INNOVATIVE PACKER TYPE GAS SEPARATOR: OPERATING PRINCIPLES AND DESIGN CRITERIA

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ABSTRACT

Wells with high depletion rate present high free gas at pump intake conditions. In all cases, the production of fluid with a high gas-liquid ratio leads to an inefficient performance of the rod pump systems. The initial solution to this problem is the installation of poor boy gas separators which have low capacity of gas separation and do not provide a high-performance solution.

Packer type gas separators are the most efficient downhole separators in the market, however, they usually have some operational limitations. This paper summarizes a new design for the packer type gas separator which uses more methods of separation than the traditional design and can be designed based on the conditions of each well overcoming the typical limitations. The design criteria are reviewed, and some operational guidelines are listed to reach the best performance in each application for gas separation.

INTRODUCTION

Now days it is well known that the sucker rod pump is the most popular among the artificial lift systems in mature fields which have a high percentage of depletion, consequence of producing fluid for many years. The more cumulative fluid these wells produce in many cases, the higher gas flow would be, unlike the unconventional resources since high gas production is normal from the beginning of the well production.

The beam pumping system generates reciprocating motions which make it easy to lift fluids from bottom to the surface in a vertical movement. The downhole pump has the function of let the fluid in and then send it to the surface through the rod string, however the mechanism of the sucker rod pump is designed to manage incompressible fluid so when gas is present inside of the pump issues such as low efficiency, gas lock or gas pounding will affect drastically on the run life of the equipment and the runtime of the well causing loses and higher investments due to interventions and pump and/or rod string changes. A normal rod pump manages an efficiency of 70 - 80%, but in presence of gas even though there are no physical damages the efficiency can drop below 40%, a low pump efficiency requires more SPM which means more power consumption reducing equipment life. The main problem resides on the start of the upstroke when there is gas between the standing valve and the traveling valve and when these two are at the bottom of the down stroke, the gas inside is compressed and when the plunger begins the upstroke the standing valve can only open when the pressure above has decreased to the submergence pressure, this delay on the opening cause less filling and therefore less fluid pumping to the surface (Figure 1).

In order to maximize the pump efficiency and prolong the equipment run life many Oil and Gas companies have developed a number of solutions to avoid free gas in the pump, by definition all separation methods include gravitational force and the fluid velocity. This research work will present a solution to eliminate gas achieving a velocity lower than 6 in/s so the gas bubbles submerged in the liquid can rise up by buoyancy effect and be eliminated from the system before reaches the pump. The packer type Gas separator has been proved as one of the most efficient downhole gas separators for sucker rod pump and monitoring field data is the best way to demonstrate the process to utilize this technology, to protect the pump run life and assures the maximum efficiency. However, there is limitation regarding the amount of free gas fluid that can be stored in the separation chamber because the typical packer type gas separators are manufacture in standard lengths that are not bigger than 24 ft. The new design proposes in this paper have some improvement that look for overcome this limitations and increases the efficiency of separation in this type of separators.

WELL CONDITIONS

A stabilized producing well will have a relatively constant fluid level and casing head pressure, in this point the position of each fluid (gas and liquid) would be determined by their densities, in the annular space the column would be divided into gas which would be at the top of the column then a mixture of gas and liquid and at the bottom below the perforations the liquid, this concept is really important to decide the depth of the seating nipple and the gas separator assembly. Considering gassy well conditions, running the pump below the perforations provides with an area between the tubing and the casing where the natural gas separation will take place, however, if the well presents sand production this option will not be viable, that is the reason why collecting as much information as possible is fundamental to determining the best solution for each well.

If for some reason the pump cannot be set below the perforations, and it needs to be set above the perforations, then a Packer Type Gas separator is a must when the well is producing a high amount of gas. It is important to highlight the fundamental concept for Natural Gas Separation so in order to eliminate the gas before it reaches the pump is necessary to take into consideration the need of reducing fluid velocity and factors that could affect the speed reduction such as the viscosity. Experimental data has proved that the influence of this property is relatively small (20%) on gas bubble slip velocity, excluding heavy oil, the viscosity will not determine the success or failure at the moment of gas separation. With this in mind, factors like the production volume and the dimensions of the gas separator combined with the fluid properties are used to calculate the change in the velocity of the fluid while the fluid is flowing through the gas separator.

PRINCIPLE OF THE NEW PACKER TYPE GAS SEPARATOR

The New Packer Type Gas separator (Figure 2) presented has a special configuration that assures the flow path through the gas separator by using a customizable packer that seals the section under the gas separator. The separator is complemented by three additional sections: the outlet section, middle section, and the intake section. All the sections are connected using the Dual Flow System (Figure 3) which has an innovative design that allows the fluid comes into the dip tube and flows upward until it reaches the pump. The main advantage of the Dual Flow System is the higher open area than the traditional connectors so, the risk of plugging issues by sand or chemical deposits is eliminated. Additionally, this system was designed to keep the flow regime and break the gas slugs when they are flowing through the tool.

The New Packer Type Gas Separator is connected below the pump and the fluid enters the system through an intake section that can be combined with a solid control system connected to the mandrel of the packer. The fluid flows upwards passing the packer and is redirected around the dip tube since the dip tube for this specific tool is sealed on the bottom to restrain fluid as we can see in figure 3. The fluid and the gas ascend liberating gas due to the pressure and the free gas separated by density would migrate out of the tool through the 75 slot screen section placed at the top of the 72 Ft long (outlet section). The New Packer Type Gas Separator, of sizes2-3/8",2-7/8" and 3-1/2" has a V-Mesh outlet section that facilitates the coalescence and later mitigation of bubbles of gas in the system (Figure 4). The principle of separation is ruled by the gravitational force. The liquids being denser than gas, flowing downward due to gravity, but gas bubbles tend to rise. As long as downward liquid velocity is lower than the terminal velocity of the gas bubbles, the resultant gas velocity is directed upward, and the gas phase continuously rises compared to the liquid phase. High liquid velocities, on the other hand, result in the gas bubbles being taken along with the liquid and no separation of the phases takes place. For an effective gas separation, therefore, the flow velocity of the liquid must be kept below the typical bubble rise velocity of 0.5 ft/s. This requirement can only be met if the cross-sectional area available for liquid flow is properly selected by considering the liquid production rate of the well. Downhole gas separators work according to this principle: they force the liquid phase to have a velocity lower than 0.5 ft/s by properly selecting the space available for liquid flow.

The velocity of the fluid would be calculated depending on the area where the fluid is flowing down which would be the area of the separation chamber (internal casing) minus the area of the OD of the tool, and the flow rate that the well is presenting, however for the application of this specific tool there are some considerations and analysis need to be done before the installation. Next section explains the criteria to design each component.

NEW PACKER TYPE GAS SEPARATOR DESIGN

As explained before the design of the New Packer Type Gas Separator is formed by the packer and three sections: Outlet, middle and intake. Each component has specific features and can be selected based on the well conditions and production.

Type of Packer

This new design considers two types of packers selected upon the well conditions and fluids production.

- Cup Packer: Illustrated in figure 5. The cups are molded from a durable oil, gas and abrasion-resistant elastomer compound that withstands wear and tear, even under pressure, making this the perfect tool to make sure that the fluid will flow through the multiple separation stages. The diameter of this cup packer depends on the casing or liner where the tool would be installed, it is very important to select properly the right size (Table 1) depending on casing drift to avoid problems at the moment of running the tool. The double inverted cup (Figure 5) seals the zone by pressuring the lower cup with the fluid coming from the perforations (from below) and the upper cup provides total isolation when the fluid is pressing from above (Fluid coming from the separation process creating the column of fluid in the annular section).

- Rotational Packer: It's designed specifically to run with a packer type gas separator. Its installation is combined with a Tubing Anchor Catcher to anchor the packer to the casing, see figure 6. In this case, to run together with the New Packer Type Gas Separator, it's recommended using a slim TAC that could be installed below the rotational packer and minimizes solids buildup around the body of the anchor. To set up this packer, the procedure is just to rotate the complete assembly already located at the installation point to the left 5 to 7 rounds to activate the TAC. After this, the packer is activated and rotating again the tubing for 3 or 4 rounds shears the rotational shear screw. The size selected depends on the casing size and the inclination of the installation point. Different sizes are summarized in table 2.

Depending on the inclination and DLS where the tools will be installed for almost vertical sections both packers can be used (figure 7), however, for installation below the KOP or near the landing point, it is recommended to install rotational packer as shown in figure 8.

Outlet Section

After the fluid enters below the packer and passes around the Dip Tube as shown in figure 3, the fluid will pass through the intake and middle section until it reaches the Top section called Outlet section (figure 9). This section has a 75-slot screen on the top used to help with the coalescence of the gas bubbles and communicate the tool with the annular section between the tool and the casing (see figures 7 and 8). For wells with chemical problems, the screen section can be replaced by slots that will provide a bigger open area and less risk of chemical deposits around the tool.

Intake Section

When the fluid exits the tool and flows downward the annular section it gets into the Dip Tube through the intake section that communicates the fluid in the annular section with the Dip Tube that is going to take it to the pump intake. The intake is formed by two slots with located right above the packer and distributed 180° each other (figure 10), this guarantee an open area 8 times bigger than the traditional packer type gas separator and in consequence, less pressure drop is perceived by the pump.

Middle Section

This section is an optional component designed for well with the gas production associate to the liquid. Wells with high GLR and with high production of liquid need to have a high amount f free gas liquid available to prevent gas interference. In order to have a higher volume of liquid free of gas in the annular section above the packer, a middle section is installed to increase the space between the outlet and the intake section which is going to be the new reservoir from where the pump is going to get the free gas fluid (figure 11). This advantage is especially useful in wells with foam in its column of fluid. A longer tool provides a higher fluid level while gas can free from the fluid column. This is one of the biggest innovations of The New Packer Type Gas Separator and the one that offers more efficiency in the pumping system for a low investment.

Each section has a length of 24 ft and depending on the fluid production and casing size, they can be run in 2-3/8”, 2-7/8” and 3-1/2”. Smaller diameters will offer higher capacity, but the pressure drop inside the tool and the dip tube needs to be calculated.

<u>CASE STUDY</u>

Well A was producing with sucker rod pump presenting issues related to gas interference, in figure 7 the pump card prior to the workover intervention on January 2019, shows gas interference. On the down stroke, the traveling valve starts its way down without opening, this is causing a low efficiency and if the problem is not dealt eventually it is a very common problem of it ending up into a gas lock. (Figure 12).

For this specific well a vortex desander was presented as an option for intake, this vortex desander has a slotted area in the upper part of the tool that allows the fluid to flows into the system, then the desander has a helix inside that creates a cyclone movement due to its geometry and generates sand separation and also helps to optimize gas mitigation before it enters into the dip tube.

The Packer Type Gas separator run for this well is a 3-section body of 72 ft of 2-3/8” and a 5-1/2” rotational packer for casing 17 #/ft, Dual flow System in each connection (3) connected to the seating nipple. The well presents a light oil, 40 API so there is no affectation of the viscosity to the gas separation process.
Under these conditions the open are available to separate the gas is given by the next expression:

Separation area: $\frac{\pi}{4}(ID_{casing}^2 - Max.OD_{Separator}^2)$ = : $\frac{\pi}{4}(4.892^2 - 2.375^2) = 14.36\ in^2$

Now to determine the separation efficiency and fluid velocity after passing the tool the next process is followed

1. Calculate PVT properties at the bottom hole conditions (BHT and PIP) using correlations or lab tests:
    - Solution gas/oil ratio at the pump intake (Rs): 94.63 scf/stb
    - Deviation factor of natural gas mixtures (Z): 0.92
    - Gas volume factor (Bg): 0.035 scf/STB
    - Volume factor of the oil (Bo): 1.09 bbl/STB
    - Volume factor of the water (Bw): 1.02 bbl/STB

2. Determine the in-situ gas volumetric rate, ft3/d

$$q_g' = q_o(GOR - Rs)Bg = 175 * (1257.14 - 94.63) * 0.035 = 7.14\ Mscf/d$$

   GOR (scf/STB) is calculated using production data at the current conditions.

3. Next step is to calculate the liquid superficial velocity in the annular section

$$v_{sl} = (6.5x10^{-5})\frac{q_l}{A_{annulus}}\left(\frac{Bo}{1+WOR} + \frac{WOR}{1+WOR}Bw\right)$$

$$v_{sl} = (6.5x10^{-5})\frac{150}{0.1}\left(\frac{1.09}{1+1} + \frac{1}{1+1}1.02\right) = 0.24\ ft/s$$

q_l, liquid volumetric rate STB/d
WOR, production water/oil ratio
$Aannulus$, annular ft^2

4. The terminal bubble rise velocity can be considered using the standard value of 0.5 ft/s or calculate it using the next formula:

$$V_b = \sqrt{2}\sqrt[4]{\frac{\sigma g(\rho_l - \rho_g)}{\rho_l^2}} = \sqrt{2}\sqrt[4]{\frac{0.04 * 32 * (55.64 - 1.85)}{55.64^2}} = 0.55\ ft/s$$

σ, interfacial tension lb/s^2
g, acceleration of gravity, ft/s^2
ρ_l, liquid density, lb/ft^3
ρ_g, gas density, lb/ft^3

5. With the parameters calculated before the natural separation efficiency is calculated

$$n_n = \left(\frac{V_b}{V_b + v_{sl}}\right)100 = \left(\frac{0.55}{0.55 + 0.24}\right)100 = 69.6\%$$

6. Next, we can calculate the gas ingested by the pump

$$q'_{ing} = q'_g\left(1 - \frac{n_n}{100}\right) = 7.14\left(1 - \frac{69.6}{100}\right) = 2.17\ Mscf/d$$

7. In-situ liquid volumetric rate entering the pump

$$q'_l = q_o(Bo + Bw * WOR) = 175(1.09 + 1.02 * 1) = 369.25\ \text{bpd}$$

The most important result of the simulation is shown in table 2.

The procedure explained before allows to determine the performance of the New Packer Type Gas Separator and its capacity for any ground of given conditions. Now it is important to determine the size of the fluid in the reservoir in the annular section before the intake section of the gas separator. In this case, the capacity for storage in the annular section for a 72 ft tool is 7.18 ft^3 which means 1-1/4 barrel of fluid stored while the gas is flowing out of the liquid in the top of the tool.

Finally, to assure no problems in the performance of the pump due to the pressure drop in the separation system, the total pressure drop through the Dip Tube needs to be calculated. The results of the simulation are shown in figure 13, where a multiphase model was used given a total loss of pressure of 8.104 psi.

RESULTS

- After the installation of the New Gas Type Separator, as we can see in figure 14 the pump presents a better pump fillage, the TV is opening earlier than It was doing it before.

- It was possible to reduce the pumping speed and achieve better filling results (Figure 15.) decreasing from 7.1 down to 6.3. spm.

- In figure 16 the efficiency of the pump after the installation increased and it maintains vales between 42% and 70% while before the installation the efficiency was oscillating between 25% to 42%.

- In February it was decided to reduce the SPM from 7.1 to 6.3 as it is shown in figure 15 and it maintained a higher production than before the installation, producing at an average of 7.2 SPM (Figure 16), this means that after the installation the downhole rod pump needs fewer strokes per minute to lift the same amount of fluid, indicating less power consumption and the production will increases with the increasing in the pumping speed.

- As we can see in figure 17 after the installation the well reduced drastically the fluid level allowing to reduce the fluid column in the annular section and reducing the PIP promoting a higher production of fluid from the reservoir.

CONCLUSIONS

- The New Packer Type Gas Separator increased the pump efficiency eliminating free gas from entering into the pump.

- New tools such as New Packer Type Gas Separator has proved to be an efficient gas separator using multiple gas separation stages and customizable designs that are build based on the well conditions.

- Run a Packer Type Gas separator downhole helps to separate a high amount of free gas reducing shutdowns caused by gas lock due to the high chamber of separation created between the tools and the casing ID.

- The inverted double cup packer and the rotational packer present a great performance when it comes to isolating the system and directing the fluid through the New Packer Type Gas Separator. It is recommend run the rotational packer with a slim TAC

- After the installation of the New Packer Type Gas Separator, the lifting cost is affected positively because the system reduced energy consumption and prevented possible future shutdowns due to a good gas downhole management.

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Table 1. Inverted Cup Diameters options

Casing		Recommended Hole Size (inches)	Tool OD (inches)	Tool ID (inches)	Thread Connections Box Up/Pin Down
Size (inches)	Weight (lbs/ft)				
3-1/2"	9.2 - 10.3	2.922 - 2.992	2.810	1.50	1.8900 NUE
4-1/2"	9.5 - 13.5	3.920 - 4.090	3.750	2.00	2-3/8 EUE
				2.50	2-7/8 EUE
	15.1	3.826	3.650	2.00	2-3/8 EUE
5"	18.0	4.276	4.130	2.00	2-3/8 EUE
5-1/2"	13.0 - 20.0	4.778 - 5.044	4.625	3.00	3-1/2 EUE
	14.0 - 20.0	4.778 - 5.012	4.625	2.50	2-7/8 EUE
	17.0 - 20.0	4.778 - 4.892	4.625	2.00	2-3/8 EUE
	20.0 - 26.0	4.548 - 4.778	4.375	2.50	2-7/8 EUE
6-5/8"	20.0	6.049	5.750	3.00	3-1/2 EUE
	20.0 - 24.0	5.921 - 6.049	5.750	4.00	4-1/2 EUE
7"	17.0 - 29.0	6.184 - 6.538	6.000	2.50	2-7/8 EUE
				3.00	3-1/2 EUE
	20.0 - 29.0	6.184 - 6.456	6.000	2.00	2-3/8 EUE
				4.00	4-1/2 LTC
7-5/8"	24.0 - 26.4	6.969 - 7.025	6.750	2.50	2-7/8 EUE
	29.7 - 33.7	6.765 - 6.875	6.375	2.50	2-7/8 EUE
8-5/8"	28.0 - 36.0	7.825 - 8.017	7.375	2.50	2-7/8 EUE
9-5/8"	40.0 - 47.0	8.681 - 8.835	8.450	3.00	3-1/2 EUE
10-3/4"	40.5 - 55.5	9.760 - 10.050	9.710	4.00	4-1/2 LTC

Table 2 Rotational packer options

Casing				Packer		
O.D.	Weight lb/ft	Min I.D.	Max I.D.	Max. O.D.	Max. I.D.	Thread Connections
4	9.5-11	3.476	3.548	3.25	1.72	1-1/2 EUE
4 1/2	9.5-13.5	3.92	4.09	3.75	2.00	2-3/8 EUE
5	11.5-18	4.276	4.56	4.125	2.00	2-3/8 EUE
5 1/2	14-20	4.778	5.012	4.64	2.38	2-7/8 EUE
5 1/2	20-23	4.67	4.89	4.5	2.38	2-7/8 EUE
6 5/8	28-32	5.675	5.791	5.5	2.50	2-7/8 EUE
6 5/8	20-24	5.921	6.049	5.735	2.50	2-7/8 EUE
7	20-29	6.184	6.456	5.97	2.50	2-7/8 EUE

Table 3. Slip Gas Bubble velocity results

Natural Gas Separation Effeciency		
INPUT DATA		
Production of total liquid barrel per day	350	BFPD
Water Cut	50%	%
Oil Rate	175	BOPD
Water Rate	175	BWPD
Gas Rate	220.00	MSCFPD
GLR	628.57	scf/stb
Produced WOR	1.00	BWPD/STBPD
Produced GOR	1257.14	scf/STB
Temp.	163.0	F
PIP	400.00	psi
Casing I.D.	4.89	Inch
Tubing O.D.	2.38	Inch
Dip Tube	1.30	Inch
Water SPGr	1.050	
Gas SPGr	0.850	
Oil API	40.0	
Oil SpGr	0.825	
Interfacial Tension	0.04	lb/sec^2
Gravtitational Tension	32	ft/sec^2

CALCULATED RESULTS		
Cross Sectional Area in Annulus, A	0.10	ft^2
In-Situ Superficial Liquid Velocity, Vsl	0.24	ft/s
Gas Bubble Terminal Velocity, Vb	0.55	ft/s
Natural Separatation Effeciency	69.54	%
Free Gas Entering Pump, q'g	7.14	Mscf/d
Gas Rate Entering After Natural Separation, q'ing	2.17	Mscf/d
Total Volumetric Liquid, q'l (Oil, water and gas)	369.83	bpd

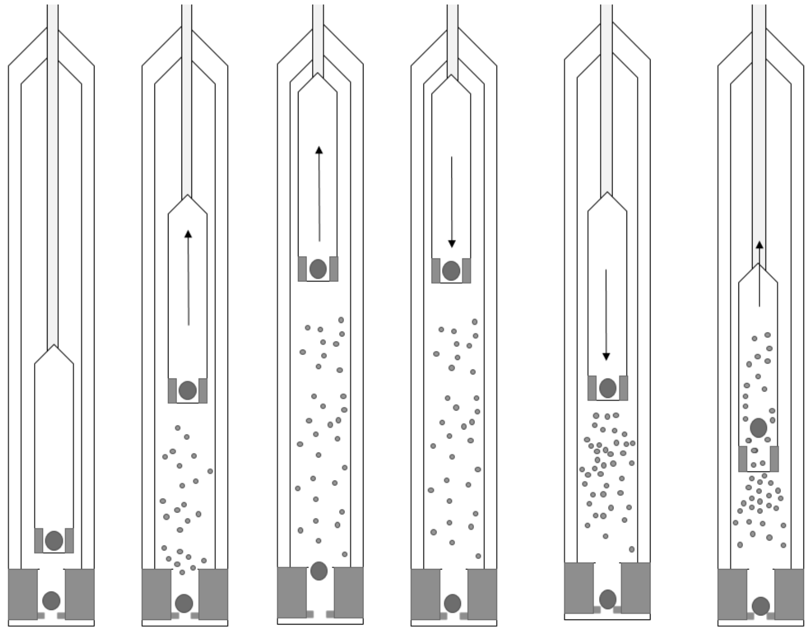

Figure 1. Free Gas effect in downhole pumping

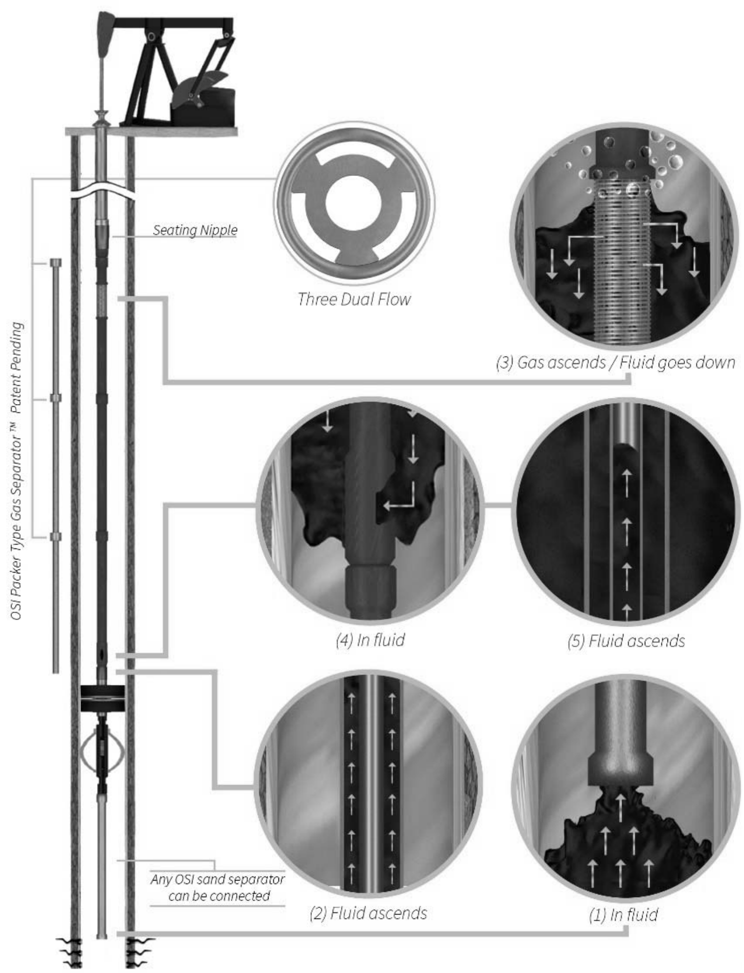

Figure 2. Packer Gas Type Separator

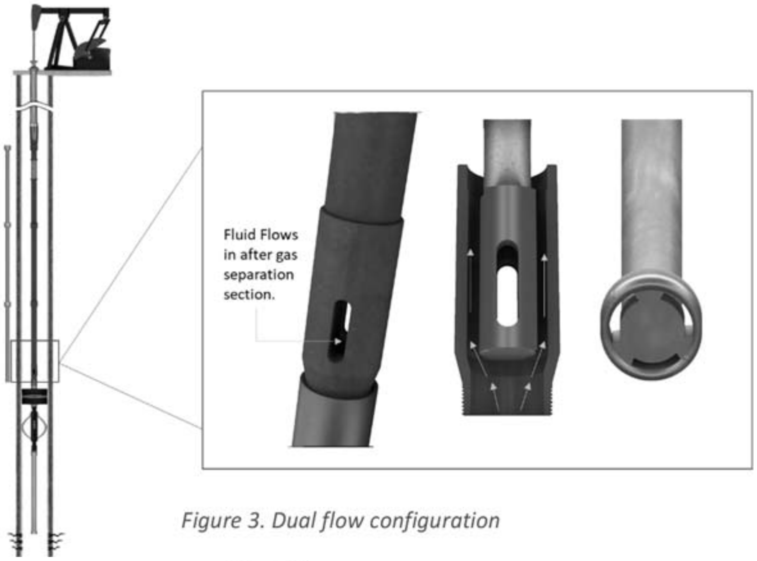

Figure 3. Dual flow configuration

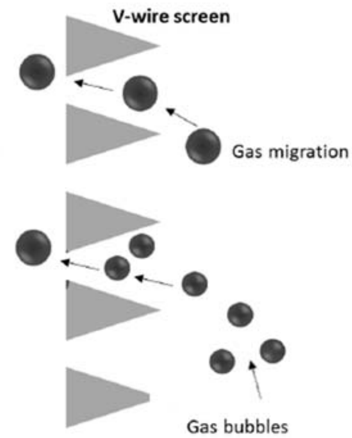

Figure 4. V-Mesh Screen- Gas migration

Figure 5. Inverted double cup packer.

Figure 6. Rotational Packer w/ TAC

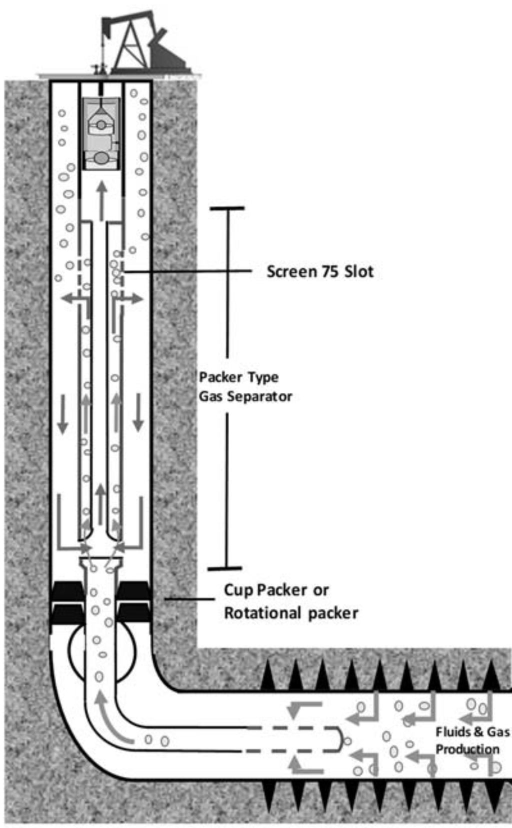

Figure 7. Flow path through the New Packer Gas Type Separator-Cup or rotational packer

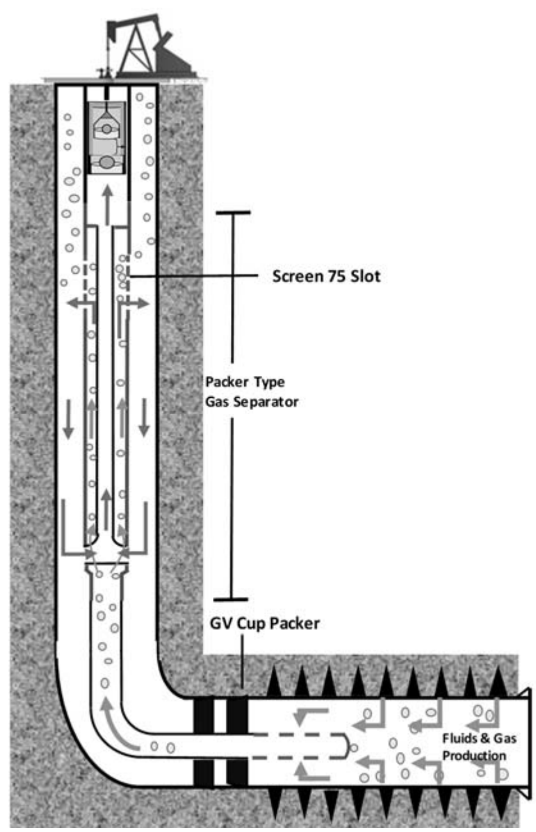

Figure 8. Flow path through the New Packer Gas Type Separator-Cup packer

Figure 9. Outlet section

Figure 10. Intake section

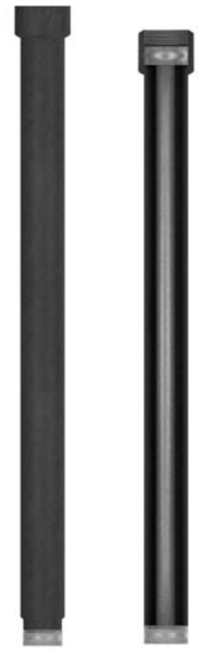

Figure 11. Middle section

PRESSURE DROP THROUGH THE DIP TUBE

Data			
Reference Pressure [PIP](psi)	400	I.D. (in)	1.38
DeltaP	40	Length (ft.)	72
Reference Depth [Pump Depth](ft)	8820	API	40
Reservoir Pressure (psi)	1500	SGw	1.05
Oil Production (BOPD)	175	SGg	0.75
Water Production (BWPD)	175	Liq Viscosity (cp)	1
Gas Production (Mscfd)	220	Gas viscosity (cp)	0.01625
Produced GOR (scf/stb)	1257.1	SGo	0.8251
Liquid Prodcution (BFPD)	350	Ap(ft^2)	0.0104
BHT (F)	163	Surf. Tension (lb/s2)	0.058

Fluid Properties			
Measured (Optional)		AVG. Pressure	
Average Pressure (psi)		420	
Rs		RS	93.7
Bo		Bo	1.09
Z (P,T)		Prd	0.64
		Trd	1.54
		Z	0.936459

8.104

Results	
Flow Regime	Slug
Relative Roughness	0.00130435
Reynolds(L)	108365
E/D	0.1480
Reynolds(g)	137004
Friction Factor	0.00576991
Delta P	**8.104**

Figure 12. Pressure drop through the Dip Tube - Well A

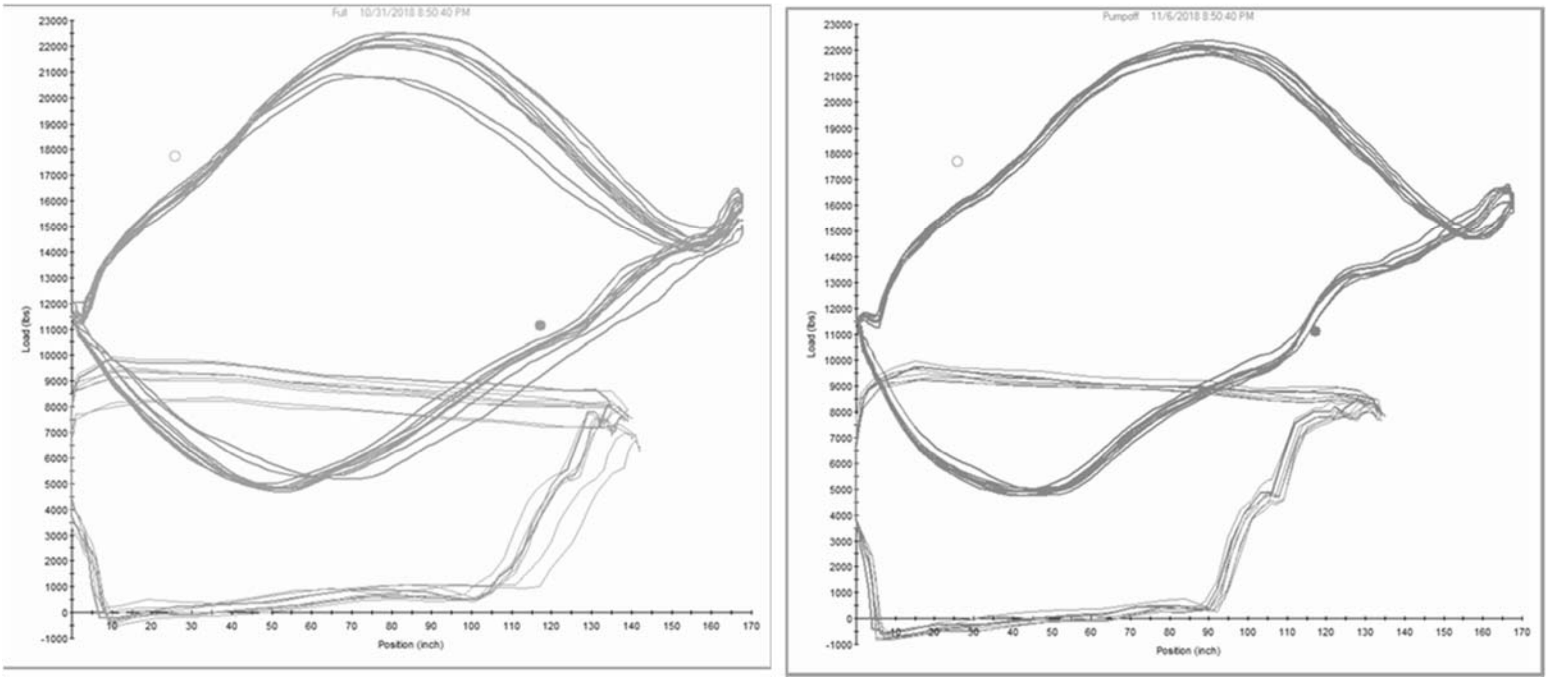

Figure 13. Pump Card WELL A Full card and Pump Off Before New Packer Type Gas Separator

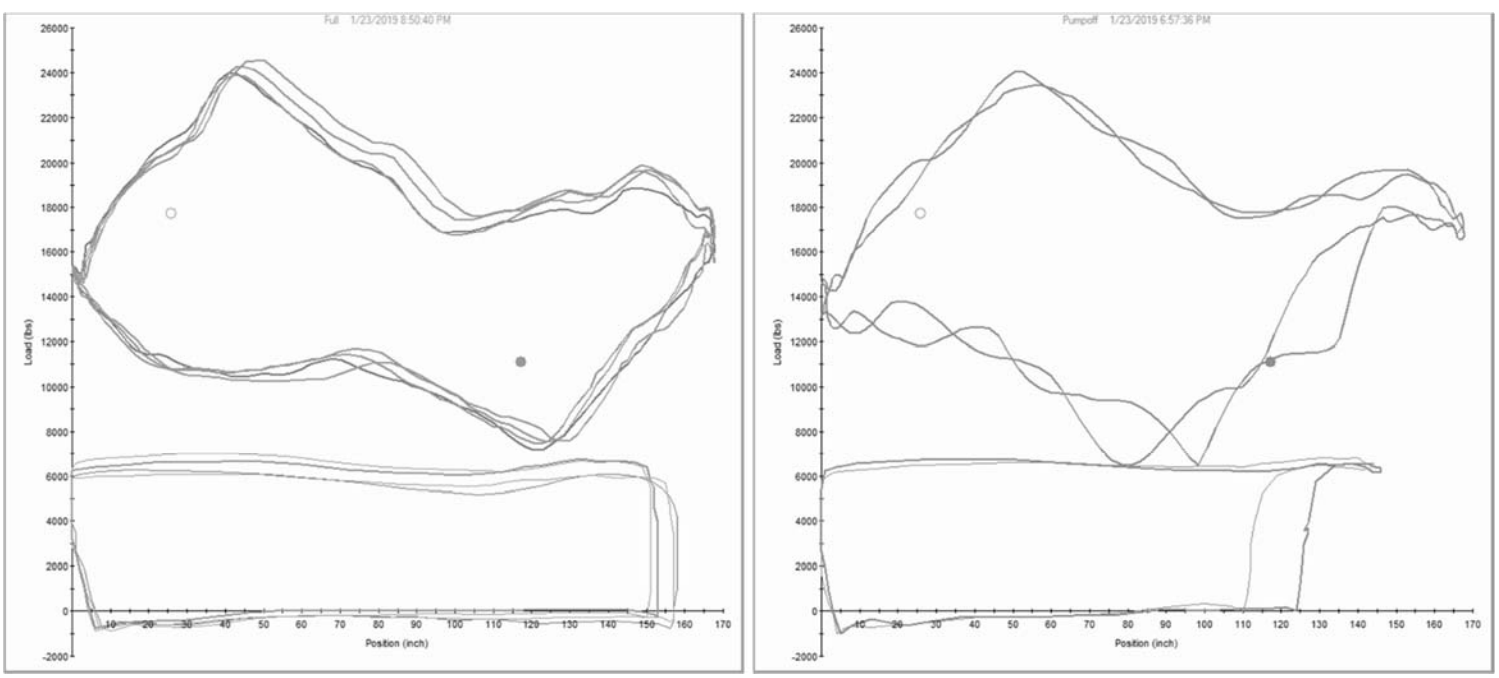

Figure 14. Pump Card WELL A Full card and Pump Off after the New Packer Type Gas Separator

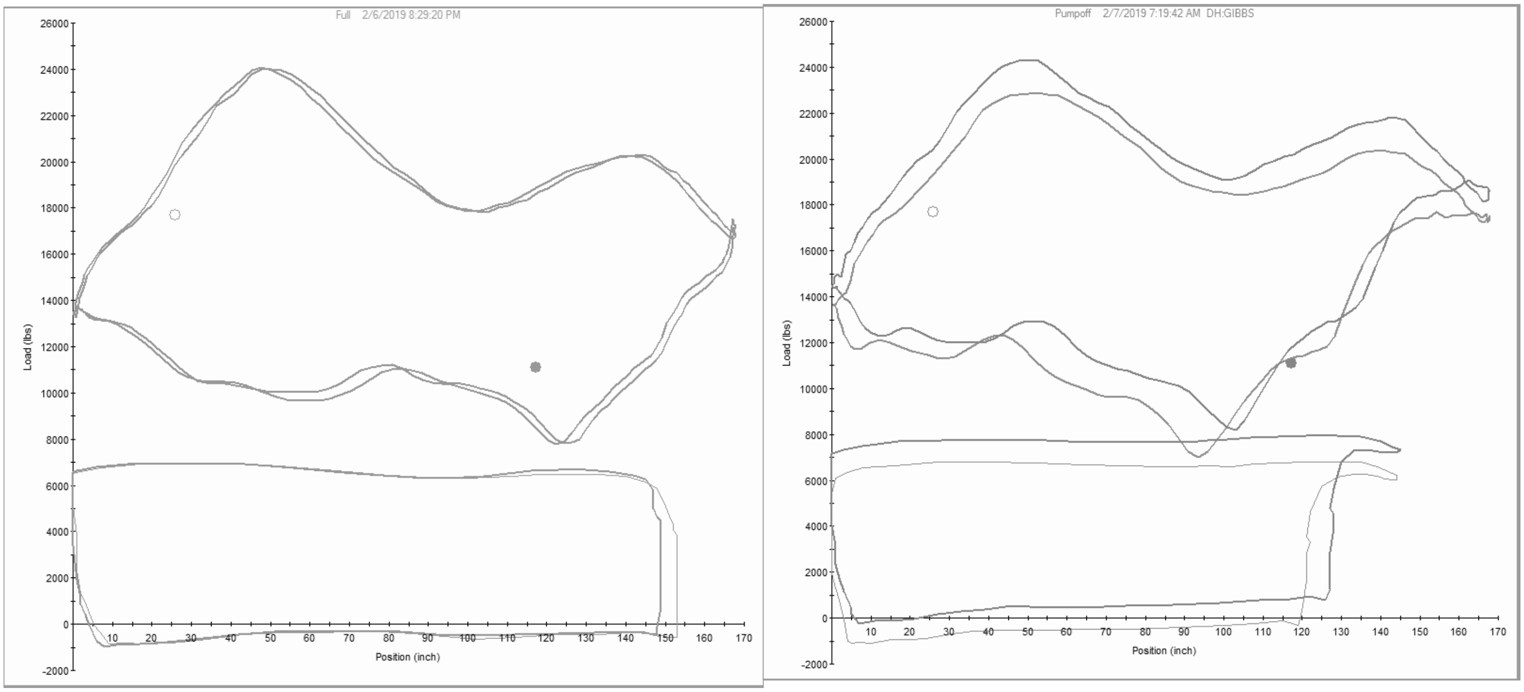

Figure 15. Pump Card WELL A Full card and Pump Off after the New Packer Type Gas Separator installation 6.3 RPM (7.1 before).

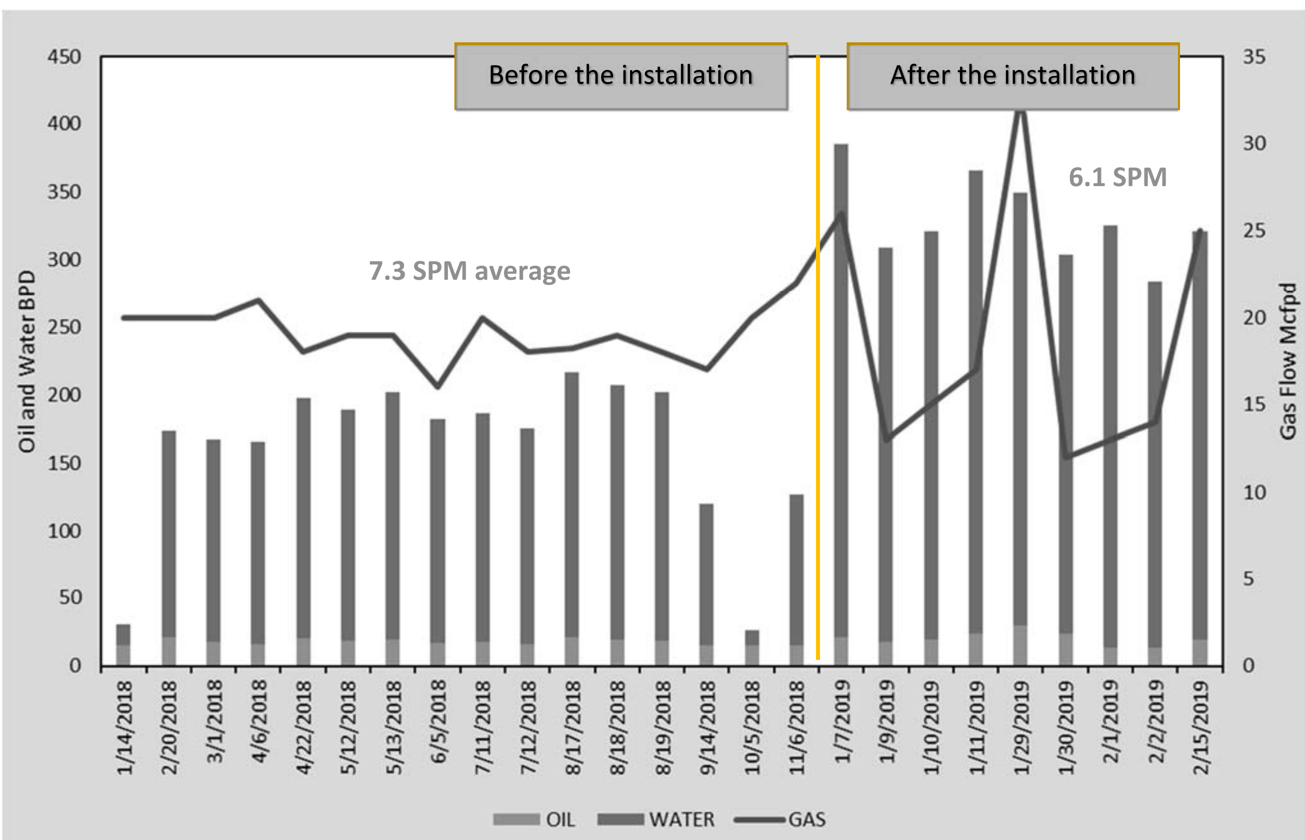

Figure 16. Production Chart

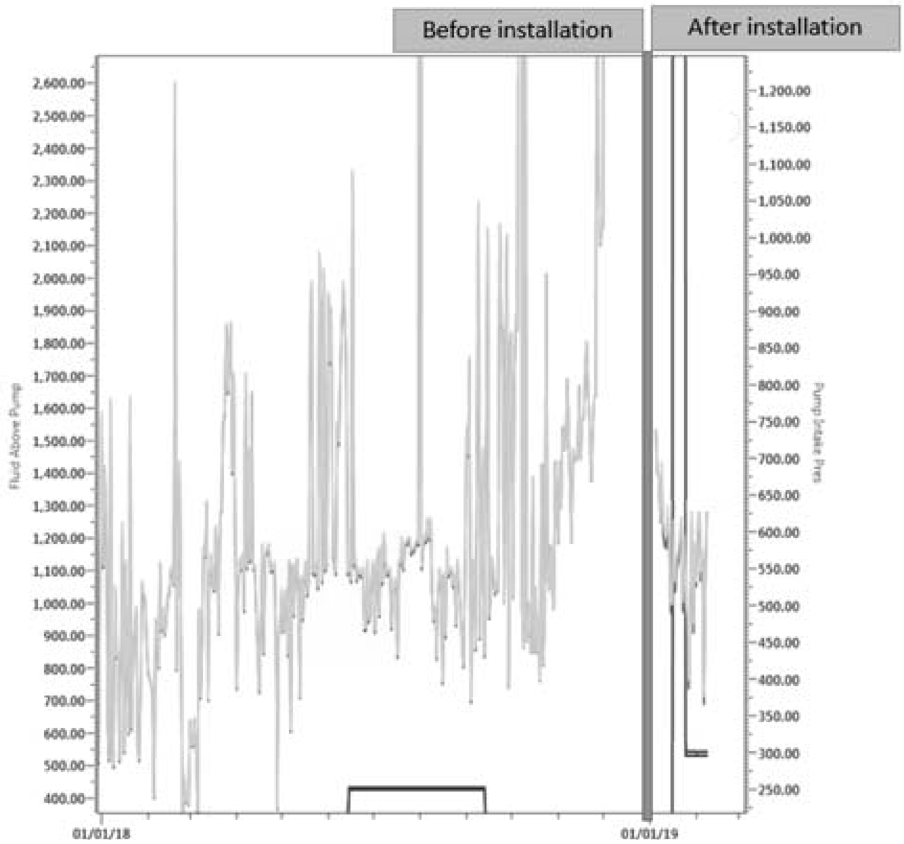

Figure 17. Fluid above the pump.