Multiphase Pumping and Measuring Technologies as an Alternative to Conventional Production.

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ABSTRACT

Nowadays the low oil prices in an increasingly competitive world, has forced the oil companies to look for alternatives that allow them to obtain cost-effective solutions with the smallest investment. That is why multiphase pumping technology continues gaining space in recent years, as it allows replacing the conventional production scheme, which includes a large number of equipment (pumps, tanks, flares and compressors) and multiple pipelines to transport the water, the gas and the crude oil separately from a flow station to a Central processing facility (CPF). With the implementation of the multiphase pump (MPP) a single technology can be used to transport all the production in only one pipeline to the CPF where it can be separated and treated properly.

Additionally, MPP technology can be implemented to extend marginal field's lifetime and increase its production by reducing the wellhead pressure. For these particular applications, simple but highly reliable pumps and systems have been developed.

Twin-screw pumps (TSP) are the most used technology for multiphase applications, because they are robust and reliable equipment, which also allows combining a large number of materials according to the application.

An additional advantage of TSP is that maintenance can be done on site; our pump supplier is capable of supplying systems with internal cartridges, which allows maintenance in just couple of hours without disconnecting the equipment from the suction or discharge pipe.

All these advantages of multiphase technology have been proven for more than 25 years by companies like Chevron, Shell, Saudi Aramco, PDVSA, among others, and allow us to affirm the following:

- Reduction of CAPEX and OPEX.
- Increased production by reducing wellhead pressure.
- Reduction of the footprint between 30 and 60%.
- Recovery of marginal or declining fields.

There is a natural and strong synergy of Multiphase Flow Meters (MPFM) combined with MPP systems, and the benefits in production optimization that can bring to conventional oil producers. Thanks to the evolution of the MPFM technologies, reaching maturity and commercial feasibility in the present time is possible, becoming an effective and flexible alternative for well testing and performance monitoring.

KEYWORDS

Multiphase flow, multiphase pump, multiphase flow meter.

INTRODUCTION

Multiphase pumping technology allow the transportation of unstable fluids coming from the wells as crude oil, associated gas, produced water, which can also contain sand, wax or other particles, without prior separation. Considering the current oil prices, this technology, which have been used for over 25 years, have become a cost-effective alternative for upstream applications, as new field development and production of marginal fields.

MPP is often compared to a conventional system consisting of several equipment and required pipelines to transport separated gas and liquids. By contrast, an MPP installation is simpler, consisting of the MPP itself and a single production pipeline to transfer the gas and liquids together.

Twin screw pumps are the most used technology for multiphase boosting applications. The principle of operation and its main design characteristics makes this kind of pump superior and reliable compared to other technologies.

Similarly, in-line multiphase meters are alternatives to the conventional method for multiphase flow measurement, as test separators. This relatively new technology have been used and improved for several years and today is a common and reliable technology to be used to measure producing wells. There is a new multiphase flow meter technology which main principle of measurement is magnetic resonance, and is the only technology available that uses a single principle to fully measure the variables involved in multiphase flow.

The combination of multiphase pumping and multiphase metering, allows the validation of measurements, effective diagnosis of the MPP system and the optimization of the production and operation of the field. MPPs boost pressure without the need to separate. MPFM measure produced fluid without the need to separate. Both technologies cost less to purchase and install, and additionally save space and weight. This paper highlights the benefits of Multiphase pumping and multiphase measurement technologies as alternatives to conventional production schemes, and the possibility to have these two innovative, but proven technologies, together as one smart system solution.

ECONOMIC IMPACT OF MULTIPHASE BOOSTING

During the past 25 years, multiphase pumps have gained acceptance in oil field production. They have replaced conventional production equipment with their simple and more economical technology.

As shown in Figure 1, conventional system can consist of production separators, tanks, transfer pumps, flare system or a gas compressor, associated instrumentation, and at least two pipelines: one for the gas and another for the liquids. By contrast, as shown in Figure 2, an MPP installation is simpler, consisting of the MPP itself and a single production pipeline to transfer both, gas and liquids. MPPs can also be used for a well, or group of wells, with any kind of artificial lift or naturally flowing wells.

Figure 1. Typical Conventional Facilities for Crude Oil Production

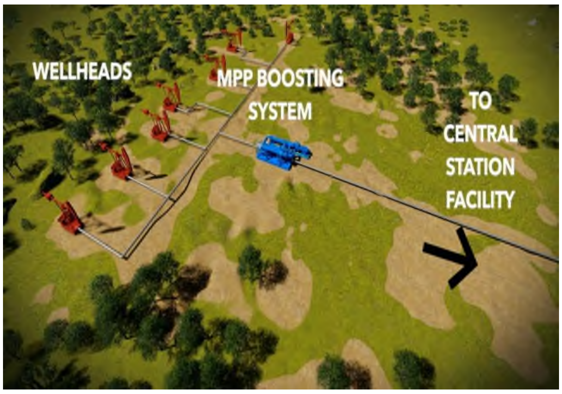

Figure 2. MPP System for crude Oil Production

Multiphase boosting helps to eliminate separators, compressors, individual pumping equipment, heaters, gas flares and separate flow lines, hence, improving production at lower costs. An additional benefit is the reduced environmental impact for onshore installations. The small footprint requires only a fraction of the space conventional equipment needs and the ability to handle gas in a closed system instead of venting and flaring guarantees low emissions and contributes to the increasing consciousness for our environment. Their ability to boost the well flow to remote centralized processing units and to handle very low inlet pressures make multiphase pumps an ideal tool to develop marginal fields. [1]

The cost of separation equipment installed at the wells site could exceed the revenues gained from production by far. Especially on aging fields the expenses for artificial lifting and field treatment can render a production site uneconomical. In old fields, the oil production drops and the water cut and gas-to-oil ratio (GOR) increases. While conventional production technology requires a constant modification of the field equipment to cope with the changing conditions, the large operating window of multiphase pumps allows a flexible reaction on changing well conditions. Already plugged and abandoned wells may return to production with multiphase pumping technology. The reduction of the wellhead pressure will allow the well to keep producing and the investment is paid off by the production very quickly. [2]

Figure 3 shows how the production can be increased using multiphase boosting. The blue line represents the curve of the well; the point of interception of it with the pipeline system curve (red line) is the point of production of the well and the wellhead pressure (P1, Q1). When a multiphase pump is added to the system, the energy necessary to overcome the loses of the pipeline, is provided by the MPP, thus the wellhead pressure is reduced. The wellhead pressure will be then the suction pressure of the pump (P2); this could be matched to the optimum producing pressure of the well. The discharge pressure of the pump will be the interception of the pump curve (approximately a straight vertical line) with the system curve (P). In consequence, the production is increased from Q1 to Q2. The use of multiphase pumping allows the reduction and maintenance of wellhead pressure as close as possible to the optimum production.

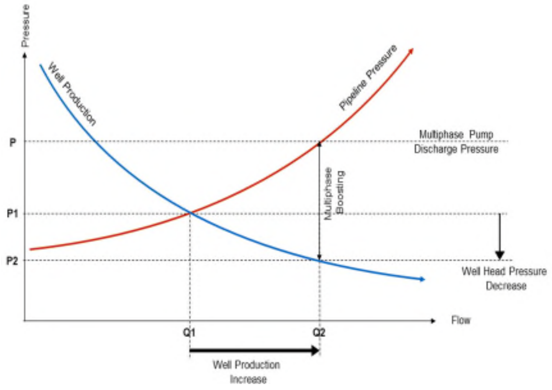

Figure 3. Well production increase due to multiphase boosting

For new Facilities, In most of the cases, MPP is less expensive than a conventional system, in that the MPP costs approximately 70 percent less, occupies approximately 25 percent less area, and weighs approximately 25 percent fewer pounds.

The majority of all multiphase pumps supplied worldwide are of the twin-screw type, about 800 in total. They can handle considerably high flow rates and pressures at a high gas volume fraction (GVF) and tolerate fluctuations. Additionally, longer gas slugs can be expected with marginal field applications. In order to maintain internal sealing for the compression of the gas phase, a small quantity of liquid must be provided during the entire operation.

MULTIPHASE TWIN SCREW PUMPS

Two rotors are positioned side by side in the horizontal plane of the MPP liner. There is a clearance between the screws and also between the screws and the liner. When the multiphase flow enters the MPP inlet, it is internally split to opposing ends of the rotor set. As the rotors turn, the multiphase flow is axially displaced through the screw cavities from opposing ends of the screws toward the center, and then pushed out through the MPP discharge.

When the multiphase flow enters the first pumping chamber of the MPP, liquids (both water and hydrocarbons) are forced to the screw profile's outer diameter by centrifugal forces. This seals off the pumping chambers traps the gases and moves them axially through the first few pumping chambers. In the final few pumping chambers, the pipeline back pressure forces liquid to flow or "slip" from the discharge chamber to suction chamber. It is this "slip" liquid that actually performs the compression work. The MPP is not creating pressure. It simply pushes the mixed flow against the pipeline back pressure, as if it were an infinite piston stroke.

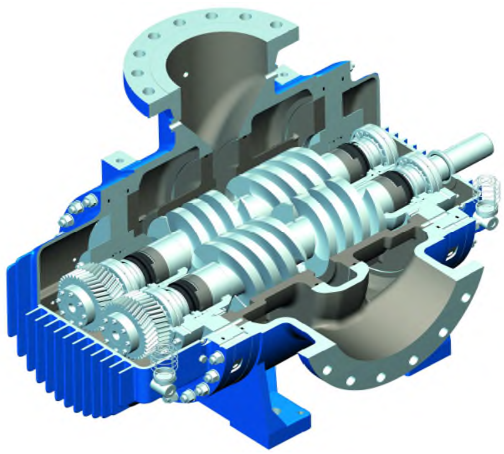

Figure 4. Internal view of a twin screw pump (courtesy of Klaus Union GmbH & Co. KG)

When selecting MPPs, the deciding factor for their size is the total liquid and gas volumes at inlet pressure and inlet temperature. This total volume is expressed in terms of total Barrels per Day Equivalent (bpde). The total actual bpde is calculated by converting the gas volume into barrels at actual conditions (see equation (1)) and then adding that value to the liquid volume (see equation (2)).

$$Q_{gas} = Q_{gas,std} * \left(\frac{14{,}7\ psia}{P_{1,abs}}\right)\left(\frac{T_{1,°F} + 459{,}67}{518{,}67}\right) * 0{,}178 \quad (1)$$

$$Q_{eq} = Q_{gas} + Q_{oil} + Q_{water} \quad (2)$$

Q_{gas} = *Gas Flow at Inlet Conditions (bpd)*
$Q_{gas,std}$ = *Gas Flow at Standard Conditions (scfd)*
Q_{eq} = *Crude Oil (bpde)*
Q_{water} = *Water Flow (bpd)*
$T_{1,°F}$ = *Actual inlet temperature (°F)*
$P_{1,abs}$ =*Actual inlet pressure (psia)*

The gas volume is often referenced in terms of percent of Gas Volume Fraction or GVF. The GVF is an average value and not a continuous gas/liquid ratio. What is typical for multiphase flow is slugging, which means random intervals of 100% gas, 100% liquid and varying GVFs. Since the MPP relies on liquid to seal the pumping chambers and take away the heat of compression, some liquid from the multiphase flow must be trapped for recirculation back to the MPP suction, thus maintaining prime.

The MPP casing is typically constructed of fabricated or cast steel and the replaceable liners either ductile iron, stainless steel or cast carbon steel. Due to the potential for abrasive elements in the multiphase flow, you can also find the option of hardening the liner and surface of the main elements in contact with the pumped fluid. Various other alloys are also available depending on the pumped fluids.

MULTIPHASE FLOW MEASURING

There are two different ways to measure multiphase flows:

- Separation: This is the traditional approach and the technologies available are three and two-phase gravity separators, being the last the most likely to be used in the world. Separators work by exploiting the differences in fluid properties of the multiphase components. The outlet streams from the separator can then be measured using single phase meters [3]. Figure 5 shows a schematic arrangement of a conventional test separator.
- Multiphase flow meters (MPFM): Compared to test separators, multiphase flow meters (see schematic arrangement in Figure 6) are a relatively new technology. There are a number of different designs on the market but they all follow the principle of measuring the bulk flow rate of the multiphase mixture, calculating the individual phase fractions, and then using these to give the flow rates of the individual streams. [3]

A third category of meter is also possible and it results of the combination of elements of separation and MPFM techniques. However, for the purpose of this paper this type is considered as a subcategory of the separation method as it does not allow measuring the bulk flow rate of the multiphase mixture.

The separation technique (traditional approach) may encounter the following problems:

- Undersized separators lead to a reduction in residence time which leads to poorer separation. This can lead to liquid being carried over into the gas stream and/or gas being carried under to the liquid stream.
- Foams and emulsions are difficult to separate.
- In very viscous liquids, micro-bubbles can be held in solution and may not be separated out.
- Poor maintenance and calibration of reference flow meters and secondary instrumentation.

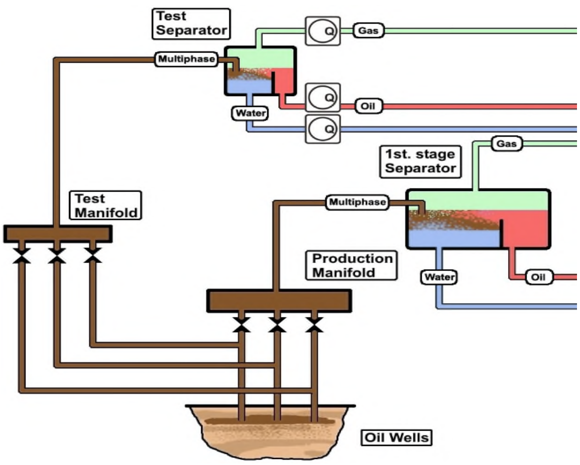

Figure 5. Conventional well testing using test separator [4].

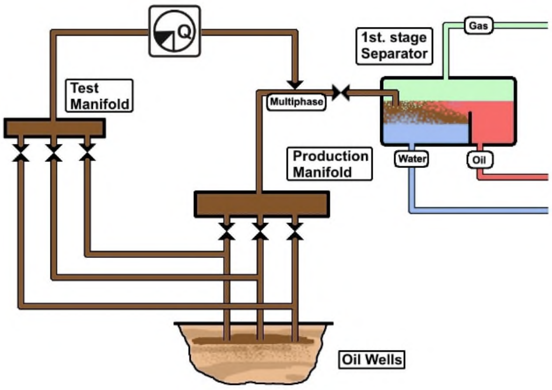

Figure 6. Multiphase meter replacing test separator and its meter [4]

MPFMs are an attractive alternative since it enables measurement of unprocessed well streams very close to the well. MPFMs can provide continuous monitoring of well performance and thereby better reservoir exploitation can be achieved.

MPFMs commonly employ a combination of two or more of the following measurement technologies and techniques:

- Electromagnetic measurement principles.
    - Microwave technology.
    - Capacitance.
    - Conductance.
- Gamma ray densitometry or spectroscopy.
- Neutron interrogation.
- Differential pressure using Venturi, V-cone or other restriction.
- Positive displacement.
- Ultrasonic.
- Cross-correlation of electromagnetic, radioactive, ultrasound signals (to calculate flow velocities).

The combination of these principles results in a complex model to determine the volumetric flow of the individual phases. None of these measurements by itself is suitable to measure multiphase flow for every phase distribution. Output from one measurement is needed as input to get the results of the other measurement tool. In this way, the error in the measurement builds up.

In addition, empirical relations and models are needed to derive multiphase flow rates from the measurement results. These empirical relations have a limited application range (normally only for the range in which they have been tested), and this adds to inaccuracy and unpredictable behavior.

In Table 1 the different measuring principles used in MPFMS are compared, the only technology available in the market that allows measuring the flow velocities as well as the water to liquid ratio and gas volume fraction, independently of the phase distribution, uses the magnetic resonance principle. The next section is dedicated to describe how this principle is used in multiphase flow measurement.

Table 1: Measuring principle for different MPFMS

Measuring Principle	Phase Velocities and volume flow	Phase fractions
Venturi Meter	Standard Venturi equations corrected or compensated (e.g. for gas fraction) to calculate the total mass flow rates based on measurement of the differential pressure over the venturi and knowledge of parameters like the density of the fluid. [4]	Gas fraction may be determined, given that information about the total mass flow rate or the total fluid density is made available by other means (e.g. gamma ray methods). [4] To determine the WLR, microwave technology electric impedance methods can be used.
Positive displacement meter	As part of a MPFM, a PD meter will usually measure the total volumetric multiphase flow rate	No suitable.
Gamma ray methods	A characteristic velocity measurement of the multiphase mixture by cross correlation	A single gamma densitometer can be used to measure the total multiphase mixture density. Other methods are necessary to measure WLR (e.g. electric impedance). A dual gamma densitometer with different energy levels can be used to calculate the gas fraction and water cut of the multiphase mixture
Electrical impedance methods (capacitance and conductance)	Velocity measurements by cross correlation. By careful selection of electrode designs one may identify velocities of the different phases. [4]	Component fraction determination based on measurement of capacitance or conductance. Permittivity and conductivity are electrical properties that will be different for each of the three components (oil/gas/water). The permittivity or conductivity of the mixture is therefore a measure of the fractions of the different components. Measurement of capacitance or conductance are limited to specific phase distributions
Microwave technology	A characteristic velocity measurement of the multiphase mixture by cross correlation	It can be used to measure WLR as it sees a high contrast between water and hydrocarbons due to the fact that the permittivity of water is high compared to that of both oil and gas. A microwave MPFM would typically also contain a gamma densitometer to obtain enough measurements to solve the system of equations.
Magnetic resonance	Convective decay method [5]	Magnetization build-up signal comparison. Crude oil magnetizes faster than water. [5]

MAGNETIC RESONANCE MULTIPHASE FLOW METER

The Magnetic resonance based multiphase flowmeter discussed in this paper is measuring both fraction and flow velocity of oil, water and gas separately. This is done by exploiting specific properties of hydrogen atoms which is present in oil, gas and water.

The nucleus of a hydrogen atom behaves as a tiny magnet in certain aspects. When hydrogen protons are exposed to a static magnetic field, their random geometrical orientation is changed towards an alignment with the direction of the external magnetic field. Additionally each proton carries out a precession movement around the direction of the external magnetic field. The frequency of that precession movement is at the Larmor frequency. [5; 6]

When excited by radio frequency pulses of exactly the Larmor frequency, the orientation of the atoms can be manipulated. The hydrogen atoms respond to the radio frequency pulses by sending back weak echo signals at the same (Larmor) frequency. [6]

By measuring the amplitude of the echoes and by measuring the decay of the signal, the flow rate of oil, gas and water can be determined. [6]

The magnetic resonance technology enables a very elegant and direct way of measuring multiphase flow without the need of nuclear source nor external device for calibration or parametrization, and has no limitations in terms of WLR nor GVF. In Table 1 the different measuring principles used in MPFMS are compared, and it can be seen that this is the only principle capable of measuring all the variables related to multiphase flow which are phase velocities and phase fractions. All other MPFMs in the market, use a combination of two or more of the described principles to be able to determine the required variables.

The improved and industrialized design of the MR multiphase flowmeter has been tested at four different flow loops over a wide range of conditions of gas and liquid flow rates, GVF, WLR, pressure, salinity and viscosity. [5]

For all the test points, the error associated with the gas flow measurement is less than 10% of the MV. For the error associated with the liquid flow measurement, all test points are within 5% of the MV. An exception is the liquid measurement at a GVF of 99%. The uncertainty in the quantification of the 1% liquid fraction flowing in the gas stream is 14.5% MV. When related to total volume flow this reading translates to an error of 0.145%, which is still good. [5]

CONCLUSIONS

The demand for oil and gas increases every year and there is no doubt that this source of energy will be used for many years to come. However, the disappearance of fields to be produced with conventional techniques, the existence of important reservoir located far away from existing facilities and limited access, the cost of operating marginal fields, the environmental regulations to follow, current oil price; all result in a difficult challenge for producers to develop and maintain commercial oil fields. Thus, it is necessary to implement smart and cost-effective solutions. MPP technology is no longer an unproven technology, even when is new for some producers. Some remarkable benefits of using multiphase boosting deserve to be summarized and considered during the economical evaluation to extend the lifetime of producing fields and for new field development:

Production:

- Reducing the backpressure on the well(s) or taking suction from an oil well(s) to increase the production and extend the life of the well(s).
- Extended life of mature wells; boosting the low-pressure wells into manifold.
- Increasing production rate by tie in of new and marginal fields.
- Bringing abandoned wells back to life.
- Producing marginal fields.
- Overcoming the static pressure from a deep subsea well.

Environmental:

- Eliminating the need for flaring gas at the well, reducing emissions.
- Eliminating local water storage, disposal and transport.
- Increasingly safer environment, reducing of facilities complexity and space.

Capital:

- Eliminating the need of separation equipment at the well.
- Eliminating gas flare system, compressor and dual pipeline arrangement for transfer of separated gas.
- Transporting production several miles through one pipeline.
- Reducing of topside/offshore equipment weight and space.
- Ability to move the multiphase pumping system from well site to well site, potentially reducing the number of required systems.
- Producing subsea reservoirs with a more cost effective installation.
- Increasing the lifetime of downhole equipment.

In reference to multiphase flow meters, most of the technologies combine several principles trough complex relations to measure both fraction and flow velocity of oil, water and gas. However, recently a new development has been introduced to the market that uses a single principle which is magnetic resonance. Although the technology is new, prototypes and industrialized designs have been already tested. The results show that for GVF up to 99% the error associated with the gas flow measurement is less than 10% of the MV and for the liquid flow measurement is equal or less than 5% of the MV.

If both technologies, multiphase boosting and measurement, are used in synergy it will allow effective diagnostic of the MPP system and production optimization. Having these two innovative, but proven technologies, together as one smart system as the example shown in figure 7, provides to oil producers a reliable and cost-effective solution.

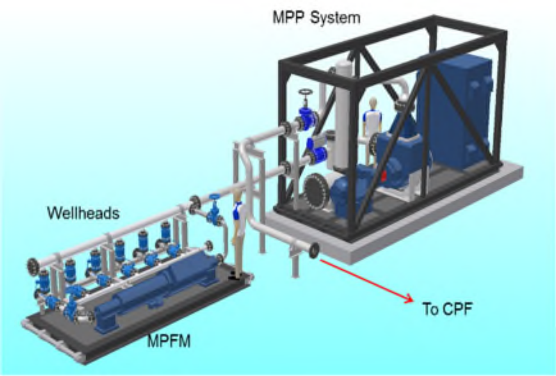

Figure 7. Smart system combining MPP and MPFM.

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AREA OF EXPERTISE

Multiphase Pumping; Oil & Gas Industry

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Patricia Nuñez Tucker, Venezuelan, Chemical Engineer graduated from Universidad Simón Bolívar, with 17 years of experience in the Oil and Gas Industry.

In 2000, her career began at Petrolera Ameriven, S.A. "Proyecto Hamaca", (joint venture between ConocoPhillips - Chevron Texaco - PDVSA), nowadays known as PDVSA PETROPIAR, S.A., where she was the Process Engineer Team Leader in the Project Management Department and ended as Project Engineer in the Production Facilities Department.

In 2005, she started working at C.T.G. 21, C. A., a Venezuelan Company that was exclusive representative of Bornemann Pumps. As Mechanical Equipment Manager she participated in the commissioning and startup of MELEM I, the first Multiphase Station for the Venezuelan Oil Company (PDVSA) and developed Dobokubi and Bare Este Project, the biggest project on shore for Multiphase Pumping Stations.

In 2010, as the New Business Manager, she was in charge of developing new opportunities for Venezuela, Colombia and Caribbean.

Since 2015, as sales director of Inglotech GmbH, she is responsible of new markets and new equipment and systems developments. The markets include, but are not limited to, Venezuela, Europe, Asia and Middle East.

More than 70% of the crude oil reserves in Venezuela are heavy and extra-heavy crude oil, especially in the Eastern part of the country, where she concentrated its work as Process and Production Facilities Engineer.

In recent years, with the experienced gain working with different Multiphase Pumps suppliers, she has had the opportunity to provide technical assessment and actively participate in the development of oil fields with multiphase pumping and measurement technologies, among other projects of great importance in Venezuela and other countries.

NUMBER OF PAPERS PUBLISHED IN JOURNALS:

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