

Mechanical Seal Reliability

The European Sealing Association e.V. (ESA) is a pan-European organisation, established in 1992 and representing over 85% of the fluid sealing industry in Europe. Member Companies are involved in the manufacture, supply and use of sealing materials, crucial components in the safe containment of fluids during processing and use. This document has been prepared by the Mechanical Seals Division of the ESA.

Introduction

Reduction of plant operating costs is a key consideration for all process plant operators.

While individual plants will have specific needs, one way of achieving this, which is common to all, is by achieving improved operating efficiencies through increased plant reliability.

Pumps are critical items of rotating equipment and are an important consideration in overall reliability. In turn, pumps are themselves highly dependent on their components, principally seals, couplings and bearings. In this document we will primarily consider the impact mechanical seals have on plant performance.

Developments in seal design and materials, along with the implementation of industry standards, such as API 682, has had a significant impact on seal performance and reliability but component reliability is not always purely down to the product itself. Installation, operation and maintenance factors play major roles in equipment reliability.

In this guide we will look at influences on mechanical seal reliability, using data from existing process plants over several years. We will show how ongoing improvements can be achieved through understanding of seal operating conditions. How, through reliability programmes in partnership with suppliers who are dedicated to aftermarket support, like ESA member companies, a 'win-win' relationship can be developed.

Historical and Updated Pump Failure Distribution.

Historical failure data from an old study, based on a Middle East refinery, indicated typical failure factors as shown in Fig. 1

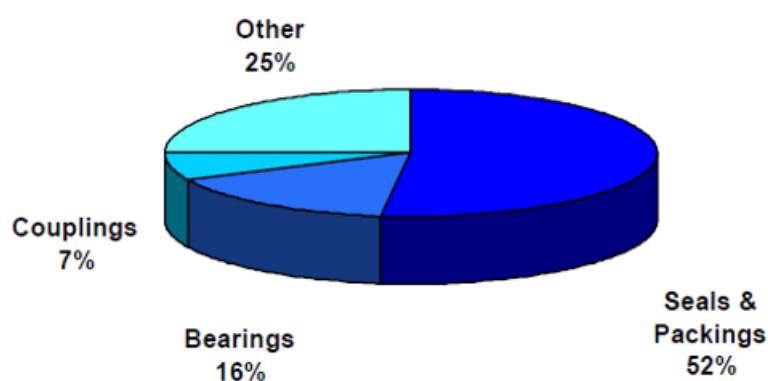


Fig. 1 Historical Pump Failure Data

New and much more recent data, Fig. 2, compiled over a period of two years (in the 2020's) records 3500 failures at 18 different end users and gives an updated picture of pump failure.

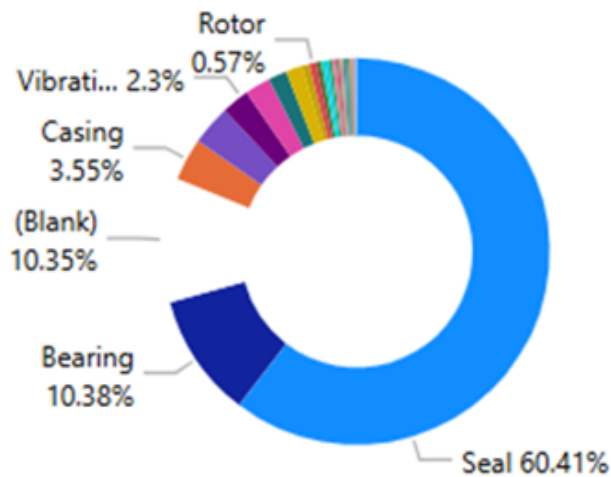


Fig. 2 Updated Pump Failure Data

Part of the change is a result of technology around bearing protection and condition monitoring, which has improved over the last 25 years, meaning that those failure types have reduced as a percentage. Also, with laser alignment becoming almost universal, coupling problems are now a very rare event.

As a consequence, although machines are now generally running for longer than ever the mechanical seal has become even more dominant in the hierarchy of components that fail. It is therefore more important than ever that end users focus on the causes of mechanical seal failure.

In any analysis, however, it would be absolutely wrong to assume that the fault always lay with the failed components. The impact of all factors must be considered. Fig. 3 shows a high-level overview for the root cause of those 3500 failures.

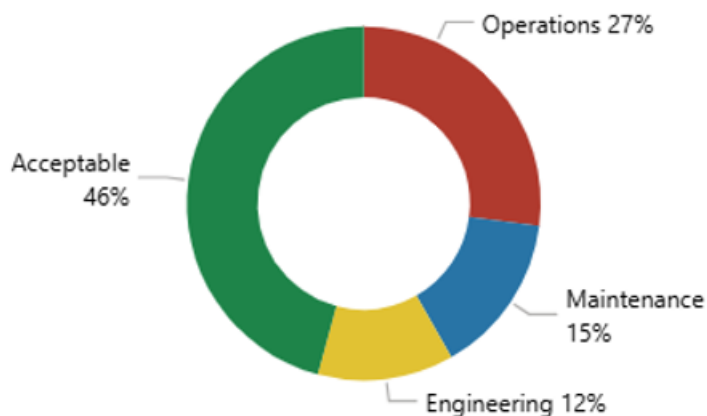


Fig. 3 Root Cause of Seal Failures

“Acceptable” simply means that there was no justification to investigate root cause because reliability was acceptable e.g. the seal was not considered to have prematurely failed.

Of course, 100% acceptable failures is the target in an ideal world, to aim for this target we need to focus on the ‘unacceptable’ failures.

If we look at Fig. 3 with the ‘acceptable’ failures removed we get a chart more like the one in Fig. 4

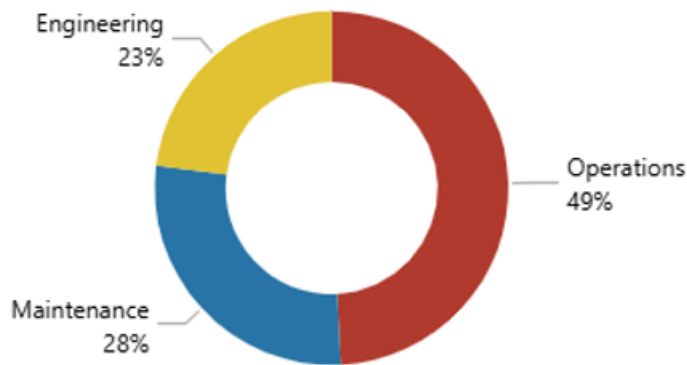


Fig. 4 Root Cause of Premature Seal Failures

Each category may have many sub-categories, typically the main causes of failure for each can be summarised as

Fig. 5 Typical Causes of Seal Failure

Operation

- Cavitation
- Cooling
- Dry running
- Flushing systems
- Foreign objects
- Inconsistent procedures
- Priming
- Process upsets
- Quench systems
- Valves closed
- Variation in sealing duty

Maintenance

- Alignment
- Assembly
- Base plate
- Bearing issues
- Cleaning
- Clearances
- Lubrication
- Run out
- Seal setting
- Venting

Engineering

- Impellor size
- Incorrect duty specification
- Pump selection
- Seal housing
- Seal selection
- Shaft stiffness
- System design

With all of these things it is important that robust data is available, so it can be examined to determine the true root cause. The most recent occurrence in the life of the seal might be a visible leak and that's just what the operator sees when they write the repair notification. That's ultimately 'seal failed' in the short text, but not the root cause.

So, while seals are clearly important, ongoing improvements must involve more than just looking at the seal in isolation. The seals working environment is critical to its performance. This is likely to involve

- methodical process of identifying bad performers
- implementing a reliability improvement programme

The effectiveness of this approach has been demonstrated on process plants especially where there has been close co-operation between supplier and end user.

In evaluating seal performance, a collective Site or Plant Index is an effective tool for comparison. Often used is 'Mean Time Between Failure'

$$\text{Mean Time Between Failure (Months)} = \frac{\text{Total Number of Pumps}}{\text{Total No. of Seal Failures in Month}}$$

This is a valuable measure for an individual plant where data is compiled in a consistent format. However, care must always be taken when trying to use this method to compare different plants. When evaluating MTBF some plants will use the date of the failure, i.e as soon as the work order is written while some use the date that the pump is taken out of service and put into the repair facility. Although MTBF continues as an important measure, in today's market we are starting to see repair cycle times and cost per repair becoming more important. Some operators will use MTRR (Mean Time To Repair), MTBR (Mean Time Between Repairs), MTBC (Mean Time Between Change) or CPR (Cost Per Repair), these however are often not measures that a seal supplier can easily determine.

The most important factor is not which method is adopted, it is consistent application of the method chosen and not attempting to compare different reporting methods.

Seal Life Improvement Programme

Any Seal Life Improvement Programme will normally start with a reliability survey; this is the simple part. To manage the changes in addition to normal workload is the challenge. There is no universal panacea to resolving mechanical seal failures and a dedicated long-term commitment is required.

- A collaborative effort between the refinery and the seal vendor can work well.
- "Workshops" or "Surgeries" have proved effective
- Record keeping is very important

In the past a seal life improvement programme would often look at resolving the 'problem' sealing duties (worst 10%). These were, and often still are

- Hydrocarbon duties above 200°C (392°F)
- Hydrocarbon duties below 200°C (392°F)
- Light hydrocarbons
- Pre-flashed crude oil (Above 120°C (248°F))
- Non-hydrocarbon duties
- Vacuum Tower bottoms or any Heavy crude high temp service

An alternative approach, often favoured these days, is to work with the Users to develop a top 10 to 15 bad actor list and do a deep dive into the failures to determine if the problem is seal, pump or process related. From this a solution can be determined.

A summary of application areas against plant type is given in Appendix 1

The importance of seal services should also be considered including

- Atmospheric quenches - water and steam
- Double and tandem seal systems
- Implementation

Refinery Life Updated

Earlier studies looked at MTBF a general overview, this was compared with the target figure (never a performance guarantee) in API 682 of 25,000 hrs. (Note, this figure is being removed in the current API 682 update.

While the API figure equates to an MTBF of under 40 months, in the mid-1990's plants were achieving MTBF rates of around 70 months (but details of how those figures were calculated is not available)

Since the original study, seal manufacturers working with end users have reported updated average MTBR/MTBF figures. That data suggests that 60 months is a good benchmark for where most sites want to be, but this does vary by industry.

- Midstream applications deal in operating hours rather than MTBR, 48 months is a often considered an acceptable benchmark.
- Some majors are targeting 100 months as benchmarks.

While the figures might appear to suggest that there has been little improvement in reliability since the original study, it should be remembered that the definition of failure has also been impacted by the introduction or modification of regulations. An example of this would be in emissions targets e.g. a seal that was leaking 1500 ppm 30 years ago could easily have been run in that condition and not deemed to have failed until liquid leakage occurred. With the implementation of more stringent environmental regulations, the same seal would not be considered to have failed. An example of this is given in 'case studies'.

4. A Proven, Systematic Approach to Performance Improvement

There is no 'perfect' definition of an approach that will work for every plant and every operator. The most important factor in improving seal (and plant) reliability is for the plant operator and seal supplier to work closely together. From this an understanding of what is being achieved and what can be achieved will be determined.

Typical considerations in this process are

- Set appropriate, outline, targets and time-scales.
- Recruit the help of your suppliers as, and when, appropriate
- Conduct a survey
- Analyse the data to determine what is being achieved on your plant.
- Identify the bad actors and problem duties
- Set up a performance improvement plan
- Set up the monitoring and reporting system
- Collect and analyse data regularly
- Compare to target
- Revise the plan identifying any changes to the list of bad actors
- Agree the revised plan with revised targets and time-scales as necessary
- Continue until targets are achieved

While these actions are important in their own right, there is another trend in the refining industry that, potentially, makes close co-operation between operator and seal supplier even more important. The last 25 years has seen increasing likelihood of end users seeking to run lower cost crudes and mixes of different crudes. In some cases, this will occur naturally as oil wells approach the end of their (cost effective) productive lives. These crudes often contain increased proportions of aggressive compounds which may require updated material selections and usage of more exotic alloys. Refineries have also become more dynamic in adjusting their product streams to meet market demands on an almost daily basis. These trends increase the potential for operating upsets with consequent increase in the proportion of failures relating to operating issues.

Case Histories

Case History 1

A plant was tasked with meeting revised emissions reduction regulations.

Thirty pump seals in relevant LDAR services in the facility's Isocracker, Naphtha, and Platformer units did not meet the regulations.

Data compiled from internal audits revealed that the pump seals in question had repetitive leakage readings greater than 2000 ppm. (So, not 'traditional' failures but failure to comply with target emissions thresholds). In fact, up to implementation of regulations they had been considered 'good performers'

Seal types were a mix of API Type A (pusher) and Type B (bellows)

After reviewing the application history, equipment envelope, and process conditions, a suitable approach was selected to resolve the re-occurring emissions issues with these pumps.

- Application of API 682 tested configurations to align with current standard edition requirements.
- Pumps were identified as pre-8th edition; steps were taken to recondition the pumps and restore fits and internal alignment readings to mitigate effects on leakage. Composite wear rings were installed to help improve dynamic stability of the rotating assembly.
- The plant opted to update to dry containment seals, plant nitrogen was utilized for purging and venting the seals.
- The improvements made were noticeable immediately and continued. Comparison of a two-year period prior and then a two-year period after implementation showed an MTBR of 7.2 months (emissions failures) before change and 240 months after project implementation.

Case History 2

This was a new build plant so was constructed using the latest technology to reduce operating costs and to minimise environmental impact.

During plant commissioning and early operation, mechanical seal 'failures' were higher than expected and, with a trend of increasing seal replacements and therefore costs, a task force which included Operations, Maintenance and the seal vendor was formed to address the problem.

The first task was to establish a true picture of the situation

- calculate the actual mean time between failures (MTBF) – around 30 months
- identify the 'bad actor' seals – 15 identified

A target for an MTBF of 5 years with an ultimate objective of 8 years was set and the team met monthly to review plant performance and improvements achieved around three measurement bases

- Seal replacements by failure type
- MTBF/ MTBR (mean time between failure/ repair)
- Repair costs

In recognising that seal failure is often the symptom rather than the problem, the failures were categorised into

- design related (incorrect selection, duty not as specified on data sheets, poorly designed circulation pipework etc.)
- maintenance related (damage during installation, incorrect pipe connections etc.)
- operations related (off duty running, closed valves, dry running etc.)
- other (non-attributable)
- replaced no failure (planned maintenance, replacement after bearing failure etc.)

Early on in the programme operations related failures were identified as a big problem, within two years of start up these had been reduced six-fold.

Within four months MTBF data showed an increase to around three years. Three years into the programme the first target of 5 yr MTBF had been achieved.
Perhaps even more significant was reduction in costs. Within two years annual spend on seal repairs had reduced by approximately 67%
Commitment from both operator and vendor and a close working relationship between the two resulted in major benefits, repaying the cost of implementing the scheme over and over again

Case History 3

Summary of the key items in a brief given for a site survey and improvement plan for seals.

- Recommendations on total management of seals from purchasing to maintenance
- Reduced cost of ownership. - safety - reliability - parts rationalisation - inventory reduction
- Increase the existing MTBF of all pumps by 25% over a two-year period.
- Identify the pumps with low seal performance and recommend upgrades
- Reduce maintenance costs of seal failures by 20% in two years.

Two essential prerequisites were identified for improving plant performance

- a firm commitment to the programme
- maintenance of good data on equipment failures Recorded data should be held in a format that allows easy input and analysis and in sufficient detail to pinpoint exact causes of seal failure (ideally a computer-based system of reliability management software which utilises a tracking database and features Root Cause Analysis)

Conclusions

Increased plant reliability, leading to reduced operating costs, is a goal for all operators on refineries and other process plant. This also comes with the challenge of changing business demands and the need for adaptable process streams.

Developments in mechanical seal design and materials and new/ updated industry standards, have had a significant impact on seal performance but the biggest improvement in performance is not solely down to these factors. Experience shows that how those seals are used is very important to achieve ongoing performance improvements. Installation, operation and maintenance factors play major roles in equipment reliability.

Implementation of reliability programmes in partnership with dedicated seal suppliers can result in significant improvements in plant reliability with consequent reduction in operating costs. Working with ESA member companies, dedicated to aftermarket support, will establish the right environment to make these objectives happen.

Appendix 1

Pump applications, by plant type, where achieving plant MTBR may be more difficult

Petrochemical Plants

Challenging Characteristics:

- Pumping temperatures below -29°C (-20°F)
- Pumping temperatures above 260°C (500°F)
- Specific gravity below 0.7
- High/low viscosity
- Low vapour margin
- Abrasive particles

Challenging Applications:

- Quench oil – *furnace coke, varying rates, hot*
- Quench tower bottoms (coke laden tar) – *Hot, abrasive*
- Demethanizer bottoms & reflux – *Very cold, low vapour margin, low lubricity*
- Ethane product (if sent to pipeline) – *high pressure, low vapour margin, low lubricity*
- Ethylene product – *high pressure, low vapour margin, low lubricity*
- Amine services – *material compatibility, face plating*

Refineries

Challenging Characteristics:

- Pumping temperatures above 260°C (500°F)
- Specific gravity below 0.7
- High/low viscosity
- Low vapour margin
- Abrasive particles

Challenging Applications:

- Heavy crude oil – *viscous, dirty*
- Atmospheric & vacuum tower bottoms – *Hot, dirty*
- Coker Charge – *Hot, dirty*
- Hot gasoline, Kerosene, Naphtha – *low vapour margin, low lubricity*
- FCC Catalyst borne services – *hot, abrasive*
- HF Alkylation services – *corrosive, lethal*
- Sulfur services – *corrosive, odd properties*
- Amine services – *material compatibility, face plating*
- Furfural services – *material compatibility (depending on plant process)*

Midstream Pipeline

Challenging Characteristics:

- High pressures 82.5 barg (1200 psig) and above
- Multi-service pipelines – *Wide viscosity range*
- High viscosity crude oils in wide pressure range.
- Identical pumps often in series – *with customer desire to use “one” seal design.*
- Remote locations requiring auto-start, etc.
- Abrasive particles – e.g. sand
- VFD usage and impacts to seal performance