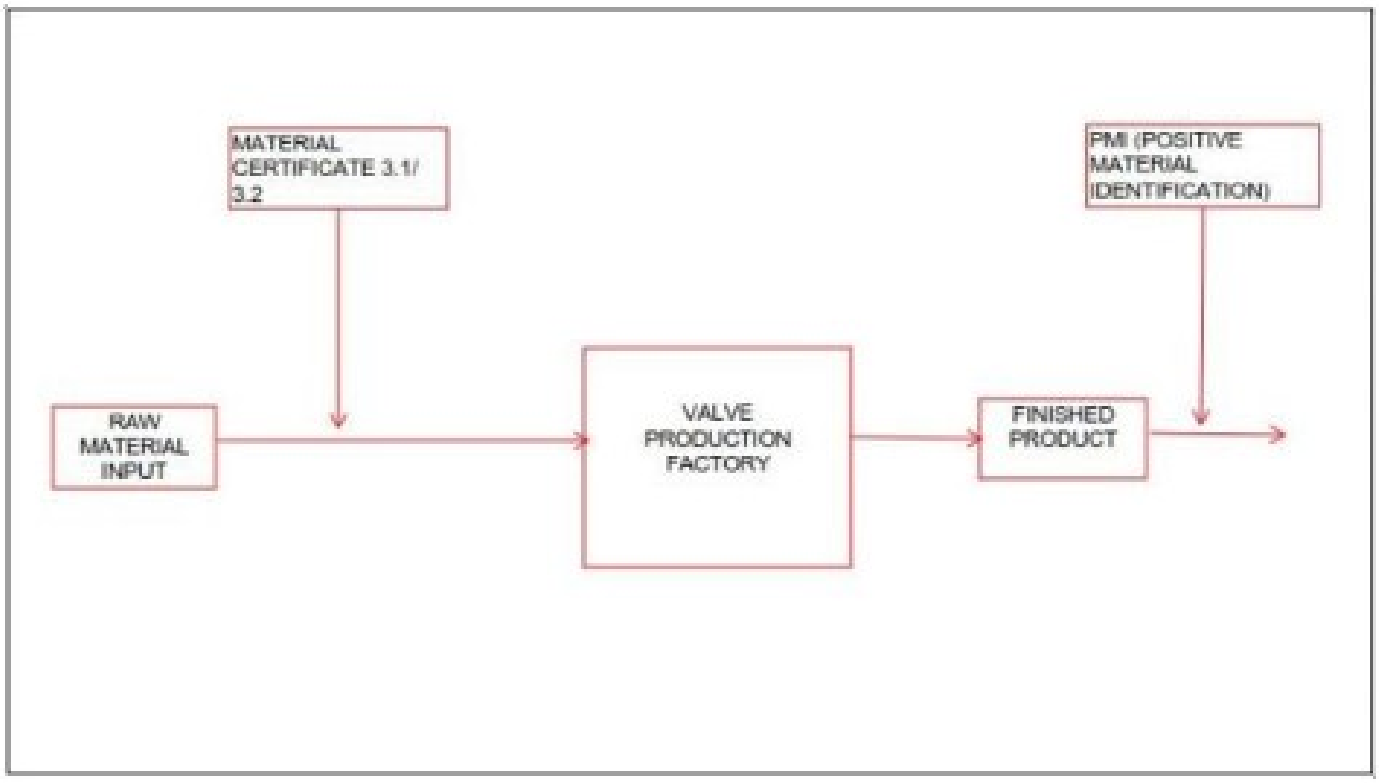
Same is with PMI (Positive material identification), the PMI could be done on few tags or entire lot of tags (Also referred as 100% of Tags) or 10% of tags etc depending on criticality etc.

Example:- In one of the projects for Bolts and stud only 10% of the lot would undergo PMI (This was finalized and agreed by client thus cost could be minimized by not checking the entire lot)

Practical "Valve" example

Suppose we want 100 Valve's of Grade A so when the vendor buys the Material from the supplier the supplier produces a Certificate called material certificate 3.1 and after the Valve is manufactured to ensure that the same material is used and no mixing has taken place PMI test is done.

In Short Material certificate is for Material Quality of Raw material and PMI is for the finished product .



Material certificate is further divided

Material Certificate 3.1:- This certificate is given by the manufactures own representative who was not involved in manufacturing process himself.

Material Certificate 3.2 :- Here a 3rd party (independent inspection authority) is involved which checks the material and the certificate is provided

Note:- It is also sometimes referred as CMTR :- Certified Material test Report

In conclusion:-

Both Techniques have their pros and cons.

PMI is costlier than Material certificate thus it depends on criticality of instrument or the material of construction. Also for exotic materials PMI is specified. Material certificate is having comparatively lesser cost but cannot guarantee material integrity as confidently as PMI testing.

Conclusion

The world of diaphragm seal is vast and this book aims to cover at least the basic practical concepts with regards to diaphragm seal systems.

The purpose of this book is to develop the thought process an engineer must have for designing a diaphragm seal system.

There would surely be more challenging situations coming your way like tough process conditions, challenging fluid properties, cost consideration, material compatibility issues and also non technical challenges like meeting project schedule or budget crunch etc.

However always keep the safety of the people as your top priority, and the environment in mind. Never let these challenges deter you from sticking to your values.

The families of the ones' who work on plant trust you and that the plant you have engineered would work safely and their loved one would return home safely, everyday.

Also, the environment depends on how we can creatively reduce pollution, fugitive emissions, leakages etc, thus we can have a greener and brighter tomorrow.

Without values nothing we do is worth doing.

All the very best for your own diaphragm seal adventure and if you are stuck, you can always send me your questions and queries on link below

https://www.asad-shaikh.com/contact.html and who knows we can have a second edition to this book soon. Till then keep exploring and sharing knowledge with other fellow engineers.

Yours' Truly,

Asad Shaikh

A special gift

What is BAW collection?

It's been years learning about this incredible branch of engineering called Instrumentation. The more I learn about it the more interesting it gets.

During this course of learning I have stumbled across great E-books, whitepapers. This includes great authors and experts like Tony R Kuphaldt, Acromag whitepapers, Engineers guide E-books, Troubleshooting guides etc. Thus I thought to compile this list and links to such amazing E-books and whitepapers in a single place called BAW Page.

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It's been a year and a half publishing articles every alternate weekend and and writing this book as well.

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It is all because of your appreciation.

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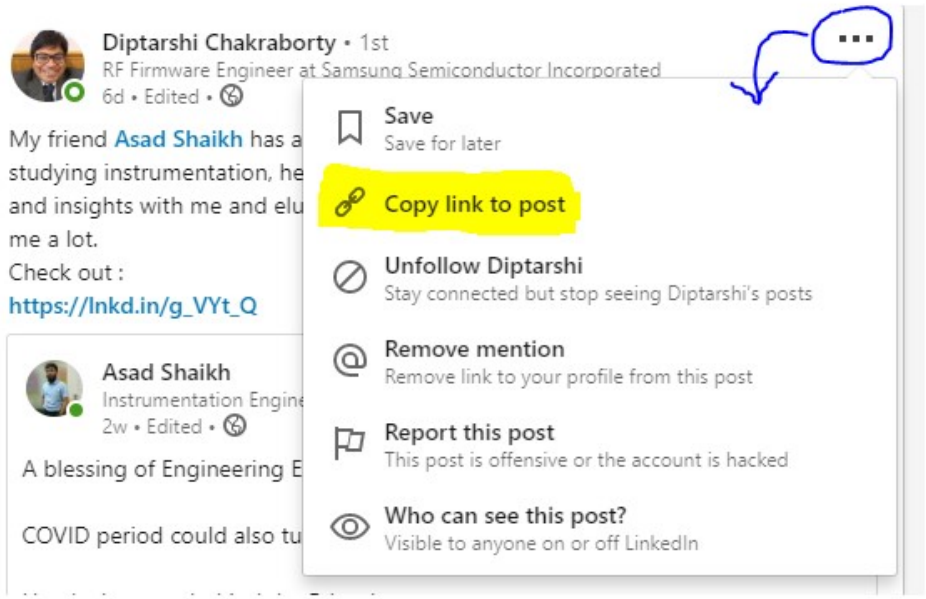

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Where to go next

I have been writing articles every alternate weekend.

I had published my first technical article on November 1st, 2018.Since then I have been publishing articles every alternate weekend and inshallah plan to do so for the coming years as well.

If you want to receive technical articles for continuous improvement, you can sign up on the free newsletter a.k.a Valueletter if you have not done so already and every alternate weekend receive valuable articles at your doorstep https://www.asad-shaikh.com/newsletter-and-books.html

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Other e-books on thermowells, summary on Instrumentation standards, Datasheet guides are in progress join the newsletter to receive your free copy as soon as they are released

Once again thanks for reading.

Acknowledgements

Firstly I am grateful to **God** for had it not been for his blessing of good health, financial stability and supportive family it would not have been possible to keep up with the consistency of writing this book.

Second, I am very grateful to **you**. Thank you for reading this book. The satisfaction of helping others is a great source of happiness and it is truly priceless. I hope to provide you even more valuable content in the near future. So stay tuned via newsletter page.

I have been very blessed to be part of a **company** that has inculcated in us the values that "safety is everyone's' business" and sharing knowledge about safety would bring about nothing but good.

Also, I am very grateful to all my mentors who have helped me in this journey of exploring diaphragm seals especially **Satish Sohani**.He would answer the most silliest of my questions and explore new concepts alongside me.It is through his encouragement that this book has come to its existence.

I could have not gained any of the knowledge that this book contains without my mentors who include Abhijeet Deshmukh**, Abhishek Singh, Chandrakant Kamble, Girish Vaishampayan, Amol Bhaviskar, Amol Pandit, Manoj Datir, Sameer Nalavde, Manish Mehta, Rakesh Kedari, Chetan Shenvi,Dhanajay Phachapurkar, Rajendra Patil,Nitesh Kshirsagar,Asif Mulla,Satish Sohani,Kailas Patil, Sachin Palange, , Ron Consemulder, Said Khan, Gurumoorthy Yegnanarayanan are few amongst the many mentors who have shapped my carrier** .

And the colleagues with whom I have had hours of discussion on technical topics **Mustafa Masurkar, Chinmay Tari, Shyantan Majumdar,,Ashish Kale to name a few among the many friends who have helped me along the way. (I sincerely apologize if I have missed someone)**

Finally thanks to **James Clear** for writing an amazing book "Atomic habits" and for his website on creativity and consistency.