

# ZERO EMISSION SOLUTIONS FOR MECHANICAL SEALS ON LIGHT HYDROCARBONS

by

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*In 1961, an agency agreement with Flexibox B.V., put the company under the direction of the Managing Director of Flexibox, Limited, and Mr. ten Houte de Lange.*

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## INTRODUCTION

The recently introduced emission regulations in the United States have attracted much attention. The implications in respect of mechanical seals have been widely debated. Proposals have been made for seals and sealing systems that can meet current regulations for existing plant.

While simple mechanical seals will continue to improve in performance and be extensively used, there are occasions where zero leakage is required, and where the currently recognized option is the glandless pump, which imposes other limitations. Similarly, tandem and double mechanical seals, which can achieve zero emission levels, may not be acceptable based on cost and/or space requirements.

The actual performance in operating plant of conventional and enhanced systems is reviewed. The conception, design, development, and tests of innovative new systems is described. These systems are designed to achieve zero emission levels without the expense and inconvenience of glandless pumps.

## LEGISLATION FOR SAFETY AND EMISSION CONTROL

### Europe

The 1974 explosion at Flixborough in the UK, the 1975 explosion at Beek in Holland, the 1976 dioxin release at Seveso in Italy, and a further toxic chemical release in the same year at Manfredonia in Italy, resulted in the commission of the EC to issue a directive on major accident hazards. This directive, 82/501/EEC (usually known as the Seveso directive) was finally adopted in June 1982. Community members then had to implement the directive in their own legislation. For instance, in the UK, it was implemented in the "Control of Industrial Major Accident Hazard Regulations 1984". Among other requirements, the directive required that certain industrial installations (as defined in the directive), handling certain hazardous chemicals (as defined in the directive), should demonstrate that they had identified the major hazards and had implemented appropriate safety measures.

### United States

A lot of American legislation has tended to concentrate on a different problem—fugitive emissions (leaks) of volatile organic compounds (VOC). These compounds are defined by the Environmental Protection Agency (EPA) as compounds that participate in photochemical reactions. The concern here is air quality and, in particular, ozone concentrations formed by photochemical reac-

tions. Regulating agencies in the various states and the EPA are in the process of defining new standards for VOC emissions and similar legislation is being enacted abroad. California's South Coast Air Quality Management Division (SCAQMD) adopted rule 1173 on July 7, 1989.

#### *The EPA and SCAQMD regulations in brief.*

The leakage of volatile organic compounds (eg., hydrocarbon fractions) into the atmosphere is no longer acceptable. Legislation has been passed at Federal level and is to be administered by the Environmental Protection Agency, the EPA. The SCAQMD regulations are derived from the EPA legislation that sets the acceptability level (minor leak) at 10,000 ppm.

SCAQMD decided to reduce to one tenth of that level as previously indicated. It is expected that a number of authorities will introduce even lower limits of acceptability.

#### *The SCAQMD regulations*

The SCAQMD regulations relate to permissible leakage levels in parts per million (ppm) and the actions required of the operator if they are exceeded. Leakages are measured (following EPA reference method 21), using a methane calibrated analyzer, as the difference between background readings (at least one meter upwind from the source) and readings taken at a distance of 1.0 cm (0.4 in) or less from the source.

The maximum number of leaking pumps is two in a population of under 200 or one percent of the population for more than 200 pumps.

Major gas leak: 10,000 ppm or more. Leaks must be repaired in less than five calendar days. (Any leak in excess of 50,000 ppm is considered a violation of the rule and must be repaired within one calendar day.)

Minor gas leak: between 1,000 and 10,000 ppm. Leaks must be repaired within 14 calendar days.

Liquid leaks are defined as dripping of volatile organic compounds at the rate of more than three drops per minute. Liquid leaks must be corrected in one calendar day.

How well can single and multiple seals measure up to the new regulations and give long life and reliable performance and how can zero emission requirements be met on new plant without the use of glandless pumps?

## CONVENTIONAL AND ENHANCED SYSTEMS

### *Conventional systems*

In any sealing system with single or multiple sealing elements, there is always one seal that performs the primary sealing function. In multiple seal systems, the other sealing elements are there to enhance the performance of the primary seal or to provide a secondary containment function.

Single mechanical seals can give good reliability and a high degree of primary safety through proper selection of well designed seals in the right materials, and with the right auxiliary services.

### *Seals for Volatile and Unstable Liquids*

Light hydrocarbons are both volatile and dangerous. They are frequently pumped at temperatures very close to their boiling points at the sealed pressure (often within two or three degrees centigrade) and well above their atmospheric boiling point. They are also poor lubricants with low viscosities and give potentially high seal face friction values. The principle problem to the seal designer is to maintain a stable liquid film at the seal face by preventing breakdown due to excessive face temperatures that lead to vaporization of the film.

This objective can be achieved by a combination of minimizing heat generation and maximizing the heat dissipation properties of the seal.

The seal shown in Figure 1 was developed in conjunction with a number of major operating companies and has been applied in hundreds of applications worldwide.

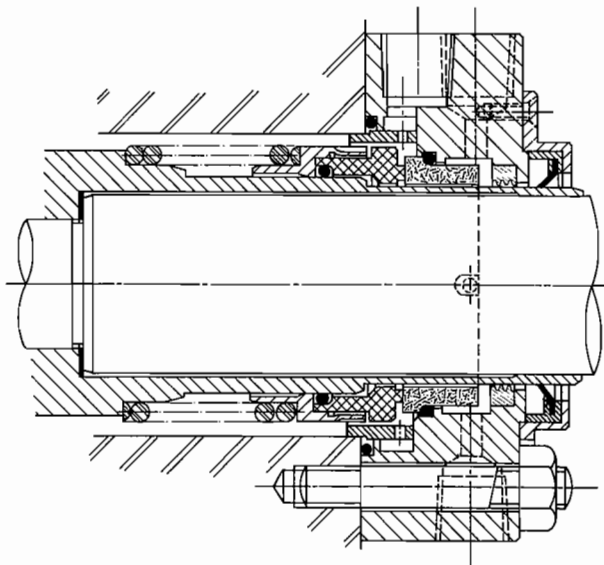


Figure 1. Light Hydrocarbon Seal.

The design uses narrow faces for minimal heat generation and a substantial and stable rotating carbon design that is insulated from spurious distortions by virtue of its two part construction. This minimizes the potential for asymmetrical face deformations that could be responsible for elevating friction values.

Symmetrical multipoint injection is the major factor in enhancing heat dissipation and eliminating the possibility of asymmetrical temperature distortions in components. High circulation rates (typically 15 liters per min) have a very significant effect on heat transfer coefficients and reduce face temperature rises from the normal 20°C to some 2/4°C.

In light hydrocarbon applications, there is always a danger of forming small vapor bubbles which can cling to the rotating component by centrifugal action, and can inhibit heat dissipation. This is another reason the high conductivity material (tungsten carbide or silicon carbide) is used in the stationary position and in the low conductivity carbon as the rotary.

Onsite measurements in a UK refinery indicate that this type of seal, operating correctly, and after a number of months in service, contains emissions to a level well below the SCAQMD requirement. Other more extensive surveys confirm this.

Liquid tandem seals are commonly and successfully used to provide secondary containment on such applications.

Liquid tandem seals have been well covered by other authors [1] and their operating capabilities in relation to emission control have been fully defined in a recent STLE Guideline [2].

In general terms, liquid tandem and double seals provide effective zero emission alternatives.

### *Enhanced systems*

Sometimes, however, liquid tandem seals are not feasible for reasons of space and/or cost.

The design, development, and application of two alternative products are considered. The first is a "contacting" or dry running standby seal and the second a full abeyant or noncontacting standby seal that is actuated into contact by a failure of the primary seal.

The detail of the design and development of these seals has been fully covered in previous papers [3, 4]. In the present study, the authors consider their relevance in meeting emission regulations.

#### Contacting Standby Seals

The seal shown in Figure 2 is a contacting standby seal fitted in tandem to a high pressure pipeline seal. The seal was originally developed to meet both the requirements of safety and emission control. A number of oil companies required a cost effective alternative to tandem seals for safety in sealing light hydrocarbons. One middle east oil company wanted to reduce hydrogen sulphide emissions from seals on sour crude oil pumps.

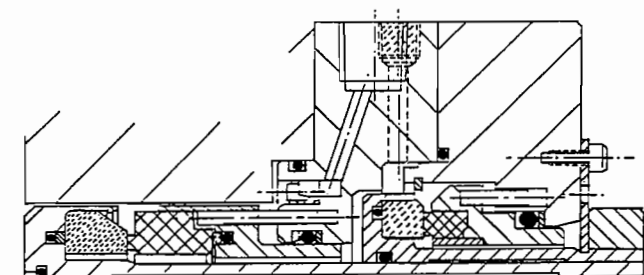


Figure 2. Contacting Standby Seal.

Since this standby seal operates in the contacting mode, it was vital to attain the correct compromise between the face area, balance ratio, and spring load, to produce low enough wear rates to give requisite life, and also give stability during all of the modes of operation. This development was very carefully followed by a number of oil companies. The seal has been subjected to additional testing by two major oil companies in their standby seal programs. Substantial numbers of these seals are now in operation in a variety of applications.

#### Noncontacting standby seals

A noncontacting standby seal (Figure 3), is shown mounted in tandem with a light hydrocarbon primary seal. The noncontacting standby seal was originally developed in the field in collaboration with a Dutch company for the secondary containment of propylene. The objective here was to reduce explosion risk. (By the nature of the seal, it was never foreseen that it would be used in containing vapor emissions. As will be seen later, it has been developed as part of emission control sealing systems.)

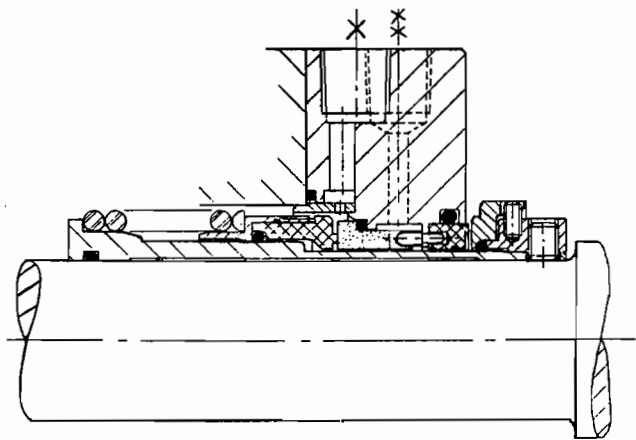


Figure 3. Noncontacting Standby Seal.

In a failure of the primary seal, fluid pressure is built up between the main seal and the secondary seal and a small amount of leakage between the noncontacting faces is allowed. At a certain level of leakage, this pressure closes the secondary seal that operates under the prevailing conditions for the time required for shutdown of the pump. It thereafter provides a static seal.

#### Applications

Several hundred noncontacting standby seals are now in service in locations throughout the world. Most are providing backup on light hydrocarbon service, although they are being considered more frequently for other duties. The lip seal shown in Figure 4 has allowed the seal to be used in many toxic services (e.g., benzene—See later for application details). The space between the secondary seal and the lip seal can either be piped to a safe place or be vented through a special filter.

The filter (Figure 5), allows a simple emission free seal cartridge to be installed with no pipework. This major advance offers emission performance achievement at until now, an unattainable low cost. It is often the only viable sealing configuration for pipeline applications where drainage pipework is out of the question.

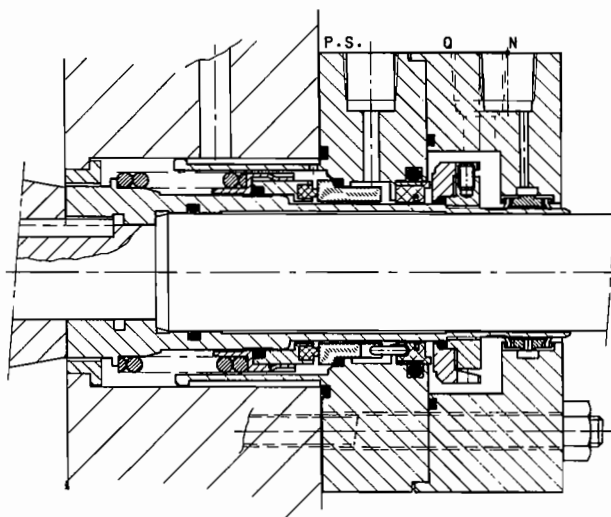


Figure 4. Noncontacting Standby Seals for Benzene Service.

The two seals described in this section offer low cost, space efficient alternatives to the traditional liquid tandem or double seal and will, hopefully, encourage operators to fit secondary containment devices where, perhaps, none would otherwise have been fitted.

#### ONSITE MEASUREMENTS OF EMISSION LEVELS FROM STANDBY SEALS

As part of the standby seal development program, measurements of emission levels under normal operating and primary seal failure conditions were made onsite.

##### Contacting Standby Seal Emissions

Details are given in Table 1 of selected applications that have been monitored both at a major UK refinery in England and at an American refinery in New Jersey, USA.

In all cases, the measured emission levels are substantially below the allowable levels in the standard, and no special preparation had been made prior to taking the measurements. All seals monitored were seals that had been operating for some time.

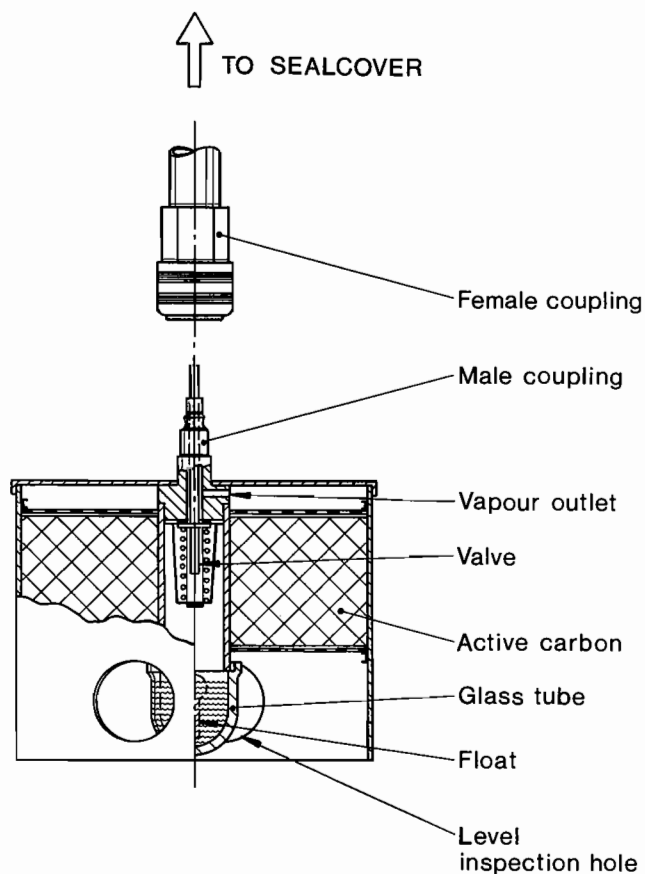


Figure 5. Toxiflex Safety Cartridge.

Table 1. Onsite Measurements of Emissions from Contacting Standby Seals.

| Location    | Seal size mm. | Product              | S.G. | Suction pressure psi | Primary seal leak yes/no | Interseal pressure psi | Emission level ppm |
|-------------|---------------|----------------------|------|----------------------|--------------------------|------------------------|--------------------|
| US refinery | 53            | Isobutane            | 0.58 | 25                   | yes                      | 85                     | zero               |
| UK refinery | 70            | Propane<br>Butane    | 0.52 | 250                  | yes                      | 7                      | 218                |
| UK refinery | 56            | Light HC             | 0.47 | 212                  | yes                      | 2                      | 295                |
| UK refinery | 56            | Propane<br>propylene | 0.49 | 263                  | no                       | 0                      | 8                  |

The measurements in the UK were made by an independent authority, and the measurements in the USA by the refinery personnel.

#### Noncontacting Standby Seal Emissions

Large quantities of non contacting standby seals have been sold over the last 10 years or so. These have been mostly without the optional lip seal and on clean light hydrocarbon applications. In recent years, the company has built up a large population of over 56 seals with one customer in Antwerp, Belgium. Because the sealed product contains significant quantities of benzene, the idea of the optional lip seal was born.

In 1988, The Belgian user conducted an inhouse survey of 10 pumps and found that emission levels were below 50 ppm in all

cases, and generally of the order of 20 ppm and less. In one case, a leakage of 200 ppm was traced to a shaft sleeve O-ring and the level reduced to under 5.0 ppm when it was replaced.

Typical duty conditions for the population of pumps are reflected in Table 2.

In two cases, the seals measured had primary seals that were leaking slightly, evidenced by the pressure rise in the interseal space.

Table 2. Typical Duty Conditions for Benzene Service.

| Noncontacting Standby + Lip Seals in Service in Belgium |               |         |                        |             |
|---|---------------|---------|------------------------|-------------|
| Seal Type   | Sealed Liquid | Temp °C | Suction Pressure (bar) | Speed (rpm) |
| TSBORRER-0600 (MBPQK)                                   | Aromatic HC   | 121     | 7.0                    | 3000        |
| TSBOLRREL-0560 (MBPQ)                                   | Sulfolane     | 177     | 1.67                   | 3000        |
| TSBOLRREL-0560 (MBPQ)                                   | Aromatic HC   | 38      | 0.26                   | 3000        |
| TSBORRER-0400 (MBPQ)                                    | Aromatic HC   | 38      | 0.54                   | 3000        |
| TSBORRER-0560 (MBPQK)                                   | Gasoline      | 30      | 0                      | 3000        |
| TSBOLRREL-0560 (MBPQ)                                   | Hydrocarbon   | 107     | 0.26                   | 3000        |
| TSBOLRREL-0560 (MBPQ)                                   | Hydrocarbon   | 27      | 0.18                   | 3000        |
| TSBOLRREL-0600 (MBPQ)                                   | Naptha        | 21      | 0.11                   | 3000        |
| TSBOLRREL-0360 (MBPQ)                                   | Gasoline      | 27      | 0.81                   | 3000        |
| TSBOLRREL-0360 (MBPQ)                                   | Gasoline      | 27      | 0.09                   | 3000        |
| TSBORRER-0280 (MBPQ)                                    | Benzene       | 27      | 0.06                   | 3000        |
| TSBOLRREL-0450 (MBPQ)                                   | Gasoline      | 27      | 0.10                   | 3000        |

#### Summary

The onsite measurements clearly confirm that both types of standby seal meet the requirements of EPA and SCAQMD.

#### NEW CONCEPT SYSTEMS

##### Glandless Pumps, Pros and Cons

Hermetically sealed compressor and pump units have been used successfully for many years in refrigeration and as boiler circulation pumps.

It is, therefore, not surprising that this group of totally enclosed pump units is gaining attention in the process industries, because of the expectation of totally solving the sealing problem, particularly at a time when environmental protection is highly topical. This group includes the following types:

*Wet stator units.* Pump/motor units in which the stator and rotor are immersed in the liquid. The insulation of the stator windings must be resistant to the product. This prevents their general use in a variety of liquids although the principle works successfully with specific liquids such as boiler water.

*Dry stator or canned units.* These units solve the insulation problem by separating the rotor and the stator with a can. The can will inevitably affect the magnetic efficiency of the motor and, therefore, is usually as thin as possible so as to reduce efficiency losses.

The selection of the material of the can is of great importance. It must be strong, corrosion resistant and have the correct magnetic properties.

*Magnetic drive pumps.* The recent development of very strong magnetic materials has stimulated the development of magnetic couplings.

Of the above types, only the canned pump and the magnetic drive pumps are of real interest to the process industries.

Canned pumps have been available for a long time and thus it is surprising that more general interest has only been evident quite recently. Canned pumps have been used in the process industries but usually only for the handling of certain dangerous or undesirable products. Their application has remained the exception rather than the rule.

Various reasons can be proposed for this pre-EPA status quo:

- Unfamiliarity
- Fear of bearing problems and can seizure
- Lower overall efficiency
- Limits in size and/or power
- Changes in pump maintenance
- Higher investment cost

Some of the reasons are becoming less valid:

- Lack of familiarity is wearing off
- The upper limit in size and/or power is still evident, although it is moving upwards
- When the hermetically sealed pump unit is compared with a conventional pump fitted with double mechanical seals complete with a system, the investment cost of the hermetically sealed pump may even be lower.

Companies are, however, shooting at a moving target and mechanical seals are being developed that require much less expensive systems.

At the same time, additional complication is being built into hermetically sealed pumps as they are developed to deal with more difficult applications.

Some of the reasons have a more permanent character:

- The maintenance of hermetically sealed units will require profound changes in workshop practice.
- The product lubricated bearings in hermetically sealed pumps and the faces of mechanical seals have a lot in common. They have both benefitted in performance from the introduction of new ceramic materials, particularly silicon carbide.

Although the effect of the sealed pressure is eliminated in the liquid lubricated bearing, there remains a great similarity in most other respects.

An exchange of a seal problem for a bearing problem is thus a realistic consideration. Like mechanical seals, liquid lubricated bearings can be affected by solid impurities and by vaporization phenomena with liquids that are near their boiling point.

Like a mechanical seal, the latter problem must be addressed by engineering a temperature margin below the boiling point for the circulating, lubricating product. Such a temperature margin is not always easy to obtain. In the mechanical seal world, technology has led to the development of pump NPSH seals, which can operate successfully with near zero temperature margins.

The difficulty of achieving a temperature margin in a hermetically sealed pump unit is further increased by the lower efficiency that generates extra heat near the bearings.

Can seizure can be the ultimate result of bearing problems? In a canned pump, the resultant leakage can remain contained in the stator housing. With a magnetic coupling pump, the result can be

more disastrous and, frequently, a back up sealing arrangement is being introduced. A seal for the sealless pump!

The graph in Figure 6 is used to illustrate the power consumption of traditional API pumps fitted with double seals compared with canned pumps and magnetic drive pumps. The values shown are obviously very dependent on the samples taken, although there is little doubt that canned and magnetic drive pumps use more power.

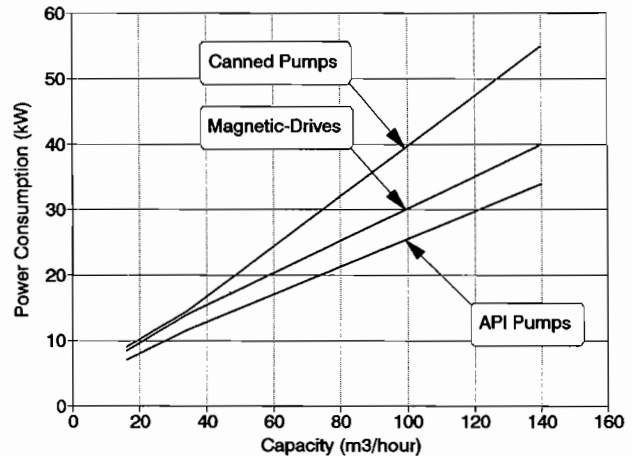


Figure 6. Power Consumption: API vs Canned Pumps and Magnetic Drive Pumps.

The cost of this extra power consumption needs to be taken into account when computing operating costs.

There is also a profound moral aspect to the use of these pumps and their increased power consumption. If the objective in using hermetically sealed pumps is environmental, then one should compare the two systems based on their respective emissions. This comparison seems easy since, for the hermetically sealed unit, the emission is generally accepted to be zero, but is this correct? Suppose that the hermetically sealed pump requires 2.0 to 3.0 kW more to operate. In that case, consider the emissions produced at the power station to provide this extra power.

If the power station is coal fired, then each extra kilowatt will require 0.25 kg of coal per hour to be burned. Each kg of coal produces approximately 3.0 kg of CO<sub>2</sub>. This leads to the astonishing conclusion that, in order to keep the hermetically sealed unit going, extra emissions of 1.5 to 2.0 kg CO<sub>2</sub> per hour are produced together with all the additional impurities!

When this is compared with the likely seal leakage of 0.5 to 3 cc/hr for a single seal and near zero emission for a double seal, one may very well ask if insistence on glandless pumps is not one pump too far in many cases!

Having said all of that, equipment choices are not made based on technical absolutes. Rather, against a backdrop of legislation and the peripheral considerations such as monitoring, record keeping and dealing with any releases of controlled substances and complying with what is seen as the correct and logical choice. (Glandless pumps ostensibly eliminate the emission problem absolutely.)

There will, inevitably, be a move to glandless pumps, although developments in sealing will provide a better alternative in many cases.

#### Zero Emission Alternatives

The authors are currently developing a new concept for emission control. In this concept, conventional mechanical seals can be used in conjunction with innovative new systems that are aimed to achieve reliable ZERO emission levels. The system is particularly

suitable to the conversion of existing equipment, but is also suitable for new equipment.

The seals and systems outlined herein are intended for use in pumps handling volatile organic compounds, with particular reference to those covered by emission legislation. This typically includes pumps handling propane, butane, naphtha, gasoline, and other such products that are commonly found in the refinery and petrochemical industries.

#### Description of System and Alternatives

Encapsulation is a concept by which fugitive emissions are prevented from escaping from a pump (or other piece of equipment). This is done by encasing all or part of the equipment in such a way that emissions can be contained within a system that has the ability to remove them safely and prevent leakage to the atmosphere.

The most extreme form of encapsulation is as shown in Figure 7. Here, the whole unit is encapsulated in a cover that is connected via a vacuum pump to an environmental control device (ECD). Other possible embodiments exist including encapsulation of the pump alone and encapsulation of the shaft ends as shown in Figure 8.

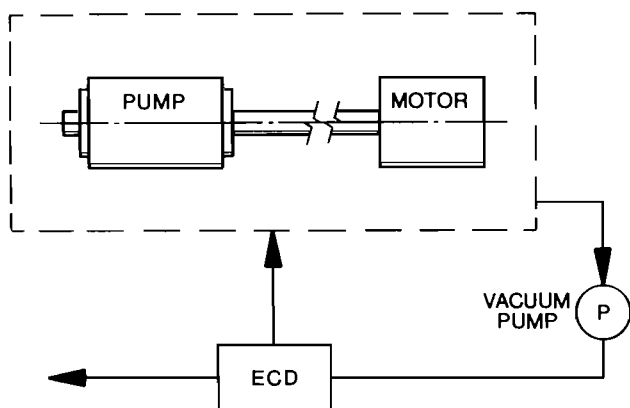


Figure 7. Full Pump/Motor Encapsulation.

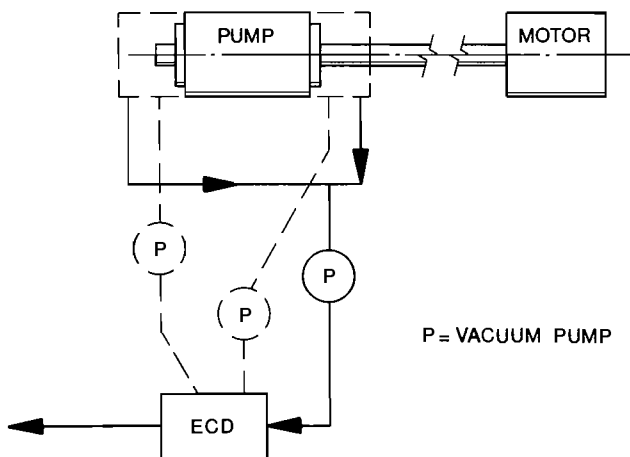


Figure 8. Shaft End Encapsulation.

In this case, only the shaft ends (where the seals are located) are encapsulated. The encapsulation may be achieved by various means including the retrofitting of special 'covers' to existing equipment.

Pump units with encapsulated ends could have the following characteristics:

- A traditional type centrifugal pump driven by a flexible coupling by a normal air cooled motor.
- The pump shafts are fitted with the appropriate types of mechanical seal.
- All liquid and vapor emissions from the mechanical seals will be extracted to a centralized collection system.

#### Efficiency

Since no change will be made to the electric motor and to the bearing system of the pump, pump units with encapsulated ends will retain their normal efficiencies. Thus, they will differ dramatically from hermetically sealed pump units to the tune of 10 to 15 percent in efficiency.

#### Centralized Emission Extraction

The liquid and vapor emissions are extracted separately. The liquid emissions are extracted via the drain connections.

To extract the vapor emissions, it is possible to connect the encapsulation to a circulation loop that contains a vapor extraction device (a refrigerative condensation plant or a regenerative type of absorption unit like the gas filter previously described.)

#### Conversion of Existing Units

The proposed method has one very important advantage over hermetically sealed pumps in that existing pumps can be converted.

It is further possible to incorporate the circulating pump into the mechanical seal itself, and to create a local circulation loop containing an absorption device such as the toxiflex filter previously described. This principle is illustrated in Figure 9. The dynamic pumping action of the pump contained within the seal ensures that an air flow enters the outer seal cavity. It carries any gaseous leakage with it toward the absorption device, where it is removed continuously.

Provision is required to control and contain gaseous leakage during standby operation where no pumping action is available. The rotating lip seal illustrates the principle of a seal that centrifugally disengages from the shaft during dynamic operation and allows the action described above. When stationary, however, the lip seal engages the shaft surface and ensures that all the gaseous leakage is still directed to the absorber unit where it is removed.

The second part of the illustration also embodies a noncontacting standby seal that provides positive sealing in the event of failure of the primary mechanical seal. The pumping ring is part of the standard noncontacting standby seal and also provides cooling to the secondary seal when it is engaged dynamically.

This system is suitable for newly supplied single or tandem seals or, more interestingly, can be supplied to mount piggy back onto existing seals. Since the absorption unit can be locally mounted direct onto the seal plate, the whole system provides tremendous potential in retrofitting existing plant to achieve zero emission performance at a cost way below that of glandless pumps and without the loss of efficiency associated with them. Thus, first cost and real cost are minimized.

#### Test Program

At the time of writing, a laboratory test program to evaluate these alternative solutions has commenced. Significant results are expected by early 1992.

A special test rig has been constructed with the help of a major UK pump company that has offered advice and provided a test pump/motor unit. The basic seal arrangement for the initial evaluation is illustrated in Figures 10 and 11. A simple mechanical seal/pump ring/lip seal arrangement is shown in Figure 10. The primary

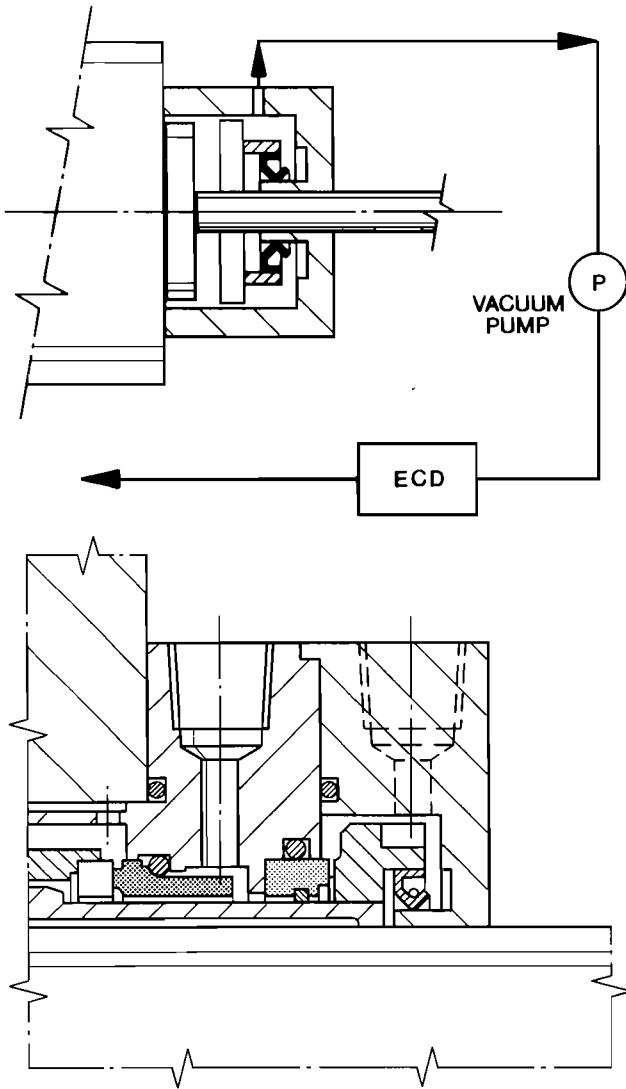


Figure 9. Circulation Pump Contained within the Seal.

mechanical seal will seal water and thus present no hazard in the confines of the laboratory. Simulated leakage will be provided by injecting controlled amounts of butane through the tapping shown to the atmospheric side of the seal. Static and dynamic leakages from the arrangement will be measured using a methane calibrated sniffer by the method spelt out for onsite measurement. Measurements will be made for various levels of simulated leakage so that the saturation level of the pump arrangement can be determined. (This will be done with the lip seal omitted.)

In Figure 11, the seal incorporates a noncontacting standby seal that is designed to close at a level below the saturation of the pump

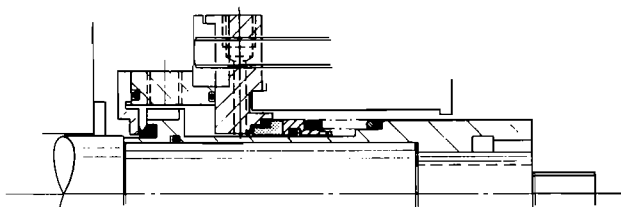


Figure 10. Test Seal: Circulation Pump Contained within the Seal.

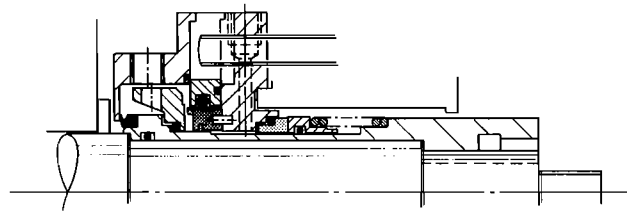


Figure 11. Test Seal: Addition of Secondary Containment Seal.

ring, to prevent gas leakage for all levels of leakage. In both cases, the outer seal plate tapping is connected to a toxiflex filter via a quick release connection.

*Field Experience of Another Zero Emission Design*

While the laboratory investigation proceeds, the authors are trying to produce arrangements to meet needs now. The seal shown in Figure 12 is such a development. The arrangement is of a primary seal with a secondary containment seal. Because the operating temperature is well below 0°C, there is a danger of ice accumulations. These accumulations could impair seal operation that could affect the emission level that is required to be zero.

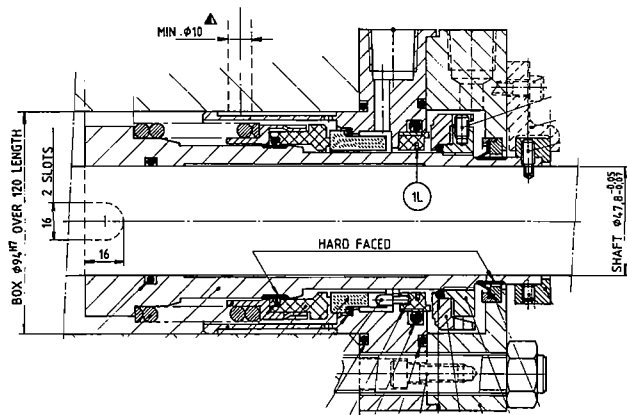


Figure 12. Low Temperature Seal with Zero Emission Requirement.

The seal is thus fitted with the double lip seal arrangement shown. Dry, bottled nitrogen at 1.5 bar G is injected between the lips at a rate of 10 L/min. The lip seal at the atmospheric side has a higher interference than the seal side lip seal and, therefore, more nitrogen flows into the space between the inner lip seal and the standby seal. This flow prevents water vapor entering the space and the flow is finally directed to flare.

The nitrogen pressure ‘unloads’ the lip seals from the sleeve surface and greatly reduces the risk of wear. This system is now in operation in Holland.

*Future Work*

When the previously mentioned work has been completed, the authors will be moving into a program of evaluation of more extensive use of the encapsulation system, with particular reference to adapting existing equipment. This work will be done in the laboratory and in the field in collaboration with users.

**CONCLUSIONS**

The results of this work are important to the future extensive use of mechanical seals in cost effective pump designs, where the requirements of initial costs and ongoing costs are satisfied. The systems proposed offer a better solution for environmental emis-

sion control, with lower energy consumption through higher efficiencies, than the more expensive alternative of glandless pumps. Real cost advantages are available in comparison to the retrospective conversion to liquid tandem seals.

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