

PORTABLE SYSTEM TAKES GUESSWORK OUT OF PLUNGER LIFT ANALYSIS AND TROUBLESHOOTING

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Abstract

One of the most important requirements to efficiently and economically operate a plunger lift well is to: KNOW THE PLUNGER LOCATION AT ALL TIMES. Without knowing the plunger location the operator must guess, even when using the most advanced electronic programmable controllers. Previously, it has been difficult to determine the position of the plunger inside the tubing during the plunger fall, when the plunger reaches the liquid level, the time spent falling through the accumulated liquid in the tubing or when the plunger finally rest on the bumper spring at bottom. Often the only known location of the plunger was when the plunger was at the surface, detected electronically or by ear. This new portable system can be used on plunger lifted wells to record at high sampling rates the acoustic and pressure signal generated by the plunger and the well during the entire operating cycle. The very sensitive monitoring system coupled with a user-friendly graphical software application becomes a tool where the operator can virtually “see” the plunger at all times during a cycle, determine its precise fall velocity, and determine when the plunger gets to bottom.

The software processes this plunger acoustic data along with the tubing and casing pressure data to display plunger depth, plunger velocity and well pressures vs. time. Plunger arrival at the liquid level in the tubing, and plunger arrival at the bottom of the tubing are identified on both the acoustic and pressure traces. Well inflow performance is determined from gas mass stored during the shut-in period and gas flow from the formation is determined for the entire operational cycle. The analysis of events during the plunger cycle is simplified through examination of an animated well bore picture showing the tubing and casing pressures, plunger location, gas and liquid flow rates in the tubing and annulus, and inflow performance relationship, where the operator may select and examine key events throughout the cycle. Examples field data collected from various plunger lifted wells is used to show how to identify operational problems such as holes in the tubing, fast or slow plungers and plungers sticking not getting to bottom. The recorded information from different field cases is displayed in various formats and is used for optimization, analysis and trouble shooting of Plunger Lifted wells.

Introduction

Plunger lift is a low cost method for lifting liquids (water, condensate and/or oil) from primarily liquid loaded gas wells and is used infrequently to produce oil wells. The cost for power is The plunger lift system reduces the cost of operating a well compared to other artificial lift methods, because the formation pressure supplies the energy required to lift the liquids. During plunger lift operations the motor controlled valve is opened and at a later time shut-in. During shut-in the gas flow down the flowline is stopped when the surface valve is closed, allowing the plunger to fall down to the bottom of the tubing. After a pre-determined amount of time elapses the surface flow valve opens and the tubing pressure begins to drop toward the low flowline pressure. The differential force across the plunger, due to the drop in pressure in the tubing above the liquid column and the high well pressure below the plunger, lifts the plunger and a portion of the liquid above the plunger to the surface. The open and shut-in operational cycle of the plunger lift system is repeated throughout the day to produce liquids and gas from the well.

In plunger lift wells, acoustic fluid level instruments can be used to passively record the acoustic signal produced as the plunger falls down the tubing and to monitor the variation of pressures during the plunger cycles. The objective of the operator is to acquire acoustic and pressure data and to process the information to determine the 1) depth to the plunger 2) fall velocity of the plunger 3) time for the plunger to fall to the liquid 4) time for the plunger to fall to the bottom of the tubing 5) the volume and rate of gas flowing into the well 6) the appropriate cycle times for optimum operation. While at the well as the collected data is analyzed, the goal for the plunger lift analyst should be to answer the WELL PERFORMANCE QUESTIONS listed in Table 1. The well can be more efficiently produced if the well performance questions are answered. Analysis of the collected data is used to optimize the operation of plunger lifted wells.

The following sections of this paper describe the procedure used to acquire the data for plunger lift analysis. Example data showing various operational problems encountered during operation off plunger lift systems will be presented.

Plunger Lift Operation Cycle

The plunger lift cycle can be divided into three distinct parts¹:

1-The **Shut-in** period begins when the flowline motor valve closes, the flow 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 should fall to the bottom of the tubing and rest on a plunger catcher or bumper spring before being lifted to the surface again. During shut-in, the casing pressure should build high enough to lift the accumulated fluids and the plunger to the surface during the next valve open period.

2-The **Unloading** period begins after a predetermined amount of time has elapsed from the start of the shut-in period. Based on meeting some type required of operational criteria a valve controller opens the motor 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 a value close to the line pressure and the differential pressure across the plunger lifts the plunger and the liquid slug above the plunger to the surface.

3-The **Afterflow** period begins when the plunger arrives at the surface. The flow valves are open, the plunger can be 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, liquids are not carried to surface because the gas velocity becomes too low² and the liquid will tend to fall back and accumulate at the bottom of the tubing. If the afterflow period is too long, the liquid accumulation at the bottom of the tubing will cause the pressure at the bottom of the well to build-up and further reduce the flow from the formation. In some cases, the bottom hole pressure may increase to the static reservoir pressure and stop the flow from the formation. After meeting specific control criteria or a predetermined time elapses, then the motor valve is closed, again starting the next Shut-in period at the beginning of a plunger cycle.

The new portable monitoring system can be used to begin acquisition of data at any time during the cycle. To be able to do a complete analysis of the plunger lift system at least ONE COMPLETE CYCLE must be acquired, consisting of one valve opening plus one valve closing or one valve closing plus one valve opening. If the operator is only interested in determining the plunger fall velocity, then data acquisition must start just before the Shut-in period begins and continue until after the beginning of the Unloading period. To analyze a wells that behaves erratically may require acquisition of data over several cycles in order to identify the problem and to correctly analyze the operation of the plunger lift installation.

Configuration

The electrical signal from downhole are digitized and stored in a computer for accurate analysis. The acoustic and pressure signals signal are recorded with special software at the optimum resolution of the analog to digital converters. The computer offers unattended operation of the equipment in that the computer can be programmed to acquire data without monitoring by an operator. The data is stored and managed efficiently and the processing speed of the laptop computer allows instant analysis as the data is acquired.

Data points are acquired at a rate of 30 per second and data is displayed in real-time minute-by-minute. The default sampling rate of 30 samples per seconds is normally used to collect data. For high-pressure wells or fast falling plungers, faster sampling rates of 60 samples per second or even higher sampling rates may need to be used.

The most common data acquisition hardware for plunger lift includes an acoustic gas gun with microphone and pressure transducer connected to the tubing through a 1/2" or larger fully opening valve connection on the lubricator and a second pressure transducer connected to the casinghead. Note that if a needle valve is present on the well at the point of gun connection, it should be replaced with a full opening ball valve, before connecting the gas gun, in order to record the best quality acoustic signal. The preferred gas gun used should be cocked manually so that well fluids will not enter the volume chamber and contaminate the gun mechanism. Other types of gas guns may require the gas gun chamber to be charged to a pressure greater than the maximum expected well pressure in order to keep the internal gun mechanisms closed throughout the test and protect the internal mechanism from the well fluids.

The gun's microphone is connected to the portable monitoring system via a coaxial cable and the microphone is used to monitor the acoustic noise throughout the cycle. The plunger generates noise during the shut-in time period and during the rest of the cycle noise is generated by flowing gas and flowing liquid.

Annotating Key Events During Plunger Cycle

The elapsed time for a plunger lift cycle is often longer than one hour of time; there usually are more than 500,000 data points in a plunger lift data set. Identifying specific events that occur during the plunger cycle will facilitate in

the analysis of the data; this activity of identifying an event is called “annotating”. To aid in the analysis of the plunger lift cycle it is recommended that specific events taking place during the plunger lift cycle be identified; events such as the exact time when the control valve opens or closes, the plunger starts to fall or gets stuck in the tubing, etc. Usually annotating is done while acquiring the data but annotating can be also done after the data acquisition is complete. **Fig. 1** shows the tubing, casing pressures and acoustic signal for one plunger lift cycle where key events are identified and annotated on the figure. A key event of the time when the plunger reaches the liquid at the bottom of the tubing is generally characterized by the disappearance of the signals generated by the plunger as it passes through the tubing collars and by a large amplitude pulse followed by reduced noise level. The events that are related to the opening and closing of the control valve are identified by rapid change in the value of the recorded pressure. A key event of the time when the plunger reaches the bottom of the tubing is generally characterized by a further reduction in the acoustic noise level. Key events during the Unloading and Afterflow period include the arrival of the liquid to the surface and the arrival of the plunger. These events are generally apparent both on the pressure and the acoustic signal and are characterized by rapid changes in amplitude and slope of the traces. The event when liquid arrives at the surface is characterized by an increase of the tubing pressure and the detection of significant noise amplitude on the acoustic signal. A key event to be identified is the arrival of the plunger at the surface. If there is liquid in the tubing above the plunger, then the time when the plunger arrives in the lubricator occurs at the point of peak tubing pressure while the motor valve is open. If liquid is above the plunger, the pressure spike always occurs and once the plunger arrives in the lubricator the tubing pressure rapidly drops as the gas is released into the surface flow line. If there is no liquid above the plunger, there may be a short duration slight increase in tubing pressure and a sharp noise on the acoustic data. The point where the tubing pressure begins to decline corresponds to the beginning of the afterflow period when gas is flowing through the open valve. Inexperienced operators benefit from annotating events while collecting the data at the well. Occasionally unexpected events may be needed to identify with a comment from the operator. Identifying specific key events that occur during the plunger lift cycle facilitate in the analysis of the collected data.

Monitoring Plunger Location

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 the field tests recorded to date, 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 in pressure. Field data in **Fig 2**, shows the drop in tubing pressure when the plunger is released from the catcher and the sudden increase in tubing pressure when the plunger stops on the dry bumper spring at the bottom of the well. As the plunger falls through a tubing collar a pressure wave is generated as each tubing collar recess temporally carries a portion of the plunger weight. When the tubing temporally holds the weight of the plunger, then the pressure above the plunger rapidly increases. 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. A 0.2-psi amplitude pressure wave and an acoustic signal are generated as the plunger fell past the 112th tubing collar recess at a depth of 3584 feet is shown in the **Fig. 3**. These tubing recess pulses are monitored at the surface so that the plunger travel is followed on a continuous basis. Therefore it is not required to periodically fire the gas gun to determine the position of the plunger by echo ranging. The method of acoustically recording plunger generated pressure waves from the tubing collar recess has been defined as “passive” monitoring of the plunger position during the fall. The schematic for the instrumentation set up is shown in the **Fig. 4**, with pressure sensors 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.

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.

When the plunger enters the liquid, these tubing recess acoustic pulses are generally not transmitted through the liquid, so the acoustic noise level drops indicating that the plunger is submerged in the liquid. The field acquired acoustic and tubing pressure data in **Fig 5**, shows tubing collar recess echoes both in the gas above the liquid and

lower frequency echoes from the collar recesses below the liquid level. In this well it is possible to see acoustic pulses as the plunger falls through the liquid. When the plunger finally rests on bottom on the bumper spring the noise level drops again and a small increase in tubing pressure is observed, and the time when the plunger reached bottom may be determined with certainty.

Tubing and casing pressure are monitored simultaneously with the acoustic signals in order to be able to identify precisely the various key events during the operation of the plunger and to undertake calculation of the pressure distribution, as a function of time, in the tubing and wellbore. The variation of pressure during the cycle is then used to calculate volumetric flow of gas from the reservoir into the well and from the well to the flow line. The objective of these calculations is to present an analysis of the performance of the plunger system in terms of gas and liquid production per cycle in order to optimize the operation of the system.

Analysis

The process to analyze the collected plunger lift data follows along consecutive steps:

1) Select Cycle – is used to select a complete plunger cycle from the data set. The purpose of this step is to select one complete cycle from the total data sequence that was recorded. The cycle may start at the beginning of shut-in or at the start of the flow period and continue until the following cycle, which are valve-opens to valve-opens or valve-closes to valve-closes.

2) Cycle Limits – is used to select key events during the cycle. During the Shut-in Period to identify within the plunger cycle the times when the following two key events take place:

1. Plunger hits Liquid
2. Plunger on Bottom

During the Unloading and Afterflow Period to identify within the plunger cycle the times when the following two key events take place:

1. Liquid Arrives to surface
2. Plunger arrives to surface

3) Plunger Fall – is used to analyze the acoustic data to determine the plunger position and fall velocity vs. time.

4) Gas Property – Allows computing or entering the gas gravity in the well.

After steps 1-4 are completed, then a complete analysis of the plunger lift system can be performed.

Plunger Fall

Each of the tubing collar echoes are identified to determine how fast the plunger falls to the bottom (or determine if it falls to the bottom) during the shut-in period and obtain the speed and depth of the plunger as a function of time. If the acoustic signals generated by the plunger are clearly visible on the acoustic trace, then software is used to identify and record the time of occurrence of each acoustic collar recess pulse and count all the tubing joints that the plunger has traversed. Using the plunger depth and the elapsed time then the plunger fall velocity is computed and a graph of the position of the plunger and plunger velocity vs. time is generated.

Fig. 6 displays the acoustic signal beginning at a time of approximately 9.3 minutes after data acquisition began (the control valve closed and Shut-in began at 2.671 minutes). The signal at 9.353 minutes in the upper trace corresponds to the time when the plunger fell past 44th the tubing collar recess at a depth of 1416.8 feet. The graph at the lower left is a representation of the acoustic signal recorded from the start of the shut-in period [A] until the marker [1] when the plunger hit the liquid near the bottom of the tubing. Note that in the lower left window the vertical white band is the 1-minute interval of the acoustic trace plotted at the top of the figure. The user may manually identify all the pulses that correspond to the plunger falling past the tubing collars or the collars may be automatically selected after the software has been “trained” to properly identify these signals. The times are marked with a line when the plunger fell past collar 44 (labeled C44 at 9.353 minutes) and when the plunger reached the next tubing collar (labeled C45 at 9.514 minutes). Using the well’s average joint length of 32.2 feet/joint, the fall velocity of the plunger is computed to be -199.18 ft/min. (Negative sign indicates falling down the tubing and positive indicates the plunger rising in the tubing). After some of the collar recesses are counted, then the plunger fall velocity past each collar can be determined and the speed and depth of the plunger as a function of time can be obtained. How fast the plunger falls to the bottom during the shut-in period is shown at the bottom of the figure; the average fall velocity through gas is -168 feet/minute and the average fall velocity through the liquid is -38 ft/minute. If the acoustic signals generated by the plunger are visible on the acoustic trace, then the occurrence time of each acoustic pulse can be identified and all the tubing joints that the plunger has traversed can be counted and the plunger fall velocity graph of the position of the plunger and plunger velocity vs. time can be generated. In the lower right corner, the table displays the time, plunger velocity and depth values that correspond to the movement of the plunger past ten previously identified collars.

Plunger Fall Velocity and Depth Graph

Fig. 7 may be used for quality control of the analysis process since it represents the position of the plunger and its instantaneous velocity up to the depth of the collars counted.

The normal trend of the plunger fall velocity and depth graph is for the plunger depth to increase smoothly as a function of time. Although there seems to be significant noise on the plunger velocity trace, notice that the left vertical scale is amplified and that the general trend of the velocity is to consistently slow down as time (plunger depth) increases. When liquid is in the bottom of the tubing, it is normal for the plunger fall to initially start to fall fast and gradually slow down as the plunger gets deeper into the well. Significant deviations from these trends would be an indication that the identification of the collar signals should be reviewed/verified OR that there may be a problem with the operation of the well. An operational problem may exist in the well if the plunger falls at a constant speed or slows down and speeds up during its fall.

Fig. 7 shows a total of 227 collars have been counted when the plunger hit the liquid at a fall velocity of -135.42 ft/min. The time for the plunger to fall from the surface to the liquid was 47.45 minutes of elapsed time. This time also corresponds to the plunger being at a depth of 7309.4 feet, based on the average tubing joint length determined for the well.

Plunger fall velocities that seem to deviate from the general trend (gradually slowing down with depth) are easily identified by examination of the plunger fall trace and the corresponding collar reflections can be examined in more detail on the acoustic trace by double clicking a point of interest on the graph.

A detailed discussion³ of the various methods that may be used for monitoring the plunger position during the shut-in periods is found in the paper: SPE 80891.

Gas Properties

The specific gravity of the produced gas must be determined to accurately calculate the pressure distribution in the tubing and casing and to undertake calculations of volumetric rates of gas influx from the reservoir during the plunger cycle. The properties of gas sampled at the sales line or even at the separator, generally are not representative of the properties of the gas within the annulus or the tubing. Therefore the best estimate of the gas gravity will be obtained from measurements within the well or at taken at the wellhead. The gas gravity may be determined in various ways:

- A value computed from the acoustic signals recorded during the plunger fall
- A measured value determined from testing a gas sample taken at the wellhead
- A computed value based on composition of a gas sample taken at the wellhead
- A value previously determined from acoustic measurements in the well

The acoustic velocity in the tubing gas can be computed by analyzing in more detail the acoustic signals generated by the plunger as it falls past the tubing collars. An acoustic pulse that is generated when the plunger goes past a collar, the pulse propagates via the gas in the tubing above the plunger, to the wellhead (where it is detected by the microphone) and then is reflected back down through the gas until it reaches the top of the plunger and is reflected back to the surface where the microphone detects it as a first echo. Since the acoustic velocity in the gas is of the order of 900 to 1400 feet/second and the plunger velocity is much slower, of the order of 200-1000 feet/minute (3.3 to 16 feet/second), the plunger has not fallen a significant distance by the time the acoustic pulse catches up with the plunger and is reflected. This reflection process is repeated several times before the plunger reaches the next collar. Examine **Fig. 6**, notice collar C47's echo occurs at 9.837 minutes and its repeat echo (marked with the vertical dashed line) occurs at 9.877 minutes. The depth to collar C47 is 1513 feet and the repeat echo traveled from the microphone to the top of the plunger and back to the microphone in 0.04 minutes. For this example the acoustic velocity calculates to be 1254 ft/second and the corresponding gas specific gravity calculates to be 0.748.

For the calculation of the gas gravity, the program uses an equation of state that relates these gas properties as a function of pressure and temperature. The program computes the gas gravity from the gas composition or the acoustic velocity. The program also computes the acoustic velocity at the specified pressure and temperature.

At a certain pressure and temperature the acoustic velocity in a gas is directly related to its specific gravity. The software uses this relationship to determine the gas gravity when the acoustic velocity in the gas has been computed. Shooting the liquid level in the tubing during the shut-in period can be make a direct estimate of acoustic velocity. However, very often it is not necessary to shoot a fluid level, since acoustic velocity in the tubing gas can be computed by analyzing in more detail the signals generated by the plunger as it falls past the tubing collars.

In some cases, due to the noise level in the wellbore or other plunger characteristics, it may not be possible to identify the multiple reflection signals. The user then should retrieve the gas gravity that was computed from the acoustic velocity when a conventional fluid level survey was done in the tubing during the shut-in period.

Cycle Analysis

Fig. 8 provides a complete analysis of the plunger cycle and a detailed summary of the pressures and volumes flowing into and out of the well as a function of the plunger position. Once the average producing bottom hole pressure is calculated, the value is compared to the static bottom-hole pressure and Vogel's IPR relationship is used to determine the well's inflow performance efficiency and the maximum obtainable gas and liquid flow rates.

On the right of **Fig. 8** is a schematic diagram of the wellbore indicating the Plunger Lift Operational Cycle and the results of flow and pressure calculations at various stages of the cycle.

On the top left are several blocks containing data about the well's performance, fluid data and reservoir parameters.

At the lower left is a slider control that is used to step through the complete plunger cycle.

In the Cycle Analysis screen, the wellbore schematic (on the right half of the display) shows the position of the plunger as well as the position of the tubing intake in relation to the formation depth.

As the display of the position of the plunger changes when the user steps through the cycle using the slider or the Auto Step button, the software computed values of parameters that are dependent on elapsed time are automatically updated.

The Plunger Lift Operational Cycle is displayed at the top left side of the wellbore diagram. This indicates the section of the plunger lift cycle that is being displayed depending on the previous analysis. Depending on the position of the plunger as controlled by user the possible values are: 1) Shut-in, 2) Unloading, or 3) Afterflow.

Surface Pressure Tubing: This is the tubing head pressure measured at the exact time selected during the cycle.

Surface Pressure Casing: This is the casing head pressure measured at the exact time selected during the cycle.

Tubing Pressure Buildup: psi/min: This is the rate of change in tubing head pressure as a function of time when the motor valve is closed, expressed in psi per minute.

%Liquid: Is the computed percentage liquid in the gaseous liquid column at the bottom of the tubing calculated based on the tubing pressure buildup⁵.

Gaseous Liquid Level: is the depth to the top of the gaseous liquid column at the bottom of the tubing.

Liquid Level (Gas Free): is the measured depth to the top of an equivalent gas-free column of liquid at the bottom of the tubing.

Gas Flow displays the instantaneous flow rates of gas in Mscf/D, or cumulative volumes, calculated from various material balances in the annulus and the tubing at the time corresponding to the displayed plunger position. At the time selected by the user the following instantaneous flow rates are displayed: 1) Formation: gas rate of flow from the formation, 2) Casing: gas rate of flow from the casing, 3) Tubing: gas rate of flow from the tubing, 4) Flow Line: gas rate of flow from the well into the flowline

The user can select to display cumulative produced gas volumes values by clicking on the units field and selecting the values of cumulative per plunger cycle or cumulative per day.

Assuming all of the liquid at the bottom of the tubing is produced to the surface, then 1) Liquid Production STB/Cyc: displays the total liquid produced per plunger cycle, and 2) Liquid Production STB/D: displays the total liquid produced per day assuming that each cycle produces the same volume of liquid.

Liquid at Bottom of Tubing: displays the volume of liquid at the bottom of the tubing as a function of time. Value is given in Bbls or height of gas-free liquid.

Tubing Intake Pressure: this is the pressure in the annulus calculated at the depth of the tubing intake (depth to bumper spring).

PBHP: This is the calculated producing bottom-hole pressure at the datum depth and the PBHP changes throughout the plunger lift cycle.

Reservoir Pressure (SBHP): This is the shut-in BHP as entered in the well data file.

The information on this schematic diagram is a complete representation of the well's operating conditions at times selected by the user at any time during the complete plunger cycle.

The top left-hand side of the Cycle Analysis Tab shows the current oil, water and gas daily flow data from the most recent production test as entered in the well data file. This information is used in subsequent calculations of well performance and should be as recent and as accurate as possible.

The Potential maximum daily production if the producing pressure (PBHP) were reduced to zero, based on the selected IPR Method and the average producing bottom hole pressure determined for the complete cycle. IPR Method – The selected method for representing the well's performance: (Productivity Index or Vogel IPR).

PBHP/SBHP-This is the ratio of the current producing bottom-hole pressure to the shut-in bottom-hole pressure. A value of 1.0 corresponds to a shut-in well. A value of zero corresponds to a well producing at open flow or maximum production rate. Producing Efficiency - Expresses the current well test flow rate as a percentage of the calculated potential maximum flow rate.

It is very important that the well data be accurate, because the program calculates bottom hole pressure and calculates the plunger's performance analysis using all these values.

At the bottom left of the window is a time line corresponding to the plunger cycle that has been analyzed. The timeline shows the sequence of operational cycles, the time (hh:mm:ss) when the plunger cycle started and when it ended as well as the start time of each operation. The duration (mm:ss) of each operational cycle is also displayed. The slider bar allows the operator to move through the plunger cycle to display the position of the plunger and view the variation of the flow and pressure variables.

The Step Increment is defaulted to 60 seconds/step and may be changed by the user to a more convenient value by entering a different time step in seconds. The smallest increment is limited to 1 second and for the default sampling rate of 30/sec is the average of 30 samples for each variable being displayed. It is recommended that initially the user look at the data at a step increment of 60 seconds. If a more detailed investigation is required, then an increment of 5 seconds is usually the best time step for display of the plunger lift data. A disadvantage of using very short time steps is an increase in processing time because all calculations are done for every time increment for all calculated data values.

The slider control is used to step through the plunger cycle in order to analyze in detail the position of the plunger and determine the overall performance of the well.

The analysis begins either at the beginning of the Shut-in period (motor valve closes) or at the start of the Unloading period (motor valve opens)

Fig. 8 shows the conditions during the Shut-in cycle when the plunger has fallen about half way to the bottom of the tubing.

At the end of a complete plunger cycle (Unloading->Afterflow->Shut-in, or Shut-in->Unloading->Afterflow), when the cumulative production from the formation is less than the cumulative flow through the flowline (as seen in the **Fig. 9** above) there will be a net decrease of the casing and tubing pressures compared to their values at the beginning of the plunger cycle. This is an indication that some of the gas flowing through the motor valve was gas originally stored in the wellbore and was not replaced by gas flowing from the formation.

Analysis Plots

Occasionally it is necessary to study in more detail the plunger performance to identify problems that may not be apparent from the usual analysis of the plunger cycle. The program provides the user with the possibility to plot a large number of diagnostic graphs that may be helpful in further analysis. Two variables may be plotted as a function of time on the horizontal axis. Most of the values that were discussed in the Cycle Analysis section that change as the user steps through the plunger cycle can also be plotted versus time and compared to each other. In **Fig. 9** the numeric values of the two variables are displayed in the boxes at the lower right, for the time corresponding to the position of the vertical indicator which is moved by the user with the Left and Right buttons or directly positioned by pointing and clicking on the point of interest on the signal trace. Plots can be viewed in great detail for all the recorded data and computed values, using the zoom feature. It is recommended that initially the user look at the data at a step increment of 60 seconds. If a more detailed investigation is required an increment of 5 seconds is usually the best time step for display of the plunger lift data. A disadvantage of using very short time steps is an increase in processing time because all calculations are done for every time increment for all curves.

Operational Problem Examples

Fig. 10 shows a common problem in plunger lift wells that produce small amounts of liquid and gas. As the pressure builds during the shut-in period, the liquid in the tubing is pushed out and the plunger arrives at the bottom of dry tubing. For these low producing wells a standing valve is needed to hold the liquid in the tubing.

Fig. 11 shows how the tubing pressure behaves when the plunger falls past a hole in the tubing, where the hole is above the liquid in the bottom of the tubing. In this example the plunger falls past the hole at a depth of 1800 feet from the surface, the increase in tubing pressure easily identifies the depth to the hole. When the plunger began the fall the gas pressure in the tubing above the plunger was depressed by the weight of the falling plunger and the increase in pressure below the plunger forced gas out the hole into the casing. When the plunger fell past the hole then the higher gas pressure from casing equalizes back into the tubing, thereby equalizing the pressure at the hole. For this type of tubing pressure increase to occur after the plunger falls past the hole, then the tubing must have some liquid in the bottom trapping the gas between the plunger and the hole.

Fig. 12 shows the plunger suddenly stopping as it was falling to bottom during the shut-in period of the cycle. In this example the plunger had fallen 1866 feet from the surface and the sharp 3-psi increase in the tubing pressure at this depth indicates that the tubing gas is no longer depressed by the weight of the plunger. The weight of the plunger is being carried by the plunger stuck onto the tubing. In 3 minutes after the plunger began the fall the operator identified that the plunger was stuck and began corrective measures to unstick the plunger.

Fig. 13 shows how the plunger fall velocity is nearly constant at 217 ft/min as the plunger falls from the surface to the hole. Once the plunger falls past the hole at 5054 feet from the surface, then the trapped gas between the plunger and the liquid in the tubing result in the plunger slowing down to a fall velocity of 200 ft/min. This 1/8" diameter hole in the tubing was located in the 156 tubing joint from the surface and the hole was causing the plunger to not arrive at the surface during the unloading period of the cycle many times per day.

Field Case

A complete plunger cycle was acquired using the compact gas gun connected to the tubing using pressure sensors on the casing and tubing. **Fig. 14** shows the recorded data for the plunger lift cycle, beginning with the unloading at point [A] through the end of the flow period at [B] and continuing to the end of the shut-in period at [C]. Liquid arrives at the tubinghead in 12 minutes followed by the plunger 2 minutes later. This corresponds to an average plunger rise velocity of 580 ft/minute. The after flow period lasted 70 minutes and the shut-in period lasted 68 minutes during which the plunger fell to the liquid level after 30 minutes. **Fig. 15** shows that the average plunger fall velocity is slightly less than 300 feet per minute.

Based on these results the shut-in period was decreased, in several steps, from 68 minutes to 33 minutes. This resulted in an increase in gas production from 168 to 241 Mscf per day but also caused an increase in the plunger rise velocity to close to 1000 ft/minute and this is excessive.

Conclusions

Troubleshooting plunger lift operational problems become much easier when the plunger depth and fall velocity are known.

1. Plunger fall velocity can be accurately measured with an acoustic 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. If the plunger becomes stuck, then corrective measures can be taken to fix the problem.
5. Holes in the tubing are identified by observing changes in the plunger fall velocity and in the tubing pressure.

Monitoring the complete plunger cycle with a new portable monitoring system is a fairly simple task. By accurately measuring the plunger fall velocity and depth to the liquid level, then the minimum shut-in time for the plunger lift installation can be determined. The plunger fall measurements 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.

The new portable monitoring system minimizes the need for wire line. A plunger can be dropped and tracked to the seat nipple or collar stop. The collars can be counted to be sure the plunger is at the seat nipple or bottom hole spring. The operator will save time by quickly identifying holes and eliminating the need to drop standing valve and pressure test the tubing before it is pulled. The new portable monitoring system increases safety of plunger lift operations by knowing where the plunger is in the tubing. If a plunger is not going to bottom and the well is pressured up, then the plunger could surface dry at a very high velocity. Plunger arrival at high velocity can cause equipment damage and could result in exceeding the mechanical integrity limits of the lubricator. Development of a new portable monitoring system has taken the guesswork out of plunger lift analysis, troubleshooting and optimization. Having a detailed analysis of the operation of the well makes optimization of plunger lift production achievable with a minimum of effort and avoids the usual waste of time due to trial and error procedures.

References

1. Phillips, Dan and Listiak, Scott, "How to Optimize Production from Plunger Lift Systems," World Oil, April 1998 presented at the Southwestern Petroleum Short Course, Lubbock, Texas, 1997.
2. Turner, R.G., Hubbard, M.G. and Dukler, A.E.: "Analysis and Prediction of Minimum Flow Rate for the Continuous Removal of Liquids from Gas Wells," SPE 2109, presented at SPE Gas Technology Symposium, Omaha, Nebraska, September 12-13, 1968.

3. Rowlan, O.L., McCoy, J.N., and Podio, A.L., "Determining How Different Plunger Manufacture Features Affect Plunger Fall Velocity" SPE 80891, presentation at the SPE Production and Operations Symposium held in Oklahoma City, Oklahoma, U.S.A., 23-25 March 2003
4. Phillips, Dan and Listiak, Scott, "How to Optimize Production from Plunger Lift Systems," World Oil, April 1998 presented at the Southwestern Petroleum Short Course, Lubbock, Texas, 1997.
5. 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.

Tables

Table 1 - Plunger Lift Survey Answers Well Performance Questions:

1. Where is the plunger? On bottom? In or above liquid? Surface?
2. What is the depth to the top of the liquid in the tubing?
3. What are the producing and static BHP's?
4. Is liquid in the casing annulus above the tubing intake?
5. What are the casing and tubing pressures during the operational cycle?
6. Does tubing gas/liquid pressure push liquid out of tubing?
7. What is the maximum production rate available from the well?
8. What is the gas flow rate? From Formation? Annulus? Flowline?
9. What is the gas gravity?
10. Are there restrictions to plunger fall in the tubing?

Figure 1 - Annotating Key Events During Plunger Cycle

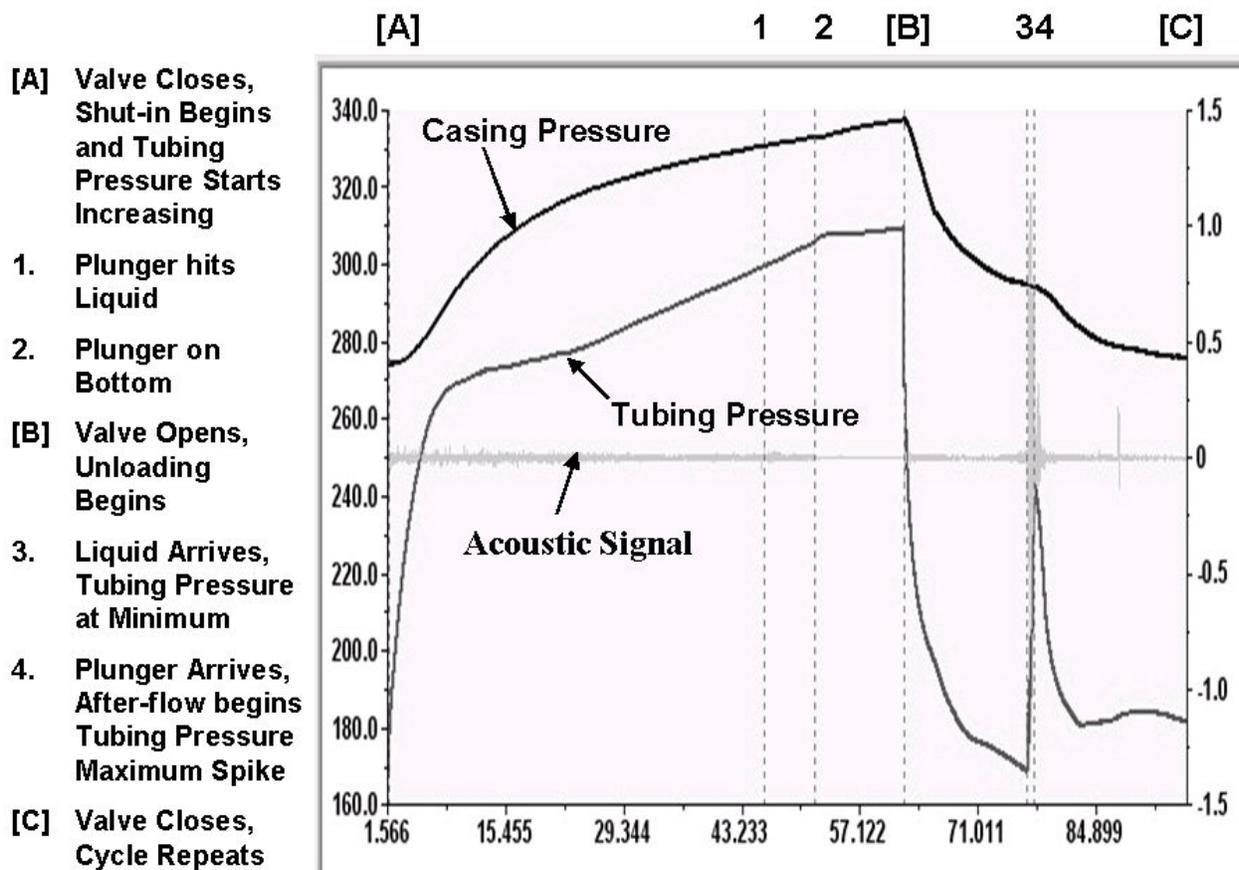


Figure 2 – Change in Pressure Due to Weight of Plunger Acting on Tubing Gas

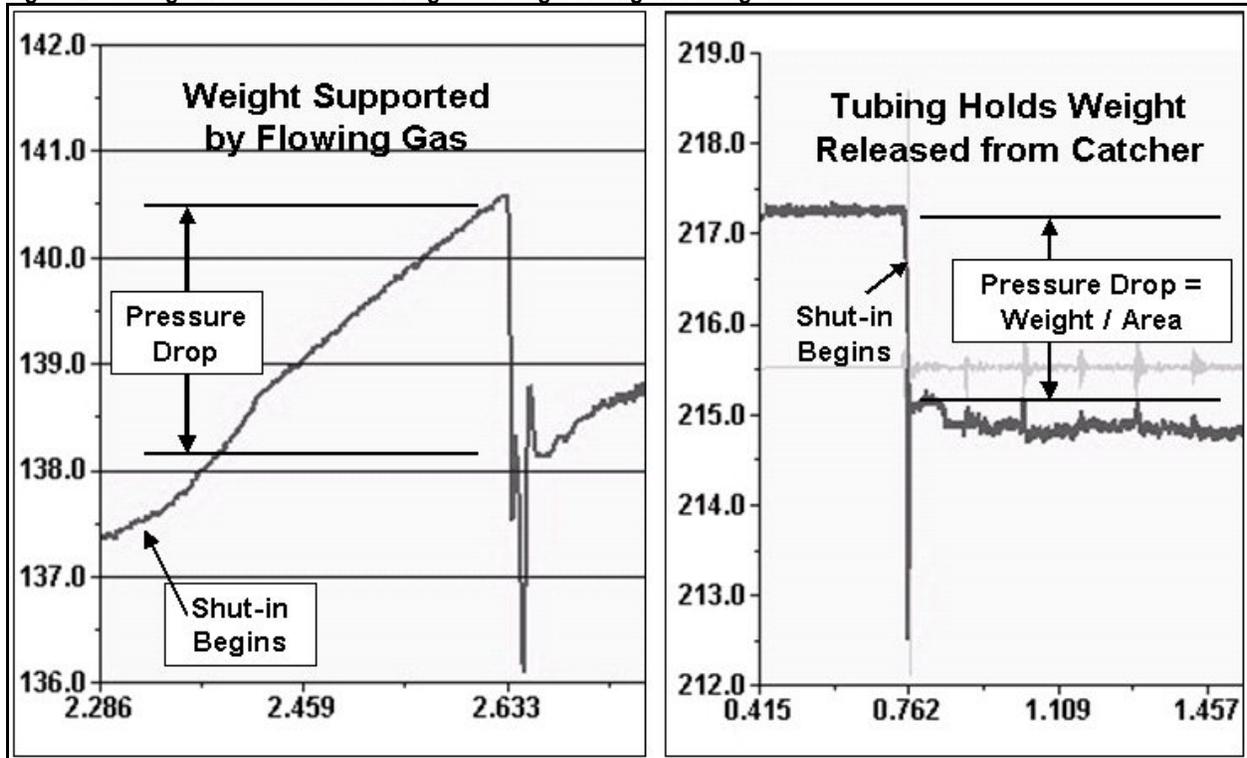


Figure 3 – Acoustic Signal from 112th Tubing Collar Recess

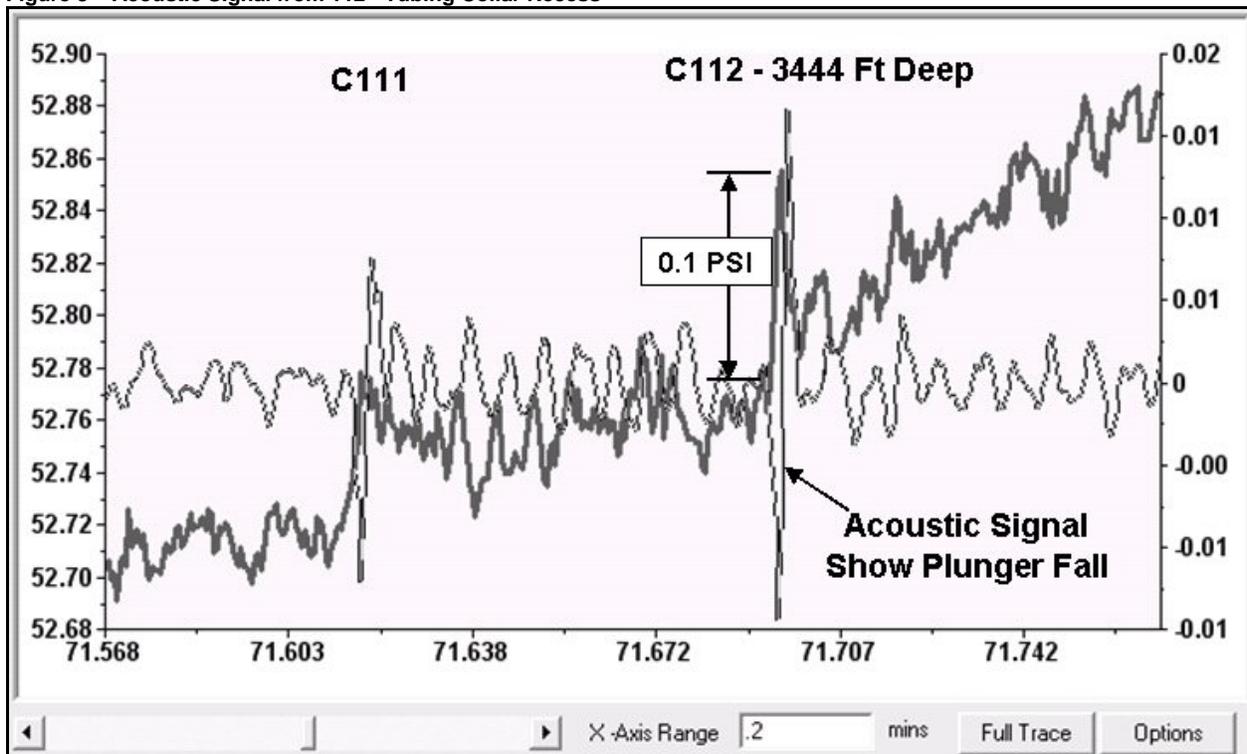


Figure 4 – Passive Data Acquisition Configuration

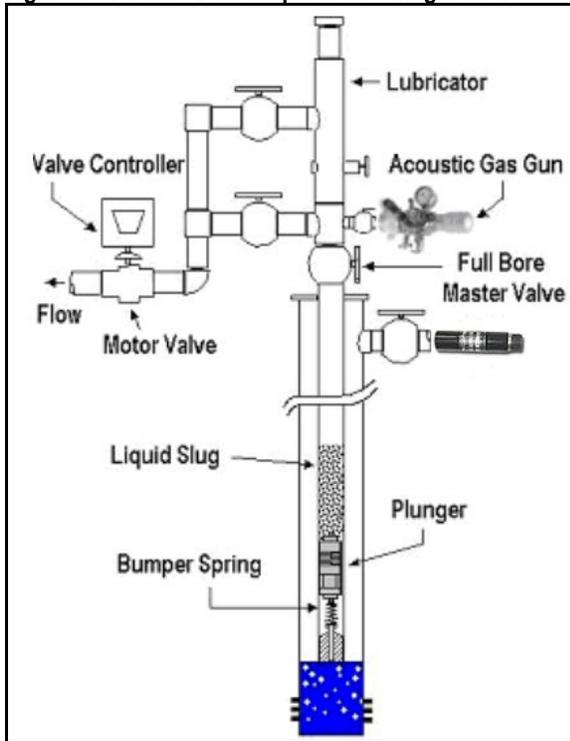


Figure 5 – Tubing Collar Recess Echoes Above and Below Liquid Level

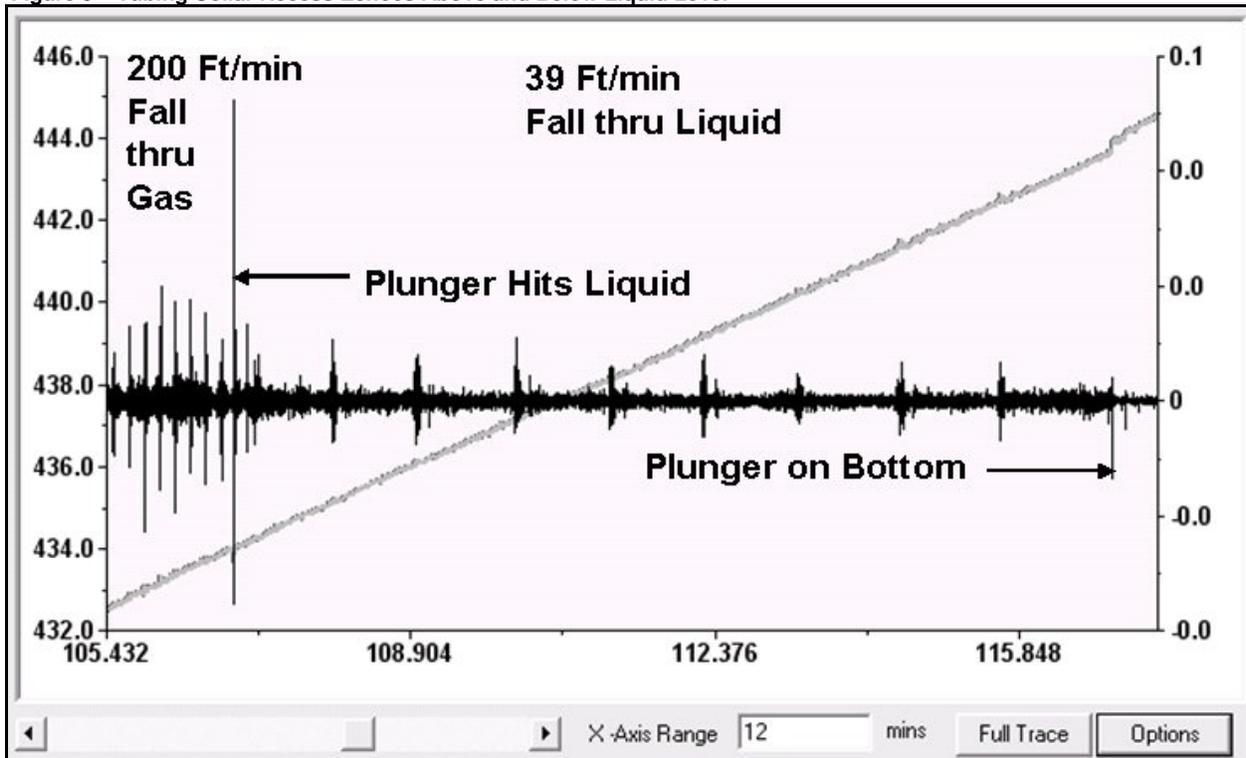


Figure 6 – Determining Plunger Fall Velocity and Depth

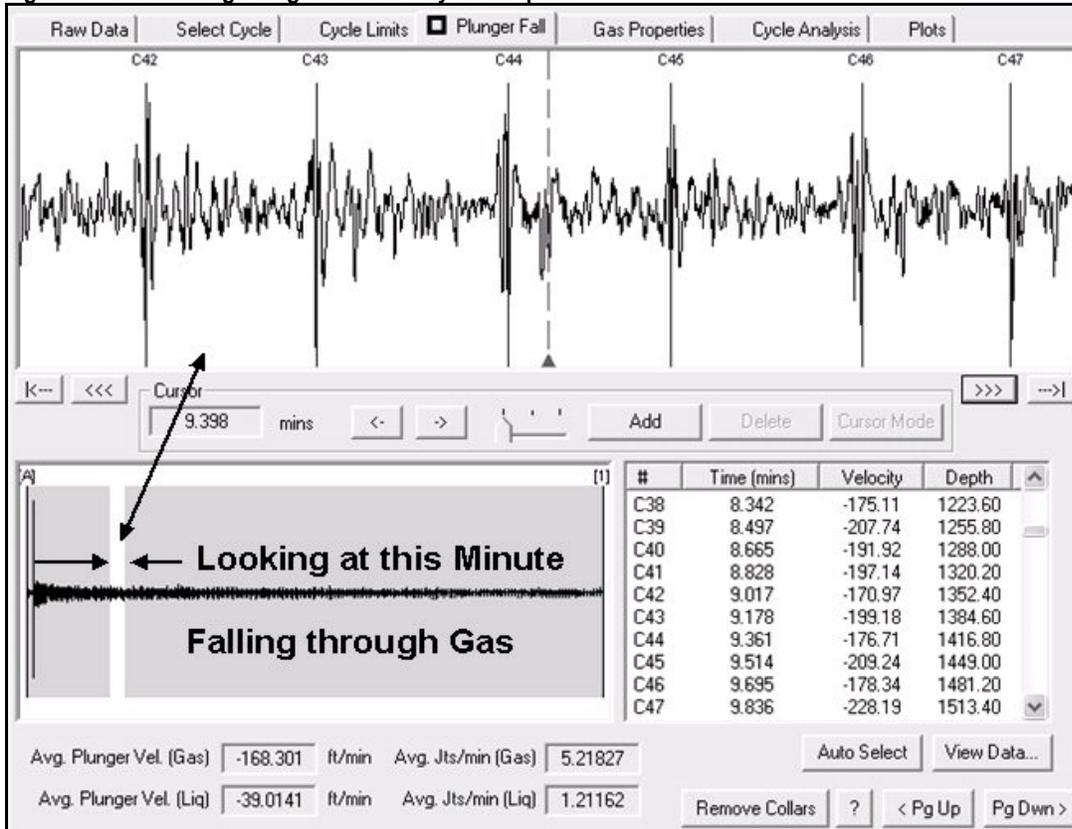


Figure 7 – Plunger Fall Velocity and Depth

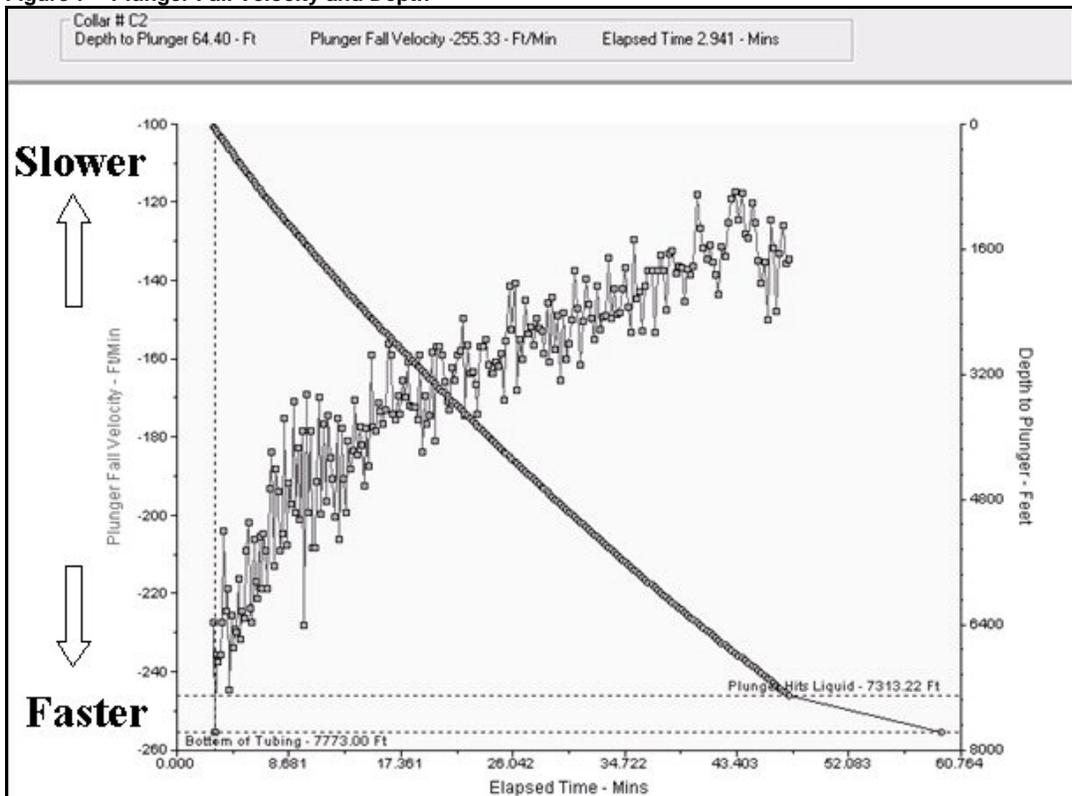


Figure 8 – Cycle Analysis

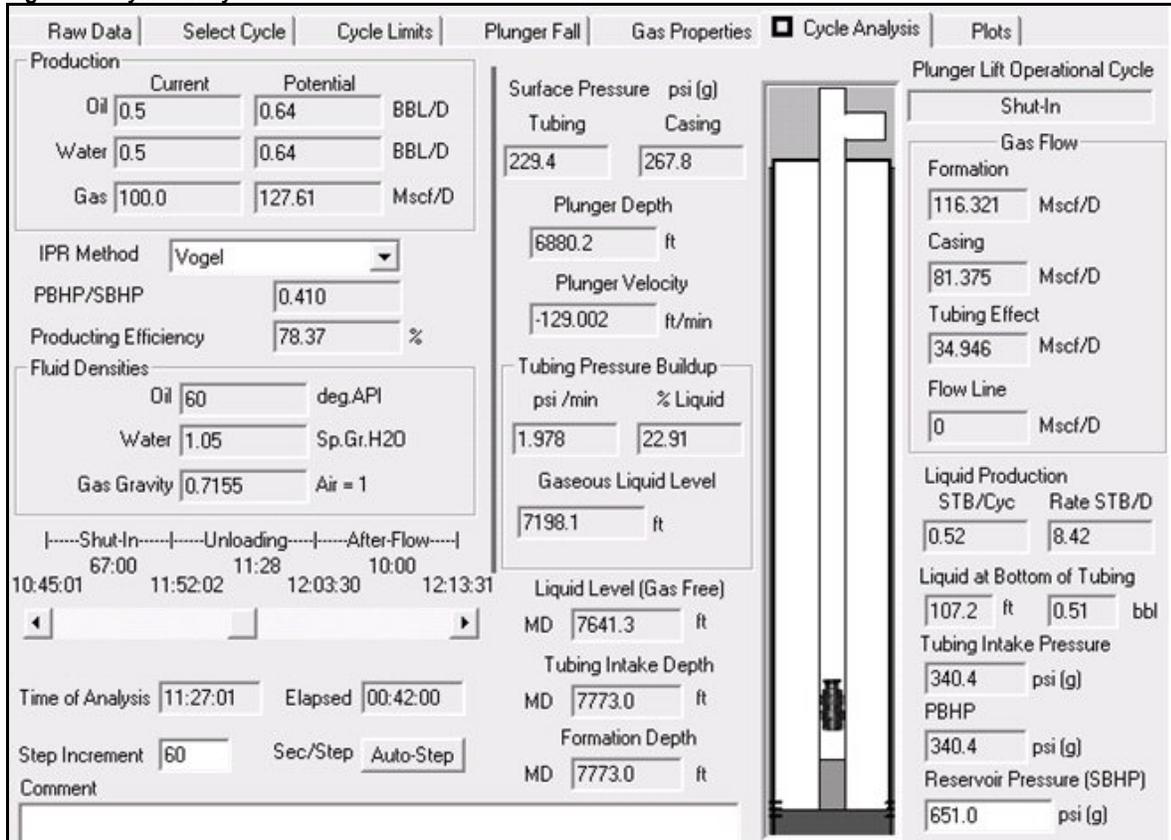


Figure 9 – Total Gas Produced from Formation and Cumulative Gas Flowing into Flow Line

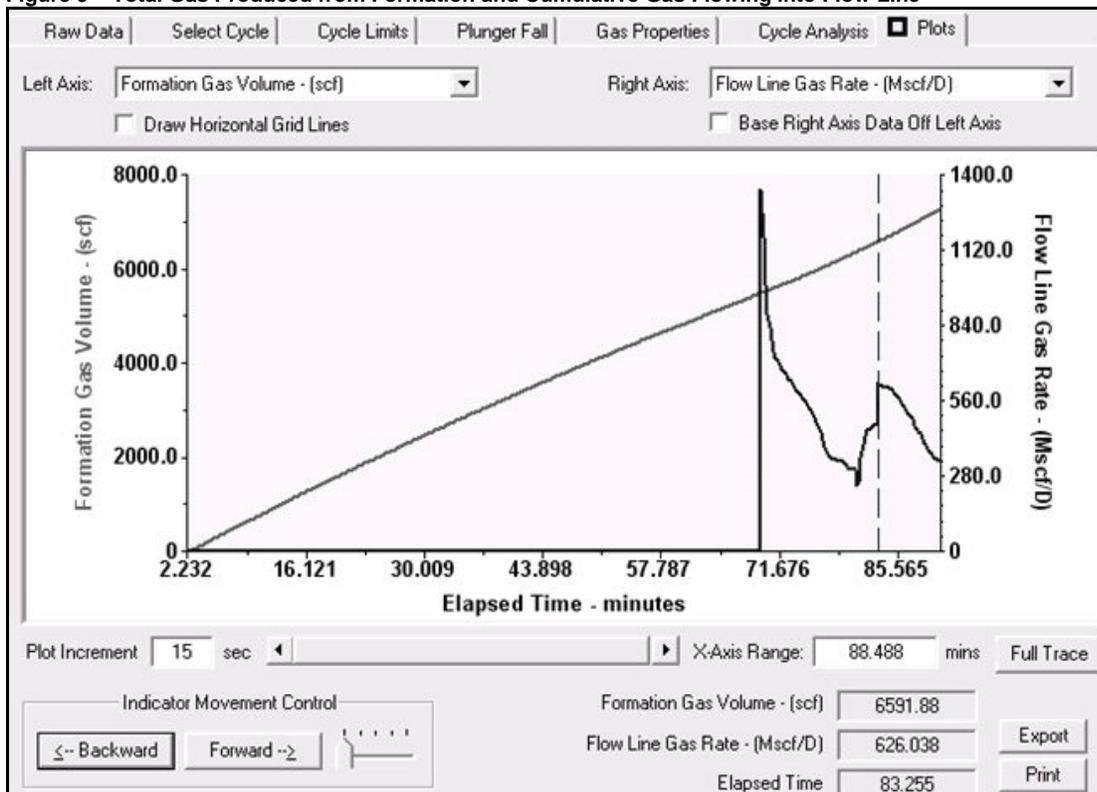


Figure 10 – During Shut-in Liquid Pushed out of the Tubing

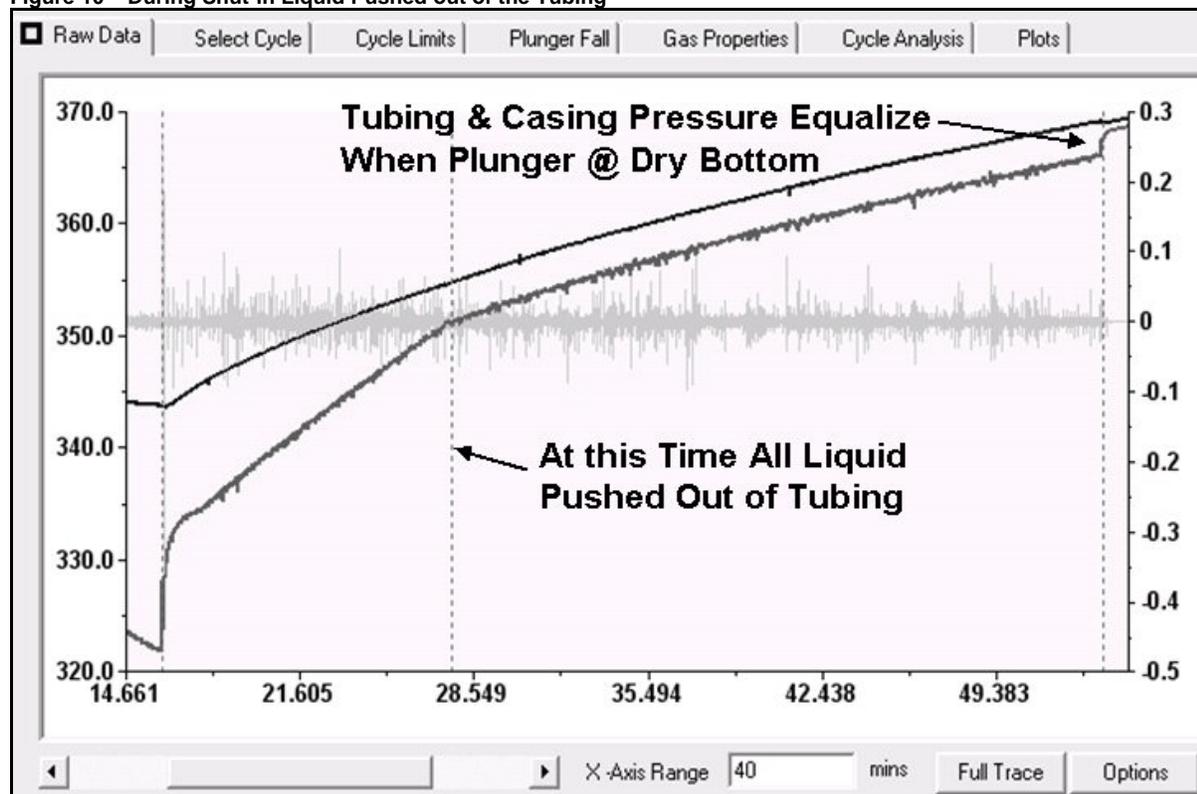


Figure 11 – Plunger Falls Past Hole in Tubing during Shut-in Period

Figure 12 – During Shut-in Plunger Sticks in Tight Spot in Tubing

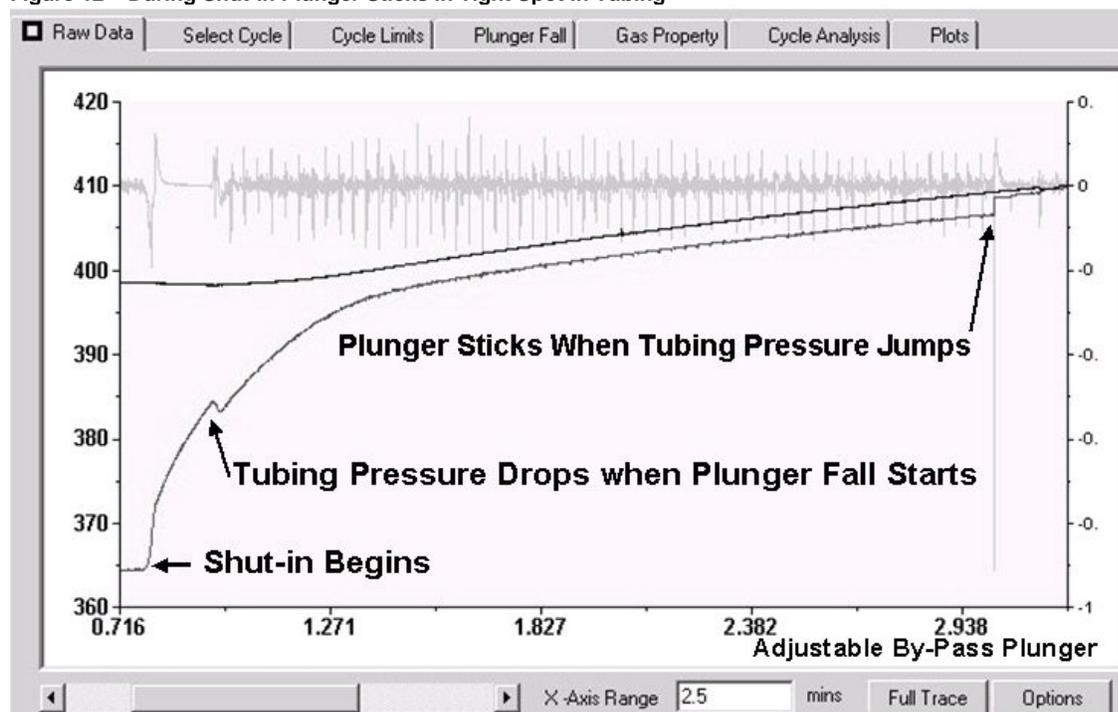


Figure 13 – During Shut-in Fall Velocity Decreases when Plunger Passes Hole in Tubing

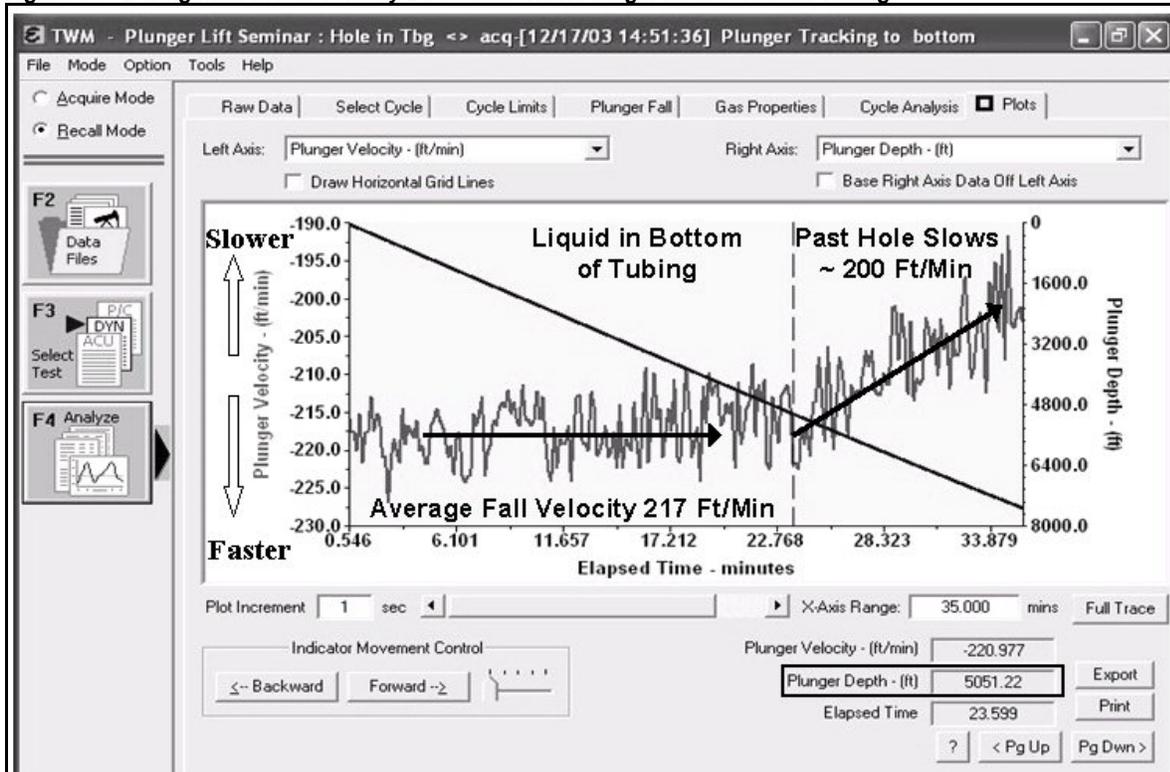


Figure 14 – Field Case Recorded Plunger Cycle

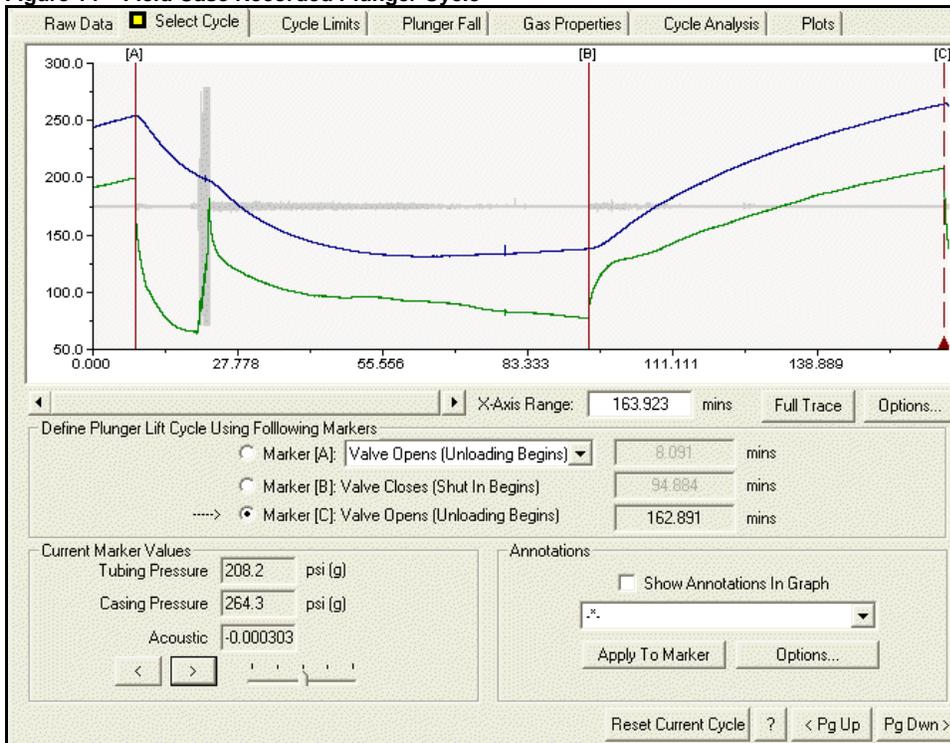


Figure 15 - Analysis of Plunger Fall in Field Case Well

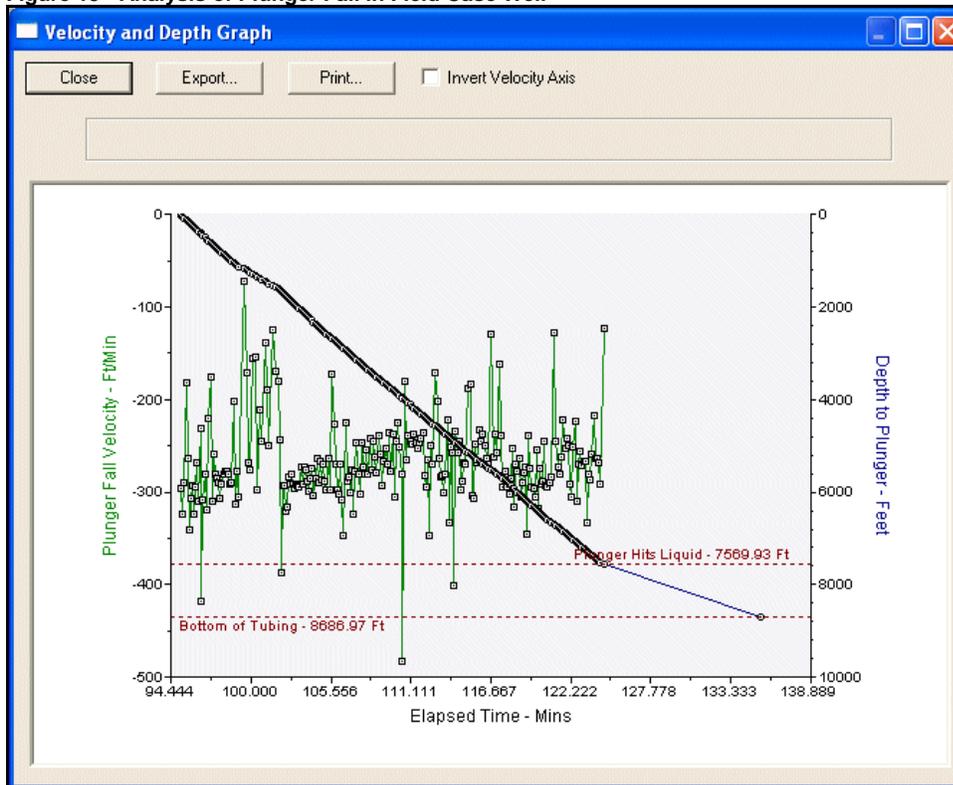


Figure 16 - Well Analysis During Unloading

