NETZSCH Pumpen & Systeme

Progressing cavity pumps for pumping multiphase fluids in oil fields.

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Summary

The peak production rates of light crude oil have passed and the world consumption is increasing. To help keep the economy stable it is important to find alternative solutions to increase the production of heavy oil, extra heavy oil or bitumen. The requirements on pumps rise, because the environmental aspect becomes more important.

Crude oils with high viscosity (typically above 100 cP), and gravity lower than 22.3° API are classified as heavy oils. These crudes generally require special producing techniques to overcome their high viscosity.

Whilst the industries main focus for increasing production from heavy oil fields is focusing on productions techniques such as Steam Assisted Gravity Drain (SAGD), Cyclic Steam Injection (CSI) and Vapor Recovery, the need and demand for solutions for flow assurance are of vital importance to the industry.

For heavy oil and extra heavy oil the use of positive displacement pumps which are able to handle fluids with high viscosity are required. The well streams are a combination of crude oil, water, gas and sand. For each region and reservoir, the proportions of the oil, water, gas and sand will vary. For economic, environment and facilities management perspectives, it can be a distinct advantage to transfer the complete well stream to gathering and processing facilities rather than separate at the well site. The selected pump system should be reliable, safe and able to handle the variations in fluid composition and process conditions. ***<u>The Progressing Cavity Pump (PCP) is able to fulfill these requirements and is a good selection for multiphase fluid transfer. In comparison to other pumping systems the PCP is an attractive cost effective solution.</u>***

The heavy oil regions in the world are illustrated below. The different regions in the world present equipment suppliers with various challenges for equipment selection and design. Some of these challenges will be discussed in this paper with a look into examples of successfully installed applications.

This paper sets out to highlight some of the technical challenges multiphase pump designs face and how the solutions and experience can be applied smartly to deliver reliable cost effective alternatives to conventional oilfield in-field design.

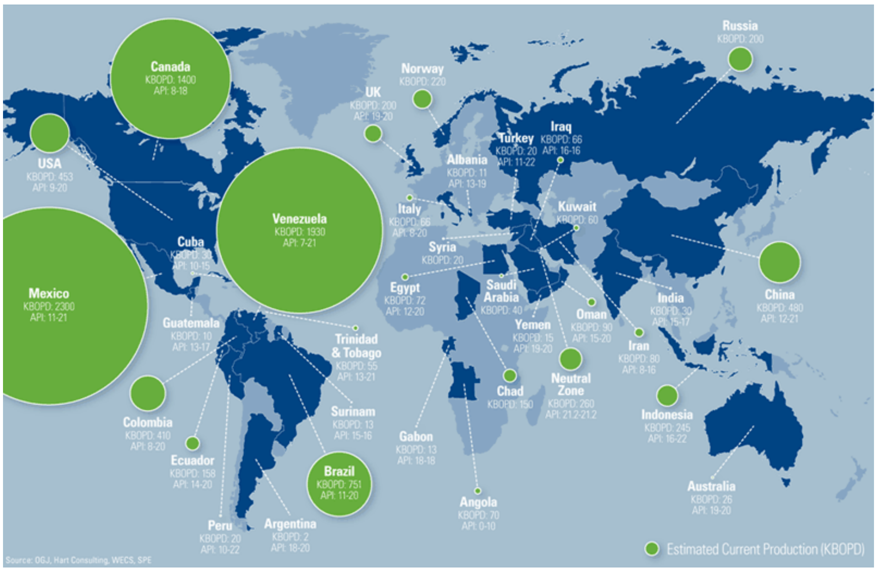


Figure 1: Heavy oil regions of the world

Progressive cavity pumps for pumping multiphase liquids in oilfields

The development of advantaged techniques to stimulate reservoirs has been the focus of recent years to increase production rates. With almost all techniques, the need for flow assurances and surface transport techniques are still an essential part of successful operation of the oil production network. Selection of the field equipment such as pumps to transport multiphase fluids is important.

Multiphase fluids consisting of oil, water, gas and formation solids such as sand in traditional field developments will typically free flow to gathering stations and through surface lines pushed by the natural formation pressure.

Heavy oil and Extra Heavy oil pose particular challenges for flow through pipe lines because of the increased viscosities resulting in high friction losses.

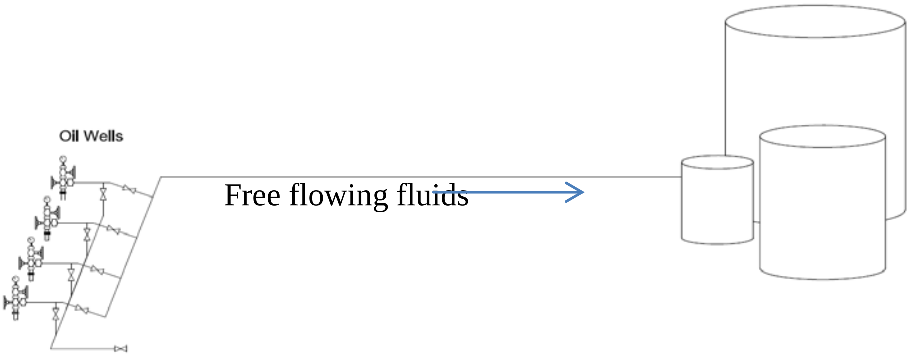


Figure 2: Well to Gathering station > free flow

Typical production model. The flow assurance aspect is critical for carefully managing production rates. Flow line resistance can have a strong influence on the production rates and for heavy oil regions becomes key factor in deciding the specific production philosophy.

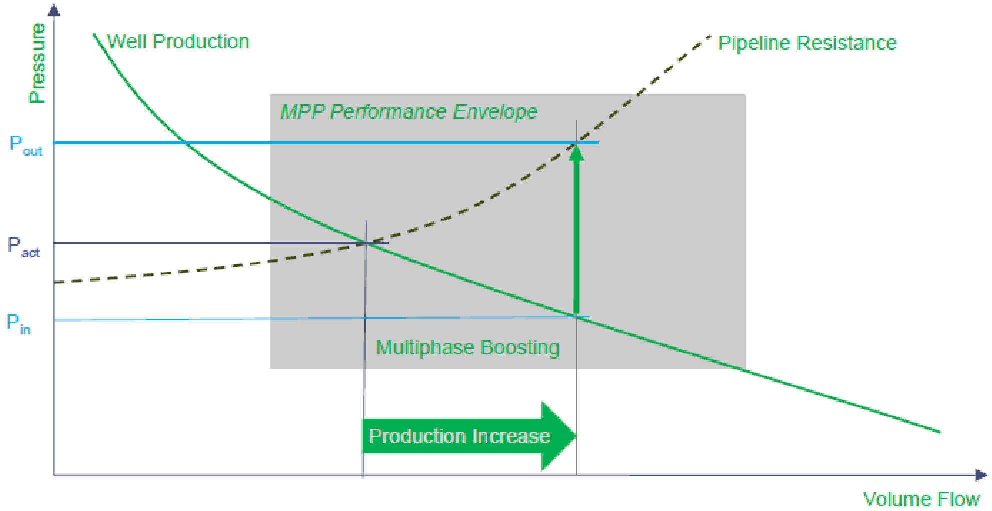


Figure 3: Business model > multiphase flow

A simple application of a multiphase pump is to apply it at the well head to simply boost the well flow to gathering and processing stations. The multiphase pumping is quite simply a means of adding energy to the unprocessed well fluids which enables the liquid/gas mixture to be transported over long distances without the need for prior separation.

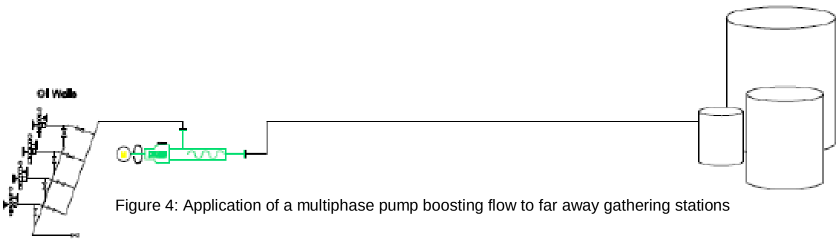


Figure 4: Application of a multiphase pump boosting flow to far away gathering stations

Options for in-field development are for separation either close to or at the well site. This is not always possible and requires significant infrastructure and investment to set up. Investment costs of facilities are significantly increased by the complexity of the extreme environmental conditions, such as the cold temperatures that Heavy oil field locations quite often seem to exist in.

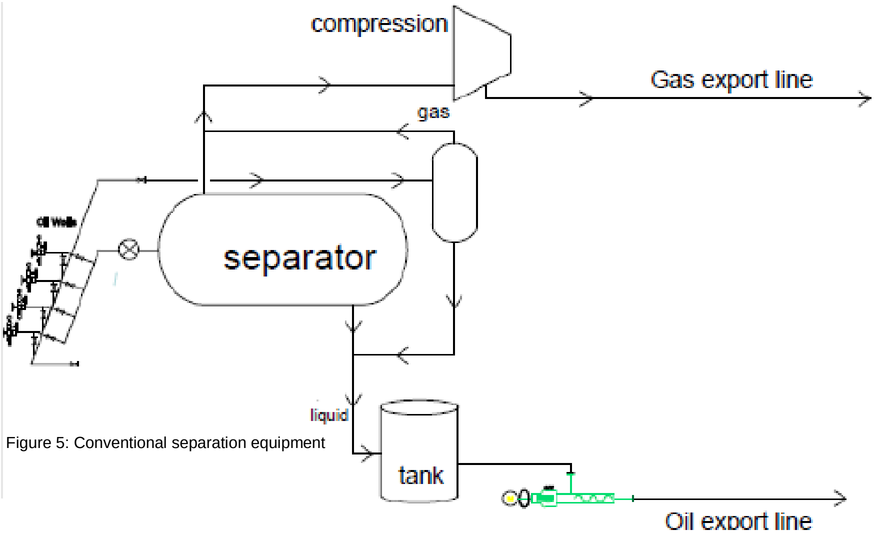


Figure 5: Conventional separation equipment

A simplified comparison of the two operating scenaerio's is shown in the below table.

ITEM	Conventional separation	Multiphase pump
LIST OF PROCESS EQUIPMENT	-2-phase Prod. Separator -2-phase Vertical Surge Vessel -Crude Oil Transfer Pump -Export LP Compressor -LP Compressor Suction Scrubber -LP Compressor After-cooler	- Multiphase Pump -Pump control system -Optional Seal Oil & Seal System
LIST OF UTILITIES PACKAGE	- Instrument Air Packages (Air Compressor/Dryer/Receiver) - Diesel Generator	- Instrument Air Packages (Air Compressor/Dryer/Receiver) - Diesel Generator
ENVIRONMENTAL CONCERN	- Yes	-No
	Continuous venting/flaring from LP Prod. Separator, Vent PCV and amount of gas venting/flaring is significant during compressor shutdown).	(Handling gas in closed system)
OPERABILITY CONSIDERATION	- Require frequent monitoring	- Usually unmanned
FOOTPRINT	>100 m²	Can be as little 20 m²

Figure 6: Comparison, conventional separation versus multiphase pump

The two strong conclusions that can be drawn from the above are that the multiphase pumping choice in many scanrio's will always be a simple solution and that environmentally, the use of an enclosed system to handle gas with no or little need for gas venting to atmosphere is always a more desirable situation to have.
Pump designs which are located at the well head or on pump pads have to handle changing process conditions due to the variations in formation and well behaviour. This is especially the case as many multiphase pumps are deployed in depleting fields which have a tendency *to* demonstrate an unstable cycling behavior characterized by an active period (producing) followed by an inactive period. In addition to this, the unprocessed multiphase oil streams have entrained or free gas fractions in the high ninties at times. The pump equipment already has to cope with a lot. So when the concept of sporadic slugging is thrown into the equation, we have to understand how this affects the pump and how we can overcome the technical design and control challenges to ensure equipment delivered is reliable and efficient in ser-vice.

1) Transient(changing flow regime)
2) Liquid phasebstarts to collect at low points
3) Pressure starts to build up and gas is compressed. Pressure behind the slugs is beoming higher than the static head on the upstream side of the liquid P1 > P2
4) The gas pressure at P1 is enough to move the liquid column at 4. All the liquid column is pushed forward.
5) As the liquid slug is expelled into the upsream pipe or separator, the liquid in the mixed flow starts to fall back and the cycle starts again.

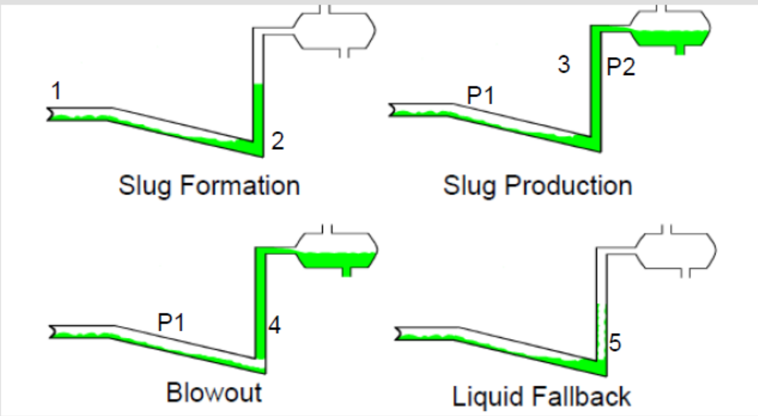


Figure 7: Slug generation explanation diagram

The slugging can result in only gas flow for periods of 15 minutes up to several hours. The pump has to be able to cope with those variations. During these times of gasslugging, it is likely that some liquid is carried with the gas as a liquid or a vapour. The worst case scenario for a pump is long duration of dry gas flows. This in effect is the dry running of the pump.

Installation challenges

We can start to see that multiphase pumps can give some beneficial options for planning and designing of in-field developments. We can also start to see some of the process challenges that would face installed multiphase pumps.

The challenges for installed equipment are not just process conditions and include environmental conditions as the most critical selection criteria. The below process and design conditions have to be addressed in any successful multiphase pump package:

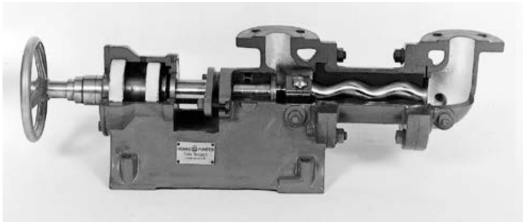
- Well shut in pressure is often high, >20 bar. Pump suction side design is for the 'shut in' pressure as well as the normal running pressure which are typically much lower.
- Varying inlet pressures have an effect of varying required displacement volumes. Variable speed drives pumps with a capability to vary the flow rate are required.
- Periods of gas slugging. A pump and system must be tolerant and be able to handle this.
- Installation is nearly always outside. Has to handle the extreme hot and cold of the geographical installation areas.

The Progressive Cavity Pump (PCP)

The PCP is an established industrial technology. It is proven to operate in a hugely wide variety of applications across many different types of industry. The pump type belongs to the positive displacement family and has been used since the 1950's when manufacturing techniques were finally available to realise the concept that Rene Moineau had patented in the 1930's. He had first conceptualised the design to be used as an aircraft gas compressor to help with high altitude flying. So it is rather appropriate after the majority of use for the PCP's made have been for liquid applications that more recently PCP's are again handling gases as they were originally concetualised to do.

Rene Moineau

Figure 8: Rene Moineau photograph



Original patented design

Figure 9: Original Rene Moineau patented design

Progressive cavity pump principle operation

The key components are a rotating rotor within a static stator. As the rotor turns within the stator, it forms cavities between the stator and the eccentrically rotating rotor. These cavities progress continuously in rotating motion along an axial direction.

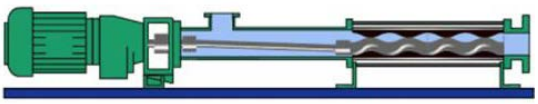


Figure 10 – Pump construction and rotor / stator position

The volume per cavity of moving medium is constant and continuous, thus there is no shearing, squeezing and pulsating action on the fluid during the transfer.

As the rotor is inserted into the stator it creates sequential cavities. When the rotor is rotating inside the stator these cavities, are moved axially, alternating the opening and closing of each one, progressively and uninterruptedly from the suction to discharge, causing the pumping action.

In other words, at the same time that one cavity reduces volumetrically another one increases at the same proportion from suction to discharge leading to a continuous and non-pulsating displacement flow (figure 3).

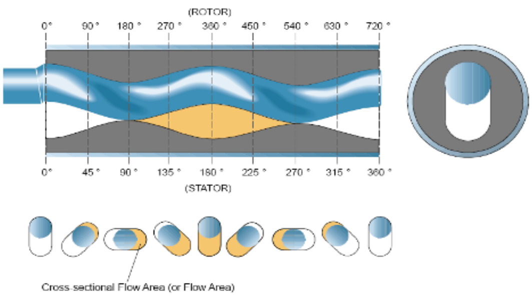
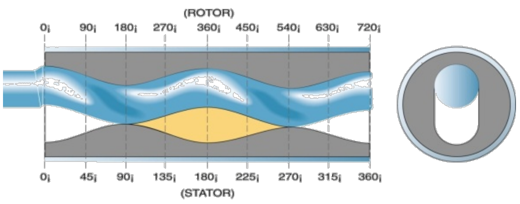


Figure 11 – Pump principle: progressing cavity

In elastomer stator designs, the pumping action is only achieved as a function of the compression fit between the rotor and stator that promotes a physical contact line along the rotor length. This is obtained by designing the rotor diameter (d_r) slightly greater than the inside diameter of the stator (d_s).

The pumped liquid lubricates and cool the compressed rubbing surfaces of the rotor and stator. Shaft speeds of generally <350 rpm and rotor effective tip speed 1.5 m/s, the interal velocities are generally considered as low velocities.

Flow rate:
Based on pump geometry the theoretical ***flow rate*** can be expressed by the cavity volume according with the following equation



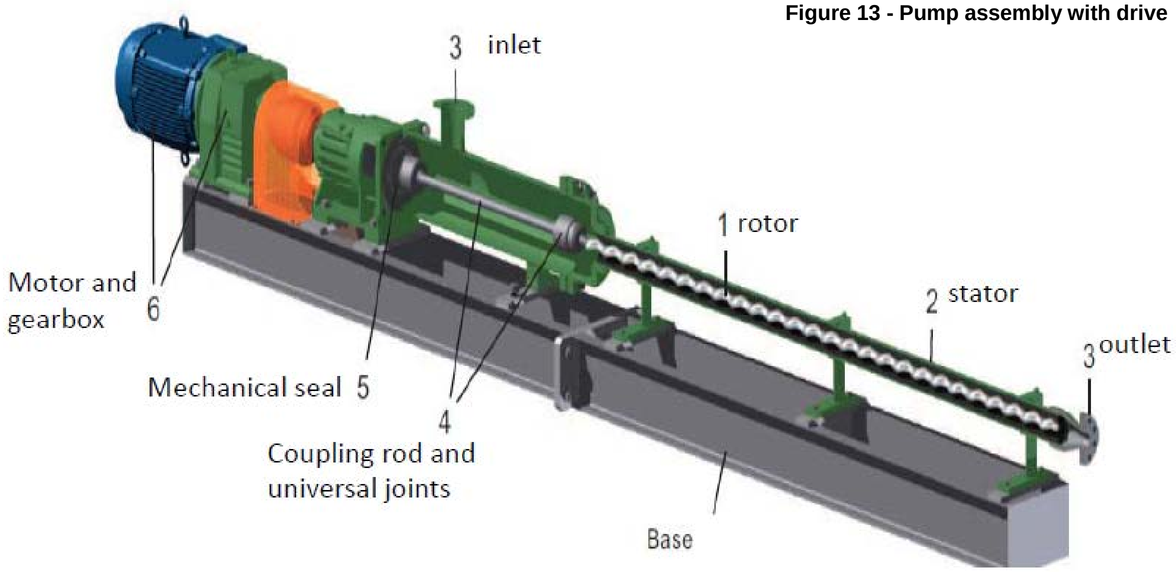
$$Q_{th} = \frac{240 * n * Dr * Pr * e}{10^6}$$

Figure 12 – Flow rate calculation

Where:

- Q_{th} = theoretical flow rate [liter/hour]
- n = pump speed [rpm-1]
- Dr = rotor minor diameter [mm]
- Pr = rotor pitch [mm]
- e = eccentricity [mm]

Figure 13 - Pump assembly with drive



For liquid applications the compression between the rotor and stator must be relatively tight to give the pump the optimum volumetric efficiency (VE). The compression fit must not be too high or the mechanical load on the rubber can become too much and the rubber material can tear. The compression fit becomes critical when the pump works in multiphase applications. A careful balance of wishing to achieve good VE and yet not having a compression fit that will encourage too much frictional heat during period of gas slugging. Higher viscosity crude oils have a positive influence on the pumps VE.

System design and integration philosophy

There is an essential need for good system integration to overcome the process challenges such as prolonged slugging. More than in any other application for progressive cavity pumps, the system needs to be orientated to work with the pumps to ensure pumps are not damaged during such times.

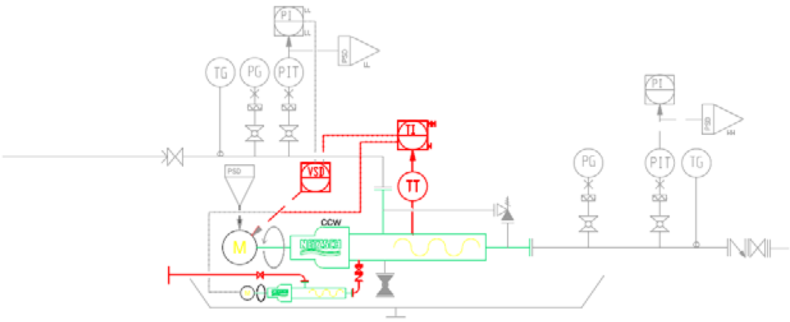


Figure 14: Control options

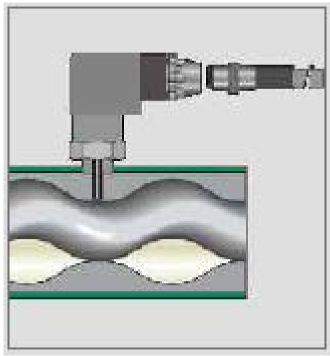


Figure 15: Dry run protection probe inserted in stator

Diagram showing a simple way of protecting against damage due to overheating caused by prolonged slugging or dry running. The dry run protection device embedded in the stator can detect a frictional heat build-up due to lack of lubrication from the pumped fluid. The control system can react by starting a lubrication pump. In the most simplest form, the dry run protection can just trip the pump until the temperature reduces. Depending on the geographical location, the wish for system complexity varies.


Figure 16: Multiphase pump with small lubrication injection pump

Small lubrication pump photographed injecting liquid into the suction side of the pump. Lubricant injected is collected process fluid or can be water or oil from separate sources.

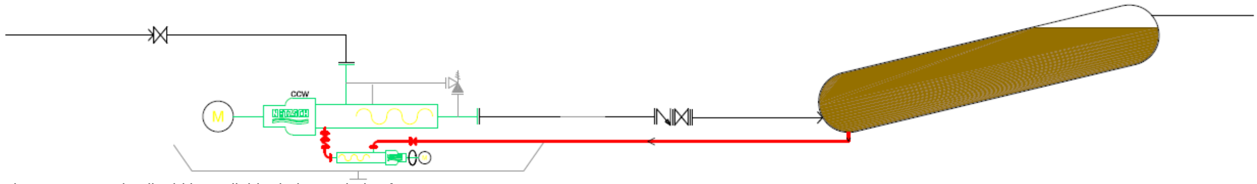


Figure 17: Ensuring liquid is available during periods of slugging

Reliably applied for Russian oilfields, a simple liquid collection tube and recycle line arrangement. Shown here as a pumped system which is in principle a reliable way of metering the flow back into the multiphase pump. Most often actually applied with recycle line flow controlled by a throttle valve which is set manually. The leakage collection device is sized to give a buffer of fluid to allow a 'reasonable' operating period which should match the experience of the field operator for slug flow typical duration times.

Figure 18: 1.Russia example of liquid collection tank and back flow line and manual valve

Figure 19: 2.Russia example of liquid collection tank and back flow line and manual valve

A working example of the leakage collection device applied in a Russian oilfield. The back flow throttle valve shown. An alternative can be a metering pump to return lubrication fluid to the suction of the pump system.

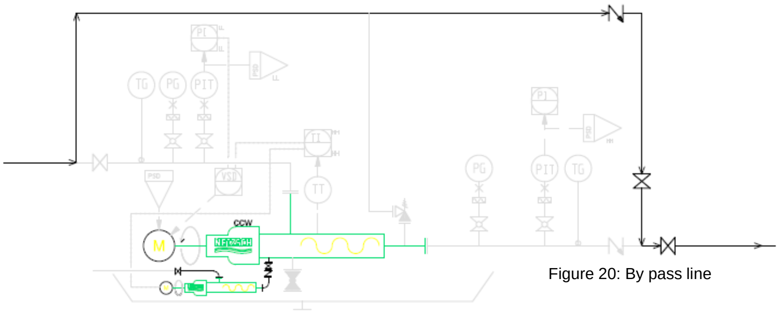


Figure 20: By pass line

The above diagram show a simple pump by pass loop which can allow gas to flow in case free flow is possible which mean that some production can be kept in the event of pumping system failure.

Environmental considerations

Protection from harsh environmental conditions is of course required for the pump equipment. The extreme cold gives more cause for concern than the extreme hot environmental temperatures.

Stator material/

The pump stator material is an elastomer and the flexible elastomeric properties are essential mechanical properties for the effective operation of the pump. The elastomeric properties reduce and the tear strength reduces as the temperature reduces and approaches the glass transition point and pieces of the stator material can become mechanical overworked and shear off. Elastomer receipes can be adjusted to increase the rebound rate and change the effect of reduced temperature. Alternative receipe for stator materials have been successfully and reliably applied in Russian oilfield where environment conditions get very cold.

Figure 21: A stator in good internal condition

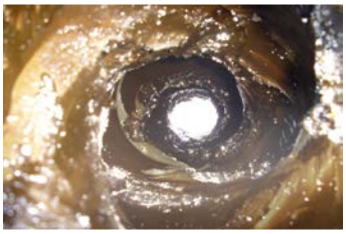


Figure 22: A stator that has suffered due to the glass transition point being reached. Chunks of material lost due to hysteresis failure.

Mechanical seals/
Mechanical seal selection is less critical than many would expect. It is of course essential that 'O' ring material is selected for the expected temperatures and especially the cold. The seal selection depends very much on the gas fraction and the expected risks that the field could operate in slugging conditions. For low gas fractions (<60%), the use of a single mechanical seal with either no quench (API plan 02) or a simple quench (plan 62) has proven successful. Where gas fractions are higher, the use of higher integrity solutions can be considered such as double mechanical seal and systems. The more simplistic the solution, the more reliable it is likely to be. Even for higher gas fractions, the use of tandem seals with simple atmospheric buffer fluid tanks is very effective and avoiding the need for more expensive and complex double seal and plan 53 systems. Careful consideration to the selection of the buffer or barrier fluid are important. Successful application of 75/25 glycol/water solutions and diesel have been used successfully with upgrades to fluids like Iso Propanol or Methanol.

PCP's are forgiving to mechanical seals as the shaft speeds are very low and stuffing box pressure are the same as the suction pressure. Only 1 shaft seal is required unlike twin screw pumps with 4 shaft seals.

Figure 23: A strong roof to keep the snow off.

Figure 24: Electrical trace heating and lagging keep the elastomer warm.

Figure 26: Pump is Sudan working since 2005. Sunshades protect critical equipment from direct sun and high black body temperatures.

The progressive cavity pumps as a reliable robust solution for handling multiphase liquids
The PCP equipment and package can be easily tailored to meet the demands of the multiphase oilfield locations. We have learned that elastomer selection is essential to deal with the cold conditions, but that there is significant experience and know how in this respect. The use of package process and control solutions is especially critical for multiphase applications. A PCP is simple to control with temperature increases easily detected and the pump responds well and quickly to control adjustments. The fluid handling qualities are extremely useful with the PCP handling low or very high viscosities. The PCP is also capable of handling gas fractions as high as 99% and can tolerate slugging conditions even without the need for control systems.

The successful operation of the PCP technology in multiphase applications will be due to a strong product line and careful selection of materials based on local application knowledge of our field teams in strong cooperation with customer's needs.

Bibliographic details

OGJ, Hart Consulting, WECS, SPE
TPoddar, GM– Engineering, On Behalf of OPE(M) , KL

Figures 2, 4 – 26, reference: NETZSCH Pumpen & Systeme GmbH
Figure 1, reference: OGJ, Hart Consulting, WECS, SPE
Figure 3, reference: BP p.l.c.

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