DEVELOPMENT AND FIELD TESTING OF NEW HIGH PERFORMANCE DOWNHOLE GAS SEPARATOR FOR ELECTRIC SUBMERSIBLE PUMPING SYSTEMS

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ABSTRACT

This paper presents research methods, designs, and field testing of a new type of mechanical gas separator for electric submersible pumping (ESP) systems which utilizes an innovative hydro-helical separation system to deliver the largest operating flow range in the industry and superior erosion protection, efficiency, and reliability.

A state-of-the-art test system for measuring and understanding the internal workings of two-phase flow conditions and throughput of mechanical separation devices was used. This testing enabled visual understanding of internal fluid flow, recirculation, separation efficiency, and collective and individual performance of various components of the gas separator.

The results led to the development of an innovative separator system, a hydro-helical separator, comprised of a stationary helix separation system with optimized throughput of fluids. The intake is designed with smooth intake flow paths to maximize flow capability and minimize erosion. A new fluid-mover stage has significantly higher capabilities of handling two-phase flow and gas lock protection. The stationary helical component replaces the dynamic vortex inducer in conventional gas separators, allowing for more efficient gas separation and increased throughput of the fluids within the separation chamber. The helical component also precisely directs the separated fluids with its increased velocity into the crossover pathways, which are designed for maximum throughput, low resistance flow passages, and erosion protection.

Field testing results show a significant improvement in production and pressure drawdown when the hydro-helical type gas separator is used, proving its superior design when compared to traditional vortex gas separators.

BACKGROUND

Armis Artunoff [2] of Reda Pump, Bartlesville, Oklahoma, USA developed and patented the first gas separator for ESP in 1938 (US Patent #2,104,339). Since that time, various new techniques, including centrifuge chamber, open paddle, auger, vortex, etc., and methods (inverted shrouds, tandem gas separators, etc.) were invented for handling gassy downhole applications.[9,11]

Basic understanding of how a gas separator operates has been somewhat of a mystery due to the many variables associated with complex two-phase flow behavior, internal and external pressure variation, vortex formation, velocity and viscosity of fluids, effect of the pump bolted above, inherent erosion issues, and single versus tandem designs. Sheth[9] and Wilson[11] provide in-depth reviews of gas separation technologies in the ESP industry. Researchers at the University of Tulsa[1,7,8] have also conducted testing and development of models based on limited test data. Parametric studies[4,5,6] based on field data is used for improvement and performance prediction with limited applicability. Computational fluid dynamics (CFD) studies[10] were unsuccessful due to partial validation of the CFD results. In the past, engineers relied on instrumentation and on educated assumptions for separator designs and performance predictions.

In 2016, a significant investment in both experienced personnel and in state-of-the-art testing technology was made to unlock many of the mysteries and improve understanding of the operation of downhole mechanical gas separation. The team investigated new innovative methods of testing and as a result, created a transparent testing system which allowed a visual understanding of individual internal flow regimes and component performance. Together with a combination of high-speed photography, CFD validation, and state-of-the-art instrumentation, every component of a mechanical separator system was enhanced for higher flow capabilities, separation efficiency, and higher reliability for a variety of downhole conditions. The hydro-helical gas separator [11] is a product of this testing experience, along with these new technologies.

DEVELOPMENT

All gas separators ingest multiphase fluid into a separation chamber, separate the gas and liquid phases, eject separated gas phase fluid into the well annulus, and provide sufficient liquid phase fluid to the pump to enable efficient pumping. Existing designs vary, but they share the traits of decreased efficiency at higher flow rates and low maximum flow rates compared to the pumps they feed. The hydro-helical gas separator (Figure 1) is the first downhole, dynamic gas separator design improvement in more than thirty years.

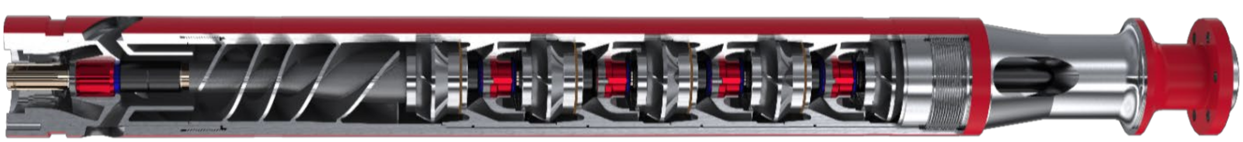

Figure 1 - Hydro-helical gas separator in cross-section

The team's goal was to develop the best gas separator in the industry by focusing on three main objectives: 1) increase the total fluid throughput through the separator, 2) reduce or eliminate erosion characteristics common in traditional gas separator designs, and 3) maximize the efficiency of every internal and external component of the system.

The hydro-helical's unique design is based on the innovative stationary helical vortex inducer and special pump stages that enable movement of large quantities of fluid, while being immune to gas locking. The vortex inducer enables increased efficiency and flow rate through the separator by reducing turbulent remixing regions within the vortex inducer and separation chamber. The intake, crossover, and exit ports are optimized by CFD and empirical testing to minimize flow losses and reduce erosion. The component designs are also optimized to provide cumulative superior performance of the gas separator.

The fluid moving stages move solids-laden, multiphase fluid at high flow rates without suffering undue erosion and gas locking, which is mitigated through a combination of advanced stage design and operating with minimal pressure differential across the gas separator. Empirical data validates the stages' immunity to gas locking at gas volume fractions up to 1.0 (100%). The stages also homogenize the fluid phases by decreasing bubble size and creating a separable fluid mixture. Modular stage design allows adjustment of flow rates, as required, while abrasion-resistant (AR) bearings provide protection in up and down-thrust operating conditions, allowing the gas separator to operate within a very wide flow range.

The stationary hydro-helix vortex inducer uses the flow of the fluid through its helical flow paths to create centrifugal separation. The flow paths allow high flow rates, and separation efficiency increases with increased flow rate. The entry and exit angles, tapering cross-section, and pitch of the inducer are optimized to minimize erosion and direct the flow into the separation chamber in patterns that significantly improve separation efficiency.

Innovative designs of the crossover and adjustable exit ports are optimized to accept precisely directed fluid phase-streams from the vortex inducer and separation chamber. Improved bearing system design provides increased torsional rigidity and support to the shaft, increasing reliability.

These optimized component designs work in conjunction with the novel hydro-helical separation concept to harness the fluid's kinetic energy and achieve high separation efficiency while operating at a high flow rate. Intelligent use of the fluid's kinetic energy drives separation and minimizes recirculation and ingestion of fluid through the exit ports. Maintaining minimal differential pressure across the separator reduces turbulent remixing areas in the separation chamber and vortex inducer and reduces flow losses across the system. These are all factors that significantly increase performance and reliability in the hydro-helical gas separator.

TEST FACILITY

Observations made during testing on a unique multiphase flow test system, which enables unprecedented visualization, prompted development of the hydro-helical gas separator. The test system consists of transparent components that allow examination of flow conditions internal and external to the gas separator, and instrumentation for collection of pressure and flow data at different points throughout the system, including within the gas separator. This provides a complete picture of conditions at any point in the test system itself or within the gas separator being evaluated.

Testing immediately highlighted deficiencies in conventional gas separator designs. Existing vortex inducing mechanisms cause regions of turbulent flow that promote remixing of fluid, resulting in complex and inefficient separation mechanisms. Increasing flow (shown from left to right in Figure 2) across a conventional vortex separator increases the scale of turbulent mixing regions within the separation chamber. Additionally, higher pressure differentials across the gas separator reduce the effectiveness of fluid moving devices and are detrimental to fluid separation patterns in the separation chamber. Flow losses due to restrictions are excessive in some conventional designs, limiting maximum flow rate and pump compatibility; efficiency decreases due to ingestion of fluid through exit ports such that there is an inadequate supply of fluid to the ESP pump.

Figure 2 – Mixing and separating regions inside the vortex gas separator

The hydro-helical gas separator design overcomes these efficiency-draining and flow-rate-limiting phenomena. Minimization of flow losses and management of differential pressure allow higher flow rates with the hydro-helical separation concept for effective separation at all flow rates. As shown in Table 1, the hydro-helical gas separator can handle maximum flow rates at least 20% greater than conventional gas separators. Reduction of turbulent mixing regions and reduction of flow losses help achieve efficiencies of 95% or greater over a wide range of flow rates and enable operation at gas volume percentages of up to 95%.

The performance of a single hydro-helical gas separator exceeds even conventional tandem gas separators. Due to inherent design limitations in conventional tandem gas separators, which cause flow losses, recirculation, and gas ingestion, their performance is inefficient compared to the hydro-helical gas separator design. When in a modular, tandem configuration, total flow capacity increases by 20% over the single hydro-helical gas separator configuration and 33% greater than conventional tandem separators.

Table 1 - Gas Separator Comparison

	Hydro-helical	Supplier A	Supplier B	Supplier C	Supplier D
400 Single Flow range (BPD)	10000 Max	8000 Max	2000-6000	180-3000	500-4000
400 Tandem Flow range (BPD)	12000 Max	8000 Max	2000-6000	180-3000	500-4000
538 Single Flow range (BPD)	20000 Max	15000 Max	2000-15000	1050-9600	1000-7000
538 Tandem Flow range (BPD)	24000 Max	15000 Max	2000-15000	1050-9600	1000-7000
% Gas handling	95% +	75%	80%	72% Max	Not Known
% Efficiency	95% +	Not Known	Not Known	Not Known	Not Known
AR Bearings	Up to 7	3	3	3	3
Erosion Protection	+++	++	++	++	++

FIELD TRIAL RESULTS AND DISCUSSION

Field Trial #1

Well #1, an unconventional well with high gas oil ratio (GOR), high water cut and severe emulsion tendencies is in the Permian Basin region of Texas. From 2018 to 2020, the operator used vortex separators on its ESP-produced wells. Average production on these wells was 100 BOPD while run life was typically 400-500+ days.

In February 2021, Vendor A installed their first ESP system with vortex gas separator which produced an average of 95 BOPD, failing within a month and a half. The operator ran back in the well with another Vendor A ESP system; the unit ran only 110 days and was pulled in June 2021. In both cases, production and run times of the Vendor A units were well below previous field averages.

In June 2021, the well was cleaned out at the request of Vendor B who ran the third ESP installation on the well. The unit produced an average of 80 BOPD and failure after running less than a month. Though severe emulsion and foaming issue downhole was the suspected cause, no signs of foaming were found when the well was treated by a chemical company. Vendor B redesigned the system to better handle the emulsion tendencies and gas levels and ran a fourth unit in mid-July 2021. When the motor temperature continuously spiked and shut the unit down, the suspected cause was once again excessive gas and emulsion which prevented adequate fluid flow for cooling the motor. Vendor B put the ESP in an operational mode that let the unit run one hour and then stay down six hours to allow fluid buildup and keep the unit from overheating. This yielded a suboptimal production rate of 30 BOPD.

At this point, the customer, who was concerned about excessive downtime and short run times, was introduced to the hydro-helical gas separator. Data comparisons of multiple scenarios, as well as before and after well performance data where the new technology had been implemented, were provided. The operator's concerns about severe emulsion and foaming, high gas volumes (484 mcf), and pump motors overheating were addressed in the pump design. During joint reviews, sensitivity analyses of various scenarios comparing tandem high flow vortex gas separators to designs with the hydro-helical gas separator were also conducted. These reviews also lead both teams to conclude that downhole emulsion and lack of reservoir pressure were not the primary cause of the well's decline; the operator ceased chemical treatments two weeks before the next installation.

In August 2021, the well was installed with an ESP system including a hydro-helical gas separator. Figures 3 and 4 show production and pressure histories of the well. Table 2 shows average production and pressure rates for each ESP installation during this time period.

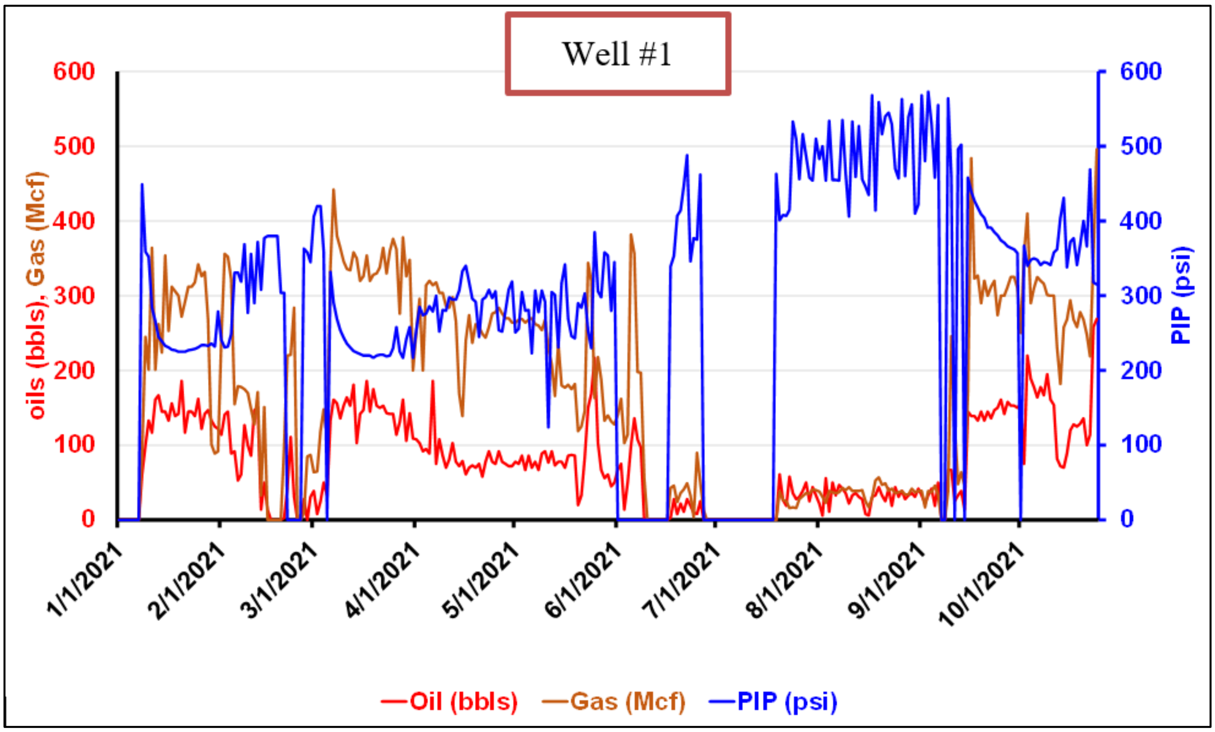

Figure 3 - Production and pump intake pressure for Well #1

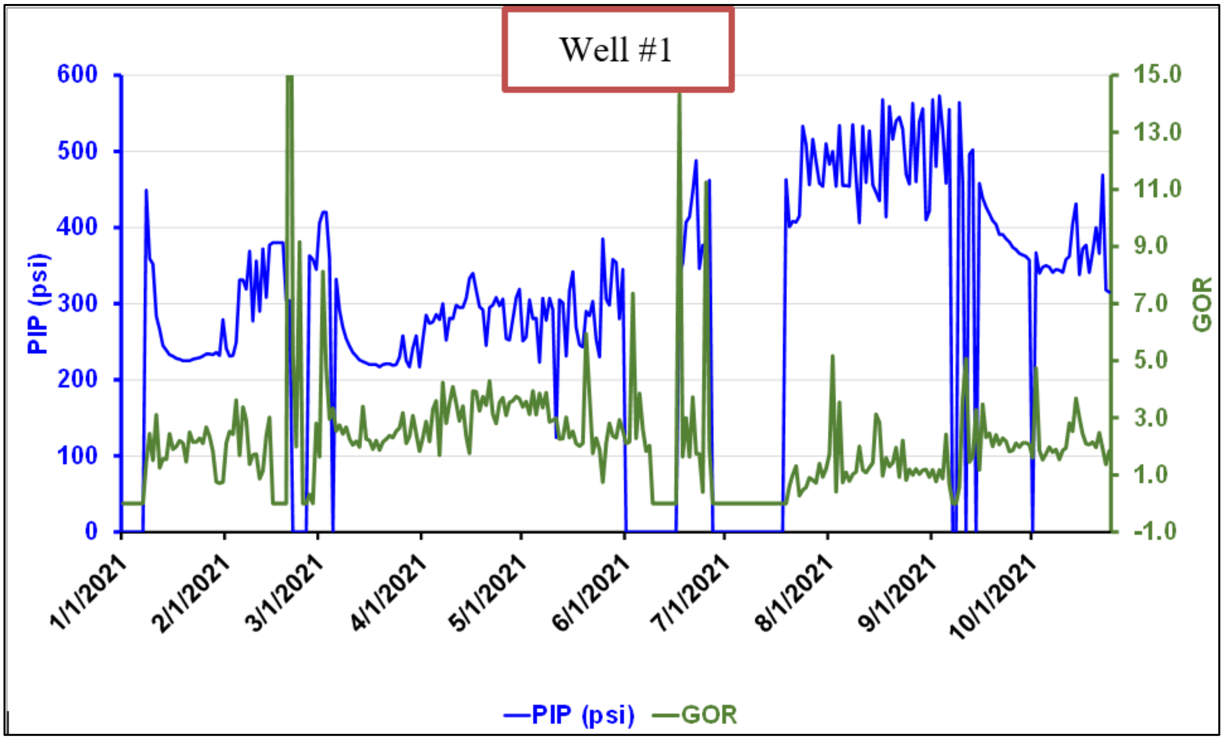

Figure 4 - Pump intake pressure and gas-oil-ratios for Well #1

Table 2 - Well #1 Average Production and Pump Intake Pressure

	Average			
	Oil (bbls)	**Gas (Mcf)**	**Water (bbls)**	**PIP (psi)**
1st Run	104	198	948	240
2nd Run	91	244	744	245
3rd and 4th Run	33	36	73	487
Current	146	302	1087	366

Despite a 210-day period where the customer spent roughly $500,000 dealing with high GOR, emulsion and four failures, the well is now stable and producing at above average rates of 146 BOPD. The hydro-helical gas separator proved to be the ideal solution for this well.

Field Trial #2

Well #2 is also an unconventional well located in the Permian region of Texas, but with a higher water cut and higher gas production than the previous example. The horizonal well was installed with an ESP and vortex tandem gas separator system in October 2019. When the customer pulled the well and installed it with a hydro-helical gas separator, oil production increased 30% and gas production 35% while pump intake pressure (PIP) dropped 17%, see Table 3.

Table 3 - Well #2 Average Production and Pump Intake Pressure

	Average			
	Oil (bbls)	**Gas (Mcf)**	**Water (bbls)**	**PIP (psi)**
1st Run	144	144	989	238
2nd Run	187	194	1187	198

The higher flow handling capacity and separation efficiency of the hydro-helical gas separator resulted in the increased production of oil and gas from the unconventional horizontal well.

Field Trial #3
Well #3 is a gas lift well in West Texas, which had previously been a strong gas producer but began to experience increased water production and decreased hydrocarbon production due to frac interference. The operator planned to convert the well to ESP for dewatering but there was the potential for emulsion and excessive gas volumes, as well as the challenge of optimally producing flow rates through 7in., 29 lb/ft casing. The customer was additionally concerned about using an ESP with a gas separator due to condensates.

The team contacted the organization's gas separator experts and set up a meeting with the customer to discuss their concerns. Because of the low liquid rate to high gas rate, together with the larger casing size, 400 series equipment was recommended with a 538 series gas separator to handle the higher concentrations of gas.

Despite an average GLR (gas-liquid ratio) of around 700 SCF/STB - maxing out at just over 1,000 SCF/STB - and an extremely high gas production of almost 3 MMSCFD, the unit is running remarkably well. In addition to the return of strong gas production, the customer has seen an increase in oil production of 100 BOPD. No work was performed on the well other than the conversion to ESP.

CONCLUSION

The hydro-helical gas separator operates at flow rates greater than 20% of conventional gas separators. It also operates at efficiencies greater than 95%, over a wider range of flow rates than existing separators. Anti-gas lock technology enables consistent operation at higher gas volume fractions than conventional separators. Reliability of the hydro-helical gas separator is greater due to the erosion-reducing design, modular AR bearing concept, and stationary-only parts in the separation chamber.

Operation of ESPs with the hydro-helical gas separator under multiphase conditions is more effective when compared to current systems. It allows operation with pumps of higher flow rate and in wells with higher gas volume fractions. Additionally, gas slug ride-through is improved due to the hydro-helical gas separator's higher separation efficiency and capability for higher fluid throughput. This technology advancement sets a new standard in the industry for gas separator flow rate, performance, and reliability.

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