Advanced Techniques for Acoustic Liquid Level Determination

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Abstract
Acoustic liquid level tests are performed successfully in many different applications throughout the world. Advanced techniques for acoustic liquid level analysis are required for wells where unusual conditions exist such as very shallow liquid levels, annular partial obstructions, flush pipe, short tubing joints, etc. Some wells have liners, upper perforations, paraffin, odd length of tubing joints, poor surface connections and other conditions which result in an acoustic trace that may be very difficult to interpret. Normally, the computer software locates the liquid level and automatically processes collar reflections to accurately count almost all of the collars from the initial blast to the liquid level. This automatic analysis will determine the liquid level depth for 95% of the wells. However, some wells have conditions or anomalies that these procedures will not function as desired. This paper describes special advanced techniques that can be used to determine the liquid level in wells with these unusual conditions.

Introduction
The most common application of an acoustic liquid level instrument is to measure the distance to the liquid level in the casing annulus of a well. A single test is performed on a well to determine the producing bottomhole pressure. The acoustic signal is digitized and stored in the computer. The computer processes this digitized acoustic data to accent collar reflections. The Total Well Management, TWM, software program automatically counts the number of collar reflections from the surface to the liquid level and determines the liquid level depth. Simultaneously, the casing pressure is acquired. If gas is flowing up the casing annulus, the casing pressure will increase because the casing valves are closed during an acoustic liquid level depth measurement. This buildup in casing pressure is utilized along with well data to determine the casing annulus gas flow rate. The casing annulus gas flow rate is utilized to calculate a gradient of the gaseous liquid column above the pump, if present. Thus, the producing bottomhole pressure is determined from an analysis of the acquired data. The producing bottomhole pressure and reservoir pressure are processed using the Vogel IPR analysis to present the operator with the producing rate efficiency and the maximum production rate of the well.

The acoustic instrument can also be applied to depth measurements inside tubing or other piping. Other applications include determination of the distance to the mud or kill liquid level during drilling and work-overs. The liquid level in a gas lift well can be determined. The bottomhole pressures in wells with extremely high surface pressures can be determined. The acoustic instruments can be used to measure the distance to any change in cross-sectional area inside pipe or in the annulus.

The following sections describe the special techniques for acoustic liquid level determination. In most cases, once an acoustic trace has been obtained and the liquid level signal selected, the number of tubing collar reflections from the surface to the liquid level are counted in order to calculate its depth. The corresponding number of tubing joints, multiplied by the average joint length yields the distance to the liquid level. In other instances other techniques are required to determine the depth to the acoustic obstructions.

Wellhead Attachments

Acoustic liquid level instruments were developed in the 1930's. An acoustic wellhead attachment is connected to an opening at the surface of a well. The acoustic wellhead attachment consists of an acoustic pulse generator, a microphone and optionally a pressure gage. The technology for generating the acoustic pulse was originally explosive materials such as a dynamite cap, 45-caliber blank, or 10 gauge black powder blank. Pulse generating technology improved by attaching a volume chamber to the acoustic wellhead and generating the acoustic pulse with a sudden release of a gas into the well (compression gas pulse) or by releasing gas from the well into the volume chamber (rarefaction gas pulse). The explosive dynamite caps and blanks are a safety hazard and have resulted in damage to wells and environment. While these explosive sources should not create a problem if the casing annulus contains only hydrocarbon gas, major explosions have occurred when oxygen was allowed to enter the casing annulus and the oxygen/hydrocarbon mixture was ignited.

The versatility, economy and convenience of gas guns have resulted in widespread use of this type of acoustic pulse generator. Sudden expansion of gas from a volume chamber into the well generates the acoustic pulse. In most cases, compressed CO2 or N2 gas is loaded into the volume chamber, which is charged to a pressure greater than the well pressure. A valve in the wellhead attachment is opened rapidly, either manually or electrically, resulting in a pressure pulse being generated in the casing annulus gas. The acoustic pulse travels through the gas in the casing annulus and is partially reflected by changes in cross sectional area. The remaining pulse energy is then reflected by the gas/liquid interface at the depth of the liquid level. The reflected signals travel back to the surface of the well where they are detected by the microphone.

The microphone within the wellhead attachment converts the reflected acoustic signal into an electrical signal consisting of a series of pulses, which correspond to the sequence of reflections. The microphone must operate over a wide pressure range from a vacuum to the maximum pressure that exists in the wells being tested. Good microphones are designed to cancel the mechanical vibrations of the wellhead while remaining sensitive to the acoustic signal reflections.

Strip Chart Recording of Acoustic Signals

One manual[1] method for processing the acoustic signal is to record the reflected signal on a paper strip chart, for analysis purposes the acoustic signal must be amplified and filtered, and then recorded. An amplifier/recorder filters and amplifies the electrical signal from the microphone and records the enhanced signals on a paper strip chart. Modern instruments use analog to digital converters and microprocessors to improve the signal quality and print the chart. The frequency content of the reflected acoustic signals varies depending on the characteristics of the initial pulse, the pressure in the gas, the distance traveled and the type of cross sectional area change. In general, as the pulse travels in a gas, the amplitude of the signal decays. The high frequency energy decays more rapidly than the low frequency energy. Thus, the acoustic response from the collars at the top of the well contains high frequency energy, the response from deep collars contains medium frequency and the signal from the liquid level is mostly low frequency energy. This is especially apparent in deep wells with low casing pressure. Fluid level instruments are designed to include various filters, which can be used to accent signals that correspond to these frequency ranges. One enhancement in recorder technology has been to record the signals on the dual channels[2]. One channel is tuned to higher frequencies from the collars while the second channel is tuned to low frequencies from the liquid level. Single channel instruments can be operated in any of these modes and it is possible to switch from one frequency response to another while the instrument is recording. Initially, the single channel instrument is operated in the collar mode (high or medium frequency), which is then switched to the liquid level mode (low frequency) when the collar signal fades. Switching may be manual or automatic.

Computer Processing of Acoustic Data

The reflected electrical signal from downhole anomalies can be digitized and stored in a computer for more accurate analysis. Five important achievements are made possible by utilization of a portable laptop computer. First, the acoustic signal is recorded at the optimum resolution of the analog to digital converters and is not limited to the resolution of the trace printed on a strip of paper. The high resolution processing available using a computer is displayed in **Fig. 1**, where the acoustic signal of a plunger falling past the 81st tubing joint (which corresponds to a 0.04 psig pressure pulse) is recorded. Second, the computer can utilize digital processing of the acoustic data to automatically obtain accurate liquid level depths. Third, the determination of bottom-hole pressures from the acoustic liquid level measurement, the surface pressure, and properties of the produced fluids is automatically available. Fourth, the computer offers unattended operation of the equipment in that the computer can be programmed to perform well soundings and obtain casing pressure measurements on command, without monitoring by an operator. Fifth, well data can be stored and managed efficiently and accurately in conjunction with the acquired acoustic and pressure data. The processing speed of current laptop computers allows instant analysis of acoustic liquid level trace, well performance, transient pressure and pumping performance, immediately at the well as soon as the data is acquired.

A laptop computer permits an operator to automatically obtain acoustic liquid level data and surface pressure measurements from which bottom-hole pressures can be calculated. A long term pressure buildup and/or draw down test in pumping wells can thus be done inexpensively. Pressure buildup data permits the operator to obtain reservoir properties such as permeability, skin damage, reservoir pressures and numerous other parameters at a relatively low cost.

Processing of Acoustic Data

Normally, the computer software locates the liquid level and then processes collar reflections between one and two seconds from the beginning of the acoustic blast to obtain the reflected collar frequency rate. Centered at the collar frequency a narrow band-pass filter processes the acoustic data and the program will automatically attempt to count all of the collars from the initial blast to the liquid level. The depth to which collars are counted should be as close to the liquid level as possible. If the depth to which collars are counted is not at least past 80% of the distance to the liquid level, then the shot should be repeated with an increased chamber pressure in order to improve the signal to noise ratio. The automatic analysis will determine the depth to the liquid level for 95% of the wells. Some wells will have an acoustic trace that may be very difficult to interpret, because of the presence in the wellbore of liners, upper perforations, paraffin, odd length of joints, poor surface connections and other conditions. In these 5% of the wells having these conditions or anomalies that the automatic procedure does not function as desired, then advanced techniques should be used to determine the depth to the liquid level.

Downhole Marker

When the lengths of tubing joints vary considerably, so that an average joint length is not representative, some operators have placed an over-sized tubing collar (marker) to serve as an acoustic reflector at a known reference depth. When other acoustic reflections are identified on the acoustic trace, such as those generated by gas lift mandrels, liner tops, crossovers where the tubing diameter changes, tubing anchors, perforations; the known depth of these anomalies can be used to calculate the depth to the deeper liquid level. This technique is to locate a movable indicator on a marker such as the tubing crossover, when the liquid level is below the tubing crossover. The operator places the movable indicator on the top of the known tubing crossover and specifies the number of joints (or the distance) from the surface to the acoustic reflector. The program will automatically calculate the distance to the indicator located at the liquid level or other anomaly of interest by comparing the ratio of elapsed times on the acoustic trace to a ratio of their depths. For example **Fig. 2** shows an anomaly detected in the annulus above the liquid level, as indicated by a strong reflected rarefaction (up kick) acoustic pulse recorded at 6.507 seconds. The anomaly was displayed at the same time in all acoustic traces collected while testing the well. The depth to the anomaly corresponds to the increase in area of the annulus volume at the depth of 4015.92 feet at the crossover from the 2 3/8 inch diameter hydril to the 1.90 inch diameter hydril collar-less tubing. A strong reflected compression (down kick) acoustic pulse recorded at 14.827 seconds indicates the depth to the top of the liquid level is 9150 feet (14.827/6.507*4015.92 = 9150) from the surface.

Shallow Liquid Level

When the fluid level is very close to the surface, such as in shut-in wells with high bottom hole pressure or most water supply wells, the recorded acoustic signal will include a large number of multiple fluid level signals (repeats). The initial signal reflected from the liquid level may be hidden in the high amplitude of the acoustic blast released from the gun. Determination of the liquid level depth may be affected by the presence of the high amplitude and low frequency signal from the liquid level. Less pressure should be used in the gas gun in cases where high fluid levels are encountered, because the amplitude of the acoustic signal may be driven off scale. If the round-trip travel time between the surface and the liquid is less than 1.0 seconds, it is difficult to pick the liquid level automatically. On shallow liquid levels the operator may be required to move the liquid level indicator manually. The liquid level indicator can be moved in increments and the operator can position the indicator on the liquid level to determine the round-trip travel time.

Measure Annular Gas Flow

Measurement of annular gas flow rate in the field usually requires using a portable tester or installing a separate flow line from the casing annulus to the test facility. This costly process can be avoided by estimating the gas flow rate from a short casing pressure buildup test[3]. The procedure for this test is to close the casing valve, as fluid continues to be produced up the tubing. Free gas at the pump intake bubbles up through the gaseous liquid column above the pump intake and collects in the known annular volume between the casing and tubing. The change in casing pressure with respect to time is recorded. The annular gas flow rate is calculated from the annular volume and pressure buildup rate.

Duration of Casing Pressure Buildup Test

The importance of the length of time the casing valve is closed and the effect of closing the casing valve on a well's production rate is shown on **Fig. 3.** Multiple surface dynamometer cards (9.68 strokes per minute) were collected immediately after the casing valve was closed. An improved collar size downhole gas separator is installed in this well and a gaseous liquid column of 79 feet was measured above the pump intake, contributing 7.2 psig to the pump intake pressure. The annular gas flow rate of 72 MCFD was determined from 1.5 psig per minute casing pressure buildup rate. The recommended length of time for the casing pressure buildup test is 2 minutes. After the casing valve had been closed in for 5.9 minutes and the casing pressure increased 8.8 psig, the 57th surface dynamometer card displayed a sudden change in shape as the increasing casing pressure temporally stopped flow from the reservoir into the well bore and forced the pump into complete fluid pound conditions. For acoustic liquid level surveys, if the gaseous fluid level is being maintained at or near the pump intake, the action of the operator of closing the casing valve can impact the steady state operation of the pump. Therefore, the operator should only close the casing valve for a short time period and the casing valve should be reopened after the casing pressure buildup test is complete. The operator should allow a period of time to pass before performing an additional test. This time will allow the conditions at the pump to return to the steady state conditions existing prior to acquisition of an acoustic liquid level survey. Note, that very accurate casing pressure measurements are necessary for a short term (2 minutes) casing pressure buildup test.

Walker Fluid Level Depression Test

C.P. Walker[4, 5] developed a process for determining the producing bottomhole pressure in wells that have gaseous liquid columns. The Walker Fluid level depression test is used for wells producing some gas from the annulus. The procedure consists of determining the pressure at the gas/liquid interface at normal operating conditions. Then, the casing pressure is increased by use of a backpressure valve and stabilized. When the liquid level is stable, the gas/liquid interface pressure is determined at the lower liquid level depth. The height of the gaseous liquid column is plotted on the vertical axis versus the gas/liquid interface pressures plotted on the horizontal axis forming a straight line. The pump intake pressure is the extrapolated gas/liquid interface pressure where the height of the gaseous liquid column is zero (0) at the pump intake depth.

The Walker procedure can be modified[6] in high rate wells (where depressing the fluid level by closing the casing valve and letting gas accumulate in the annulus) without using a backpressure valve to stabilize the casing pressure. The acoustic liquid level device is used to determine the pressure at the top of the gaseous liquid column periodically as the closed in casing pressure builds up. This modified Walker procedure can be used to determine the pump intake pressure in high rate ESP lifted wells and verify that the downhole pressure sensor is operating properly. Using this technique, **Fig. 4** shows the pressure at the gas/liquid interface extrapolated to 936 psig at the pump intake, which confirms the output of well 5529 ESP sensor reading of 883 psig. The results from the modified Walker method give the most accurate calculation of pump intake pressure when the liquid level is pushed down "close" to the pump intake. One advantage of the test is to minimize possible error from estimating the gradient of the liquid column above the pressure sensor. The operator performing the test needs to monitor the fluid level periodically so as not to drive the fluid level to the pump intake and create a "pumped-off condition". In low PI wells, errors are usually introduced, if pushing the liquid level down toward the pump displaces casing fluid into the pump and restricts flow from the formation. In low PI wells, the best results are obtained[6] when a backpressure regulator is used and time is allowed to pass until the gaseous liquid column stabilizes between fluid level shots.

Gaseous Liquid Column Gradient Correction

As shown by the Walker Fluid Level Depression test, when a gaseous liquid column exists in the annulus of a well producing at stabilized conditions, the pressure at any depth in the gaseous liquid column is independent of the surface pressure. The producing bottom hole pressure and pump intake pressure remain unaffected by the changes in surface casing pressure and liquid level as long as the production rates through the tubing and casing annulus remain constant. The Echometer gaseous liquid column gradient correction curve[3] shown in **Fig. 5** was obtained from extensive field tests using Walker's method. With one acoustic fluid level measurement and use of this curve, the operator can rapidly determine the pressure contributed from the gaseous liquid column to the pressure in the casing annulus.

Using this technique to determine the pressure exerted by a gaseous liquid column, the operator should close the casing valve and continue to pump the well. Immediately, an acoustic liquid level test should be taken to determine the depth to the top of the gaseous liquid column (L). The well should be pumped with the casing valves closed for approximately 2 minutes. The increase in casing pressure (dP) and the time period (dT) during the increase in casing pressure is recorded. Using the value of L x dP/dT and **Fig. 5,** the operator determines the value of Fg, the approximate fraction of gas present in the liquid column. Multiplying Fg times Hp (or the gaseous liquid column height) determines the equivalent amount of gas in the gaseous liquid column. Add this equivalent height of gas in the gaseous liquid column to the gas column length (L) to obtain Da. Da is the distance from the surface to the gas/liquid interface, if the gaseous liquid column were separated. Again using **Fig. 5** and the value of Da x dP/dT determine fo, the effective oil fraction. The effective oil fraction, or gradient correction factor, should be multiplied by the gradient of the gas free oil to determine the gradient of the gaseous liquid column. Multiplying the height of the gaseous liquid column by the gradient of the gaseous liquid column determines the pressure exerted by the gaseous liquid column.

Liquid Level Tracking

A liquid level tracking test is defined as the process of automatically monitoring the position of the liquid level in a well for a time period at a user specified frequency. The test is usually performed using the Well Analyzer and the Remote Fire gas gun. These components are controlled by software to perform acoustic well soundings on a scheduled basis without operator attention. The computer-based acoustic measurement system records depths to the liquid level at user selected specific time intervals, as short as once a minute. Automatically, the system acquires the liquid level data, determines depth to the liquid level, and displays the position of the liquid level. Then it checks whether the liquid level is within given depth limits and generates an electrical signal when the specified limits are exceeded. **Fig. 6** shows the flexibility available to the user in specifying the liquid level tracking alarm limits. The electrical signal from the relay is used to alarm the operator that a liquid level is outside a specific range and a limit has been exceeded. The relay alarm signal could be used to sound an alarm horn or to operate a switch to power off or on an electric motor controlling a pump.

Liquid Level tracking has numerous applications in drilling, workover, completion, and production operations. Some examples of these applications are: 1) Monitoring fluid level in offshore risers, 2) Monitor fluid level while drilling with no returns[7], 3) Keeping fluid level within limits to minimize formation damage, 4) Monitoring position of batch treatments, 5) Following progress of continuous unloading of a gas lift well, 6) Controlling the electric motor on a Progressive Cavity pump to maintain a liquid level above the pump, and 7) Acquiring a permanent record of fluid levels during a critical test or operation. The ability to monitor the liquid level improves the operator's ability to safely and efficiently control his operations.

Pressure Transient Digital Data Acquisition

A digital pressure transient data acquisition and processing system[8] uses an acoustic liquid level instrument to determine the annular fluid distribution and the producing bottom hole pressure. Unattended remote operation is possible by using a laptop computer and data acquisition software to control the taking of fluid level shots according to a predefined schedule for an extended buildup or draw down test. Bottom hole pressures are automatically determined and the various types of pressure transient analysis are presented to the operator in real time. **Fig. 7** is an example plot a Horner pressure transient analysis.

A well should be producing at steady state conditions, prior to shutting in the well for an extended buildup test. Shutting in the well to install a dowwnhole pressure bomb can disturb the steady state conditions of a well. The presence of artificial lift equipment installed in a well usually prevents installation of a pressure bomb in the bottom of the well, without shutting down the well and pulling the artificial equipment. The process of shooting fluid levels and measuring the casing pressure allows the determination of bottomhole pressure and eliminates the need to pull the artificial lift equipment. Data can be acquired as soon as the well is shut in. Analysis at the well site can be done to determine if enough data has been acquired for a complete analysis of the well.

Rate of Fill-up

When determining the depth to the liquid level on a well, the recommended practice is to acquire two acoustic liquid level shots on the same well. The two acoustic traces should repeat and downhole reflectors should appear at the same elapsed times on the traces. If the acoustic traces do not repeat or the liquid level is not obvious, then the liquid level should be moved. The liquid level can be identified as the downhole reflector that will move. A high liquid level on an acoustic test can be depressed by increasing the casing pressure, if casing gas is produced. Turning off the pump on a well producing only liquid will cause the liquid to rise.

Shutting down a well producing only liquid will cause a rise in the liquid level in the casing annulus. When shutting down a well, the fill-up rate will depends upon the producing rate of the well and the annular area of the casing. A fill-up chart for various production rates in different sizes of pipe is shown in **Fig. 8**. The rate which liquid initially fills the casing annulus is shown on the chart. As liquid enters the wellbore the fill-up rate decreases and the bottom hole pressure increases as the height of liquid exerts increasing backpressure on the formation. If the well is producing gas up the casing annulus, the rate of fill-up is not as predictable. A casing pressure build-up rate in excess of 0.3 psi/minute indicates that the casing annulus liquid contains a substantial amount of free gas and the fill-up data should be used with caution.

Other Methods to Determine Acoustic Velocity

Another technique to determine the distance to the liquid level is for the operator to input the acoustic velocity and then measure the acoustic roundtrip travel time to the liquid level. The velocity can be obtained from prior data obtained in the field, from plots of acoustic velocity, from a gas analysis, or calculated from a computer program that uses gas properties or composition. Echometer Company provides free of charge downloads of a paper[9] from the Internet that displays the acoustic velocity of various hydrocarbon gases at various pressures and temperatures. Also, the acoustic velocity can be determined from a sample of gas obtained from the casing annulus. The sample of gas can be collected into a tube of known length, and the acoustic velocity of the sample of gas can be determined from a measured acoustic pulse travel time in the tubing. The acoustic velocity of the gas that was determined at surface conditions should be adjusted for the changes in pressure and temperature that occur in the well. This technique is reasonably accurate only if the well continuously vents gas from the annulus so that the sample of gas at the top of the well is representative of the composition of the gas in the annulus. This procedure should not be used on most shut-in wells since different gases tend to separate with the lighter gases rising to the surface. After the acoustic velocity is determined or estimated, the acoustic wave round-trip travel time from the initial pulse to the liquid level reflection is read directly from the acoustic trace. The round-trip travel time is divided by two and multiplied by the acoustic velocity to calculate the depth to the liquid level.

When the specific gravity or the composition of the gas is accurately known, then the velocity of sound in the gas can be calculated. Free of charge software programs, AWP2000[10] and TWM[11], provide the operator the ability to select from four options to calculate the acoustic velocity at a known pressure and temperature using: 1) gas specific gravity, 2) gas composition analysis, 3) depth markers, or 4) tubing joint collar reflections.

Presence of CO2 in Casing Gas

Fig. 9 compares the gradients of various components (oil, CO2 and 0.85 SG hydrocarbon gas) that are found in the casing annulus of some CO2 flooded oil wells. The presence of large percentages of CO2 in the annular gas requires that special attention be given to the acquisition of acoustic fluid levels and to the calculation of the pump intake pressure. At low pressures, the CO2 behaves as a hydrocarbon gas, and the CO2 gas column pressure can be calculated accurately. At flowing bottomhole pressures in excess of 1000 psi and temperature in the range of 100 degrees F, the density of CO2 increases rapidly and approaches the density of 35 degrees API hydrocarbon liquids. The CO2, oil and water may become miscible, and this mixing of the fluids will result in difficulties in detecting the acoustic gas/liquid interface reflection since a distinct interface does not exist. From 600 psi to 1400 psi, rapid changes in CO2 density can make the fluid gradient below the gas/liquid interface difficult to determine, since the phases are becoming miscible, and other techniques such as the Walker method may need to be employed. As the flowing bottomhole pressure increases above 1500 psi, the miscibility characteristics of CO2, oil and water usually result in relatively little gas being produced up the annulus, even though large volumes of gas are produced through the tubing and pump, and are observed at the surface as large Gas/Oil ratios. At the pump intake, the CO2-oil mixture behaves essentially as if it were mostly oil, and the presence of CO2 in the miscible phase instead of a gas phase increases the pump efficiency.

Conclusion

Technology for acoustically determining the depth to the liquid level is continually evolving and is improving the accuracy of acoustically determined downhole measurements, including distances and bottomhole pressures. Normally, the computer software automatically locates the liquid level and processes tubing collar reflections to accurately determine the number of collars reflections from the surface to the liquid level. Downhole distances and pressures are calculated automatically. Advanced techniques for acoustic liquid level analysis are required for wells where unusual conditions exist. There are many difficult or abnormal wells where advanced techniques can be used to determine the liquid level in these wells. Acoustic liquid level well sounding is used successfully in almost all possible applications throughout the world and its applications continue to expand.

The advent of portable computers and software has made analysis and acquisition of acoustic well soundings easier, faster, and more accurate. Use of a portable system permits further in-depth well and reservoir analysis by acquisition and analysis of acoustic data, while unattended; for example, permitting liquid level tracking and pressure transient data acquisition and analysis.

References

1. McCoy, J.N., Becker, Dieter, Podio, A.L., and Drake, B., "Improved Analysis of Acoustic Liquid Level Depth Measurements Using Dual Channel Analog/Digital Strip Chart Recorder" presented at the Southwestern Petroleum Short Course, Lubbock, Texas, 1997.
2. McCoy, J.N., Podio, A.L. and Huddleston, K.L.: "Analyzing Well Performance XV," presented at the 1987 Artificial Lift Workshop, Houston, TX, Apr. 22-24.
3. McCoy, J.N., Podio, A.L. and Huddleston, K.L.: "Acoustic Determination of Producing Bottomhole Pressure," paper SPE 14254 presented at the 1985 SPE Annual Technical Conference and Exhibition, Las Vegas, NV, Sept. 22-25.
4. U.S. Patent No. 2,161,733, C.P. Walker, Method of Determining Fluid Density, Fluid Pressure and the Production Capacity of Oil Wells. Date issued, June 6, 1939.
5. Walker, C.P., "Determination of Fluid Level in Oil Wells by the Pressure-wave Echo Method," presented at the Los Angeles Meeting, October, 1936, Transactions of AIME, 1936.
6. McCoy, J.N., Podio, A.L., Rowlan, Lynn and Garrett, Mark, "Use of Acoustic Surveys for Field Calibration of Surface Readout BHP Gages in ESP Installations," SPE 37452, presented at the SPE Production Operations Symposium, in Oklahoma City, Oklahoma, March 9-11, 1997.
7. Schubert, J.J. and Wright, J.C.: "Early Kick Detection Through Liquid Level Monitoring in the Wellbore," presented at the 1998 IADC/SPE Drilling Conference held in Dallas, Texas 3-6 March 1998.
8. McCoy, J.N., Podio, A.L. and Becker, D.: "Pressure Transient Digital Data Acquisition and Analysis From Acoustic Echometer Surveys in Pumping Wells," paper SPE 23980 presented at the 1992 SPE Permian Basin Oil and Gas Recovery Conference, Midland, TX, Mar. 18-20.
9. McCoy, J.N., "Acoustic Velocity of Natural Gas", WWW.Echometer.com\papers\nat_gas.html
10. Echometer Company, "Download AWP2000 Software", WWW.Echometer.com\software\index.html
11. Echometer Company, "Download TWM Software", WWW.Echometer.com\software\index.html

Fig. 1 – High Resolution Processing of Acoustic and Pressure Signal.

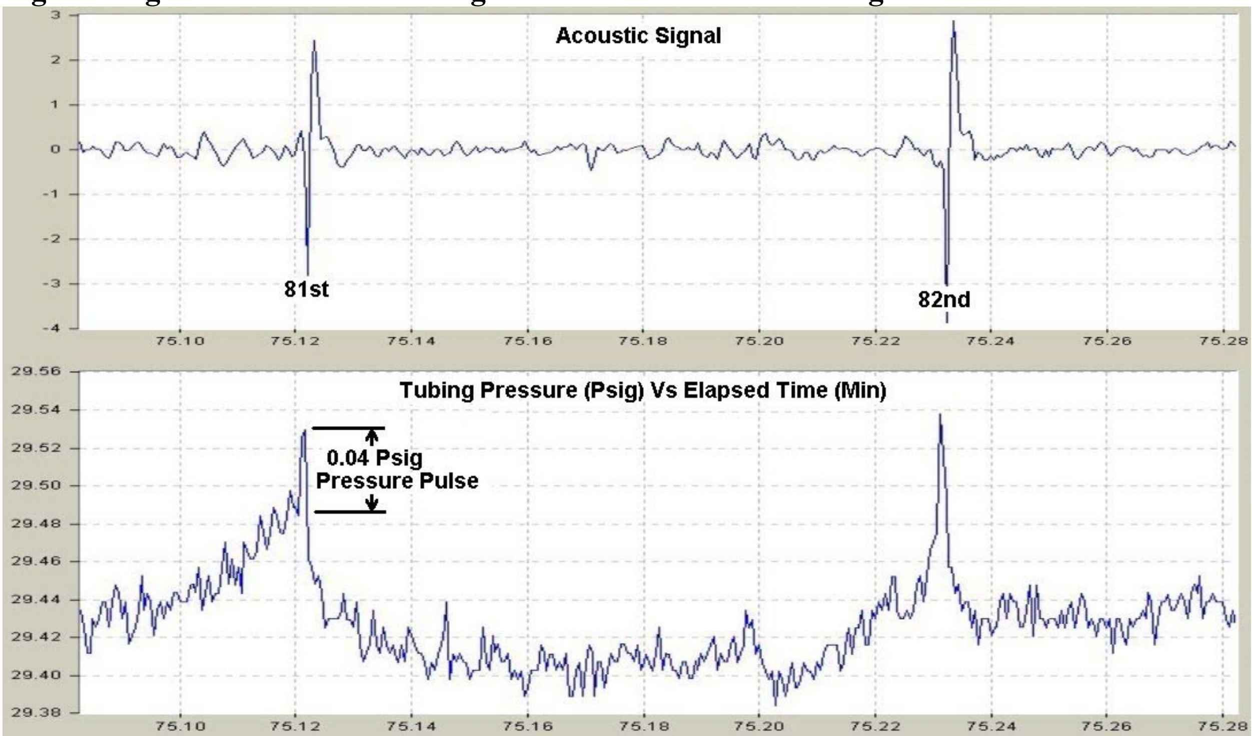


Fig. 2 – Known Depth of Downhole Marker determined Depth to Liquid Level.

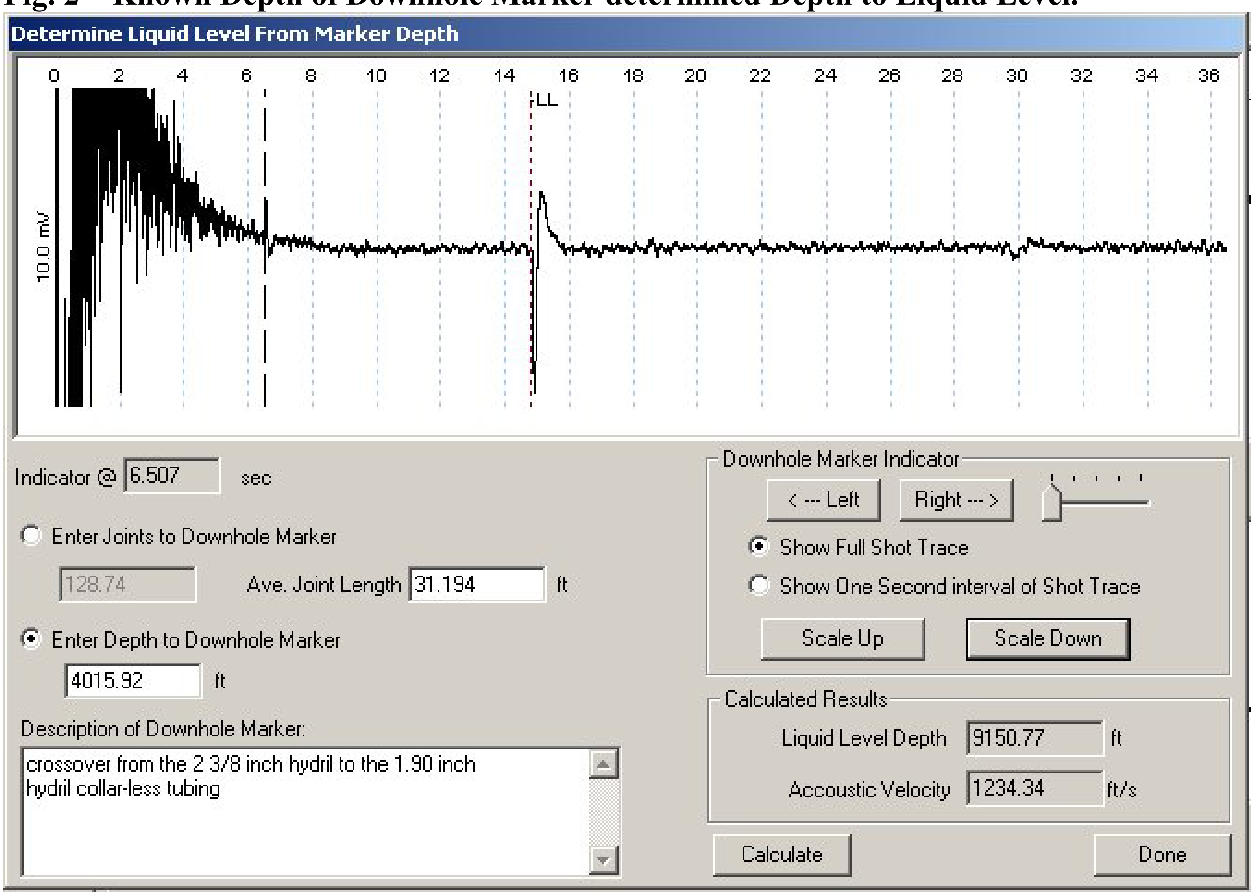


Fig. 3 – Change in Steady State Conditions Caused by Closing Casing Valve.

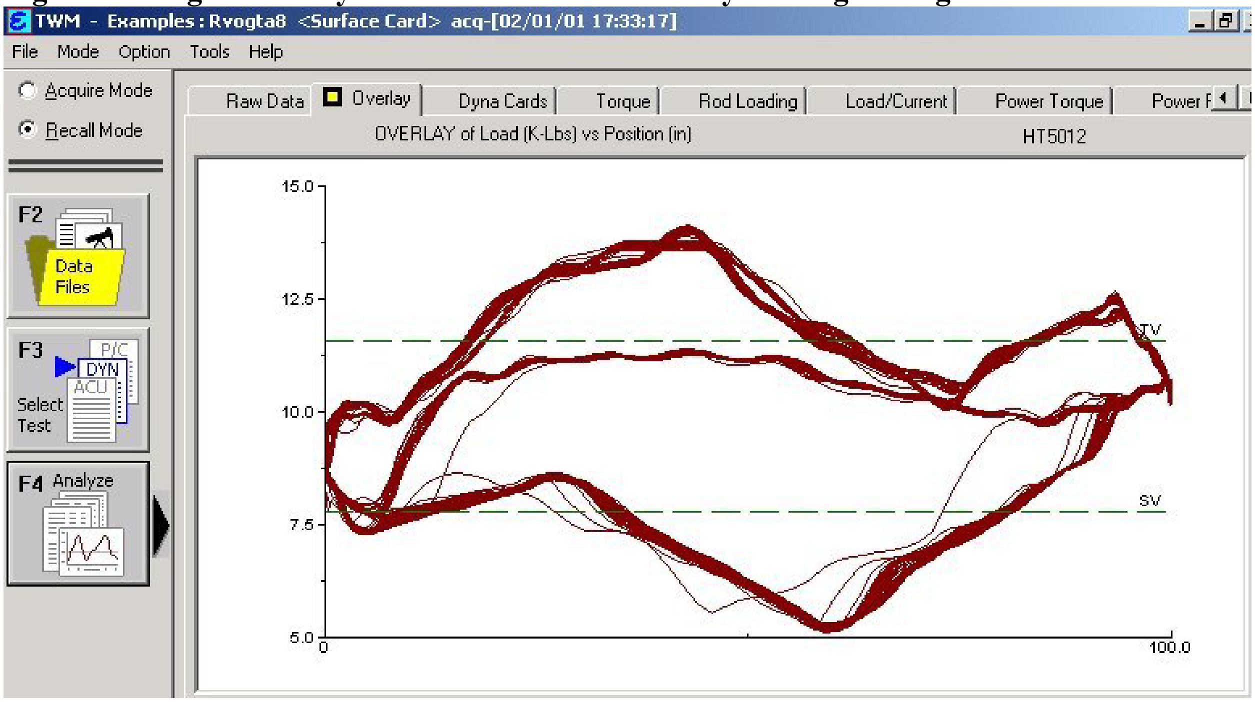


Fig. 4 – Gaseous Liquid Column Height vs. Pressure at the Gas/Liquid Interface

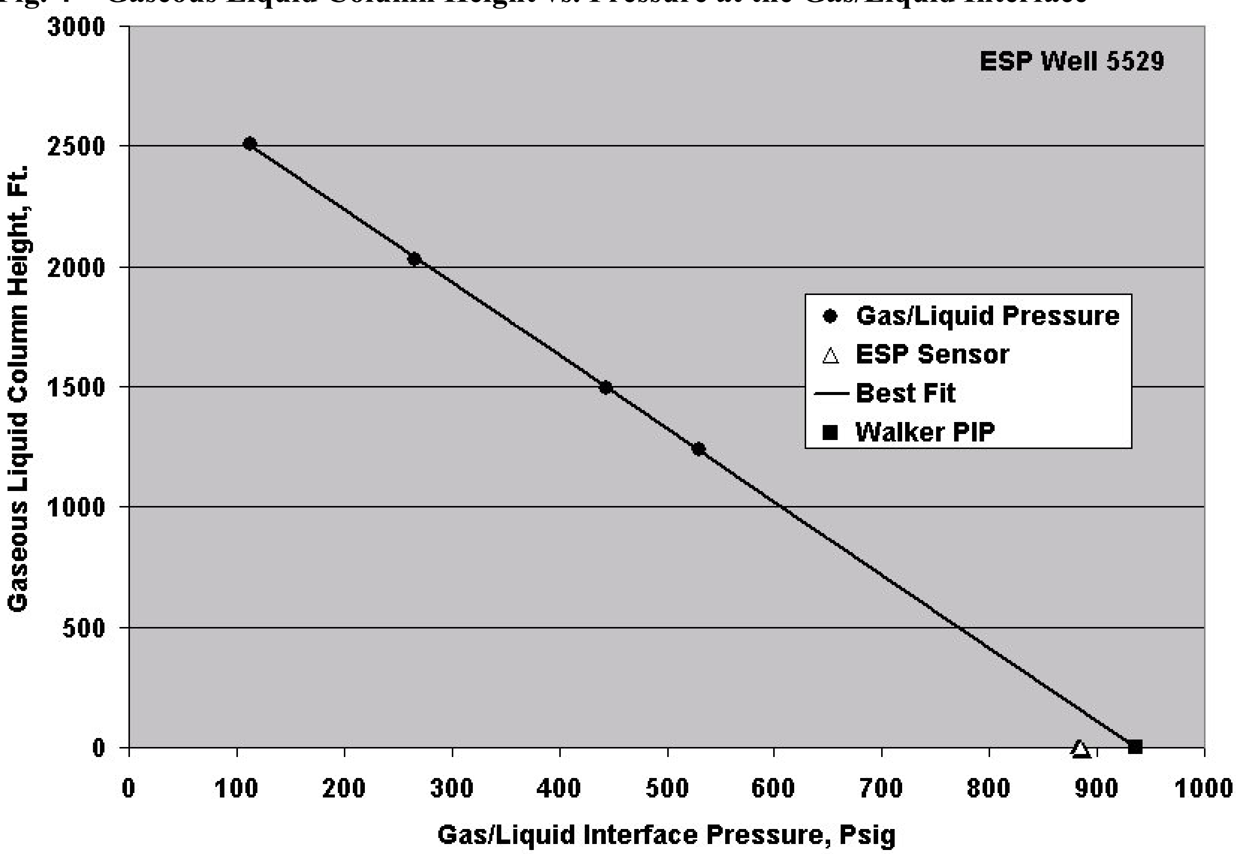


Fig. 5 – Echometer Gaseous Liquid Column Gradient Correction Curve

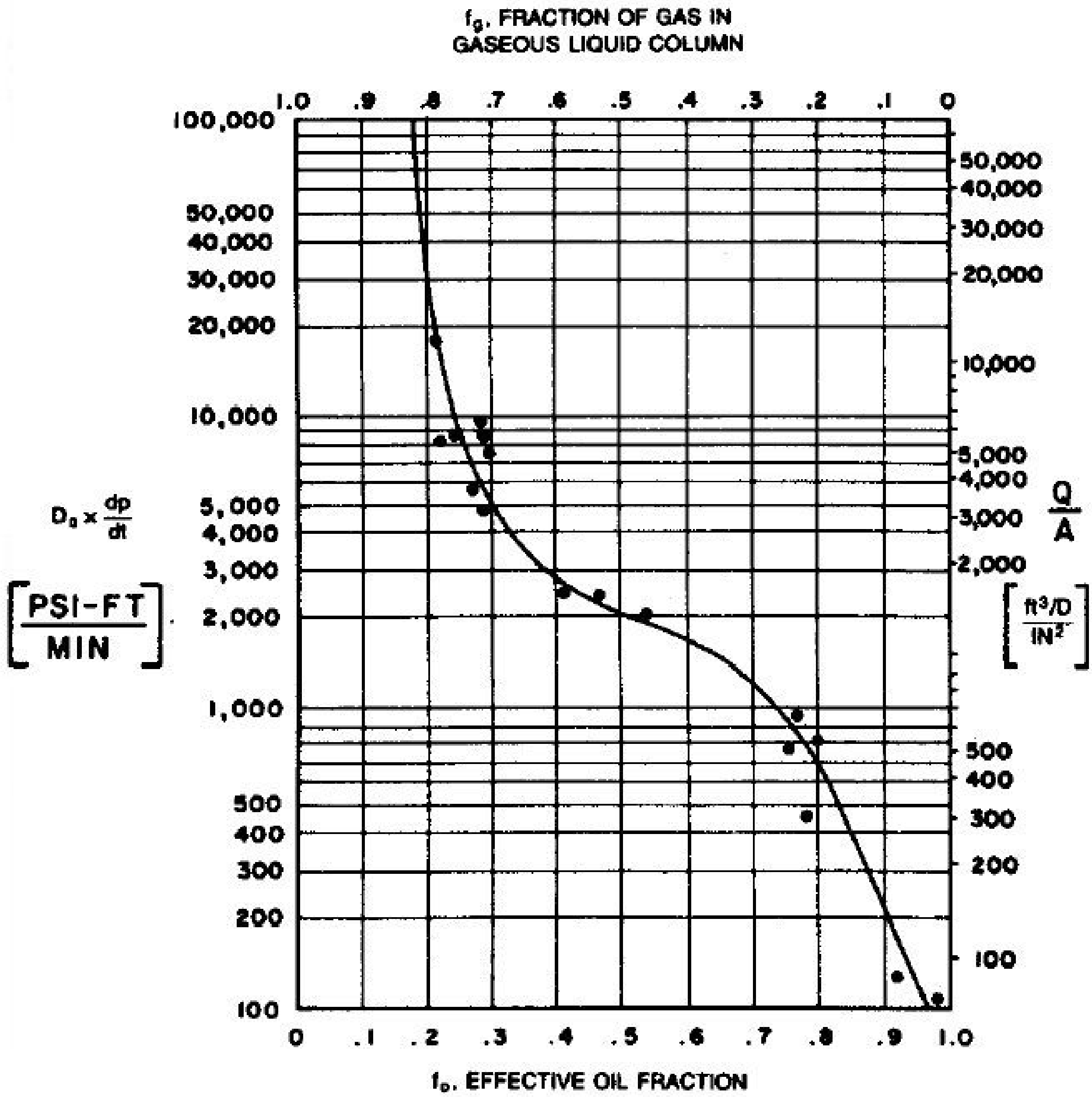


Fig. 6 – User Specified Liquid Level Tracking Alarm Limits.

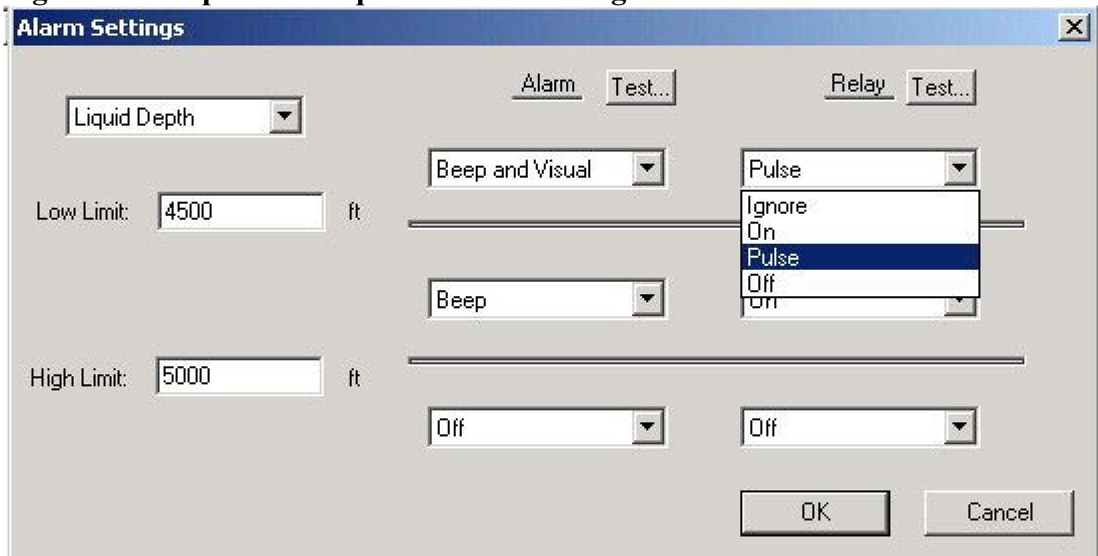


Fig. 7 – Pressure Transient Analysis with Horner Analysis Plot.

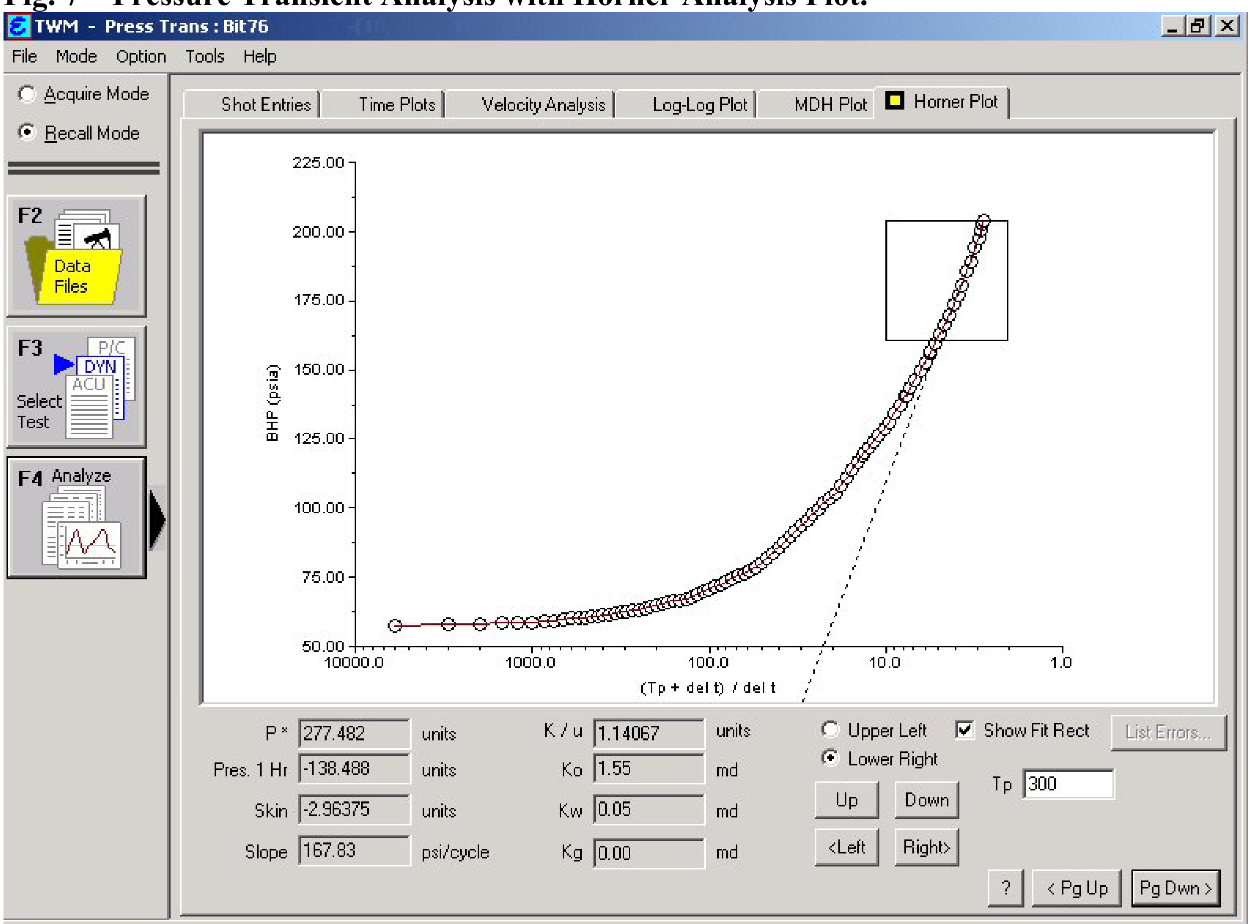
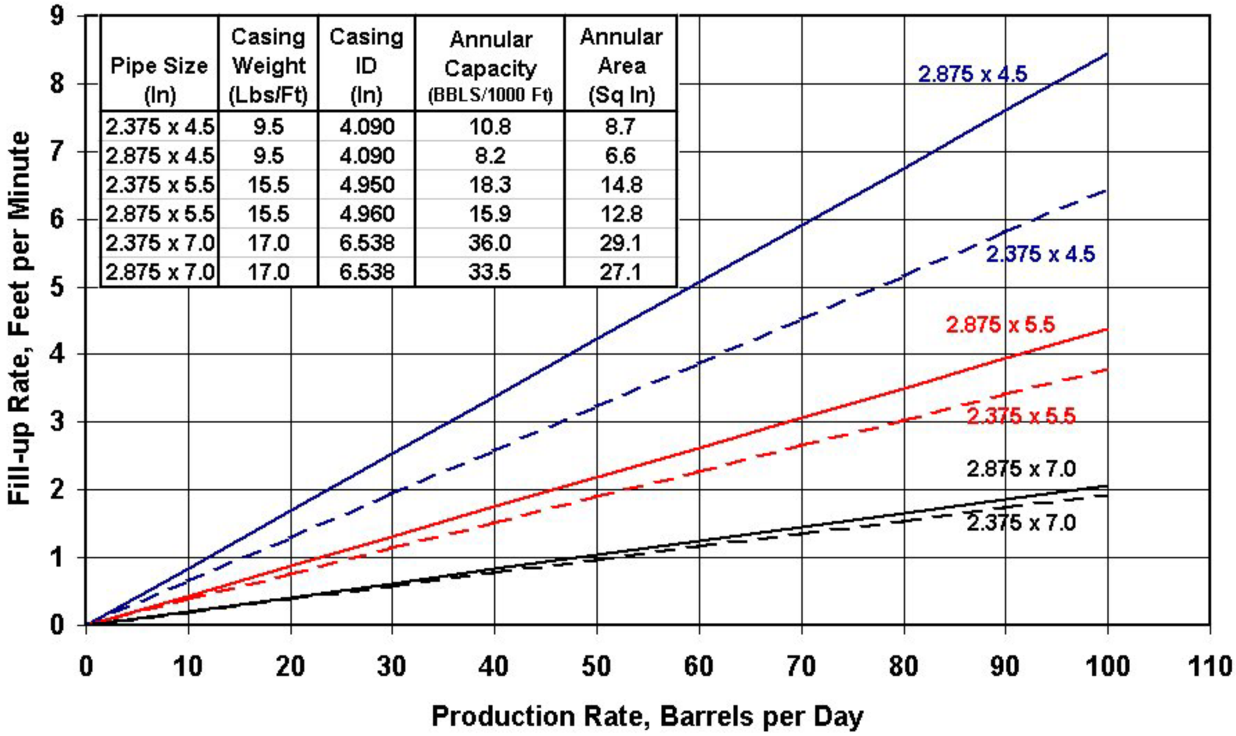


Fig. 8 - Fill-up Rate for Various Production Rates in Different Sizes of Pipe



Pipe Size (In)	Casing Weight (Lbs/Ft)	Casing ID (In)	Annular Capacity (BBLS/1000 Ft)	Annular Area (Sq In)
2.375 x 4.5	9.5	4.090	10.8	8.7
2.875 x 4.5	9.5	4.090	8.2	6.6
2.375 x 5.5	15.5	4.950	18.3	14.8
2.875 x 5.5	15.5	4.960	15.9	12.8
2.375 x 7.0	17.0	6.538	36.0	29.1
2.875 x 7.0	17.0	6.538	33.5	27.1

Fig. 9 - Comparison of Oil, CO2 and 0.85 SG Hydrocarbon Gas