Pumping Molten Sulfur:
A Challenge for Pump Design, Sealing Systems and Material of Construction

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Bibliography

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Abstract

Pumping molten sulfur is a very challenging application with a wide variety of available solutions. Selection of the “best” solution depends on the requirements on site but also the process conditions. Many times the “best” solution is not chosen, due to the lack of understanding of all possible solutions or from lack of experience. Many aspects need to be considered to choose the best pump type, sealing system and material of construction.

One of the most important issues is to consider the properties of sulfur. Due to the abnormal variation of viscosity with temperature, which only allows sulfur to be pumped satisfactorily within the range 135-155 °C, most pumps used for molten sulfur applications have a heating jacket in order to keep the temperature constant in all parts of the pumps. In addition, the percentage of Hydrogen Sulphide (H_2S) directly influences the temperature range, in which sulfur can still be pumped with an acceptable viscosity. Low flow conditions within the pump could generate an increase in temperature, which could effect lubrication of the bearings. This issue also needs to be considered when talking about operating speeds for sulfur lubricated submerged sleeve bearings. The material of construction selected is also affected by the H_2S content.

Shaft sealing is another critical design decision and there are several alternatives. For vertical pumps, stuffing box packing could be adequate, while for horizontal pumps, hydrodynamic shaft sealing, mechanical seal or magnetic drive arrangements are recommended. With a high H_2S content often times gas lubricated mechanical seals are used with vertical pumps.

The design of vertical pumps depends not only on the purity of sulfur, but also on the size of the sulfur tank or vessel. For example, cantilever pumps are limited in their submergence depth. For clean sulfur, single or multistage pumps with foot and intermediate bearings can be used for longer submergence depths. Applications with impure sulfur the solid size, hardness and concentration have an influence on the design. Sleeve bearings in hardened material with internal product lubrication or even with external grease lubrication, cantilever pumps offer a suitable solution for such applications.

Although vertical pumps are widely used on sulfur melting plants, it is not uncommon to use various designs of horizontal pumps.

Horizontal pumps for molten sulfur can either be of heavy duty design with hydrodynamic shaft sealing (e.g. for molten sulfur containing solids), or of modern magnetic drive design (e.g. for clean sulfur). Magnetic drive pumps have the advantage of safe operation without any leakage of hazardous hydrogen sulphide. Different versions of mechanical seals (e.g. steam quench) are available.

This paper will discuss the different technical solutions including advantages and disadvantages users will have to face. It will show a few examples of experiences gained in different plants world wide as well as some guidance how to find the best possible pumping solution.

INTRODUCTION

As a result of increasing demand of fuels with low sulfur content due to environmental reasons, the yearly production of sulphur is steadily growing. The demands and the requirements for pumps to move this increasing amount of sulfur are getting more complex year after year. Special solutions are continuing to be developed to cover a wide range of different installations.

For sulfur tanks / pits installed below ground level it is common practice to use a vertical pump type if centrifugal pumps are required. Various designs of vertical pumps are available. For recovered “clean” sulphur, pumps with shaft support bearings are suitable. Submergence depths longer than 6 foot (2000 mm) normally require additional intermediate bearings. The vertical shaft is supported by anti-friction bearings on the top outside the tank, and by sleeve bearings below the mounting flange. The sleeve bearings are lubricated by the sulfur.

Generally it is recommended that the maximum pump speed of this type of vertical sulfur pumps is limited to 1500 rpm at 50 Hz or 1800 rpm at 60 Hz, in order to reduce the risk of temperature increase in the sleeve bearings. The radial forces and the pump vibration can also be limited.

Vertical pumps for “dirty” molten sulfur are normally executed in a cantilever design and are therefore limited to a setting length of approximately 6 foot (2000mm).

Tanks installed above ground level horizontal and vertical centrifugal pumps can be used, often depending on the philosophy of the user regarding shaft seals and capital cost.

For the different shaft seals available for horizontal pumps there are also technical limits which need to be considered when looking at these seals. This paper will also have a closer look at these limits and the advantages and disadvantages of the different seal types.

OVERVIEW

When designing a pump for molten sulfur, it is important that the properties of sulfur are taken into consideration. Due to the abnormal variation of viscosity with temperature, sulfur can only be pumped satisfactorily within the 275-311 °F (135-155 °C) range. Most pumps used for molten sulfur applications have a heating jacket in order to keep the temperature constant in all parts of the pump. The presence of Hydrogen Sulfide (H_2S) directly influences the temperature range, in which sulphur can still be pumped with an acceptable viscosity (Figure 1).

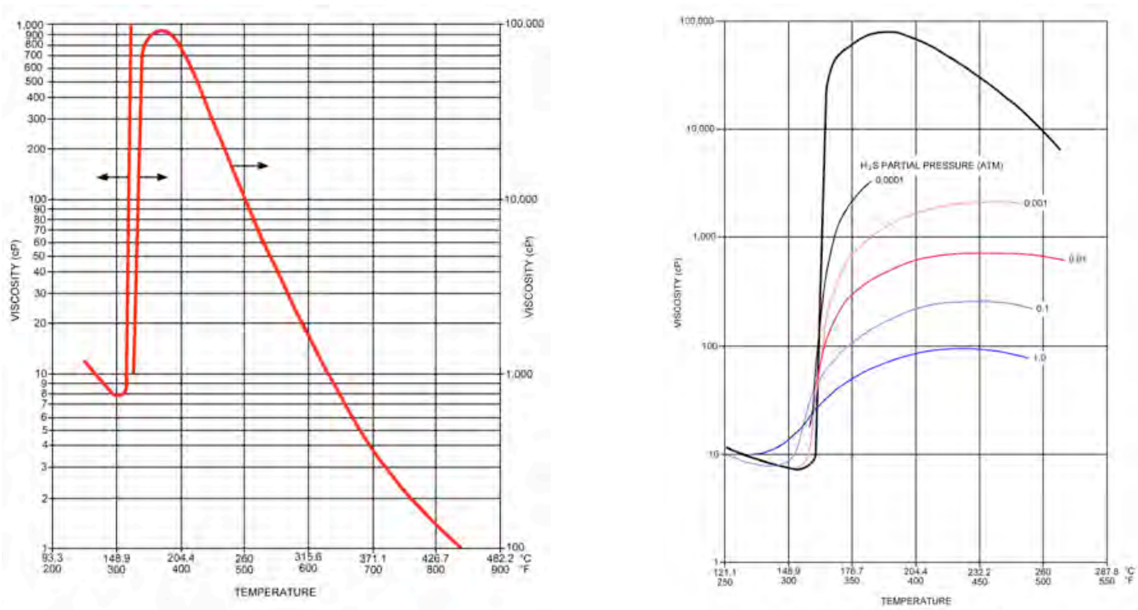

Figure 1: Viscosity of sulfur and influence of H_2S on the viscosity [1]

Figure 2 gives an overview of available pump designs, common materials and suitable sealing systems for sulfur applications. The following chapters will focus on the details and also show advantages and disadvantages of each solution.

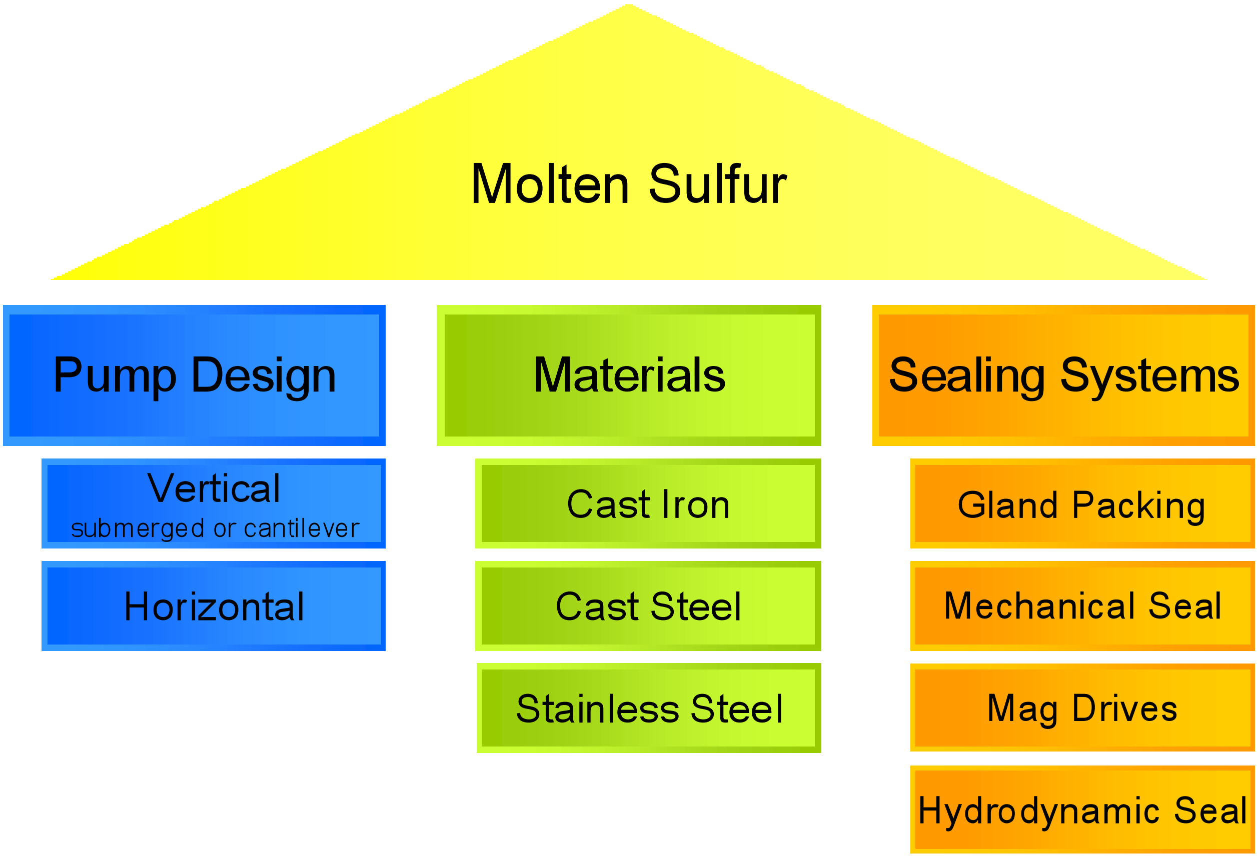

Figure 2: Overview of pump designs, materials and sealing systems

PUMP DESIGN

- For clean and “dirty” sulfur.
- Suction conditions are important criteria to size the seal.
- Speed should be fixed, no VSD.
- Permanent operation preferred.
- Small leakage during start-up and shut down.
- No wear parts in the sealing area

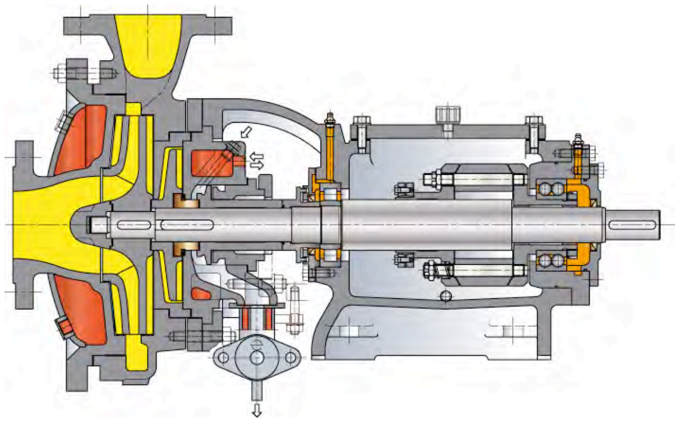

Figure 3: Heavy duty horizontal pump with hydrodynamic seal

- For clean sulfur.
- 100% leakage free
- Steam heating is critical to avoid solidification
- Limits of sizes to due torque transmittal by magnets

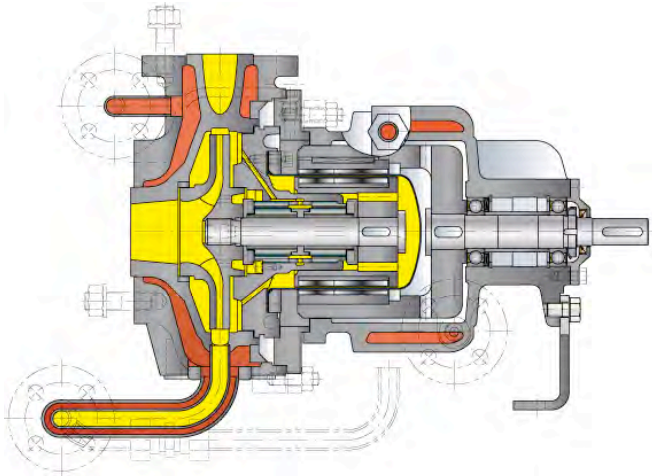

Figure 4: Horizontal pump with magnetic drive

When using horizontal pumps the tank has to be tapped leading to additional risk. Therefore vertical pumps installed on top of the tank minimize this risk, a suction valve is also not required as a horizontal pump should be equipped with one in case the seal fails.

- For clean sulfur.
- Flexible in length.
- Possible multi stage design allowing a high differential head at low speed.
- The discharge and the shaft column should be built as a compact unit to give optimum stability, especially for pumps longer than 6 foot (2000 mm).
- The entire unit requires only a very small opening in the tank/pit.
- Double volute casings are recommended to minimize the radial forces, which results in lower wear of the sleeve bearings.
- Shaft coupling system should allow reverse rotation (combination of thread and fitting key).
- Different gap sizes and lubrication groove system depending on application.
- Temperature interaction needs to be considered when looking at materials of construction.

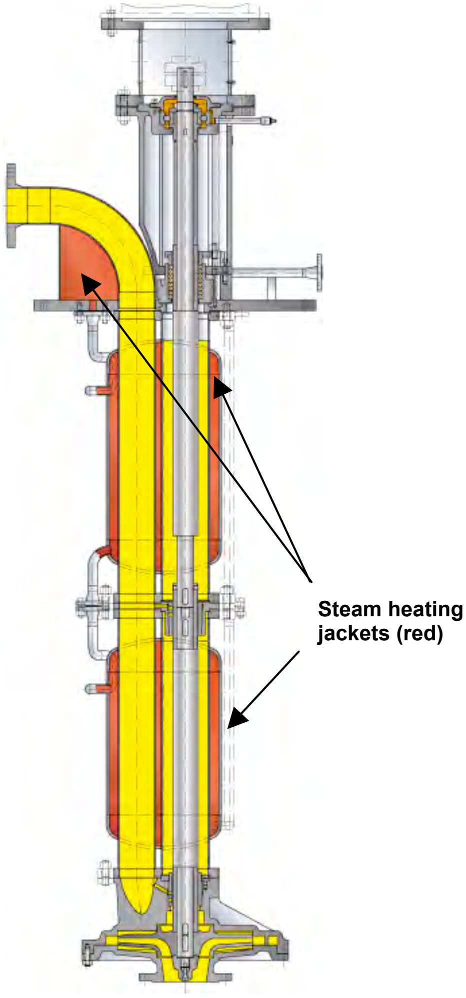

Figure 5: Vertical pump with one intermediate bearing and heating jackets

- For “dirty” sulfur.
- Limitation on length (app. 6 feet).
- Dry running no problem.
- Double volute casings are recommended to balance the rotor.
- No wear parts besides antifriction bearings outside of the tank.

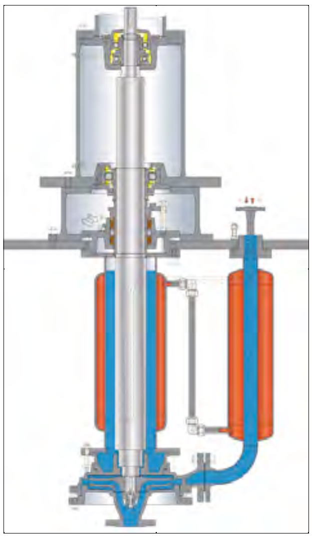

Figure 6: Vertical cantilever pump with heating jackets

As already mentioned, the operating speed of vertical pumps with sulfur lubricated sleeve bearings is a very important and critical issue. As higher speeds result in increased friction in the sleeve bearings it is possible that the sulfur solidifies and damages (e.g. bearing seizures, Figure 7) are caused. These phenomena could be accelerated under low flow conditions.

Figure 7: Seizured sleeve bearing

Multistage hydraulics can be used to achieve higher discharge pressures with speeds at maximum 1750 rpm. Figure 8 shows a pressure test of a two stage hydraulic.

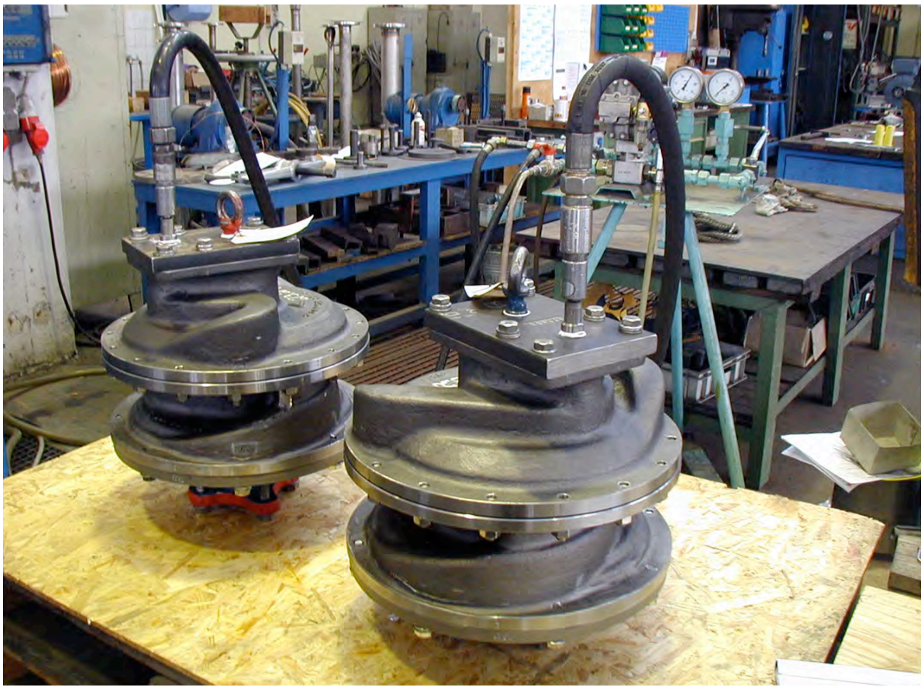

Figure 8: Pressure test of a two stage hydraulic

Most of the vertical pumps will be exposed to a back flow resulting in reverse rotation after it has been shut down. Now it is a question of how the shaft pieces and the impellers are connected to enable the rotating unit to spin in reverse rotation. A combination of threads and feather keys are the best solution (refer to Figure 9).

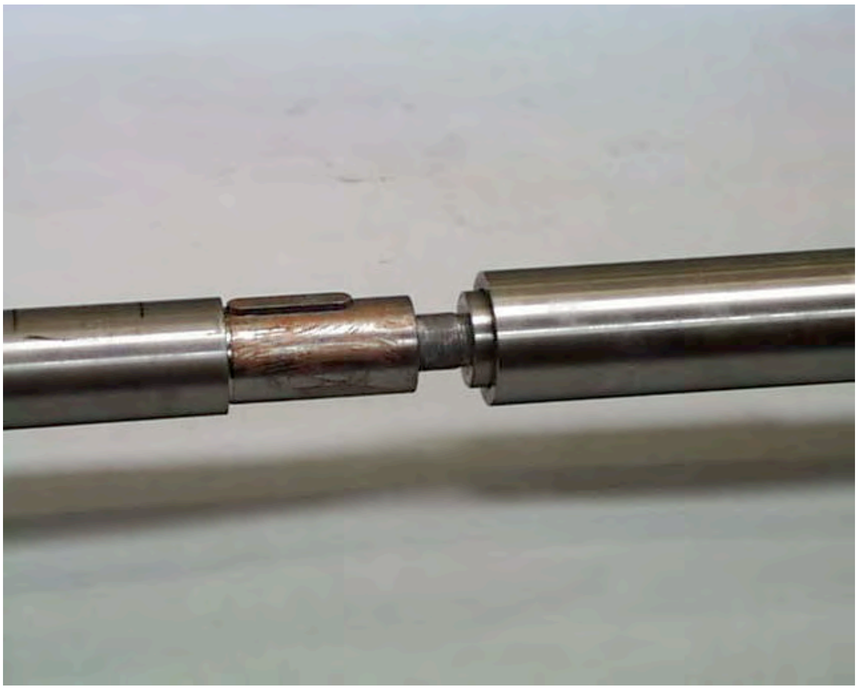

Figure 9: Threaded shaft with feather keys and sleeve

The internal groove design of the bushing, the clearance gap between sleeve and bushing as well as the material combination is based on each manufacturer's experience.

The gap behind the impeller (Figure 10) also has to be calculated while considering the different growth rate of pipes (thin-walled) and shaft (solid material).

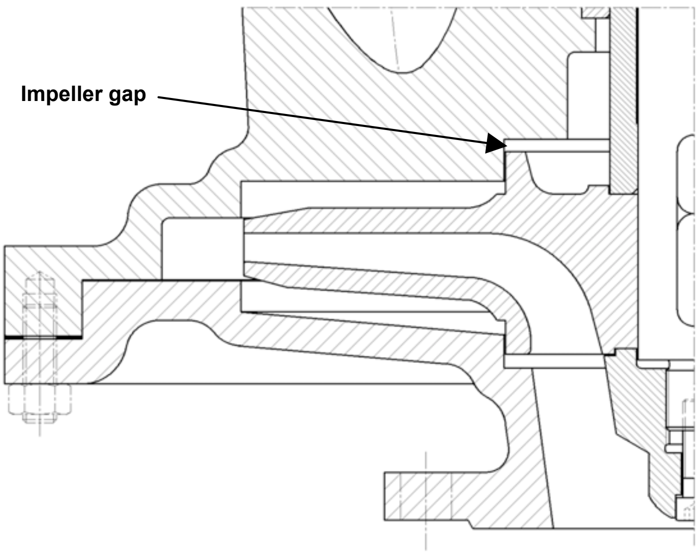

Figure 10: Impeller gap

With increasing shaft length of vertical pumps the hydraulic section will move in an orbit during operation; tank or pit designers need to make sure that there are no obstacles (e.g. heating coils or walls, refer to figure 11) which will block this movement. If the pump cannot move freely there is a risk of sleeve bearing damage.

Figure 11: Installed pumps in a pit with side walls

The latest development in pump operation shows the tendency to use variable speed drives. When using variable speed drives it is mandatory to calculate natural frequencies. Speed areas where the pump should not be operated need to be determined. With the FEM method it is also possible to calculate the thermal expansion properties, which are dependent on the liquid levels in the tank. Figure 12 shows an example of the deformation of an entire pump system caused by a frequency of 27.6 Hz.

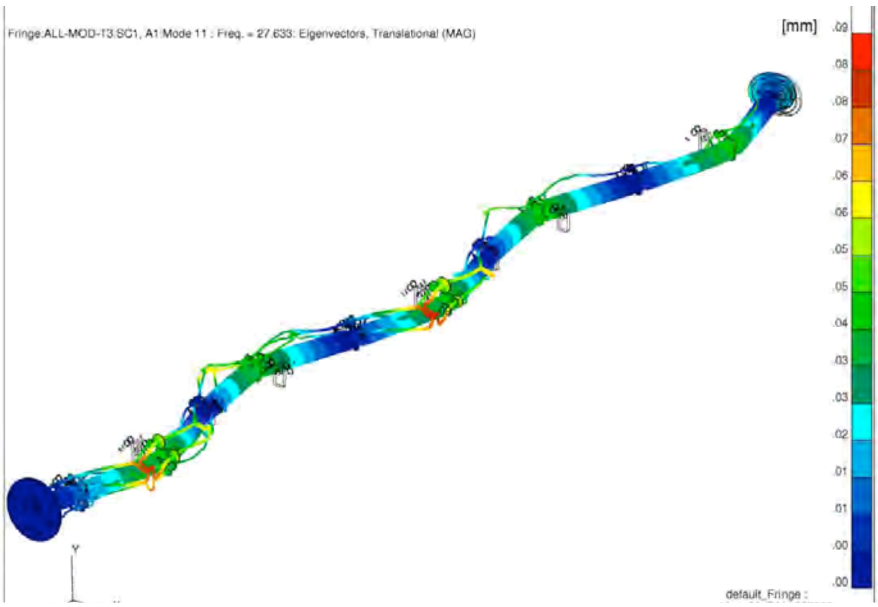

Figure 12: FEM analysis of the pump

MATERIALS

When it comes to material of construction, there are three main groups. In addition to customer specific requirements, the H_2S content determines the use of materials. Cast iron is resistant at low H_2S contents up to 10ppm, but it induces pyrite stains and sometimes clogs impellers. Carbon steel is resistant at a range of H_2S from 10 - 300 ppm but corrodes at phase interface. Small amounts of water or some water vapour will support reactions of iron based alloys with H_2S to FeS. This reaction needs water wet sulphur. FeS has a black color, which sometimes may show metallic shininess.
Stainless steel is resistant at full range and is the preferred material for phase interfaces with a high H_2S content (pipe columns).

Figure 13 shows pyrite deposits on auxiliary impellers made of cast iron intensified by humid sea air at the French Atlantic Coast.

Figure 13: Pyrite deposit on auxiliary impellers

Figure 14 shows black pyrite deposits in a foot bearing of a stand-by pump at a plant in the Middle East that has never been operated.

Figure 14: Black pyrite deposit in a foot bearing

One phenomenon we see quite often is corrosion even on stainless steel; this happens when water comes into contact with sulfur containing H_2S at the atmospheric boundary layer. A chemical reaction will lead to H_2SO_4 which is very aggressive at temperatures above 260 °F. Figure 15 shows the corrosion effect on a stainless steel shaft.

Figure 15: Corrosion on a stainless steel shaft

When selecting a material there is often a discussion about the NACE standard and its validity for sulfur pumps (NACE R 0175). It is more or less a guideline to prevent sulfide stress cracking (SSC).

Quote from D. Bush, Valve Magazine 02/1998:
"According to NACE MR0175, sulfide stress cracking is defined as "brittle failure by cracking under the combined action of tensile stress and corrosion in the presence of water and H_2S". Actually, sulfide stress cracking is a special case of hydrogen embrittlement that occurs when H_2S dissociates, in the presence of water, into hydrogen and sulfide ions. Diffusion of hydrogen into the metal is catalyzed by the presence of the sulphide ions, promoting hydrogen embrittlement. As such, all materials that are susceptible to hydrogen embrittlement are very susceptible to sulfide stress cracking. In addition, some metals that are resistant to other forms of hydrogen embrittlement are susceptible to sulfide stress cracking. The term "sulfide stress cracking", or SSC, is used most commonly in the oil and natural gas production industry. This term leads to some confusion, since the sulfide ion is not actually the embrittling species. The refining industry prefers the term "wet H2S cracking", which is actually a more accurate designation. ***NACE MR0175 defines the term "sour" as a fluid containing water as a liquid*** *and H_2S exceeding particular limits. What are the factors affecting sulfide stress cracking susceptibility? There are actually quite a number of factors affecting the susceptibility of a material to sulfide stress cracking".*

With sulfur pumps we never experienced SSC, as the liquid sulfur will not contain any water! In our opinion the NACE material recommendations are not valid for sulfur applications.

Last but not least, sometimes the sulfur pit is just too dirty for pumps. Figure 16 shows a clogged suction strainer.

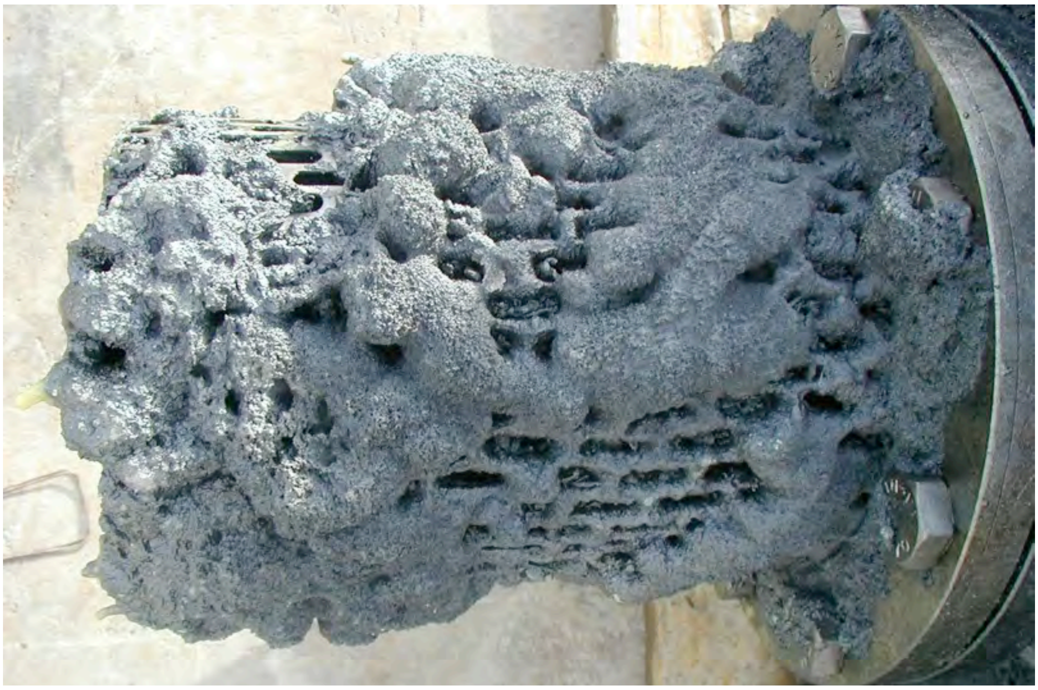

Figure 16: Clogged suction strainer

SEALING SYSTEMS

When it comes to choosing the best sealing system many aspects have to be considered. There are three solutions to choose from for horizontal pumps:

-Hydrodynamic shaft sealing
-Mechanical seal
-Magnetic drive

Each sealing system has advantages but also disadvantages or technical limits. The magnetic drive is a 100% leakage free but it can only be used in clean sulfur and the size is limited to maximum torque transmission depending on magnet sizes and type.
Specially designed mechanical seals are common in sulfur applications but require a high grade of maintenance and the external steam or barrier fluid supply systems are expensive. A mechanical seal also requires a lot of know-how from the operators.
Another solution is the contact free hydrodynamic shaft seal which is the best solution for permanent operation. This seal requires low maintenance and no auxiliary systems, however it can only be operated at fixed speeds. The suction condition needs to stay in a small pressure window and there is a leakage during start-up and shut down. For intermittent operation this might not be the best solution.

Figure 17 shows a pump with a hydrodynamic shaft seal with a special standstill seal, which is operated by a centrifugal weight assembly connected to the pump shaft.

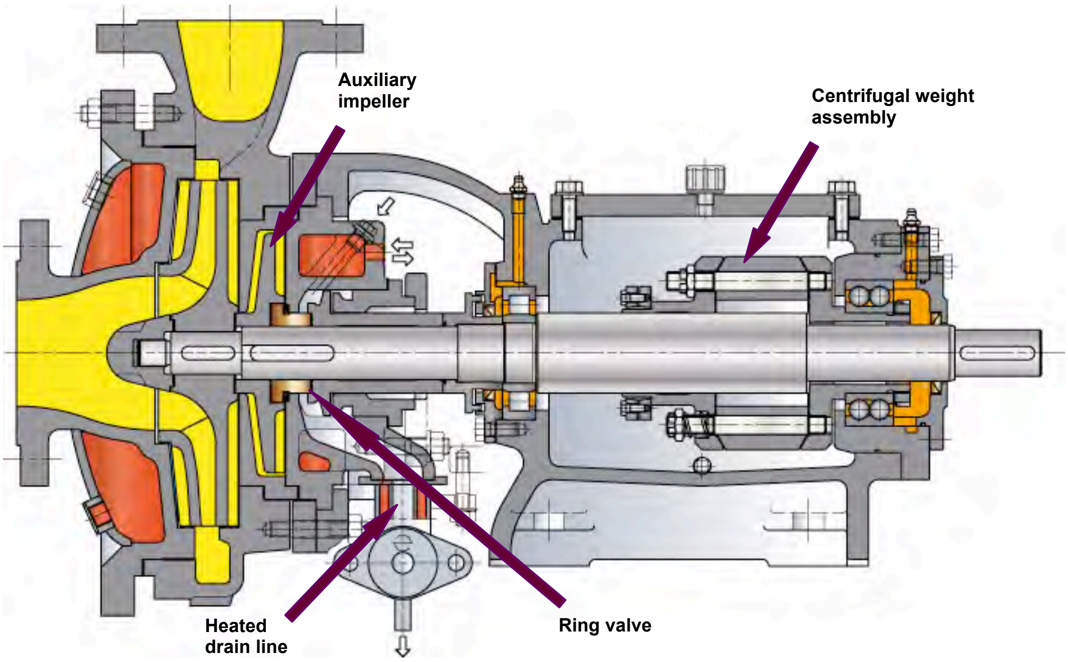

Figure 17: Hydrodynamic shaft seal

When the pump is started the weights move away from the centerline of the shaft due to centrifugal forces which results in a movement of the shaft towards the suction side. This opens up the ring valve and the hydrodynamic seal takes over sealing the pump during operation. Once the pump is stopped, a set of springs will pull the shaft back and close the ring valve. Figure 18 shows the centrifugal weight assembly with the set of springs.

Figure 18: Centrifugal weight assembly with set of springs

Another solution is the magnetic driven pump (refer to figure 19) which is 100% free of leakage. As already mentioned it can only be used with clean sulfur due to the very small gap between spacer can and inner magnet. Also the silicon carbide bearings are sulfur lubricated. The pump size is limited to available magnet systems and the related maximum torque transmission. Magnets lose their force with increasing temperature. Magnetic driven pumps are often used as loading pumps with a high number of start and stop cycles per day.

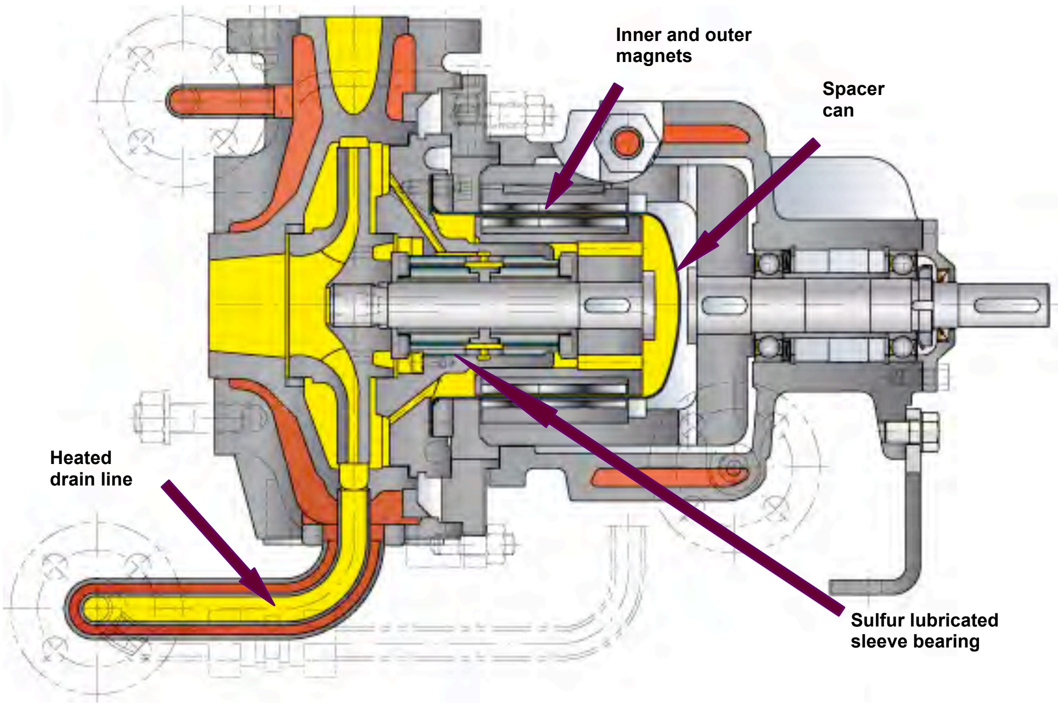

Figure 19: Magnetic driven pump

Today mechanical seals are still the most common seals for molten sulfur. In single or double execution as cartridge with steam quench or external barrier fluid systems, depending on the actual requirements regarding pressure, speed, size, etc. These type of seals require a high level of maintenance on the operations side.
As steam is normally always available at the pump due to steam heating most seals today are equipped with a steam quench to avoid crystallization on the atmospheric side of the seal. Depending on the actual quench configuration there have been issues with sulfur flocculation (refer to figure 20) on the outside of the seal.

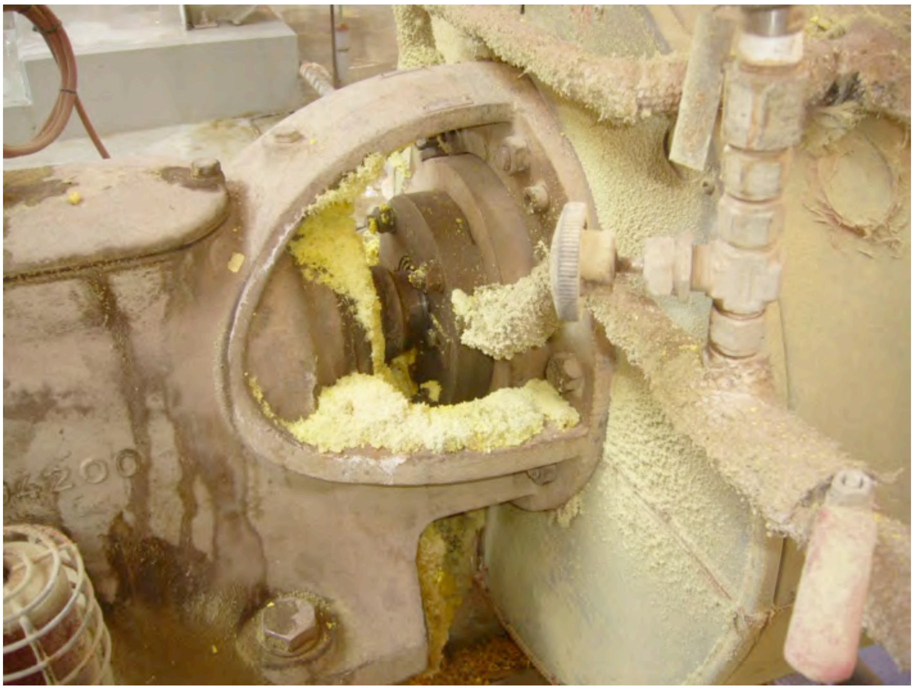
Figure 20: Sulfur flocculation on a seal with steam quench

Figure 21 shows the pump with a seal and quench system from a different supplier, this technology was more suitable in this case for the application.

Figure 21: Perfectly operating mechanical seal with steam quench

Looking at the sealing systems of vertical pumps, stuffing box packing is the most common seal, often supplied with an N_2 purge. Sometimes it is necessary to use a mechanical seal to avoid any leakage at all if H_2S is present. Gas lubricated cartridge seals are used in many cases. Figure 22 shows a vertical pump at a test field with a panel to supply N_2 to the cartridge seal.

Figure 22: Gas panel to supply N_2 to the cartridge seal

CONCLUSION

Pumping molten sulfur is a very challenging application with a wide variety of available solutions. Selection of the "best" solution depends on the requirements on site but also the process conditions. Many times the "best" solution is not chosen, due to the lack of understanding of all possible solutions or from lack of experience. Many aspects need to be considered to choose the best pump type, sealing system and material of construction.

Hopefully this paper can provide a guideline for the reader with different aspects to keep in mind when looking for molten sulphur pumps. It always is not just one single matter which needs to be considered, it is a mix of different requirements.

The pump manufacturer needs to understand the application and process "behind the pump" to provide the best possible solution, it is not enough to just provide required capacity and discharge pressure.

REFERENCES

[1] Douglas K. Louie, Handbook of Sulfuric Acid Manufacturing,
DKL Engineering, Inc. Ontario, 2005

All other pictures and drawings from Friatec AG