# A Review on a Multiphase Twin Screw Pump Technology for Downhole Wet Gas Compression

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**Abstract**— By introducing a multiphase twin screw pump as an artificial lifting device inside a marginal gas well (downhole) for wet gas compression application; i.e. gas volume fraction (GVF) higher than 95%, the unproductive or commercially unattractive gas well can be revived and can be made commercially productive. This strategy provides energy industry with an invaluable option to significantly reduce greenhouse gas emissions by reviving gas production from already existing gas reserve infrastructure, which reduces the cost, time and efforts for new exploratory and development projects. This review paper provides a critical assessment of the research activities related to the applications involving multiphase twin screw pump and outlines the opportunity that the new frontier of multiphase fluid research has to offers in the domain of wet gas compression; i.e. GVF higher than 95%. For GVF above 95%, the existing mathematical models are inadequate for evaluation of volumetric efficiency under different operating conditions. Experimental validation procedure is the only alternative that is available for reliable evaluation of the volumetric efficiency, which is costly, time consuming, inflexible, in some cases even unsafe and therefore impractical. For the novel concept of productivity improvement using a downhole wet gas compression to be practicable and commercially more attractive than other production improvement strategies available today, a more affordable, reliable, fast and a standardized approach to affirm the volumetric efficiency of the multiphase twin screw pump above 95% GVF is essential.

**Index Terms**— Downhole compressor, integrated research, multiphase pumping, numerical modelling, wet gas compression, productivity.

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## 1 INTRODUCTION

The geopolitical scene and socio-economic factors are significantly influencing the ongoing evolution in exploration and production of hydrocarbon reserves and would continue to transform the energy sector as per expert analysis of Dewhurst (2011) and Stanislaw (2013). For example, recent widening of Panama canal now provides more economical route for very large liquefied natural gas carriers, political reforms in the Middle Eastern, the African and the Central Asian nations is redefining the corridors of movement of goods and services, rate of rising population has already outpaced the economic growth and the current models of the economy are unable to keep up with the demand of providing employment, tax reforms in energy sectors is compelling exploration and production companies to reorganize their business models and their market presence, rapidly increasing application of technology and data analytics is making energy supply chain more affordable, efficient and effective. Above are just few examples that put in to perspective the intertwined and the complex nature of geopolitical and socio-economic aspects that are currently transforming the energy industry and global economy as a whole.

The rapid evolution in science and technology of exploration and production over last couple of decades is being made to suit the geopolitics and socio-economic requirements of the government. For example, floating liquefied natural gas technology and floating production systems has opened up opportunities to produce from stranded gas reserves. Another striking example is of enhanced reservoir characterization in which data analysis is carried out using computation techniques with the help of faster computers that are able to combine the historical production data with the geological data of better resolution acquired by using sensors with superior sensitivity. This multidiscipline integration has made it possible to visualize the geology more clearly, thereby significantly improving productivity and lowering exploration risks and costs. Artificial lift technology is yet another remarkable example that is currently enabling reduction in erosion of the value of investments in the existing reserves due to limited recovery factor and pressure depletion in wells. Gordon and Feldman (2016) argue, "While the associated gas in an oil reservoir has a monetary value that governments and oil companies can recoup, unfortunately technical, regulatory, economic, or geopolitical constraints too often result in its disposal through flaring or other methods." There is an increasing market push to improve financial efficiency by reducing unit development cost and even bigger focus on reduction of carbon emissions from production facilities.

At the time of writing this paper the world is grappling with sudden structural shift and transformation in global energy and commodities demand-supply equilibrium. Renewed vigor and determination of governments to tackle harmful effects on climate due to man-made greenhouse gas emissions was demonstrated by signing of United Nations Framework Convention on Climate Change agreement in Paris in 2015 by the Intergovernmental Panel for Climate Change. Amongst many sustainable development goals for the planet earth laid out in Paris Agreement (2015); one of the priority objective is to aggressively pursue reduction in carbon emissions and limit the irreversible effects on the earth's ecosystem by holding average global temperature rise to well below 2 deg. C above pre-industrial levels.

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Statistical studies of Stoian & Telford (1966) on depleted and nearing depletion Canadian gas pools reveals that average recovery factors for gas wells with different reservoir driving mechanisms is approximately 85%, which means that at least 15% of valuable resource remains unrecovered from the legacy investments. For the economy to rapidly adapt and energy industry to transition in to 'low carbon' and thereafter to 'carbon-neutral' environment, it would be uneconomical, unethical and inefficient if the industry continues to adopt the 'business as usual' strategy. What it means in moral sense is that a significant quantity of hydrocarbon gas is left behind in the existing gas wells because of inability to improve recovery factor by extracting efficiently and while the industry keeps exploring and developing new gas fields, is continuing to add to the unrecovered quantities. Resources to Reserves (2013) a comprehensive report published by International Energy Agency (IEA) makes a compelling case for productivity improvement; "Even a 1% increase in the average recovery factor could add more than 80 bb or 6%, to global proven oil reserves." In above context there is a remarkable dichotomy is beginning to emerge in the energy industry. Firstly, slow down in aggressive pursuit of new fossil fuel reserves, as evident in Goswami (2015) and secondly, newfound interest of deepening of the understanding of existing reserves and infrastructures. With the above approach, the industry is trying to double down on improving recovery factors; a fundamental scientific approach emphasized by Wyckoff (1940).

The national study report of Interstate Oil and Gas Compact Commission (2007) looked at the contribution to the United States' economy made by production from marginal oil and gas wells. The report confirms realization of incremental production of 1.03 billion barrels of oil and 14.9 Tcf (trillion cubic feet) of gas in 2006 alone. The report also showed that although the number of marginal gas wells increased by 3%, the marginal gas production was lower than that reported in the year earlier, but on the other hand the marginal oil production had increased by 4% during the same period. This shows that the oil producers are making significant progress to improve recovery from the marginal reserve by implementation of innovative technology such as artificial lift and enhanced oil recovery methods. The gas producers on the other hand have not been as effective in emulating the improvised strategies adopted by the oil producers. Low gas prices, fundamental difference in nature of sales and purchase agreement of oil and gas, dearth of proven, efficient and cost effective technologies to improve the recovery factor in marginal gas wells are some of the contributory factors that have encumbered marginal gas business to be as successful as marginal oil business. To address plethora of above technical, environmental and business challenges; lot of research and development efforts has been ongoing on variety of sub-sea, sub-surface and downhole technologies. The IEA report Resources to Reserves (2013) states that the sub-sea separation and the sub-sea boosting are the fields of extensive research, development and deployment.

Multiphase pumping technology is a sub-set of sub-sea boosting technology and this paper critically reviews the research that has been conducted on multiphase twin screw pumping technology and highlights the shortcomings in evaluation of performance of a multiphase twin screw pump technology specifically for gas volume fraction (GVF) above 95%; i.e. wet gas compression.

## 2 STATE-OF-THE-ART IN MULTIPHASE PUMPING TECHNOLOGY

The conventional multiphase pumping systems for subsea and subsurface applications in oil and gas industry has been around for a long time and has undergone different phases of evolution in order to meet ever growing demand for more challenging applications and operating conditions, as demonstrated in Derks et al. (2000), Hua et al. (2011) and Olson (2011). The graphical representation in the Figure 2.1 depicts the current state-of-the-art in the field of sub-sea pumping technology. It is observed that choices of technology rapidly reduce with increasing GVF and differential pressure. The region of interest of critical review presented in this paper is shown by circled portion in the Figure 2.1 below.

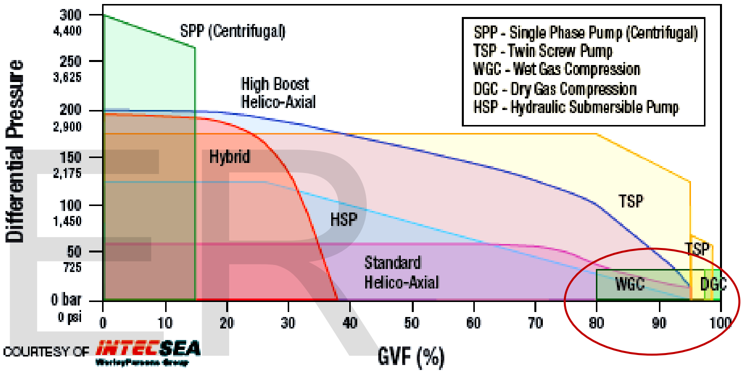

Figure 2.1: Boundaries of sub-sea pumping applications, (Intecsea, 2014)

The evolution process of design of a multiphase pump, selection of hydraulics and refinement in its component design have happened up until now based on traditional principles and understanding of component failure modes, examples of which are represented in Bibet et al. (2009), Cooper et al. (1996) and Olson (2011). The novel developments in the multiphase pumping technology published in Abelsson et al. (2011), Bibet et al. (2009) and Scott (2003) highlights that the novel technology electric submersible pump (ESP) and its variants called as hybrid booster pumps, whose initial stages consist of gas tolerant impeller design; are able to handle fluids up to 20% GVF. The Figure 2.2 is a pictorial representation of a typical ESP variant - hybrid booster pump.

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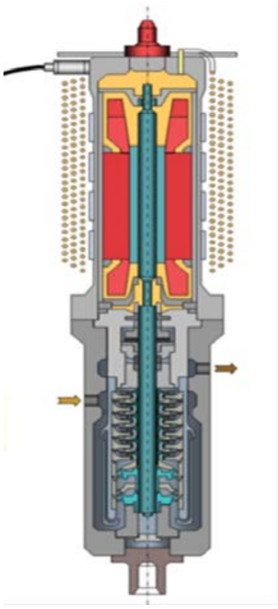

Figure 2.2: Typical Hybrid Booster pump design, (Intecsea; OneSubsea, 2014)

Due to constantly increasing gas content in well fluids as the field reaches its maturity, the existing ESP technology and its variants will not be able to find a suitable place in exploration and production strategies. Above limitations was addressed by a 'helico-axial' pump technology that introduced some radical modifications to the hardware of existing ESP technology. A pictorial representation of typical helico-axial pump is shown in the Figure 2.3.

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Figure 2.3: Typical Helico-Axial Multiphase Pump, (on top), Intecsea; OneSubsea, (2014). Typical Helico-Axial impeller design, (bottom) Cao et al. (2004)

It consists of fully axial flow impellers that are separated by axial diffuser stages, which can operate on well fluids up to 65-70 % GVF.

As the applications begins to approach GVF of above 80%, clear demarcation between a multiphase pump and a multiphase compressor begins to diminish and this situation led to emergence of two promising frontiers in the multiphase compression technology. One of the promising frontiers is the multiphase twin screw pumping technology that is a successful extension of proven capabilities of a twin screw pump operating with Newtonian and non-Newtonian fluid applications. A pictorial representation of typical multiphase twin screw pump is shown in the Figure 2.4.

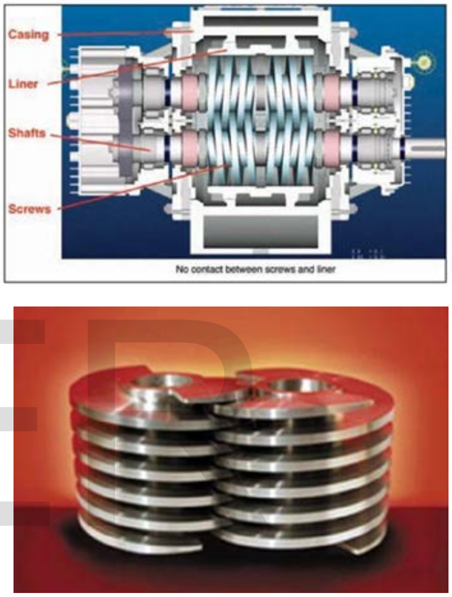

Figure 2.4: Typical Multiphase Twin Screw Pump (on top); Typical screw elements (bottom), Bornemann Pumps.

The multiphase twin screw pump technology has proven its capability to operate until 95% GVF, but has not been proven beyond 95% GVF sustainably. Supported by the research works of Bibet et al. (2009), Derks et al. (2000) and Hua et al. (2011), it is worthwhile to conclude that the multiphase twin screw pump is one of the only two proven technologies that is considered to be best suited for sub-sea multiphase pumping applications. The only other technology is the helico-axial multiphase pump, which is based on roto-dynamic (centrifugal) principle, which poses design and operating limitations for applications above 95% GVF. Helico-axial multiphase pump is outside the scope of this review paper.

## 3 NOVEL APPLICATION OF MULTIPHASE PUMPING TECHNOLOGY

As demonstrated in Al-Anazi et al. (2013), Alwan (2011), Alwan et al. (2016), MacNeil et al. (2012), Ohanyere et al. (2015) and Tullio et al. (2009), efforts are being made to focus on application of multiphase pumping to increase productivity and to improve recovery factors of existing hydrocarbon liquid reservoirs. Production gains in the range of 30 to 40%; from what is commonly known as the ‘marginal oil fields’, has been realized due to renewed scientific efforts. While the current multiphase pumping technology has been focusing on ‘marginal oil fields’; not much focus has been provided on the research of multiphase artificial lift technology for ‘marginal gas fields’, which is an application where GVF is above 95% most of the time.

The sections below provides a critical review of the novel approach of miniaturization of existing multiphase screw pump technology and its adaptation as a downhole wet gas compressor. It is a brand new opportunity in the realm of a reliable artificial gas lift technology, which does not exist as of today. The novel approach complements the pace of ongoing technological improvements happening in field of gas reservoir characterization for productivity enhancement. The miniaturized multiphase twin screw pump and its integration with downhole production system provides an efficient, economical and sustainable solution for reviving depleting gas reserve and those that are proclaimed as technically and/or commercially unattractive.

## 3.1 Case for Integrated Research

As debated in Wyckoff (1940), the interdependent science between the reservoir, production wells and production processes is adequately known and consists of palpable interplay amongst variety of factors. The factors affecting reservoir performance can be broadly divided in to those that cannot be influenced or controlled and others that can be either partially or fully controlled. As explained in Wyckoff (1940), each reservoir has its own unique natural behavior, which cannot be influenced. However, the factors such as production wells and production processes, which can be either controlled partially or fully can affect the overall reservoir performance and can impede realization of maximum production efficiency of the reservoir. It is therefore recognized that the concept of miniaturization of a multiphase twin screw pump technology and its application as a downhole wet gas compression discussed in this review paper requires a significant level of integration between the reservoir behavior, the production equipment and the production processes.

The scientific arguments put forth in Wyckoff (1940) about the factors affecting reservoir performance, when applied in conjunction with the research work of Hatesuer et al. (2010, 2011), Muller-Link et al. (2014), Rausch et al. (2005) highlighting the importance of evolution of the flow regimes in the upstream and the downstream of a multiphase twin screw pump; signifies that research related to an improvement of recovery factor of a reservoir or an improvement in performance of a multiphase twin screw pump, both need to encompass elements of the reservoir behavior, wells and the production processes right up to the surface.

The groundbreaking research work of Feng et al. (2001), Gao et al. (2011), Groth et al. (2009), Nakashima et al. (2006), Neumann (1991), Prang et al. (2004), Räbiger et al. (2008), Vetter et al. (2000) provides a firm understanding on key parameters that affect the performance of a multiphase twin screw pump, such as evolution of temperature across the pump, deformation of screw elements due to thermal expansion, effects of increasing and decreasing fluid GVF on pump volumetric efficiency and heat generation due to compressibility at high fluid GVF. The focus of their research work is mainly to study liquid production improvement and not production improvement of gas.

With above brief overview of a reservoir and its relation to a multiphase twin screw pump, it is observed that there is no published record of an integrated research work, which encompasses the reservoir, long sections of the inlet and outlet piping of the multiphase twin screw pump and the multiphase twin screw pump itself. To further exemplify the shortcoming, it is also reasonable to state that there is no record of research work related to a downhole multiphase pump or a wet gas compressor involving a multiphase twin screw pump technology.

The Figure 3.1 below is a depiction of typical concept of a downhole gas compressor installation integrated with a production system. The boundary denoted by a dotted line defines the optimum scope of integrated research based on the critical review discussed above.

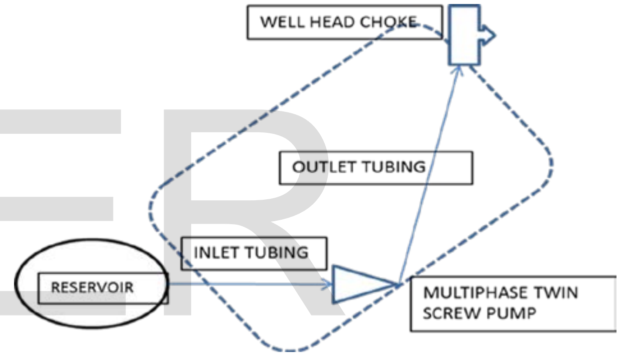

Figure 3.1: Conceptual sketch of downhole compressor and its integration with production system.

## 3.2 Miniaturization for Productivity and Efficiency Improvement:

The basic concept of a downhole gas compressor and its benefits are reported in US patent Vandevier & Bearden (2008), which is a premonition that the industry is serious about studying the feasibility of novel concepts of downhole gas compression. Apart from the fact that a downhole gas compression provides a higher recovery factor over currently available sub-sea compression technologies or a conventional gas compression system on a platform, is that a downhole gas compression has a highest overall process efficiency than the other production processes, as shown in Hossain et al. (2013) and Muller-Link et al. (2002). The introduction of an artificial lift device in the form of high speed axial compressor inside the depleting gas well is presented in Tullio et al. (2009) and Hossain et al. (2013). Both these studies demonstrated dramatic productivity improvements. Tullio et al. (2009) studies only dealt with water vapor condensation from gas stream and Hossain et al. (2013) studies only dealt with single phase, dry natural gas, neither of which are realistic representations of actual multiphase fluid conditions inside a typical gas well.

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For an artificial gas lift device that is introduced inside the downhole gas application, it entails that the fluid dynamic and the thermodynamic interactions of an integrated production system can be realistically accounted only by considering the fluid to be a multiphase and a multicomponent hydrocarbon fluid.

### 3.3 Multiphase Twin Screw Pump Technology for Downhole Wet Gas Compression

A multiphase twin screw pump brings unique advantages to the miniaturization concept of a downhole wet gas compressor application. The virtues of a positive displacement principle bestows following merits to the concept of downhole wet gas compression:

1. The twin screw design is more efficient, as energy is imparted gradually with every small degree of rotation of the screw elements. The compression process is able to maintain quasi-equilibrium state and is therefore relatively more efficient. This topic carries more scientific relevance for a multiphase fluid compression with different droplet sizes and droplet concentrations.
2. Reduced fluid friction losses due to very low rate of shear makes the compression process more efficient.
3. Flow path design is relatively insensitive to molecular weight variations and therefore also insensitive to the constraints set by speed of sound in gas during compression process. This makes a twin screw pump type design relatively compact and more versatile, in particular for a gas application with significant CO2 and H2S content, which tends to increase the molecular weight.
4. The design is sturdier and more reliable for a wet gas compressor application, where large variations in GVF can cause variety of multiphase flow regimes; e.g. slug, dispersed, annular flows, which give rise to constantly changing liquid droplet sizes and droplet velocity in the production system.
5. Liquid 'unloading' inside the well tubing or pipeline increases differential pressure once a critical velocity threshold is reached. This behavior is the main reason for reduction in production rates and wells to become commercially unproductive prematurely. The characteristic of the positive displacement principle is that it provides almost constant flow across the range of differential pressures. The linear behavior is a significant advantage when it comes to a down hole and a sub-sea process control application. In contrast an artificial lift technology that is based on roto-dynamic principle possesses non-linear 'drooping' characteristics like that of a centrifugal pump or compressor, which would set serious constraints on management of critical velocity that have to be dealt by implementation of complex process and production control strategies.

### 3.4 Gap Leakages and Volumetric Efficiency

As described above, although multiphase twin screw pump for a downhole wet gas compressor offers significant advantages, the following sections explains the significance of research in the area of predicting and improving volumetric efficiency by reducing gap leakages between the screw elements and the crucial role it plays for making the concept of a downhole wet gas compressor using a multistage twin screw pump a practical reality.

A typical volumetric efficiency of a multiphase twin screw pump is given as:

$$\eta_v = \frac{V_{act}}{V_{theo}} \tag{1}$$

Where, $\eta_v$ is the volumetric efficiency, $V_{act}$ is the actual displaced volume and $V_{theo}$ is the theoretical (geometrical) displaced volume.

The author performed extensive reviews of analytical and experimental performance data of the multiphase twin screw pumps published by other researchers. The published volumetric efficiency performance data sets for a variety of different GVF, differential pressure, inlet pressure and speed were regrouped in to one single set of raw data. The author analyzed the combined data set to understand the behavior of multiphase twin screw pump in wet gas compression region; i.e. GVF above 95% and observed peculiarities in the trends of performance variations.

The figure 3.2 and 3.3 shows pattern of performance variations in the neighborhood of 95% GVF and 100% GVF. The data set was taken from experimental validation work of Groth et al. (2009), Morrison et al. (2012), Rausch et al. (2005) and Vetter et al. (2000) for various % GVF, suction pressure, differential pressure and operating speed. It was then combined into a single data set to then project a meaningful pattern of volumetric efficiency performance over a wide range of variations in the suction pressure, the differential pressure and speed.

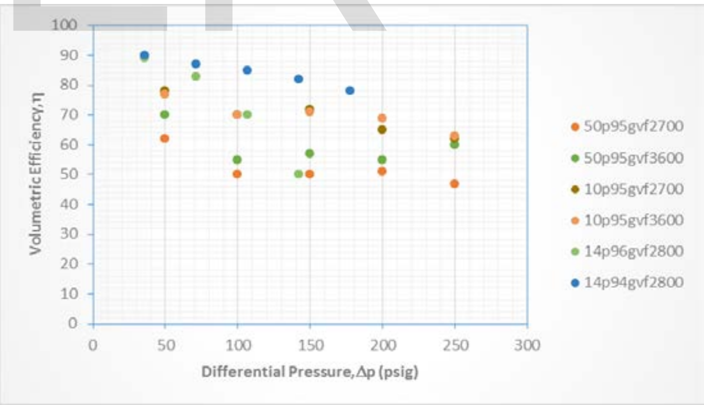

Figure 3.2: Multiphase Twin Screw Pump performance in the neighborhood of 95% GVF

It is evident from the two patterns that there is a significant step change in the volumetric efficiency between the data set in the neighborhood of 95% GVF and the data set in the neighborhood of 100% GVF. At approximately 95% GVF the spread of the volumetric efficiency is in the range of 50% and 90%, whilst around 100% GVF there is a sharp decline in the volumetric efficiency and the spread is between 35% and 85%.

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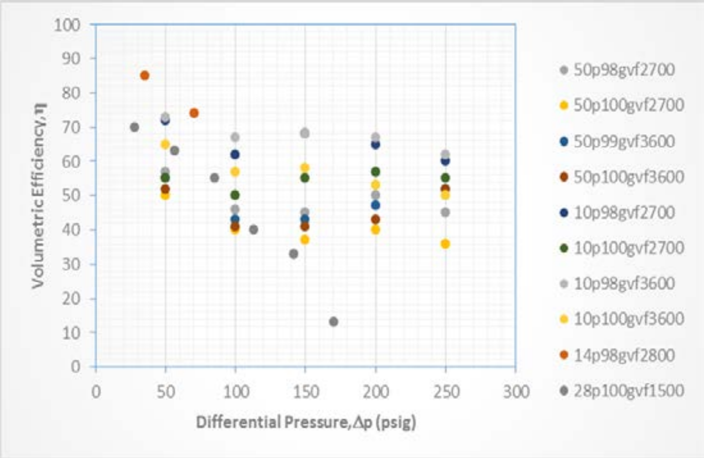

Figure 3.3: Multiphase Twin Screw Pump performance in the neighborhood of 100% GVF

The above comparison of volumetric efficiencies at 95% GVF and 100% GVF; i.e. 50-90% and 35%-85% respectively; reconfirms that the idea of a downhole wet gas compressor using a multiphase twin screw pump is practicable and meaningful. It also confirms that there is a significant opportunity to extend the higher volumetric efficiency demonstrated by a multiphase pump at 95% GVF to operating conditions at 100% GVF. For example, a meager 5-10% increase in volumetric efficiency for operating conditions above 95% GVF will translate into significant improvements in the recovery factor of a marginal gas reserve.

The Figure 3.4 represents typical gap leakages in multiphase twin screw pump, which are major areas where variety of research on characterization of the gap leakages with significant level of success has been performed.

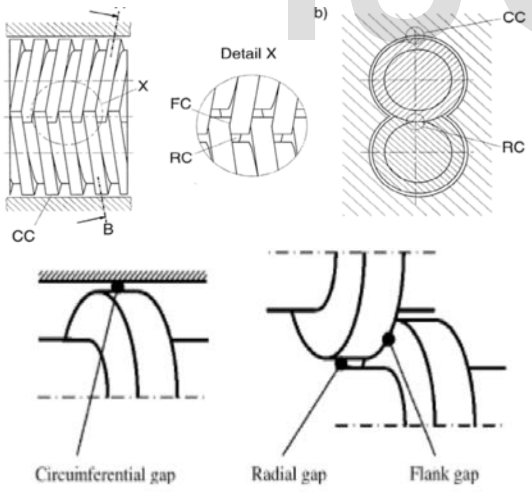

Figure 3.4: Gap leakages; CC-Circumferential, RC-Radial, FC-Flank, (top) Vetter et al. (2000); (bottom) Rabiger et al. (2008)

However, the research outcomes are valid only for specific operating conditions and flow characteristics. In Figure 3.2 and Figure 3.3, it is also interesting to note that there are large variations in the volumetric efficiency performance data of the researchers when the similar data types are compared.

This analysis demonstrates that the performance evaluation of a multiphase twin screw pump is a complex science that is sensitive to a variety of factors directly related to the pump, such as fluid properties, suction pressure, differential pressure, operating speed and screw element geometry.

As evident in Feng et al. (2001), Neumann (1991), Prang et al. (2004), Rabiger et al. (2008) and Vetter et al. (2000), the gap leakages contributes to majority of mass and energy losses that are experienced during the compression process. Over several decades researchers have attempted to estimate leakages as accurately as possible but even to date, the best practical approach to determine gap leakage remains elusive.
As observed in Nakashima et al. (2004) and Rausch et al. (2005), while approaching threshold of 85% GVF, the fluid in the perimeter gap area becomes genuine multiphase liquid-bubble mixture whose density is a function of bubble distribution and bubble size, as reported in Patil (2013).

Gao et al. (2011), Nakashima et al. (2006), Rabiger et al. (2008) and Xu (2008) studied and reported results of transient effects of slug flows; i.e. GVF of 98% to 100% for a limited time period. The temperature increased within short period of time due to heat generation by multiphase compression process and eventually caused rotor deformation followed by rapid decline in pumping efficiency and ultimately leading to the loss of pumping action.

For a reliable and efficient operation, it is essential to abate the temperature rise inside the pump by evacuation of heat of compression. The alternatives of how this can be achieved is either by continuous injection of 5-6% of liquid or increasing the volumetric efficiency or combination of the two. Vetter et al. (2000) estimates that of the total leakage flow, the perimeter leakage flow accounts for 80% of the total leakage flow, whilst the rest is contributed by the radial and the flank clearances. As reported in Feng et al. (2001) and Prang et al. (2004) that the leakage flow through the flank gap does not significantly contribute to the total leakage and therefore it does not affect the performance of the pump. However, the performance evaluation made in Mewes et al. (2008), with and without the flank gap leakages confirmed that the leakages through the flank gap does significantly affect the performance in high GVF cases, which is in complete contrast to observations made in Feng et al. (2001), Prang et al. (2004) and Vetter et al. (2000).

A typical graph in the Figure 3.5 represents the role of flank gap leakages under high GVF conditions, which is quantified through experimental investigations by comparing the calculated pressure increase profile against the actual pressure rise in Mewes et al. (2005, 2008). The experiment also measured and recorded the volumetric efficiency and the temperature rise; in a steady state boundary condition and in an unsteady state boundary condition scenario of the slug flow at the pump inlet.

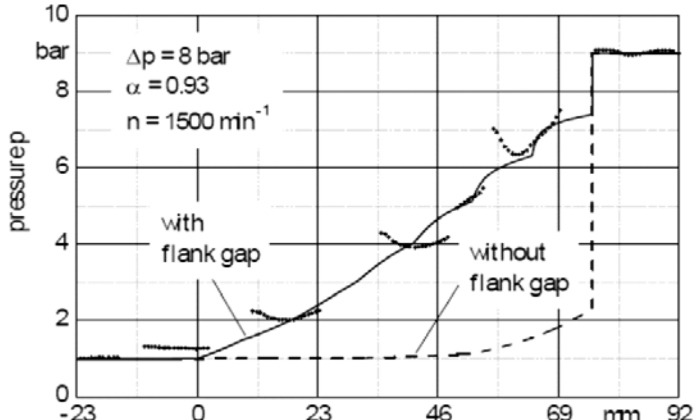

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Figure 3.5: Actual pressure rise with flank leakage and calculated pressure rise without flank leakage, Mewes et al. (2008)

### 3.5 Physics of Multiphase Flow Related to Gap Leakage

The review and evaluation of the mathematical models that are used by researchers to study the multiphase twin screw pump behavior consider the gap leakages broadly into the following two types of flow characteristics:

1. A homogenous two-phase fluid for the perimeter gap, the radial gap and the flank gap leakage.
2. A single-phase incompressible viscous liquid for the perimeter gap leakage and a homogenous two-phase fluid for the radial gap and the flank gap leakage.

Above hypothesis is verified in Hatesuer et al. (2010), Rabiger et al. (2008) and Patil (2013) through direct flow visualization using a camera recording of visible variations in the quality of flow characteristics. If the evolution of flow characteristics are not represented correctly in the mathematical models then these can significantly induce unwanted errors in the gap leakage flows and ultimately performance prediction results.

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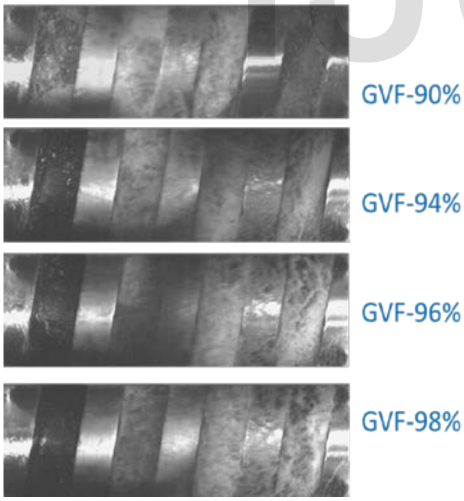

Figure 3.6: Typical flow characteristics in perimeter gap, Rabiger et al. (2010)

A typical flow characteristics in the perimeter gaps of the screw element from the excellent research work of Rabiger et al. (2010) is shown in Figure 3.6. The slides show interesting evolution of flow characteristics in the perimeter gaps when a specific model of multiphase twin screw pump was operated in the range of GVF from 90% to 98%.

In the fundamental research work on friction pressure drop in microchannel Sur et al. (2011) compared experimental results of two-phase friction pressure drop and predicted values of three different flow models; i.e. separated flow model, homogenous flow model and flow pattern based phenomenological models (bubble, ring, slug and annular). The conclusion from research work is that two-phase friction pressure drop in microchannel can be predicted more accurately by flow pattern based phenomenological models instead of treating the fluid as per homogenous flow model or separated flow model. The author noted that above fundamental research work of Sur et al. (2011) is not applied to the mathematical models in Aleksieva et al. (2006), Egashira et al. (1996), Feng et al. (2001), Groth et al. (2009), Nakashima et al. (2004, 2006), Prang et al. (2004), Rausch et al. (2005) and Vetter et al. (2000). It is reasonable to conclude that none of the gap leakages flow prediction models for a multiphase twin screw pump are based on flow pattern phenomenological model, which as mentioned above is one of the more accurate methods of predicting friction pressure drop than the other methods.

### 3.6 Limitations in Gap Leakage Prediction Models:

The computational models based on the analytical equations in Aleksieva et al. (2006), Egashira et al. (1996), Feng et al. (2001), Groth et al. (2009), Nakashima et al. (2004, 2006), Prang et al. (2004), Rausch et al. (2005) and Vetter et al. (2000) do not explicitly confirm reliability of the models in the region of wet gas compression; i.e. GVF more than 95%, under different operating conditions. The researchers tested and experimentally validated their analytical models for a specific pump geometry and specific suction and differential pressure. There are also very little literature regarding experimental validation of the mathematical models in the region of wet gas compression. Xu (2008) modeled performance of twin screw pump for variety of GVF, including 95% GVF case using Lockhart- Martinelli correction parameter to account for two phase fluid, but without considering the effects of phase change during compression process. Morrison et al. (2012) and Patil (2013) experimentally validated the computational fluid dynamic (CFD) model for 50% GVF, but then again the validation exercise is not performed with actual fluid and therefore not representative of the actual fluid properties.

Based on the review of published information regarding the multiphase twin screw pump simulation models, it is observed that a realistic gap leakage evaluation model of a multiphase twin screw pump for a practical application of wet gas compression remains elusive even today. To evaluate the volumetric efficiency of a multiphase twin screw pump for a wet gas compression application and to attempt improvement of the volumetric efficiency in the high GVF region, it is essential to overcome shortcomings in the existing gap leakage assessment models. The section below enumerates the shortcomings, and provides critical assessment for each shortcoming to be tackled:

1. The most popular analytical models in Feng et al. (2001), Nakashima et al. (2004), Prang et al. (2004) and Vetter et al. (2000) considered the gap leakages either as a single-phase incompressible liquid or as a homogenous two-phase fluid. Although models built on above approximation significantly simplifies the evaluation of gap leakages problem, the models still demonstrates good compliance with the experimental results for cases

below 85% GVF. The models with such an approximation are not adequate for evaluation of the gap leakages problem when it comes to wet gas compression operating regime; i.e. GVF above 95%. Ideally the gap leakage evaluation models should be able to incorporate the unreliability and uncertainty in heat and mass balance arising due to heterogeneous and anisotropic fluid characteristics in the gap leakage that is encountered while operating in the region of high GVF values.

2. The numerical techniques implemented in Aleksieva et al. (2006) and Patil (2013) solve the governing equations over 2-dimensional fluid domain for the sake of economical computing and again, although a deliberate simplification, it has shown good compliance with the experimental data. The 2-dimensional model for 50% GVF case in Patil (2013) reveals that the gap leakages in the screw elements is significantly sensitive to fluid characteristics and necessitates further research to confirm the suitability of approach at different GVF by using a more complex 3-dimensional computation approach. For evaluation of the performance in the region of wet gas compression; i.e. high GVF, it is implied that the numerical techniques of Aleksieva et al. (2006) and Patil (2013), although scientifically more elegant than the analytical models of their predecessor researchers, are still not adequate to incorporate valuable information regarding flow characteristics and combined effects of pressure driven and shear force driven gap leakages.
3. The factors like the phase change phenomenon in multicomponent hydrocarbon mixtures described in Nakashima et al. (2004) and the other factors like the solubility of gas in a hydrocarbon liquid phase, degassing due to pressure drop, the liquid-bubble mixture, the bubble size, the bubble distribution, are described elsewhere in Groth et al. (2009), Hatesuer et al. (2011) and Patil (2013). The unsteady fluid velocities and fluid properties can only be fully understood when the above knowledge is combined and it is fundamental that any gap leakages characterization model incorporates unreliability and uncertainties of above aspects. The effects of above factors are even more pronounced at higher GVF due to more efficient phase (liquid-gas) separation, which causes increase in compressibility and density variations. The property transport equations solved in Patil, (2013) using numerical technique involves large number of properties with spatial and temporal variations. Therefore, it is impractical and inflexible for an analytical modeling procedures to incorporate the above complex behavior without compromising the quality of results.
4. The numerical models described in Aleksieva et al. (2006), Groth et al. (2009), Hatesuer et al. (2010), Patil (2013) and Rausch et al. (2005) are not validated using a representative hydrocarbon gas, oil and water mixtures. The experimental validation of the models were performed by the researchers using water-air, water-air-paraffin oil mixtures, and / or paraffin oil-carbon dioxide mixture, which is a pragmatic approach to reducing the risk and managing safety during the experiments. However, this approach oversimplifies the intricate multiphase physics inside the pump and therefore the existing models are not fully representative of actual fluid characteristics.

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## 4 CONCLUSION

A downhole wet gas compressor is a sustainable, effective and efficient artificial lift technology for improving the recovery factor of marginal gas reserves. A multiphase twin screw pump technology is best suited for the application as a downhole wet gas compressor involving fluids with GVF of 95% and higher. For a sustainable and economical improvement in the recovery factors of a marginal gas reserve by using the concept of a downhole wet gas compression, it is mandatory to integrate the evaluation of fluid and thermodynamics, encompassing the reservoir behavior, the well and the production system up to the surface. For a successful and meaningful integrated evaluation of improvement in recovery factor of a marginal gas reserve using a downhole wet gas compressor; a standardized, reliable and rapid predictability of the volumetric efficiency of a multiphase twin screw pump under various operating conditions is also equally essential.

As per published records, the existing mathematical models for performance prediction of a multiphase twin screw pump are based on the assumption that fluid in the perimeter and flank gaps of screw elements is either a single-phase liquid or a homogenous two-phase (gas-liquid) fluid with a characteristics of foam. Although the existing models are adequate for evaluation of gap leakages for fluid up to GVF of 85%, but these models are inadequate for evaluation of gap leakages of fluid with GVF above 95%. Apart from prohibitive and time consuming experimental validation techniques, which has limited flexibility and reliability, there are no other standardized, reliable, fast and economical alternative to affirm volumetric efficiency of multiphase twin screw pump for application above 95% GVF that can evaluate the performance for a variety of operating the suction pressure, the differential pressure and speed in a more scientific manner.

Therefore, the author will focus on using numerical techniques to fully understand the unreliability and the uncertainty in heat and mass balance arising from heterogeneous anisotropic fluid characteristics that prevail in the perimeter and flank gaps of screw elements above 95% GVF. This understanding is crucial to affirm the volumetric efficiency under various operating conditions in the wet gas region and ultimately successful integrated evaluation of downhole wet gas compression in a marginal gas reserve.

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