Design for Emission Control and User Experience

This document is divided into two principal areas,

- Good design practice for emission control as identified by industry over many years of testing and experience
- An overview of performance at end user plants, as recorded using Method 21 measuring techniques

Overview

General industry guidelines give information on emission control rates for varying seal arrangements. The emission figures stated were chosen as ‘reliable targets’

- General purpose single seals with a plain gland - down to 1000 ppm
- Emission control single seals (API 682) with a plain gland - down to 500 ppm
- Emission control single seals (API 682) with plus secondary containment:
    - Segmented bushing, piped to flare, no purge - down to 500 ppm
    - Segmented bushing, piped to flare, purged - down to 300 ppm
    - Containment seal, piped to flare, no purge - down to 300 ppm
    - Containment seal, piped to flare, purged - down to 100 ppm
- Dual, unpressurised (tandem) seals with liquid buffer fluid - down to <100 ppm
- Dual, pressurised seals with liquid barrier fluid - down to 0 ppm
- Dual, pressurised seals with gas barrier fluid - down to 0 ppm

Good Design Practice

At the heart of the 1st Ed. of API standard 682 was the mission statement
This standard is designed to default to the equipment types most commonly supplied that have a high probability of meeting the objective of at least three years of uninterrupted service while complying with emissions regulations.
This statement no longer exists in the standard as some readers thought it a ‘guarantee’ and not the ‘target’ which was its original intention. (Most seals fail due to installation or operational errors which are beyond the control of the seal manufacturer)

To give a mechanical seal the best chance of attaining this target API 682 defaults to design practice and materials that have been proven in refineries across the world.

Cartridge construction

The first seals were, primarily, component (non-cartridge) designs, the seal was assembled onto the pump shaft and set by measuring from reference points on the pump. Seal performance and reliability was therefore very dependent on the skills of the installer. Older pumps had also been designed for soft packing meaning that dimensions were not always closely controlled

A cartridge seal is pre-assembled by the seal manufacturer, ensuring proper face loading and seal alignment. They can also be air pressure tested to verify correct assembly by the manufacturer prior to shipment. Cartridge construction is proven to reduce seal leakage, and therefore emissions.

Seal Materials

Seal materials of construction are not an immediately obvious consideration for reducing seal emissions but they can have a significant impact on seal performance. In practice, advancements in seal face and secondary packing materials have led to improvements in meeting stricter regulations. This will be demonstrated in the 'User Experience' section of this document.

Face Materials
Generally, unless overridden by the specific application, mechanical seals default to a combination 'hard' and 'soft' face materials. The general principle is that the 'soft' face conforms to the 'hard' face, complying with pressure and temperature distortions. This combination has the added benefit that it can accommodate process upsets better than two 'hard' face seals.

API 682 4th Edition defaults to a standard face material combination of silicon carbide v carbon graphite.
This type of face pairing provides

- low coefficient of friction,
- low combined surface roughness,
- the ability to "run in"
- consequent low leakage.

Secondary Seals
Secondary seals e.g. o-rings, prevent leakage of fluids through secondary paths and confine seal emissions to leakage past the seal faces. API 682 4th Ed. groups elastomers dependant on the base polymer used. Correct selection of secondary seal materials is another important factor in the emission control capability of a seal assembly. Material selection is, however, strongly dictated by the process fluid e.g ethylene propylene is not recommended for hydrocarbon applications.

Elastomeric o-rings are the default for emission control, PTFE materials are not recommended due to their potential for temperature and pressure set. Elastomeric o-rings are available in a variety of materials dependant on required chemical compatibility.
API 682 4th Edition identifies recommended secondary seal material options including FKM (Fluoroelastomer), FFKM (Perfluoroelastomer), NBR (Nitrile) and EPDM (Ethylene Propylene)

Seal Arrangement
The biggest influence on emission control is without doubt seal arrangement. Of course, increasing complexity of the seal increases the need for support systems and increases cost. Selection of more complex arrangements often come down to hazard considerations rather than emissions.
There is no definitive guide as to the emission control capabilities of any seal arrangement or type, measurements made in the controlled environment of a test laboratory will differ from those in the field where performance can be impacted by general condition of the rotating equipment (e.g. bearings), maintenance, variation in process. The following figures should only be taken as a general guide. Elsewhere in this document we will look at real life measurements taken from process plants around the world

General guidelines:

- General purpose single seals - emissions down to 1000 ppm
- API 682 qualified single seals - emissions down to 500 ppm
- API 682 qualified single seals, plus secondary containment:
  - Segmented bushing, piped to flare, no purge, emissions down to 500 ppm
  - Segmented bushing, piped to flare, purged, emissions down to 300 ppm
  - Containment seal, piped to flare, no purge, emissions down to 300 ppm
  - Containment seal, piped to flare, purged, emissions down to 100 ppm
- Dual, unpressurized seals with liquid buffer fluid, emissions down to less than 100

ppm
- Dual, pressurized seals with liquid barrier fluid, emissions down to 0 ppm
- Dual, pressurized seals with gas barrier fluid, emissions down to 0 ppm

Experience at Process Plants

Seal emission performance has been compiled from a number of sources. Some data has been compiled from a monthly survey at a European process plant while other data has been compiled from a series of surveys across European and US plants. These are reported separately and the results combined to give an overview of real life emission performance. This was possible as the same equipment and methodology was used in both programmes.

All results should be used with caution
- No 'full plant' surveys were conducted, operators choosing what equipment could be checked. As a result, a high percentage of measurements were made on perceived 'leakers and bad actors' which may mean overall results are an under estimate of true performance
- None of the plants were subject to emission monitoring regulations so equipment was not normally repaired if found to have high emission readings

Measurements were made using an organic vapour analyser (OVA) in accordance with EPA Method 21**.** As anyone experienced in carrying out Method 21 measurements will understand, strict adherence to this guideline is not always possible. Method 21 requires a measurement to be taken 1 metre upwind of the equipment and 1 cm from the source of leakage. Leakage is determined from the difference between the two. In practical terms
- When you are surrounded by pumps, valves, pipework etc. swirling of wind will make it hard to be sure where 'upwind' actually is
- I metre upwind might be in close proximity to a heavily leaking valve, strict adherence to the guide could mean a seal appears to be reducing emissions from the environment
- Some pump designs mean it is very difficult (sometimes impossible) to complete the 1 cm 360 degree check specified by Method 21

Study 1 Regular site monitoring
The study itself was a regular monitoring programme, initiated with the purpose of
- Determining current emission performance of units featuring light hydrocarbon services
- Identification of pumping equipment that would be deemed 'a leaker' if EPA emission regulations were in place
- Assess the impact to maintenance procedures if regulations were implemented
- Compare performance of seal arrangements
- Assess performance trends over a period of time

It should be noted that this study dates from times of API 682 2^{nd} Ed. so may underestimate emission performance achievable with more 'up to date' designs.
It is also worth noting that, while these measurements were made at the plant of a major international company, the plant was not required to conform to emission standards at this time. It is therefore likely that the readings established were poorer than might be expected at a regulated plant.

The seals monitored were all operating on light hydrocarbon duties. Monitoring was conducted at monthly intervals. The study comprised 4 seal arrangements

- Single seal, both API 682 and general purpose designs
- API 682 single seal with secondary seal
- Dual unpressurised (tandem seals)
- Dual pressurized (double) seals

Of the seals surveyed, 79% were single seals. A very small number (3) of these included containment seals, this technology being relatively new and, again, achieving specific limits did not dictate the use of better seal performance. All single seals were operating on light hydrocarbon duties with most operating on fluids with sg's between 0.52 and 0.64

An overview of results showed that 62% completed the programme without exceeding 500 ppm emissions and 69% less than 1000 ppm, by contrast 12% regularly exceeded 10,000 ppm and a further 12% reached this level on at least one occasion. As this was a study and not tied to maintenance the plant did not carry out repairs.
Most seals performed consistently and an overall assessment showed that 50% of all measurements were below 50 ppm and 69% were below 1000 ppm.

Study 2 Individual site surveys
Site surveys were conducted across Europe in a series of 'one-off' evaluations
Measurements were taken involving seals from a variety of manufacturers. Interesting points to note are

- Most seals were 'old technology' designs
- Some plants only selected their 'problem equipment' for evaluation
- It was therefore expected that results would be 'poor'

Most seals (79%) were single. Of these 54% maintained emission levels below 500 ppm and 63% below 1000 ppm. These levels are surprisingly good but it should be noted that 27% of single seals exceeded 10,000 ppm.
Containment seals (6%) gave 72% below 500 ppm and 87% below 1000 ppm. Although below normal expectations, the seals in the survey were mostly on equipment showing signs of primary seal failure (in one case operational issues had resulted in failure of both primary and containment seal) on a small sample this has a significant impact on overall results.
Dual seals gave consistently low readings, apart from one which had been in operation for over 5 years and was at the end of its working life. Even this seal maintained levels below 150 ppm.

Further site measurements were made but these were generally 'small scale' and have not been evaluated individually but are included in the combined review

Studies 1 and 2, overall evaluation
When combined the measurements from the site monitoring exercise and individual site surveys gave the following results.
Measurements were made across a total of 14 sites, in 7 countries and featured 5 different seal manufacturers

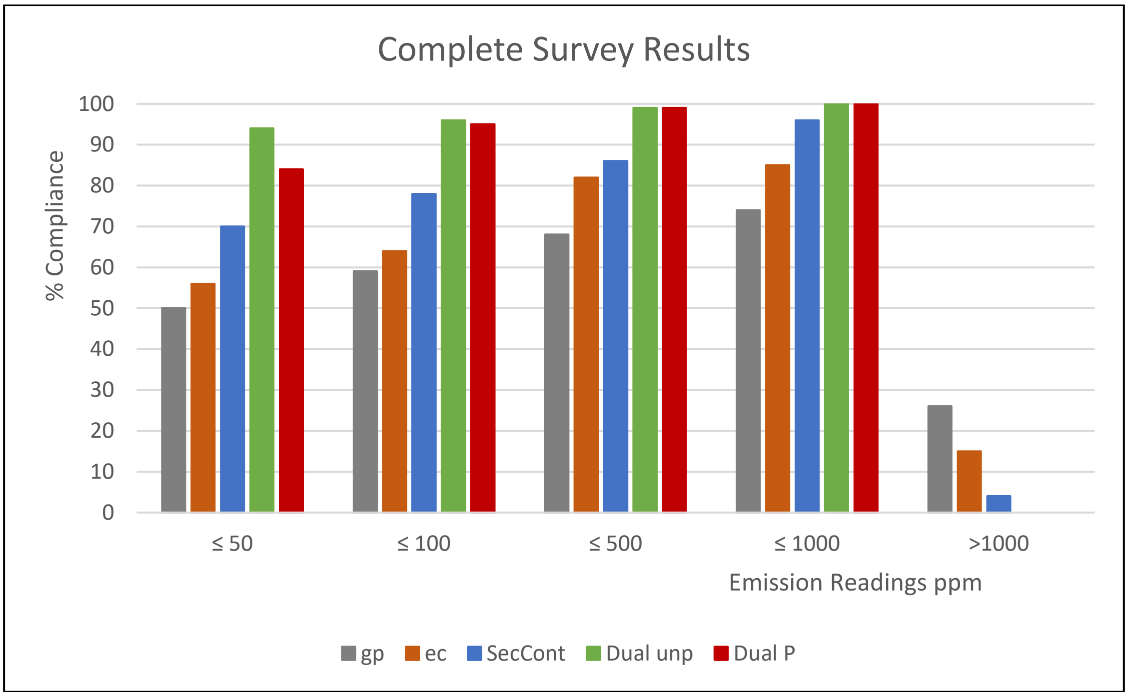
Total individual measurements	1089	comprising
Single seals	744	
API 682 designs	376	
General purpose	368	
Single seals with containment seal	201	

Dual seals	
unpressurised	108
pressurized	19
Insufficient information	7

Full seal and duty information was not available for all seals because

- Some operators did not wish to release the data for all equipment
- Measurements involved a number of manufacturers and confidentiality was maintained

How do seal arrangements compare?

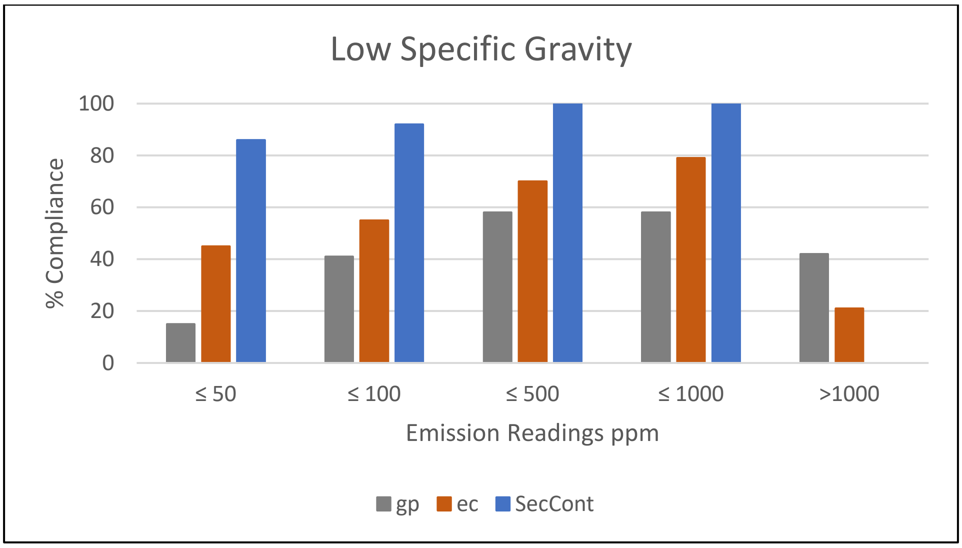


If the overall data is taken in isolation, then, comparatively, API 682 and general purpose seals showed little difference in performance but a significant number of gp seals were sealing higher specific gravity fluids where leakage is less likely to result in emissions. Where operational data was made available, only 4% of general purpose seals were identified as operating on fluids with s.g. ≤ 0.5 (29% on s.g. ≤ 0.6); for API 682 designs these figures were 21% on s.g. ≤ 0.5 and 45% on s.g. ≤ 0.6. So, while the chart shows similar levels of performance it is clear that API 682 designs were on more demanding duties. Containment seals provided significantly reduced emissions despite duties being more demanding again with 45% on s.g. ≤ 0.5 and 78% on s.g. ≤ 0.6.

As would be expected, dual seals gave the best performance but, again, the chart should be read with care. As previously stated, plant operators tended to choose ‘suspect or bad actor’ seals for surveys rather than ‘full plant’. Based on the chart alone dual unpressurised seals performed better than dual pressurized, the sample size for the latter was, however, small and so the overall results are easily distorted

The general overview from the results would suggest that the greater the complexity of seal design the greater the emission control (lower leakage) results

Perhaps a more relevant picture can be obtained from just comparing seals operating on lower specific gravities.



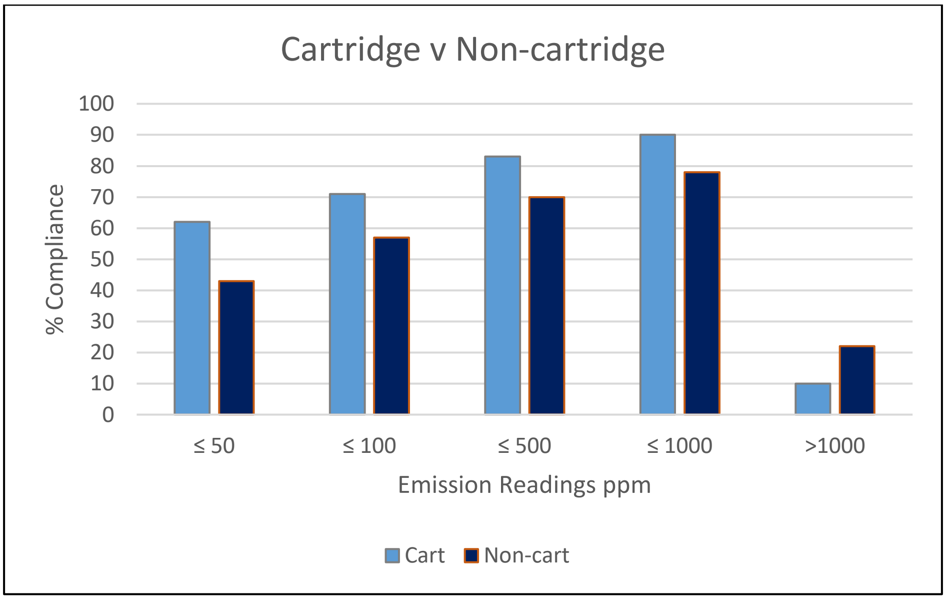
Here we see the much greater differential between API 682 and general purpose designs plus the big difference that can be achieved by addition of a containment seal.

Good design practice suggests that performance is improved by

- Cartridge construction
- Specific face material combinations
- Secondary seal materials

This programme enabled these to be considered.

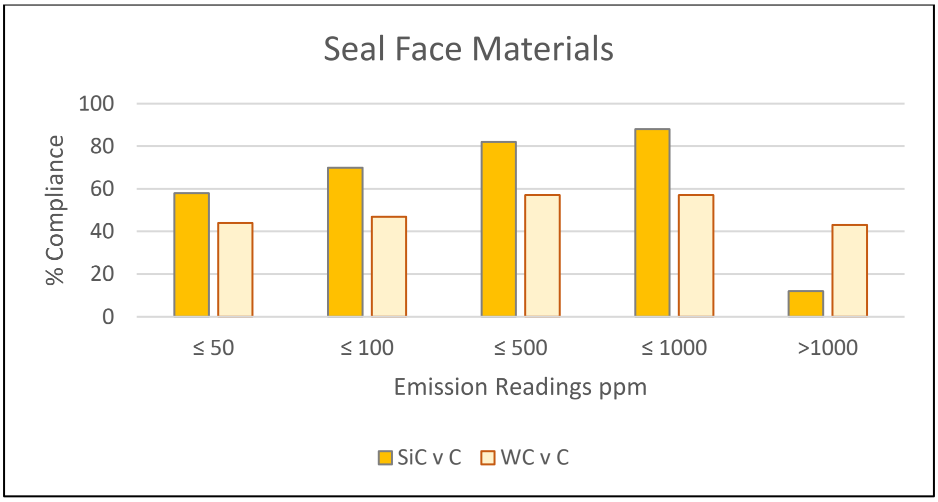
Cartridge construction



The results (limited to single seal arrangements) do not show a large improvement for cartridge over non-cartridge designs but other factors should be considered.

- API 682 designs are all cartridge construction, non-cartridge are all gp construction
- Most gp seals were operating on 'lower emission' fluids so would be less likely to produce high emission readings
- Being assembled units, often pressure tested before shipment, cartridge seals are far less likely to suffer from 'installation issues'

Seal faces

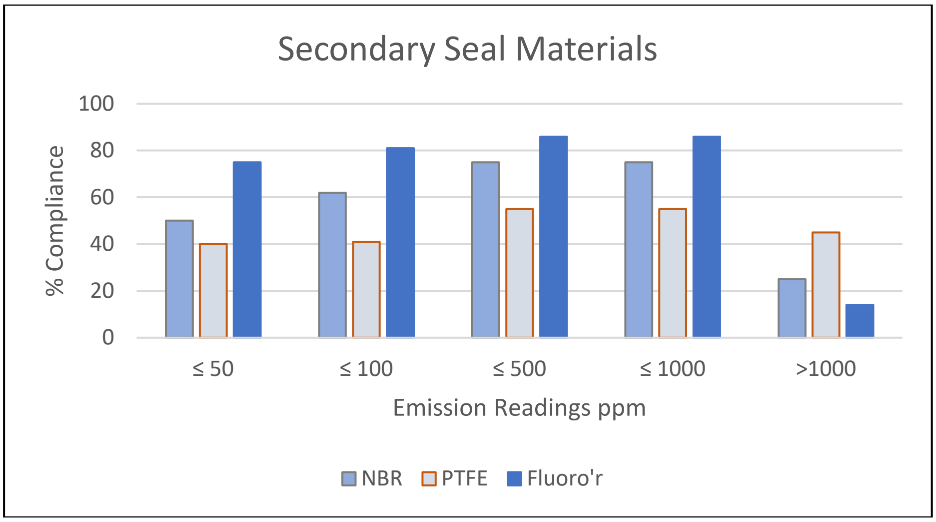


Evaluation of emission performance for differing seal face combinations consistently demonstrated that the preferred combination of silicon carbide v carbon performed better than the second most common combination of tungsten carbide v carbon. Unfortunately the seal face results cannot be evaluated in greater depth due to the availability of some application data. As we know that API 682 designs will all have silicon carbide faces and mostly operating on more demanding duties, it is therefore reasonable to recognize that the tungsten faces gave significantly worse performance while operating on (overall) less challenging duties.
Why else might silicon carbide provide improved emission performance over tungsten carbide?

- In practice seal faces operate with an extremely thin fluid film (thick films equal greater leakage). This means that a limited amount of contact between hard and soft face is inevitable. The silicon carbide v carbon combination is very tolerant of this type of operation (it is the core standard for dry running seals) so is less likely to be damaged which can result in higher leakage.
- Thermal conductivity of silicon carbide is typically 50% higher than for tungsten carbide. It is therefore more effective at conducting heat away from the seal faces and so promoting fluid film stability

Part of the sample was of sprayed faces (Stellite) v carbon. This appears to give excellent results but these applications were exclusively on non-emitting duties and generally only remained in use because the equipment they were installed on was not seen as 'problematic'.

Secondary seals



Three material options were identified in sufficient numbers to allow inclusion in the analysis, NBR (Nitrile rubber), Fluoroelastomers and PTFE, though the sample size for NBR was relatively small so the results may not be truly representative.
As with seal faces the results should be viewed with recognition that PTFE would only be in use where there were specific chemical demands, these were extremely unlikely to also be 'high emission' duties.
Beyond the survey results there are three reasons why use of PTFE can result in an emission source.

- PTFE is far less resilient than elastomeric materials and so less capable of conforming with irregularities
- Low resilience can be the source of high mechanical forces on seal rings which can result in distortion and leakage
- PTFE has poor tolerance to thermal cycling and can be 'moulded' by temperature and pressure. This is not an issue if pressure and temperature remain constant but can result in leakage if these vary.

Other work

Missing from the results in the survey are gas lubricated seals. These were used in very limited numbers at the time surveys were being carried out and were not included in work undertaken. More recent papers have presented an overview of emission performance of this seal type and this is summarised below

Data from European and USA plants studying single seals with gas lubricated mechanical containment seals concluded that 93.8% had Method 21 emission levels less than 1000 ppm and over 70% less than 50 ppm. To achieve near complete elimination of emission to the atmosphere some plant operators connect a flow of Nitrogen buffer gas to purge the gas lubricated, containment seal of process VOC's and help channel them to the recovery/disposal system. (API Plan 72)

Dual non-contacting seals with a pressurised nitrogen barrier fluid are showing near zero emissions in field applications Dual (gas) pressurised seals on a hydrocarbon plant in the USA have been measured at between 0-5 ppm after 12 months operation from start-up.

APPENDIX

Leakage of Mechanical Seals

All mechanical seals leak they require a fluid film between the faces to lubricate the interface and prevent rapid face wear. This means that there must be some leakage. This doesn't mean seals will visibly leak, mostly leakage will be measured in ppm (for a VOC) not in drops of liquid. A seal does not therefore prevent leakage but, when properly designed and operated, will control leakage to very low level that require specialist instrumentation to measure.

There are generic equations for calculation of seal leakage and seal manufacturers will often have their own, specific, equations.

These may include as part of the calculation process

- inner and outer seal face diameters
- seal face 'gap'
- pressure differentials
- speed
- viscosity of the sealed fluid

Generally, variation in these parameters have a linear impact on seal leakage. The exception is seal face gap which is often referenced as a cube of the value.

It is not the purpose of this appendix to look at specific equations but to highlight some considerations

The start point is to recognise that any leakage calculation can only ever be an estimate with a deviation dependant on the level of confidence required. All seals come with manufacturing tolerances which will impact real life leakage. But these tolerances are minute when seal operation is factored in, something out of the control of the seal manufacturer. (A simple way to think of this is by considering a car. A manufacturer may quote an expected figure based on standard tests; a very cautious driver may achieve lower fuel consumption but someone 'more sporty' will be unlikely to achieve the predicted consumption. So it can be considered with mechanical seals, operation and maintenance impact performance far more that the manufacturer is able.

General comments

- variation in seal face gap has a greater impact on seal leakage that other variables
- large seals tend to leak more than small seals
- although simple some calculation methods indicate that leakage will be greater for a narrow face seal than for a wide face seal, in practice narrow face seals often leak less because the sealing gap is usually smaller than for wide faces
- most equations do not attempt to consider seal ring distortion due to temperature, speed and pressure variations
- operational factors that will affect leakage performance include
    - equipment runout and alignment
    - vibration
    - variation in process conditions
    - variation in process fluid
    - contaminants in the process fluid

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