

# ANALYZING UNACCEPTABLE SEAL PERFORMANCE

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## ABSTRACT

For many years, acceptable seal performance was defined as "minimal or no visible leakage." During the last decade, these definitions have changed immensely as government and industry have combined in a massive effort to clean up the environment. As the requirement to conform to new emission regulations has become reality, greater attention has been given to seal performance and the sealing system selection process. Presented here is an action plan that, when implemented in conjunction with the application of new standards and guidelines, will improve seal life, while reducing emissions. Actual data are used to demonstrate how sealing system performance has been improved over both the short and the long term.

## INTRODUCTION

Many users ask, "How do I determine if a mechanical seal is performing acceptably, and what actions should I take if it is not living up to expectations?" The answer involves undertaking a disciplined, problem-solving approach and, when necessary, thoroughly reviewing the seal selection process. This action plan is not as complex as it may seem, and can be broken down into the following eight steps:

- Define acceptable seal performance.
- Troubleshoot the equipment in the field.
- Review the process and sealing system data.
- Select the sealing system.
- Investigate the operational history.
- Perform a seal analysis.
- Perform root cause analysis.
- Implement the solutions and monitor the results.

In order to improve sealed equipment reliability, it is important to look at the big picture, in addition to looking at each case where a seal is not performing acceptably. Therefore, it is important to gather data on all repairs, so that these data can be analyzed to yield useful information, such as determining the most common causes of unacceptable performance and which pieces of equipment must be repaired most frequently.

## ACTION PLAN

### *Define Acceptable Seal Performance*

More often than not, acceptable seal performance means conformance with published standards. Federal, state, and local governments have enacted regulations that define maximum allowable emission levels for a number of fluids. Users have also created their own definition of acceptable performance for fluids not covered by these regulations, or when more stringent requirements are desired for plant safety.

Acceptability varies widely, depending on the product being sealed. As an example, leakage from a clean water pump is usually not considered unacceptable until it is visible, and is frequently defined in terms of measurable volume per unit of time. On the other hand, leakage of a volatile, hazardous air pollutant (VHAP) from a piece of rotating equipment is probably not visible and must be kept to extremely low levels. In the case of a VHAP, leakage is typically measured by sampling the environment adjacent to the equipment with a portable organic vapor analyzer (OVA) or "sniffer." The allowable concentration is usually stated in parts per million (ppm), although in some extremely sensitive situations allowances are in parts per billion (ppb).

### *Troubleshoot the Equipment in the Field*

When a sealing system is not meeting expectations, troubleshooting the equipment in the field is often the first step in improving a sealing system's performance. It takes the straightforward, commonsense approach, focusing on issues and corrections that can be made onsite without shutting down the process or taking the equipment out of service. It starts with visual observations of the equipment, the seal, and the sealing support system. The objective is to determine where the leakage is coming from and, if possible, correct it without removing the equipment from service. Typical sealing system corrective actions include turning on a flush line, adjusting a quench, tightening gland bolts, and checking pipe or tubing connections. Operational corrections might include opening a suction valve to stop cavitation or adjusting a discharge valve to improve efficiency and reduce internal recirculation.

### *Review Current Process and Sealing System Data*

If the unacceptable performance cannot be corrected by actions taken in the field, the equipment must be taken out of service for repair. Before analyzing the equipment and sealing system, however, it can be very useful to review the current process and sealing system data along with the repair history for the piece of equipment. In order to perform this step effectively, it is critical to have a database in which extensive information can be stored and accumulated for each piece of equipment. The database should

provide detailed information on the equipment, process fluid, operating conditions, sealing system, and repair history. By entering the necessary data into this database, a baseline is established from which any changes can be made and progress monitored.

During the review of the current process conditions and the sealing system, one may find the conditions have changed to the point that the current sealing system cannot function reliably. In this case, it will be necessary to select a new sealing system for the application.

### *Select the Sealing System*

When it is determined that the sealing system needs to be changed (which could occur at this stage or after the root cause of unacceptable performance has been determined), it is important to have established guidelines for selecting the new system. Many users have established their own standards for seal selection based on the experience they have gained in their plants. In addition, seal manufacturers and users have worked together to establish guidelines and standards that can be used in place of, or as a supplement to, a user's own standards.

The Society of Tribologists and Lubrication Engineers (STLE) was the first engineering organization to address the selection process of mechanical seals. They published an "Application Guide to Control Emissions" in their Special Publication SP-30 in 1990 (STLE, 1994). This guide was quickly adopted by many users to select a seal arrangement (single, tandem, or double seal) based on specific gravity and permissible emission levels. SP-30 was revised in April 1994, based on the CMA/STLE Mass Emission Study (Kittleman, et al., 1994). The revised document features an updated "Mechanical Seal Application Guide" and gives insight into the use of contacting, noncontacting, and dry-running seal technology. Since 1994, it has been more widely adopted by the user community.

The American Petroleum Institute (API) published the first mechanical seal standard in the world (API, 1994). The intent of this standard is to identify the requirements of a sealing system that will run at least three years and meet emission regulations. It features a selection process for most refinery processes and some chemical/general industry applications. As this standard is revised, it most likely will address many more applications.

### *Investigate Operational History*

It is critical to determine if deviations from normal operation of the equipment could have played a part in causing the failure. With today's modern control rooms, it is possible to gather a wealth of operational data. Items that are frequently looked at when investigating a failure include flows, temperatures, tank levels, barrier pot pressures or levels, and motor amps.

Much can be learned from analyzing trends of the above variables. These data, however, do not replace the information that can be gained by speaking to the people responsible for operating the equipment. The operators will not only be able to discuss any operational deviations that could have led to a failure, but they will also know why the operation of the equipment deviated. In order to gain this valuable information, the operational personnel must want to help solve the problem. One of the best ways to do this is to make them feel that they are a part of the solution rather than a part of the problem. This is not always easy. In many cases, years of finger-pointing among the operational, maintenance, and engineering groups must be overcome.

### *Perform Seal Analysis*

In order to perform a failure analysis on a mechanical seal, the seal should be disassembled and carefully cleaned so that a piece-by-piece inspection can be conducted. During the analysis, each observation is categorized as being chemical, mechanical, or thermal in nature.

- Chemical damage is usually in the form of general corrosion, pitting, corrosion/erosion (including fretting), or crevice corrosion under dynamic O-rings. Also included is any chemical attack of O-rings, and the leaching of the binder or secondary phase from the seal faces.

- Mechanical problems can develop from excessive hydraulic pressure that could cause face deflection, secondary seal extrusion, or erosion. Other mechanical problems can come from improper installation, uneven torquing of gland bolts, or misalignment.

- Thermal damage manifests itself in the form of heat checking, phonographing, carbon blistering, pullout, setup deposits, or polymerization between the faces. Coking, O-ring failures, and loss of spring load for bellows or springs could also be considered as thermal failures.

By grouping observations in this manner, a simple statistical analysis can be performed at a later date identifying the primary types of problems seen within all, or part, of a plant. For the database to work effectively, it is strongly recommended that all observations be recorded each time a seal is evaluated.

#### *Perform Root Cause Analysis*

Root cause analysis assigns the ultimate responsibility for unacceptable performance. In other words, the original cause of failure must be deduced from a combination of experience and the observations made during troubleshooting, data gathering, and failure analysis. For statistical purposes, the findings were organized into nine primary causes, then further defined by secondary and tertiary causes. As an example, the first classification may be "Process," with a secondary cause, "Poor Lubrication," and the tertiary cause being "Flush Flow Blocked or Reduced." Each of the nine primary causes along with their secondary and tertiary causes are posted to the database. By analyzing these root causes and the success of various corrective efforts, recommendations can be made with a high degree of probability that the problem will be fully identified and corrected.

Breaking down the root cause into primary, secondary, and tertiary causes permits data to be statistically analyzed for an operating unit or an entire facility, or to be expanded across many facilities. This enables users of this system to improve reliability in two ways. First, they can focus their attention on a particular piece of equipment or a certain type of service; second, they can look for general trends in the root causes recorded in the database and come up with an action plan to improve overall equipment performance. For example, it would make sense to implement an operator training program if an analysis of the root causes shows that a large percentage of seal failures were due to operational issues.

As with any statistical analysis, good data are the keys to success. Good data are not always easy to obtain, since original cause of poor performance is sometimes contradictory to one's instincts. For instance, it is common to blame any dry-running pump situation on operator error. While this may sometimes be the case, dry-running can also be due to poor system design, inadequate net positive suction head (NPSH) during startup, or it might simply be more cost-effective to allow a pump to cavitate periodically. In these cases, the system design must be improved or the sealing system must be changed to make it more tolerant of actual conditions.

#### *Implement Solutions and Monitor Results*

The first step to implementation is documentation. Documentation of equipment design or process changes may be required by federal, state, or local government regulations. Implementing a management of change (MOC) process normally satisfies these regulations. At a minimum, this process requires the reason for a change to be stated along with necessary drawings, installation and operational procedures, updated files, and training

when necessary. Once the MOC is approved, the person responsible for implementing the change should monitor each step outlined in the MOC to ensure that the process runs smoothly.

Monitoring should start upon commissioning the piece of equipment and continue under watchful eyes for the first 24 hours. This time frame is sometimes called the "infant mortality" period. When failures occur during the first 24 hours, they are frequently caused by installation or operational errors. Once through the infant mortality period, the reliability of the equipment should continue to be monitored to ensure the implemented change has produced the desired result.

#### ANALYSIS OF DATA IN THE REPAIR DATABASE

The repair database can be used to look at the repair history for a particular piece of equipment, to develop a "bad actor list," or to analyze the data to determine the most common root causes of repair.

When a piece of equipment is being pulled, it is helpful to look at the records for past repairs. This brings the analyst up to speed on problems that have been seen before on this piece of equipment, along with any solutions that have been implemented to improve reliability.

A bad actor list can also be formulated by analyzing the repair data. The most rudimentary bad actor list is generated simply by finding the pieces of equipment that have been repaired the most frequently during the chosen time frame. Other variables, such as repair costs and the criticality of the piece of equipment to production, can also be included in this evaluation. In any case, it is important to generate a list of the equipment that is causing the most problems, so more time and effort can be focused in this area.

The repair data can also be used to determine the most common causes of repair. In order to do this, the root causes of unacceptable performance must be broken down into categories so an analysis can be performed. The results of such an analysis are shown below.

#### RESULTS

##### *Analysis of Root Cause Data*

Root cause data from five chemical plants and three refineries were analyzed to determine the most common causes of repair at these locations. For statistical purposes, the findings were organized into nine primary causes, then further defined by secondary and tertiary causes. The nine primary causes are as follows:

- Process
- Maintenance
- Equipment/piping
- Scheduled maintenance (the equipment did not fail)
- Seal design/selection
- Seal quality
- Acceptable life (normal wear)
- Other (does not fit any of the defined categories)
- Cannot be determined

A total of 4,133 equipment repairs were analyzed. The cause of failure could not be determined for 553 of these repairs, while 104 others were pulled for scheduled maintenance. This left us with 3,476 repairs to analyze statistically. As shown in Figure 1, "Process" was the most common root cause accounting for 38 percent of the repairs. "Seal design/selection" and "Equipment/piping" were also significant contributors with 24 percent and 20 percent, respectively.

The root cause data were segregated by industry to see if there were significant differences between the root causes of repair for oil refineries (Figure 2) and chemical plants (Figure 3). While the

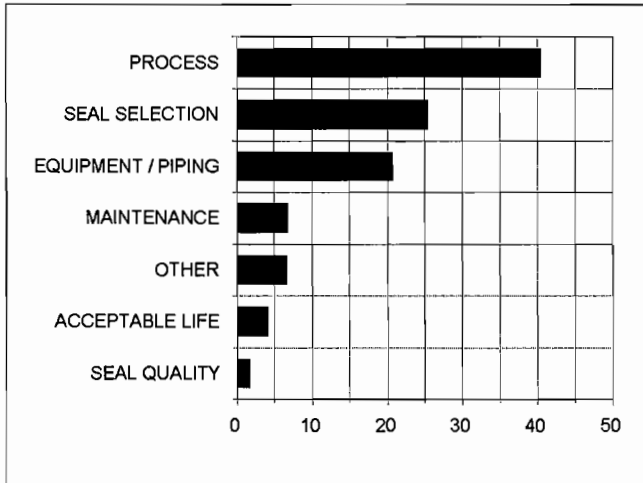


Figure 1. Breakdown of Root Causes for All Plants.

three most common root causes were the same, the breakdown within these three areas differed significantly. Process issues were more prevalent in the chemical plants, while equipment and piping problems were more common in the refineries.

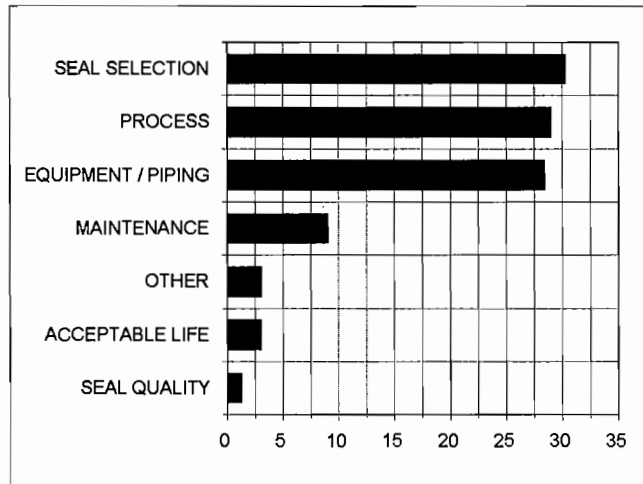


Figure 2. Breakdown of Root Causes for Oil Refineries.

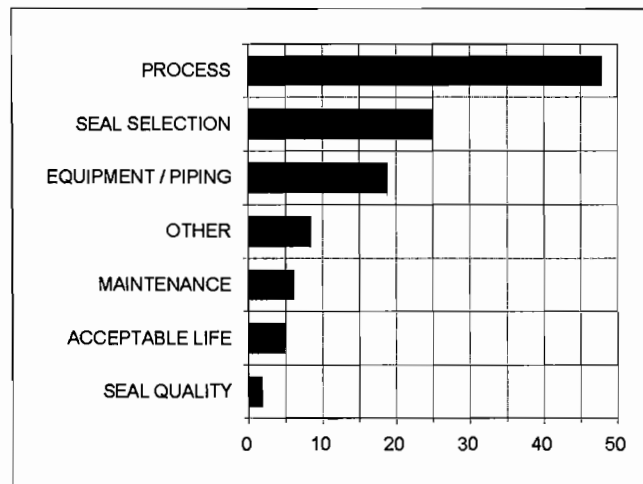


Figure 3. Breakdown of Root Causes for Chemical Plants.

To break down the analysis further, the secondary causes shown below were analyzed for the "Process" primary cause:

- Operational upset
- Face lubrication (poor seal face lubrication)
- Product setup
- Other

Analysis of the data show that 53 percent of the "Process" repairs in these plants were due to "Face lubrication" (Figure 4). This is obviously an area requiring additional attention, so the tertiary causes associated with "Face lubrication" were further investigated. These tertiary causes are:

- Air entrained in product.
- Cooling water flow blocked or reduced.
- Flush flow blocked or reduced.
- Heat tracing not working.
- Shutdown or startup.
- Barrier fluid level or pressure.
- Low flow recirculation.
- Low suction pressure.
- Other.
- Quench blocked.
- Recirculation flow blocked or reduced.
- Suction screen blocked.

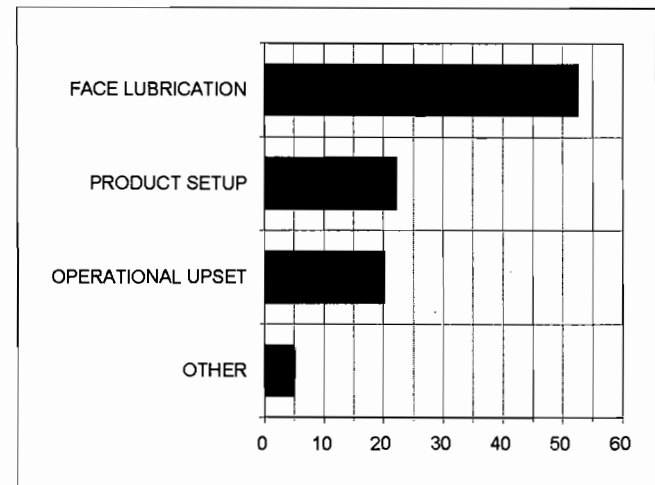


Figure 4. Breakdown of Process Root Causes for All Plants.

There were a total of 678 repairs caused by poor seal face lubrication. Of these, 185 fell into the "Other" category. This is obviously a large percentage that needs to be reduced. This can be achieved either by revising the tertiary causes in this section, or by further training the individuals performing the analysis to ensure that the proper tertiary cause is chosen. For the purpose of this analysis, the repairs that fell into the "Other" category were ignored, which left 493 repairs to analyze.

In order to narrow down these repairs into a more manageable number of categories, the categories were grouped as follows:

- Any cause for which a valve was closed or partially closed was put into a category called "Valve closed or reduced." This includes the causes "Cooling water flow blocked or reduced," "Flush flow blocked or reduced," "Quench blocked," and "Recirculation flow blocked or reduced." The cause "Heat tracing

not working," which only accounted for three repairs, was also included in this group.

- The tertiary causes "Low suction pressure," "Air entrained in product," and "Suction screen blocked," were put in a category called "NPSH available." "Low suction pressure" accounted for 122 of the 147 repairs in this category.

The results of the analysis are shown in Figure 5. The "Valve closed or reduced" and "Barrier fluid pressure or level" tertiary categories can generally be eliminated by a trained, diligent operator. The "Shutdown or startup," "NPSH available," and "Running back on curve" categories, on the other hand, can sometimes be more difficult to prevent.

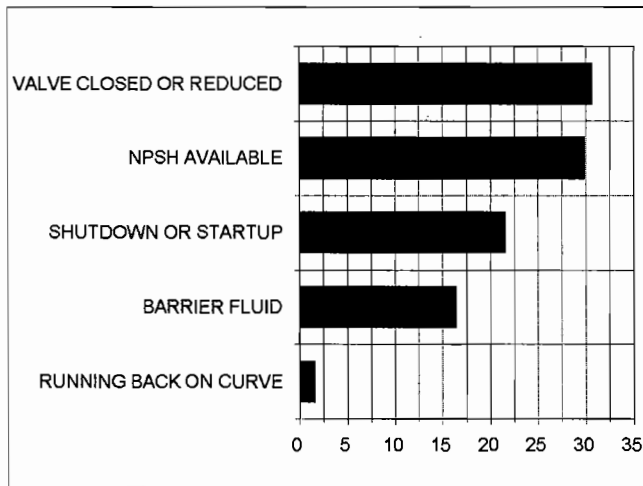


Figure 5. Poor Seal Face Lubrication Breakdown for All Plants.

Each of the other primary and secondary causes can be broken down as shown previously. By analyzing the causes of repair, an action plan can be formulated to improve reliability on a plant-wide basis. A plant with a significant number of repairs attributed to "Seal design/selection" should consider a seal standardization program to upgrade designs to the latest technology. A plant with a high percentage of process related repairs, on the other hand, should look into operator training programs along with a plan to encourage operators to "take ownership" of the equipment.

#### Improvements Achieved

To quantify the rewards that can be achieved when following the eight-step action plan described, typical improvements for a chemical plant and an oil refinery are shown in Figures 6 and 7. These improvements are shown as the percent increase in reliability over time. It was calculated in this manner in order to remove any controversy regarding how mean time between repair (MTBR) should be calculated.

In this study, mean time between seal usage is the reliability measuring stick that was used. Every case in which a seal was used on a repair after the equipment was installed in the field and turned over to operations was counted as a repair or a seal usage. For example, if the equipment was taken out of service due to poor performance or high vibration, this was counted as a usage even in cases where the seal never leaked. It would also be counted if the same seal were reinstalled during the repair. On the other hand, if a coupling needed to be realigned in the field, this was not counted as a usage.

#### CONCLUSION

A focused, disciplined approach is the key to improving equipment reliability. By following the eight-step plan outlined, a strategy can be implemented to improve seal performance.

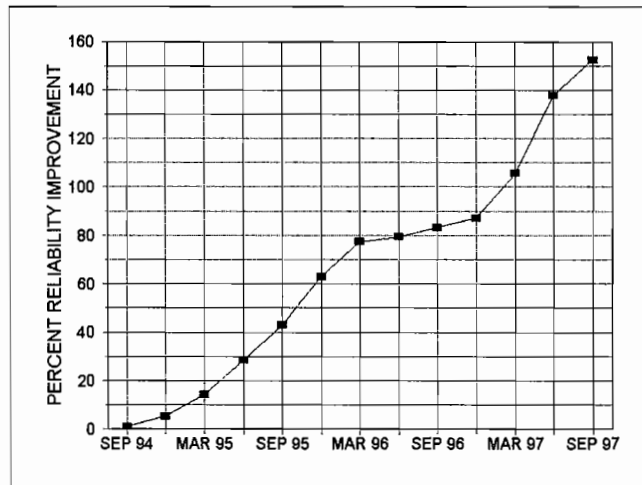


Figure 6. Reliability Improvements at a U.S. Chemical Plant.

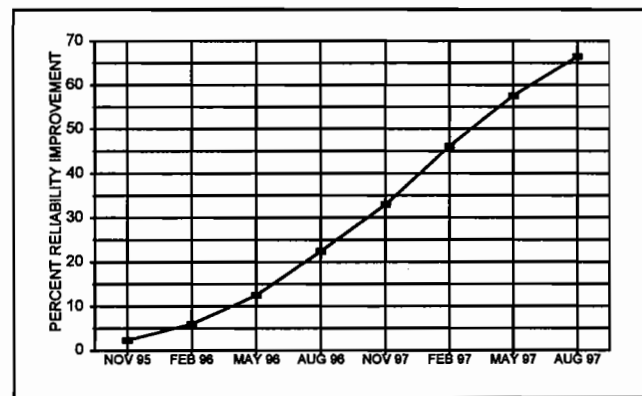


Figure 7. Reliability Improvements at a U.S. Oil Refinery.

As shown in Figures 6 and 7, a considerable improvement can be achieved. In fact, all the plants in this study have experienced a steady overall increase in reliability. In time, ongoing data collection can be used in other studies. For instance, reliability improvements achieved by converting from a component seal to a cartridge seal can be analyzed. This could also be done for any other solutions that are implemented. For example, these data could be used in the future to help answer the long-standing question of whether a single seal is more reliable than a dual sealing system.

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