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Development of a Single Mechanical Seal equipped with a High-Pressure Containment Seal for Multiple Fluid Pipeline Pumps.

Andreas Pehl
Senior Application Engineer
EagleBurgmann Germany
Wolfratshausen, Germany

Peter Droescher
Senior Director Engineering Pump Seals
EagleBurgmann Germany
Wolfratshausen, Germany

Andreas Pehl *is Senior Application Engineer for Mechanical Seal applications. He joined EagleBurgmann Germany in 2010. His responsibilities include sales, application engineering, and project fulfillment. He covers the upstream, midstream and downstream in Oil and Gas, the Petrochemical and Chemical market, mainly in North America, Europe and the Asia-Pacific region. In 2004 he completed a 3-year apprenticeship in mechatronics. In 2010 Diploma in Industrial Engineering at the Munich University of Applied Sciences.*

Peter Droescher *has more than 25 years of experience in sealing technology. After several years in engineering, R&D and compressor seals he took the engineering responsibility for the EagleBurgmann Pump Seal products. Peter Droescher holds a Diploma in Mechanical Engineering of the University of Applied Sciences Munich*

ABSTRACT

This paper discusses the critical design aspects, calculations, laboratory verification testing and field experience of a mechanical seal arrangement for multiple fluid Pipeline Pumps. The seal cartridge consists of a single wet lubricated mechanical seal on the product side in combination with a high-pressure containment seal on the atmospheric side. The single mechanical seal has been designed to operate in a product range from the flashing hydrocarbons ethane, propane, butane all the way up to non-flashing hydrocarbons like Natural Gasoline. Basically the single seal runs product lubricated in the media with a specific gravity range of 0,35 up to 0,65 and is designed for a pressure window up to 100bar, respecting the Pipeline Pressure. To assure this, a lift off of the mechanical seal faces at all media and at all operation conditions was targeted. To achieve this the functional components of the mechanical seal were subject of an extensive performance calculation and optimization with FEM (Finite Element Method. The mechanical seal concept includes a containment seal which withstands the full pipeline pressure in the unexpected event of a catastrophic mechanical seal failure of the single product side seal. This means massive leakage cannot leave the seal gland in an uncontrolled way under any case. To achieve similar safety and environment protection with a mechanical seal in a multiple fluid pipeline pump, conventionally a double pressurized mechanical seal with a pressurized supply system was needed. The proposed mechanical seal design provides a reliable pump sealing solution for these critical applications with a “single mechanical seal” in combination with a “high-pressure containment seal”. It provides the performance advantage and the safety philosophy of a double pressurized seal arrangement with the more cost-efficient single seal arrangement.

1. INTRODUCTION

Multiple Fluid pipeline applications can be very different from the typical 'process' pump in a hydrocarbon processing plant. A high number of peculiarities related to the size of the equipment, process medium and plant operation make these applications very challenging.

1.1 Pipeline operation

A pipeline has two or more pumping units per pump station, which are arranged in series over the length of the pipeline. The individual stations are typically equal in terms of design and arrangement but have different normal operating conditions to suit geographical location, terrain between upstream and downstream stations, etc. In several cases the operating conditions are highly variable to adjust the flow rate. The operating philosophy may vary from station to station if some stations are used to cover the base load, where additional stations designed to run when production is high. According to the operating regime, some pumps may run in parallel, others in series, some with variable speed and others with fixed conditions. Consequently, duty conditions will change from station to station; That implies that a vast majority of the large pipeline pumps end running over a range of conditions and just not at the BEP (Best Efficiency Point). Last, depending on the hydraulic pipeline conditions, pipeline pumps are subject to various transient loads because of upset conditions and changing process variables.

1.2 Process fluid composition and properties

Generally, a pipeline handles the transport of one specific media. The mechanical seal can be adjusted specifically for this condition. In Multi Fluid Pipelines, several different products are pumped in the same pipe. The products are usually hydrocarbons, in total different grates and properties. To pump multiple fluids the pipeline operator usually has to send different products in “batches” through the Pipeline. This could be light flashing hydrocarbons for several hours, and then switching to non-flashing hydrocarbons, before switching to ethane for example. The different batches are usually directly connected to each other if possible. If this is not possible, a mixed zone is in between. To assure best performance during operation, the pumps installed in the pipeline will be operated at variating speed, pressure and temperature conditions, depending on the pumped fluid. The tracking of the customer’s product through the pipeline is usually done by scheduling.

1.3 Pump location & Utilities

Pumping stations are often operated remote and lightly manned, possibly unmanned. This requires very reliable equipment and the possibility to monitor the conditions remotely. Pumps may be located outdoor or indoor. With outdoor locations, the effects of ambient temperature on the process fluid at standstill conditions must be considered. Pumping stations are often in remote locations, hence the availability of utilities will be restricted. Typically cooling water, steam and nitrogen are not available. In normal operating conditions the mechanical seal installed in the pump shall be operated with minimized consumption of utilities. In addition, the sealing system must be capable to contain the pressurized fluid in unexpected emergency condition with a catastrophic failure of the main mechanical seal.

1.4 Operating conditions & special requirements

Pumped fluid:	Multiple Fluids (Ethan, Flashing Hydrocarbons, Non-Flashing Hydrocarbons)
Seal chamber pressure range:	2.5 to 100 bar
RPM range:	up to 3000rpm
Specific Gravity:	0,35 – 0,65

The wide operating range, large shaft diameters and the expected high longevity with contact-free operation implies the need for a relatively wide leakage rate allowance. The containment system that collects and disposes the leakage must be designed to deal with the expected leakage rates. In addition, the design of the containment seal has to ensure zero leakage to the environment in an emergency case.

This requirement is even valid in case of events such as seal installation errors, pump bearing malfunction or other events that could cause a complete loss of the mechanical seal sliding faces. This stringent requirement would normally direct the selection of the seal arrangement towards a double seal pressurized. Yet, a single seal equipped with a High-Pressure Containment Seal for Multiple Fluid Pipeline Pumps was developed.

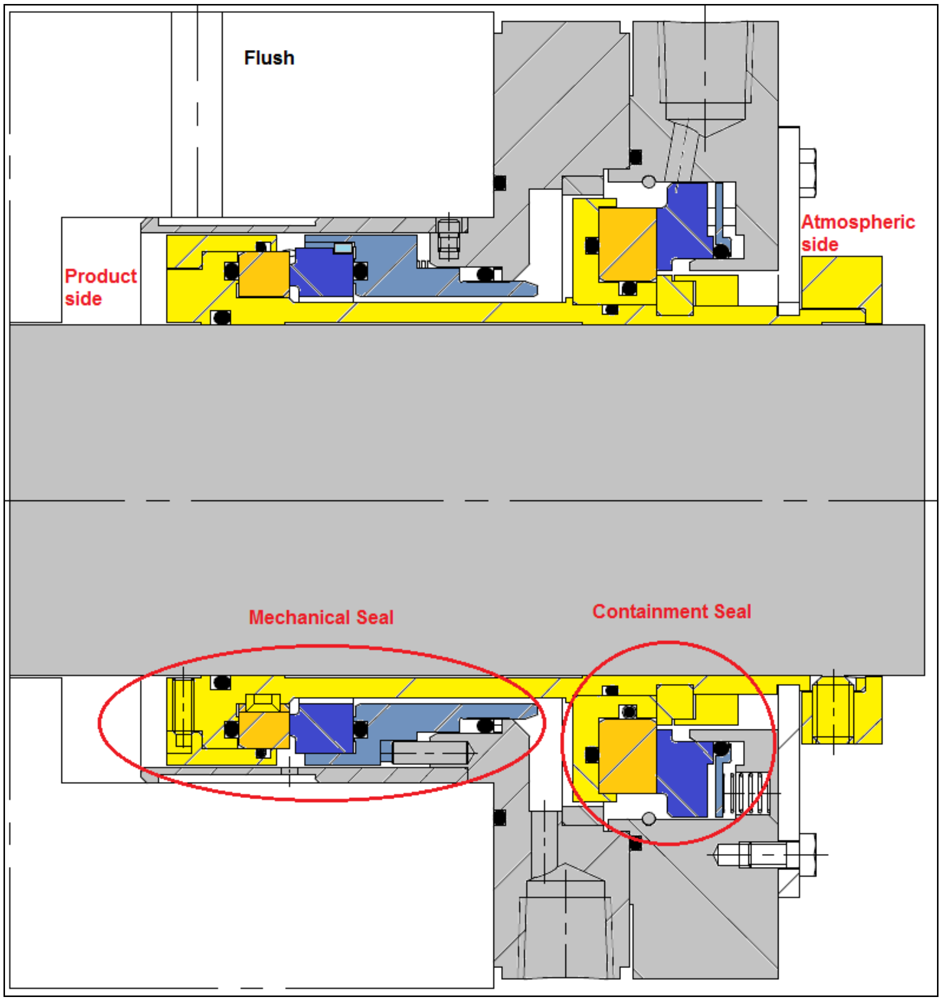
2. MECHANICAL SEAL DESIGN

The initial evaluation of the application lead to two essential design characteristics that must be achieved mandatorily with a single seal arrangement:

1. Make sure that the mechanical seal faces (on the product side) are capable to handle the different fluids, which occur in a Multi Fluid Pipeline. The design of the single mechanical seal has to ensure a stable sealing gap with contact-free operation in the wide range of operation conditions. State of the art seal performance calculation with a combined structure and flow simulation software provides the foundation to optimize the functional seal parts for a broad field of operation.

2. Ensure that the containment system installed outboard of the single seal is capable to handle a release of process fluid at 100 bar without any potential for collapse or failure. The solution was the installation of adjusted components of a DGS (Dry Gas Seal). The containment seal cartridge can handle the high pressure in the seal housing and create an emission free sealing possibility to the environment. The Gas Seal provides safe sealing for a period until the pumping unit can be safely depressurized.

Fig. 1: Seal design that was validated and met the test objectives of this project.



The mechanical seal design is characterized by a stationary spring loaded carrier (blue) with loosely inserted seal faces (see Fig. 1). The torque transmission between seal face and carrier is achieved by a positive soft drive (light blue) whereas the seal face carrier is connected with the seal gland by a robust metal-to-metal connection using anti-rotation pins (grey). The brittle seal faces have no direct metal contact reducing the potential risk of fractures initiated in intermediate upset operation of the pump, which causes poor lubrication, high vibration or shocks. The stationary seal face (dark yellow) has a torque transmission to the shaft sleeve by a special designed key drive. Both, stationary and rotating seal faces are covered by a metal shroud. These shrouds provide additional stiffness and robustness to the seal faces, reducing seal face distortions. In case of a catastrophic failure of the seal faces this feature keeps the parts in place, ensuring minimum leakage path in un-expected scenario.

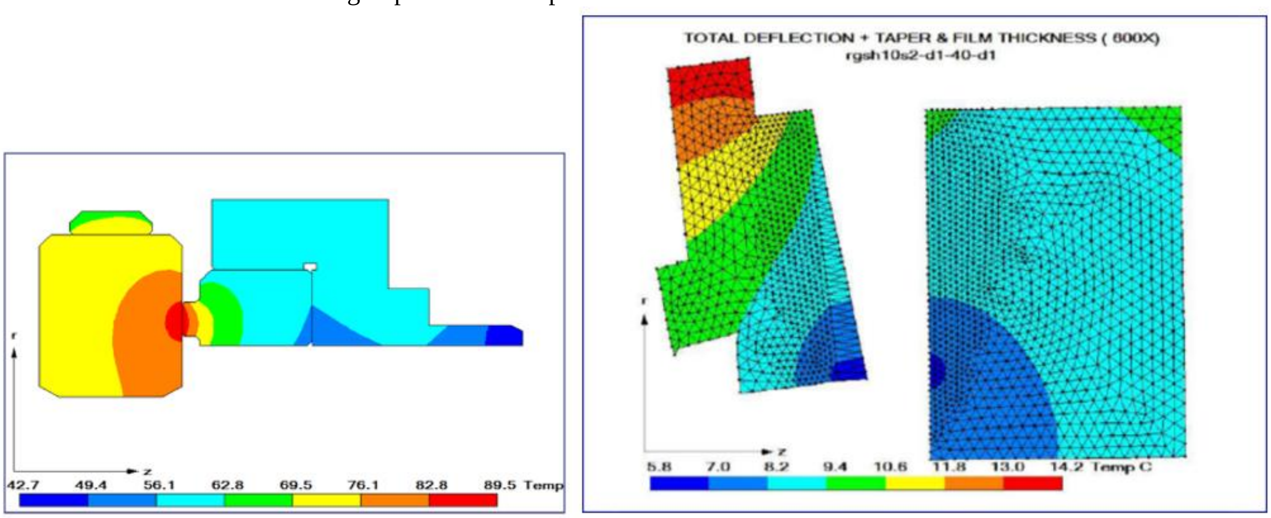
The containment seal is also using a stationary spring loaded design (blue). The solid seal face is spring energized by a thrust ring behind the seal face. The rotating seat (dark yellow) is also loosely inserted. The seal is able to absorb the complete pipeline pressure differential. Under normal operating conditions, the product side mechanical seal reduces the full pressure. The space between the product side seal and the atmospheric side seal is cleared by a connection according to the API (American Petroleum Institute) seal supply plans 75 and/or 76. The pressure differential on the containment seal equals the primary drain/vent pressure, so the leakage to the atmosphere is very low. If the main seal fails, the contaminant seal acts as a safety seal.

The selected seal face materials are reaction-bonded silicon carbide for the rotating inboard mechanical seal face (dark yellow) and a compound material of silicon carbide and carbon for the stationary inboard mechanical seal face (dark blue). The SiC-Carbon-Composite provides enhanced dry-running characteristics and superior heat transfer properties to cover short-term (intermediate) events. The material is used as a standard for high pressure and high speed applications. High robustness of the face material is essential for the application in Multi Fluid Pipelines, where different media characteristics influences the propagation of a safe lubrication film in the seal faces can be critical. For further enhancement of the robustness, especially when intermediate dry-running is expected the application of DiamondFace technology would be feasible. The seal face material on the containment seal is antimony impregnated Carbon graphite (dark blue) whereas the rotating seat (dark Yellow) is made out of reaction-bonded silicon carbide

3. MECHANICAL SEAL CALCULATION

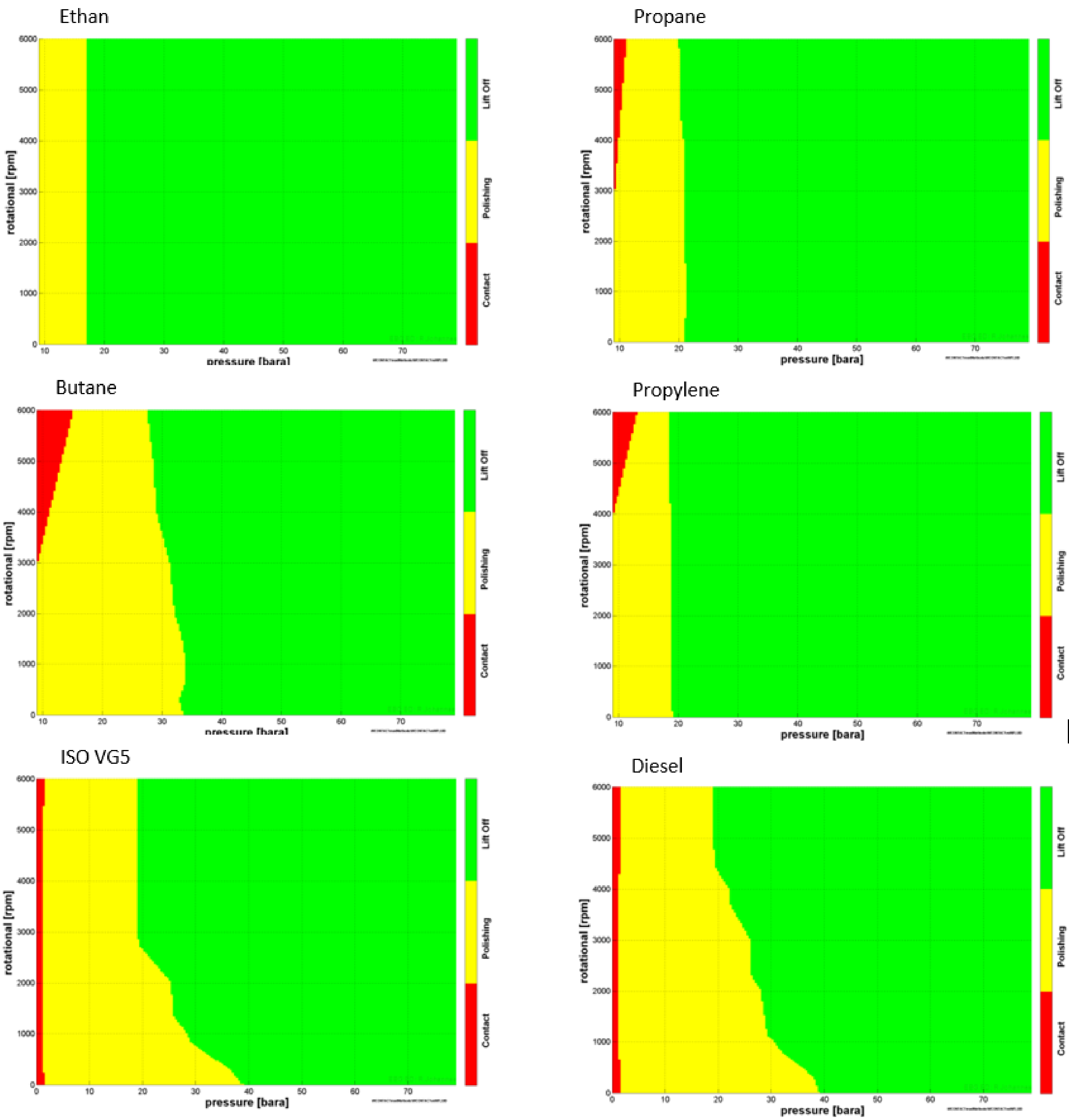
The seal performance calculation is carried out with a combined structure and flow simulation software. The FEM part delivers the elasto-mechanical adaption of the geometry under pressure and temperature influences, see Fig. 2. To reduce the complexity the system is working with 2D models. Deflections of the sliding face can be introduced with the face geometry. The software calculates the pressure distribution, the operating gap geometry, the seal leakage and the power consumption.

Fig 2: predicted Temperature distribution of the seal faces



Maintaining a stable sealing gap geometry in all possible operating modes is the key to consistent leakage and friction behavior of the seal faces. All results out of the seal faces calculation taken into account to predict the performance of the seal.
The plot in Fig. 3 illustrates the predicted lubrication behavior of the seal faces in different media as a function of operating speed and pressure. The classification criteria for the different zones are based on theoretical and experimental studies. The seal faces lift off in the green zone that means no contact hence no wear. In the yellow zone, a small contact force could occur and some polishing can happen whereas in the red zone contact will definitely occur which will result in wear of the seal faces with an increased likelihood for face damages. By knowing all the possible operating conditions, i.e. normal as well as unusual, it is possible to avoid operation of the seal in conditions that would make the seal faces prone to damages and wear. Because of the wide operating span in this particular application, special face lubrication grooves were incorporated at the compromise of higher leakage rates.

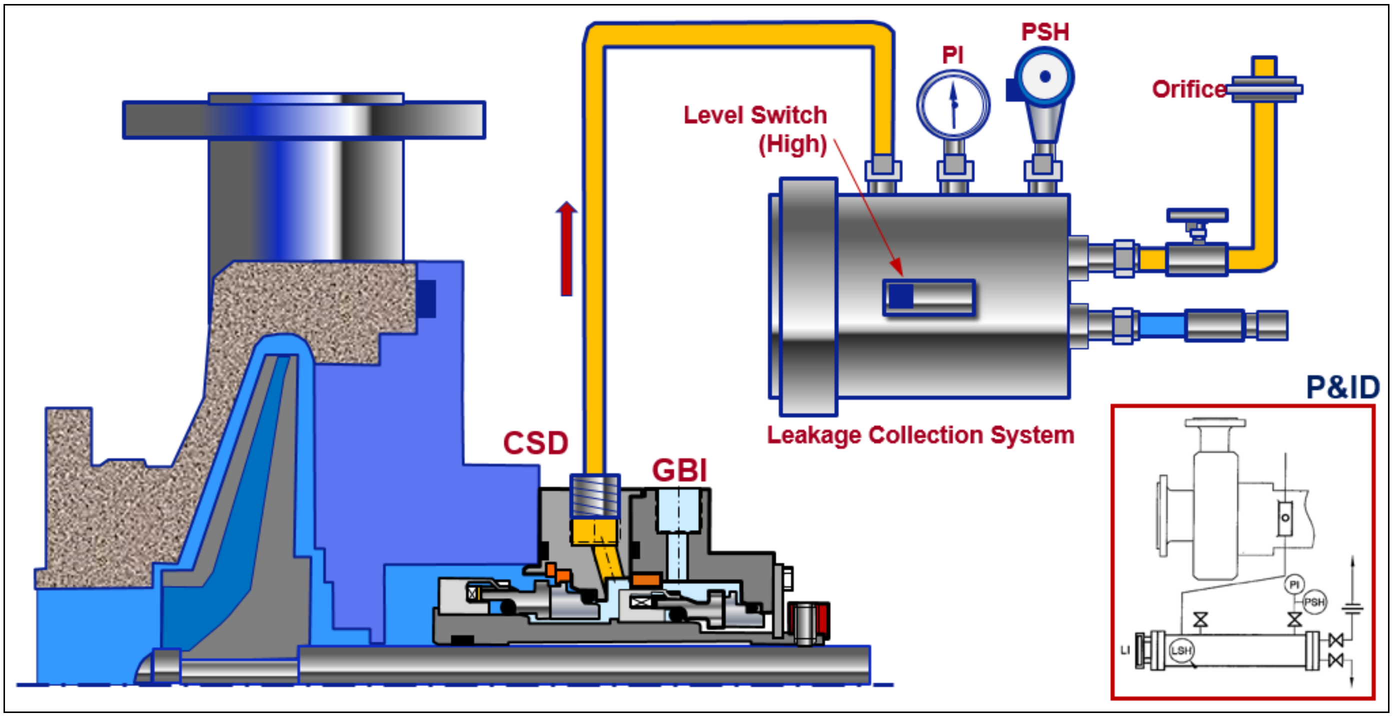
Fig 3: predicted contact force in the sealing gap for different fluids



4. SUPPLY SYSTEM

The API plan 75 applies when pumped fluid leakage condenses at ambient conditions. It provides a containment seal chamber drain for condensing or mixed phase leakage of the inboard mechanical seal.

Fig 4: API supply system plan 75



API plan 75 can be used in combination with a buffer gas (API plan 72) or without buffer gas (API Plan 71). It avoids direct leakage of the pumped media from the inboard mechanical seal to the atmosphere. The leakage is collected and gas vapor can pass the collection system.

The API plan 75 consists of a leakage collection reservoir, see Fig 4. A level indicator (Level Switch) is installed to determine when the tank needs to be drained. A Pressure gauge (PI - Pressure indicator) tracks and indicates the mechanical seal leakage. This system is usually supplied by the seal vendor.

This setup is an emission-free arrangement with the corresponding API supply plan connection. In case of a catastrophic failure of a mechanical seal occurs is the total loss of the mechanical seal faces. A standard arrangement of a containment seal according to API 682 is designed to contain normal leakage under atmospheric pressure, but not the full product pressure. In pipeline applications the Product pressure can be up to 100 bar must be contained in case of a catastrophic failure. Therefore, the high-pressure containment seal is designed to hold the full product pressure.

5. TESTING

The purpose of the mechanical seal qualification test see Fig 5 was to verify the theoretical performance calculation with respect to leakage and power consumption under conditions, set as close as possible to the field operating conditions.

Fig 5: EagleBurgmann Test rig setup

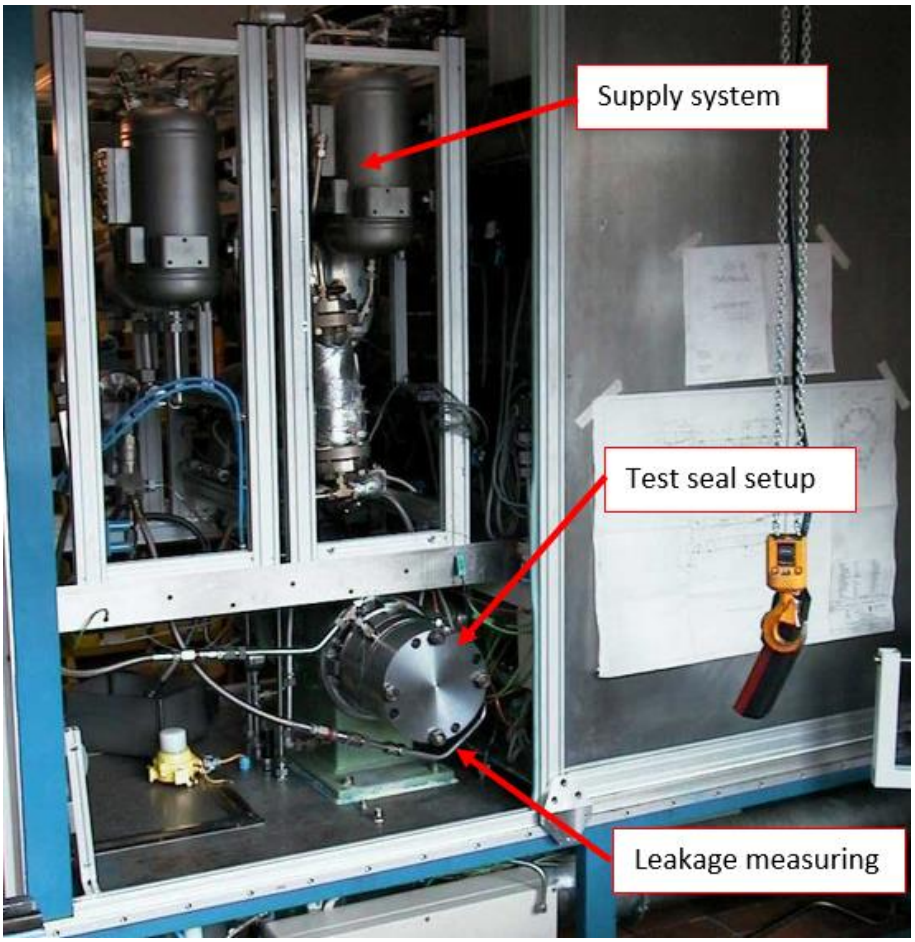


Figure 5: EagleBurgmann Test rig setup

During the test was the temperature of the media as well as the temperature of the seal seats measured. After the test run, the mechanical seals have been inspected. The inspection was an overall inspection of the mechanical seal as well as measurement of the seal face flatness and roughness. The seal face and seat inspection confirm a good running behavior under acceptable low leakage rates over the hole test period.

6. CONCLUSION

The results of the test program and acquired field experience validates that it is possible to provide a single mechanical seal which operates in a product composition between ethane, all the way up to flashing and non-flashing hydrocarbons like Natural Gasoline.

The main feature on the mechanical seal is to have a single wet mechanical seal on the product side, which can handle all operation conditions. On the Atmospheric side a high pressure containment seal is installed. The DGS type is designed to withstand the full design pressure in a catastrophic failure of the mechanical seal. The operation leakage can be either liquid or gas. Therefore, it has to be an API Plan 75 or 76 selected. The API Plan 75 would cover both and should be used over SG 0,6. Even under severe upset conditions that can lead to loss of the seal faces altogether, safe containment of the pumped media can be guaranteed by the high pressure containment seal. Secondly, a high pressure containment seal allows early detection of seal troubles which provides the user a greater reliability with a single seal design.

This provides a cost efficient way by sealing high pressure Multiple Fluid Pipeline applications with a Single Mechanical Seal equipped with a High-Pressure Containment Seal.

7. NOMENCLATURE

API	= American Petroleum Institute
BEP	= Best Efficiency Point
FEM	= Finite Element Method
DGS	= Dry Gas Seal

8. ACKNOWLEDGEMENTS

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