EFFICIENT MULTIPHASE PUMP STATION FOR ONSHORE APPLICATION AND PROSPECTS FOR OFFSHORE APPLICATION

by

Winfried Neumann

Project Manager

J. H. Bornemann Pumps GmbH and Company, KG

Obernkirchen, Germany

Winfried Neumann has been Project Manager with Joh. Heinr. Bornemann GmbH and Company KG, Germany, since 1988. His main scope of work is within the multiphase activities in this company.

Dr. Neumann obtained an M.S. degree in Mechanical Engineering in 1980 at the Technical University of Clausthal and a Ph. D. in 1987 at the University of Dortmund, both in Germany.

ABSTRACT

With oil consumption increasing worldwide, the petroleum industry is being forced to find ever more efficient ways. Not only the exploration of inaccessible and inefficient oil fields, but also the increasing demand for efficiency, safety, assurances of environmental protection, and automation are among the challenges of the future. The technology of multiphase transport provides an economical and safe alternative for these problems.

Gas fractions in the multiphase mixture cause considerable changes in flow as compared with the handling of liquids only and, consequently, affect the pump performance curves. A new pump type was developed especially for multiphase pumping. The first two prototypes are equipped with comprehensive metering devices and are being tested under laboratory and production conditions. The laboratory tests show reproducible results in systematically produced performance curves. The field tests are proving the pump qualifications by pumping actual multiphase medium.

As a result of all these tests, the screw pump design is not only suitable for handling multiphase flow, but is also approved for practical applications on the well. The performance data have been reached, but problems with the mechanical seals have prevented a long running time. With gas fractions higher than 95 percent, a reliable minimum liquid recirculation should be available.

These tests provide valuable results for further development of the multiphase pump design concept. This is a good basis for a new generation of multiphase pump stations.

INTRODUCTION

With oil consumption increasing worldwide, the petroleum industry is being forced to find more efficient ways to meet worldwide demand. The exploration of inaccessible and inefficient oil fields with increasing demand for safety, assurances of environmental protection, and automation is among the challenges of the future. With these constraints, the handling of crude oil direct from the well becomes increasingly more important. Multiphase transportation (mixture of gas and oil) provides an economical and safe alternative for these problems.

The installation of small multiphase pump systems (200 to 1000 kW), or so called "subsea booster stations," can now be built. However, the application of larger multiphase pumps (2000 to 7000 kW), aimed at replacing existing offshore platforms, are the real challenge of the future. However, before subsea installed pump stations become a reality, they must pass rigorous performance tests onshore, on either mainland or production platforms.

Rotary screw pumps have been used for multiphase pumping for over 40 years, but only with small quantities of gas (i.e., less than 60 percent). To meet future requirements, the development of pumps designed specifically for multiphase operation is required. The most significant differences between multiphase pumping and liquid only pumping is the generation of heat due to gas compression, changes from gas to liquid conditions, changing release of gases from liquids, unstable inlet conditions (i.e., slugs or pockets of nonhomogeneous liquids), reexpansion of gases during nonoperation, and the danger of explosion. Gas fractions in this multimedium cause considerable changes in flow as compared with the handling of liquids only and, consequently, affect the pump performance curve. Additionally, the pump performance varies with varying inlet pressures. If inlet conditions exceed a fixed, analytically not yet determined operating point, the flow process is impaired due to interrupted internal sealing against leakage and can even stop completely. Furthermore, a multiphase pump is strained by solids such as sand and gravel as well as by aggressive chemicals such as H_2S.

A new technology like the multiphase pumping will never be installed untested in a production plant, so there are different projects for testing several components like multiphase pumps under real production conditions. In the Tritonis test field, which is run by two oil companies, we got the possibility to test our first prototype, which is especially developed for multiphase pumping.

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Conventional Solutions

Some European countries are able to cover a considerable part of their crude oil requirement by exploiting their own offshore oil fields, the availability of onshore oil fields being only minor. Oil and gas fields are explored by installing drilling and production platforms. These platforms are quite expensive, and their application is limited regarding water depths.

The oil-gas-water mixture flowing under extreme pressure is separated on the platform and transported via pipeline or tanker to the mainland for further processing. The separated multiphase mixture is further processed by pumps and compressors. Separate pipe systems are required for handling liquid and gas. Some gas is reinjected into the field.

Alternative Solutions

In the future, there is no alternative for subsea technology. The application of multiphase pump systems is in competition with subsea separation technology, where liquids and gas are processed in separate pipes under water. The oil industry often regards multiphase handling to be the technology of the future.

It is imperative for pump manufacturers to offer a multiphase pump also suitable for handling liquids only and to cover both technologies.

MULTIPHASE TRANSPORT TECHNOLOGY

Fields of Application

Multiphase pump stations can be installed both offshore and onshore. The following fields of application are possible:

- Dry installation (onshore) on the mainland to economically exploit smaller oil fields.
- Dry installation (offshore) on a platform, enabling further processing on land and simplifying the setup of a platform.
- Wet installation (subsea) on the sea bed, enabling exploitation of smaller offshore fields so that platforms are no longer required.

Besides different fields of application, pump manufacturers focus on different sizes. According to present development, the following ranges of operations are possible for multiphase pumps:

- Designed for high capacity (e.g., more than 500,000 bpd), installed behind a reservoir, and aimed at increasing the pressure of a pipeline. These features allow simplification of platforms or, with subsea installation, the transportation of the multiphase mixture to the mainland and to further process it. No platforms are required.
- Designed for medium capacity (e.g., between 50,000 and 500,000 bpd) and installed behind a reservoir of an oilfield which is only a little productive. The liquid is transported to the next larger reservoir or to a tanker.
- Designed for low capacity (e.g., less than 50,000 bpd) and installed between a remote well and a reservoir to exploit the flow of wells with low field pressure.
- Designed for low capacity, installed next to the well, and aimed at keeping the delivery head pressure at a constantly low level with changing operating conditions. This allows a more steady flow and higher exploitation of the field.

The pressure rise of the pump, which is minimum necessary, depends on the piping configuration.

Besides the possibility of reducing the costs for installation and operation of oil fields, which could be exploited at higher cost by applying conventional methods, multiphase transportation methods allow the exploitation of fields whose exploitation was uneconomical up to now or not possible at all, provided these fields were not profitable to run, not easy accessible, or were located in too great water depths.

REQUIREMENTS

The special requirements for subsea installed multiphase pump stations are:

· pumping of multiphase mixtures
· subsea installation
· remote monitored operation
· subsea power supply

The following problems occur when pumping multiphase mixtures (the type of handling equipment is not relevant):

· gas fractions up to 100 percent
· compression heat
· slug flow, instationary flow conditions
· corrosive and abrasive components
· formation of hydrate
· change of gas formations
· solving and dissolving of gas
· reexpansion
· danger of explosion.

Subsea installations require:

· highest operational safety
· sealing against sea water for high ambient pressure (e.g., more than 100 bar)
· special connections for piping and electric installations
· robots for assembly and disassembly in great depths (e.g., 1000 to 3000 ft)
· special power supply
· high reliability with large mean time between failures (mtbf)
· high mean time between outages (mtbo) for scheduled maintenance.

Requirements for remote monitored operation are:

· special metering and control systems
· data storage and transfer for subsea installation.

Subsea power supply is a real challenge and requires:

· special transmission of energy
· handling of energy (i.e., transformer) for subsea installation
· subsea power plants.

Great water depths (more than 1000 ft) require assembly by robots. Gas fractions in the multiphase mixture create considerable changes in the flow behavior (compared with only the pumping of liquids) and, consequently, produce different pump curves. Since gas fractions compress during the pump process, the system is affected by compression heat. If the gas fraction exceeds a value which impairs the duty point of the pump, the back flow losses in the pump could increase, and the performance could collapse (breakdown point). Consequently, heat transfer is no longer possible, and the pump is at risk due to overheating and instability caused by gas pulsations. This breakdown point is to be avoided by adequate action, i.e., minimum liquid injection.

DESIGN OF A SUBSEA MULTIPHASE PUMP SYSTEM

The design of a subsea installed pump was developed and patented in Germany [1]. Pump unit and driver are installed in one casing, and internal pressure is identical to the inlet pressure of the pump. Pump and driver are mechanically separated but hydraulically combined; i.e., the internal pressure is always identical. Pressure balance between pump inlet and pressure casing is illustrated in Figure 1 by bellows. The final technical solution has not yet been decided.

This procedure has advantages, since sealing between liquid handled and lube/cooling agent is not affected by differential pressure. Particularly regarding mechanical seals at the shaft ends, the requirements are considerably simplified.

The pump unit is designed for 1000 kW. This pump motor unit is to be installed vertically in an existing subsea installation or an installation to be developed jointly with a partner from the offshore industry. Any installation is to be provided with required supply and information systems.

Prior to this installation, the pump system is to be tested in the pressure chamber of a subsea simulation laboratory of the

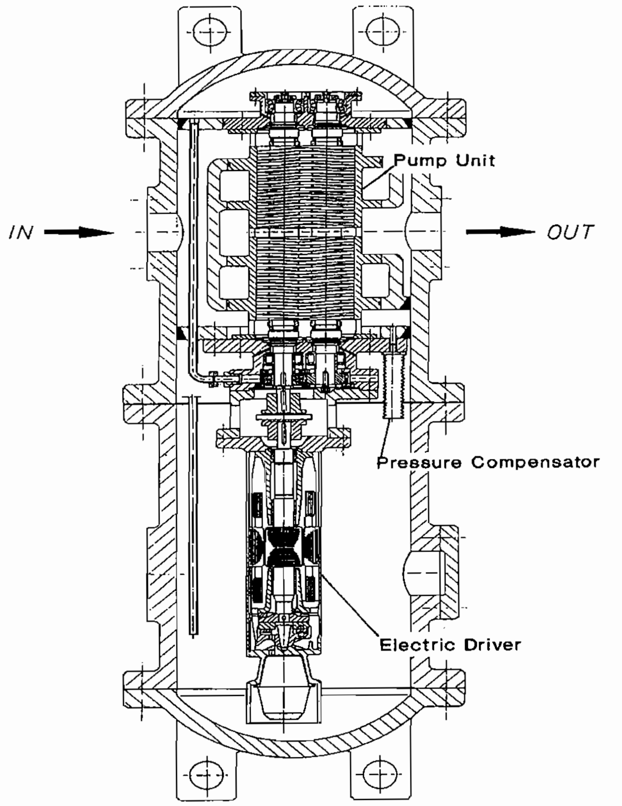

Figure 1. Design of a Subsea Installed Multiphase Pump Unit.

German research center GKSS-Forschungszentrum Geesthacht GmbH.

TEST OF A MULTIPHASE PUMP ONSHORE

The screw pump type MPC 355-45F, has been developed and particularly designed for handling multiphase flow. Two prototypes of this design have been manufactured. The first one (after having performed tests at the research center GKSS) is in operation in the Tritonis test field in Tunisia, run by two oil companies.

Performance date of this pump type are:

Total inlet flow	$Q_{mix\text{-}in}$	=	400	m^3/h
Total power	P	=	900	kW
Inlet gas ratio	$alpha_{in}$	=	95	%
Pressure rise	delta p	=	64	bar
Inlet pressure	P_{in}	=	22,5	bar (operation)
Inlet pressure	P_{in}	=	50	bar (non-operation)
Speed	n	=	1400	rpm

The first prototype of this new pump type is shown in Figure 2 with the following features:

· forged casing made of carbon steel without any welds

· liner made of austenite cast iron with chromium-plated inner borings

· screws made of duplex steel with coated outer diameter

· double acting mechanical seals

· external lube and seal oil system for roller bearings and mechanical seals

· connection for a direct oil injection into the screws

· special design for symmetrical temperature distribution

· electric driver, 1100 kW

· weight = 12 tons (without skid and driver).

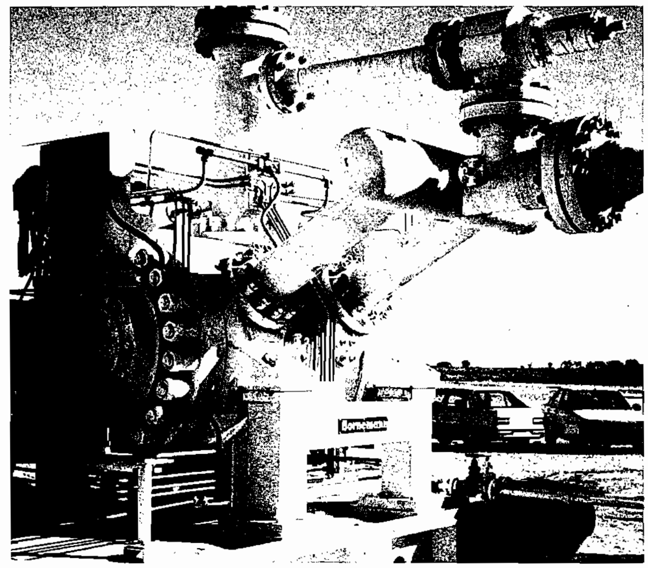

Figure 2. Multiphase Pump Prototype MPC 355-45 F located in a Tunisian Test Field.

Both test pumps are equipped with comprehensive metering devices. Values of particular interest are:

· chamber pressures
· chamber temperatures
· deflection between screws and liner
· deflection between screws and outer casing
· axial shaft deflection
· bearing forces
· bearing temperatures
· bearing vibrations.

While the first prototype is tested under production conditions with original liquid, the second prototype is tested in the laboratory of the research center GKSS in a closed multiphase loop. Due to this procedure, it is possible:

· to obtain reproducible laboratory results parallel to field testing of the first prototype.

· to reproduce problems occurred during field testing in the laboratory.

· to test different profiles of the screws and materials.

· to check hydraulic and thermodynamic solutions.

· to carry out measurements that are not possible in hazardous areas during field testing.

Generally, laboratory and field tests are aimed at different objectives. Laboratory testing covers following sections:

• Reproducible performance curves by systematically changing the operating conditions

• Instationary flows (i.e., slug)

• Protection devices to guarantee operational safety (i.e., shut down limits, minimum liquid injection)

• Maximum operational conditions

The following information is to be expected from field testing:

- Performance data
- Operational behavior for actual mixture
- Long term behavior (wear)
- Realistic operational conditions
- Possible extreme situations

The above results do have a considerable influence on future multiphase pump developments.

LABORATORY TEST SELECTION OF RESULTS

Due to comprehensive metering devices, a large number of test results are available from laboratory tests within a short time. Only a few selected results with significant information are presented herein.

All components of the test setup, i.e., closed test loop, recording of measured values, and the pump to be tested are prototype developments; i.e., the pump was required to test the loop, and then the pump could be tested by means of the loop.

During the early test period, it was not always possible to adjust the closed loop in a way that the pump inlet had constant operating conditions as required for multiphase performance curves. For better understanding and for easier interpretation, following curves have been recalculated for constant inlet conditions.

The following operating conditions are addressed in Figures 3, 4, 5, 6, and 7:

speed	n	=	1400 rpm
inlet pressure	p_{in}	=	9 bar
inlet gas fraction	$alpha_{in}$	=	92 %
liquid tested		=	H_2O/N_2 mixture

Illustrated in Figure 3 is a comparison of the effective flow capacity (at the inlet site) and the effective power consumption for multiphase flow and liquid only. The liquid is normal tap water with nitrogen added. Contrary to the liquid curve, the multiphase curve illustrates a minor tendency to higher differential pressures. However, the driving power is slightly lower.

The maximum deflection of the drive shaft is shown in Figure 4, which also compares multiphase flow with liquid only, illustrated as a free gap between screw and liner. Shaft deflection with multiphase flow is higher than with liquid only, since the hydraulic force of one screw has a greater effect on the pressure side of the screw. This can be explained in Figure 5, where pressure distribution along the screws for multiphase flow is compared with liquid only.

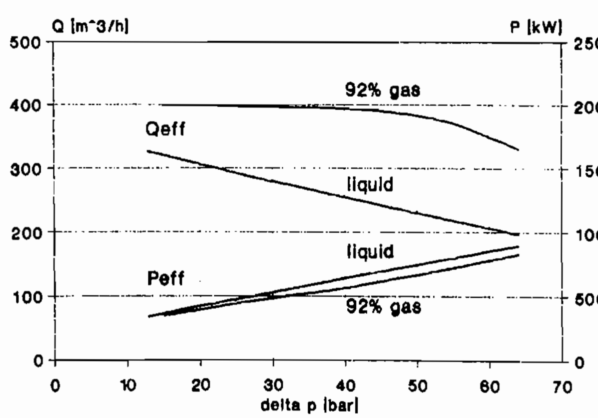

Figure 3. Flow Capacities Qeff and Power Consumption Peff.

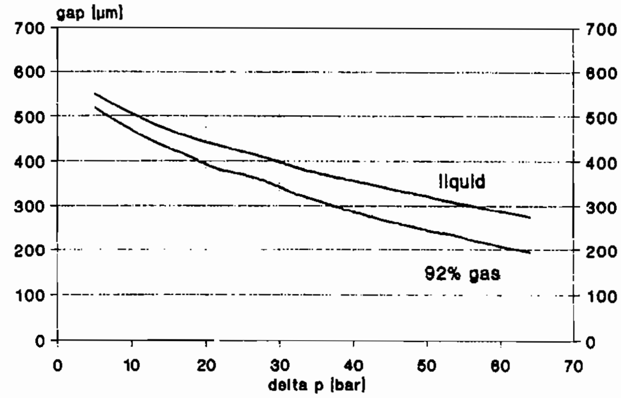

Figure 4. Shaft Deflection (Gap between Screw and Housing).

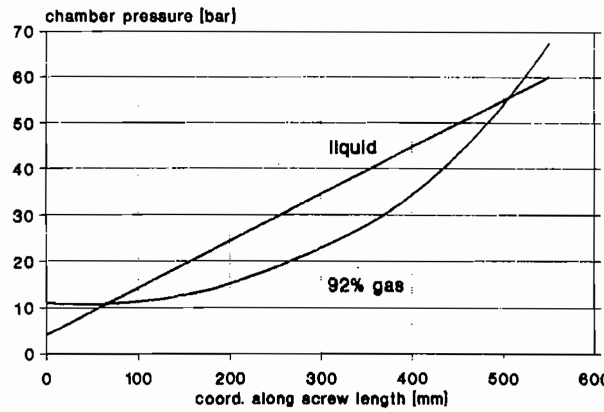

Figure 5. Profiles of Chamber Pressure along the Screws.

While handling liquid only, the pressure increase is linear. With multiphase flow, the pressure distribution is almost parabolic. In the first case, the differential pressure is identical in each chamber, while in the second one, it increases linearly (Figure 6). The hydraulic force, as a result, depends on differential pressure in each chamber. With liquid only, the hydraulic force is active almost in the center of a screw, while with multiphase flow, it is active more in the direction of the pressure side.

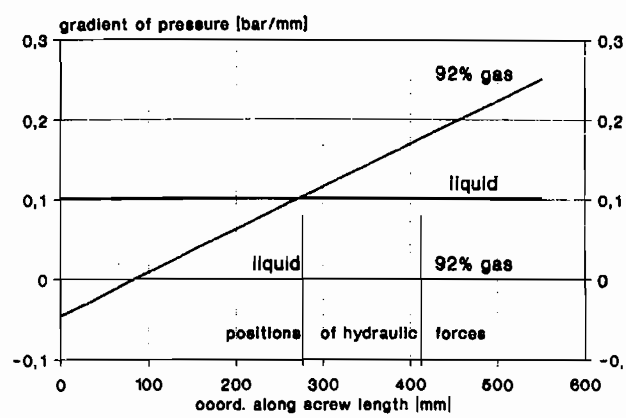

Figure 6. Gradients of Chamber Pressures along the Screws and Positions of Hydraulic Forces at the Screws.

A comparison of two efficiencies is shown in Figure 7. Due to lower mechanical-hydraulic losses, at lower differential pressures, the efficiency with multiphase flow is higher than with liquid only. Due to losses by thermodynamic compression, at higher differential pressures, the efficiency with multiphase flow is lower than with liquid only.

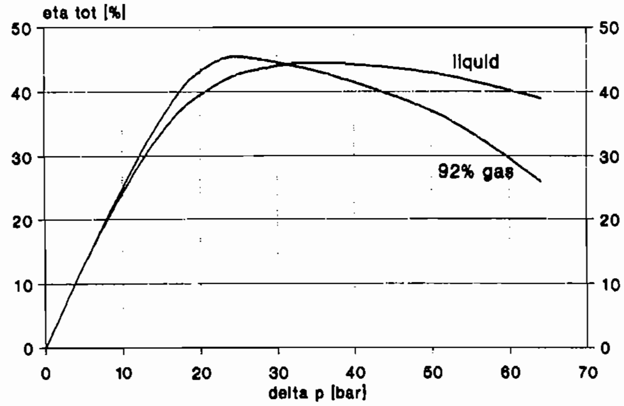

Figure 7. Total Efficiency.

A comparison of forces of a radial roller bearing for alpha = 0 percent and alpha = 92 percent gas is shown in Figure 8. In general, lower forces were measured with all bearings for multiphase flow.

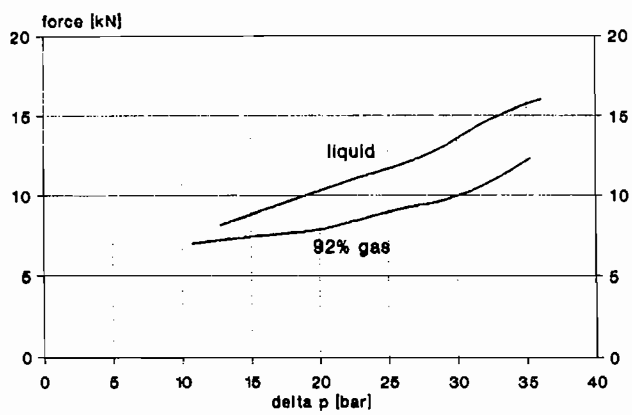

Figure 8. Bearing Forces at the Drive End Side.

FIELD TEST SELECTION OF RESULTS

From the large number of measured data, only two examples can be shown here. Contrary to the results so far, the following two diagrams show operating data versus time. A time evaluation of "slug" according to following definitions is illustrated in Figure 9:

P in	:	pump inlet pressure
P out	:	pump outlet pressure
P k.o.	:	separator pressure
T in	:	pump inlet temperature
T out	:	pump outlet temperature

The separator is located behind the pump. Separator and pump are disconnected by a check valve. The pump handles original multiphase flow as originates from the well.

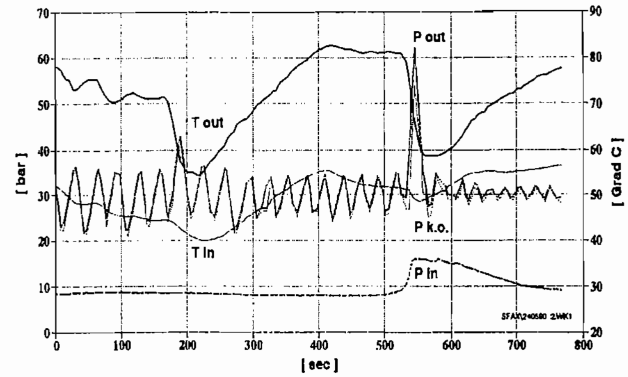

Figure 9. Field Test—Illustration of Pressures and Temperatures during a Time Period—"Slug" Recording.

Since the multiphase mixture flows from various wells into the pump, detailed information on liquid composition is not available. The gas fraction from well to well is expected to vary within a range of 80 percent to 100 percent.

The outlet pressure fluctuations are induced by the control loop of the test installation.

Typical slug performance is a peak in the outlet pressure, a slight increase of inlet pressure, considerable drop of outlet temperature since gas compression stops abruptly, and a slight decrease of inlet temperature since there is no reaction from increased outlet temperature. The peak in the outlet pressure causes a corresponding peak in the torque and bearing forces.

The time sequence of a break down point is illustrated in Figure 10. The unit was operated with a mixture of almost 100 percent gas over a longer period. Therefore, the separator behind the pump did not have sufficient liquid, and minimum liquid recirculation was no longer guaranteed. After the pump was running troublefree over a longer period, the outlet pressure began to vary with increased pulsations, and then dropped to a low value. At that time, the flow had totally collapsed. While the flow was leveled almost at zero until the unit was shut down, the outlet pressure slowly recovered and reached the initial value. Due to lack of flow, the pump heated up as a result

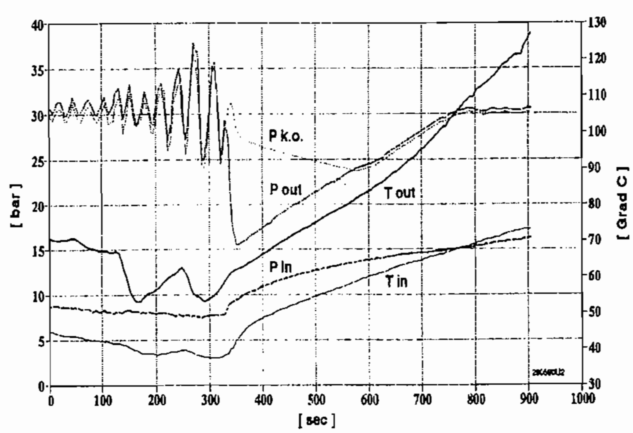

Figure 10. Field Test—Illustration of Pressures and Temperatures during a Time Period—"Breakdown Point" Recordings.

of insufficient heat transportation. As a result of the high outlet temperature, the unit was shut down.

EVALUATION

These tests show the suitability of the screw pump design for multiphase pumping.

A long time running test was planned as a field test in Tunesia. The pump was expected to run for half a year without any break and deliver a crude oil/gas mixture directly on the well. This objective has not been reached, since problems with the mechanical seals have stopped the operation several times. A running time of only about 1000 hr has been reached.

Statements about wear are not possible without reservation, as during this short running time, no wear inside the pump, due to sand for instance, have appeared.

A screw pump is able to deliver multiphase mixtures with a gas fraction of nearly 100 percent. For this running condition, the heat production is the highest, and the heat transport of the liquid phase is the lowest. After a certain running point, flow capacity and pressure rise break down so an overheating of the pump is possible. This is the reason a maximum gas fraction of 95 percent has been defined for these multiphase pumps.

When a pump is installed directly at the well, the operator cannot guarantee that the gas ratio will stay under 95 percent. Therefore, it is necessary to connect a minimum liquid injection for injecting through a minimum of 5 percent of liquid directly into the pump. This liquid comes from a separator down stream the pump. An additional liquid tank is not required.

As a result of all these tests, the screw pump design is not only suitable for handling multiphase flow, but is also approved for practical application on the well. The higher loads and stresses for multiphase pumping due to e.g., the parabolic pressure profile along the screws, the compression heat and instationary loads like slug and gas pulsation have to be considered for the pump design.

These prototype tests show that the screw pump design has basic features for developing a complete subsea pump system.

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