

OPTIMIZING PLUNGER LIFTED WELLS BY ACOUSTICALLY TRACING THE PLUNGER FALL

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ABSTRACT

Tracing the fall of the plunger down the tubing can be used to optimize the operation of plunger lifted wells. On plunger lifted wells an acoustic liquid level instrument can be used to collect a series of liquid level shots down the tubing. These measurements are used to monitor the position of the plunger, as the plunger falls down the tubing during the time period the controller has closed the surface valves and the well is shut-in. The collected data is used to determine the 1) fall velocity of the plunger and 2) time for the plunger to fall to liquid.

By accurately measuring the plunger fall velocity with an acoustic liquid level instrument, then the minimum shut-in time for the plunger lift installation can be determined. The plunger trace measurements will ensure that the plunger has reached the liquid at the bottom of the tubing by the end of the shut-in period. Setting the well's controller to have the shortest possible shut-in time period can maximize oil and gas production from plunger lift installations.

INTRODUCTION

Some wells produce gas with a small amount of liquid. The gas is usually produced only up the tubing and is normally not produced up the casing annulus. The produced gas carries the liquid into the tubing and the produced liquid may accumulate in the tubing. If the gas velocity up the tubing is above the Turner critical velocity, then the liquid will be carried with the gas to the surface. If the gas velocity up the tubing is below the Turner critical velocity, then the produced liquid will accumulate in bottom of the tubing'. Gas and liquid flow from the formation will decrease or even stop, if enough liquid is allowed to accumulate in the bottom of the tubing. Back pressure on the formation increases as the height of the accumulated liquid increases, eventually flow from the formation will cease when the back pressure on the formation is equal to the static pressure of the reservoir. Artificial lift methods to produce the accumulated liquid vary. Sometimes pumping units are used to lift the liquid to the surface, but Plunger Lift is an artificial lift technique that has become popular for lifting the liquid accumulated in the tubing to the surface.

Plunger lift is a low cost method for lifting liquids (water, condensate and/or oil) from gas and oil wells. The plunger lift system reduces the cost of operating a well compared to other artificial lift methods, because the formation pressure supplies the energy used to lift the liquids. During plunger lift operations, a cycle of surface gas flow and surface gas shut-in occurs. During shut-in, the surface flow valve is closed which allows the plunger to fall down the tubing. After a pre-determined amount of time elapses, then the surface flow valve opens the tubing to the low-pressure flow-line and the pressure below the plunger lifts the plunger and most of the liquid above the plunger to the surface. Lifting the plunger, accumulated liquids, and gas from the tubing allows additional gas to flow from the formation and casing annulus and be produced at the surface. The plunger operation cycle is continually repeated to produce the well.

An operator can produce the well more efficiently if the plunger fall rate, plunger location, and time the plunger takes to fall to the liquid are determined. An acoustic liquid level instrument can be used to measure the distance from the surface to the top of the plunger during the shut-in cycle. The distance to the plunger and the rate of fall can be measured when the plunger is above the liquid. When the plunger enters the liquid, the acoustic pulse reflects from the top of the liquid so that the distance to the liquid level is measured.

FIELD TESTS

Data used to trace the plunger fall in this paper came from field test performed on three different wells. Field test 1 was done on the Spradley #1 well near Fort Smith Arkansas and the Plunger Fall Trace plot is shown in **Figure 1**. Field test 2 was done on the Chambers C12 well near Canadian Texas and the Plunger Fall Trace plot is shown in **Figure 2**. Field test 3 was done on the Livengood #1 well near Paradise Texas and the Plunger Fall Trace plot is shown in **Figure 3**. The fall of a brush type plunger, **Figure 4**, was traced in field test-1, while a fall of a pad type plunger, **Figure 5**, was traced in field test 2 and 3. Three different types of data collection methods were performed used to trace

the fall of the plunger. Test 1 data was a manual process and the data was collected using an acoustic liquid level paper strip chart recorder². Test 2 data was a manual process and the data was collected using a computerized well analyzer to capture the acoustic shot traces. Test 3 was fully automatic using software in the well analyzer to both remotely fire the gas gun and the data was collected using a computerized well analyzer to capture the acoustic shot traces. In test 1 and 2 an EXCEL spreadsheet was used to tabulate and plot the plunger fall trace data. While for test 3 the Plunger Tracking option of the Total Well Management, TWM, software was used to automatically tabulate and plot the acquired data.

PLUNGER LIFT OPERATION CYCLE

The plunger lift's operation cycle' is similar to intermittent gas lift and the operation cycle can be divided into three parts:

1. **Shut-in** - Surface valves are closed, flow up the tubing the well is shut-in and the plunger falls down the tubing. The plunger falls through the gas until it hits the accumulated liquid at the bottom of the tubing. The plunger then falls through at least some of the liquid and ideally falls to the bottom of the tubing. The plunger rests on a plunger catcher located at the bottom of the tubing. During the shut-in period casing pressure builds at least high enough to lift accumulated fluids and the plunger back to the surface.
2. **Unloading** – After a preset elapsed time the surface valves are opened and pressure stored in the casing is used to lift the accumulated liquid and plunger to the surface. During the unloading period of the plunger operation cycle the tubing pressure at the surface drops below the pressure at the bottom of the tubing and the differential pressure on across the plunger lifts the plunger and trapped fluid above the plunger to the surface.
3. **Afterflow** - Surface valves are open, the plunger is held at surface by differential pressure caused by the flow of gas up the tubing. The well is producing gas up the tubing to the sales line. If the gas velocity in the tubing is high enough to lift fluid to the surface, then some fluid will also be produced with the gas. Although, in plunger lifted wells most liquid produced from the formation tends to fall back, accumulating at the bottom of the tubing. If given enough time the afterflow period is too long the pressure at the bottom of the tubing from the liquid level will build-up to the static reservoir pressure and kill the gas flow from the formation.

The plunger lift operation cycle is repeated frequently enough to remove the flow-restricting liquids that accumulate at the bottom of the tubing. Operation data from the Spradley #1 well of field test 1 is used as an example of a typical plunger operation cycle; with a complete cycle time of 1 hour and 18 minutes, 18 shut-in minutes required for the plunger to fall, 12 unloading minutes for the plunger and liquid to travel to the surface, and 48 after-flow minutes for gas to flow from the well. For the three field test example wells the time period for each cycle varied tremendously widely depending on type of plunger, well depth, formation GLR, fluid properties, well productivity and other factors. For comparison purposes **Table 1** list some of these parameters from for the field test wells.

PROCEDURE

An acoustic liquid level instrument is used to shoot down the tubing and track the fall of the plunger. The depth to the plunger is determined by analyzing the reflected acoustic trace recorded by acoustic liquid level the instrument. The chamber of the gas gun should be charged 500 psig above the tubing pressure, because the normal 100 psig charge is not sufficient to detect the internal recesses of the tubing collars. The time of each shot was recorded: 1) by being printed on the paper strip chart or 2) automatically by the computer. The elapsed time between each shot was approximately one minute. The time for the acoustic pulse to travel from the gas gun to the plunger and reflect back to the gas gun's microphone was accurately determined, this time is called the round trip travel time⁴. The plunger fall velocity between each shot and the overall average plunger fall velocity was determined. The depth to the liquid level in the tubing was determined when the round trip travel time of two consecutive shots was remained constant, this occurred after the plunger fell into the fluid at the bottom of the tubing. The plunger's fall velocity between each shot and the overall average plunger fall velocity was determined.

CALCULATIONS

The depth to the plunger in feet was calculated by multiplying the acoustic velocity' times $\frac{1}{2}$ the round trip travel time or $D = (TV_g)/2$. Where:

D = Distance to the Plunger, ft.

T = Time between initial wave generation and reflected wave, sec.

V_g = Acoustic velocity, ft/sec., obtained from collar frequency or computed from gas gravity.

The plunger fall speed, S , between two consecutive shots is calculated by dividing the difference between the depth to

the plunger by the difference between the elapsed time

$$S = (D_i - D_{i-1}) / (T_i - T_{i-1} + \frac{1}{2} RTT)$$

where:

S = Plunger fall speed, ft/sec

D_i = Distance to the Plunger, ft, at the time of the current shot ,

T_iD_{i-1} = Distance to the Plunger at the previous time, ft, at the time of the previous shot ,T_{i-1},

RTT = Acoustic round trip travel time, sec.

FIELD TEST 1

A plunger fall trace test was done on a brush type plunger in the Spradley #1 well near Fort Smith Arkansas. The data was acquired using a manual process and the data was collected using an acoustic liquid level paper strip chart recorder. An EXCEL spreadsheet was used to tabulate and plot the plunger trace data (a copy of the EXCEL spreadsheet is available on request to Info@Echometer.com).

The 16 paper strip charts are shown on **Figure 6**, notice how well the plunger reflects the pressure pulse of the shot back to the microphone at the surface. The paper strip charts collected during the test were analyzed to determine the time of the shot, the time between shots, and the round trip travel time for the acoustic pulse to travel from the surface to the plunger and back to the surface. Eleven point dividers were used to measure a tubing collar frequency of 22.8 joints per second. Pertinent well and operational information should be recorded onto a form similar to the attached, **Plunger Lift - Data Collection Sheet**⁶, well data such as the average joint length is required in order to determine the acoustic velocity from the collar count. The average tubing joint length of 32.22 feet and the tubing collar frequency was used to calculate a sonic velocity of the acoustic pulse in the tubing of 1428 feet/second.

During the shut-in time from 10:07 until 10:25 the casing pressure built-up enough sufficiently to unload the accumulated fluid and plunger from the well. During the 18-minute shut-in time the pressure in the casing built up to 120 psig; storing gas in the annulus. When the surface valve opens and flow of gas up the tubing is resumed, then the compressed casing gas expands and unloads the tubing by driving the liquid in the tubing captured above the plunger toward the surface. During the unloading cycle the brush plunger acts as a mechanical seal between the liquid and gas to minimize liquid falling back down the tubing. The sum of the unloading and after flow times for this well was equal to one hour. During the afterflow period, gas production from the gas well declines, the velocity of the gas in the tubing decreases and liquid falls back, to accumulate in the tubing. At the end of the afterflow period the tubing head pressure had decreased to 32 psig.

During the test the plunger had reached bottom or fallen through the liquid accumulated in the bottom of the tubing, because both acoustic fluid level shots at 10:23:18 and 10:24:19 had the same round trip travel times of 10:03 seconds. Using the measured sonic velocity of 1428 feet/second, the depth to the fluid level was measured calculated to be 7140 feet. During the afterflow period approximately 260 feet of gas liquid fell back to accumulate in the tubing. Both the depth to the plunger and the plunger fall velocity are plotted in **Figure 1**. The fall of the plunger began at 10:07 and plunger hits the top of the fluid 260 feet above the 7400-foot standing valve depth 15 minutes later at 10:22. **Table 2** displays the results from analyzing the paper strip charts.

Figure 7, the wellbore schematic, shows the 2 3/8 inch tubing to be 7400 feet in length. A standing valve without a ball is set at the bottom of the tubing with a spring above the standing valve to cushion the fall of the plunger. The open-ended tubing is set close to the bottom of the production interval, with the perforations from 7052 to 7568.

FIELD TEST 1 OBSERVATIONS

1. The plunger fall velocity varied from a high of 571 ft per minute (fpm) for the first 1:15 minutes of the test to a minimum velocity of 408 fpm just before the plunger hit the liquid. The average brush plunger fall velocity was measured to be 477 feet/minute fpm. This is less than the typical plunger fall velocities published in the literature of 1000 fpm in dry tubing. The plunger lift installation will operate properly if the actual plunger fall velocity is used to set the cycle times. (Instead of a 1000 fpm rule of thumb estimate)
2. The 3 minutes of time after the plunger hits the liquid is probably sufficient for the plunger to reach the bottom of the fluid. Published plunger fall velocities through liquid are 200-400 fpm and a fall velocity as slow as 100 fpm would still allow the plunger to fall through the 260 feet of fluid and reach bottom in three minutes.
3. The height of the gassy liquid column in the tubing was measured to be 260 feet above the standing valve. Dividing the difference between the casing pressure and tubing pressure by the water gradient can confirm this

measured height. $[203 \text{ feet} = (120 \text{ psig} - 32 \text{ psig}) / 0.433 \text{ psi/ft}]$

FIELD TEST 2

A plunger fall trace test was done on a pad type plunger in the Chambers C12 well near Canadian Texas. The data was acquired using a manual process and the data was collected using a computerized well analyzer to digitally capture the acoustic shot traces. **Table 3** displays the detailed data collected at the well plus the calculated information used to plot the plunger fall trace.

For the Chambers C12 well the average tubing joint length of 31.66 feet and the tubing collar frequency was used to calculate a sonic velocity of the acoustic pulse in the tubing of 1266.7 feet/second. During the shut-in time from 16:21 until 17:03 the casing pressure built-up to 262 psi.

During the test the plunger had reached bottom or fallen through the liquid accumulated in the bottom of the tubing, because both acoustic fluid level shots from 16:33:42 to 16:51:58 had the same round trip travel times of 5.33 seconds. Using the measured sonic velocity of 1266.7 feet/second, the depth to the fluid level was measured computed to be 3379 feet. During the afterflow period approximately 629 feet of gaseous liquid fell back to accumulate in the tubing. Both the depth to the plunger and the plunger fall velocity are plotted in the Figure 2. The fall of the plunger began at 16:21:00 and plunger hits the top of the fluid 629 feet above the 4008-foot standing valve depth, 12.4274 minutes later, at 16:33:42

FIELD TEST 2 OBSERVATIONS

1. The plunger fall velocity varied from a high of 286 fpm to a minimum velocity of 162 fpm just before the plunger hit the liquid. The average pad plunger fall velocity was measured calculated to be 265 feet/minute. This is less than the typical plunger fall velocities published in the literature.
2. 7 minutes of time after the plunger hits the liquid level is probably sufficient time for the plunger to reach the bottom of the tubing. Published plunger fall velocities through liquid are 200-400 fpm and a fall velocity as slow as 100 fpm would still allow the plunger to fall through the 629 feet of gaseous liquid and reach bottom.
3. The minimum shut-in time required for the plunger to fall from the surface and reach the bottom of the tubing should be 20 minutes. (12.74 through gas + 7.00 through liquid).

FIELD TEST 3

A plunger fall trace test was done on a pad type plunger in the Livengood #1 well near Paradise Texas. The data was acquired automatically using software in the well analyzer to both remotely fire the gas gun and store the digitized acoustic shot traces. The Plunger Tracking option of the Total Well Management, TWM, software was used to automatically tabulate and plot the acquired acoustic data.

For the Livengood well the average tubing joint length of 31.69 feet and the tubing collar frequency was used to calculate a sonic velocity of the acoustic pulse in the tubing of 1216 feet/second.

During the test the plunger had reached bottom or fallen through the liquid accumulated in the bottom of the tubing, because the five acoustic fluid level shots from 12:01 to 12:12 had approximately the same round trip travel times of 9.16 seconds. Using the measured sonic velocity of 1216 feet/second, the depth to the fluid level was measured calculated to equal be 5568 feet. During the afterflow period approximately 245 feet of gaseous liquid fell back to accumulate in the tubing. Both the depth to the plunger and the plunger fall velocity are plotted in the Figure 3. The fall of the plunger began at 11:39 and plunger hits the top of the fluid 232 feet above the 5800-foot standing valve, depth 9.16 minutes later at 12:01.

FIELD TEST 3 OBSERVATIONS

1. The plunger fall velocity varied from a high of 396 fpm to a minimum velocity of 193 fpm just before the plunger hit the liquid. The average pad plunger fall velocity was measured calculated to be 259 feet/minute. This is less than the typical plunger fall velocities published in the literature.
2. 3 minutes of time after the plunger hits the liquid level is probably sufficient time for the plunger to reach the bottom of the tubing. Published plunger fall velocities through liquid are 200-400 fpm and a fall velocity as slow as 100 fpm would still allow the plunger to fall through the 259 feet of gaseous liquid and reach bottom.
3. The minimum shut-in time required for the plunger to fall from the surface and reach the bottom of the tubing should be 13 minutes. (9.16 through gas + 3.00 through liquid).

CONCLUSIONS

The following conclusions were made from analyzing the data collected during the three field tests:

1. Plunger fall velocity can be accurately measured with an acoustic fluid level instrument,
2. Minimum shut-in time for the plunger lift installation can be determined.
3. Plunger trace measurements will ensure that the plunger will reach the fluid at the bottom of the tubing by the end of the shut-in period.
4. Maximum production from the plunger lift installation will be obtained by having using the shortest possible shut-in time equal to the time required for the plunger to reach bottom.

Based on the limited data collected from the three field test wells:

5. Measured plunger fall velocities for both pad and brush type are much less than the typical 1000 ft/min plunger fall velocities published in the literature.
6. Brush type plungers (477 ft/min) fall twice as fast as pad type plungers (262 ft/min).

Tracing the fall of a type plunger down the tubing by shooting the depth to the plunger with an acoustic fluid level device is a fairly simple task. By accurately measuring the plunger fall velocity and depth to the liquid level with an acoustic fluid level instrument, then the minimum shut-in time for the plunger lift installation can be determined. The plunger trace measurements will ensure that the plunger will reach the fluid at the bottom of the tubing by the end on the shut-in period. Maximum production from the plunger lift installation will be obtained by having the shortest possible shut-in time, as long as there is sufficient pressure stored in the casing annulus to return the plunger to the surface during the next unloading cycle.

REFERENCES

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4. McCoy, James N., Podio, Augusto, L. and Huddleston, Ken L., "Acoustic Determination of Producing Bottomhole Pressure," SPE 14254, presented at the 1985 SPE Annual Technical Conference and Exhibition, Las Vegas, Nevada, September 22-25, 1985.
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Table 1
Comparison of Well Information

Field	Acoustic Velocity (Ft/sec)	Plunger Type	Tubing Depth (Feet)	Height of Liquid (Feet)	Average Fall Velocity (Ft/min)
	1424	Brush	740C	26C	47;
	1269	Pad	4008	608	261
	1216	Pad	5800	232	256

Table 2
Brush Type Plunger Fall Trace Data for Field Test 1 on Spradley #1 Well

Shot #	Time of Shot	Time between Shots	Acoustic Round Trip Travel Time Sec	Elapsed Time Minutes	Depth to Plunger Feet	Plunger Fall Speed Ft/Min	Remarks
1	10:01:38						Well Flowing Gas to Sales Line
	10:07:00	0	0.00	0.00	0		Valves close & plunger begins fall
2	10:08:15	0:01:15	1.01	1.26	719	571	
3	10:09:17	0:01:02	1.82	2.31	1296	550	Average Velocity 561 for 2.31 min
4	10:10:16	0:00:59	2.58	3.31	1837	538	
5	10:11:17	0:01:01	3.32	4.36	2364	504	
6	10:12:11	0:00:54	3.95	5.29	2812	481	
7	10:13:10	0:00:59	4.64	6.31	3303	481	
8	10:14:14	0:01:04	5.30	7.42	3773	423	
9	10:15:12	0:00:58	5.92	8.44	4214	434	
10	10:16:25	0:01:13	6.63	9.71	4720	397	
11	10:17:15	0:00:50	7.18	10.60	5111	438	
12	10:18:15	0:01:00	7.75	11.67	5517	381	
13	10:20:14	0:01:59	8.97	13.73	6386	422	
14	10:21:34	0:01:20	9.78	15.14	6962	408	
	10:22:00	26.20		15.58	7140	408	Time plunger hits fluid
15	10:23:18	0:01:44	10.03		7140		
16	10:24:19	0:01:01	10.03		7140		
Average Plunger Velocity (Ft/Min)						477	

Table 3
Pad Type Plunger Fall Trace Data for Field Test 2 on Chambers C12 Well

Shot #	Time of Shot	Time between Shots	Acoustic Round Trip Travel Time Sec	Elapsed Time Minutes	Depth to Plunger Feet	Plunger Fall Speed Ft/Min	Remarks
1	16:21:00	0	0.000	0.00	0		Valves close & plunger begins fall
2	16:21:42	0:00:42	0.260	0.70	165	235	
3	16:31:00	0:09:18	4.475	10.04	2839	286	
4	16:32:50	0:01:50	5.094	11.88	3232	209	
5	16:33:42	0:00:52	5.326	12.74	3379	162	Time plunger hits fluid
6	16:34:33	0:00:51	5.323	13.59	3377	-2	
7	16:35:52	0:01:19	5.294	14.91	3358	-14	
8	16:37:10	0:01:18	5.294	16.21	3358	0	
9	16:40:43	0:03:33	5.243	19.76	3326	-9	
10	16:44:34	0:03:51	5.235	23.61	3321	-1	
11	16:47:50	0:03:16	5.200	26.88	3299	-7	
12	16:51:58	0:04:08	5.177	31.01	3284	-3	
Average Plunger Velocity (Ft/Min)						265	

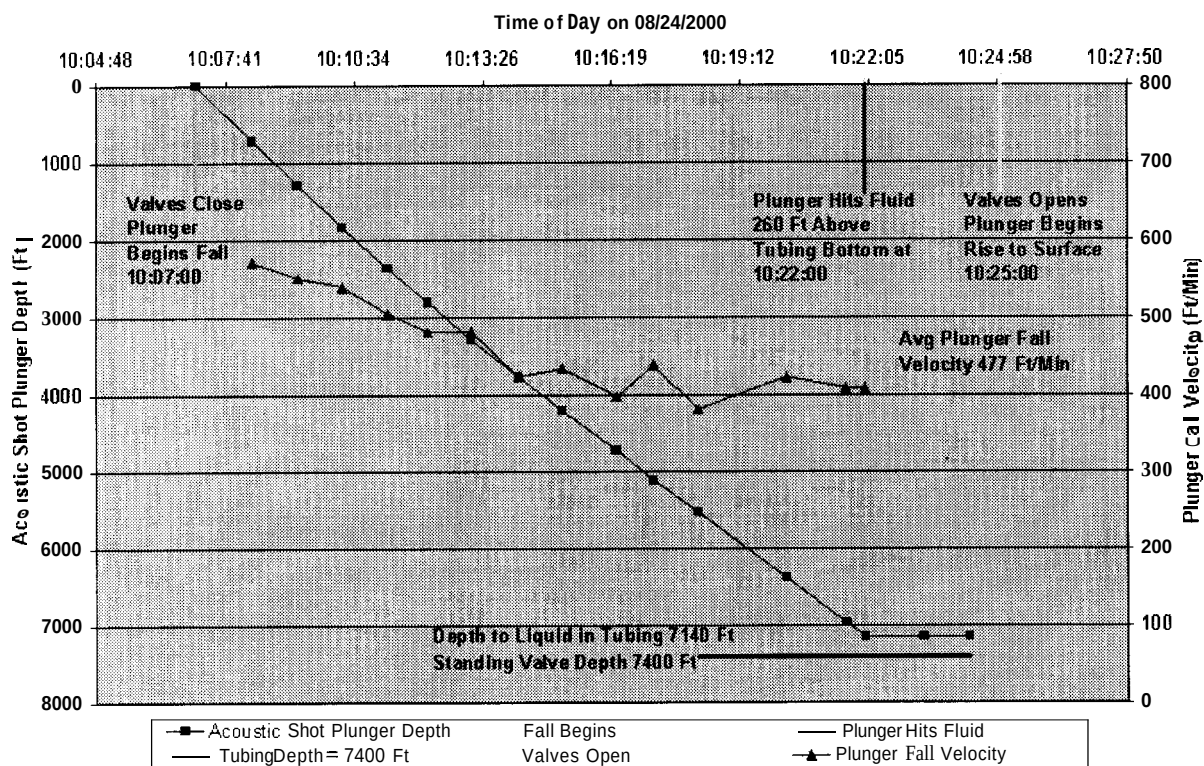


Figure 1 - Brush Type Plunger Fall Trace Plot for Field Test 1 on Spradley #1 Well

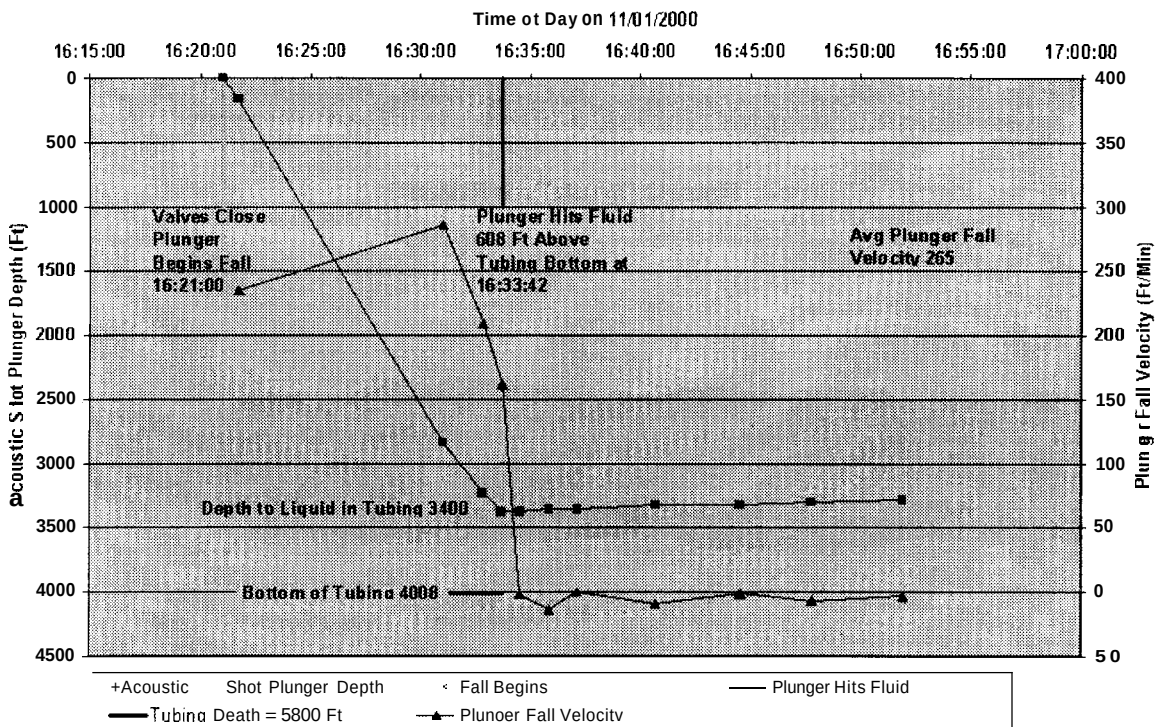


Figure 2 - Pad Type Plunger Fall Trace Plot for Field Test 2 on Chambers C12 Well

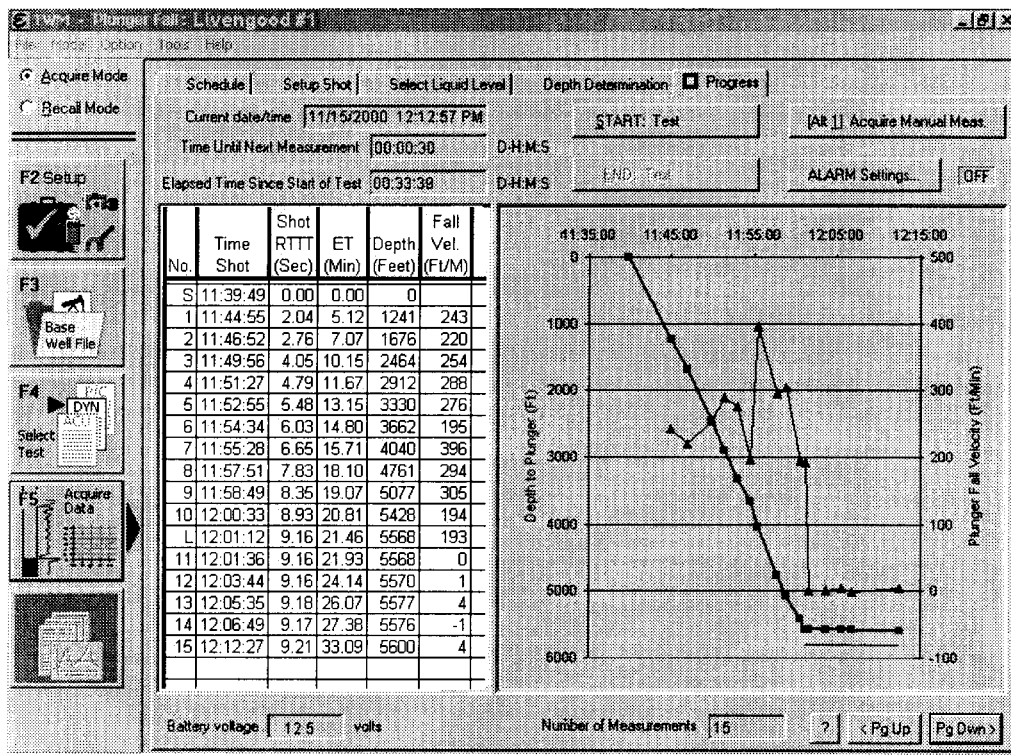


Figure 3 - Pad Type Plunger Fall Trace Plot for Field Test 3 on Livengood #1 Well



Figure 4 - Brush Type Plunger



Figure 5 - Pad Type Plunger

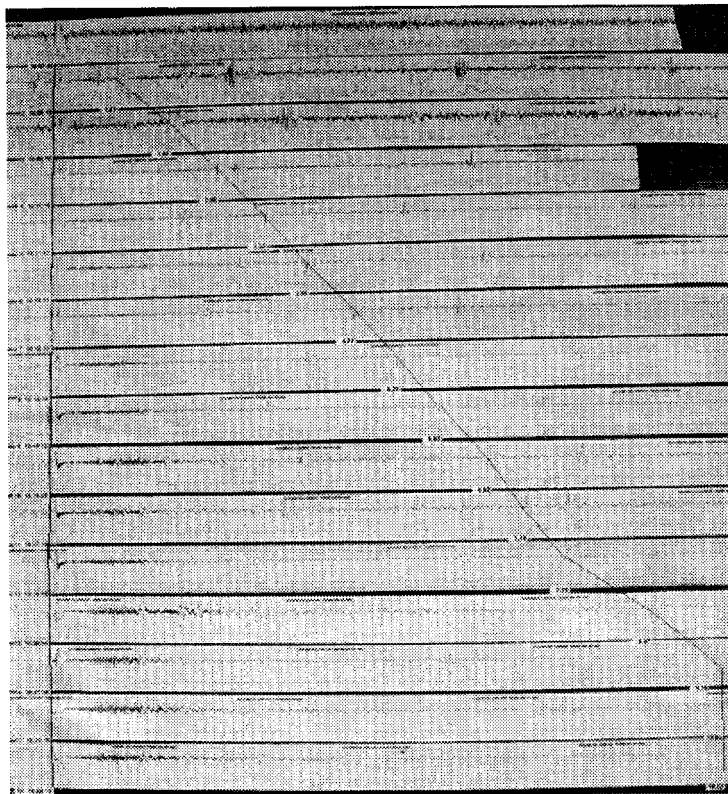


Figure 6 - Paper Strip Charts Tracing Plunger's Fall

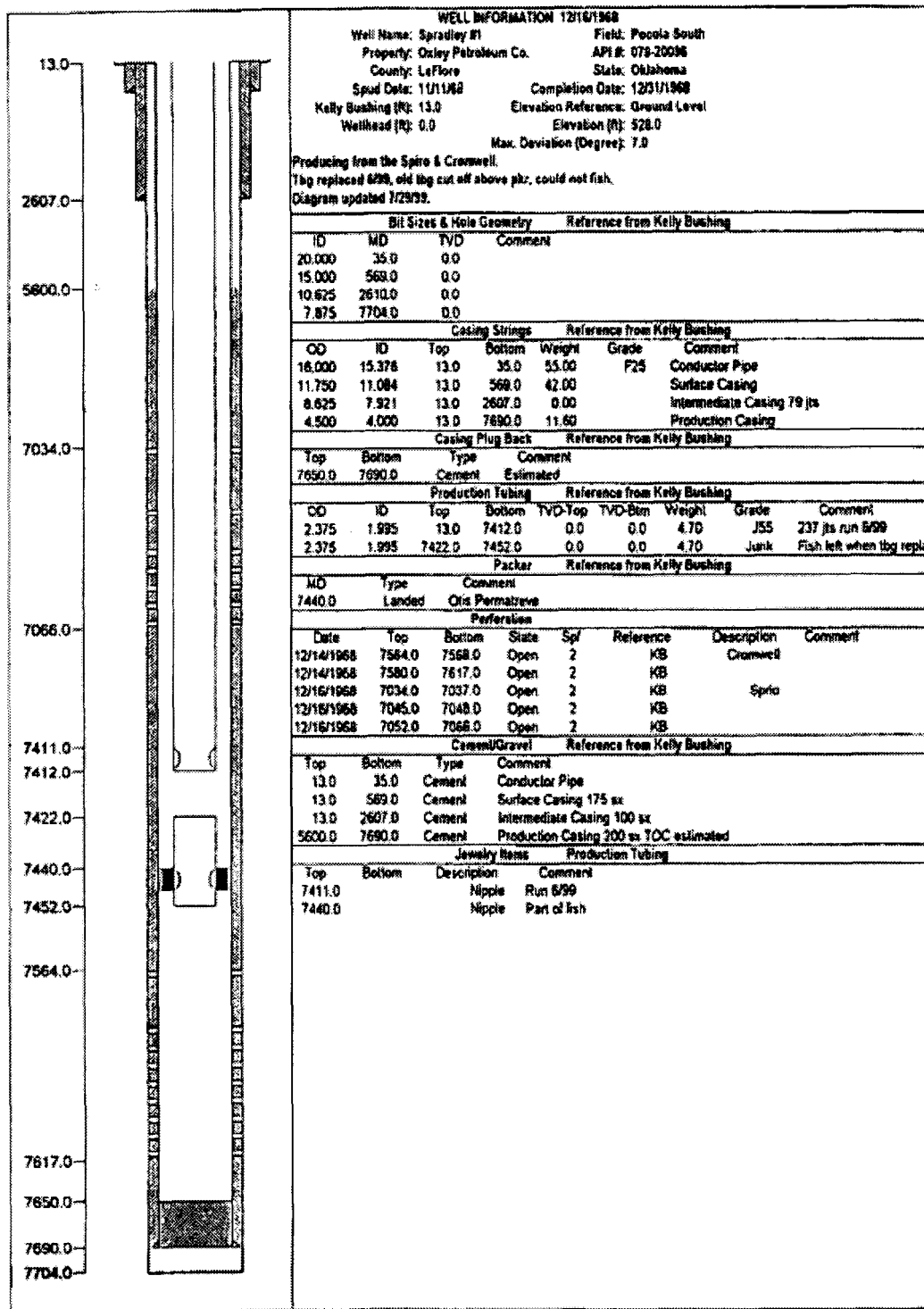


Figure 7 - Spradley #1 Well Bore Schematic

Plunger Lift ~ Data Collection Sheet

Date: _____

(((ECHOMETER)))

Operator: _____

Contact Person/Phone: _____

Well Name: _____

County/State: _____

Well Depth: _____

Casing Size & Weight: _____

Casing Setting Depth: _____

Perfs: Top _____ Bottom _____

Tubing Size & Weight: _____

Tbg Depth: Anchor _____ Intake _____

Number of Tubing Joints: _____

Avg Joint Length: _____ Tally Attached: _____

Plunger Mfr: _____

Plunger Size/Type/Make/Wt.: _____

Standing Valve Depth: _____

SV Description: _____

Flowline : (OD) _____ ID: _____

Length: _____ Material: _____

Gas Gravity: _____

Oil/Condensate Gravity: _____

Water Gravity: _____

Bottomhole Temp (est): _____

Average Static Reservoir Pressure: _____

Static Date: _____

Well Test Data (Actual Plunger Performance Information): Test Date: _____

Cycle times: Shut-in _____

Unloading _____

Afterflow _____

Gas Rate, Mcf/day: _____

Oil/Condensate Rate, BOPD: _____

Water Rate, BWPD: _____

Average Velocity: _____

(From bottom to surface)

Max. Tubing Pressure: _____

Min. Tubing Pressure: _____

Max. Casing Pressure: _____

Min. Casing Pressure: _____

Separator/Line Pressure: _____

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