Underbalanced Drilling Review

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Executive Summary

The MSDU1 (Mary Scharbauer Devonian Unit No. 1) was completed in December 1998. It was Mobil Drilling Midland's first attempt to drill a horizontal lateral while underbalanced. The Mary Scharbauer experience provided valuable data on the benefits and drawbacks of UBD (Underbalanced Drilling) in the extended reach environment.

Increasing ROP in order to reduce cost was the primary goal of the MSDUl project. Increases in ROP from UBD were apparent when optimal bottom hole pressure was achieved. Maintaining optimal bottom hole pressure was impossible do to the limitations of conventional MWD (Measurement While Drilling) equipment. Extensive drill stem deterioration caused project costs to skyrocket and placed any future UBD projects on hold until a solution to the problem could be developed.

Investigation of the drill stem corrosion showed that the most severe pitting occurred on the drill pipe in the lateral section of the well. Analysis of the drill fluid as well as formation fluids showed that the most reasonable explanation for the deep pitting observed on the drill pipe was "Oxygen Erosion Corrosion." Oxygen erosion corrosion was then simulated in the laboratory in an apparatus that produced conditions like those found in the lateral section of the MSDUl well. Many corrosion tests were completed in an effort to find inhibitors that would function in a deep, hot, oxygenated, and abrasive well bore environment like that of the MSDUl well. While this was being done 99.9+ % oxygen free UBD methods were evaluated. Eventually a corrosion inhibition system that worked under conditions like those of the MSDUl was located and proven on Mobil Midland's second UBD extended reach well the PFU 23-24 (Parks Field Unit 23-24).

Conventional MWD equipment required that the drill pipe be loaded with water in order to generate a readable mud pulse. When surveys were needed underbalanced conditions were eliminated and ROP on the MSDUl dropped from 26ft/hr to 8ft/hr. Optimum underbalanced conditions were recovered after the well bore could be re-gasified. It was estimated that using a MWD system that did not require the drill pipe to be loaded would cut the cost of drilling a MSDUl like lateral by $60,000. Midland Drilling located an EM MWD (Electromagnetic Measurement While Drilling) company that stated their equipment would work for drilling a Devonian lateral underbalanced. When the equipment was evaluated on the PFU 23-24 it performed acceptably but learning were documented that will improve future operations.

Mobil Drilling Midland continues to develop technology to improve bottom line profitability. Currently work is being done to determine the feasibility of drilling extended reach horizontal laterals with air compressors and a water/foam drilling fluid. If feasible this method will be half as expensive as our current lowest cost UBD option. The drilling curve will continually shift to the left as key learnings are implemented on fume projects.

Introduction

The first "Oil Well Driller" was a blacksmith that made tools for Pennsylvanian salt drillers. His name was William "Uncle Billy" Smith. His boss the first, "Oil Well Drilling Foreman," was of course Edwin L. Drake. Colonel Drake, Uncle Billy, and Uncle Billy's sons drilled the first oil well in August 1859[1]. It was not long after this historic event that the Pennsylvanian countryside was flooded with copycat drillers. The first one of these wells that flowed on its own (The first underbalanced well) was drilled in 1861. In today's language it would have been referred to as a blowout or more euphemistically as an unplanned release. Today we have the equipment available that allows us to drill wells while

[1] Yurgin, Daniel: "The Prize," Copyright 1992. Pg.27-30.

essentially having a controlled blowout. This technology can provide many benefits to those who choose to drill underbalanced.

Benefits from UBD include increased penetration rate, increased bit life, less trouble time (lost circulation and stuck pipe), and in some cases increased production. As the dynamic pressure of the drill hole drops toward the formation pressure ROP starts to increase. The smaller the differential pressure between the drill hole and the formation gets the faster ROP climbs as a function of overbalance pressure. ROP continues to climb as the drill hole pressure decreases below the formation pressure. The extent of the gain in ROP from UBD is dependent on the formation pressure, rock type, and psi underbalance as well as expected drilling parameters such as weight on bit and rotary speed.

There are many different ways to achieve underbalanced conditions while drilling. If formation pressure is high enough lightweight mud or water may provide a low enough pressure gradient to achieve underbalanced conditions. Typically in West Texas a gasified drill fluid is required to achieve underbalance.

There are multiple methods for injecting gasified fluids for UBD. Popular methods used in the Permian Basin include drill pipe injection and intermediate casing by production casing annular injection. Other methods include parasite string, and concentric drill pipe injection. The later two methods being the most cost prohibitive and limited in utility for Mobil's extended reach application. All of the methods were explored for use in the Parks Field near Midland, TX. The most cost-effective options can be seen in the graph UBD ALTERNATIVES in the background section of this report. Continued learnings promise to provide lower cost methods in the future.

Drill fluid selection must be done on a case by case basis. Cost and corrosivity are the two primary factors that determine the drill fluid choice. Operators must also consider the potential for down hole combustion. Gases used to lighten drill fluid pressure gradient include air, nitrogen membrane unit gas, bulk nitrogen, flue gas, carbon dioxide, and methane. Each of these gases impose a unique set of equipment and corrosion inhibition requirements. Some of the liquids used for UBD drill fluid include mud, fresh water, brine water, oil based mud, and oil based mud emulsions.

When the best case gas and fluid have been selected for use surface equipment and corrosion inhibition requirements can be determined. Local chemical companies must be required to supply case histories that coincide with the planned well's depth, deviation, temperature, pressure, and formation fluids. Extreme care must be taken when oxygenated drill fluids are used. Abrasive drilling conditions can also exacerbate corrosion problems.

Discussion

➢ Bottom Line

Our bottom line for UBD is cost savings. Mobil Drilling Midland has not yet achieved economically viable successes with UBD in the extended reach horizontal application. As with the inception Mobil Midland's horizontal drilling program, significant learnings had to be achieved before the application of the technology became cost effective and paid great dividends in increased production

It is known that significant increases in ROP can be achieved with UBD. To date the high cost of UBD services, onsite contractor and operator inexperience, corrosion problems, and application effective MWD technology have hindered UBD project success. Each new attempt brings us closer to an economically beneficial UBD system for horizontal extended reach wells.

➢ Rate of Penetration

Listed below is a *summary* of ROP data for some of Mobil's Parks Field Unit horizontal wells. Keep in mind that the MSDUl and the PFU 23-24 were the two UBD wells.

- The entire PFU 23-24 lateral was drilled underbalanced. BHP was maintained well below 1100 psi throughout the drilling of the lateral.
- Assuming comparable pay quality on offset wells, UBD increased the average overall ROP (weighted average) by 78% (35.6 fph Vs 20 fph) when compared to the PFU 24-17H (offset); by 103% (35.6 fph vs. 17.5 fph) when compared to the PFU 19-17H (offset); and by 38% (35.6 fph Vs 25.8 fph) when compared to the MSDUl (gasified fluid rate).
- Rotating ROPs for the PFU 23-24H were 60% faster (39.7 fph Vs 24.7 fph) than the PFU 24-17H; 100% faster than the PFU 19-17H (39.7 fph Vs 19.8 fph); and 39% faster (39.7 fph Vs 28.6 fph) than the MSDU1.
- Slide drilling on the PFU 23-24H was 15% slower than the PFU 24-17H (12.4 fph Vs 10.4 fph); 91% faster than the PFU 19-17H (12.4 fph Vs 6.5 fph); and 27% faster (12.4 fph Vs 9.8 fph) than the MSDUl.
- The PFU 23-24H averaged 191 Wday (from picking up lateral BHA to beginning trip out of hole once TD'd). The PFU 24-17H averaged 354 ft/day. The PFU 19-17H averaged 217 Wday. The MSDU1 averaged 274 Wday. Although the PFU 23-24H had higher ROP's, daily footage drilled was low due to flat time associated with UBD operations.
- The average trip time for the PFU 23-24H was 1213 fph. Approximately 40% slower than the PFU 24-17 and the MSDUl (2 well average 2038 fph). The additional time is attributed to unloading the hole and running the EM MWD antenna.

Note that the ROP's for the PFU 23-24 well are highest but the overall daily footage is a lot less.
This can be explained by the following delays: rigging-up UBD equipment (20hrs), attempting to use a glycol based drilling fluid (32hrs), personnel inexperience with UBD and poor contractor support (63hrs).

➢ Corrosion

As previously mentioned Mobil Drilling in Midland, TX experienced a severe setback to its UBD program in December 1998. Drill pipe and drill collars being used to complete the MSDUl (see pipe failure diagram) were severely pitted and corroded. The damage to the drill pipe was estimated to be $250,000.00. A solution to this problem was imperative for Mobil Drilling Midland, or the drilling of horizontal wells while underbalanced would not continue.

On the November 29,1998 Mobil had drilled the MSDUl lateral to a measured depth of 15,024 ft. The drill pipe parted approximately 1271 ft from surface while working some tight hole.

When all of the work string had been fished from the hole 32 hr later, massive corrosion was discovered. Available data indicates that mechanical damage and pitting had occurred previous to the drill pipe parting. The pitting previous to a trip made at 14,266 ft was not as extensive as the pitting that occurred while drilling from 14,266 ft to 15,024 ft. The drill pipe in the vertical section of the well bore was not corroded severely.

Canadian UBD experience under similar conditions indicated that corrosion can be extensive in the horizontal sections of such wells. Abrasion from pipe contacting the formation face removes corrosion inhibitors from the pipe leaving it unprotected.

MEPTEC verified that the only plausible explanation for the severe drill pipe corrosion was oxygen erosion corrosion. A Canadian UBD company then simulated pitting like we had experienced on the MSDUl in a laboratory-testing device. The device rotated a piece of drill pipe against a limestone core in a pressurized vessel. Membrane gas (approximately 95% N_2, 5% 0_2), water, corrosion inhibitor, CO_2, H_2S, etc. were pumped through the vessel to simulate well conditions. Researchers noted that a small increase in the wall force acting between the pipe and the core dramatically increased the corrosion rate.

MEPTEC research recommended staying away from oxygenated drilling fluids when drilling under conditions like those of the MSDUl well unless an inhibition program had been successfully proven in laboratory. The Canadian Company mentioned above tested a variety of inhibitors without success. Midlands UBD program was on hold until a major UBD contractor agreed to provide drill pipe risk free to Mobil for another attempt at drilling a Devonian lateral underbalanced. Mobil Drilling personnel made a decision to drill the Parks Field Unit 23-24 lateral underbalanced.

UBD contractor representatives believed that a glycol based drilling fluid would sufficiently reduce corrosion by chemically tying up the drill water thus reducing conductivity and corrosion. Unfortunately the "proven" system was a failure. Incompatibilities between the glycol/water/membrane gas mixture and the foaming agent necessitated displacing the glycol out of the well. After this was done a decision was made to continue on with the project using membrane gas, water, and foamer. The corrosion engineer stayed on site to continually monitor corrosion, inhibitor injection rates, and inhibitor recycling. The efforts of the on site corrosion engineer were a complete success. Initial corrosion to the drill stem was quickly discovered and corrective actions throughout the drilling of the lateral maintaining the integrity of the drill stem. When the pipe was returned for inspection only light pitting was visible on some of the pipe and it was determined to be in excellent condition.

The corrosion inhibition program on the MSDU1 consisted of batch treatments of inhibitor products.. These products were C202 and CL9390. C202 is an amine based inhibitor and CL9390 is a phosphate derivative. The mud company attempted to contribute to corrosion inhibition efforts by adding oxygen scavenger.

Amine inhibitors work by forming a protective film on the surface of the drill pipe. Amines have a positive charged end that is attracted to the negatively charged surface of the steel pipe. The other end of the molecule is petrophilic and attracts oil. This property helps enhance the protective inhibitor film.

Phosphates are called passivation inhibitors. They form a thin film on the steel that conducts electricity and is cathodic to steel. Corrosion is slowed down because the film keeps the anode from coming into contact with the electrolyte stopping current flow.

The readily available inhibitors used on the Mary Scharbauer DU No. 1 did not function because they were easily wiped off of the pipe by the abrasive forces acting between the drill pipe and the well bore wall. Continuous treatment with these inhibitors would have improved their effectiveness but not sufficiently. Amine inhibitors do not form a tight enough molecular packing to keep oxygen from getting in between the amine molecules. The phosphate inhibitors that were used did not have a bond with the steel that was aggressive enough to prevent oxygen contact with the steel even if continual reapplication was carried out.

The oxygen scavenger that was added by the mud company was a waste of money. When the project was reviewed Mobil learned that the mud company had been adding 26gal/day of oxygen scavenger. The amount of scavenger required to reduce the oxygen content of the drilling fluid to an acceptable level (**99.9%N_2**, 0.1%O_2) under the conditions that existed on the MSDU1 would have been cost prohibitive. Use of oxygen scavenger for UBD in conjunction with membrane units is impractical. See example:

The gas flow rate was roughly 1000 scf while drilling, which corresponds to 60 mol/min or 4.2 lb/min of O_2

$$1000\ \mathrm{ft^3/min} * (2.54 * 12\ \mathrm{cm/ft})^3 * 1\ \mathrm{Liter}/1000\ \mathrm{cm^3} * 1\ \mathrm{mol}/22\ \mathrm{Liter} * 4.5\% = 60\ \mathrm{mol/min}$$

$$60\ \mathrm{mol/min} * 32\mathrm{g/mol} / 454\ \mathrm{g/lb} = 4.2\ \mathrm{lb}\ O_2/\mathrm{min}$$

The oxygen scavenger NH_4SO_3 was pumped at 26 gal/24 hr at an unknown concentration. Assuming it was 100% (most favorable) at 8 lb/gal gives 0.66 mol/min:

$$26\ \mathrm{gal}/(24\ \mathrm{hr} * 60\ \mathrm{min/hr}) * 8\ \mathrm{lb/gal} * 454\ \mathrm{g/lb} / 98\ \mathrm{g/mol} = 0.66\ \mathrm{mol/min}$$

We know that 0.66mol/min costs $294/day. We know we needed approximately 60mol/min oxygen scavenger.

60mol per min / (0.66mol per min / $294) = $26,727 per day

The onsite corrosion engineer provided an inhibition program that used CAD12 and CAD13. CADI2 is a complex blend of organic phosphonates that are strongly attracted to steel surfaces. The adsorbed phosphonates incorporate hardness ions (calcium and magnesium) into their molecular structure thereby decreasing oxygen diffusion through the inhibitor film. This cross-linked inhibitor film is also much more resistant to mechanical removal than traditional film forming amines. CAD13 is a nitrite based passivation inhibitor that works with the phosphonate inhibitor to isolate the pipe from the electrolytic drill fluid.

➢ Measurement While Drilling Underbalanced

Conventional MWD equipment required that the drill pipe be loaded with water in order to generate a readable mud pulse. When surveys were needed underbalanced conditions were eliminated and ROP on the MSDUl dropped from 26ft/hr to 8ft/hr. Optimum underbalanced conditions were recovered after the well bore was re-gasified. This process took up 17% of the total lateral drilling time on the MSDUl. The Lateral rig time - ROP broke down as follows for the MSDUl: Drilling with a gasified fluid (34% - 25.7fph), Transitioning from/to a gasified fluid (17% - 16.lfph), Drilling with water (8% - 7.9fph), and Flat time (25% - 0fph). The MSDUl MWD experience necessitated the use of EMWD (Electromagnetic Measurement While Drilling) equipment.

A decision was made to use EMWD on the PFU 23-24 project . The EMWD system allows real time measurements of direction and pressure without wireline to surface. This technology has greatly reduced the complexity of obtaining down-hole data previously encountered in UBD applications. EMWD technology sends the down-hole data by a signal, through the surrounding formation to a receiver on the surface. Due to the depth and the formations encountered in this well, it was required to use an antenna, which brought the wireline to with in 1000 feet of surface.

Although the performance of the EMWD system was acceptable, two problems were encountered that must be addressed. The primary problem centered on the connection time required for a survey. Survey times averaged 15 minutes to allow the tool to settle down after gas flow was stopped. This is three times greater than the usual 5 minutes reported for EMWD measurements. This increase resulted in an additional 5.25 hours to drill the well. It is felt that the long survey time can be attributed to the long length of the antenna. EMWD systems without antenna have a float above and below the survey tool. The top float on this system was located at the termination point of the antenna. Sufficient time to bleed down the fluid in the space above the survey tool may have caused the problem.

It is recommended that a float be placed above survey tool using wet connection technology on all future applications. The increase in survey time can not be tolerated, as it makes it even more difficult to achieve the break-even rate.

➢ Connections

It was noted on the Parks Field Unit 23-24-H2 that it took several minutes to build up pressure across the motor before affective drilling would occur. A similar problem was noted in drilling the ARUN UBD wells. This can be attributed to the high quality of the fluid used to achieve the low BHP. For multi-phase fluids, motor horsepower must be generated by a sufficient volume of fluid moving across the motor generating a differential pressure across the motor. The equivalent volume of the fluid is dependent on the pressure at the top of the motor.

The high quality fluid used must be sufficiently compressed to create the required pressure at the top of the motor. The rig attempted to create a backpressure by trapping pressure prior to shutting down the pumps for a connection. This had some positive effect.

➢ Lessons Learned

General:

- Written standard operating procedures should be in place for operations unique to UBD (i.e.: blow-down drill pipe; shutting down air compressors; bypassing air manifolds, etc.). The procedures should be included in the drilling package. All rig crews should become familiar with them prior to starting the project via an on-site pre-spud meeting.

- Compatibility tests for all lubricants, corrosion inhibitors and surfactants should be conducted with the foam system used. Standpipe pressure swings can be expected if the fluids are not compatible as was experienced on the PFU 23-24H.

- Use a float directly above the EM MWD using wet connection technology to reduce the time it takes to survey.

- Expect to see a variance in the predictions made by the various simulation models. Actual conditions should be matched once work begins to verify which model works best.

- A top drive system is a must when drilling UBD in order to reduce the number of connections made.

MIRU:

- Assure rig is level to increase longevity of RBOP rubber life.

- Include cost of nipple up crews in AFE cost estimates.

- Build pit to handle blow downs via the blooie line without spraying fluids outside of pit.

- Design the separator to handle large surges of liquid and gas. Assure ample safety margin in the design to prevent over-loading of the separator.

- Conduct a pre-start safety review after rigging up and prior to spudding (picking up curve drilling assembly).

Window:

- Make a trip in hole with Trackmaster mill (or equivalent mill) prior to running whipstock to assure casing ID can accommodate whipstock and mills. If feasible, this step can be implemented in the wellbore preparation phase.

Curve:

- Do not attempt to kickoff the curve on foam or air-mist. The casing has a tendency to amplify the vibrations giving erroneous EMWD readings. If deemed economically feasible, blow the hole down and drill the curve on foam/air-mist once away from the casing.

- Consider running a shock sub instead of a BHP sensor to reduce the vibration effect on MWD.

Lateral:

- It takes 20 minutes (average) to make a connection, survey and energize the wellbore when foam drilling.
- Industry standard is to design for a liquid velocity of greater than 177 fpm to properly clean the hole. During the drilling of this lateral, velocities were well below this limit indicating that gas velocity should be considered also. The minimum gas velocity limit should be 1300 fpm.
- Glycol foam did not work as predicted. The system did not form stable foam to carry cuttings out of the hole.
- The glycol foam system may have helped increase the ROP while slide drilling. The highest recorded ROPs (while sliding) were experienced while using glycol.
- Corrosion rates can be held to an acceptable level using a water based foam system. The post job drill pipe inspection indicated little to no corrosion due to UBD operations.
- Setup a semi-closed system for the corrosion inhibitor to help control cost.
- Lubra-Glide beads seem to be the most effective in reducing torque and drag. Coasta-Lube seemed more effective than Enviro-Lube but had an adverse effect on the foam.
- Conduct wiper trips frequently to improve slide drilling.
- Use motors with bends greater than 1.5 degrees to help orient more aggressively when sliding.

Conclusions

UBD technology is a must for the future of oil & gas drilling. As older fields are depleted around the world lost circulation, differentially stuck pipe, and tighter economic margins will necessitate the use of UBD. Those companies who develop the technology will have a decidedly greater advantage over those who do not. Much headway has been made in the application of UBD technology to the extended reach horizontal application. As with horizontal drilling technology, UBD technology must be given time to develop. Documented key learnings will be applied to future UBD operations and will continue to reduce UBD cost and shift drilling curves to the left.

Learnings from the MSDU1 and the PFU 23-24 have been significant. Solving the, “Oxygen Erosion Corrosion” problem through corrosion inhibition was a tremendous step forward for UBHD (Underbalanced Horizontal Drilling) technology. EMWD was employed with positive result as well. Foam drilling fluid helped achieve instantaneous ROPs between 78 to 103% greater than offsets drilled with conventional fluids.

The next step for UBHD for Mobil Midland is currently being researched. Corrosion inhibition processes used to control corrosion on the PFU 23-24 may be able to control oxygen erosion corrosion even with oxygen levels up to 21%. This would mean that air compressors could be used instead of nitrogen membrane units. If down hole combustion can be safely repressed it will be possible to accomplish foam UBHD for approximately $3,100.00/day which is 58% of the current lowest cost option.

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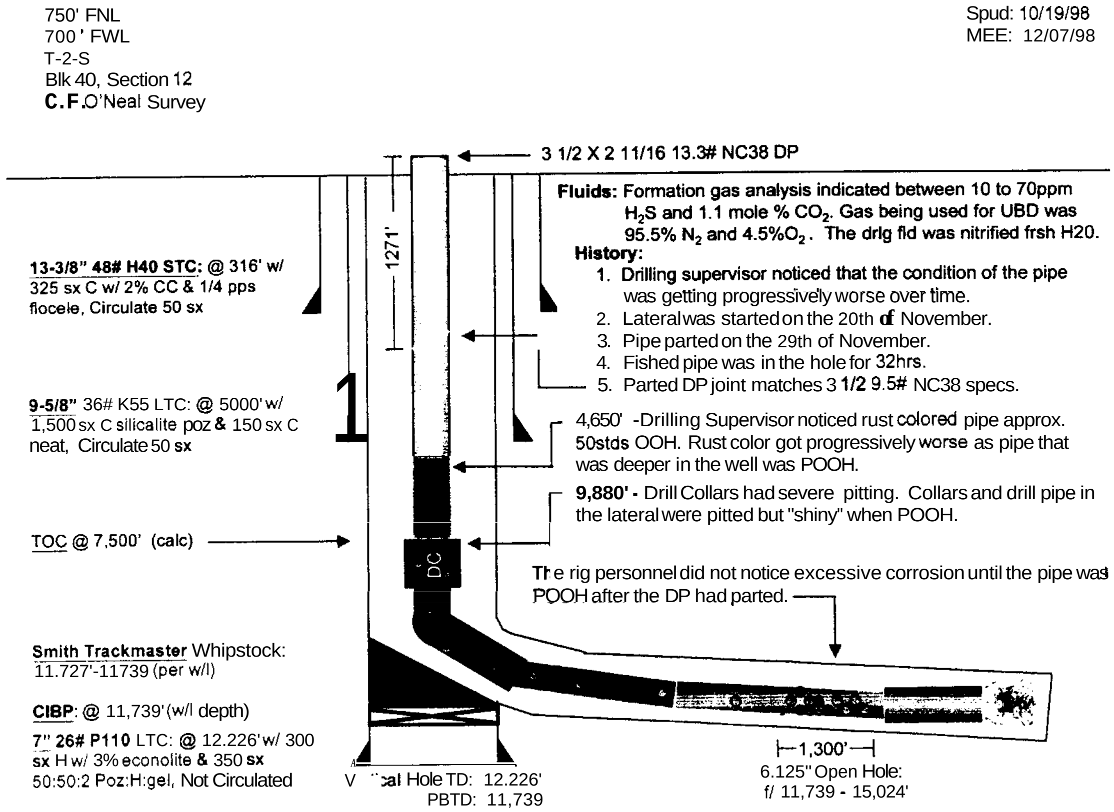

Figure 1 - Mary Scharbauer Devonian Unit No. 1 Pipe Failure Diagram
Parks Field, Midland County, Texas

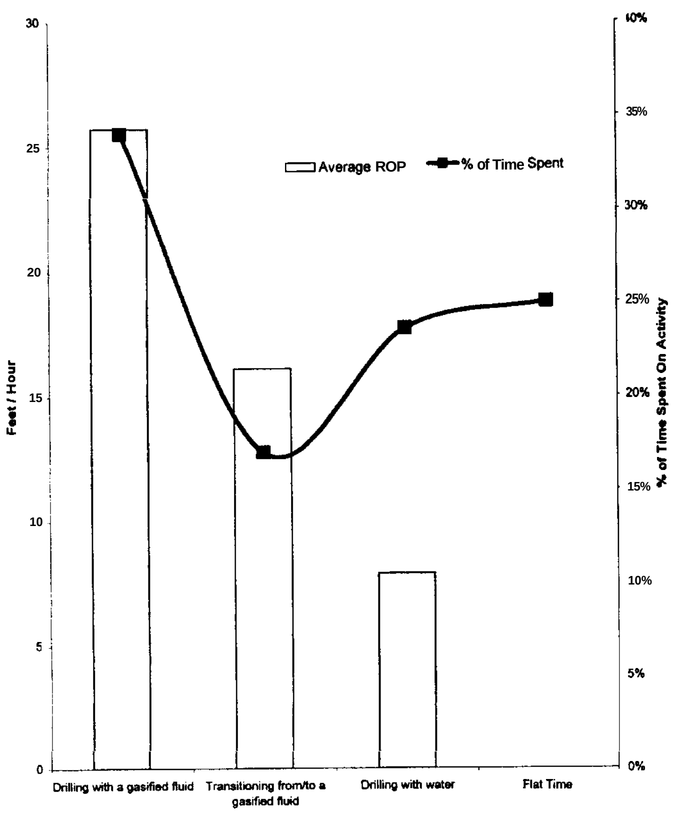

Figure 2 - Mary Scharbauer Lateral - Average ROP

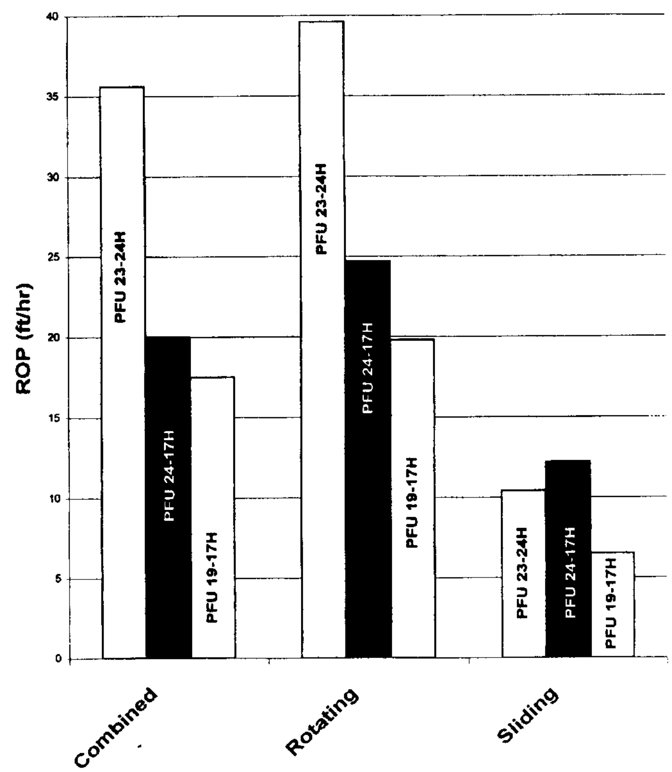

Figure 3 - Drilling Performance Comparison

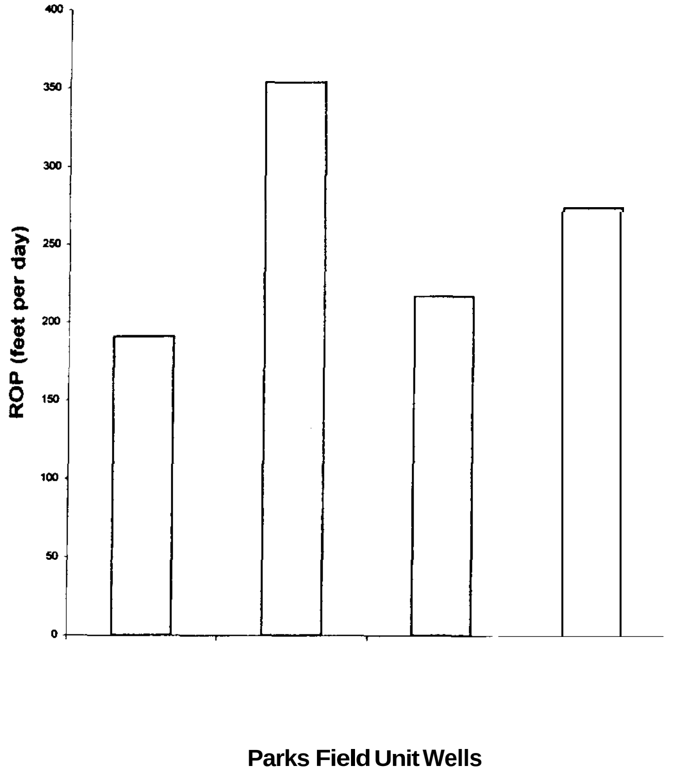

Figure 4 - Average Daily Footage

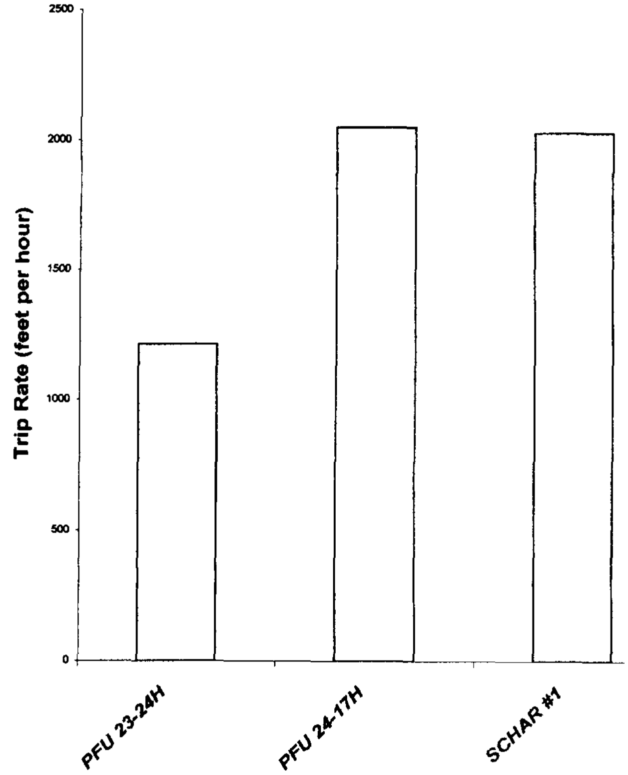

Figure 5 - Trip Rate Comparison

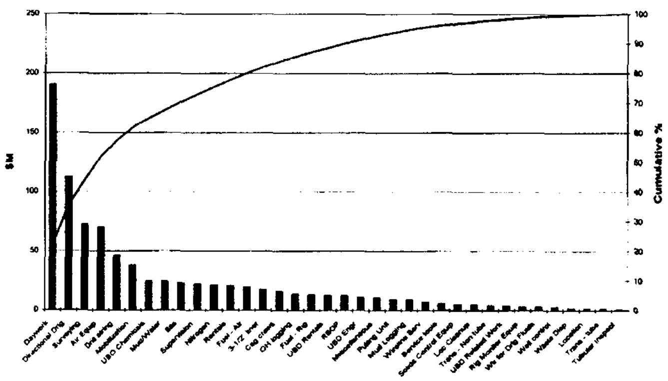

Figure 6 - PFU 23-24H Cost Breakdown

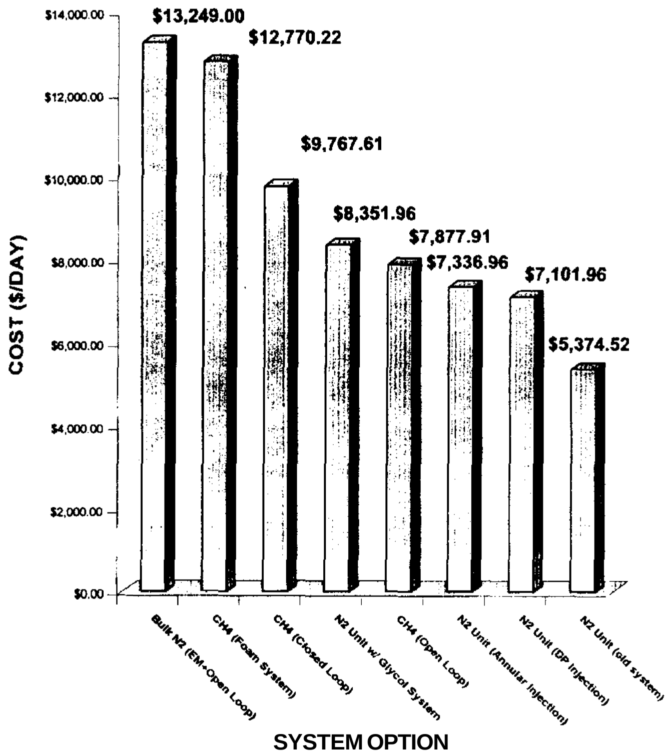

Figure 7 - UBD Alternatives

System	Contractor	Total Days for Lateral	*1 UBD EQP. $/Day	*2 Oar $/Day	*3 Mobilization $/day	*4 Compression $/Day	*5 RBOP $/Day	*6 Chemicals	*7 Metering Cost.	8 Pipe Rental	9 Miac.	Total Day Rate
Bulk N_2 (EM+Open Loop)	BJ	9.4	$5,527.00	$5,167.00	$200.00	$0.00	$720.00	$1,535.00	$0.00	$0.00	$100.00	$13,249.00
CH_4 (Foam System)	ECD Northwest	4.8	$3,800.00	$1,938.00	$420.17	$0.00	$720.00	$3,119.30	$2,100.84	$571.91	$100.00	$12,770.22
CH (Closed Loop)	Northland	9.4	$5,850.00	-$1,250.00	$425.08	$850.16	$720.00	$1,100.00	$1,062.70	$309.67	$700.00	$9,767.61
N_2 Unit w/ Glycol System	ECD Northwest	9.4	$4,069.42	$0.00	$212.54	$0.00	$720.00	$3,250.00	$0.00	$0.00	$100.00	$8,351.96
CH_4 (Open Loop)	ECD Northwest	9.4	$0.00	$1,938.00	$212.54	$2,000.00	$720.00	$1,535.00	$1,062.70	$309.67	$100.00	$7,877.91
N_2 Unit (Annular Injection)	ECD Northwest	9.4	$4,069.42	$0.00	$212.54	$0.00	$720.00	$1,535.00	$0.00	$0.00	$800.00	$7,336.96
N_2 Unit (DP Injection)	ECD Northwest	9.4	$4,069.42	$0.00	$212.54	$0.00	$720.00	$2,000.00	$0.00	$0.00	$100.00	$7,101.96
N_2 Unit (old system)	ECD Northwest	12.9	$4,069.00	$0.00	$155.52	$0.00	$720.00	$330.00	$0.00	$0.00	$100.00	$5,374.52

'1 This includes all UBD equipment that the contractor feels is necessary to drill a Devonian well underbalanced.
'2 This includes any gas purchases both For nitrogen or natural gas.
'3 This is the mobilization do-mobitition cost divided over the day to complete the lateral.
*4 This includes compression not covered as part of the UBD package.
*5 This includes the RBOP cost plus the cost of one rubber/10days.
*6 Inhibition cost in $/day for the system.
7 Metering cost indudes gas hook up and meter run installation cost.
*8 Pipe rental is the cost of 5500ft. 3" polyurethane gas line.
'9 Other not included.

Figure 8 - UBD Cost Comparison

INPUT DATA:	
Conventional average ROP =	20 fph
Conventional average daily footage drilled =	354 ft/day
Conventional daily drilling cost =	17000 $/day
Footage to drill (underbalanced) =	2500 ft
Survey increments (30', 45' or 90') =	45 ft
UBD survey time =	0.33 hr
UBD trip time (round trip) =	20 hr
Anticipated number of trips =	1
UBD daily drilling cost =	29000 $/day
Pre-startup UBD cost =	20000 $
Post job UBD cost =	5000 $

Calculated daily flat time (conventional) =	6.3 hrs
Calculated number of days to drill (conventional) =	7.1 days
Cost to conventionally drill footage under evaluation =	120056 $
Equivalent time to drill underbalanced =	3.3 days
	79 hrs
Number of UBD surveys and connections =	55.6
UBD survey and connection time =	18.3 hrs
UBD trip time =	20 hrs
UBD drilling time =	40.3 hrs

Required footage to drill per day to justify UBD =	763 ft/day
Required average ROP to justify UBD =	62 fph
Average UB drilling hours =	12.3 hrs/day
Average UB flat time hours =	11.7 hrs/day
Flat time percent	48.7 %

Figure 9 - UBD Justification Worksheet, Parks Field, Midland County, Texas

INPUT DATA:		
Conventional average ROP =	20	fph
Conventional average daily footage drilled =	354	ft/day
Conventional daily drilling cost =	17000	$/day
Footage to drill (underbalanced)=	2500	A
Survey increments(30', 45 or 90') =	45	ft
UBD survey time =	0.33	hr
UBD trip time (round trip) =	20	hr
Anticipated number of trips =	1	
UBD daily drilling cost =	29000	$/day
Pre-startup UBD cost =	20000	$
Post job UBD cost =	5000	$

Calculated daily flat time (conventional) =	=24-(F8/F7)	hrs
Calculated number of days to drill (conventional)=	=F11/F8	days
Cost to conventionally drill footage under evaluation =	=F21*F9	$
Equivalent time to drill underbalanced =	=(F22-F17-F18)/F16	days
	=F23*24	hrs
Number of UBD surveys and connections =	=F11/F12	
UBD survey and connection time =	=F25*F13	hrs
UBD trip time =	=F14*F15	hrs
UBD drilling time =	=F24-F26-F27	hrs

Required footage to drill per day to justify UBD =	=FI1/F23	Wday
Required average ROP to justify UBD =	=F11/F28	fph
Average UB drilling hours =	=F30/F31	hrs/day
Average UB flat time hours =	=24-F32	hrs/day
Flat time percent	=F33/24*100	%

Figure 10 - UBD Justification Worksheet, Parks Field, Midland County, Texas