"Using ESP's with Variable Frequency Drives to Perform Well Tests on Multiple Lateral Horizontal Producing Wells In the 4-Corners Area''

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Abstract

This paper describes the use of electrical submersible pumping systems (ESP's) with portable variable frequency drives (VFD's) to perform step-rate testing on multi lateral horizontal producing oil wells in the **4** – Corners area of New Mexico, Colorado, Utah, and Arizona. A major Operator drilled and completed several of these multi lateral wells in the area. High volume ESP's were installed due to the success of the multi lateral concept and resultant high producing rates. Down hole sensors were installed to monitor drawdowns and changes in reservoir pressure and temperature as the step-rate tests were performed. Surface measurements of fluid producing rates, well head pressures, and VFD parameters were also made, and were communicated to the Operator via SCADA systems and cellular phone links. The units were initially started at low frequencies on the VFD's, and the rates and pressures monitored until stable. Then the VFD was sped up, with new rates and pressures measured. The process was repeated in several steps until the well either pumped off or became gas locked. This paper presents the results of these operations and illustrates with schematics, system drawings, and production decline rates how the wells performed and how the well testing program was successful.

Introduction

The use of single lateral or horizontal wells has long been known to aid in production operations by attempting to keep the wellbore in the productive section of the reservoir rock. In some formations with multiple porosity sections, short radius and medium radius laterals have been cut from the same well in order to minimize costs and maximize recovery. A paper by Storbeck and Williamson at the Southwestern Petroleum Short Course in 1997 details the procedures used to drill and complete these multi lateral wells. The challenge then becomes how best to produce these wells.

In most wells, the upper lateral is drilled first. Then subsequent laterals are drilled either in opposing or in some cases stacked (same azimuth, with different TVD's or true vertical depths), from a central wellbore. Technology now allows, through the use of innovative downhole tools, methods to drill, complete and stimulate the multi laterals. The wells then usually come in flowing, or often with high fluid levels, which lead to high volume pumping equipment to produce. (See **Figure 1)**

A major operator in the Ratherford Unit of the Greater Aneth Field first started using multi lateral drilling practices in the mid 1990's. These wells penetrated the Desert Isamay formation, typically found at depths of from 5100 feet to 5500 feet. Figures 2, 3, and 4 provide maps of the field and typical wellbore sketches. Initially only horizontal or single lateral wells were attempted. After initial successes, technology improvements allowed for the drilling of multiple laterals from the central wellbore. These lateral sections often penetrated from ¼ to ½ mile of reservoir, and even longer laterals have been reported. The lateral sections often had small rises and depressions, which caused the wellbore to be somewhat serpentine. As will be shown later, this serpentine up – and – down orientation caused some problems with fluid flow and gas handling / slugging when the well was brought on to production.

Well Completion and Testing

After the horizontal laterals were drilled, the well was completed and brought on to production. Several completion methods were tried, with various degrees of success. The easiest method utilized was to perforate the zone in an underbalanced condition, and to allow the well to come in flowing. This method worked well when skin damage or formation damage was not a problem. In some cases, small acid treatments were required to stimulate the well or to remove damage to the reservoir / wellbore interface. In most wells, there was sufficient reservoir pressure and permeability to allow the well to flow initially. Wellhead chokes were used to control rates and pressures.

After an initial period of time, the wells lost pressure and artificial lift was required. In these cases, where there was still fairly high reservoir pressure, electric submersible pumps were used to perform the tests.

The sizing of the submersible was done using initial reservoir pressure and flow rates, then calculating a productivity index (PI) or inflow performance relationship (IPR) to predict future producing rates at various drawdown pressures. Portable well test units, consisting of trailer – mounted variable frequency drives, electrical junction boxes, transformers, and temperature / pressure sensor readouts were connected to the downhole equipment. SCADA equipment was installed on these systems, allowing for remote monitoring of both surface parameters and downhole conditions.

Electric submersible pumping equipment follow certain Affinity Laws when connected to Variable Frequency Drives. These relationships are between pump performance and pump speed ratios. For test purposes, the speed ratios are between rated RPM and Test RPM. These equations are presented below:

a) $$\textbf{Speed Adjusted Flow} = \frac{\textbf{Rated RPM}}{\textbf{Test RPM}} \times \textbf{test flow}$$

b) $$\textbf{Speed Adjusted Head} = \left(\frac{\textbf{Rated RPM}}{\textbf{Test RPM}}\right)^2 \times \textbf{test head}$$

c) $$\textbf{Speed Adjusted Brake Horsepower} = \left(\frac{\textbf{Rated RPM}}{\textbf{Test RPM}}\right)^3 \times \textbf{test Brake Horsepower}$$

It is required to use these laws when using VFD's in welltesting operations with electric submersible pumps.

The steps used in performing the well test are as follows:

1.) Install the submersible equipment, initially designed for the expected Q_{max} or maximum production of the well.
2.) Set up the test system, transformers, variable speed drive, and turn the system on to commence production. Start at a low frequency, take pressure measurements and fluid level shots. Allow the production to stabilize.
3.) Speed up the variable speed drive, usually 2 or 3 Hertz, and again measure the pressures, producing rate, and fluid level. Allow the well to stabilize.
4.) Repeat the process again, until the well pumps down, starts to gas lock, or until the desired production is reached.

Data is collected and tabulated, as shown in **Figure 2.** A graph is then plotted, showing the relationship between drawdown and VFD frequency **(Figure 3).** As expected, when the Frequency is increased in Steps, the bottom hole pressure decreases. The data for well drawdown is collected as shown in **Figure 4,** and a Productivity Index / Inflow Performance Relationship Plot is drawn (P.I./ I.P.R. Plot), as shown in **Figure 5.**

Remember that the production rate is directly proportional to the speed, or frequency of the motor (and pump); the lift or head generated by the pump is proportional to the speed, or frequency of the motor (and pump) **squared;** and the horsepower required for the system is proportional to the speed or frequency of the motor (and pump) **cubed.** If care is not taken in the initial design work, the system will not be able to lift the fluid or power from the motor will not be sufficient to adequately perform the well test as the speed of the system is increased, especially at frequencies above 60 Hertz.

During each of the steps above, it is important to monitor the producing rates, pressures (both surface and down hole), VFD operating frequency, motor current, and VFD current. This monitoring is best accomplished by a good SCADA system, which can gather all of this information and save the data in an electronic memory bank. The data then can be accessed remotely by computer via cellular telephones or radio. Some SCADA systems not only monitor the test information but also automatically download to remote locations and can send out an alarm if any problems are encountered. In even more sophisticated systems, the VFD’s can be “sped up” or slowed down, depending on the well responses, from remote locations. This prevents having to manually go to the well site to perform these duties. In some remote locations, the data has been transmitted via satellite communications. A schematic of the Well Test Trailer with remote communications box is shown on the attached **Figure 6.**

Summary and Conclusions

In this testing program 12 wells were completed with multiple laterals. Then the portable Variable Frequency Drives and ancillary SCADA and surface equipment were utilized to perform step – rate drawdown tests. The best effective producing rates for the wells were determined, and **8** of the wells remain on electric submersible pumping systems today. In the remaining wells, porosity or permeability constraints were such that other methods of artificial lift proved more effective, primarily beam pumping units. In wells with high gas production, the serpentine wellbores caused gas slugging, especially at higher rates.

Performing the well testing operations initially allowed the operator to maximize production and prevented costly mistakes that could have occurred by purchase of the incorrect type of artificial lift equipment. The use of the SCADA equipment provided easy access to real time production data, rates, pressures, and equipment performance parameters. The program is still ongoing today and will be used in the future as additional multiple lateral wells are drilled.

References

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3.) Vogel, J.V.; "Inflow Performance Relationships for Solution – Gas Drive Wells", Journal of Petroleum Technology, January, 1968, pages 83-92
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FIELD CONDITIONS

QUANTITY	FROM	TO
Number of Wells	16	
Avg. BFPD	800	3400
SIBHP (psi)	2700	3600
PUMP INTAKE PRESSURE(psi)	300	2600
API GRAVITY	35	38
WOR	1:1	6:1
BHT, F	145	175
CSG, OD.(in), WT.	5.5", 15.5#	7", 26#
TVD (ft)	4980	5600
MD (ft)	6500	9750
SCALE	light	medium
SAND	none	
H_2S (ppm)	1	50
CO_2 (%)	10	40
EMULSION	NO	
ON / OFF SHORE	ON SHORE	

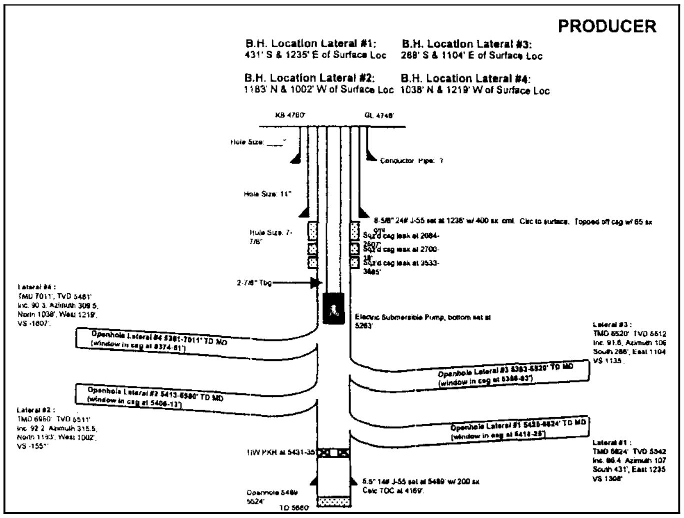


Figure 1

WELL TEST DATA
E.S.P.. Inc.

Operator: MAJOR OPERATOR
Well Name: MULTI-LAT # I
Field: Mid Depth
County: Rio
State: Colorado

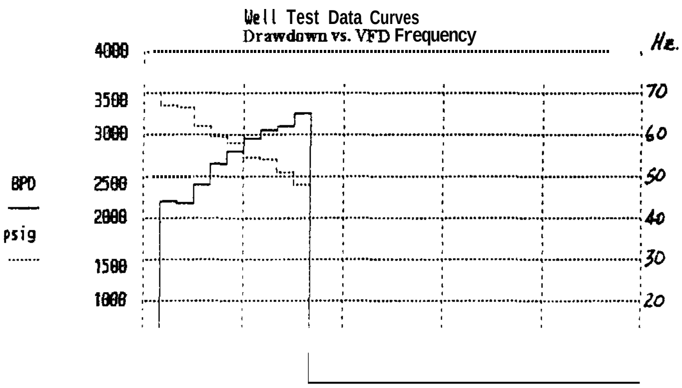
Perforation Depth: 5100-5400
Pump Depth: 5000

Date	Measured Bolls Hole Pressure (psig)	Fluid Rate (BFPD)	Oil Rate (BOPD)	Car Rate (MCFD)	Tubing Pressure (psig)	Freq. (Hz)	Fluid Level (Ft FS)	Casing Pressure (psig)	Fluid Gradient (psi/ft)	Gas Gradient (psi/ft)	Calculated Bottom Hole Pressure (psig)
1-2-91	3,500.0	0.0	0 0	0.0	150.0	0.0	5 0 0	250.0	0.3614	0.0060	2,039.2
1-3-91	3,350.0	2,200.0	610.0	160.0	115.0	45.0	9500	125.0	0.3614	0.0060	1,594.4
1-4-97	3,325.0	2,180.0	615.0	780.0	125.0	45.0	1,100.0	125.0	0.3614	0.0060	1,541
1-5-97	3,110.0	2,410.0	E30.0	815.0	125.0	50.0	1,140.0	125.0	0.3614	0.0360	1,526.8
1-6-97	2,980.0	2,650.0	6550	3100	125.0	55.0	1,270.0	125.0	0.3614	0.0060	1,480.6
1-1-91	2,890.0	2,810.0	715.0	910.0	125.0	510	1,3500	125.0	0.3614	0.0060	1,452.2
1-8-91	2,720.0	2,950.0	740.0	995.0	125.0	60.0	1,380.0	125.0	0.3614	0.0060	1.441.5
1-9-91	2,690.0	3,050.0	760.0	1,025.0	125.0	60.0	1,455.0	125.0	0.3614	0.0060	1,414.9
1-10-97	2,550.0	3,100.0	775.0	1,040.0	125.0	6 5 0	1,550.0	125.0	0.3614	0.0060	1.381
1-11-97	2,400.0	3,250.0	780.0	1,060.0	125.0	67.0	1,700.0	125.0	03614	0.0060	1.327.5

Note: Bottom Hole Pressures represent BHP at pup depth

Comments: Multi-Lateral Yell Test w/ VFD

Figure 2



RESERVOIR PERFORMANCE DATA
E.S.P , Inc.

operator: MAJOR OPERATOR
Well Name: MULTI-LAT # 1
Field: Mid Depth
county: Rio
state: Colorado

Perforation Depth: 5100-5400
Pump Depth: 5000

ACTUAL PERFORMANCE (Stabilized):

Point	Fluid Rate (BPD)	Bottom Hole Pressure (psig)
I *Static	0.0	3,500.0
2	2.150.0	2,950.0
3	2.400.0	2.750.0
4	2,700.0	2.650 0
5	3.000 .0	2,510 0
6	3,100.0	2,440.0
7	3.200.0	2,425 0

PERFORMANCE CALCULATIONS

Static BHP (psig)	3,500.0	Calculated PI (BPD/psi)	2 977
Stabilized Rate (BPD)	3,200.0	PI Max. Prod. (HPD)	10,418.6
Stabilized BHP (psig)	2.425.0	Vogel Max. Prod. (BPD)	6,703.1

Note: Bottom Hole Pressures represent BHP at pump depth

Figure 4

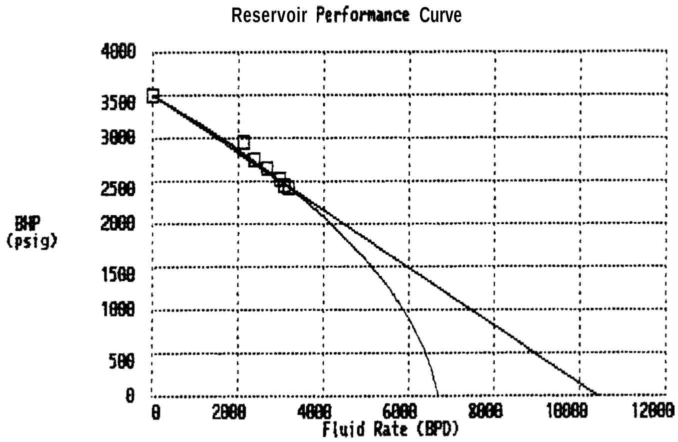


Figure 5

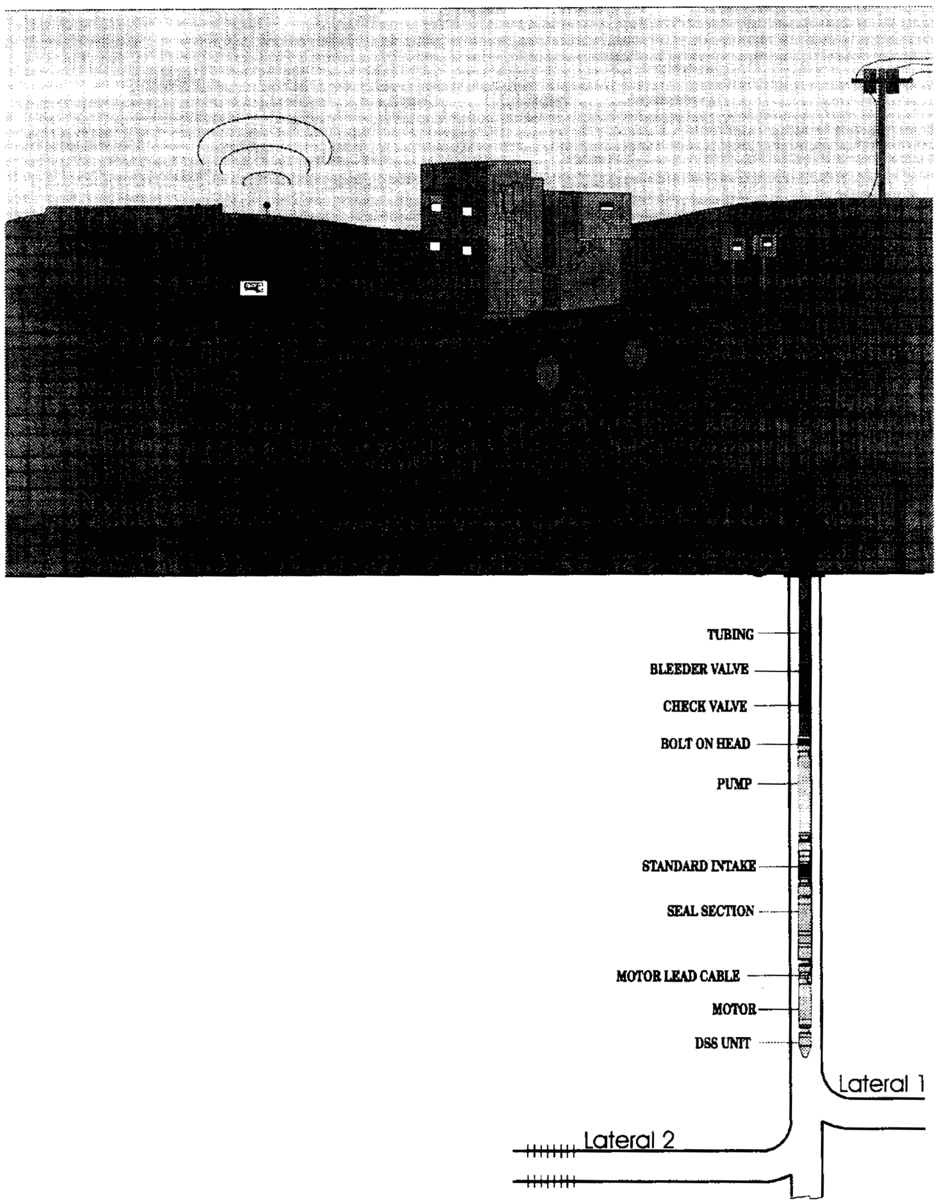


Figure 6 - VFC Test Trailer, Cell Phone Communications Link