DETERMINING HOW DIFFERENT PLUNGER MANUFACTURE FEATURES AFFECT PLUNGER FALL VELOCITY

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ABSTRACT

Tracking the fall of the plunger down the tubing can be used to optimize the operation of plunger lifted wells. Acoustic fluid level instruments can be used on plunger lifted wells to acquire a series of plunger/fluid level soundings and/or to record the acoustic signal produced as the plunger falls down the tubing. Five different data acquisition and analysis methods can be used to monitor the position of the plunger, as the plunger falls down the tubing during the controller's shut-in time period. The acquired data is used to determine the 1) fall velocity of the plunger 2) depth to the plunger and 3) time for the plunger to fall to fluid. Results acquired from field case studies from 15 sessions at various wells are used to correlate the various construction features of different types of plungers with their fall velocity. Some construction features cause a plunger to fall rapidly through the tubing, while other features cause the plunger to have a slow fall velocity.

By accurately measuring the plunger fall velocity, the proper shut-in time for the plunger lift installation can be determined. The plunger trace measurements will ensure that the plunger has reached the fluid 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 to allow the plunger to fall to bottom 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 generally 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 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 well. Backpressure on the formation increases as the height of the accumulated liquid increases and eventually flow from the formation will cease when the backpressure 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 dewater gas wells by pumping the liquid to the surface, but plunger lift is the technique that is most frequently used to lift the liquid accumulated at the bottom of the tubing of low productivity gas wells to the surface.

Plunger lift is a low cost method for lifting liquids (water, condensate and/or oil) from gas and oil wells. This 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, repeated cycles of surface gas flow and surface gas shut-in occurs. During shut-in the gas flow down the flowline is stopped when the surface control valve is closed. This allows the plunger to fall down to the bottom of the tubing. After a pre-determined amount of time the surface flow valve opens and the tubing is connected to the low-pressure flowline. This reduces the pressure in the tubing above the liquid column and the pressure below the plunger lifts the plunger and most of the liquid above the plunger to the surface. During this process the bottomhole pressure is reduced and this 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 and bottom of tubing are determined. Five different data acquisition and analysis methods can be used to monitor the position of the plunger, as the plunger falls down the tubing during the shut-in time period. An acoustic liquid level instrument is used to determine the distance from the surface to the top of the plunger during the shut-in portion of plunger lift operational 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. This paper discusses the procedures used to apply five different data acquisition and analysis methods to track the fall of the plunger, and gives examples of the data collected by each method.

PLUNGER LIFT OPERATION CYCLE

The plunger lift cycle[3] can be divided into three distinct parts:

1. The **Shut-in** period begins when the surface valves close, the well is shut-in and the plunger falls down the tubing. The plunger falls through gas until it hits the accumulated liquid at the bottom of the tubing. The plunger then falls through at least some of the accumulated liquid at the bottom of the tubing. Ideally the plunger falls to the bottom of the tubing and rests on a plunger catcher. During the shut-in period casing pressure should build high enough to lift the accumulated fluids and the plunger to the surface.
2. The **Unloading** period begins after a predetermined amount of time has elapsed from the start of the shut-in period and some type of controller opens the surface valve between the tubing and the flowline. The pressure from the reservoir and the pressure from the gas stored in the casing annulus are used to lift the accumulated liquid and plunger to the surface. During the unloading period the surface tubing pressure drops to the line pressure and the differential pressure across the plunger lifts the plunger and trapped fluid above the plunger to the surface.
3. The **Afterflow** period begins when the plunger arrives at the surface. The 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 liquid to the surface, then some additional liquid will also be produced with the gas. During the afterflow period, as the gas rate decreases, liquid tends to not be carried to surface because the gas velocity becomes too low and the liquid tends to fall back and accumulate at the bottom of the tubing. If the afterflow period is too long the pressure at the bottom of the tubing will build-up to the static reservoir pressure and kill the flow from the formation.

Fig. 1 is a plot of the casing pressure, tubing pressure and acoustic data acquired during one complete cycle of a plunger lift system that includes the **Unloading,** the **Afterflow** and the **Shut-in** periods. Data acquisition started 48.7 minutes prior to the beginning of the unloading period. Unloading of the well lasted for 7.3 minutes. The plunger arrived at the surface at 56 minutes, beginning the afterflow period that lasted for 10.2 minutes. The shut-in period begins at 66.2 minutes for an elapsed time for the cycle of 30.4 minutes. The plot shows only one complete cycle of data. The plunger lift operation cycle had a period of 48 minutes and repeated at a frequency of 30 cycles per day, which was sufficient to remove the liquids that accumulate at the bottom of the tubing thus keeping the gas flowing at the desired rate.

PLUNGER FALL TRACKING

One of the most critical elements in optimizing plunger lift is having accurate information about the location of the plunger to determine the plunger fall time. Two types of systems for monitoring the acoustic signal can be used: 1) active monitoring and 2) passive monitoring. The five different acoustic data acquisition and analysis methods used to monitor the position of the plunger, as the plunger falls down the tubing during shut-in period are:

1) Manually shoot down tubing and analyze data by hand (Active Type),
2) Computerized control to automatically shoot down tubing and analyze fall (Active Type),
3) Determine round trip travel time for acoustic pulse created by plunger (Passive Type),
4) Determine the elapsed time from valve close to plunger hitting liquid (Passive Type), and
5) In high-speed acoustic signal recording count acoustic pulse from each collar (Passive Type).

All methods yield information regarding the plunger position and can be implemented using various commercially available acoustic fluid level instruments.

Active Monitoring - In this analysis, the fall of the plunger is monitored from the beginning to the end of the shut-in period by obtaining acoustic liquid level tests down the tubing at periodic intervals during the plunger fall. **Fig. 2** shows a schematic of the field installation for the active type of test. A Gas Gun with a pressure pulse generator and a sensitive twin-disc noise canceling acoustic microphone is attached to the tubing at the surface. The round-trip travel time is measured for each test either manually using a strip chart record (Method 1) or automatically with digital data acquisition system (Method 2). The round-trip travel time is divided by two to obtain the one-way travel time and then multiplied by the acoustic velocity of the gas in the tubing to determine the depth to the plunger or the liquid level (when the plunger has fallen below the liquid level). The acoustic velocity and gas properties are determined at the beginning of the plunger-lift analysis by conducting an acoustic test down the casing annulus. The acoustic velocity is adjusted for variations due to pressure changes. The acoustic liquid level test cannot monitor the plunger location when the plunger is submerged in the liquid. The data displayed in **Fig. 3** was collected manually using an acoustic liquid level paper strip chart recorder[2] and analyzed by hand (Method 1).

Passive Monitoring - When using a digital fluid level instrument the sensitivity of the system is such that the Gas Gun microphone can be used to detect plunger location during the plunger fall by monitoring and digitally recording the noise inside the tubing as a function of time. During all of the plunger fall field test, it has been observed that an acoustic pulse is generated when the plunger falls past a tubing collar recess. A difference in pressure exists across the plunger as it falls depending upon the weight and area of the plunger and other factors. This difference in pressure above and below the plunger might be from 2 to 10 PSI. Thus, as the plunger falls past the recess, an acoustic pulse is generated from the rapid release of the differential pressure across the plunger. This acoustic pulse, which is generated at the tubing collar recess, travels through the gas to the surface and is detected by the microphone and also by the tubing pressure transducer. These acoustic pulses are normally obtained when a plunger falls down the tubing in a well that produces a limited amount of liquid so that the tubing interior is relatively dry. These tubing recess pulses are monitored at the surface so that the plunger travel is followed on a continuous basis. Methods 3, 4, and 5 do not require the periodic firing of the gun to determine the position of the plunger by echo ranging and thus they have been defined as "passive" monitoring. The schematic for the instrumentation set up is similar to **Fig. 2,** except that in addition to the gas gun, pressure sensors may be connected to both the tubing and casing. For passive monitoring, high frequency (30Hz or greater) data acquisition is used to record the signals from both tubing and casing pressure sensors, plus the acoustic signal from the microphone.

When the plunger enters the liquid, these acoustic pulses are not transmitted through the liquid, so the acoustic noise level drops, indicating that the plunger is submerged in the liquid. When the plunger finally rests on bottom on the bumper spring the noise level may drop again; in some of the field tests, the time may be determined when the plunger reached bottom after the plunger was submerged in the liquid.

CALCULATIONS

For the Active methods the depth to the plunger is determined by analyzing the reflected acoustic trace recorded by the instrument. The clock time when each shot is fired is recorded and the elapsed time between shots is determined. The travel time for the acoustic pulse to propagate from the gas gun to the plunger and reflect back to the gas gun's microphone is accurately determined. This time is called the round trip travel time[4]. The depth to the plunger in feet is calculated by multiplying the acoustic velocity[5] times ½ the round trip travel time, (RTTT), for the acoustic pulse to travel from the gas gun to reflect off the plunger and travel back to the microphone in the gas gun or

$D = (T \times Va)/2$. Where:

- D = Distance to the Plunger, ft.
- T = Time between initial wave generation and reflected wave, sec.
- Va= Acoustic velocity, ft/sec, obtained from collar frequency or computed from gas gravity.

The plunger fall speed, S, between two consecutive acoustic measurements is calculated by dividing the difference between the depth to the plunger by the difference between the elapsed clock time.

$S = (Di - Di\text{-}1) / (Ti - Ti\text{-}1)$ Where:

- S = Plunger fall speed, ft/sec
- Di = Distance to the Plunger, ft, at the time of the current shot, Ti
- Di-1= Distance to the Plunger at the previous time, ft, at the time of the previous shot, Ti-1
- (Ti - Ti-1) = Time between shots, in seconds.

METHOD 1 – MANUAL SHOOTING GAS GUN (ACTIVE)

This method, to manually shoot down tubing and analyze the acquired data by hand, was used to trace the fall of a **brush type plunger** in the Spradley #1 well near Fort Smith, Arkansas. The 2 3/8 inch tubing is 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 producing interval, with the perforations from 7052 to 7568. The data was acquired manually 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 by request to Info@Echometer.com).

Shown on **Fig. 3** are the sixteen paper strip charts acquired during this test, 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 Plunger Lift - Data Collection Sheet[6]. Well data such the average joint length is required in order 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 for the gas in the tubing of 1428 feet/second.

During the shut-in time from 10:07 until 10:25 the casing pressure built-up 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; as gas was stored in the annulus. When the surface valve opened and flow of gas up the tubing was resumed, then the compressed casing gas expanded and unloaded 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 well declined, the velocity of the gas in the tubing decreased and liquid fell back, accumulating 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 feetisecond, the depth to the fluid level was calculated to be 7140 feet. During the afterflow period approximately 260 feet of liquid fell back to accumulate in the tubing. In **Fig. 4** both the depth to the plunger and the plunger fall velocity are plotted. The fall of the plunger began at 10:07 and plunger hit the top of the fluid 260 feet above the 7400-foot standing valve depth 15 minutes later at 10:22.

METHOD 2 – AUTOMATIC SHOOTING GAS GUN (ACTIVE)

Method 2 was used to automatically acquire the acoustic shots and determine the plunger fall velocity. The test was done at the B3 well near Odessa, Texas having a **dual-pad type plunger** in 2 7/8 inch tubing with a tubing length of 9748 feet. Digital data acquisition and processing software caused the acoustic liquid level instrument to automatically fire the gas gun, store the digitized acoustic shot traces, and process the data to determine the depth to the plunger. The depth data versus elapsed time was processed to determine the average plunger fall velocity of 200 feet per minute. With this method, unattended acoustic liquid level acquisition is possible since a laptop computer and data acquisition software control the taking of fluid level shots. In this test the shots were acquired at a predefined schedule of 1.67 minutes between each shot. **Fig. 5** shows a time plot of the depth to the plunger and the fall velocity of the plunger fall.

During the test the plunger had reached bottom or fallen through the liquid accumulated in the bottom of the tubing, because the last 4 acoustic fluid level shots from an elapsed time 50 to 55 minutes had approximately the same round trip travel times of 16.83 seconds. Using the measured sonic velocity of 1141 feetisecond, the depth to the fluid level was calculated to equal 9634 feet. During the afterflow period approximately 150 feet of liquid accumulated in the tubing. The 5 minutes of time the plunger was below the liquid was of sufficient duration for the plunger to reach bottom.

METHOD 3 – RTTT PLUNGER'S ACOUSTIC PULSE (PASSIVE)

Method 3 uses the round trip travel time, RTTT, from an acoustic pulse generated by the plunger at the tubing collar recess to determine the depth to the plunger. Tubing and casing pressures and the acoustic signal were passively acquired on a **dual pad type plunger** in the Livengood #1 well near Paradise Texas. **Fig. 6** shows the acoustic signal encompassing the time the plunger was falling down the tubing during a portion of the shut-in time period. The shut-in time period began at an elapsed time of 65 minutes, the plunger entered the liquid at an elapsed time of 85.8 minutes, and the amplitude of the acoustic signal became very small approximately 1.4 minute later when the plunger rested at the bottom. For the 2 318 inch tubing with a tubing joint length of 31.7 feet, the acoustic velocity of 1042 feetisecond was determined from the gas specific gravity.

Notice the interval from 70 to 71 minutes that is highlighted on **Fig. 6,** this one-minute portion of the plot is expanded to produce the detailed acoustic trace displayed in **Fig. 7.** To determine the depth to the plunger an acoustic pulse over a small portion of the 1-minute trace must be analyzed, this acoustic pulse has to first travel from the recess to microphone, reflect back to the plunger, and reflect back to the microphone. The acoustic pulse created by the 40 tubing collar recesses occurs at an elapsed time of 70.02 minutes and the reflected pulse takes 0.04 minutes to travel round trip. The equation, $D = (TVa)/2$, is used to calculate the depth to the plunger of 1251 feet (0.04x60x1042/2). At the 47th tubing collar the reflected acoustic pulse from the recess takes 0.05 minutes to travel round trip, this increased round trip travel time increases directly proportional to the increased depth of the plunger in the tubing.

METHOD 4 – FALL VELOCITY FROM ELAPSE TIME (PASSIVE)

Method 4 is the simplest technique for calculation of the fall velocity because the average plunger fall velocity is determined by dividing the depth to the liquid in the tubing by the plunger fall time. The fall time is determined by subtracting the elapsed time when the shut-in period begins from the elapsed time when the plunger enters the liquid at the bottom of the tubing. **Fig. 8** displays only the acoustic signal acquired during the plunger fall. But in this test, high frequency signals from both tubing and casing pressure sensors, plus the acoustic signal from the microphone were acquired using the passive type of data acquisition.

The data was acquired on the B 12 well near Odessa, Texas. The 2 718 inch tubing had a length of 10235 feet with approximately 150 of liquid accumulated in the bottom of the tubing. The type of plunger in this well had **dual pads with a bypass valve** (the valve was open when the plunger falls during the shut-in period and the valve is closed during the unloading portion of the cycle). The fall time of 5.97 minutes was calculated by the difference between the time when the plunger began its fall at an elapsed time of 74.8 seconds and the elapsed time of 432.8 seconds at the end of the fall. The average fall velocity was calculated to equal to 1690 feet per minute (1008515.97) by dividing the fall depth by the fall time.

METHOD 5 – COUNT PULSE FROM COLLARS (PASSIVE)

Method 5 is also a simple process to determine the plunger fall velocity, but it can be time consuming to manually count each acoustic pulse created by the plunger passing a tubing collar recess. This method is suited for computer processing of the acoustic data, where each collar reflection would be counted by software. Once the elapsed time for each collar reflection is determined, then it is a simple process to determine the depth to the collar reflection by multiplying the average tubing joint length times the count of the recess acoustic pulse. An example of this calculation can be seen in **Fig. 7,** where the depth to the 40th acoustic pulse would be equal to (40x31.7) 1268 feet. **Fig. 9** displays the plunger depth determined by counting each recess reflection versus elapsed time. The fall velocity is the slope of the plunger depth versus elapsed time line. The fall velocity is calculated by dividing the average joint length by the difference in elapsed time between acoustic pulses from the plunger passing collar recesses at the top of successive tubing joints.

The test was done on the same well B3 well near Odessa, Texas as **Fig. 5** having a **dual-pad type plunger** in 2 718 inch tubing with a tubing length of 9748 feet. During the test the plunger reached bottom and there appears to be limited liquid accumulated in the bottom of the tubing. Master valve closed at 15:30:59 to begin the shut-in period. The plunger hit the bottom of the tubing at 16:22:58. The average fall velocity of 192 feet per minute compares well with the fall velocity of 200 determined by automatically shooting the depth to the plunger using Method 2.

RESULTS

The plunger fall velocities determined from the acquired acoustic data from 15 sessions at various plunger lift well throughout Texas are displayed in **Table 1** and **Table 2. Table 1** is for tubing size of 2 318 inch and each data set was collected from a different type of well and usually a different type plunger. **Table 2** is for a tubing size of ***2*** 718 inch and the performance of different types of plungers was studied in the same well. Two different data acquisition methods were used to determine the fall velocity in Well B9 in **Table 2** and the 200 fpm fall velocity using active method 2 compared favorably with the 192 fpm fall velocity frompassive method 5.

OBSERVATIONS FROM FIELD TEST

The plunger fall velocity of the worn brush plunger 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 fpm. The data from the field test usually shows the plunger fall velocity decreases as the plunger get closer to the bottom of the tubing.

Two sets of data acquired using the passive method displayed acoustic signal changes as the plunger fell through the liquid at the bottom of the tubing. The signal changes could be interpreted to calculate the fall of the plunger through liquid using a calculation procedure similar to method 4. The fall velocity was calculated to be 150 fpm. Published plunger fall velocities through liquid are 200-400 fpm. The shut-in time was sufficiently long enough for all of the plungers in the study to reach bottom, and the slower fall velocity through liquid of 150 fpm would still allow the plunger to fall through fluid and reach bottom.

In test 1 the height of the gassy liquid column in the tubing was measured to be 260 feet above the standing valve at the end of the shut-in period. This height was confirmed by calculating the height of fluid in the tubing by dividing the difference between the casing pressure and tubing pressure by the water gradient. [203 feet = (120 psig – 32 psig) 10.433 psi/ft]

As plungers fall through the gas of the tubing a differential pressure across the plunger resist the fall. This differential pressure could be seen in one set of passive data when the plunger became stuck while falling down the tubing during the shut-in period. Immediately when the plunger became stuck, the tubing pressure increases by approximately 3 psi and when the plunger began to fall again the tubing pressure decreased by an equal 3-psi amount.

PLUNGER FEATURES

The various construction features of different types of plungers affect the fall velocity. Some of these features are: diameter, effectiveness of seal, increased friction due to contact with the tubing, if the plunger falls straight or spins, and the age of plunger or amount of wear. Some construction features cause a plunger to fall rapidly through the tubing, while other features cause the plunger to have a slow fall velocity.

As the diameter of the plunger increases, the fall velocity of the same type plunger decreases. As the diameter of a plunger increases, then the weight of the plunger increases. Friction between the plunger and tubing should increase as the diameter increases, because the increase in diameter causes a larger surface area of the plunger to contact the tubing. The cross-sectional area of the plunger increases by the square of the diameter and a smaller differential pressure is required to resist the fall of the plunger. The larger diameter plunger increases the friction and the larger area increases the force due to differential pressure applied to the plunger cross-sectional area, which result in slower fall speed. Pad fall velocity in 2 3/8 inch is approximately 260 fpm, while the fall velocity of the heavier 2 7/8 inch diameter dual pad plunger is approximately 190 fpm.

The effectiveness of the seal to prevent or allow fluids to flow past the plunger has a major impact on fall velocity. The plunger (Ultra-seal in test 4) has neoprene seals between the lower set of pads and the plunger body, this feature might be desired if liquid slipping past the plunger was a problem. The neoprene provided a good seal to gas flowing past the plunger and resulted in almost the slowest fall velocity of 159 fpm. The by-pass plunger has a valve that opens during the shut-in period creating a large opening through the plunger and there is low restriction to fluids flowing through the plunger. The ability to by-pass fluids through the plunger resulted in the highest fall velocity of 1690 fpm.

The brush plungers had the largest difference of fall velocity of any type of plunger. The fall velocity of the worn brush plunger ranged from a high speed of 477 fpm down to the slowest speed of 150 fpm of a new brush. A new brush has nylon bristles that are stiff and contact the tubing wall. A worn brush appears to be smooth and shiny due to paraffin clogging the bristles, also contact with the tubing wearing the ends of the bristles off. Throughout the life of a brush plunger, the fall velocity of the plunger increases as the brush bristles wear off with age.

The presence of pads on a plunger results in slower fall velocities when compared to solid plungers of the same diameter. The slower fall velocity of the pad plunger must be due to the additional friction between the tubing and plunger caused by the springs behind the pads that force the pads against the tubing wall.

In all cases when new plungers fall velocities were compared to the existing plunger in the same well, the older worn plunger fell faster. Generally, as the plunger wears out due to age, then the fall velocity increases.

The clean out plunger had spiral groves at the top and bottom of the plunger. The purpose of the spiral groves was to spin the plunger at it falls during the shut-in time period. The spinning motion of the clean out plunger resulted in slower fall velocities when compared to a solid grooved plunger of the same diameter.

CONCLUSIONS

Following are the conclusions made through analyzing the collected data:

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 fall 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) Different plungers manufacturer features have direct impact on the plunger fall velocity.

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 fall measurements will ensure that the plunger will reach the bottom of the tubing by the end of 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.

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Table 1
Plunger Fall Velocity (2 3 / 8 Tubing)

Field Test	Acoustic Velocity (Ft/sec)	Plunger Type	Tubing Depth (Feet)	Height of Liquid (Feet)	Average Fall Velocity (Ft/min)
1	1424	Brush	7460	260	477
2	1269	Pad 2 3/8	4008	608	265
3	1216	Pad 2 3/8	5800	232	259
4	1280	Ultra Seal	7485	41	159
5	1242	Grooved	3042	13	408
6	1320	Clean Out	9896	1400	326

Table 2
Plunger Fall Velocity (2 7 / 8 Tubing) – Similar Wells

Date	Well	Description	Condition	Tbg Length (FT)	Fall Speed Ft/Min
09/11/01	B3	Brush Plunger	New	10123	150
09/11/01	B3	Dual Pad Plunger	New	10123	162
09/13/01	B12	Dual Pad Plunger	Existing	10235	179
09/11/01	B3	Dual Pad Plunger	4 Mo Old	10123	187
06/05/0[illegible]	B9	Dual Pad Plunger	Existing	9784	200
09/13/01	B12	Solid, Grooved, Tapered End	Repeat	10235	364
09/13/01	B12	Solid, Grooved, Tapered End	New	10235	368
09/[illegible]01	B3	Solid, Grooved, Tapered End	New	10123	423
09/[illegible]/0[illegible]	B12	By-pass Valve, Dual Pad	New	[illegible]0235	1690

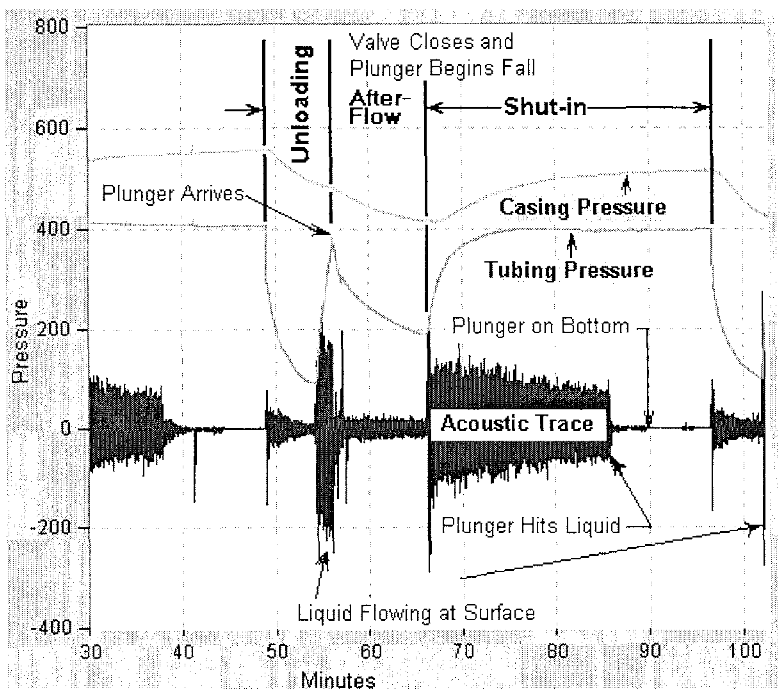

Figure 1 - Complete Cycle for Plunger Lift System

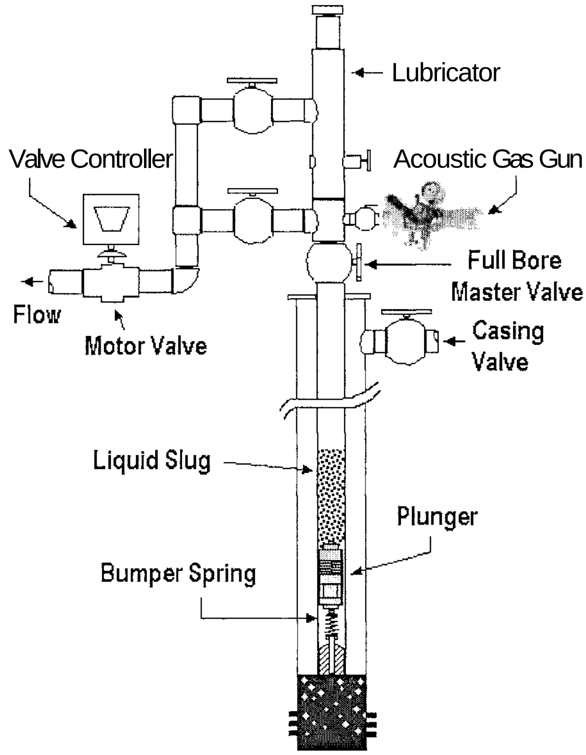

Figure - 2 Schematic Showing Active Type of Test

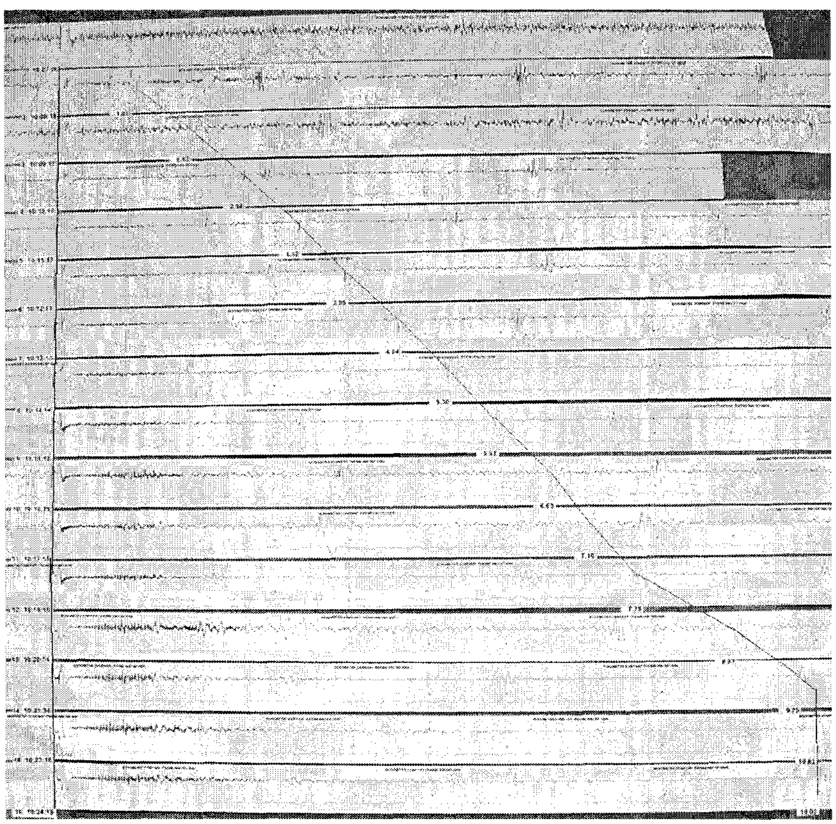

Figure 3 - Paper Strip Charts Collected Using Manual Method #1

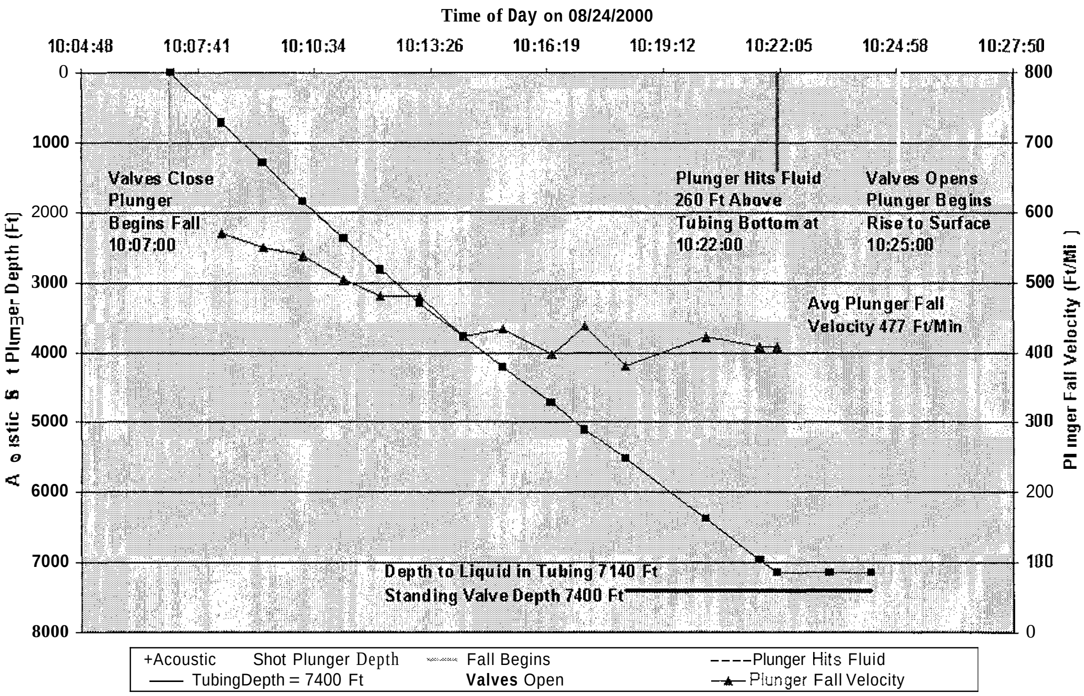

Figure 4 - Method 1 – Manual Shooting Gas Gun (Active)

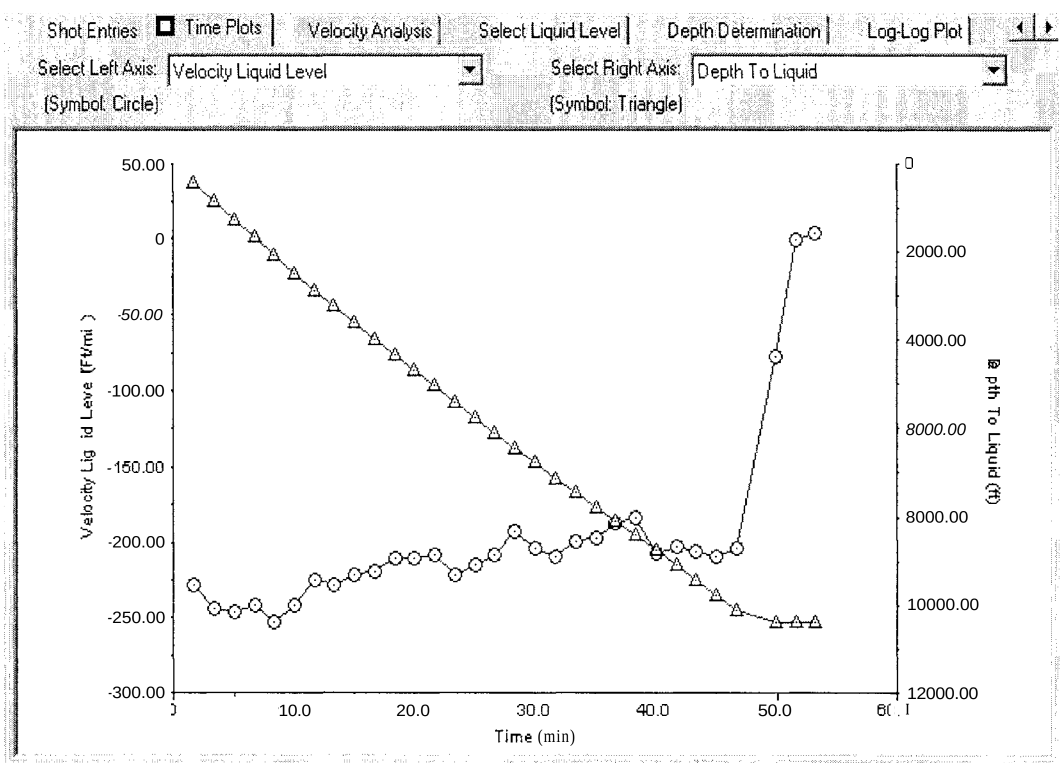

Figure 5 - Method 2 – Automatic Shooting Gas Gun and Software Analyzes Acquired Data (Active)

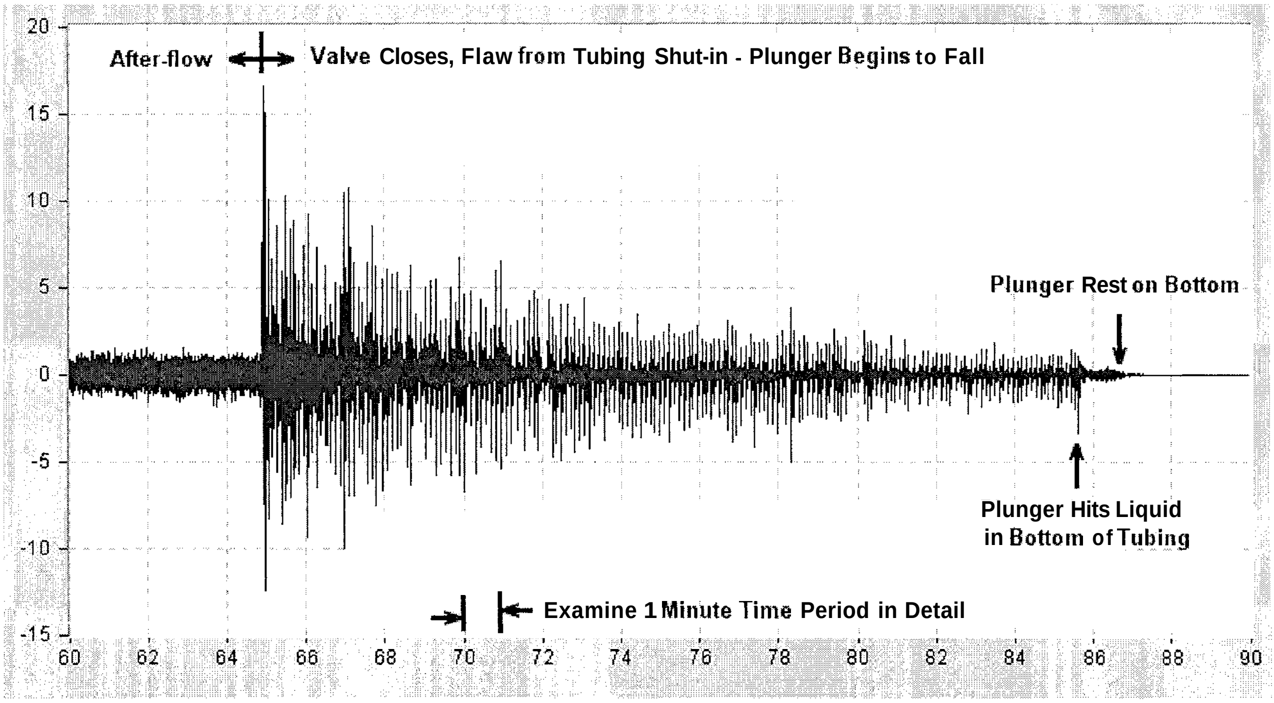

Figure 6 - Method 3 – Acoustic Signal During Shut-in Period (Passive)

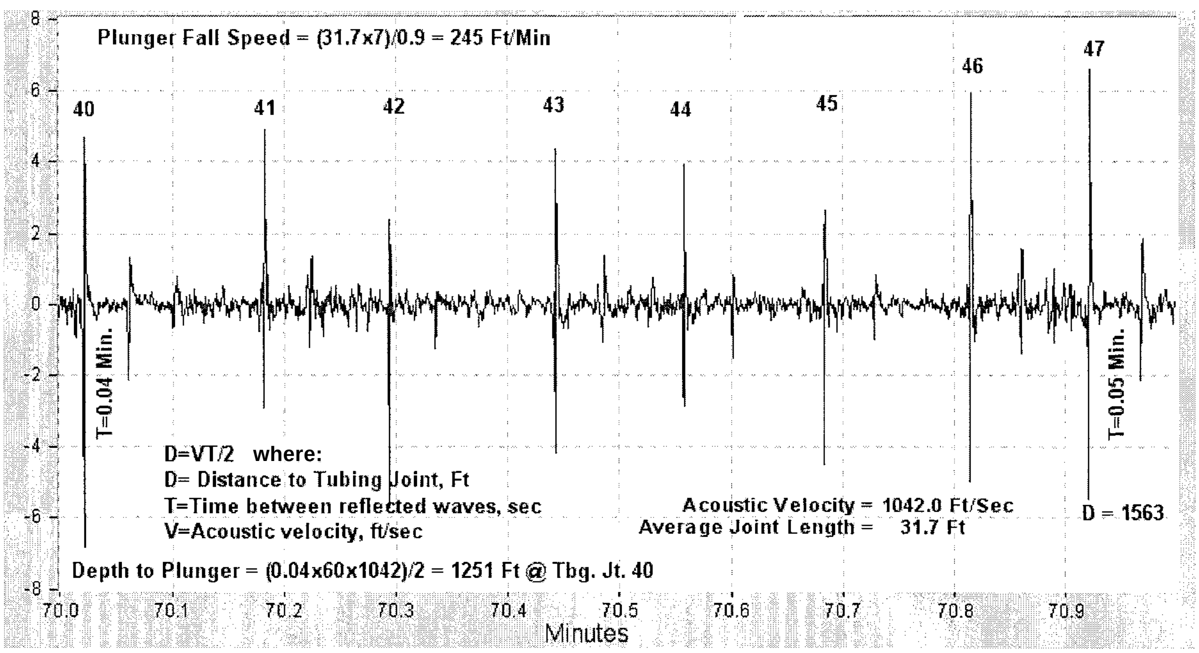

Figure 7 - Method 3 – RTTT Plunger's Acoustic Pulse (Passive)

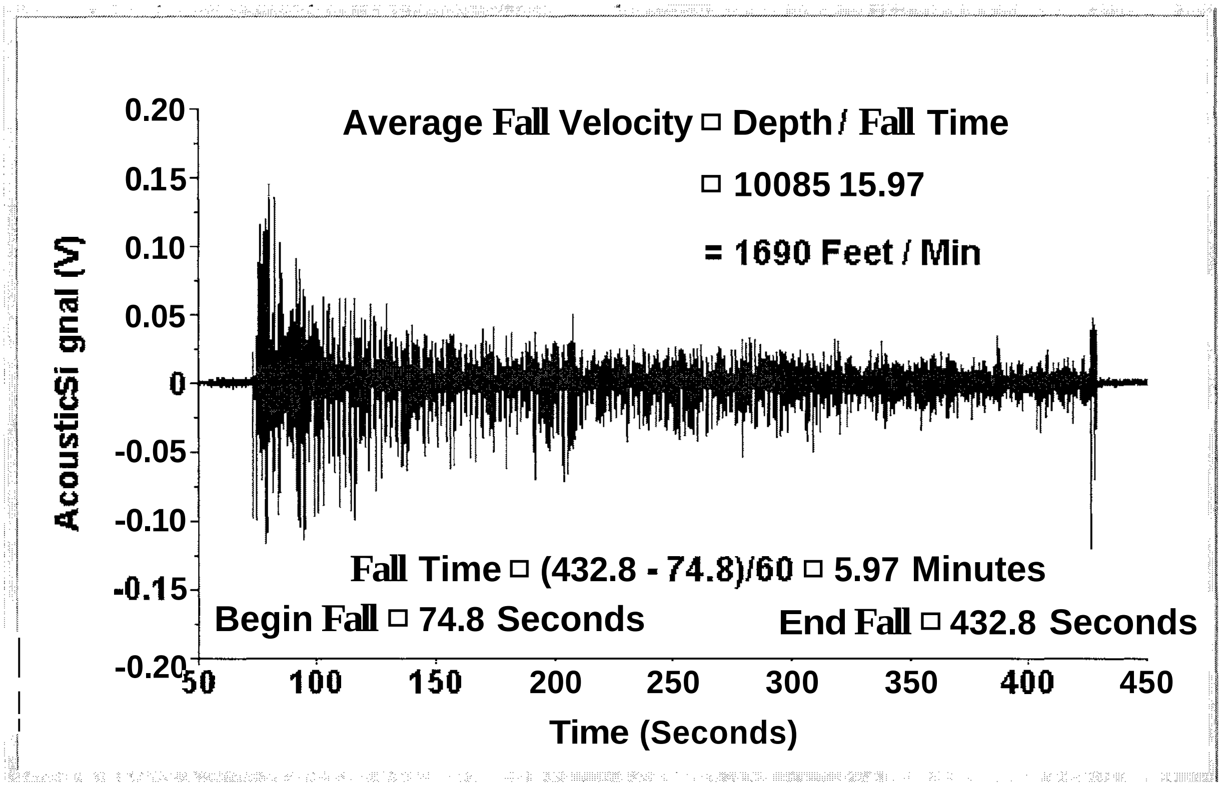

Figure 8 - Method 4 –Determine Plunger Fall Velocity Based on Elapsed Time (Passive)

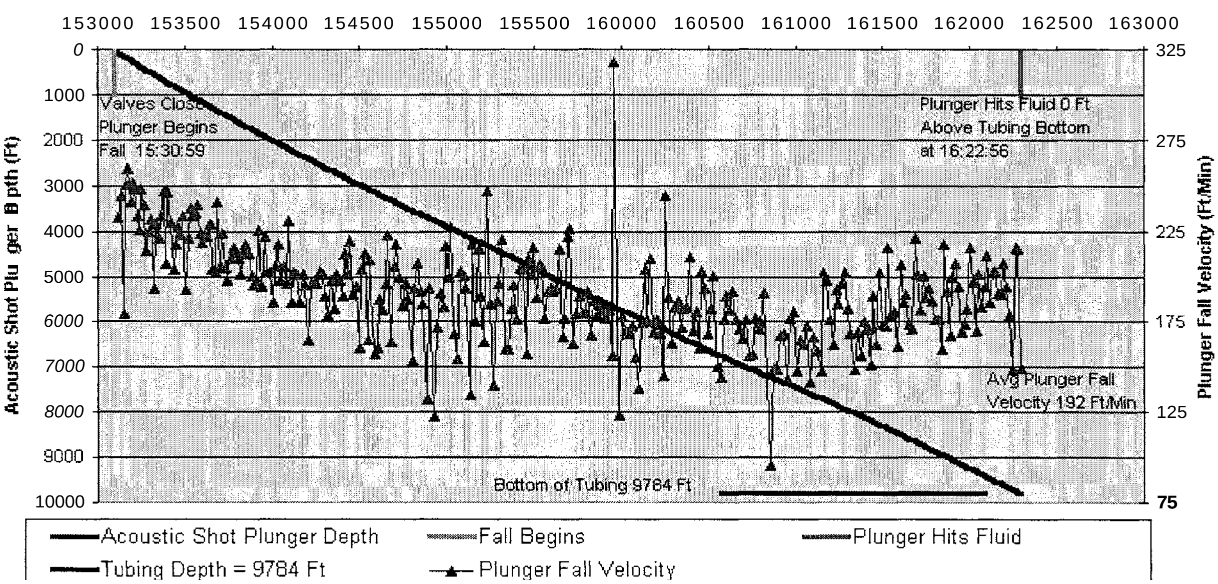

Figure 9 - Method 5 –Count Each Collar's Acoustic Pulse Created by Plunger Passing Recess (Passive)