ADVANCES IN MECHANICAL SEALING— AN INTRODUCTION TO API 682 SECOND EDITION

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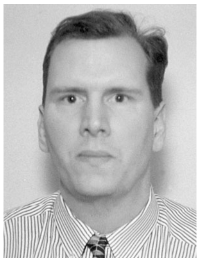

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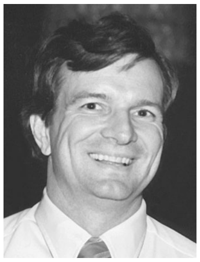

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ABSTRACT

The first edition of API 682 was the first broad-based standard covering the design and application of mechanical seals in centrifugal and rotary pumps. One of the main goals of this standard was to capture successful field experiences in refineries and create a methodology that would guide the reader to a successful solution. Since its introduction, sealing technology has continued to advance. New designs such as gas seals and dry running containment seals have been developed. In addition, industries other than refining have recognized the advantages of the first edition. Many of these industries use pump designs that

were not covered by the standard. The second edition task force has expanded the scope of the standard to include applications in more pumps, document new seal designs, and introduce new piping plans and testing requirements. API 682, Second Edition, has also been reformatted in preparation for its release as an ISO standard. These changes would be made while keeping the focus of improving reliability and meeting emissions requirements.

INTRODUCTION

Mechanical seals have been accepted as the standard method for sealing rotating pumps for many years. Until the early 1990s, though, there had been very little effort to standardize the use, design, features, or dimensions of seals. Seal standards existed as specifications buried in other standards. DIN 24960 specified seal interface dimensions for a range of seals in DIN pumps. ANSI (and later ASME) B73 and ISO 3069 recognized the value in standardizing seal chamber dimensions for mechanical seals. API 610 (1995) went even further and specified many design features, materials of construction, and seal codes. All these standards, though, were primarily pump standards and any seal references were directed at how seals would interact with the referenced pumps.

In the late 1980s a group of refinery equipment engineers and managers began to compare sealing solutions in refinery applications. This group, led by V. R. Dodd of Chevron, came up with the general plan for what would become API 682 (1994). There was a great need for this standard for several reasons. Many of the refineries had been losing experienced rotating equipment engineers and mechanics. This loss of experience was seen as a risk to future operation of the refineries. New employees were being brought in to replace these experienced people, and there were no standard procedures on how to select or apply mechanical seals. It was not unusual for refiners to have different seal policies from plant to plant or even between different operating units in the same plant. Engineering contractors, who were often responsible for selecting seals for these refineries, had their own set of specifications. It had become difficult for all these parties to communicate on seal requirements.

The American Petroleum Institute (API) agreed to establish a standard for mechanical seals: API 682. A task force was formed in 1990 and the first meeting was held in January 1991. This task force comprised 14 members from various refineries, seal, and pump manufacturers. API 682, First Edition, was published in October 1994.

The goal for the first edition task force was simply to document and duplicate successful seal solutions to common refinery applications. Early in this process, they recognized the need to address many issues that are not normally considered in standards. They recognized the need for standardizing on nomenclature for seals, arrangements, and piping plans. They recognized the importance of breaking up the many different commercial offerings for seals into a number of discrete seal groups. Perhaps most importantly, they recognized the need for guiding the reader in how to choose a seal for a specific application. To accomplish these goals, API 682 sometimes had to look more like a tutorial on mechanical seals than it did a conventional standard.

API 682, First Edition, has been one of the most successful standards in APIs history. It has been sold in over 25 countries. It has been the subject of numerous training sessions at seal and pump conferences. It has almost universally been adopted as *the* standard for mechanical seals. Despite these successes, the standard was largely viewed as being purely American. Utilizing it in different parts of the world was often cumbersome because of the bias toward referencing local regulations, codes, and other U.S. standards. While the first edition task force had in effect created a standard that was used throughout the world, they had not authored a truly international standard. In an industry with such wide applications, true global standardization was a logical step for the pump market. End users needed a guide for seal selection that was valid worldwide; that was as helpful in Dhahran, Saudi Arabia, as it was in Houston, Texas.

In order to gain international acceptance, the American Petroleum Institute (API; Washington, D.C.) opened up the standards' development process to global input from the International Organization for Standardization (ISO; Geneva, Switzerland). In creating globally accepted standards, API hoped to eliminate the redundant cost of standardizing at the corporate, national, and international levels. The second edition of API 682 was recognized as an ISO new work item in April 2001 and was voted by the international community to be developed into a draft international standard (ISO 21049, 2001). The publication of ISO 21049 is scheduled for November 2002.

The publication date is tied to the release of the next revision of API 610 (2001), which is also being released as an ISO standard (ISO 13709). Although the current revision of API 610 defaulted to API 682 for seal selection, it also includes a section of specifications for mechanical seals. The next revision (ninth edition) will remove this section and default entirely to API 682 Second Edition (ISO 21049).

Moreover, since the publication of API 682 in October 1994, there have been many advances in seal technology. There has also been a desire to take the foundation of the first edition and apply it to a broader scope of pumps in other industries. The second edition of API 682 was modified to provide a basis for selection also in the chemical industry, not simply the oil and gas industries.

OVERVIEW OF FIRST EDITION

The mission statement for the first edition task force is captured in the first section of the standard:

> 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 (API 682, 1994).

There were several key assumptions made by the first edition task force in meeting this goal.

- The standard would only try to address 90 percent of the seal applications in a typical refinery. Some applications, such as hydrofluoric acid, were defined as being outside the scope of this standard.
- The standard addressed a limited range of shaft sizes as well as a limited range of operating conditions. A survey of refinery pumps and seals was used to set these limits. Equipment that was outside the range of normal equipment might reference API 682, but would require a more thorough engineering review before using a seal engineered for that service.
- The standard would default to one solution. Throughout the standard, there are many alternates, referred to as "standard options" that are considered as equals to the defaults. This would allow users to have some flexibility and still comply with the standard.

The standard was notable, and perhaps unique, for many reasons. It was filled not only with the technical details normally associated with a standard, but also with a thorough explanation of how seals should be applied and the background behind many of the requirements of the standard. The document contains notes and comments that give the reader an insight into the task force's reasoning behind many of the requirements. Originally, these notes and comments were intended only for the task force; however, the reviewers of the draft standard asked that they be kept in the finished document. Some comments were expanded to become tutorials and were moved to the appendix.

The standard also needed to provide a guide on how to select the correct seal for a number of common refinery applications. Before this could be done, it was necessary to categorize these applications into a number of services—nonhydrocarbon, nonflashing hydrocarbon, and flashing hydrocarbon. The nonhydrocarbon category was further subdivided into water, sour water, caustics, amines, and acids. These services are further broken down by pressure and temperature.

It was also necessary to categorize the many different type seals that were used in these services. Three seal types, A, B, and C, were designated to cover pusher seals, bellows seals, and high temperature seals, respectively. Each of these seal types was defined relative to the basic seal design, materials of construction, and additional features (such as injection type and bushings).

Prior to API 682, First Edition, multiple seals were designated as being either "tandem" or "double" seals; however, advances in seal design had rendered these classic terms obsolete. As a result, there was some confusion on how multiple seals were designated. The task force decided to use a more descriptive designation and chose to define *dual* seal arrangements. A dual seal would be two seals used in the same seal chamber. The fluid between these two seals could be either pressurized or unpressurized. Three standard arrangements were defined:

- Arrangement 1 would be a single seal,
- Arrangement 2 would be a dual unpressurized seal, and
- Arrangement 3 would be a dual pressurized seal.

Each of these arrangements was further described relative to the seal orientation and design features.

After having defined the services, seal types, and seal arrangements, a series of flowcharts was created to select a default seal type, special material or design requirements, and supporting piping plan.

One of the other areas that the standard addresses was seal qualification testing. While it was easy enough to require that seals should have a high probability of three years of service, it was more difficult to prove this. The task force members wanted some assurances that the seals offered by the OEMs were capable of meeting these goals when run under actual conditions. The only way to do this was to require seal performance testing on process fluids under representative pressures and temperatures.

The general idea of the qualification test was to prove that the design was sound. The goal of the qualification test was to simulate a long-term steady-state run followed by a process upset. The simulated process upset consisted of pressure changes, temperature changes, and included loss of flush. The results of these tests were made available to the purchaser. There were no acceptance criteria presented in the standard.

Five fluids were selected for the qualification tests: water, propane, 20 percent sodium hydroxide (NaOH), cold oil, and hot oil. These five fluids include a wide range of viscosity, vapor pressure, specific gravity, specific heat, and atmospheric boiling point. In addition, there were actually three other "test fluids"—the buffer/barrier fluids: glycol/water, diesel, and a lighter oil.

Although the exact cost is unknown, it is estimated that the seal manufacturers have invested between 5 and 10 million U.S. dollars in capital equipment in order to conduct these qualification tests. As the tests have been ongoing since 1994, there are perhaps three to five million dollars of operating costs associated with the tests. It is likely that all manufacturers have not completed a full slate of tests and that testing will continue for years.

OVERVIEW OF SECOND EDITION

Goals of Second Edition

In the years since the release of the first edition, sealing technology has continued to evolve and advance. Gas seals and dry running containment seals are now commonly used in many industries. New piping plans for gas seal control panels and containment seals have been developed. In addition, there has been a desire to formalize some of the different seal configurations (or seal orientations) when using dual pressurized liquid and gas seals.

One of the criticisms of API 682, First Edition, was that it considered only API 610 pumps and only refinery applications. But API 610 pumps are used in processes other than refineries and not all pumps in refineries are API 610 pumps. Especially in recent years, ASME B73 pumps have also been used in refinery services. The chemical and petrochemical industries routinely use ASME pumps as well as DIN or ISO designs, but also use API 610 pumps. Broadening the scope of pumps covered by the standard would allow standardized seals to be applied to a greater number of industries.

Users recognize the need to select pumps and seals according to the severity of the application. The first edition of API 682 specified seals that had features required for the most demanding seal applications with the expectation that these seals would be used in API 610 pumps. That seal design included features like multiport injection and floating throttle bushings. Since many applications do not require these features to perform satisfactorily, the ability to provide seals with varying levels of features would allow more flexibility in terms of physical fit and cost justification.

The second edition task force addressed these topics in the latest revision. As in the first edition, the goal of the standard is to provide seals that will run uninterrupted for a minimum of three years while meeting emission goals. The standard will also reference technologies that have proven to meet this goal in actual service.

Categories

The second edition introduces the concept of seal categories. A seal category describes the type of pump into which the seal will be installed, the operating window, the design features, and the testing and documentation requirements. There are three categories designated as Category 1, 2, or 3.

Category 1 seals are intended for non-API 610 (ISO 13709) pumps. These will generally be applied into ASME B73 big bore or ISO 3069 type C seal chambers. This category is applicable for temperatures between −40°F and 500°F (−40°C and 260°C) and pressures to 315 psi (22 bar). The seal will be provided with minimal documentation and qualification testing is limited.

Category 2 seals are intended for API 610 (ISO 13709) pumps. This category is applicable for temperatures between −40°F and 750°F (−40°C and 400°C) and pressures to 615 psi (42 bar). The seal will be provided with minimal documentation and qualification testing is limited.

Category 3 seals are also intended for API 610 (ISO 13709) pumps. These seals will be provided for the most demanding applications. This category is applicable for temperatures between −40°F and 750°F (−40°C and 400°C) and pressures to 615 psi (42 bar). Design features include a distributed flush and floating throttle bushing for single seals. This seal must have been qualified according to the qualification test procedures. Additional documentation must also be provided.

New Seal Types

Three new seal types have been introduced in the second edition: dry running containment seals, noncontacting seals, and dual gas barrier seals.

Containment seals are the outer seals in a dual unpressurized seal arrangement. In the second edition, containment seals can be used with a liquid buffer fluid, a gas buffer fluid, or without a buffer fluid. In the case of a dry running containment seal, the containment seal will be exposed primarily to buffer gas or vaporized process fluid. Such containment seals must therefore be designed for continuous dry running while meeting the reliability goals of the standard. Dry running containment seals may be either contacting or noncontacting.

Noncontacting inner seals are also introduced in this edition. A noncontacting inner seal is designed to operate on liquid, vapor, or mixed phase fluids. One of the primary targets for noncontacting inner seals is in flashing hydrocarbon services. In some of these services, it is impossible to obtain adequate vapor margins to prevent flashing of the fluid in the seal chamber. A noncontacting seal is designed for lift-off on vapor phase fluids. If the seal is exposed to liquid phase fluids, it will lift-off and continue to run though the leakage past the seal will be higher. This seal will be used with a dry running containment seal and the leakage past the inner seal will be piped to a vapor recovery system.

The other new seal type is the dry running gas seal used in dual pressurized arrangements. This seal is designed to run primarily on a gas barrier fluid such as nitrogen.

Arrangements

The seal arrangement describes the number of seals per cartridge, the orientations of dual seals, and the relative pressure of the buffer/barrier fluid. A chart of available arrangements is shown in Figure 1. Where multiple arrangements are listed in a column, they are shown in order of preference. The arrangements are described by an arrangement code shown in the figure.

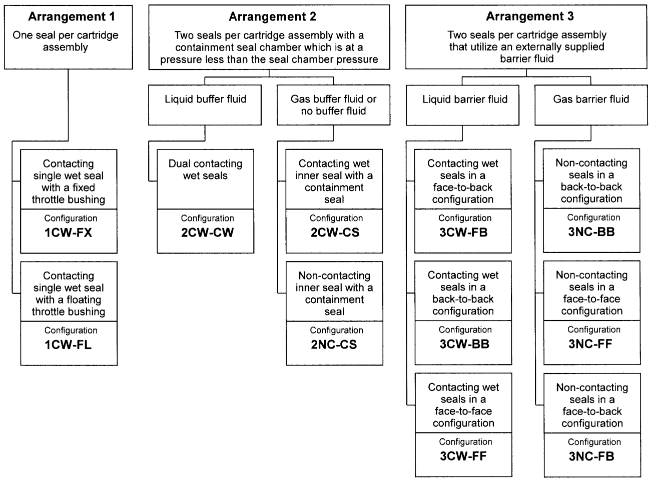

Figure 1. Seal Arrangements.

Arrangement 1 seals are defined as a seal configuration having one seal per cartridge assembly. These are also commonly called single seals. Arrangement 1 seals are available with a fixed throttle bushing (1CW-FX) or a floating throttle bushing (1CW-FL).

Arrangement 2 seals are defined as a seal configuration having two seals per cartridge assembly with a containment seal chamber that is at a pressure less than the seal chamber pressure. Arrangement 2 seals can be used with a liquid buffer fluid (2CW-CW) or with a dry running containment seal (2CW-CS). The dry running containment seal may be either a contacting or noncontacting (lift-off) seal. In addition, there has been some success in using a noncontacting inner seal with a dry running containment seal (2NC-CS) in services such as flashing hydrocarbons.

Arrangement 3 seals are defined as a seal configuration having two seals per cartridge assembly that utilize an externally supplied barrier fluid. By definition, the barrier fluid is at a pressure higher than the seal chamber pressure. Arrangement 3 seals can be used with either a liquid or gas barrier fluid. These seals can also be configured with the seals in a face-to-back, face-to-face, or back-to-back orientation.

New Piping Plans

Several new piping plans have been introduced in the second edition. These include additional options for dual pressurized liquid seals as well as new piping plans to support containment seals and dual pressurized gas seals.

- *Plan 14*—This plan is a combination of Plan 11 and Plan 13. This was introduced in API 610, Eighth Edition, and is now included in API 682. This plan is primarily used in vertical pumps to allow for injection into the seal chamber while continually venting the seal chamber back to suction (Figure 2).

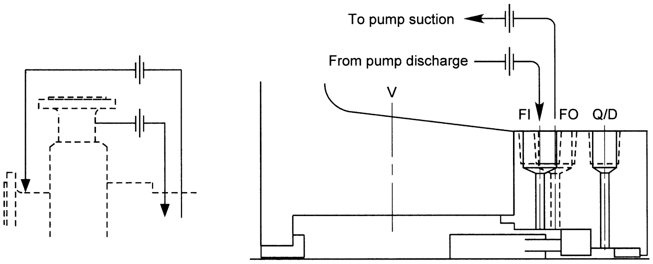

Figure 2. Standard Seal Flush Plan 14.

- *Plan 53*—This plan is used to provide pressurized barrier fluid to Arrangement 3 seals. In the first edition, this was shown as a pressurized reservoir. While this style of Plan 53 is commonly used, other variations do exist. These variations have not had an official designation but have assumed names like "Plan 53 Modified." The second edition has defined three variations of Plan 53 and uses the designations Plan 53A, Plan 53B, and Plan 53C. If the user wishes to specify a specific variation, they can use these designations. If the user does not specify a specific variation and uses the term Plan 53, any of the variations are considered acceptable.

  - *Plan 53A*—This plan is the same as Plan 53 in the first edition of API 682. An externally supplied gas such as nitrogen pressurizes a barrier fluid reservoir. Barrier fluid is pumped from the seal to the reservoir by a pumping device on the seal and flows back to the seal by gravity. An advantage of this system is that cooling coils can be provided in the reservoir. Combined with the large volume of fluid in the circulation system, fluid conditions remain very stable. Barrier fluid pressure can also be controlled very accurately with a pressure regulator on the nitrogen line. The disadvantage of this system is that, at high pressures, the pressurization gas can dissolve into the barrier fluid. This may cause instability in the seals (Figure 3).

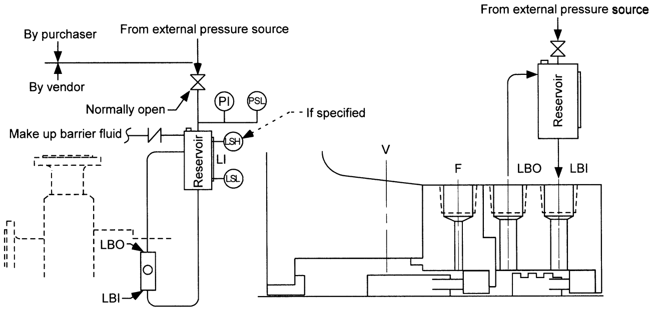

Figure 3. Standard Seal Flush Plan 53A.

  - *Plan 53B*—This plan uses a small closed loop without a reservoir. Barrier fluid is pumped into the loop by a pumping device and is circulated back to the seal. In most cases a seal cooler (either air-cooled or water-cooled) is placed in the loop to control the barrier fluid temperature. A bladder accumulator that is connected to the loop pressurizes the barrier fluid. The accumulator serves the dual role of providing makeup fluid and pressurization to the loop. This accumulator is pressurized so leakage from the loop does not drop the barrier fluid pressure below the seal chamber pressure. The advantage of this system is that it can be used at high pressure without pressurization gases dissolving into the barrier fluid. It is also common to use this system in areas where cooling water is not available and air-cooled seal coolers must be used. The disadvantage is that the accumulator must be sized adequately to prevent large pressure fluctuations due to seal leakage and an external seal cooler must be provided. These can make this variation more expensive than Plan 53A (Figure 4).

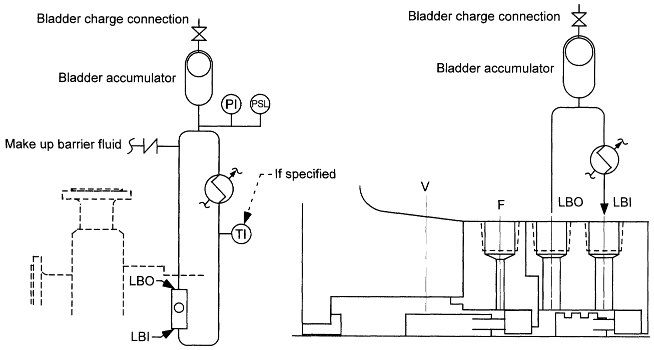

Figure 4. Standard Seal Flush Plan 53B.

- *Plan 53C*—This plan also uses a small closed loop without a reservoir. Barrier fluid is pumped into the loop by a pumping device and is circulated back to the seal. A piston accumulator that is connected to the loop pressurizes the barrier fluid. The accumulator serves the dual role of providing makeup fluid and pressurization to the loop. The piston accumulator is designed to take a reference pressure line (generally off the seal chamber) and provide a higher pressure into the barrier fluid loop. Because of the design of the accumulator, the pressurization of the loop is at some constant ratio over the reference pressure (e.g., 1:1.15). The advantage of this system is that the pump pressurizes the loop and no external gas supply is required. The system automatically tracks the pressure in the seal chamber to compensate for variations in pump operating conditions. The system can be operated at high pressures without dissolving pressurization gas into barrier fluid. A disadvantage is that the piston accumulator is exposed to pump fluid. It is therefore exposed to corrosion and contamination from the pump process. It is also generally more expensive than a Plan 53A (Figure 5).

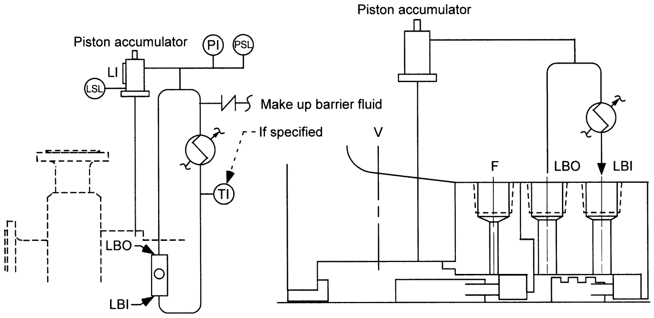

Figure 5. Standard Seal Flush Plan 53C.

- *Plan 71*—This plan is designed for dry running containment seals. Ports are provided for buffer gas but are plugged during installation. This plan is used when barrier gas may be required in the future (Figure 6).

- *Plan 72*—This plan is designed for dry running containment seals (2CW-CS and 2NC-CS). A buffer gas is supplied to the containment seal chamber to sweep leakage from the seal to a collection system. The buffer gas pressure is lower than seal chamber pressure. The plan describes a control panel to filter the buffer gas, regulate the pressure, and provide instrumentation to monitor operation (Figure 7).

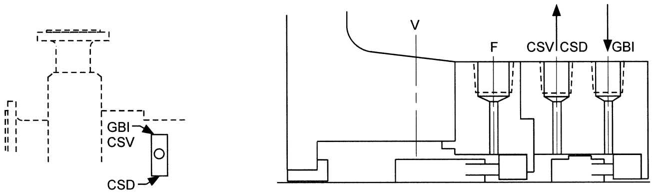

Figure 6. Standard Seal Flush Plan 71.

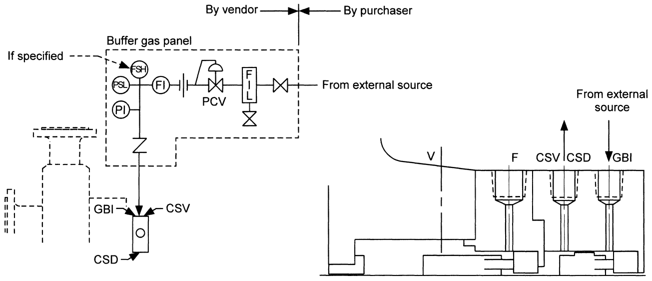

Figure 7. Standard Seal Flush Plan 73.

- *Plan 74*—This plan is designed for dual pressurized gas seals (3NC-FB, 3NC-BB, and 3NC-FF). A barrier gas is supplied at a pressure higher than seal chamber pressure. The plan describes a control panel to filter the barrier gas, regulate the pressure, and provide instrumentation to monitor operation (Figure 8).

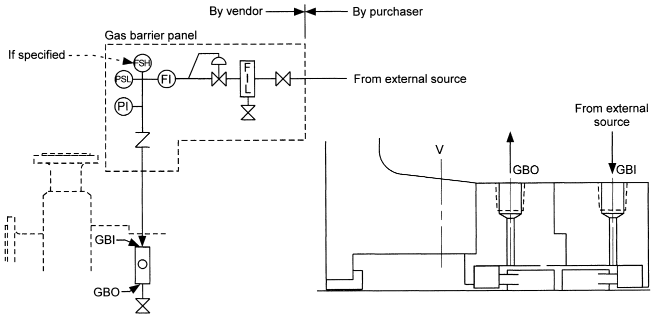

Figure 8. Standard Seal Flush Plan 74.

- *Plan 75*—This plan is used for dry running containment seals (2CW-CS and 2NC-CS). This plan is designed for applications where leakage past the primary seal does not completely vaporize. Leakage is piped from the containment seal chamber to the collection chamber where liquid and gas phases of the leakage are separated (Figure 9).

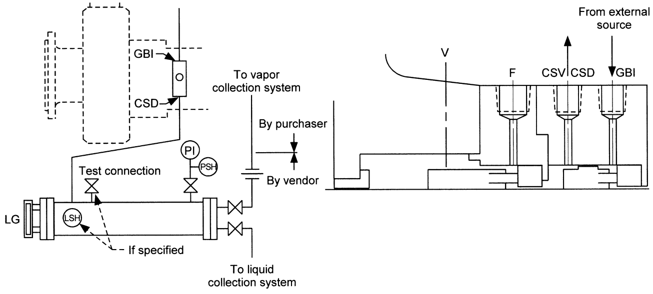

Figure 9. Standard Seal Flush Plan 75.

- *Plan 76*—This plan is used for dry running containment seals (2CW-CS and 2NC-CS). This plan is designed for applications where the leakage past the primary seal completely vaporizes. Vapors are collected and piped to a vapor recovery system (Figure 10).

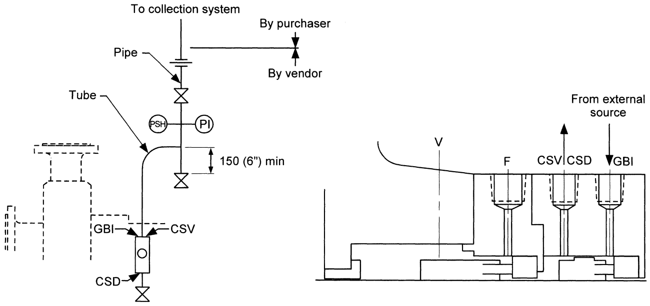

Figure 10. Standard Seal Flush Plan 76.

New Qualification Procedures

One of the strengths of the first edition was to provide qualification tests where seal vendors would be required to prove the suitability of their seals for a given service. The second edition expands on these requirements by adding new tests for containment seals and dual gas seals, as well as defining acceptance criteria for all tests.

Containment seals operate under low pressure, dry running conditions for the majority of their life. They are primarily intended to contain process fluid in case of failure of the inner seal. The testing of a containment seal is designed to simulate such a failure. First, a seal cartridge (consisting of a liquid inner seal and dry running containment seal) is subjected to the standard seal qualification test. The standard seal qualification test includes a 100 hour dynamic phase, a four hour static phase, and number of pressure and on/off cycles. During this portion of the test, the containment seal is seeing only normal leakage past the inner seal. Afterward, the containment seal will be operated for 100 hours on propane at 10 psi (0.7 bar) at 3600 rpm. The seal will be stopped, pressurized to 25 psi (1.8 bar), blocked in, and held for five minutes. The containment seal chamber will then be filled with diesel at 40 psi (2.8 bar) and operated at 3600 rpm for an additional 100 hours. The seal will again be stopped and maintained at 250 psi (17.2 bar) for four hours. Results of leakage will be taken at specified points during the test (Figure 11).

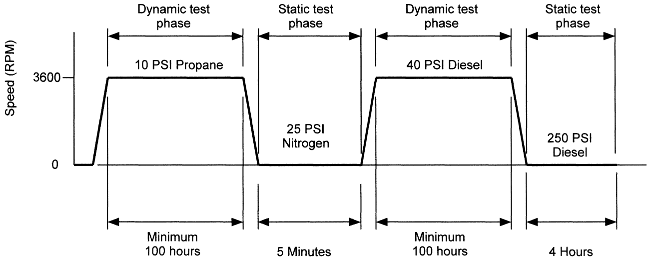

Figure 11. Containment Seal Test Cycle.

Dual pressurized gas seals will first be tested to the standard seal qualification test. After this, the seal will be tested for loss of barrier gas pressure. The seal will be stopped and the barrier gas pressure will be reduced to 0 psi for one hour. The barrier gas will be reapplied and the seal operated until the system reaches equilibrium. The barrier pressure will then be reduced to 0 psi for one minute and then the pressure reapplied. This will simulate a gas barrier pressure loss in operation. The seal will then be stopped and blocked in for 10 minutes. Results will be recorded at specified points during the test (Figure 12).

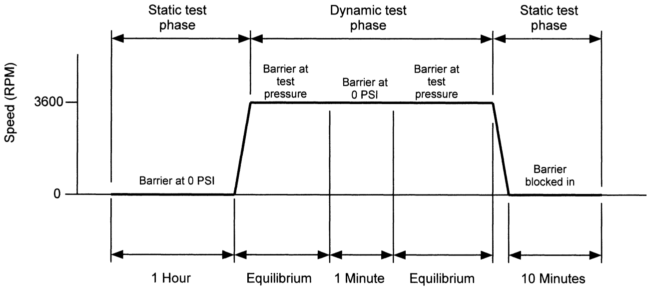

Figure 12. Dual Gas Seal Test Cycle.

Category 3 seals must be tested in the same configuration, type, design, and materials as the commercially available seal design. Category 1 and 2 seals must also be tested. However, if Category 1 and 2 seals are constructed of seal faces that are used in a previously qualified Category 3 seal, no further testing is required. The maximum allowable leakage during testing is 1000 ppm (volume) vapors (as measured by EPA Method 21) or 5.6 g/h liquid leakage per pair of sealing faces. The maximum allowable face wear at the completion of the testing must be less than 1 percent of the available seal face wear.

SEAL SELECTION PROCEDURE

The seal selection procedure provides the user with a standard methodology for selecting a seal for a variety of refinery and general services. Although chemical and petrochemical industries are now covered by API 682, the selection procedure did not attempt to cover every application due to the myriad process fluids involved in these industries. The procedure is a series of steps that directs the user to collect information on the application, regulations, and local requirements. This information is used to select the seal category, type, arrangement, and piping plan. A flowchart that describes the sequence of steps is shown on Annex A (Figure 13).

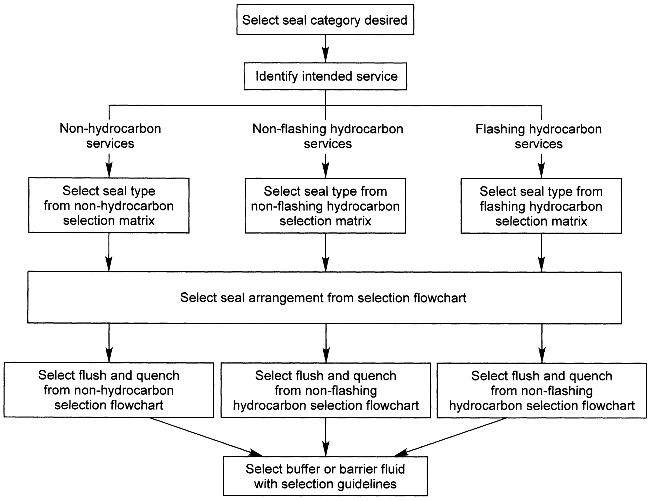

Figure 13. Seal Selection Procedure.

Seal Category

The first step in selecting a seal is to determine the seal category required for the service. The category is a function of the pump design, the operating conditions, the design features of the seal, and the documentation required by the user. A comparison of the seal categories is shown in Annex A of the standard.

Seal Type

Seal applications are divided into three major services: nonflashing hydrocarbon, flashing hydrocarbon, and nonhydrocarbon.

Nonhydrocarbon services are further divided into water, sour water, caustic, amines, crystallizing services, and acids. Each of the service groups is defined for a range of pressures of temperatures. The applicable seal types are listed under each of the groups along with any special design or material recommendations for the specific service.

Seal Arrangement

The selection of the seal arrangement is a function of regulations, hazard assessment, and process fluid properties. All applications start with an Arrangement 1 (single seal). The user follows a flowchart of "yes or no" questions until they reach the end of the chart. At this point, the final arrangement (1, 2, or 3) is determined.

Seal Flush and Quench

The selection flowcharts for piping plans are divided into the same three services as the seal type selection: nonflashing hydrocarbon, flashing hydrocarbon, and nonhydrocarbon. Each of these flowcharts has a starting point for each of the arrangements. The user answers a number of questions about the process conditions, fluid properties, and the presence of contaminants. The user then follows the flowchart to arrive at the suggested piping plan for the seal flush and quench.

Barrier Fluid

The selection of a barrier or buffer fluid is critical to the success of liquid dual seals. Barrier and buffer fluids must be compatible with the process fluid and seal materials of construction. In addition, it must provide adequate lubrication for the seals and have suitable fluid properties over the entire range of expected operating conditions. Guidelines for barrier/buffer fluid selection are given in Annex A of the standard.

CONCLUSIONS

The second edition of API 682 (ISO 21049) has been developed to address advances in seal technology and expand the scope of applications beyond that covered in the first edition. New seal categories and seal designs (such as dry gas seals) have been introduced. Additional piping plans and seal qualification testing have been added. While there have been many changes, the objectives of the standard have remained the same—to provide longer seal life while meeting emissions requirements. The review of the document by the international community has provided valuable contributions to the standard. The release of this document as an ISO standard will allow more international companies to realize the benefits of using one standard for mechanical seals worldwide.

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