GAS ANCHOR DESIGN CHANGES USED TO IMPROVE GAS SEPARATION IN COALBED METHANE OPERATIONS IN WYOMING

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PURPOSE

Limited field-testing of gas separators used with progressing cavity pumps have shown improved gas separation with the pump set in the producing interval. This paper is presented to illustrate these changes and their associated improvement and to exchange information with other operators. While these modifications are not fully understood or tested with a significant number of installations the improvement observed warrants discussion.

INTRODUCTION

In Power River Basin Coal Bed Methane wells downhole gas separation is a problem on roughly 10% of our wells. Standard practice has been to initially run a pump without a gas anchor since 12 to 18 months of water production are required before significant gas production. Gas that is not separated downhole is produced up the tubing and is subsequently vented from the produced water tanks. Most of these wells have minimal volumes (5 to 15 MCFD) coming up the tubing. However, some wells have significant gas, 30 to 100 MCFD, coming up the tubing. Wells that have gas separation problems tend to be in the initial dewatering period producing high water rates and have high bottom hole pressure.

Case histories and mud anchor / gas anchor design changes will be reviewed on two wells, 43-26 and 24R-24. The discussion will be ordered in the well listing above since this was the progression of changes that were made to these wells to improve downhole gas separation.

GAS SEPARATOR DESIGNS

Gas separators are typically designed to have a downward velocity that does not exceed 0.5 ft/sec and for beam pumping the following Rules-of-Thumb are used in design:

1. Use the largest OD mud anchor allowed by the casing allowing for overshot dimensions.
2. Minimum gas separator annulus area for 0.5 ft/sec downward velocity
   Area, in^2 = 0.00935 x pump displacement, BLPD / velocity in annulus, ft/sec
   Area, in^2 = [0.00935/0.5] x BLPD = 0.0187 x BLPD
3. Minimum slot area in mud anchor = 4 x annulus area
4. Minimum slot area in dip tube = 4 x ID area of dip tube
5. Volume of annulus area from the bottom slot in the mud anchor to the top slot of the dip tube should be 1.5 x pump displacement for a “quiet space”.

A PC pump operation is slightly different than a rod pumping operation in that there is not a “stagnant period” that exists with rod pumping. **A** schematic for a typical gas separator is shown in Attachment 1.

It is typical to have ½” wide by four inches long slots in the mud anchor with some designers having maximum slot size equating to 50% of the area removed. ***However, the designs tested and evaluated in these installations intentionally used smaller slot width and added vent holes. This concept assumes that a smaller slot width will reduce the amount of gas entering the gas separator and the vent holes will allow the gas that enters to vent back to the casing.***

Well 43-26

Well 43-26 is a 7” completion with a 14” under reamed open hole as shown in Attachment 2. Each of the different pumping installations is also shown in Attachment 2. Attachment 3 plots the production history including water and gas production plus intake pressure and PCP RPM when available. An analysis of the pump performance is shown in Attachment 4 including the pump RPM, pump efficiency, mud anchor inlet slot fluid entry velocity and the downward velocity between the ID of the mud anchor and the OD of the dip tube (gas anchor). Attachment 6 provides the tabulated information of the data plotted in Attachment 3 on each installation and the calculation results of the gas separator velocities and pump efficiencies.

Attachment 2 shows the six different pumping installations for this well as follows:
Installation #1 - A progressing cavity pump (PCP) without an anchor. Mud anchor intake at 1429'.
Installation #2 - PCP with a "standard" gas separator with a 3.5" OD x 8' mud anchor and a 1.75" OD x 6' dip tube. Mud anchor intake at 1419'.
Installation #3 - PCP with a longer "standard" gas separator with a 3.5" OD x 24' mud anchor and a 1.75" OD x 22' dip tube. Mud anchor intake at 1410'.
Installation #4 – PCP with a new design (see Attachment 5) including vent holes. A 5.5" OD x 26' mud anchor and a 1.75" OD x 24' dip tube. Mud anchor intake at 1374'.
Installation #5 – Same as installation #4, but pump depth raised to 1344'.
Installation #6 - Due to coal plugging the gas separator, a 5 ½" slotted liner was run with the bottom 20 feet being blank pipe which allowed the pump intake to be "sumped" or placed below the bottom slot of the liner. Intake at 1446'.

The water rate is measured with a turbine meter at the surface and any gas produced with the water up the tubing will cause a significantly higher rate from the turbine meter (see Attachment 3). With gas being produced up the tubing an estimated water rate was determined by measuring the rate into a "bucket". The initial PCP (installation #1), without a gas anchor, had significant gas being produced up the tubing as indicated by difference in the turbine meter and the bucket tests. While the turbine meter was registering 670 to 1180 BWPD, in actuality, bucket testing indicated that the water rates were much lower at 225 to 75 BWPD.

The PCP was pulled and a "standard" gas separator (installation #2) was installed. A "standard" gas separator made by a local supplier consisted of 3 ½" tubing for the mud anchor with two slots cut with a torch that were 0.3" wide by 6" long. The length of the mud anchor was 8' with a 6' by 1.75" OD dip tube or gas anchor. Attachment 3 shows significant gas up the tubing based on the turbine meter and the gas produced up the tubing became worse as the water production decreased.

The PCP was pulled and another "standard" gas separator (installation #3) was run except the mud anchor and dip tube were lengthened. This combination would not produce water to surface and only gas was produced from the tubing. It is not clear why fluid was not surfaced but what can be observed in Attachment 2 is that the pump intake depth changed between installations. It is possible that the gas anchor intake was set next to a cleate/fracture that had an extremely high gas flow rate. Installation #3 had gas flowing up the tubing before the rotor was landed, but with the shorter assembly in installation #2 gas was not flowing out the tubing before the rotor was landed.

Since the well has 7" casing, this allowed for a larger mud anchor to be run as shown in well bore schematic in Attachment 2 and the photograph in Attachment 5. The differences in installation #4 included using more but smaller slots (eight 3/16" wide by 10" long) plus the addition of three ½" vent holes in the swedge. The performance difference was dramatic – essentially no gas up the tubing with very little difference between the hourly produced water rates and the 24 average. Installation #4 ran from June 21,2002 until August 7,2002 (47 days) when the PCP was shutdown by the drive due to excessive torque. When the well was pulled the bottom of the 5 ½" mud anchor was full of coal fines and had plugged the end of the dip tube. The same gas separator (installation #5) was re-run but set higher as shown in Attachment 2 and the same good gas separation results were obtained.

After the gas separator was plugged a second time, a 5 ½" slotted liner was installed with a 20' blank at the bottom. The blank liner allows for the pump intake to be sumped (installation #6) as shown in Attachment 2. The performance of the sumped pump intake out performed the other installations.

43-26 evaluation

Attachment 4 plots the data identified in Attachment 6. Calculations were made using the produced water rate, PCP size and the geometry of the gas separators to determine pump efficiency, inlet velocity through the mud anchor openings and downward velocity in the annular space between the mud anchor and the dip tube.

For installation #2, the first 3 ½" "standard" gas separator, the total inlet area into the mud anchor is 3.60 in^2 and the cross sectional area between the mud anchor ID and the OD of the dip tube is 4.63 in^2. Comparing both the graph in Attachment 3 and the tabulated data in Attachment 6, the following is noted:

1. Significant difference in the turbine meter hourly rates and the "bucket" test rates indicating significant gas

being produced up the tubing.

2. Actual water rates per "bucket" testing drops with subsequent tests as the hourly-metered rates continue to increase. Indication is that as the bottom hole pressure is reduced and the water rate is lowered that the actual gas rate into the tubing is increasing.
3. Pump RPMs are increasing in subsequent tests as the actual water rate is decreasing showing a reduction in pump efficiency and is indicative of more gas being produced up the tubing. Pump efficiency based on actual water ("bucket" test) rate starts at 100% and consistently declines to 23% by the fourth test. Although pressure measurements are not provided, the fluid level was measured and the well was not pumped off indicating that the loss of pump efficiency was due to poor gas separation not a pumped off condition.
4. As the actual water rate is reduced both the inlet velocity and the downward velocity is reduced. The inlet velocity starts at 1.04 ftisec and declines to 0.39 ft/sec by the fourth test. The downward velocity starts at 0.81 ft/sec and declines to 0.30 ftlsec by the fourth test.

Gas separators are typically designed to have a downward velocity that does not exceed 0.5 ftisec. However, this is for rod pumping in which the production occurs only on the upstroke. In PCP operations there is not a "stagnant period" and the fluid flow is more continuous. The downward velocity, based on water production only, is 0.81 ftlsec as the well is placed on production and starts the unloading process. As the unloading process continues and the water production decreases the downward velocity is reduced. However, as the water rate is reduced and the downward velocity is reduced the gas separation gets worse as identified by the increase in the turbine metered rate, the decreasing pump efficiency and the physical observation of free gas blowing out the tubing bleed valve. Attachment 2 also shows there is a ten foot difference in the depth of the pump intake without a gas anchor at 1429' in installation #1 and with the 3 ½" gas separator inlets being at 1419' in installation #2. Comparing results of this installation there was very little, if any, improvement in performance over the PCP without a gas separator.

Data for the second 3 ½" gas separator (installation #3) in which the mud anchor and dip tube lengths were increased is shown in Attachments 2 installation schematic and the tabulated data in Attachment 6. Only gas was produced up the tubing, no water was surfaced. The only difference was the length of the gas separator and the position of the intake at 1410' or nine feet higher than the previous installation at 1419'. It appears that the intake was positioned adjacent to a cleat or fracture since gas was being produced up the tubing before the rotor was installed.

Installation #4 is a 5 ½" gas separator installation with the 15.0 in^2 total inlet area into the mud anchor and the cross sectional area between the mud anchor ID and the OD of the dip tube is 16.84 in^2. Comparing both the graph in Attachment 4 and the tabulated data in Attachment 6, the following is noted:

1. The 5 ½" gas separator design has 15.0 in^2 of inlet area (approximately 4 times the 3 ½" design) and 16.84 in^2 cross sectional area (approximately 3.6 times the 3 ½" design).
2. The 5 ½" gas separator inlet slots were 3/16" or 0.1875" wide by 10" long as compared to 0.3" wide by 6" long. There was more inlet area in the 5 ½" design due to more slots (8 versus 2) but the 5 ½" gas separator slots were 40% smaller in width than the 3 ½" design.
3. The 5 ½" gas separator had three ½" vent holes in the swedge above the mud anchor. The 3 ½" design did not have any vent holes. The vent hole area is not included in the inlet area calculation but three ½" diameter holes would only add 0.59 in^2.
4. Very little difference in the turbine meter hourly rates and the 24-hour average rate indicating very little gas being produced up the tubing with the 5 ½" gas separator.
5. Pump RPMs are decreasing in subsequent tests as the water rate is decreasing and pump efficiency remains high and greater than 85%.
6. As the water rate is reduced both the inlet velocity and the downward velocity is reduced. The inlet velocity starts at 0.27 ft/sec and declines to 0.22 ftisec by the fourth test. The downward velocity starts at 0.24 ftisec and declines to 0.19 ftisec by the fourth test.

It should be noted that both the inlet velocity (0.27 to 0.22 ftisec) and downward velocity (0.24 to 0.19 ftisec) calculated with turbine meter water rates with the 5 ½" gas separator are significantly lower than the 3 ½" (inlet velocity – 1.04 to 0.39 ftisec, downward velocity – 0.81 to 0.30 ft/sec). However, in all tests with the 3 ½" gas separator there was significant gas being produced up the tubing and with the 5 ½" design there was essentially NO gas up the tubing. Also the 3 ½" gas separator performance continued to deteriorate as the water rate decreased and as the downward velocity decreased below the typical design downward velocity of 0.5 ftlsec to 0.30 ftisec.

The pump intake was moved up the hole with the 5 ½" gas separator with the pump intake now at 1374' or 45 feet higher (1419' – 1374') than the original 3 ½' gas separator.

After 47 days the PCP was pulled due to high torque and found the bottom of the 5 ½" mud anchor full of solids which bridged across the 1.75" gas anchor starving the pump. The same installation was run with the intake just below the 7" casing shoe moving the pump intake to 1344' or 75' higher (1419-1344') than the original 3 ½" gas separator pump intake. Attachment 3 shows the test data and performance and was similar to the pervious performance of the 5 ½" gas separator set 30' deeper. After 46 days of production the 5 ½" gas separator plugged again and it was decided to run the slotted liner.

As shown in production graph in Attachment 3 and the tabulated data in Attachment 6, sumping the pump in the blank section of the liner made a significant difference in the gas rate and water production.

Why did the gas separation improve with the larger gas anchor? Was it merely because the larger OD mud anchor reduced the downward velocity?

Looking at the first test with the 5 ½" design in Attachment 6, 433 BWPD and no gas was produced with a downward velocity of 0.24 ftisec through a cross sectional area of 16.84 in^2. If we equate that to the 4.63 in^2 cross sectional area of the 3 ½" gas separator, then the 3 ½" gas separator should have been able to produce 433 BWPD x 4.63/16.84 = 119 BWPD at the same downward velocity of 0.24 ft/sec. However, at 0.30 ft/sec downward velocity or 150 BWPD the 3 ½" gas separator was still producing significant gas up the tubing. Although the larger diameter helped the difference between 0.24 ftisec and 0.30 ftisec should not have made such a dramatic difference in gas separation performance.

There are three other differences between the 3.5" and the 5.5" design including – the 5.5" design had more but smaller mud anchor openingsproviding greater inlet area, vent holes in the mud anchor and was set 45' to 75' higher (less submergence and different locations within the well bore).

In both the 3 ½" and 5 ½" gas separators the downward velocity was less than 0.5 ft/sec, but only the 5 ½" design had adequate gas separation. The lowest downward velocity in the 3 ½" design was 0.30 ftlsec as compared to the 5 ½" design being less than 0.25 ftisec in all tests. It should also be noted that the 3 ½" gas separator had more submergence than either of the 5 ½" installations.

In the 5 ½" gas separator design three ½" vent holes were placed in the swedge on top of the gas separator. The area of the vent holes is 0.59 in^2 as compared to the 15 in^2 of the inlet slots. The vent hole area is only 4% of the inlet slots so this additional area would not significantly decrease the inlet velocity. However, with the vent hole position in the reduced area of the swedge (see Attachment 5) the flow enters a larger cross sectional area which will cause a slight reduction in pressure allowing gas that has entered the gas separator to vent.

Each of these differences listed above could have an impact on gas separation and would appear that some combination of these differences has a greater influence on gas separation than only increasing the cross sectional area.

Well 24R-24

Well 24R-24 is a 7" completion with a 14" under reamed open hole with a 5 ½" slotted liner as shown in Attachment 7 installation scematic. This well was originally a 7" completion with an under reamed open hole with a scab line set across a shale. When the 5 ½" slotted liner was run it was set on top of the scab liner. There is an offset between the scab liner and the bottom of the slotted liner so than the pumps cannot be set in the scab liner.

Each of the different pumping installations is also shown in Attachment 7 installation schematics. Attachment 8 plots the water and gas production plus the pump RPM and the pump intake pressure. An analysis of the pump performance is shown in Attachment 9 including the pump RPM, pump efficiency, mud anchor inlet slot fluid entry velocity and the downward velocity between the ID of the mud anchor and the OD of the dip tube (gas anchor).

Attachment 7 installation schematic shows the four different pumping installations for this well as follows:
Installation #1 - Progressing cavity pump (PCP) without an anchor. Pump intake at 1328'.
Installation #2 - PCP with a 3 ½" gas separator, modeled after the 43-26 5 ½" design, with a 3.5" OD x 11' mud anchor and a 1.75" OD x 8' dip tube. Mud anchor intake at 1319'.

Installation #3 – ESP with the intake at 1328' and 1318'.
Installation #4 – PCP with a new 4" design with baffled vent holes with a 4.0" OD x 23' mud anchor and a 1.75" OD x 20' dip tube. Mud anchor intake at 1311'.

In each installation the gas anchor was set as close to the bottom of the 5 ½" slotted liner and the gas separator inlet position or pump intake was within 17 feet (1311' to 1328') in any of the installations.
The PCP run without a gas separator (installation #1) shows the same trend as the 43-26 in that the bucket testing of water rate is lower than the metered sate. Sampling of the flow indicated that significant gas was being produced up the tubing. Gas interference made it difficult to get the BHP below 130 psi and as the pressure increased to 150 psi the gas rate decline drastically.

A decision was made to pull the PCP and install a 3 ½" gas anchor (installation #2) modeled after the 5 ½" installation in 43-26. This design was constrained by the 5 ½" slotted liner so a 3 ½" by 11' mud anchor was used with 8 slots (3116" wide by 8" long) and 3 vents (½" diameter) were drilled in the 2 ½" x 3 ½" swedge. Upon installation and start-up the performance was worse as shown by the lower gas rate than the PCP without an anchor but still surfaced water.

Since the PCP with the "modified" 3 ½" gas separator did not work the equipment was pulled and an ESP was installed (installation 3#). The ESP would not surface fluid and was raised ten feet with the same results. This ESP did not have a rotary gas separator (RGS). The first ESP installation had the intake at 1328', which was the same depth as the initial PCP. It should be noted that other ESP wells with a RGS excellent gas separation.

It was felt that the due to the smaller well bore size that fluid impingement on the vent holes was not allowing gas to vent from the separator. The next design utilized 4" line pipe for the mud anchor with the same slot size and length previously used on the "modified" 3 ½" design. The swedge was replaced with a 6" 2 *718*" nipple with three ½" holes phased at 120 degrees. To keep fluid from impinging on the vent hole a piece of 4" pipe was positioned to cover the vent holes with bar stock used to weld the baffle to the nipple as shown in Attachment # 10. The PCP installation with the 4" baffled gas separator showed tremendous improvement with no gas observed at the surface tubing vent.

24R-24 evaluation

Attachments 9 and 11 show the test results and calculations for the 3 ½" "modified" gas separator. The total inlet area into the mud anchor is 12.0 in^2 and the cross sectional area between ID of the mud anchor and the OD of the dip tube is 4.63 in^2. Comparing both the graph in Attachment 8 and the tabulated data in Attachment 11, the following is noted for installation #2:

1. Design similar to the 5 ½" design run in 43-26 except the OD of the mud anchor was 3 ½". The slots were *31* 16" wide but were 8" long rather than 10". In the 2 ½" by 3 ½" swedge there were three ½" diameter vent holes were drilled.
2. Significant difference in the turbine meter hourly rates and the "bucket" test rates indicating significant gas being produced up the tubing. Physical observation during the bucket tests indicated significant gas up the tubing.
3. Actual water rates per "bucket" testing drops with subsequent tests (150 to 35 BWPD) as the hourly-metered rates continue to increase.
4. Pump RPMs are increasing in subsequent tests as the actual water rate is decreasing showing a reduction in pump efficiency and is indicative of more gas being produced up the tubing. Pump efficiency based on actual water ("bucket" tests) rate starts at 130% and consistently declines to 29% by the fifth test.
5. As the actual water rate is reduced both the inlet velocity and the downward velocity is reduced. The inlet velocity starts at 0.12 ftlsec and declines to 0.03 ftlsec by the fifth test. The downward velocity starts at 0.30 ftlsec and declines to 0.07 ftlsec by the fifth test.

The ESP (installation #3) that was run after the failure of the PCP with the 3 ½" modified gas separator, produced only gas up the tubing, no water was surfaced. The ESP was raised ten feet with the same results. A 4" 7.5 HP NEMA motor (2.4' long) operated the pump and did not have a shroud or a RGS.

Installation #4 is the 4" "modified" baffled gas separator that has a total inlet area into the mud anchor of 12.0 in^2 and the cross sectional area between the mud anchor ID and the OD of the dip tube is 4.63 in^2. Comparing both the graph in Attachment 7 and the tabulated data in Attachment 11, the following is noted:

1. Design similar to the previous 3%" design except the OD of the mud anchor was increased to 4". The slots were 3116" wide by 8" long". In the 2 ½" by 3 ½" swedge there were three ½" diameter vent holes were drilled.
2. The vent hole placement and configuration was changed from placing the holes in a swedge to placing the vent holes on a 2 718" nipple and covering the holes with a 4" OD baffle.
3. Physical observation indicated essentially gas free water produced up the tubing.
4. Pump efficiency based on actual water rate and pump RF'M starts at 130% and was maintained above 85% in all tests. Efficiencies above 100% is probably due to the calculations used a pump RF'M too high due to the speed variation from the drive to maintain the intake pressure set point.
5. As the actual water rate is reduced both the inlet velocity and the downward velocity is reduced. The inlet velocity starts at 0.21 ftlsec and declines to 0.07 ftlsec by the sixth test. The downward velocity starts at 0.35 ftlsec and declines to 0.12 ftlsec by the sixth test.

Why did the 4" gas separator improve separation over the 3 ½" with the 4" gas separator?

Was it merely because the larger OD (4" versus 3 ½") mud anchor reduced the downward velocity? Attachment 11 shows that the 3 ½" modified design had lower inlet (0.12 to 0.03 ftlsec) and downward velocities (0.30 to 0.07 ft sec) than the 4" design with the baffled vent holes (0.21 to 0.14 ftlsec inlet and 0.35 to 0.19 ftlsec downward velocity). At a higher downward velocity the 4" design had no gas up the tubing and maintained pump efficiency greater than 85%. The 3 ½" design pump efficiency fell off to less than 30%. Although pressures were not available for all tests, fluid levels indicated that the fluid level was maintained above the pump and therefore the poor pump efficiencies are due to poor gas separation and not pumping the well off.

It does not appear that the increased area resulted in the improvement.

·Does the additional length of the mud anchor in the 4" design (23') over the 3 %"design (11') account for the improvement?

Within this field test there were not sufficient different lengths of gas separators built to answer this question. Also, the mud anchor intake positions were at different depths complicating the comparison. There have been previous studies by other investigators indicating that increasing length does not continually improve separator performance.

Could the baffled vent holes be providing benefit?

Comparing Attachment 8 and the data in Attachments 11, the main difference in the design between the 3 ½" and the 4" were the increase in mud anchor diameter and the use of the baffle around the vent holes. As previously discussed the increased diameter does not support the increased performance since the downward velocity is greater in the 4" than the 3 ½". Going from the 3 ½" to 4" mud anchor has a cross sectional area ratio of 7.22/4.63 = 1.6 times area increase for the 4". The ratio of the increase in BWPD for the 4" is 1.8 to 4.2 times greater than the 3 ½" and the 4" was gas free in the tubing as opposed to significant gas produced up the tubing with the 3 ½" gas separator.

The inlet slots and the vent holes were the same in both designs but the 4" used a "baffle" to cover the vent holes. For vent holes to work a pressure drop must be created at the annular side of the vent holes. Since the gas flows up the annulus, a change in cross sectional area from larger to smaller, between the casing and the gas separator, will cause a reduced pressure from gas expansion. In the 5 ½" design the holes were cut in the top of the 3 ½" by 4 ½" swedge. In this design there was an area increase in the direction of flow. The 3 ½" design had holes cut in the 2 ½" by 3 ½" swedge which produces a much smaller increase in area. By adding the 4" baffle across the 2 7/8" nipple a recessed area is created. This recessed area at the top of the baffle (see Attachment 10) could produce a slight pressure drop to allow the holes to vent gas out of the gas separator.

The baffle may also help gas to vent by preventing gas and water from impinging on the vent holes. The offset distance may be critical which may be why the 5 ½" design worked without a baffle and the 3 ½" design did not.

Again within the limitations of the field test there were not enough installations and variations to make hard conclusions. In well 24R-24 the intake positions varied only 17 feet (1328' – 1311') as compared to the 85 feet difference (1429'-1344') in 43-26. Although the change in the inlet position is not as great as with 43-26, having the intake line up with a high gas entrance point cannot be ruled out.

CONCLUSIONS

1. These results are based on limited field-testing but show encouraging results. Additional installations are planned

depending on cost and opportunity. Other operators are encouraged to try these modifications and share results. Visual modeling would also help in evaluating the different geometries and configurations.

2. These installations were for dewatering gas wells. While these concepts could also work on oil wells, these differences should be recognized and additional field-testing would be required.

3. Wells 24R-24 and 43-26 show that the addition of vent holes appears to substantially improve gas separator performance especially when the gas separators are set in the perforated or producing interval.

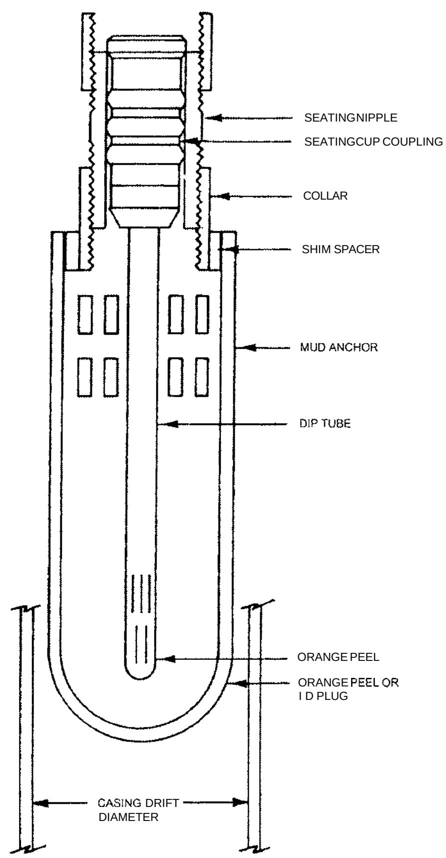
4. Well 24R-24 showed that a baffle to protect the vents holes was required in smaller diameter casing or slotted liners with intakes set in the producing interval to allow gas to vent. Additional 4' baffled gas separators are to be installed in problem wells that do not have the ability to place the intake below the producing interval.

5. Smaller mud anchor openings MAY reduce the amount of gas initially entering the mud anchor. This separation appears enhanced by the addition of vent holes.

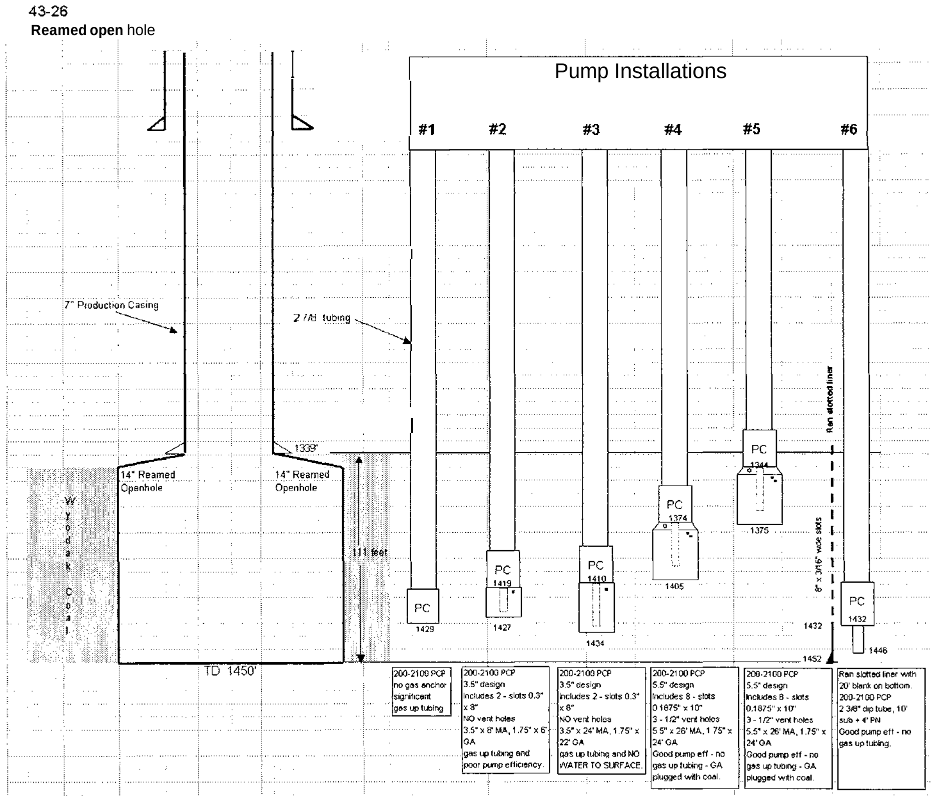
6. Both success and failures in gas separation was observed when the downward velocity in the gas separators under PC pumped wells was less than 0.5 ft/sec. The modified gas separators worked but the downward velocity was always less than 0.36 ft/sec. It should be noted that the modified gas separators have not been produced at their limit in these installations. However, it does indicate that the 0.5 ft/sec limitation may be optimistic for "standard" gas separators used with progressing cavity pumps.

7. Position of the inlet within the perforated interval could influence the performance of a gas anchor with "high" rates of gas and water impinging on the openings.

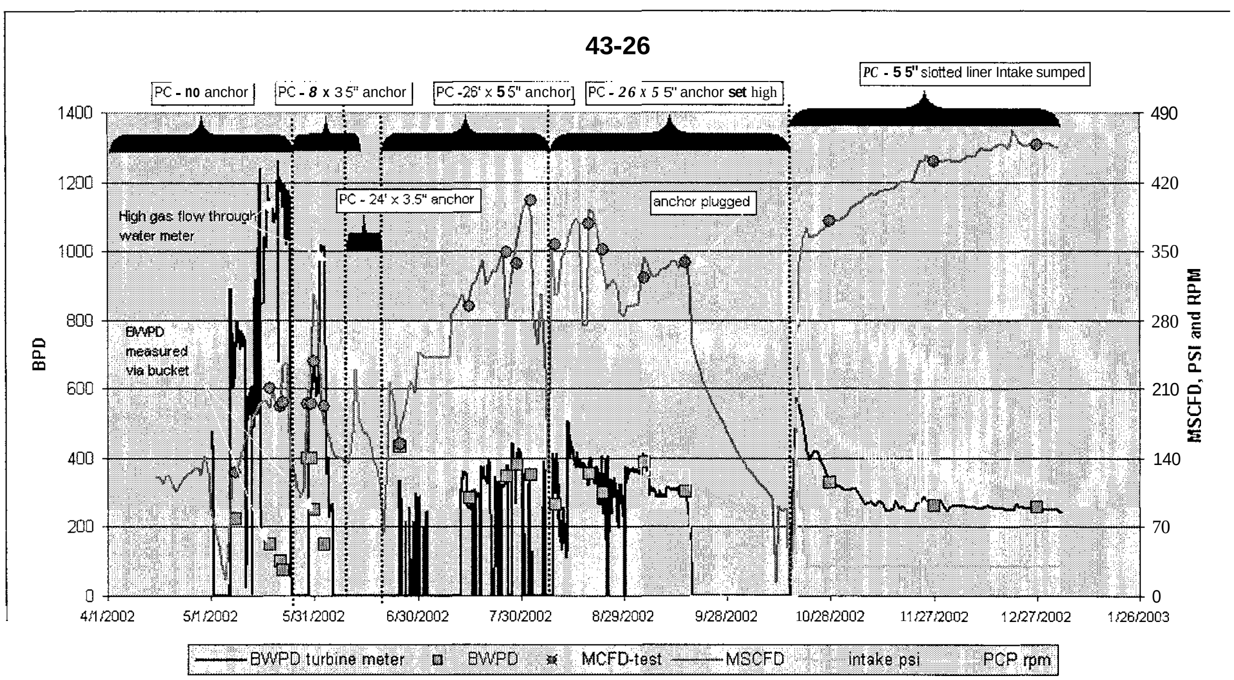
8. Well 43-26 illustrates that well construction can improve gas separation and supports the "age old theory" that placing the intake to the pump below the perforated interval creates an effective natural gas anchor. In this case adding a 20' blank on the bottom of the slotted liner created the necessary sump. ***The first choice in gas separation should always be providing a sump below the lowest producing interval.***



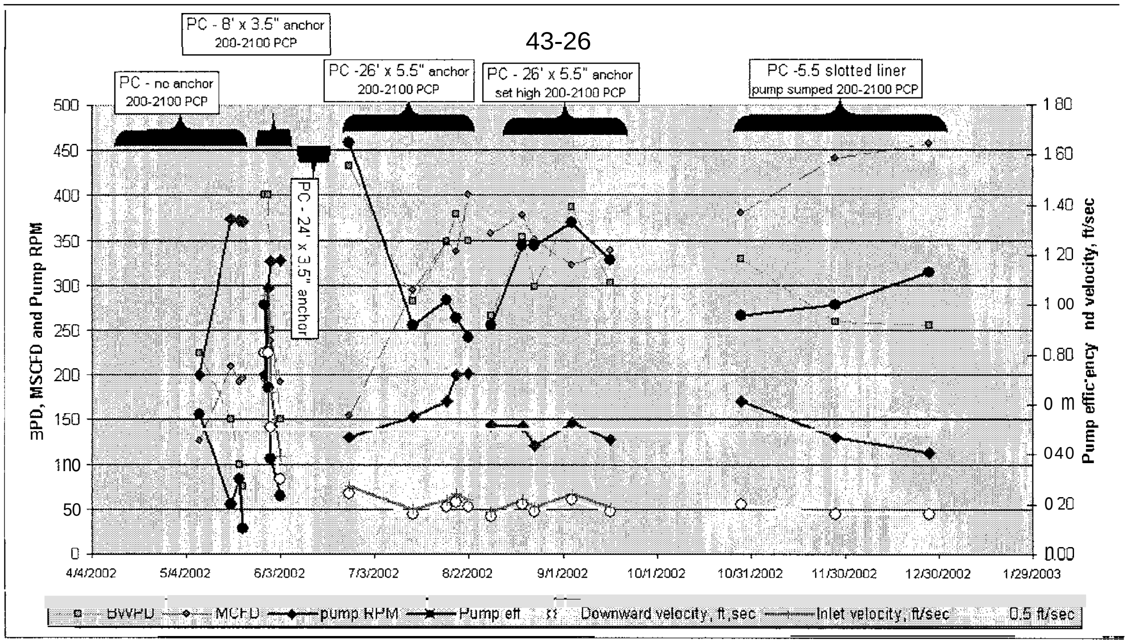
Attachment 1 – Typical Gas Separator Design



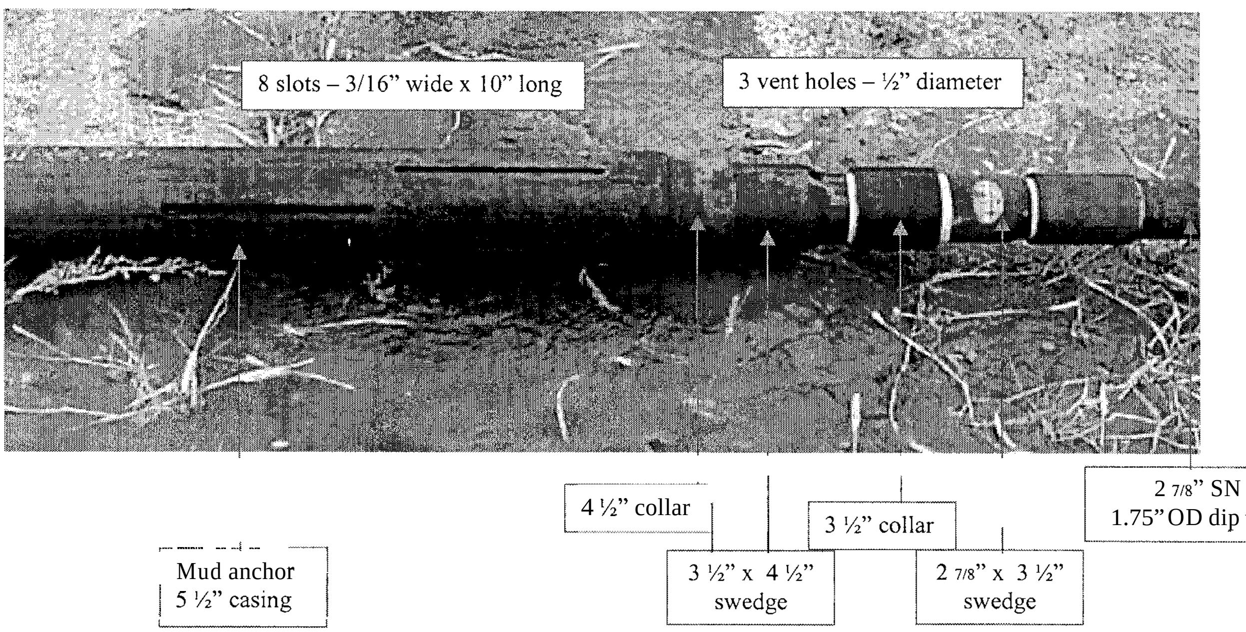
Attachment 2 – **Well 43-26** - Well and Pump Installations



Attachment 3 – **Well 43-26** – Graph of Production Rate, BWPD and MCSFD



Attachment 4 – **Well 43-26 –** Graph *of* Production Rate and Gas Separation Evaluation, BWPD, MSCFD, Pump RPM and Efficiency, Mud Anchor Inlet Velocity, Mud Anchor Downward Velocity

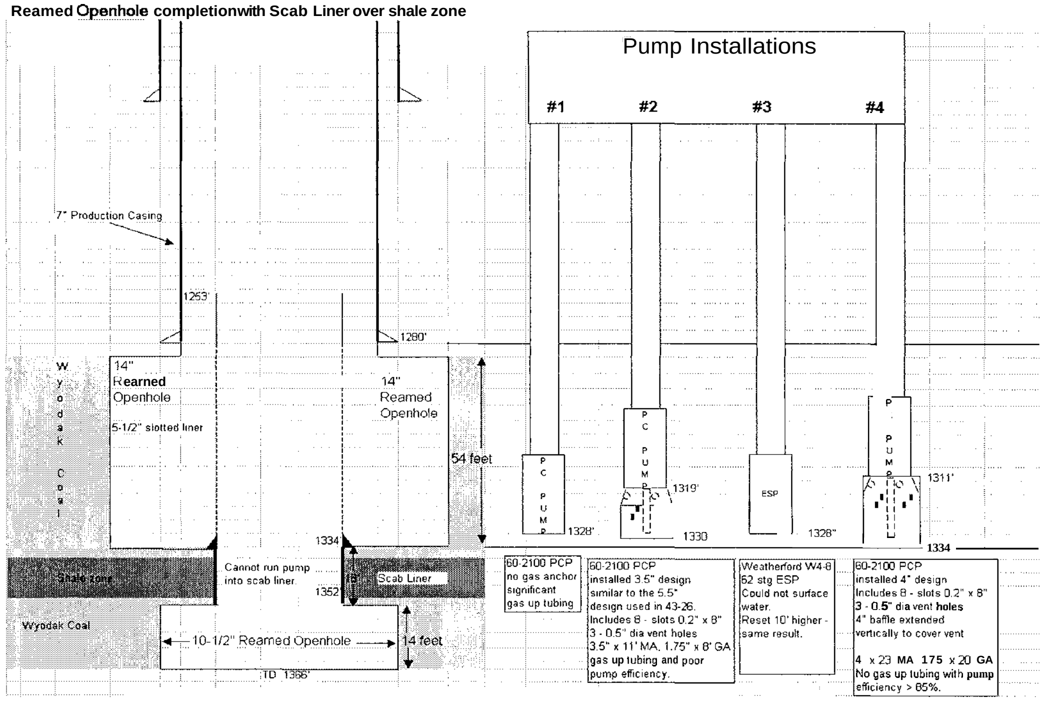


Attachment 5 – **Well 43-26** - Photograph of 5 ½" Gas Separator with Vent Holes

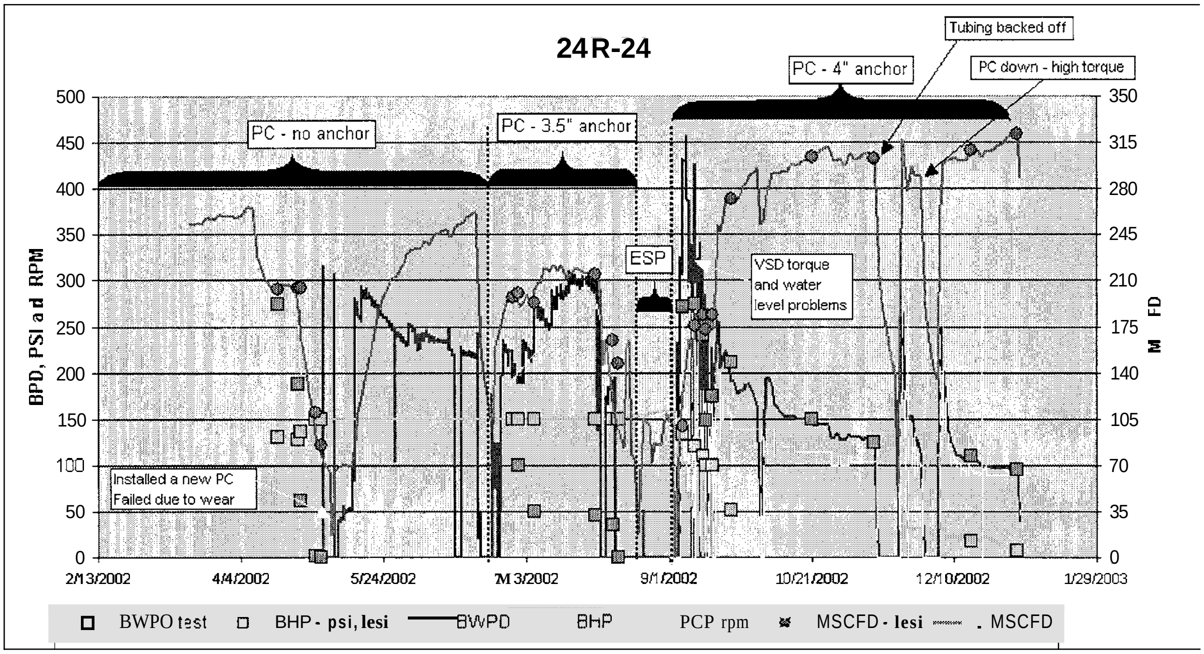
	43-26 Installation Description																		
1	Casing size and weight	7" 17#																	
2	Casing depth	1339'																	
3	Open hole size	14"																	
4	Open hole depth	1450'																	
5	Slotted Liner size and weight	NA																	
6	Liner depth	NA																	
7	Liner slotted interval	NA																	
8	Liner slot size	NA																	
9	Pump description	200-2100				200-2100				200-2100	200-2100					200-2100			
10	Pump setting depth, feet	1429				1419				1410	1374					1344			
11	Mud anchor OD, inches	none				3.5				3.5	5.5					5.5			
12	Mud anchor ID, inches	none				2.992				2.992	4.95					4.95			
13	Mud anchor length, feet	none				8				24	26					26			
14	Mud anchor setting depth (at bull plug), feet	none				1427				1434	1405					1375			
15	Mud anchor distance from BP to bottom slot, feet	none				6.5				22	24					24			
16	Dip tube OD, inches	none				1.75				1.75	1.75					1.75			
17	Dip tube length, feet	none				6				22	25					25			
18	Mud anchor Intake slot width, inches	none				0.3				0.3	0.1875					0.1875			
19	Mud anchor Intake slot length, inches	none				6				6	10					10			
20	Method used for slots (torch, saw, mill)	none				torch				torch	plasma torch					plasma torch			
21	Mud anchor number of slots	none				2				2	8					8			
22	Mud anchor vent hole diameter, inches	none				none				none	0.5					0.5			
23	Mud anchor number of vent holes	none				none				none	3					3			
24	Mud anchor vent hole deflector used (yes/no)	none				none				none	no					no			
25	MA inlet area, in^2	NA				3.6				3.6	15.0					15.0			
26	MA xsect area, in^2 (ID MA - OD GA)	NA				4.6				4.6	16.8					16.8			
	Pump Installation	#1	#1	#1	#1	#2	#2	#2	#2	#3	#4	#4	#4	#4	#4	#5	#5	#5	#5
	Peformance description	test 1	test 2	test 3	test 4	test 1	test 2	test 3	test 4	test 1	test 1	test 2	test 3	test 4	test 5	test 1	test 2	test 3	test 4
	Date	5/8/02	5/18/02	5/21/02	5/22/02	5/29/2002	5/30/2002	5/31/2002	6/3/2002		6/25/2002	7/15/2002	7/26/2002	7/29/2002	8/2/2002	8/9/2002	8/19/2002	8/23/2002	9/4/2002
	Pump intake pressure, psi	NA	NA	NA	NA	NA	NA	NA	NA	NO WATER TO SURFACE	NA	NA	NA	NA	NA	NA	NA	NA	NA
	BWPD, turbine meter	677	1097	1159	1179	593	422	635	1010		433	282	348	379	350	266	353	299	387
	BWPD, actual from bucket test	225	150	100	75	400	400	250	150		NA	NA	NA	NA	NA	NA	NA	NA	NA
	Estimated gas up tubing	50	75	+100	+100	50	50	75	+100		0	0	0	0	0	0	0	0	0
	Gas rate up casing	126	210	192	196	195	195	238	192		154	294	349	337	401	357	378	351	323
	Pump RPM	200	373	372	371	200	297	327	328		131	153	171	200	201	144	142	121	146
	Pump displacement @ RPM, BPD	400	746	744	742	400	594	654	656		262	306	342	400	402	288	284	242	292
	Pump efficiency (BWPD/pump displacement)	56.3%	20.1%	13.4%	10.1%	1.00	0.67	0.38	0.23		1.65	0.92	1.02	0.95	0.87	0.92	1.24	1.24	1.33
	water flow ft^3/sec	NA	NA	NA	NA	0.0260	0.0260	0.0162	0.0097		0.0281	0.0183	0.0226	0.0246	0.0227	0.0173	0.0229	0.0194	0.0252
	inlet velocity, ft/sec	NA	NA	NA	NA	1.04	1.04	0.65	0.39		0.27	0.18	0.22	0.24	0.22	0.17	0.22	0.19	0.24
	downward velocity, ft/sec	NA	NA	NA	NA	0.81	0.81	0.51	0.30		0.24	0.16	0.19	0.21	0.19	0.15	0.20	0.17	0.22

Attachment 6 **–Well 43-26** –Installation Descriptions

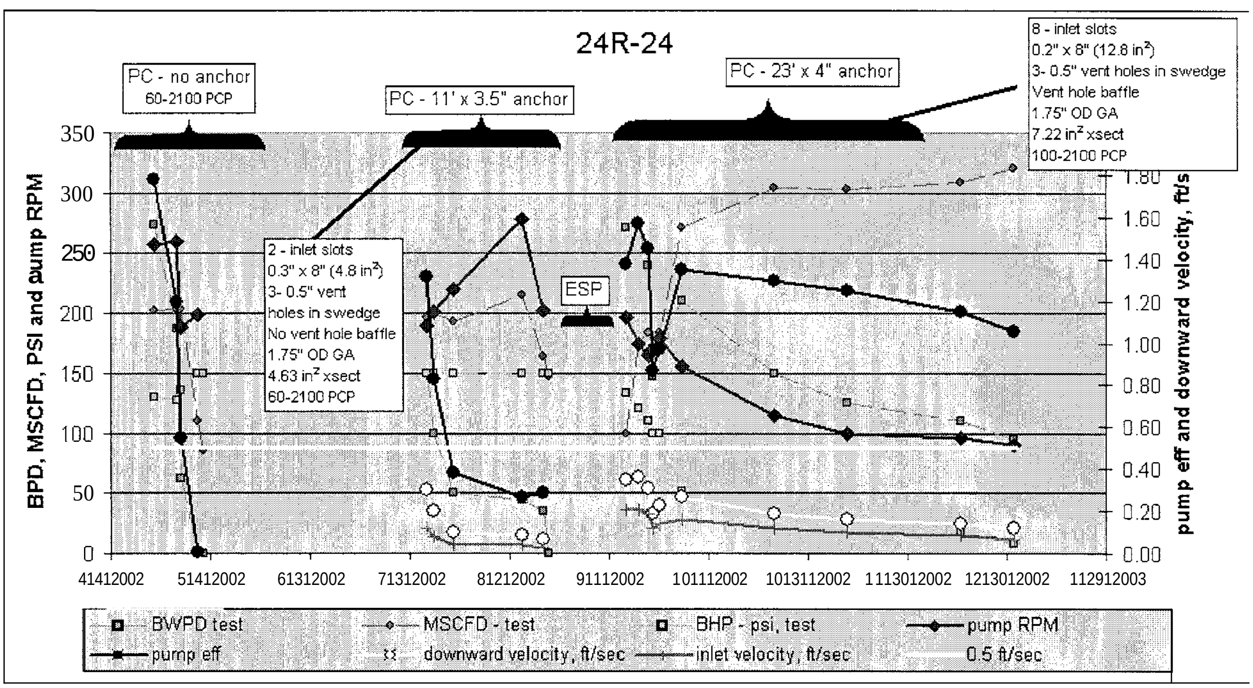
21 Mile Butte 24R-24
Reamed Openhole completion with Scab Liner over shale zone



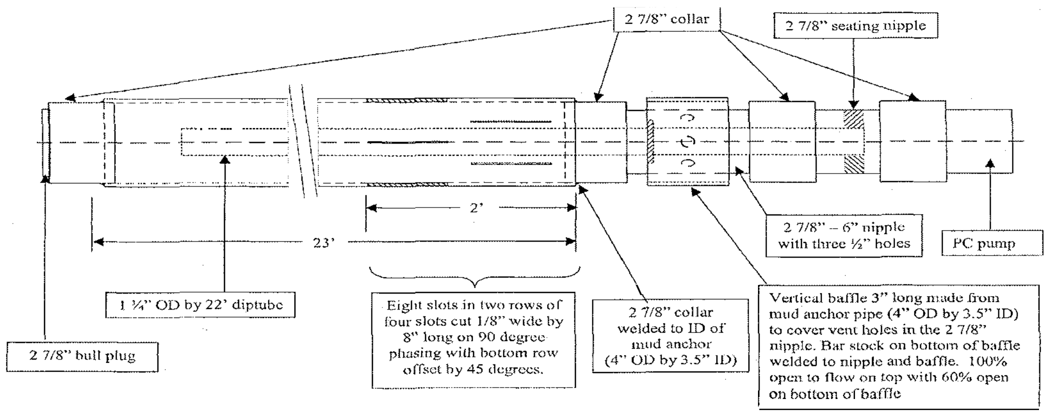
Attachment 7 – **Well 24R-24** - Well and Pump Installations Schematic



Attachment 8 – **Well 24R-24** – Graph of Production Rate, BWPD, MCSFD and BHP



Attachment 9 – **Well 24R-24** – Graph of Production Rate and Gas Separation Evaluation, BWPD, MSCFD, BHP, Pump RPM and Efficiency, Mud Anchor Inlet Velocity, Mud Anchor Downward Velocity



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Attachment 10 – **Well 24R-24** - Schematic of 4" Gas Separator with vent holes and baffle

	24R-24 Installation Description	#1	#2	#3	#4
1	Casing size and weight	7" 17#			
2	Casing depth	1280			
3	Open hole size	14"			
4	Open hole depth	1369			
5	Scab Liner size and weight	5-1/2" 15.5#			
6	Scab Liner interval	1334'-1352'			
7	Slotted Liner size and weight	5-1/2" 15.5#			
8	Liner depth	1252'-1334'			
9	Liner slotted interval	1280'-1334'			
10	Liner slot size	4 1/4"x12" 45 degrees apart			
11	Pump description	60-2100	60-2100	ESP	100-2100
12	Pump setting depth, feet	1328	1319	NO GAS SEPARATOR	1312
13	Mud anchor OD, inches	none	3.5		4
14	Mud anchor ID, inches	none	2.992		3.5
15	Mud anchor length, feet	none	11		22.81
16	Mud anchor setting depth (at bull plug), feet	none	1330		1334
17	Mud anchor distance from BP to bottom slot, feet	none	1321		19.5
18	Dip tube OD, inches	none	1.75		1.75
19	Dip tube length, feet	none	8		20
20	Mud anchor intake slot width, inches	none	0.1875		0.1875
21	Mud anchor intake slot length, inches	none	8		8
22	Method used for slots (torch, saw, mill)	none	plasma torch		plasma torch
23	Mud anchor number of slots	none	8		8
24	Mud anchor vent hole diameter, inches	none	0.5		0.5
25	Mud anchor number of vent holes	none	3		3
26	Mud anchor vent hole deflector used (yes/no)	none	no		yes
27	MA inlet area, in²	NA	12.00		12.00
28	MA xsect area, in² (ID MA - OD GAS	NA	4.63		7.22

Pump Installation	#1	#1	#1	#1	#1	#2	#2	#2	#2	#2	#2	#3	#4	#4	#4	#4	#4	#4	#4	#4	#4	#4
Peformance description	test 1	test 2	test 3	test 4	test 5	test 1	test 2	test 3	test 4	test 5	test 6	test 1	test 1	test 2	test 3	test 4	test 5	test 6	test 7	test 8	test 9	test 10
Date	4/17/2002	4/24/2002	4/25/2002	4/30/2002	5/2/2002	7/8/2002	7/10/2002	7/16/2002	8/6/2002	8/12/2002	8/14/2002	NO WATER TO SURFACE	9/6/2002	9/10/2002	9/13/2002	9/14/2002	9/16/2002	9/23/2002	10/21/2002	11/12/2002	12/16/2002	1/1/2003
Pump intake pressure, psi	130	128	136	150	150	150	150	150	150	150	150		134	120	110	100	100	51	NA	NA	17	8
BWPD, turbine meter	274	187	62	1	0	220	203	218	294	175	0		271	274	240	148	174	211	150	125	110	95
BWPD, actual from bucket test						150	100	50	45	35	0											
Estimated gas up tubing	30	50	50	75	75	50	50	50	50	60	75		0	0	0	0	0	0				
Gas rate up casing	203	204	204	110	85	197	200	193	215	164	147		100	176	184	172	184	272	304	303	309	289
Pump RPM	258	260	189	199	0	190	201	220	279	202	0		197	175	165	170	179	156	115	100	96	90
Pump displacement @ RPM, BPD	154	156	113	119	0	114	121	132	167	121	0		197	175	165	170	179	156	115	100	96	90
Pump efficiency (BWPD/pump displacement)	177.9%	119.9%	54.9%	0.8%	0	131.6%	82.9%	37.9%	26.9%	28.9%	0.0%		137.6%	156.6%	145.5%	87.1%	97.2%	135.3%	130.4%	125.0%	114.6%	105.6%
water flow ft³/sec	NA	NA	NA	NA	NA	0.0057	0.0065	0.0032	0.0026	0.0023	0.0000		0.0176	0.0178	0.0156	0.0086	0.0113	0.0137	0.0097	0.0081	0.0071	0.0062
inlet velocity, ft/sec	NA	NA	NA	NA	NA	0.12	0.03	0.01	0.04	0.03	0.00		0.24	0.21	0.19	0.12	0.11	0.16	0.12	0.10	0.09	0.07
downward velocity, ft/sec	NA	NA	NA	NA	NA	0.36	0.20	0.10	0.09	0.07	0.00		0.35	0.30	0.31	0.19	0.23	0.22	0.19	0.16	0.14	0.12

Attachment 11 – **Well 24R-24** –Installation Descriptions