DRY RUNNING BELLOWS TYPE TANDEM SEALS FOR VOC SERVICES

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ABSTRACT

Dry running bellows seal technology, where the secondary (outer) seal operates in a dry condition, was originally developed in the UK and Europe for protection against primary seal failure. Over the past three years, it has been successfully applied in the United States to control volatile organic compound (VOC) and volatile hazardous air pollutant (VHAP) emissions.

A history of development, a description of the unique bellows seal design, and a summary of the widespread application of this technology by a U.S. refiner are presented. Statistical data for performance, reliability, and relative cost are presented.

INTRODUCTION

The present population of dry running, bellows type, tandem seal installations is approximately 1500 worldwide. Recent U.S. applications have focused on VOC controlled services, where use of the dry running seal eliminates the need for the traditional tandem seal buffer fluid circulation system.

Refiners in the Los Angeles, California, area fall under the jurisdiction of the South Coast Air Quality Management District (SCAQMD). As such, pump emissions and seal design must comply with SCAQMD regulations. Dry running bellows seals have recently been installed in large numbers to satisfy these requirements.

Most Southern California refiners are in the process of modifying their refineries to produce reformulated gasoline by 1996. These modifications involve the construction of new processing plants, as well as modifications within existing refinery operating units. Process services that are most affected are the gasoline and LPG streams. One refiner chose dry running bellows type tandem seals, on a project-wide basis, for these VOC services, thereby meeting SCAQMD requirements for construction and operational permits.

SEAL DEVELOPMENT

United Kingdom and European Development History

In 1983, the UK and European market demanded a need for a dry running secondary seal for two major reasons:

• The installation costs of a wet tandem seal and ancillary barrier equipment were high and difficult for most customers to justify. In addition, there were high maintenance costs associated with the operation of wet tandem seal systems (i.e., physical monitoring, barrier fluid consumption, and poor reliability due to improper or difficult to understand operating instructions).

• A tandem seal design was needed to provide a safety or backup seal to a single primary seal in case of massive primary seal leakage [1]. Environmental emission concerns were not a significant consideration in the UK and Europe at this time.

One major seal manufacturer had a noncontacting seal on the market that satisfied the need for a dry running tandem. The wet barrier system was replaced with a gas barrier. The initial installation costs were lower because the gas barrier did not require a tank and associated hardware. Operating costs were lower because there was no liquid level to inspect and maintain. However, the dry gas seal would not contain a fluid in the case of massive primary seal leakage. The ability of the secondary seal to run dry for extended periods at low differential pressures while containing liquid at high pressures during primary seal failure, was considered an important requirement for a secondary seal [2].

An initial test program was performed in the UK. Several seal vendors and refineries participated in the program. The standard test procedure was developed by Dolan [1]. The program was designed to test the integrity of the seal in the standby, in service, and containment modes. The initial test specification was arranged in two phases requiring the seal to endure the following operating conditions:

Phase I (preliminary screening)

10 hours	@	1 Bar (in air)
2 hours	@	20 Bar (in air)

Phase II

1000 hours	@	0.2 Bar (in air)
10 hours	@	1 Bar (in air)
2 hours	@	20 Bar (in air)
measure leakage	@	1 Bar (in water)
measure leakage	@	20 Bar (in water)

The actual procedure was modified depending on the seal design and performance. Leakage was not to exceed 3000 ml/min for air and 10 ml/min for water. Four different sealing technologies were used to meet this test challenge. The various types of seals tested included: lip seals, end face seals with low face loads, gas seals, and abeyant seals (noncontacting seals designed to contact during the high pressures of primary seal failure) [1, 2].

In 1984, a bellows seal manufacturer in the UK began development on a full contacting, dry running, bellows seal. Early in the development program, it became evident that the major design challenge would be to determine the correct seal face combination and loading. The commonly used face material grades and loads for wet contacting seals had excessive wear rates when used in the dry running mode. Extensive testing to determine the optimum tribopair and load was conducted. The testing focused on the dry-sliding tribopairs that exhibited the lowest friction and wear at various face unit loads. The best dry-sliding combinations were then tested in a lubricated-sliding environment. By 1985, the tests by the seal manufacturer had indicated the best selection for face material. In addition, the optimum face unit load was determined.

Test results showed that a stationary mounted bellows gave consistently lower wear rates than rotating bellows with the same tribopair. In addition, stationary flexible elements can accommodate for shaft to seal chamber misalignment better than rotating flexible elements. Rotating flexible elements must "flex" each revolution to adjust for this type of misalignment.

The test program continued through 1987 [2]. It was announced at the 11th International Conference on Fluid Sealing Conference in 1987, at Cannes, France, that no seal had successfully completed the test program. All of the seals ultimately failed the high pressure dry-running phase of the test due to heat generation. This contributed to a variety of failure modes that were design specific. The high pressure phase of the test, two hr at 20 bar pressure in air, was considered to be unrealistic for a seal that is intended to contain primary seal failures of the pumped liquid. The abeyant seal concept was viewed unacceptable for seal systems connected to flare lines because of unpredictable performance during the primary seal failure mode [2].

While the test program [2] continued, dry running, bellows seal prototypes were installed in refineries in Italy (1988) and France (1989). These prototypes were installed in light hydrocarbon services in place of wet tandem seals.

U.S. Development History

It wasn't until 1989 that engineers in the U.S. began to recognize the need for development of the dry running secondary seal. By this time, growing environmental concerns had forced U.S. industries to provide cost effective solutions to VOC and VHAP emissions. Driven by new more stringent emission regulations, like California's SCAQMD Rule 1173, single seals were rapidly being replaced with costly wet tandems. The timing was right to provide a more reliable, cost effective alternative to the wet tandem seal.

Testing began at a U.S. division of the same seal manufacturer, using the stationary seal design, face materials, and face loads identified from the previous UK tests. The design work centered around a method to control the face load. A bellows design that used thin, uniformly loaded plates, to produce a low spring rate, was considered essential to deliver this control. As the history of successful performance grew, the design was released as a standard product in the winter of 1991. The plate thicknesses that were selected have pressure carrying capabilities up to 450 psig for containing the pumped product in the event of primary seal failure. Since the introduction, in excess of 1500 seals have been specified by more than 75 refineries and chemical plants throughout the world. Of the original prototypes, the longest running seal, installed in September 1990, has operated successfully without repair.

Regulatory Requirements

The SCAQMD has two basic requirements that must be met:

• Pumps in "light liquid" service must comply with "Rule 1173," emitting no more than 1000 ppm VOCs during operation. (It is expected that this will be reduced to 500 ppm in the future.) "Light liquid" service is defined as any hydrocarbon service where more than 10 percent of the liquid is evaporated at 150°C, using ASTM Method D-86. Gasoline and lighter services typically fall within this definition, with typical ambient specific gravities of 0.5 to 0.7. Dry-tandem seals were applied throughout this range.

• Equipment must comply with best available control technology (BACT) regulations in order to get construction permits to install the equipment. For new pumps, and for re-rated pumps with larger drivers, BACT can be satisfied by installing a sealless pump or a pump with dual seals (i.e., either double seals or tandem seals).

DESIGN AND TESTING

Basic Seal Design

The stationary bellows design uses a proprietary tribopair, a very closely controlled face load and spring rate, and a unique mounting arrangement. The tribopair selection was based on preliminary testing in the UK and confirmed in the U.S.. The optimum design load to achieve low face wear and heat generation, was determined from many hours of lab testing.

A bellows seal was the logical choice for this application. The bellows design eliminated the traditional design problems associated with dynamic O-rings [3]. Face tracking ability was a major consideration when using the low face loads required to control face wear. In addition, a high temperature bellows seal was easily designed by replacing all the O-rings with flexible graphite packing.

Test Stand Results

The rotating mating ring was designed to draw frictional heat away from the faces by contacting the sleeve. This, in combination with lighter loads, helped to minimize face temperatures during dry running operation. A graph is shown in Figure 1 of the typical face temperatures measured during a test (at one atm pressure and 3600 rpm).

Wear results from several tests are shown in Table 1. The highest face wear occurred during the first 400 to 500 hr and remained unchanged for the remainder of the test [4].

An unexpected phenomenon occurred during testing of new production sizes. An intermittent sound was being emitted by the stationary face. The occurrence seemed to be somewhat size dependant but occurred in all sizes occasionally. Field and test data confirmed that, apart from the annoyance factor, noisy seals performed as well as seals emitting no noise. The wear and leakage rates were unaffected by noise level. The sound energy was absorbed by some unique methods of damping. The damping method had no effect on the seal face tracking capability.

The final product was a user friendly, contacting bellows seal (Figure 2) that would run dry through its lifetime but minimize leakage during primary seal failure. Lab tests and field data show that this seal will reliably contain emissions during normal and upset conditions (including primary seal failure).

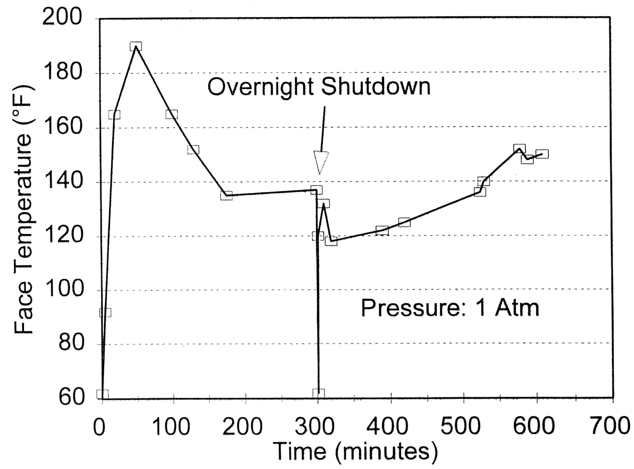

Figure 1. Face Temperature Vs *Time.*

Table 1. Wear Data.

TEST NUMBER	DURATION (hours)	TOTAL WEAR (inches)
801	100	0.003
802	1000	0.002
701	200	0.005
001	300	0.002
301	400	0.0045
401	1000	0.003
402	1000	0.003

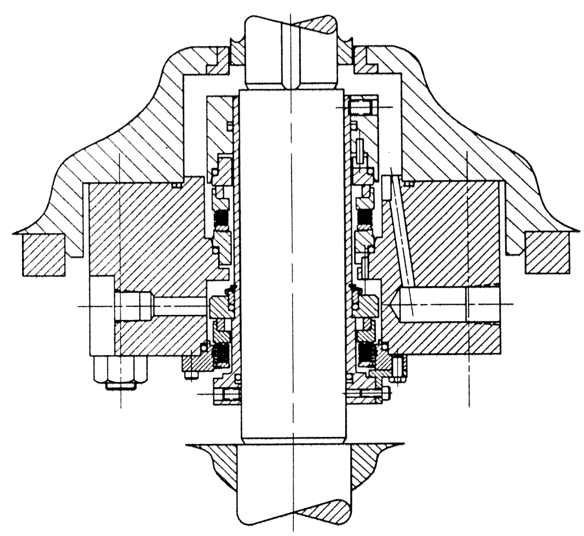

Figure 2. Cross Section of a Bellows Secondary Seal.

Emissions Test Stand Results

Results from extended leakage testing are shown in Figure 3. The average leakage over a 3300 hr test in nitrogen was 5 × $(10)^{-5}$ scfm (approximately XX ppm). The test chamber pressure and temperature varied over the test duration, averaging 6.0 psig and 73°F.

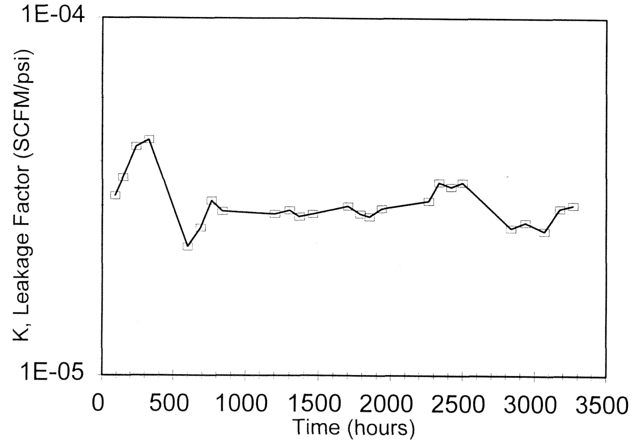

Figure 3. Seal Leakage Vs *Time.*

Test stand results for a dry running bellows type tandem seal running in propane show that emission levels were below 100 ppm for varying operating conditions. Seal cavity pressure, temperature, pump flowrate, and emissions data are shown in Figure 4.

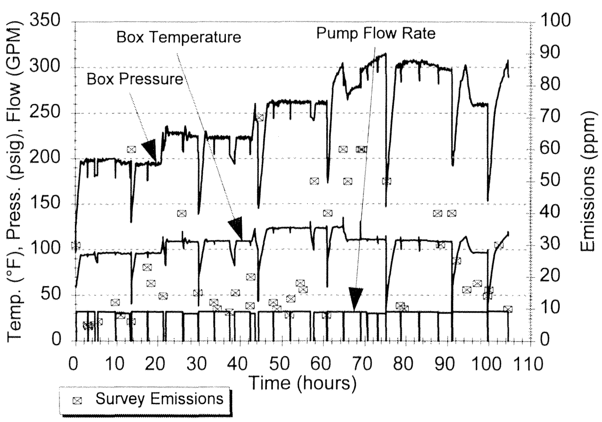

Figure 4. Propane Test Stand Data.

The dry-running end of this seal was also tested in propane at 300 psig for a 12 hr period. Emissions measured 300 ppm or less throughout the test. Face temperature averaged 15°F to 20°F hotter than the product temperature, and about 40°F cooler than was measured in the dry-running mode of operation.

Field Emissions Data

Field VOC emissions data are summarized in Table 2. Measurements were made on 29 refinery pumps in light hydrocarbon service, in accordance with SCAQMD regulations. All pumps are fitted with dry running, bellows type tandem seals. None have failed emissions testing. In all cases, the field VOC reading is well below the allowable 1000 ppm.

Some refinery retrofits have been fitted with dry tandem seals, and installed without connection to the refinery recovery system. This is permissible (under air district rules) as long as the emissions limit is complied with. Field test readings for these seals have verified this compliance, as shown in Table 2.

An added benefit is the ability of the dry seal to continue to run after the primary seal has failed. Recent experience with a gasoline pump (specific gravity 0.66), operating at 140°F and 280 psig discharge, indicates the normally dry outer (secondary) seal, will perform well in a light-hydrocarbon liquid environment. This pump was operated with a failed primary seal for a period of six weeks. Field emission readings, which were taken weekly, ranged from 100 to 300 ppm (well below the 1000 ppm allowable). It is noteworthy that this pump did not have a vent system connection.

Table 2. Field Emissions Data.

PUMP #	LOCATION	SERVICE	INSTALLED	FAIL/DATE	EMIT PPM	COMMENT
2317 295.02	ALKY	ISOBUTANE	Dec-91	NONE	30	
0355 295.02	SFIA	STAB. FEED	Apr-92	NONE	500	NO VENT SYSTEM
1775 295 02	STORAGE	BUTANE	Mar-93	NONE	3	
1035 295 02	REFORMER	STAB. FEED	May-93	NONE	100	NO VENT SYSTEM
0721 295 02	FCC	BTM INT'COOL	May-93	May-93	10	WRONG PRIMARY FACE MAT.
0713 295 02	FCC	DEBUT REFLUX	Jun-93	NONE	10	NO VENT SYSTEM
1079 295 02	CRUDE	DEPROP FEED	Aug-93	NONE	3	NO VENT SYSTEM
2043 295 02	REFORMER	DEPROP FEED	Aug-93	Jan-94	5	GREASE IN SEAL
0771 295 02	FCC	DEPROP REFLUX	Oct-93	Sep-94	10	WRONG PRIM. BELLOWS MAT
1053 295 02	REFORMER	PROPANE	Nov-93	Apr-94	300	PARTICLES IN PRIMARY SEAL
1081 295 02	CRUDE	DEBUT REFLUX	Dec-93	NONE	3	NO VENT SYSTEM
1234 295 02	REFORMER	STAB. REFLUX	Jan-94	NONE	30	NO VENT SYSTEM
1760 295 02	ALKY	DEPROP REFLUX	Apr-94	NONE	100	NO VENT SYSTEM
1844 295 02	CRUDE	NAPHTHA	Jun-94	NONE	10	
1845 295 02	CRUDE	NAPHTHA	Jun-94	NONE	10	
2373 295 02	ALKY	OLEFIN FEED	Jul-94	NONE	50	
2634 295 02	DEHEX	DEHEX REFLUX	Aug-94	Aug-94	3	WELD SCALE IN PRIMARY
2635 295 02	DEHEX	DEHEX REFLUX	Aug-94	NONE	3	
2640 295 02	DEHEX	DEHEX REFLUX	Aug-94	NONE	3	
2641 295 02	DEHEX	DEHEX REFLUX	Aug-94	NONE	20	
2632 295 02	DEHEX	DEHEX BOTTOMS	Aug-94	NONE	3	
2633 295 02	DEHEX	DEHEX BOTTOMS	Aug-94	Oct-94	3	WRONG PRIM. O'RING MAT
2638 295 02	DEHEX	DEHEX BOTTOMS	Aug-94	NONE	3	
2639 295 02	DEHEX	DEHEX BOTTOMS	Aug-94	NONE	3	
2672 295 02	DEHEX	FLARE KNOCKOUT	Aug-94	NONE		
2656 295 02	CRUDE	DEBUT CHARGE	Aug-94	NONE	50	
2652 295 02	CRUDE	STRIPPER O'HEAD	Aug-94	NONE		
2653 295 02	CRUDE	STRIPPER O'HEAD	Aug-94	NONE		
2654 295 02	CRUDE	TOWER O'HEAD	Aug-94	NONE		
2644 295 02	SFIA	NAPHTHA	Nov-94	NONE		
2645 295 02	SFIA	NAPHTHA	Nov-94	NONE		
2666 295 02	SFIA	DEBUT REFLUX	Sep-94	NONE	10	
2667 295 02	SFIA	DEBUT REFLUX	Sep-94	NONE	3	
2664 295 02	SFIA	DEPENT REFLUX	Sep-94	NONE	100	
2665 295 02	SFIA	DEPENT REFLUX	Sep-94	NONE	50	
2097 295 02	TANK	PENTANE	Nov-94	NONE		VERTICAL TURBINE PUMP
2098 295 02	TANK	PENTANE	Nov-94	NONE		VERTICAL TURBINE PUMP

Support System Design

A typical support system is shown in Figure 5. This simple system takes the place of the traditional buffer fluid pot, piping, and instrumentation that must be supplied with conventional wet tandem seals. The system consists of vent piping, with orifice, and block/check valves, connected to a contained, low pressure recovery, or vapor recovery system. A simple pressure indicator (PI) registers an increase in pressure in the event of a primary seal failure.

Pressure switches, which are often used to sound alarms on wet tandem systems, are not required. This is because field tests have revealed continued compliance with the 1000 ppm VOC limit, even after the primary seal has failed. Primary seal failure does not, therefore, constitute cause for alarm. When the PI indicates a primary failure, it is registered during routine operator rounds, and maintenance is scheduled on a routine (i.e., nonemergency) basis.

Seals may be connected to a low pressure recovery or to a vapor recovery system. Spring loaded, stainless steel check valves are recommended to prevent back flow into the seal

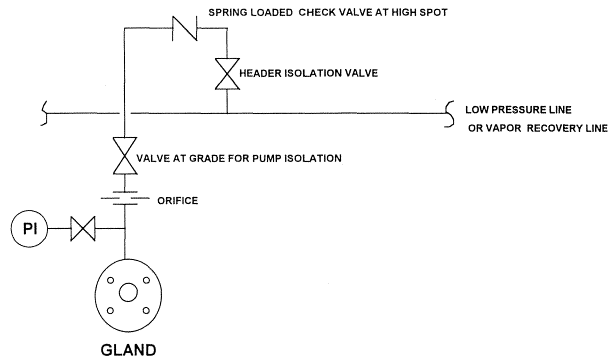

Figure 5. Typical Support System.

cavity, if hydrogen sulfide or other harmful gases are present in the recovery system header. Check valves are preferably located at the high spot in the piping system, to prevent condensate from gathering on the downstream side of the valves. For connections to vapor recovery systems, which run at a slight negative pressure, the check valve spring should be chosen for positive pressure in the outer seal cavity. This is to prevent air leakage into the recovery system, in the event of a dry seal leak or failure.

U.S. REFINER'S APPLICATION EXPERIENCE

Early Experience

Before the implementation SCAQMD Rule 1173, a group of machinery engineers was reviewing available mechanical seal technology in order to meet stringent proposed emissions limits. The main emphasis of this task was concentrated on the existing pumps, which were installed anywhere between three to 50 years ago. Pump types ranged from single stage overhung to multistage, centerhung designs, operating at speeds ranging from 1,800 rpm to 3600 rpm.

Selection criteria at this time were rather simple—the seals must meet or exceed regulatory emission target requirements, have overall reasonable cost, and be reliable. Experience with conventional liquid tandem seals in VOC services taught some important lessons:

• Overall installed cost is high.

• Liquid tandems require continuous attention from operators and maintenance personnel.

• It is not unusual for the secondary seal to fail before the primary seal.

Upon review of the dry running tandem seal technology, a decision was made to install one seal in a VOC service to see how it actually performed. The selected pump was a single stage overhung pump in butane service, which was equipped with a conventional liquid tandem seal and its accessories. The seal oil tank was already connected to a vapor recovery system. A new dry running tandem seal was installed in the pump. Oil in the buffer fluid tank was drained and the tank was connected to a the dry running seal cavity. The pump was run for six months, then the seal was removed and sent to the seal manufacturer for analysis. During these six months in service, the seal worked very well and emission levels were very low. The seal manufacturer could not measure any wear on the dry running secondary seal and the same seal was put back in service. This same seal is running today, approximately three years since originally installed.

These seals have now been installed in various units of the refinery in old and new pumps. In some retrofit cases, a new API 610 Seventh Edition bearing housing was installed in order to accommodate the new seal. Installation of this seal is no different from other tandem seals.

Project Experience

The recent reformulated gasoline project has resulted in the purchase of 55 pumps for VOC services, all fitted with dry running, bellows type tandem seals. A seal selection study was completed prior to the decision to install these seals on this widespread basis.

Seal Selection Criteria for Project Pumps

Early in the project, a list of selection criteria was prepared in order to establish a consistent sealing program that could be applied throughout the four year project duration. The following categories were established for evaluating sealing system designs:

• Ability to meet SCAQMD "Rule 1173" emissions limits

• Ability to meet SCAQMD best available control technology (BACT) regulations

• Proven reliability of technical design (with field experience)

• Operability/maintainability (i.e., simplicity of support system)

• Cost

• Vendor technical/service capability

Dry running, bellows type, tandem seals were ultimately selected over seal-less pumps, conventional "wet tandem" (i.e., buffer fluid type) seals, and pusher-type dry-running tandem seals. Sealless pumps were not selected because of concerns about reliability (i.e., product-lubed bearings in VOC service), maintenance cost, and efficiency. Pusher type dry running tandems were rejected because there was too little operating experience. There were also concerns about the dynamic, secondary O-rings effects on outer (i.e., dry) seal operation. The dry running bellows design was found to satisfy all the requirements listed above, at lower installed cost than the conventional "wet tandem" pusher design.

Reliability

This user's experience, with 37 current field applications, is very encouraging. Longest continuous inservice time is three years (and counting). Cumulative inservice time is approximately 27 years (see Table 2 for installation dates). To date, there have been no failures of the secondary (dry running) portion of any of these seals.

Since most seals were installed within the last year, MTBF data are not very meaningful. A total of six primary (i.e., wet end) seal failures have occurred within the 37 pump data base. Root causes of these failures is (summarized in Table 2):

• One failure due to a misapplied face material

• Two failures due to particle contamination

• One failure due to grease contamination from an overgreased valve packing gland

• One failure due to a misapplied O-ring material

• One failure due to misapplied bellows material

An added reliability benefit is the ability of the dry seal to operate after the primary seal has failed (*Field Emissions Data* section). The pump can continue to run until maintenance is scheduled and performed, with no violation of regulated emission levels. This is highly desirable because maintenance can be scheduled on a routine basis, and does not have be performed as an emergency.

Cost

Project experience indicates the installed cost of the dry running bellows seal to be substantially less than a conventional, pusher type, "wet tandem" seal, primarily because the dry-tandem seal eliminates the need for a buffer fluid pot and auxiliaries. For large projects, this per-seal savings adds up quickly. Elimination of the seal pot, return piping, and pressure switch, saves 10 to 25 per cent of the original capital cost of API Seventh Edition pump skids (see table three). Since sealing systems make up a greater portion of the overall cost of small pump trains, the savings percentage is higher on small pumps than on larger pumps. This comparison includes the difference in seal costs, with bellows tandem seal costs substantially higher than pusher tandem seal costs. The cost comparison does not include maintenance or operating cost savings, which will favor the dry running tandem seal. There is no barrier fluid system to maintain, no liquid level to monitor, and no hazardous waste cost for disposal of the barrier fluid.

Table 3. Installed Cost Savings, Dry Tandem Seal Vs *Wet Tandem.*

PUMP TYPE	SIZE	COST SAVINGS*
Single Stage Overhung	2" Disch X 3" Suction	25%
Single Stage Overhung	3" Disch X 6" Suction	20%
Single Stage Centerhung	6" Disch X 8" Suction	15%
Seven Stage Centerhung	3" Disch X 4" Suction	10%

* vs same pump with pusher-type, wet tandem seal, including. stainless steel seal pot with level gage

CONCLUSION

Dry running, bellows type, tandem seals were developed through a long term program that initiated in the UK and Europe. In the U.S., this technology has successfully been applied to control emissions. Continuous service runs as long as three years have been achieved. In addition, this seal design has complied with emissions regulatory requirements while operating with a leaking primary seal. Based on a U.S. refiner's experience, this alternative to wet tandem seal systems has a lower installed cost, is simpler to operate, and requires less support system maintenance.

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