Universal Journal of Aerodynamics **7 (2019), 1-8**
www.papersciences.com

New Aspects of Modern Multiphase Pumps for Wet Gas Compression in Petroleum Engineering by improving the Aerodynamic Behavior

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Abstract
A modern Multiphase Compressor Method is further improved for wet gas compression in petroleum & gas engineering. Usually the fluid to be handled by the wells operate under wet gas conditions, where the fluid contains a mixture of liquid and gaseous phases. So, the proposed multiphase pumps have the ability to handle directly the wet gas without the need for separation equipment, which is very attractive from an economic view, as it reduces very much the weight, size and cost of the gas compression devices. Thus, the growing interest in wet gas compression in petroleum engineering leads to a general request for accurate performance calculation procedures and proper measurement techniques for multiphase flow metering in compressors. According to the proposed sophisticated method the multiphase pumps used for wet gas compression will be extended to modern forms. Besides, the efficiency and operating range of a compressor are constrained by aerodynamic instabilities. Consequently, the aerodynamic behavior of such multiphase pumps is studied and investigated. In such way, by the present research the different flow phenomena associated with compressor instability are investigated and presented recommendations for suitable instrumentation and measuring techniques. Thus, with the high demand of wet gas compression system, it is necessary to model the performance of twin-screw multiphase pump with wet gas conditions and provide solutions to increase both efficiency and reliability. Hence, a calculation model is studied to evaluate the suitable form of the multiphase compressor and to find the proper parameters for its operation. Thus, the major petroleum companies must be ready to face the new challenges of using the "next generation" multiphase pumps for wet gas compression.

Key Word and Phrases
Wet Gas Compression, Next Generation Multiphase Pumps, Multiphase Compressors, Petroleum and Gas, Gas Processing, Polytropic Compression.

1. Introduction

Generally, the typical production system of petroleum & gas reservoir consists of a separator, a liquid pump, a liquid meter, a gas meter, a gas compressor and buffer tank. Then the produced fluid from the well, which is normally petroleum and gas mixture, is first separated and then boosted by liquid pump and gas compressor, respectively and transferred through separate pipelines to the processing facility a long distance away. In addition, sometimes a test separator is needed for well testing and flow rate measurement. Also, different from the conventional production system, the multiphase production system eliminates the use of separator. So, the full well stream are boosted directly and transported through a single pipeline to the processing facility without separation. The multiphase pump replaces both the single phase liquid pump and the gas compressor. Besides, test separator and manifold are replaced by multiphase meter and multiport valve.

The production of each well can be selected by multiport valve through multiphase meter for well testing and measurement. Then by eliminating the above equipments, multiphase production system can save about 30% in investment for equal flow station capability and significantly reduce the footprint of flow station, which is a big advantage for offshore application. Consequently, in several cases, the application of multiphase production system can eliminate gas flaring and gives "zero" emission.

Multiphase production system provides further option for subsea production system. The dramatic reduction of development cost and small footprint are the biggest advantages driving the increasing use of subsea multiphase pumping system. In addition, multiphase pump can lower the subsea wellhead pressure and improve the hydrocarbon recovery. It also provides additional energy to boost the full well steam through long-distance pipeline, which make the development of remote marginal and deepwater fields more economical. With the multiphase pumping technologies being approved both on-shore and on the topside of platform, subsea is the next big challenge.

In general, a very big challenge for multiphase pumping technologies is wet gas compression. So, “wet gas” is natural gas containing significant amounts of liquefiable hydrocarbons. But there is no standard of what percentage liquid phase should be in wet gas. Typically, The Gas Volume Fraction (GVF) or gas quality is used to define the amount of liquid in wet gas. Since most of the pump manufacturers recommend that the average GVF at the inlet of the pump should be limited to 95% to ensure the pump operability, for the purpose of research, GVF of 95% and above will be considered as wet gas compression.

Beyond the above, interest in the deployment of wet gas compressors is very much increasing as companies seek for economical way to improve recovery of gas reservoirs both onshore and offshore. High gas price is also one of the reasons driving the application of wet gas compression on stranded gas reservoir.

On the contrary, multiphase flows in compressors have complicated characteristics including interfacial interactions and relative movement between phases. Determination of actual fluid and thermodynamic properties is a challenge in multiphase compressors due to this phase exchange. The instrumentation and measurement techniques employed for single-phase compression may have insufficient accuracy due to the liquid introduced in wet gas compression.

Consequently, wet gas compression technology is of great importance to the petroleum and gas industry for boosting of unprocessed well stream and to reduce investment costs related to equipment and personnel. The growing interest in wet gas compression leads to a general request for accurate performance calculation procedures and proper measurement techniques for multiphase flow metering in compressors. Furthermore, the efficiency and operating range of a wet gas compressor are constrained by aerodynamic instabilities. Hence, different flow phenomena are associated with compressor instability and so recommendations should be presented for suitable instrumentation and measuring techniques. Moreover, visualization techniques can be evaluated to determine the suitability for multiphase compressors.

Furthermore, the energy demand for oil and gas will increase up to 2030 by 50-60%, as it is increasing worldwide yearly at a pace of 1.5 to 2.0%. Thus, for the on-shore and off-shore petroleum and gas reserves exploration was proposed by E.G.Ladopoulos [1]-[15] the new theory of *"Non-linear Real-Time Expert Seismology"*. According to the above modern technology a non-linear 3-D elastic waves real - time expert system was proposed for the exploration of petroleum and gas resources all over the world, including the off-shore petroleum reserves, of the seas and oceans in the whole world in deep waters ranging from 300 to 3000 m, or even much more. Furthermore, the above technology is the best device for searching the on-shore and off-shore hydrocarbon resources in very deep depths, even approaching 20,000 m or 30,000 m.

Over the past years, several studies have been published on wet gas compression by using multiphase pumps [16] – [33]. Thus, for the new and the existing oilfields there is an absolute need for the improvement of the existing methods of wet gas compression. For this reason, by the present paper the *“Next Generation Multiphase Pumps”* are proposed and studied. According to the above modern method the well known multiphase pumps used for wet gas compression will be extended to next generation forms. Hence, an easiest method is proposed for the quicker compression of the wet gas in each new oilfield. The new method has many benefits beyond the existing multiphase pumps methods, as the wet gas production for each well is increased very much and so there no limits for the oil well production any more.

From the above described analysis it is clear the evidence of the applicability of the new method of *“Wet Gas Compression by New Generation Multiphase Pumps”*. Moreover, its novelty, as it is based mostly on a theoretical and very sophisticated model and not to practical tools like the existing methods. The new method will be therefore the best technology for wet gas compression for a single oil well. In addition, the aerodynamic behavior of such multiphase pumps is studied and improved.

2. Improvements by Gas Analysis of a Single Phase

Generally, a compressor has as primary variables of interest the pressure rise produced, the amount of flow delivered and the required power. Additionally, the thermodynamic evaluation of the centrifugal compressors is based on the polytropic procedure. Thus, an accurate method for performance calculations is important to ensure a correct evaluation of the centrifugal compressor.

Identical compressors operating at different suction pressures will have variation in isentropic efficiencies due to the deviation in the isobars. The above thermodynamic characteristic is taken into account when assuming a polytropic process. Then, the deduction of the polytropic head is based on the assumption of a constant polytropic exponent along the compression path.

Hence, the polytropic compression process for the centrifugal compressors is the best device for handling a wide range of gases used in petroleum & gas industry. At high pressures and temperatures, the ideal gas behavior is not valid due to changes in fluid properties. The ASME PTC 10 [34] has implemented the J.M.Schultz polytropic procedure [35] for thermodynamic performance evaluation of a compressor. Real gas behavior therefore is taken into account when utilizing the Schultz procedure.

The procedure by J.M. Schultz assumes a polytropic compression path based on averaged gas properties of inlet and outlet conditions. Schultz introduced a polytropic volume exponent, to account for changes in fluid properties. Then, the polytropic volume exponent is defined as a constant in solving the polytropic head equation due to assumed negligible variation.

The polytropic head coefficient μ_p is given by the following formula: [34]

$$\mu_p = \frac{H_p}{u^2} \tag{2.1}$$

where H_p *(m)* denotes the polytropic head and u *(m/sec)* the tangential velocity.

Additionally, in (2.1) the tangential velocity u is equal to:

$$u = \frac{\pi D N}{60} \tag{2.2}$$

with D *(m)* the impeller exit diameter and N *(rpm)* machine rotational speed.

Moreover, in (2.1) the polytropic head H_p is given as follows:

$$H_p = \frac{n}{n-1}(p_2 v_2 - p_1 v_1) \tag{2.3}$$

in which n denotes the polytropic volume exponent, p_2 *(Pa)* and v_2 (m^3/kg) are correspondingly the pressure and the specific volume of the machine discharge, while p_1 *(Pa)* and v_1 (m^3/kg) are correspondingly the pressure and the specific volume of the machine inlet.

In (2.3) the polytropic volume exponent n is equal to:

$$n = \frac{\ln\left(\frac{p_2}{p_1}\right)}{\ln\left(\frac{v_1}{v_2}\right)} \qquad (2.4)$$

Beyond the above, the flow coefficient ϕ can be given by the formula:

$$\phi = \frac{Q_1}{2\pi \frac{N}{60} D^3} \qquad (2.5)$$

where Q_1 $(m^3/\sec)$ is the actual volumetric flow.

Head *H* is referred to the specific work done by a compressor. The compressor actual head, as given by the following equation (2.6), describe the total change in enthalpy *h (J/kg)* for the compression process. The relationship between pressure, temperature and enthalpy are determined by utilizing an appropriate equation of state. The actual head remains constant independently of the given compression process:

$$H = h_2 - h_1 \qquad (2.6)$$

Furthermore, the polytropic efficiency η_p is defined as the relationship between polytropic and actual head as shown by the following equation (2.7):

$$\eta_p - \frac{H_p}{H} \qquad (2.7)$$

In addition, the power *P (*in *KW)* of the compressor is given by the following formula:

$$P = \frac{\gamma Q_1 H_p}{\eta_p \cdot \eta_m} \qquad (2.8)$$

where γ is the specific gravity of the liquid (KN/m^3) and η_m (usually 0.97÷0.985) is the mechanical power efficiency.

The above formulas are used for a single process gas. Hence, if the compressor inlet contains both gas and oil, which means wet gas, then the above formulas should be properly modified.

3. Improvements by Multi-Phase Wet Gas Analysis

If the compressor is working under wet gas, then there is no description by standards, as in the case of dry gas. However, the previous approach of single phase gas, can be applied for a multi-phase approach. Then, the previous mentioned formulas should be properly be changed, in order the multi-phase approach to be used.

For the case of a multi-phase compressor, the multiphase polytropic volume exponent n_{MP} is given as following:

$$n_{MP} = \frac{\ln\left(\frac{p_2}{p_1}\right)}{\ln\left(\frac{v_{MP1}}{v_{MP2}}\right)} \tag{3.1}$$

where v_{MP} denotes the multiphase specific volume (m^3 / kg).

Additionally, the multi-phase polytropic head $H_{p,MP}$ is given as follows:

$$H_{MP} = \frac{n_{MP}}{n_{MP} - 1}(p_2 v_{MP2} - p_1 v_{MP1}) \tag{3.2}$$

In (3.2) the multi-phase specific volume is base on an homogeneous equation:

$$v_{MP} = \frac{1}{GVF \cdot \rho_g + (1 - GVF)\rho_1} \tag{3.3}$$

with ρ_g the gas density (kg/m^3), ρ_1 the liquid density (kg/m^3) and GVF the gas-volume fraction defined as:

$$GVF = \frac{Q_g}{Q_g + Q_1} \tag{3.4}$$

in which Q_g denotes the gas flow $(m^3/\sec)$ and Q_1 the liquid flow.

4. New Generation Multi-Phase Wet Gas Analysis

Another approach could be proposed for the new generation multi-phase pump. Thus, a two-phase fluid model is proposed, where each phase is treated individually. Then, the polytropic head is equal to:

$$H_{MP} = x_1 \left(\frac{n}{n-1}\right) \frac{R_0}{M_{W_{g1}}} Z_1 T_1 \left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right] + (1 - x_1) v_{l1} (p_2 - p_1) \tag{4.1}$$

where R_0 denotes the universal gas constant, $M_{W_{g1}}$ is the molecular weight *(kg/kmol)*, Z_1 compressibility factor, T_1 the temperature $({}^o K)$ and x_1 is the fluid quality given by the next formula:

$$x_1 + \frac{\dot{m}_g}{\dot{m}_g + \dot{m}_l} \tag{4.2}$$

with $\dot{m}_g$ the gas mass flow *(kg/sec)* and $\dot{m}_l$ the liquid mass flow *(kg/sec)*.

Besides, the multi-phase head coefficient is equal to:

$$\mu_{MP} = GVF_1 \frac{v_{g1}}{v_{MP1}} \frac{H_{MP}}{u^2} \tag{4.3}$$

and the multi-phase flow coefficient is given by the following formula:

$$\phi_{MP} = \frac{Q_{tot1}}{GVF_1 \cdot 2\pi \frac{N}{60} D^3} \tag{4.4}$$

Finally, the power P_{MP} *(*in *KW)* of the multi-phase compressor is given by the following formula:

$$P_{MP} = \frac{\gamma Q_{tot1} H_{MP}}{\eta_{MP} \cdot \eta_m} \tag{4.5}$$

in which γ is the specific gravity of the liquid (KN/m^3) and η_m (usually 0.97÷0.985) is the mechanical power efficiency.

A description of the multi-phase wet gas compression is shown in Figure 1.

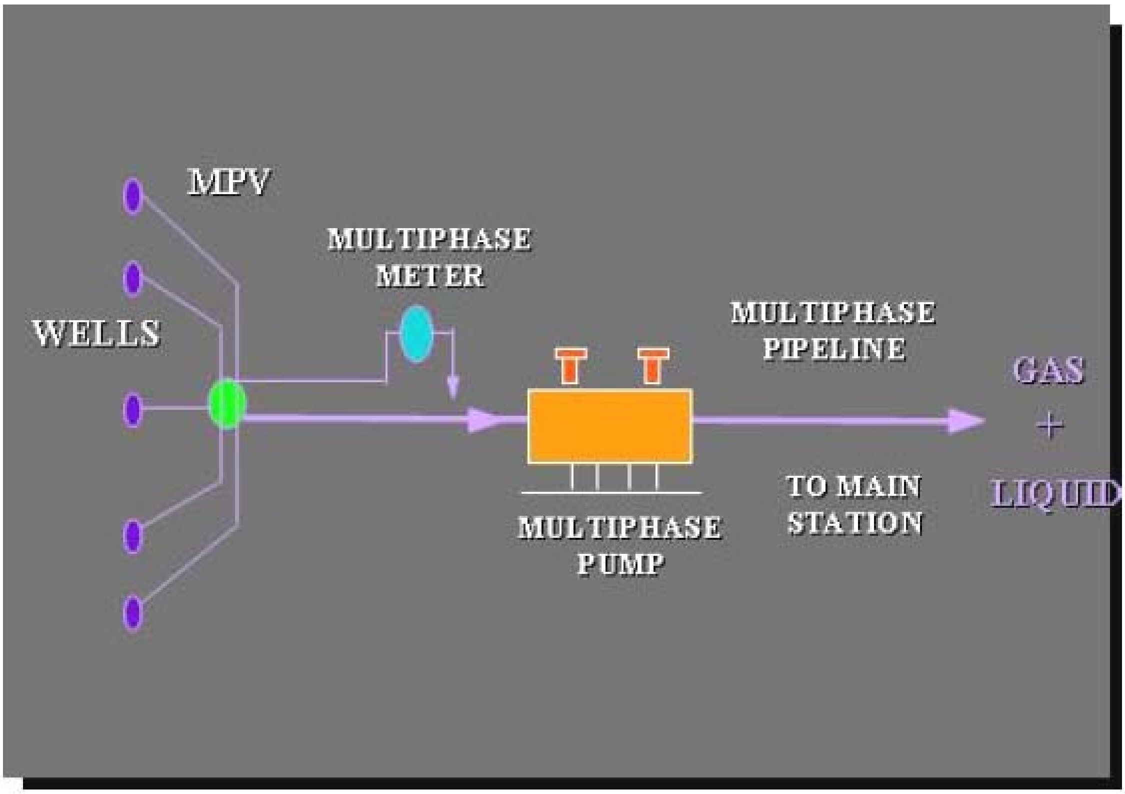

Fig. 1 Mult-phase wet gas compression.

5. Conclusions

By the current research the new theory of *"Next Generation Multiphase Pumps for Wet Gas Compression"* has been further improved and investigated for the petroleum well development. Consequently, by using the proposed new method then it will be possible the production of very big quantities of oil and gas in each well.

As is well known, normally the fluid to be handled by the wells operate under wet gas conditions, where the fluid contains a mixture of liquid and gaseous phases. Hence, by the proposed modern method for energy applications it will be established a strong scientific and technical base for the Science & Technology worldwide in the emerging areas of well development in the energy field. Thus, through the sophisticated technology of *" Next Generation Multiphase Pumps for Wet Gas Compression "*, the production of very big quantities of oil and gas for each well will become possible.

Beyond the above, the petroleum and gas markets are multi-billion markets all over the world. Thus, such a contribution requires an international approach, rather than a local approach, as it is referred to a market all over the world with value of many billions. It is therefore expected in order the major petroleum companies to keep and to improve their leading role in the worldwide Science & Technology in the petroleum field, to get involved in the new and groundbreaking technology in the area of Energy, which is proposed by the present investigation.

Finally, as the proposed sophisticated method *"Next Generation Multiphase Pumps for Wet Gas Compression"*, is based on a very modern method, then it is expected to get the best results. Thus, our proposed high technology method is based on a very sophisticated model by using multiple net generation compressors, instead of using the existing compressors. Consequently, the proposed multiphase pumps have the ability to handle directly the wet gas without the need for separation equipment, which is very attractive from an economic view, as it reduces very much the weight, size and cost of the gas compression devices.

Additionally, efficiency and operating range of a compressor are constrained by aerodynamic instabilities. In such way, by the present paper the different flow phenomena associated with compressor instability are investigated and presented recommendations for suitable instrumentation and measuring techniques.

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