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Revision Memo

12/01	Editorial revision for clarity and brevity. Expanded seal arrangement description. Added reference to API 682 Second Edition with gas seals and no buffer required on unpressurized dual seals. Added seal category per API 682 Second edition. Added reference to EHM in monitoring. Revised flush plan section and added plans 72, 74, 75, 76 per API 682 Second Edition. Added caution not to specify face materials. Added Table 3 flush plans versus self or external. Revised Appendix examples to show gas seals.
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SCOPE

- ◆ This section provides the background required to specify shaft sealing systems for centrifugal and rotary pumps. Sealing systems to minimize worker exposure, mitigate safety concerns and reduce fugitive emissions are included. The goal of the information in the Design Specification is to completely specify the seal type, arrangement (control level) and required auxiliary systems. Final design of the attendant sealing systems is performed during detail engineering after a pump is selected. In specifying a sealing system the designer must address those Job Specification issues which require that the purchaser make a decision or provide additional information. Sealing system specifications are contained in **Global Practices 10-1-1** and **10-1-3**. These Global Practices include the requirements of **API Standard 610 (GP 10-1-1, Centrifugal Pumps)** and **API Standard 682 (GP 10-1-3, Sealing Systems)**. Seals for rotary pumps (**GP 10-2-2**) are not specified to be in accordance with **GP 10-1-3** or **API 682** but may be selected in accordance with these documents if required by the Owner. In addition, the personal computer program **SealExx (CPEE-42)** and *The Pump Sealing and Sealless Pump Technology Manual* (TMEE-023) are referenced as the primary methods for selection of sealing system details.

REFERENCES

DESIGN PRACTICES

- [Section X](#) Pumps, Subsections A, B, C, F, and H
[Section XVIII-B2](#) Guidelines and Considerations for Industrial Hygiene

GLOBAL PRACTICES

- GP 3-3-10 Strainers for Mechanical Equipment
GP 10-1-1 Centrifugal Pumps
GP 10-1-3 Shaft Sealing Systems for Centrifugal and Rotary Pumps
GP 10-2-2 Positive Displacement Pumps - Rotary

OTHER REFERENCES

- CPEE-42, Seal Selection PC Program SealExx, Version 2.0
◆ ExxonMobil, *Pump Sealing and Sealless Pump Technology Manual* (formerly Pump Sealing Technology Manual), Manual No. TMEE-23
Exxon Biomedical Sciences Report MR.19DQ.93, *Equipment Selection Matrix for Industrial Hygiene Design Review*
◆ API Standard 610, *Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Services*
API Standard 682, *Shaft Sealing Systems for Centrifugal and Rotary Pumps*

BACKGROUND

GENERAL

- ◆ The original method of sealing the rotating shaft of a pump was to fill the annulus between the shaft and inside of a stuffing box with braided rope or metallic foil packing rings (**Figure 1D**). However, virtually all services (except firewater and sump pumps) in a modern plant now use either mechanically sealed or sealless pumps.

The reasons for considering shaft sealing during the plant design phase are:

1. Pump shaft sealing has a significant impact on plant safety, worker exposure, fugitive emissions and reliability.
2. Some shaft sealing systems need auxiliary streams for flushing and process stream isolation which should be selected during the process design phase.
3. Certain process services require special shaft sealing features which may impact the plant and process design.
4. Shaft seals are the largest single pump maintenance activity and therefore significant Owner preferences are normally involved.

MECHANICAL SEAL OPERATION AND SEAL TYPE

Sealing action in a mechanical seal is accomplished by the contact of a rotating seal ring rubbing against a stationary seal ring or by a small but defined gap between two seal rings and injection of a barrier medium (liquid or vapor) which flows into the pumpage. Both systems employ the construction features shown in **Figure 1A**.

The faces of the seal rings are in a plane perpendicular to the shaft and are made extremely flat and smooth. The rotating and stationary seal rings are sealed against the shaft sleeve and gland plate by secondary sealing elements in the form of o-rings, flat gaskets or graphite rings.



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BACKGROUND (Cont)

- Some axial compliance of one of the rings is needed to allow for shaft motion and wear of the face. In a pusher seal (API Type A Seal), this is accomplished through springs which position one of the faces and help keep the faces together. In a pusher seal the secondary sealing element must slide along the sleeve or in the gland. The secondary sealing element is usually an o-ring. In a bellows seal (API Type B or C seal), axial motion is allowed by stretching or compressing a metal bellows which also serves as the spring. The secondary sealing elements do not slide in a bellows seal and may be either an o-ring (Type B seal) or graphite rings (Type C seal) for high temperature operation. Type A seals (also known as pusher seals) and Type B seals are generally used for temperatures below 350°F (176°C) due to temperature limits on the secondary seals while Type C bellows seals are generally used above this temperature having graphite ring secondary sealing elements.

MECHANICAL SEAL ARRANGEMENT AND CONTROL LEVEL

Arrangements

- In order to provide increased control over leakage, mechanical seals can be used with different back-up devices to form what is called an "arrangement". **API 682** defines three seal arrangements, single (Arrangement 1), unpressurized dual (Arrangement 2), and pressurized dual (Arrangement 3). Within each of these arrangements there may be several hardware combinations which may influence the ability of the seal to contain the pumpage. Because of these options, ExxonMobil further classifies various arrangements into "Control Levels".
- An Arrangement 1 seal consists of one mechanical seal followed on the outboard side by a restrictive, non-contacting bushing (**Figure 1A**). The bushing maintains a fixed clearance to the shaft and thereby restricts the leakage of process fluid in the event of seal failure. It does not change clearance when pressurized and does not provide a positive seal to the shaft in the event of seal failure. Restrictive bushings can be fixed relative to the housing (having the largest clearance) or they can be radially floating (having much lower clearance) or segmented and floating (having almost no clearance). Arrangement 1 seals are most commonly used for streams that do not represent significant safety, exposure or environmental risk.
- When two, complete mechanical seals are used the arrangement is called a dual seal (**Figures 1B and 1C**). Both seals must have the same pressure, temperature and operating life capability. An **API 682** Arrangement 2 seals is called an Unpressurized Dual Seal (**Figure 1B**) and has two complete seals in series. The outer seal (atmospheric side) is called the containment seal and the space between the inner and outer seals is called the containment seal chamber. The containment seal chamber pressure is **less than** the pressure in the pump. This seal arrangement was formerly called a tandem seal.
- As defined in **API 682** Second Edition, an Arrangement 2 seal **may or may not utilize a buffer "fluid"** injected into the containment seal chamber to dilute leakage from the inner seal. This fluid may be liquid or gas depending on the type of containment seal used. The use of a buffer fluid has a significant impact (reduction) on the concentration of the pumped fluid that may escape to atmosphere. In services where worker exposure or emissions govern selection of the seal, a buffer fluid must be used. This is one reason why ExxonMobil uses the concept of Control Level to further classify seal arrangement and select the hardware required.
- When an Arrangement 2 seal uses a liquid buffer fluid, it is circulated from the seal, through a reservoir (commonly known as a seal pot) and back to the seal. The reservoir provides a point for instrumentation connections to detect failure of the inner seal or containment seal through high pressure or low liquid level as specified in **GP 10-1-3**. The reservoir also provides cooling of the fluid and connection to a collection system. The reservoir and attendant instrumentation is called API Flush Plan 52 for a liquid buffer fluid.
- An Arrangement 2 seal may also use a gas buffer fluid. This is a relatively new concept arising from the use of gas seals in recent years. The gas is fed into the containment seal chamber after control and instrumentation systems as specified in **API 682**. These supply plans are covered in API Flush Plans 71 and 72. There are also different API flush plans which may be selected to collect leak off. These are designated Plans 75 and 76. Specification of these different flush plans will be presented later in this section. Criteria for selecting gas versus liquid buffer are presented in TMEE-023.
- An API Arrangement 3 seal, or Pressurized Dual Seal (**Figure 1C**), uses two complete seals (regardless of orientation) with a barrier fluid injected between the seals. The **barrier fluid is required** and must be at a higher pressure than the pressure in the pump. The barrier fluid may be a liquid or a gas. For liquid barrier fluid there may be a reservoir, piping and leakage detection instrumentation similar to an unpressurized dual seal termed an API flush plan 53. Liquid may also be supplied from a circulating system or other process source in which case the plan is termed flush plan 54. When a gas (almost always nitrogen) is used as the barrier it is termed API flush plan 74. Pressurized dual seals offer the highest level of leakage control and provide the highest reliability in hot and or dirty services.

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BACKGROUND (Cont)

◆ Sealing Control Level

- ◆ The different seal arrangements discussed above provide varying levels of pumped fluid containment when the primary seal fails. The term "Sealing Control Level" is used to describe specific seal hardware having similar containment characteristics. The distinction between arrangements and control level is that within an arrangement, the level of control provided by the available hardware options differs. **Table 1** provides a summary of the six Sealing Control Levels and the seal arrangements (both default and options) corresponding to each level. As the Sealing Control Level increases, the amount of leakage to the environment upon failure of the primary seal decreases while the cost and complexity of the system generally increases. Control Levels also include specific instrumentation and monitoring requirements.
- ◆ Determination of Sealing Control Level requires specific information on the pumped fluid characteristics, local regulations, and owner preferences. This information is provided in the GII and through the Owner survey presented later in this section. Control Level selection is based on procedures presented in TMEE-023.

MECHANICAL SEAL CATEGORY

- ◆ **API 682** Second Edition presents a new variable for seal specification, seal category. In an effort to expand the application of API 682 seals to other industries, the concept of seal categories was developed. Category I seals have a different (and smaller) cross-section from Category II and III seals. Category I seals are intended primarily for non-API pumps but must incorporate many of the material qualities of API 682 seals. Category II and III seals are intended for API pumps with Category II being the most predominately used seal and equivalent to API 682 First Edition seals that were applied. **GP 10-1-3** requires Category II seals for most services. Category III seals require all of the documentation of API 682 seals and will only be used in the most critical or hazardous services. Since the Global Practices specify the default seal category, this does not need to be entered into the GII or Design Specification.

PACKED STUFFING BOXES VERSUS MECHANICAL SEALS

The packed stuffing box is the simplest type of shaft seal, **Figure 1D**. It consists of a stuffing box cavity with a restrictive "throat" bushing at the pumpage end, several rings of packing, a hollow spacer or lantern ring, several more rings of packing and a follower or gland. The lantern ring provides a point to inject external fluid in order to cool and lubricate the packing and provide better sealing in vacuum services. A slight continuous leakage is required between the packing and shaft for lubrication. Leakage ranges from 0.5 to 5 gal/hr (0.0019 m³/hr to 0.019 m³/hr) depending on fluid characteristics, pump mechanical condition and the type and adjustment of the packing.

Compared to packing, mechanical seals offer the following benefits:

1. Reduced worker exposure.
2. Reduced product loss.
3. Lower maintenance cost and effort.
4. Fewer unplanned pump shutdowns for maintenance.
5. Reduced fire potential.
6. Reduced emissions.
7. Reduced housekeeping.
8. Reduced power consumption.

Packing is no longer recommended for hydrocarbon services primarily due to the continuous leakage required. The only service for which packing may be required is firewater pumps. The contractor is responsible for ensuring all pumps meet applicable codes and must add packing for firewater pumps if this is required.

SEALLESS PUMPS

Sealless pumps are devices which transmit pumping energy across a stationary pressure boundary usually by electromagnetic or magnetic fields or flexing of a mechanical component. There are three basic styles of sealless pumps: canned motor, magnetic drive and diaphragm pumps.

1. Canned motor sealless pumps contain the pump impeller, shaft, motor rotor and bearings in a pressurized housing. Surrounding this housing are the motor windings. A second sealed housing then surrounds these windings. This second housing provides inherent "secondary containment" in the event of failure of the inner pressurized housing. The pumped fluid lubricates all bearings and cools the motor. The only perforation of the pressure housing is for the motor electrical leads which are stationary. No shaft seals are required.

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BACKGROUND (Cont)

2. Magnetic drive sealless pumps also contain the pump impeller, shaft, rotating magnets and bearings in a pressurized housing. Rotating outside this housing are powerful magnets which form a magnetic coupling with the inner magnets. The pump is driven by a conventional external motor. Magnetic drive sealless pumps can be either centrifugal or positive displacement (rotary vane, gear, screw, etc.). The major difference compared to a canned motor pump is that the rotating outer magnets are driven by a conventional shaft and motor. Should the inner pressurized housing fail, pumpage would leak to the environment. To obtain secondary containment with a magnetic drive pump, a conventional mechanical seal is used on the shaft with the rotating outer magnets.
3. Sealless Diaphragm pumps are reciprocating machines which flex a diaphragm (mechanically or hydraulically) to cause the pumping action due to check valves on the inlet and outlet. There are no pressure housing perforations and no shaft seals are required.

For additional information on sealless and diaphragm pumps, see [Sections X-C](#) and [X-F](#) and TMEE-23. At the present time there are no API or GP specifications covering sealless pumps.

DESIGN SPECIFICATION CONSIDERATIONS

SUMMARY

- ◆ The specification of mechanical seals consists of the following steps and documentation. Each item will be further described below:

- **API 610** (Pumps) and **API 682** (Seals) form the primary governing documents.
- **GP 10-1-1** (Pumps) and **GP 10-1-3** (Seals) provide general ExxonMobil modifications to the API specifications.
- Development of a job specific GII (General Instructions and Information Specification) to indicate Owner Preferences in addition to or changing the Global Practice. See PC Program SealExx User Manual, Appendix IV for a sample questionnaire on Owner Seal Preferences.
- Determination of seal and sealing system detailed requirements and inclusion of these requirements on the Pump Data Sheet.

The basis for seal and sealing system selection will normally be either:

- EMRE procedure utilizing PC Program SealExx (CPEE-42) modified to include Owner Preference items and **API 682** Second Edition plus TMEE-023 or
- An Owner specified seal selection practice or
- **API 682** selection process alone.
- ◆ The EMRE procedure combines Owner Preferences (obtained through the use of a questionnaire as described above) with the default seal selection procedures in SealExx to give all of the information needed to fill out the Pump Data Sheet. The program should normally be configured by a Machinery Specialist using the results of the Owner Preference Questionnaire. The program can then be locked and used either by the Process Designer or the Machinery Specialists. A Machinery Specialist should always review the specific sealing information on each Pump Data Sheet. The results of SealExx must also be reviewed to incorporate the flush plans and other auxiliaries associated with gas seals.
- ◆ An Owner specified seal selection practice is one where the Owner has provided a specific procedure for selecting seals. An example of this would be the European Seal Selection Handbook. Machinery Specialist input should be obtained to help interpret Owner practices for seal selection.
- ◆ The annexes of **API 682** also provide a selection procedure for seal type, seal arrangement and flush plan. The API procedure does not include a process for selecting seal category. The API procedure alone should be used only if no other procedure is presented.

The **General Instructions and Information Section (GII)** of the **Job Specification** should provide shaft sealing information generally related to most project pumping services. When completed, The GII must contain the following items as a minimum. All these items are discussed in detail later in this section.

1. Table or paragraph listing the specific hardware to be used for each Sealing Control Level.
2. Table or paragraph listing the Sealing Control Level to be used for each Respiratory Exposure Class.
3. Paragraph stating which Sealing Control Levels require the addition of bearing monitoring and what type of bearing monitoring should be applied.
4. Paragraph(s) providing Owner preferences which modify the API or GP seal requirements such as preferred seal vendors and buffer fluid for dual seals.

The **Design Specification Pump Data Sheets** for each service should provide the following information specifically related to selection of the sealing system. Again, each item is discussed in detail later in this section.

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DESIGN SPECIFICATION CONSIDERATIONS (Cont)

1. Fluid boiling range (narrow, medium, wide).
2. Fluid specific heat.
3. Whether the fluid contains aromatics, polymerizing agents or solids.
4. Whether the seal will be exposed to a vacuum.
- ◆ 5. Sealing Method, packing or mechanical seal (or sealless pump if most appropriate) and API 682 Seal Type. (Note: Seal Category is specified by **GP 10-1-3**. Category II is the default for all streams except non-hazardous water which is Category I).
6. Sealing Control Level.
7. Respiratory Exposure Class.
8. Flushing System, self or external.
9. API 682 flush plan(s).
10. API 682 quench plan.
11. Special Features.

GENERAL INSTRUCTIONS AND INFORMATION (GII) CONTENT

The General Instructions and Information Design Specification (GII) should address the following issues as a minimum.

Seal Arrangement Versus Sealing Control Level

- ◆ As previously described in this section there are six Sealing Control Levels. Each level has a default hardware option and several alternatives (**Table 1**). A paragraph (or table) should be added to the GII section for pumps which explicitly states which hardware arrangement should be used for each Control Level. Only one mechanical seal hardware option is permitted for each Control Level in the GII table. However, if the Owner wishes to obtain dual bids for mechanical seal arrangements and sealless pumps, the table should list both the preferred seal arrangement and sealless pump.

An example used in previous GIIs is as follows:

"The following seal arrangements and hardware shall be used for the Control Level specified:

Control Level 6:	Pressurized Dual Seal with leak detection
Control Level 5:	Unpressurized Dual Seal with leak detection
Control Level 4:	Single seal with contacting, dry running backup and leak detection.
Control Level 3:	Single seal with segmented floating carbon bushing and leak detection
Control Level 2:	Single seal with floating carbon bushing
Control Level 1:	Single seal with API fixed bushing"

Sealing Control Level Versus Respiratory Exposure Class

- ◆ As part of the design review process, Industrial Hygienists will review each stream and assign a Respiratory Exposure Class or "R Class". Information on the different R classes and optional Control Levels to mitigate the exposure concern will be included in the GII Environmental and Industrial Hygiene Considerations section (see **Section XVIII-B2**) and TMEE-023. . However, in the pump section, the designer must state which of the optional Control Levels are to be used explicitly for each R Class.

To assist in this determination, **Table 2** of this subsection presents the default and options that will be put into the environmental considerations section. **Table 2** should be reviewed with the Owner and then a paragraph should be added to the GII Section covering pumps listing the Owner preferred Sealing Control Level for each Respiratory Exposure Level. The following paragraph is typical and suitable for use in the GII:

- ◆ "Streams classified as R1 shall use Sealing Control Level 6, R2 streams shall use Control Level 5, R3 streams shall use Control Level 3, and R4 streams shall use Control Level 2 with the exception of aqueous streams below 150°F (65°C) which may use Control Level 1."



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DESIGN SPECIFICATION CONSIDERATIONS (Cont)

Preferred Application of Bearing Monitoring

- ♦ The GII should reflect when bearing monitoring should be used and whether this monitoring should be installed in conjunction with Equipment Health Monitoring (EHM) facilities. The majority of reported pump fires are due to bearing failure which results in seal failure. When the thrust or radial bearing in a pump fails the delicate seal often fails catastrophically. In addition, the heat generated by the failing bearing provides a ready ignition source. Therefore, if one is providing increased leakage control (and cost) to prevent material from escaping to the environment due to safety or worker exposure concerns, then bearing monitoring should be considered an integral part of the protection system. It is recommended that bearing monitoring be added whenever Control Level 5 or 6 is being used due to safety or worker exposure concerns. The paragraph below provides details on when the stream may be a safety or exposure concern.
- ♦ The type of monitoring should also be addressed. Bearings are usually monitored by either temperature or vibration measurements. Vibration provides long term trending capability enabling a pump to be shut down well in advance of a failure. However, it is more expensive than temperature monitoring. Temperature monitoring may not provide long range trending and prediction of failure. However, since virtually all bearings that fail exhibit high temperature it may be a more reliable variable on which to provide automatic shutdown. The GII should explicitly state under what circumstances the Owner wants bearing monitoring, what the monitoring should be and whether it should cause a shutdown or alarm. The designer should also contact machinery specialists to determine whether EHM criteria provide additional guidance on when to apply monitoring as part of an EHM package and what type of monitoring to use.

A typical paragraph, based on the machinery specialist recommendations as a default is as follows:

"All pumps specified as Control Level 5 or 6 with any one of the following additional stream characteristics shall be provided with bearing monitoring:

- Vapor pressure at 100°F (38°C) equal to or above 14.7 psia (1 bara).
- More than 40% of the volume of the fluid vaporizes when flashed from pump suction conditions to atmospheric pressure.
- Respiratory Class is R1 or R2.
- pH is less than 4.
- The stream contains phenol or HF acid (even in trace amounts).
- The fluid burns with an invisible flame.
- The fluid is defined as an H₂S hazard per EE.15E.85 (more than 2% by volume H₂S in any vapor that results from leakage of the pumped fluid).

Monitoring shall be via thermocouples sensing the highest temperature on the radial bearing and on the thrust bearing of the pump. The monitoring system shall be capable of providing an alert (alarm) level and danger (shutdown) level independently."

Other Owner Preferences

Owner Preferences which may affect all or a large number of seals they should be added to the GII at this point. Typically, these preferences include:

- Preferred seal vendors and/or seal models. This is usually a very strong Owner Preference.
- Fluid to be considered for the buffer fluid in unpressurized dual seals (Plan 52 or 72) and pressurized dual seals utilizing **API Plan 53, 54 or 74**. Information on the choices can be found in TMEE-023. This should be put in the GII only if it known that dual seals will be used.
- Any other Owner Preferences which add to or modify **API 682** or **GP 10-1-3**.

Note that Owner Preferences which affect only the configuration of SealExx do not need to be added to the GII.