Status Report MP-Technology. Developing the state-of-the-art of science and technology - to be geared to operational needs

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Bornemann Pumps

1. Introduction

This status report of Multiphase Pump Technology is mainly based on research and development activities within the MPA-Joint Research Project (1997 to 2006) and the MPT-Joint Research Project (presently proceeding till end of January 2011).

Both joint research projects are partly supported by the German Federal Ministry of Education & Research and the Ministry of Economics. Bornemann as a major project partner initiated the R&D-activities in the early 90s, with regard to Multiphase-Twin-Screw-Pumps, to work out a wider theoretical foundation for this technology and to start extensive research on the whole multiphase transport process. The following chart shows the project partners and their main focus.

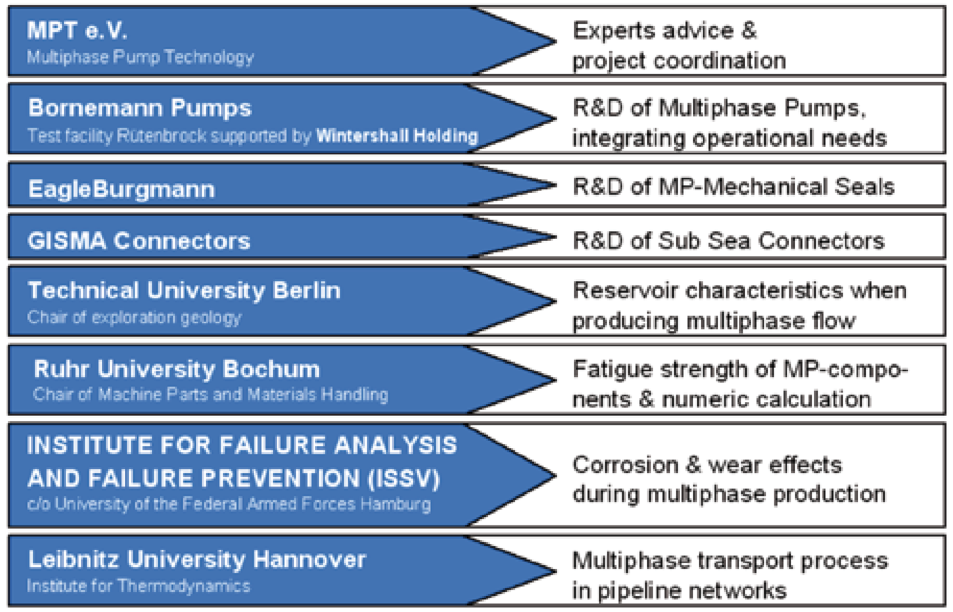

Figure 1: Projekt partners and their main focus

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During the first years, one of the supporting pillars of the R&D activities had been engineered: the multiphase pump test plant. This test plant ensured to develop multiphase technology integrated in a real production scenario. Furthermore Bornemann profits from the experimental laboratory for multiphase pump components at its site, the R&D activities at the project partners (see the named universities and industrial enterprises) and the scientific support of the MPT e.V. experts. In 2003 Bornemann got the opportunity to install this test plant with two screw pumps, type MPC 268, based at the WINTERSHALL sour gas well Rb10z at Rütenbrock (in the north of Germany; operation as wet gas compressing multiphase pump). Since then Wintershall and Bornemann have operated this test facility together. While Wintershall Holding has cared about the legal approvals and the integration in the existing field layout, Bornemann has provided the operators for the multiphase pump system, the mechanics and electricians who cared about maintenance and troubleshooting and engineers, who planned and carried out the test programs. The very close cooperation between Bornemann and Wintershall during planning, installation, operation and service activities has placed Bornemann in the position to understand the daily needs of the operators and allows Bornemann to develop this technology based on this experience.

Figure 2 shows the multiphase test plant at Rütenbrock. It is described in detail in the MPA-Project Status Report of 2005 [1].

The whole Multiphase Pump System has been designed and operated according to the relevant European directives, with detailed hazard analysis and according to the latest operational safety regulations. This included quality inspection before start-up by two independent third parties (TÜV-Nord and German Lloyd Offshore) and periodic inspections of pressure vessels and electrical systems with special attention to automatic fire and gas detection system.

Figure 2: Multiphase test plant Rütenbrock

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During the MPA Joint Research Project the multiphase screw pump for sub-sea operation itself had been the focus, whereas later on the sustained production and transport of hydrocarbons and the engineering systems needed on- and offshore became the area of activity.

Within this report research and development supported by operational experience from the Rütenbrock test plant is presented. It can be subdivided into the following topics:

- Development of multiphase pump system components
- Wear, corrosion and lifetime
- Enlargement of multiphase pump size
- Interaction between multiphase pump system, formation and transport pipelines

2. Development of multiphase pump system components

During the operation time of the Rütenbrock test plant the development of the following multiphase pump system components had been pushed on amongst others:

- pump casing
- rotor and liner design
- mechanical seals
- auxiliary system for mechanical seals
- o-ring seals
- concept of bearings
- control system

Regarding the pump casing, material selection and necessary manufacturing processes had been developed. Duplex steel casings for high pressure sour gas applications have been qualified according to the WEG directive for sour gas loaded systems and the NACE MR0175. The welding procedures for pressure vessels with a wall thickness above 100mm, especially but not only made of duplex steel, and experiences in more efficient seam geometries as well as welding process control had their major roots during the planning and manufacturing of the test field equipment. The know-how, which is basically one of the foundations for the extrapolation of the pump size, is described later on.

Figure 3 shows the casing of multiphase test pump No. 1 (called UW MPC) during the welding process. The pump casing is made of 1.4462 duplex steel and designed for max. 100bar.

Figure 3: Pump casing of UW-MPC268 test pump

Future pump casings for high pressure sub-sea multiphase pumps, based on these experiences, have been conceptually designed together with the project partner LMF at the University of Bochum by using the finite elements method.

Looking at the core of the multiphase pump, the rotor, the know-how regarding the theoretical calculation basis and therewith the expansion of the rotors performance limits has made substantial progress.

Together with the University of Bochum Bornemann has improved the state-of-the-art of science concerning calculation of rotor stiffness, fatigue resistance of the screws, thermal impact for high temperature applications and improved inlet and outlet geometry of the screws.

Based on the structural finite element models, new analytic calculation methods have been worked out, which allow to dimension the rotor in a shorter time than using FEM, but with nearly the same accuracy (also see previous and current reports of LMF of University Bochum). With this new analytic calculation basis parametrical optimisation is possible much more effectively. This helps to design the rotor again more reliably for its specific operational mode.

These new analytic calculation methods are also the basis for the extrapolation to larger rotor sizes and for a new "high delta-p" design of the screws.

Rotors with improved screw design according to the new calculation method have been operated for several years with best results in the test pumps in Rütenbrock even under extreme operation condition with high pressure ratio, up to a value of 12, or long periods of gas production without free liquid.

The following figure 4 shows for example a FE-Model of a screw's tooth flank, generated to analyse the tooth fatigue resistance and to derive an alternative analytic calculation method.

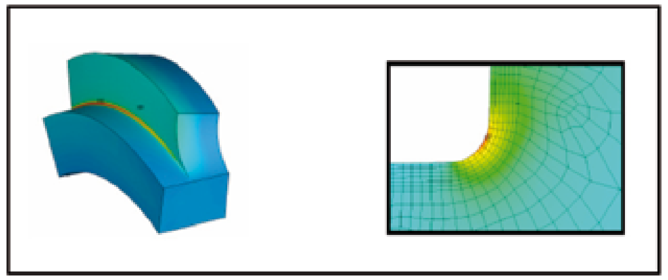

Figure 4: FE-Model of pump screw's tooth flank

Figure 5 shows a FE-Model of the engineered rotor, generated to analyse the heat distribution after fast temperature changes in the medium. This know-how is a key factor to withstand in multiphase flow scenarios as known from steam driven hydrocarbon recovery.

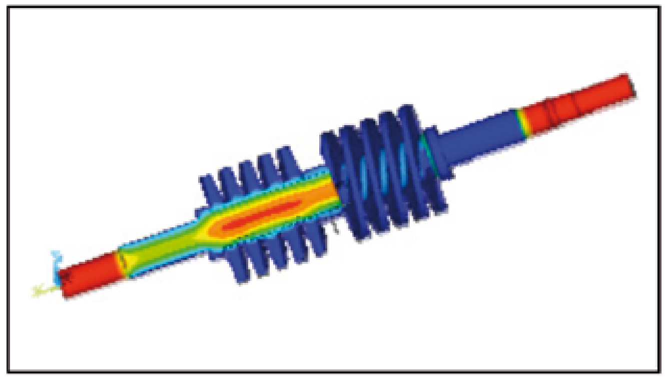

Figure 5: Heat distribution in engineered rotor

Regarding the development of multiphase mechanical seals, all efforts were focused on a highly reliable sub-sea seal system.

In 2003 Bornemann started its own concept in cooperation with the R&D partner Burgmann. The Smart Seal System (S3), patented by Bornemann, is based on separation of functions. While a throttle bushing reduces the operating pressure just in front of the mechanical seal, the throttled process fluid will be fed back to the suction side of the pump. The mechanical seal is flushed by the throttled medium from the product side as well as by a pressurised barrier fluid from the outer side. An auxiliary system permanently generates a seal oil pressure slightly above the product pressure and provides fresh lubricant to the seal faces. This allows the mechanical seal to work under ideal conditions and forces the necessary lube oil replacement by a controlled oil leakage.

During the operating time of the multiphase test pumps in Rütenbrock the design of the S3 seals had been improved from time to time, but it has to be pointed out that there was no mechanical seal failure, that has stopped the test plant over the years. The improvements are related to improved thermal conditions, better flushing and a predictable barrier fluid consumption. This outcome has a positive effect on lifetime and service intervals, which is even more important for subsea than for on-shore installations. The improvements could have been achieved by designing fewer dead spots near the seal faces and by integrating conveying elements in the seal design to intensify the flushing effects. New seal materials and surface treatments had been positively tested in Rütenbrock as well (more details, see R&D Reports of Burgmann).

Concerning the concept of the mechanical seal arrangement for the whole pump unit, several improvements were made step by step.

Starting from the conventional on-shore seal concept, where the pressurized process fluid is sealed against the oil mist lubricated gear and bearing housing, which is on atmospheric pressure level, the idea of a completely flooded and pressurized lube oil area was born. While today often double acting mechanical seal systems with oil mist bearing and gear lubrication on atmospheric pressure level are used in on-shore multiphase pumps,

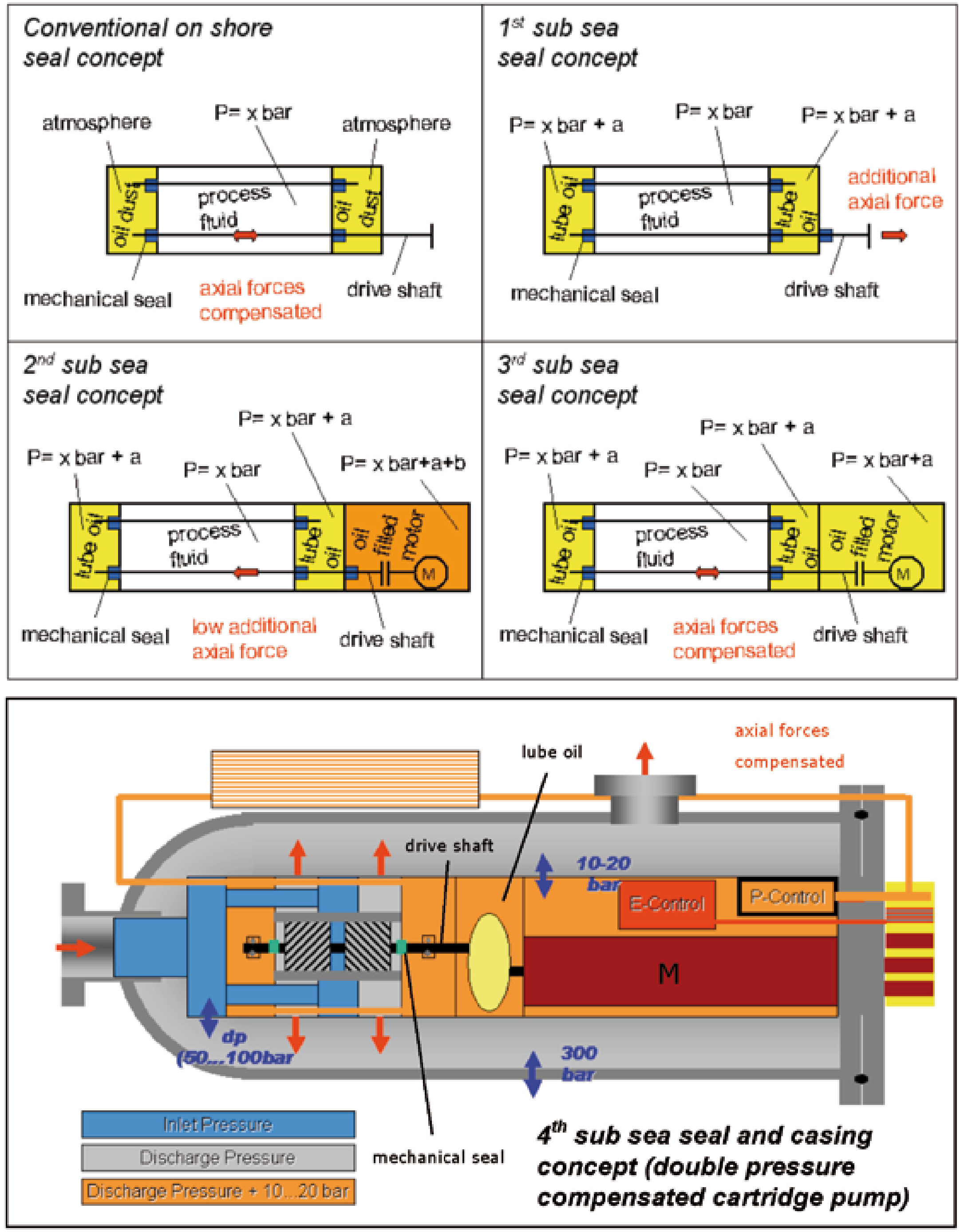

Figure 6: Concepts of mechanical seal arrangements for sub-sea pumps

the inner areas with atmospheric pressure are disadvantageous for sub-sea pumps, because of the high outer ambient pressure. Therefore the first sub-sea pump seal concept was designed with a completely flooded lube oil area, which was pressurized to unload the used S3 mechanical seals. A fifth mechanical seal had to be used to seal the clean lube oil against the ambient area. However an additional hydraulic force, which affects the drive shaft, had to be handled by a stronger axial bearing.

In a next stage of development, an oil-filled electrical sub-sea motor was adapted. The liquid filling of the motor may be pressurized too, so that the additional force on the drive shaft will be compensated. By that, the conventional axial bearings can be used in the pump again. This concept is of hermetical type, as no mechanical seal to the ambient area exists any longer. The whole motor/ pump aggregate is integrated in a pressure vessel. As a result any leakage at the mechanical seals can't cause environmental pollution anymore.

The 3rd evolution used the same lube oil for pump and electrical sub-sea motor. Modification of lube oil quality and analysis of the components resistance against the lube oil prepared this step. Especially the resistance of all polymer materials like the isolation system of the motor and the sealing compound of the sub-sea connectors have been analysed and improved where necessary. This stage of development allows the elimination of the fifth mechanical seal between pump and motor. The seal concept was practically tested in the Rütenbrock under water (UW) test pump and has been the helpful basis for the current Bornemann sub-sea pump, the "double pressure compensated cartridge pump", realised as demonstrator and detailed presented in Bornemann's MBS sub-sea project.

In parallel to the development of the mechanical seal and the complete seal concept, the seal auxiliary systems have been improved too within four stages.

Even with the first small auxiliary system for the prototype of the smart seal system, a simple bladder accumulator, a dynamic adjustment of the barrier fluid pressure was realised in the late 90s in order to bring the mechanical seal under comfortable operating pressure. In the next stage a piston type accumulator was used with a switch-controlled refill pump. This system was able to adjust the barrier fluids pressure dynamically, while boosting it proportionally to the relation of the piston areas.

Development stage three was able to boost the barrier fluids pressure to a fix level in relation to the referenced operating pressure of the pump. Two hydraulically operated differential pressure control valves effected the lube oil supply and by this the pressure level that is needed. Using the hydraulic energy of a charged bladder accumulator, the auxiliary system was prepared for power failure, a must regarding operation in remote areas. A connected high pressure oil cooler handled the thermal losses of the timing gear, the mechanical seals, the bearings and the electric motor. Two slightly different types of this auxiliary system were tested together with the multiphase pumps in Rütenbrock and worked quite well. Still a challenge is the pure number of components of the auxiliary system, which effected its reliability with an increasing number of components. Every component increases the probability of a failure of the complete system, so additional efforts were necessary to reduce the number of components, making them even more reliable or find a way to do completely without the auxiliary system.

Following this direction, the latest development stage is an electro-hydraulic auxiliary system, using the experiences from the described models, but replacing the hydraulically operated differential pressure control valves with electronically controlled valves, which are more reliable and more flexible. This system, especially designed for the Bornemann sub-sea pumps, profits from the Bornemann Seal Oil System (BSOS), a current standard auxiliary system for double acting mechanical seals in on-shore multiphase pumps.

This system allows to connect the oil cooler at a lower pressure level, which had to be designed before for the high pressure level of the barrier fluid. Figure 7 shows the four described auxiliary systems for the mechanical seals.

Regarding O-ring seals, the effect of explosive decompression was analysed in the very beginning of the research projects. In a test installation for the S3-seal system near Rütenbrock in the Netherlands a standard viton compound was used in the beginning. Producing also a high-gas content on a pressure level of 36barg parts of the gas phase diffused into the compound and expanded explosively, when depressurising the system during the stop procedure. This explosively expansion damaged the o-rings massively, as illustrated in figure 8.

In general this context is known from deep whole helical eccentric screw pumps, but never before in topside multiphase pumps. In cooperation with the o-ring manufacturer a special ED-resistant (ED stands for explosive decompression) compound was selected and had been also tested in the multiphase pumps in Rütenbrock. Furthermore, the start and stop procedures had been modified. The decompression time had been increased and the number of decompression events had been reduced. While the old procedures depressurises the system whenever it stops, the new one only do that during an emergency shut down or when the operator wants to depressurise the system manually. The gradient of depressurisation has also been influenced to give the gas more time to diffuse.

Figure 8: O-ring damaged by explosive decompression

Figure 7: R&D stages of seal oil systems

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Regarding the rotor concept of multiphase screw pumps, research concentrated on the reduction of the bearing span, to increase the rotor stiffness. Improvements of the rotor design had been realised up to a 11% shorter bearing span, which increases the maximum radial load the rotor can bear in the same portion. The lube oil quality had been analysed and improved, with the intention to expand lube oil lifetime. The use of new roller bearing materials like silicon carbide ceramic or special stainless bearings offer an increased resistance against impurities and a longer lifetime compared to conventional bearings. Finally completely new roller geometry was tested in the multiphase test pumps in Rütenbrock: the toroidal roller element bearing. This product comes with elevated static and dynamic load carrying capability and a line contact over the whole working range which allows smaller bearing size. The bearing design realizes a higher angular misalignment tolerance, an adjustable radial tolerance and a special "NoWear Coating" reduces dry friction and smearing behaviour by creating a microhardness of 1200HV. Figure 9 shows a special toroidal roller bearing, implemented and tested in the Rütenbrock multiphase test pumps.

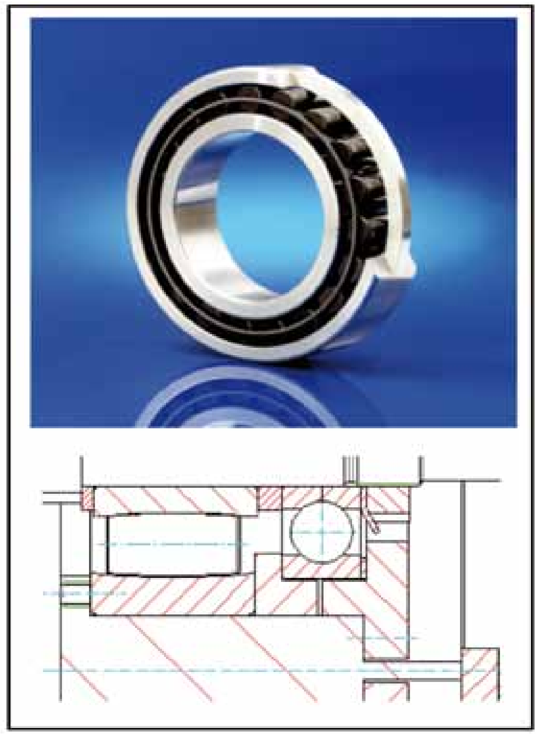

Figure 9: Toroidal Roller Bearing (Photo: SKF)

Regarding the control system the multiphase screw pumps at the Rütenbrock test field are the foundation for several improvements which have been integrated in commercial pump systems later on or even for completely new products, concerning remote access technology or condition monitoring experiences [2]. Already in the year 2000, when the basic engineering for the test systems in Rütenbrock started, extensive control and communication hard- and software were provided at the latest state-of-the-art, to gain as many experiences as possible. The following technology has been integrated and tested:

- Use of external peripheral I/O-bus modules (meanwhile in the 2nd generation)
- Profibus dp signal communication for more than 100 analogue signals
- Industrial Ethernet communication
- Connection to operator control room via Profibus with limited possibility to influence system performance
- Full remote access to all control functions (system start excluded) via different communication technologies, i.e. directional radio, ISDN or satellite. Special attention was paid to world wide access and high level protection against misuse
- Active communication system, i. e. operator information about warnings or system malfunction via SMS or E-mail
- Vibration protection system
- Vibration monitoring including operator alarm and optional connection to a vibration monitoring centre [2]
- Structuring and build-up of a condition monitoring centre in Obernkirchen/Germany to handle and develop remote access and condition monitoring data and technology.
- Separate closed-circuit TV for the plant and all pump and piping containers with data storage (use verified and harmonized with the Wintershall work council)
- Comprehensive, self-contained emergency shut down system with output to plant ESD-System
- New data compression routines for MP-process data (high information content, reduced memory requirements)

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Actually one test pump has been equipped with further instrumentation to analyse the theoretical background of appearing pressure pulsations during operation at and above limit range of the multiphase pump. The analysis and tests have been planned together with the project partner LMF (Ruhr University Bochum) and will be realized in close cooperation with the project partner and the Wintershall production management. In parallel to the real operational test scenario in Rütenbrock, supplementary tests in the lab of the University of Hannover (project partner IfT) are organized to build up and verify the new theoretical approaches.

3. Wear, corrosion and lifetime

Just for ambitious multiphase service, lifetime of the conveyor elements has been a subject over the years. Bornemann and the project partner ISSV (Helmut Schmidt University of Hamburg) early assumed that wear (abrasive and erosive) and corrosion effects interact in different processes. So the ISSV started to work on the theoretical models, by using experiences like:

- Analysis of the pumps screws and liner during inspection of the pump systems in Rütenbrock
- Corrosion and wear tests in the ISSV lab.
- Corrosion test of material samples, mounted in the well stream in Rütenbrock
- Experimental wear tests in a specialized test facility at Bornemann

(also see project reports and 2nd EMBT Paper of ISSV Prof. Hoffmeister and Dr. Klein)

A major step forward was the specialized wear test facility and modified test procedures at Bornemann Obernkirchen, which allows reproducible wear tests with different kinds of sand fractions under individual operating conditions. This allows to compare the benefit of different wear protection, if needed in relation to an individual process parameter. Figure 10 presents a photo of this wear test facility at Bornemann, where a complete multiphase screw pump had been integrated. Solids can be injected constantly regarding capacity and quality.

Figure 10: New wear test facility at Bornemann

Bornemann analyses the different wear influencing operating parameters for different materials and protection methods.

Furthermore, Bornemann and the project partner developed methods to evaluate the working envelope of special materials for multiphase service, considering individual medium mixture and individual load scenario. The foundation of these methods were gained at the ISSV by working with the original Rütenbrock reservoir water and recently also medium from the German oil field Mittelplate (operated by RWE Dea and Wintershall Holding). The availability of this original medium and the test equipment and procedures, developed by the ISSV, allowed research work on corrosion scenarios, not having been analysed for multiphase service and standard multiphase materials before. Similarly this know-how is the basis for the current qualification of new selected high corrosion resistant materials for multiphase service in the future (see also reports of project partner ISSV). Bornemann has also built up a multiphase medium database, to gain related ex-

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periences with regard to corrosion and wear. In future the cooperation with raw material and component suppliers has to be intensified as well, to merge their product-related know-how with the worked-out know-how about multiphase oil and gas service.

4. Enlarging multiphase pump size

Already in the early 90s Prof. Dr. Schafstall and some multiphase pump pioneers worked to predict the future market of multiphase pump technology. At the beginning of the MPA Research Project these predictions were the basis for the first theoretical scale up of the pump size. Figure 11 shows the result of this scale up by listing the existing multiphase pump size for 0,8 MW drive power in 1997 up to the pump size expected to be necessary for the market in 2009 with 5 MW drive power.

Figure 11: Multiphase pump sizes planned and realized

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After these first calculations and outlines the MPA research project began to build up the theoretical calculation basis and with the Rütenbrock test installation also established a basis of operational experience. These R&D activities brought the different technical disciplines together, which developed to the existing multiphase expert network. The new theoretical basis, developed in the MPA and MPT project, an increasing operational experience and the expertness of the Bornemann design engineers, headed by Bernd Struckmeier, allowed to follow the visionary development path. So in accurate congruence with the planned scaling of the pump sizes from the early 90s, figure 11 presents the manufactured and fully tested multiphase pump, type MW11, made for 5 MW drive power, and two multiphase pumps for 3 MW drive power, which have already been brought in operation.

5. Interaction between multiphase pump system, formation and transport pipelines

Beside operational safety (pump system acc. to European safety regulations and self-contained Bornemann safety system) and reliability of the multiphase pump systems (proven technology state-of-the-art), R&D activities focused more and more on interactions between the MP-System, the formation and the up-stream and downstream pipelines for multiphase transport. Together with the chair of exploration geology from the University of Berlin, the experienced engineers of the Wintershall Holding, the institute for thermodynamics from the University of Hannover and the experts of the MPT-association, Bornemann analyses special operation behaviour of the multiphase pump, with regard to the influence on the flow composition and the depending pressure development. According to operational experience at the test installation in Rütenbrock and analysis of degassing scenarios in the test lab at the IfT (University Hannover), it could be demonstrated that multiphase transport needed different start scenarios, depending on what kind of formation, medium composition, flow line diameter and geographical profile the pipeline follows. The key parameter to influence the start scenario is the gradient of pressure drop the volumetric multiphase pump generates. At the test well Rb10z a fast and significant pressure drop caused highly alternating flow rates and in the worst case a longer reduced flow. In order to overcome this effect a slow pressure drop with a reduction of 1 bar over several days helped to balance the gas production of the well and to generate a steady flow. This example demonstrates the necessity to combine the knowledge about the formation and the phase behaviour with the specific hydraulics of the multiphase transport process. To intensify the research activities on this subject, a cooperation between Russian and German scientists was started within the MPT-Project and two additional multiphase pump systems were engineered to install them at different Russian oil producing wells, to get additional operating experience and analyse different operating scenarios. The multiphase test systems were assembled at the Russian partner's workshop and first tests have been successfully completed.

Figure 12: MSL pump system for Russian test field

Two Russian teams have been trained especially in multiphase transport and pump technology to be able to support further activities at the test pumps and to be able to service them during operation. Training took place at Rütenbrock test plant and at Bornemann Obernkirchen training centre. Figure 12 shows a picture of one of the multiphase test pumps in Russia after assem-

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bling.
Similar to the research on different start scenarios present and future research has to include interaction of different multiphase pumps in a big field development. Already the parallel operation of several multiphase pump systems on one well pad can be influenced significantly by the header design for the incoming flow lines. The latest development, based on design analysis by flow simulation and hydraulic tests, is an intelligent header system. Together with the project partner IfT (University Hannover), the Bornemann R&D team and the dept. of system engineering, a header design was developed, which is able to support equal flow distribution and an expanded dry running capability, nearly independent from the number of pumps. Figure 13 shows a flow simulation for a conventional header which feeds five multiphase pumps in parallel (gas phase in red, liquid phase in blue). An unbalanced flow splitting and a minimum liquid hold-up have to be noticed. The new technique is able to optimise flow splitting and to maximize liquid hold-up and thereby to expand multiphase pumps operation limits.

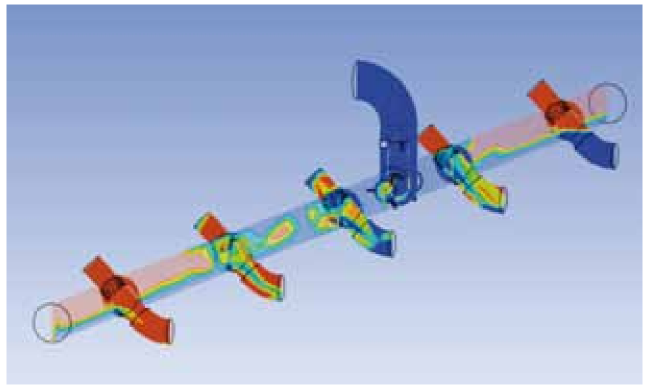

Figure 13: Flow simulation of conventional header

Concluding it is safe to say that the last decade of research activities has formed a wide and resistant foundation for the existing and the developing multiphase technology. Also it has to be mentioned that with ongoing research activities and operational experience, the know-how about the whole multiphase transport process has become more and more relevant. The beneficial use of this still young technology will at last mainly depend on the capability to manage the interaction between the transport system and the multiphase mixtures.

ACKNOWLEDGEMENTS

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