ASIA TURBOMACHINERY & PUMP SYMPOSIUM
SINGAPORE | 22 – 25 FEBRUARY 2016
MARINA BAY SANDS

MECHANICAL SEALS WITH DIAMONDFACE TECHNOLOGY USED IN DIFFERENT PIPELINE SERVICES

Nikolaus Necker
Senior Expert
EagleBurgmann
Wolfratshausen, Germany

Nikolaus Necker is a Senior Expert for Engineered Mechanical Seals at EagleBurgmann Germany GmbH & Co. KG, Wolfratshausen, Germany. He is responsible for the application engineering in all kinds of Oil and Gas services. His job includes sales and applications of sealing technology for pumps world-wide (On- and Offshore) since he started with Burgmann in 1990. Nikolaus Necker has a Masters of Engineering (Mechanical Engineering, 1989) from the Munich University of Applied Sciences.

ABSTRACT

Mechanical seals are used in a wide range of industrial applications, sealing gases in a compressor or sealing liquids in a pump. Reliability, longevity, emission control and safety are now more important than ever. This purpose sounds simple, but designing mechanical seal components and selecting the most appropriate materials is a real challenge, especially when sealing fluids under harsh operating conditions. This paper describes two applications using a unique sealing solution, an engineered seal design and a specific sliding face diamond material.

In the first case, the end-user in Venezuela is using Multiphase Pumping Technology to transfer a mixture of crude oil and gas in a single pipeline without separation. The installed seals have to handle a mixture of crude oil, formation water, solids and natural gas. Previously, no mechanical seals were available for such conditions and consequently engineered seals have been developed for this purpose. The pumped fluid does not provide the required stable liquid lubrication film for their mechanical seal faces. Another challenge is the presence of abrasive particles. So the selection of the seal face materials is important. Extremely robust face materials are required to avoid unacceptable deformations and to minimize abrasive wear which may result in a mechanical seal failure. Multiple seal arrangements available today can handle multiphase fluids, using hard/hard face materials in combination with a complex auxiliary/flush system, but have only limited capabilities with regard to poor lubrication and necessary cooling, when handling crude oil with high viscosity and natural gas. In this specific application described in this paper, a sophisticated Single Mechanical Seal has been used successfully over many years. However, due to changing oil well conditions, the lifetime of their mechanical seals was reduced dramatically. To solve this problem, a slurry seal design in combination with the diamond seal face material, well-known for its ultimate hardness, was installed. Seal faces with diamond surfaces offer outstanding abrasive resistance due to their unique hardness similar to natural stone and, at the same time provide considerably improved dry running performance due to their low friction coefficient.

In the second case, the end-user in Brazil is using High Pressure Pipeline Pumps for the transportation of the heavy crude oil. In case of high pressures, high speed and abrasive particles, which is typical in crude oil applications, their mechanical seals need special attention. Extremely hard and strong face materials are required to avoid unacceptable deformations and to minimise abrasive wear which may result in high leakage. State of the art hard/hard face material combinations cannot handle crude oil with high viscosity and have limited capabilities with regard to poor lubrication associated with the necessary cooling.

In both applications, in a multiphase twin screw pump and in a centrifugal pipeline pump, engineered mechanical seals with diamond seal face material solved the problem and are used successfully since the start-up of the pumps. This new sealing technology offers significant benefits to the end-user.

THE OIL FIELD IN VENEZUELA

In this upstream facility in the Zuata Field, in the Orinoco Belt in Venezuela, Extra Heavy Oil is produced, oil with very high viscosity. The oil is diluted with Naphtha to reduce the viscosity and to enhance the performance of the pumps. Diluted crude oil mixed with produced gas is pumped in a single pipeline from clusters to the main station by Multiphase Pumps. In the main station the pumped media is degassed and dehydrated. The client has a lot of experience with Twin Screw Multiphase Pumps with Single Seals or with Dual Pressurized Mechanical Seals.

THE TWIN SCREW MULTIPHASE PUMPS

Multiphase Pumps have demonstrated their ability to operate successfully in pumping the product extremes, 100 % liquid to 100 % gas, as well as solids. This duty is difficult for a pump and thus even more difficult for its mechanical seals, which are a critical part of any pump. Mechanical seals are readily available for liquid or gas applications. However in a multiphase pump the mechanical seals will see transient conditions. Consequently special mechanical seals have to be developed to handle multiphase mixtures.
Twin Screw Pumps consist of two contra-rotating metal screws. They could already handle “Gas Void Fractions” up to 70 %. So only some minor improvements had to be made by the pump manufacturer in order to handle 100 % gas!

Figure 1: The Twin-Screw Pump layout with the installed mechanical seals

Multiphase operation means the continuous fluctuation of gas and liquid flow rates at pump suction side, where generally the mechanical seals are located.
The pumped media can contain wax, salts (chlorides), H_2S or CO_2 (Sour gas or Carbon-dioxide) and solids, which affects the operating performance of the seal and results in corrosion and erosion of seal faces.
So, the mechanical seals must be designed to handle density variations, viscosity variations, erosion effects (sand particles), high (discharge) and low (suction) operating pressure, insufficient lubrication and cooling as well as high or extremely low media temperatures.
Several Multiphase Twin Screw Pumps are handling this field production in Venezuela. The originally installed single acting mechanical seal was a standard cartridge multiphase seal design with rotating multiple spring arrangement in a hard-soft material combination. This seal was in operation for many years in combination with API 682 Piping Plan 32 and 62. The observed mean time between overhaul was always 24 to 36 months. However, due to early field production and changing oil well conditions, the pumped fluid changed to extra-heavy crude oil with a high sand content, and the lifetime of the pump rotors and mechanical seals was reduced to 3 months. The seal was inspected and showed heavy erosion of the seal faces and the metal parts, as the solids entered the seal chamber and could not be removed by the Flush. So, a better sealing solution was needed quickly.

Figure 2: Mechanical seal faces damaged by dry running and sand erosion

THE CRUDE OIL PIPELINE IN BRAZIL

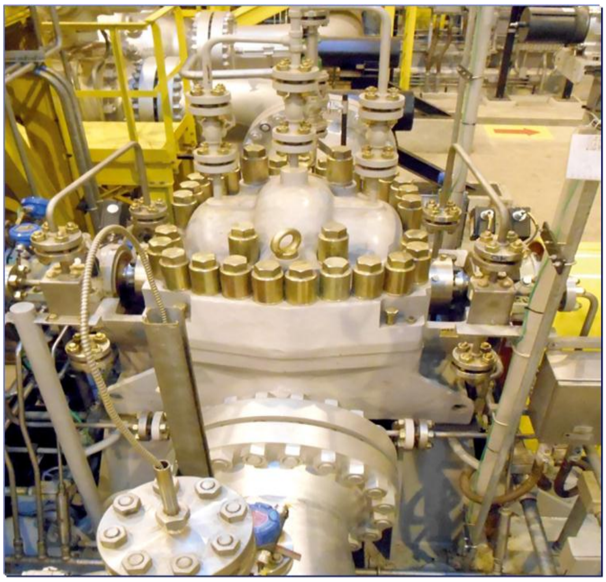
Crude oil could be classified as light, medium or heavy crude oil, according to its measured API gravity. The American Petroleum Institute gravity (API gravity) is defined by the density of the crude.
In this pipeline application different API grades of crude oil are transported. The crude oil explored from new wells has a high viscosity up to 500 cSt and is pumped to the terminal in the Sao Paulo state in Brazil.

In total, 5,5 million liters per hour flows these pipelines, this is approx. 55 % of the crude oil explored in Brazil. The next terminal is in Guararema where another four Pipeline Pumps are installed. From this terminal the crude oil could be pumped to the REVAP Refinery (30 km) or to the REPLAN Refinery (150 km) for further processing.

So in total, 16 Heavy Duty Pipeline Pumps are responsible for the transportation of the crude oil in those locations.

THE CENTRIFUGAL PIPELINE PUMPS

For this critical application heavy duty multistage centrifugal pumps have been selected. The pumps were custom-engineered for this application to match the hydraulic fit and mechanical requirements of the end-user. The pipeline pump is an axially split casing design, double volute construction in a between-bearing arrangement, well known as an API 610 BB3 pump. This type meets the requirements of API 610 / ISO 13709, which is the standard for heavy duty centrifugal pumps in the oil and gas industry. The mechanical seal chambers, one at Drive End (DE) and one at Non Drive End (NDE) are at the same pressure due to throttling bushings and the integral balance line. The seal chamber dimensions are in full compliance with API 610 / ISO 13709 and offers space for all seal configurations. The API 610 BB3 pumps are probably the most widely used API 610 BB3 pumps in the world on onshore and offshore oil and gas applications.



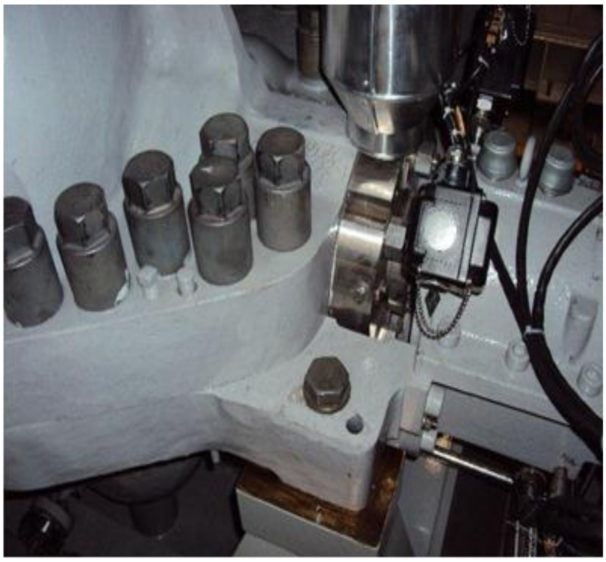


Figure 3: The Crude Oil Pipeline BB3 Pump with the installed mechanical seals

The other pump used in this service is an API 610 BB1 type, with an axially split design, two stages in a between-bearing arrangement. The two-stages are arranged back-to-back in order to reduce the axial load to the bearings.

For both pump types the same sealing concept was selected.

THE NEW MECHANICAL SEALING CONCEPT

As engineering professionals, it is the mechanical seal manufacturer's duty to design seal components and select materials best for the application and result in reliable and safe operation of the pump. In this respect, Single-acting mechanical seals have been selected due to simplicity and function without a complex supply system. The used seal type is a well-proven design for slurry applications, so just some minor modifications have to be made in order to handle crude oil with high viscosity and solids.

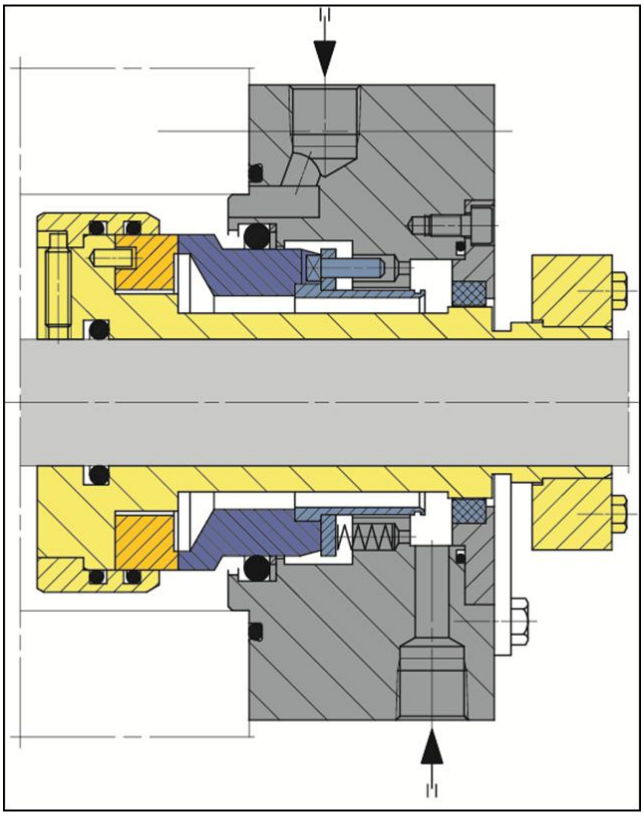


Figure 4: The single seal arrangement

This seal type is a stationary, multi-spring seal arrangement, which is hydraulically balanced. The stationary and rotating seal face assembly consists of a solid silicon carbide seal face. This assembly is uniformly loaded by multiple springs in Hastelloy C4 material. The springs themselves are housed in the face housing and are not in contact with the pumped fluid in order to keep them clear of debris. This ensures the seal face assembly remains free to move and prevents the springs from becoming clogged. The stationary seal face assembly (see Figure 4 in orange) runs against a uniform profile large solid section silicon carbide rotary mating ring (see Figure 4 in blue). This mating ring sealing face includes a specific surface topography to enhance the reliability of the crude oil fluid film between the faces for perfect lift-off the faces. This ring is supported against, and driven by the shaft sleeve, which is in stainless steel to DIN 1.4404 or Duplex (UNS S 31803). This ring is sealed and contained by an outer support sleeve.

Seal face lubrication and cooling is provided by a Flush connection (API 682 Piping Plan 31). In this Flush Plan the crude oil is recirculated through a cyclone separator from the discharge nozzle of the pump. The clean fluid is routed into the seal chamber, while the fluid with the heavier solids is routed back to the pump suction side.

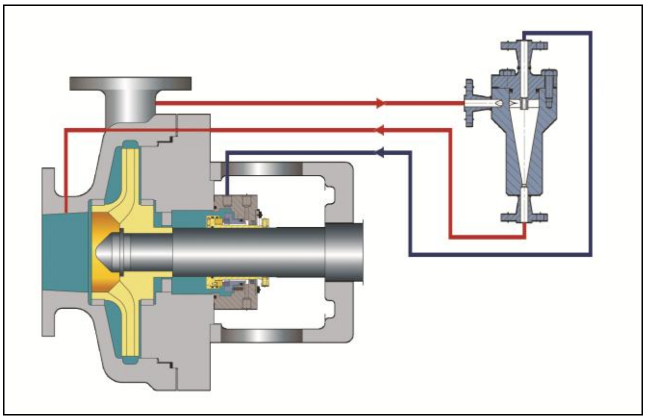


Figure 5: API Piping Plan 31, using a Cyclone Separator to remove solids

The cartridge seal design incorporates an enhanced close clearance auxiliary floating throttle bushing arrangement. This is to allow normal leakage to be contained and directed to the closed drain. The leakage accumulates in the housing annulus and then flows down the drain connection (API 682 Piping Plan 65). The floating bushing prevents leakage loss to atmosphere.

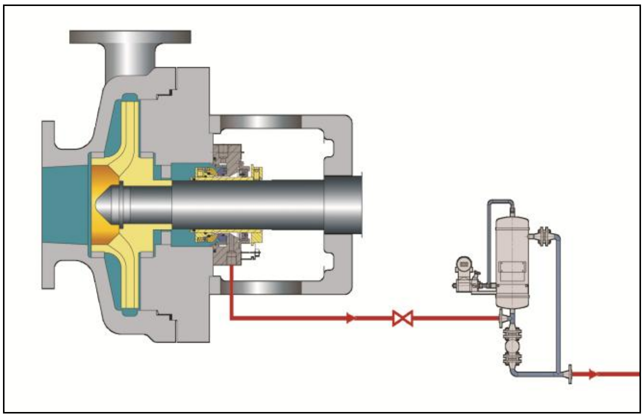


Figure 6: API Piping Plan 65, the leakage collection and alarm system

The cartridge is designed to fit the pump envelope where physically practical. Cartridge components are to be in stainless steel DIN 1.4404 or Duplex (UNS S 31803). The maximum dynamic pressure rating of the mechanical seal is 100 bar g.

THE SEAL FACE MATERIALS

Silicon carbide versus silicon carbide seal face combination is essential when sealing crude oil at these face velocities. It has been shown through experience that a carbon graphite seal face can blister at high speeds on some specific crude oil types. In these two applications, high viscosity crude oil and/or a high amount of natural gas, a unique seal face technology was used, which is the Diamond material.

The mechanical seals used in many industrial applications to seal liquid and gaseous media have to meet partly high demands regarding chemical and thermal resistance. Design and material selection play a major role in order to ensure the operational reliability and the service life of the seal under the respective operating parameters.

The selection of suitable sliding face materials, which meets tribological demands and is wear-resistant to the media to be sealed, depends essentially on the content of solids of the pumped fluid and its lubricity. For pure medias, hard/soft material combinations are mainly chosen, the soft seal face material is usually made from impregnated carbon graphite. If the fluid contains solids, then hard/hard material combinations are normally chosen as the soft carbon graphite is not sufficiently resistant to abrasion or respectively there is the risk that abrasive particles deposit in the soft material and works like a grinding wheel against the hard face. Hard/soft material combinations have a good operating performance even under poor lubrication (high amounts of natural gas) whereas hard/hard combinations do not perform well under such conditions.

The advantages of the classical hard/hard material combinations used for sealing fluids containing solids are faced with their disadvantages under poor and/or insufficient lubrication conditions. In practice, poor lubricating conditions can arise due to or high viscosity fluids or high Gas Void Fractions (GVF) and create a lot of frictional heat in the sealing gap. Insufficient lubrication may lead very quickly to premature failure of the seal due to dry-running and/or overheating.

That is precisely where the Diamond material technology comes in. This micro-crystalline diamond layer on both seal faces is produced by a Chemical Vapor Deposition (CVD) process and is chemically bonded to the ceramic surface of the substrate. The chemical SiC bonding is the presupposition to achieve an excellent adhesion, see Figure 7.

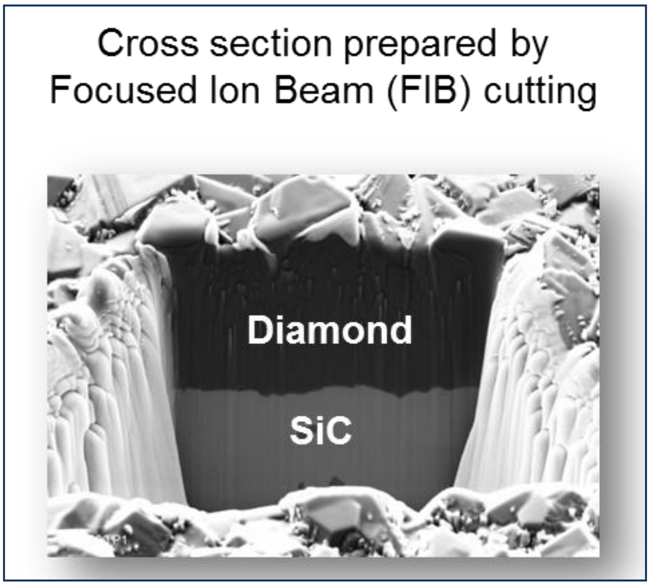


Figure 7: Material SiC and the Diamond chemical bonding section

Micro-crystalline diamond seal faces offer an outstanding abrasive resistance due to their great hardness and, at the same time, a considerably improved performance under poor lubrication conditions like in high-viscous fluids and even in dry-running conditions due to their extremely low friction coefficient.
Diamond is known for its unmatched hardness and its excellent chemical and thermal resistance. In an inert atmosphere, diamond is stable up to a temperature of approx. 1500°C, in an oxidation environment the oxidation of diamond begins at a temperature of approx. 600°C. Acids and caustic solutions do not attack diamond.

The difference between carbon graphite and diamond is the number of covalent bonds. This pure Diamond material is not a soft coating like diamond-like-carbon coatings (DLC). This material is micro-crystalline diamond, with 4 covalent bonds in an SP3-orientation, which offers a strong atomic structure (bonding) in vertical and horizontal directions. This results in its unique hardness and wear resistance. The increased hardness of diamond is a result of the higher packing density of the diamond structure. The atomic structure of carbon can be shifted; this is the reason for the good self-lubrication properties of carbon graphite but is associated with high wear.

For the uniform treatment of the seal faces, a Hot Filament Chemical Vapor Deposition (HF-CVD) process is used. In a vacuum chamber diamond crystals are formed from a gas mixture of hydrogen and methane. These diamonds are deposited onto the silicon carbide surface and grow up to a continuous diamond film (film thickness of approx. 8 microns within 48 hours).

The deposition process is initiated with Tungsten filaments which are located horizontally across the reactor and heated to 2000 °C. The horizontal arrangement of the filaments is the key factor for ensuring perfectly flat seal face surfaces as there is no procedure to relap or polish these materials.

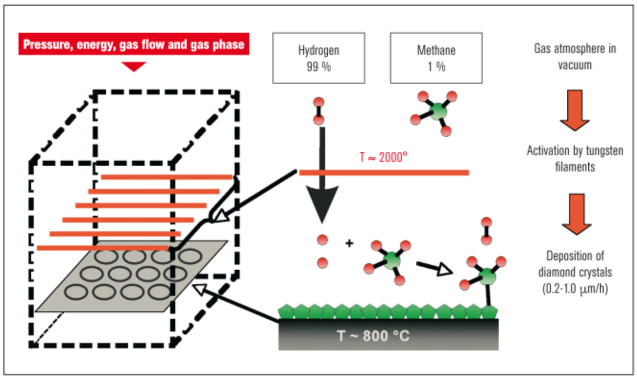


Figure 8: The HF-CVD process reactor for the seal faces

Conventional seal face materials for these kinds of applications is silicon carbide versus silicon carbide, which is lapped and polished to a certain degree of flatness and roughness. This material is very strong and very wear-resistant, but suffers in high viscosity fluids or in case of gas slugs, both are transient conditions in multiphase applications. Under these operating conditions, the seal faces get damaged by insufficient liquid lubrication and dry running. However, this Diamond material, which is a micro-crystalline diamond layer on both seal faces, can handle such conditions, still using silicon carbide as the substrate. A film thickness of approx. 8 microns and a grain size of 2 to 5 microns offer the best performance in case of high gas flow rates and solids.

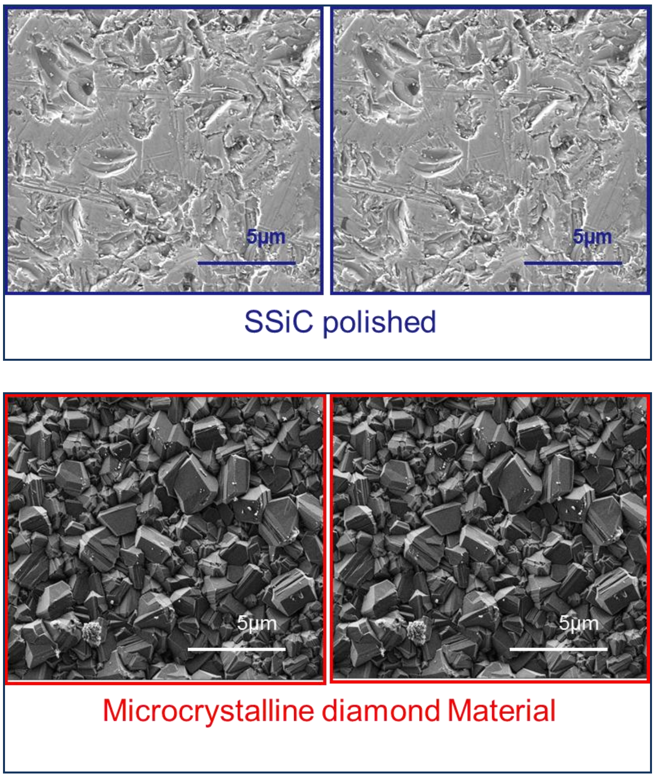


Figure 9: The surface structure of Silicon Carbide compared to microcrystalline diamond Material

THE TRIBOLOGICAL TEST

To identify the friction coefficients with typical hard/hard sliding material combinations and Diamond material, a benchmark test was carried out in the R&D test center. For the measuring of the friction coefficient a Tribometer was used.

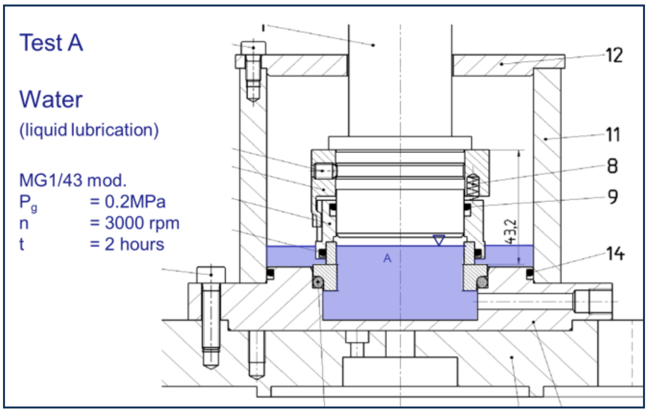


Figure 10: The test arrangement, filled with water

In a vertical test rig arrangement, a single mechanical seal was installed in a seal chamber filled with water. In Test A the seal was running at 2 bar and 3000 rpm in a designated liquid lubrication scenario for 2 hours continuously. This test is considered as a normal lubrication test.

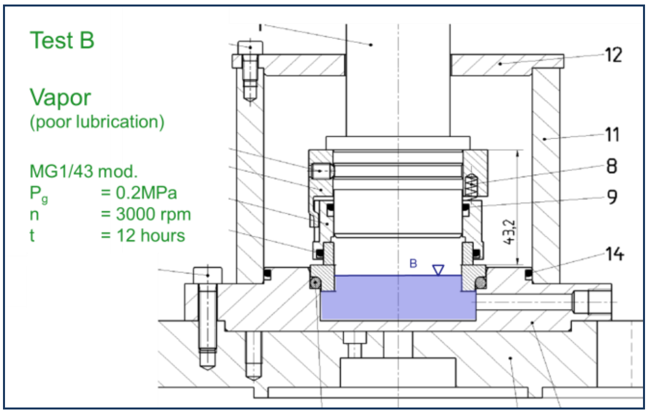


Figure 11: The test arrangement, with reduced level of liquid

In Test B the level of liquid was reduced, so the running conditions have been tightened. In this so called “poor lubrication” scenario the test was carried out for another 12 hours. In this situation, the lubrication is provided by a few drops of water and the stationary seals face surface is partly cooled by the water.

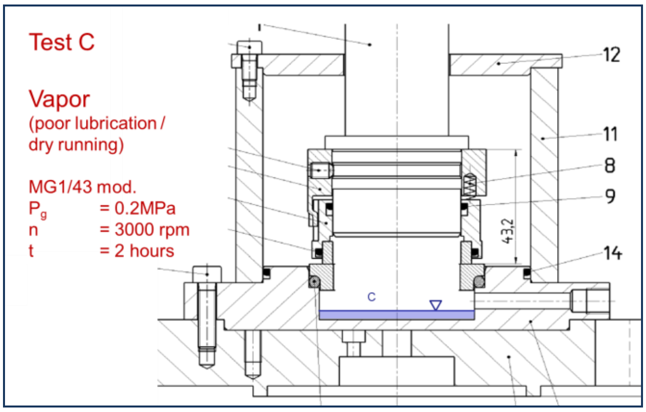


Figure 12: The drained test arrangement

In Test C the test arrangement was drained completely and the seal faces were run without any lubricant for another 2 hours. This test is considered as a real dry-running condition.

Every test was repeated with 3 pairs of identical seals, test 1, 2 and 3. The following figures show the test results, three tests in three different liquid levels, A, B and C (blue, green and red).

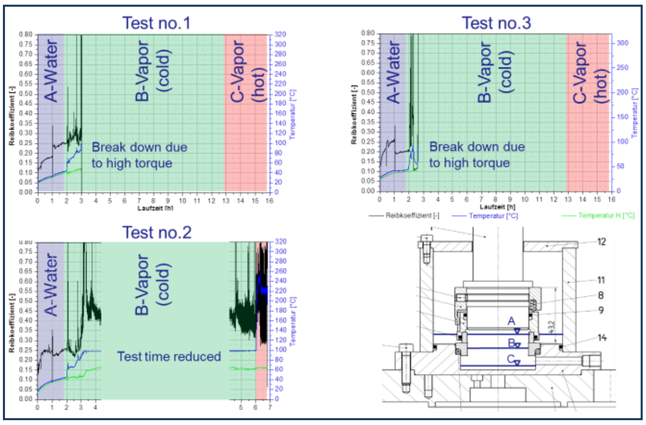


Figure 13: The measured friction coefficient of Silicon carbide running against Silicon Carbide

Figure 13 shows the test results with the original material combination, silicon carbide running against silicon carbide. In the liquid lubrication phase (Test A in blue color) the friction coefficient was measured in the range of 0,15 up to 0,25. As the test continued and conditions become worse, the friction coefficient increased dramatically and seal test was stopped due to high torque peaks measured by the tribometer after a short period of time. In Test B with the reduced liquid level of water, the seal showed unstable running behavior after one hour, so the planned test duration of 12 hours could not be continued.

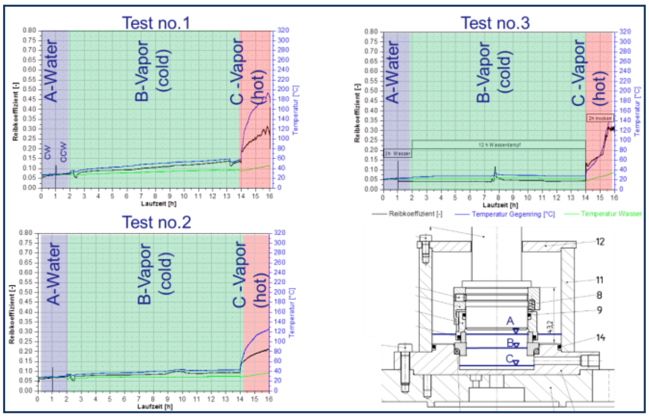


Figure 14: The measured friction coefficient of the Diamond material

Figure 14 shows the test results with the new Diamond material. In the liquid lubrication phase (Test A) the friction coefficient was measured in the range of 0,05 up to 0,08. In test B, simulating a "poor lubrication" phase, the seal continued to run without any significant change of the friction coefficient for another 12 hours. In test phase C, simulating pure dry-running condition, the test was continued under stable and safe operation of the mechanical seal. After 16 hours of intensive operation the wear rates were marginal, the sliding surfaces just showed some minor polishing of the diamond tips.

The coefficient of friction was reduced by a factor of 5. Due to the excellent dry-running properties the micro-crystalline diamond technology withstood several hours of dry-running with a reduced formation of heat.

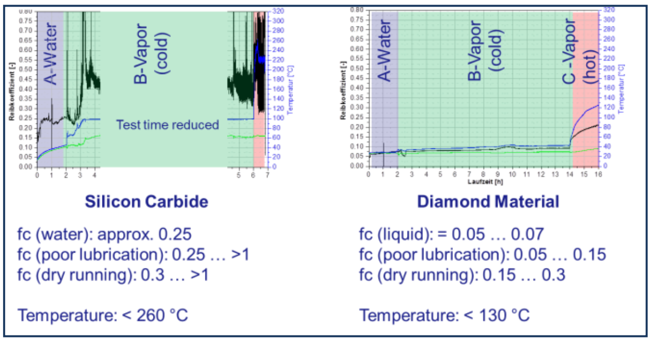


Figure 15: Direct comparison of the test results

Figure 15 shows the direct comparison of the two different materials and the absolute values of the measured friction coefficient in all three phases of the test and compares the maximum measured temperatures of the seal faces. Significant results of this test is the reduced friction, the reduced measured seal face temperatures and the perception of the Diamond material capability to run under poor lubrication conditions.

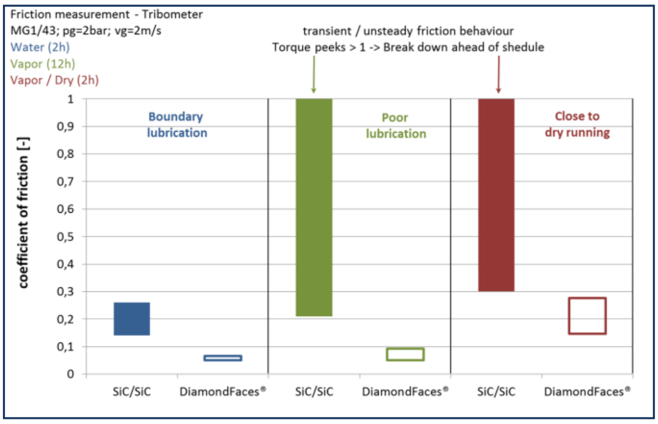


Figure 16: The spread range of the measured coefficient of friction

Figure 16 summarizes the tests and shows the fluctuation characteristics of the different materials. Significantly wide spread range of the measured friction values for the SiC-SiC material combination means an unsteady running behavior of the seal. The diagram shows also very clearly the small spread of the friction values for the Diamond material combination and the significant reduction of friction by a factor 5.

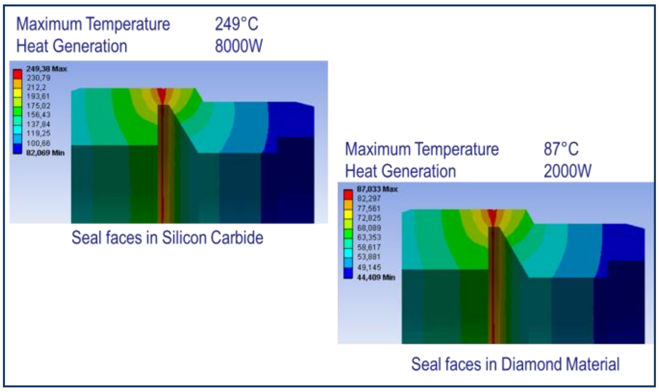


Figure 17: The result of the Finite Element simulation under unfavorable operating conditions

Figure 17 shows a Finite Element calculation, and an exemplary temperature distribution of this dedicated seal type used in these two applications. This analysis was carried out under unfavorable boundary conditions and fluid film characteristics. In transient conditions of the pump, their mechanical seals are running in an undefined situation and seal faces suffer due to insufficient lubrication and cooling. In such situations, this new material combination can reduce the frictional heat generation significantly, which leads into a stable and steady-state operation of the mechanical seal. Our field installation in multiphase services has shown that in case of unexpected running conditions in the seal cavity the seal is much more tolerant and robust.

CONCLUSION

Single mechanical seals are able to seal different kinds of crude oil gravities, formation water and solids. Seal face material like Silicon Carbide (SiC) is well-known for this kind of application, but has limitations handling gas slugs or high viscosity fluids. By using micro-crystalline Diamond material for mechanical seals the lifetime could be improved significantly.

The mechanical seals installed in the Multiphase pumps in Venezuela have been in continuous operation since March 2014. Previously the lifetime of the mechanical seal was only 3 months.

The mechanical seals in the heavy crude oil pipeline pump in Brazil have been in operation since May 2012. The seals are performing very well with low leakage values and long MTBR values.

This success was only possible due to the selected seal design and the specific seal face material. The crystalline diamond layer is characterized by its extreme hardness, wear resistance, excellent thermal conductivity, highest chemical resistance and lowest friction coefficient combined with maximum adhesive strength to the base material. This innovative technology is suitable for a wide range of applications in the upstream, midstream and downstream industry. It’s a key to improving the mechanical seal reliability in critical applications.

REFERENCES

[1] Schäfer, L., Höfer, L., Kröger, R.:
The versality of hot filament activated chemical vapor deposition.
Thin Solid Films 515 (2006), S. 1017 - 1024

[2] Blug, B., Höfer, M, Hollstein, T., Schäfer, L:
“Diamantbeschichtete Gleitringdichtungen für den Einsatz
in wässrigen Medien”
Tagungsband Reibung, Schmierung und Verschleiß 2005,
Gesellschaft für Tribologie e.V., Deutschland, 2005, ISBN 3-00-017102-9

[3] Schrüfer, Andreas; Lewerenz, Jörg:
Operating Experience with Diamond Coated Seals in Multiphase Pumps.
Proceedings of the 4th international EMBT conference Hannover, pp 39-50, Joh. Heinr. Bornemann GmbH Obernkirchen, 2013

[4] Matthée, Thorsten; Schrüfer, Andreas:
CVD-Diamantinnovation setzt sich durch.
Diamond Business, pp 6-9, Heft 1/2011

[5] EagleBurgmann Competence Brochure
“DiamondFace coated DF-HRS8 in crude oil application”
No. E14071/E1/1.000/09.14/9.7.5

ACKNOWLEDGEMENTS

Figure 1: Courtesy of ITT-Bornemann Pumps, Germany

Figure 3: Courtesy of Sulzer Pumps, Brazil