

BEST PRACTICES FOR PRESSURE TRANSIENT TESTS USING SURFACE BASED MEASUREMENTS

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ABSTRACT

Proper reservoir management and production optimization require timely knowledge of formation pressure, permeability and well bore skin factor. To this effect, pressure transient tests using wireline conveyed pressure gauges are commonly run in flowing wells. The presence of artificial lift equipment complicates and often precludes the use of wireline conveyed devices so that conventional pressure transient tests are seldom performed in these wells, resulting in poor reservoir and production management. Since the 1980s, the industry has used programmable equipment for calculation of bottomhole pressure from surface pressure and acoustically measured liquid level data in pumping wells. Advances in electronics, computer software and transducer technology have vastly improved the data quality and the usability of this equipment to the point that routine determination of BHP using surface measurements is reliable, cost effective and provides real-time data with the quality necessary for pressure transient analysis. Three field cases are presented to illustrate application of the acoustic pressure transient system in different wells and to illustrate best practices that guarantee high quality data.

INTRODUCTION

The present economic climate in the oil industry requires that maximum production efficiency be achieved with minimum engineering and technical manpower. Considering that the majority of US land oil wells are produced through artificial lift and the majority of these by means of beam pumping systems, it becomes apparent that there exists an increasing need to easily monitor and analyze the performance of beam pumped wells. Flowing bottom hole pressure surveys, pressure buildup tests, pressure drawdown tests, and inflow performance analyses are the principal tools available to determine reservoir pressure, formation permeability, productivity index, pump efficiency, skin factor, as well as other indicators that can be used in the optimization of producing well operations. These techniques are widely used in flowing wells and in some gas lift wells, where the pressure information is easily obtained from wireline-conveyed bottomhole pressure recorders. The presence of the sucker rods in beam pumped wells essentially precludes practical, routine, direct measurement of bottomhole pressure, thus eliminating the single most important parameter for well analysis. Permanent installations of surface indicating bottomhole pressure gages have not become cost effective or reliable over long periods of time. Wire line measurements through the annular space involve operational difficulties, risk and high cost.

The solution of this problem has been found through calculation of the bottom hole pressure from casinghead pressure measurement and determination of the annular fluid head from echometric surveys that yield the depth of the gas-liquid interface.^{1,2,3}

A microcomputer-based system for automatic acquisition of pressure transient data was developed in 1987 as a hybrid system using analog filtering and recording of the acoustic signal^{4, 5}. Such system still depended in some measure on the operator's interpretation of the acoustic chart recordings to determine the average acoustic velocity in the annular gas.

The present system is a fully digital data acquisition and processing package which automatically determines the position in time of the gas-liquid interface, digitally filters the acoustic data to enhance collar reflections and calculates the depth to the liquid level from the acoustic velocity obtained from a count of collar reflections. Operation is pre programmed by the user.

DESCRIPTION OF THE DIGITAL ACOUSTIC PRESSURE TRANSIENT SYSTEM

The Automatic Acoustic Pressure Transient system is based on the Digital Well Analyzer¹ configured for long term unattended operation and controlled by software specially developed for pressure transient data recording and analysis. Figure (1) depicts a schematic diagram illustrating the various components of the system. The equipment consists of an electronic package that includes a computer, analog to digital converter, amplifying and conditioning circuits. This is connected to the wellhead assembly with interconnecting cables. A 12-volt battery and a large gas

supply container are the needed power sources. Figure (2) illustrates the functional relationships between these elements. Note that the data acquisition and processing package can be also used in conjunction with dynamometer and other sensors if desired.

The Acoustic Source / Detector

This wellhead assembly consists of a microphone, solenoid gas valve, pressure transducer and volume chamber. Nitrogen gas is readily available and commonly used.

Signal Acquisition, Processing and Recording

A good 100 amp-hour, 12 volt, deep-cycle battery should be used. A battery that is fully charged will last two or three days at normal temperatures. The Well Analyzer will drain the battery approximately 0.007 volts per hour or 0.17 volts/day. The initial A/D battery voltage when beginning pressure transient testing is approximately 11.6 volts. This battery voltage is indicated on the main analysis screen that is displayed during the test. A record of A/D battery voltage vs. time is available in the plotting routines. The battery voltage vs. time display screen can be used to estimate the remaining battery life. The voltage drops linearly to 10.2 volts and then drops rapidly. The estimated remaining battery life is calculated by utilizing the battery drain rate, the last voltage reading and then predicting when the voltage will drop to 10.2 volts. Data acquisition ceases when the voltage drops to 10.0 volts. Please use this analysis procedure to verify that the computer, A/D battery and external 12 volt deep-cycle battery are all operating normally and in good condition. The amplifier, A/D converter are not allowed to acquire data when the battery voltage is less than 10 volts.

Transducers

A high accuracy strain gage pressure transducer provides a signal proportional to pressure. Direct connection to the wellhead assembly is through a quick-connector so that casinghead pressure can be monitored continuously during the test. Various pressure ranges can be used depending on the estimated maximum buildup pressure. The standard range is 0 to 1500 psig. Isothermal accuracy of the transducer is 0.11% of full scale. Calibration curves for each transducer are obtained in a temperature controlled chamber over the temperature range 0 F to 150 F. A thermistor is installed within the transducer housing so as to determine the actual operating temperature so as to introduce appropriate zero and sensitivity shift corrections in the data processing so as to maintain the accuracy throughout the test.

The pressure transducer used with the buildup system is a precision instrument. Accordingly it should be used carefully and maintained in good condition. The following are suggested practices to be followed to insure the maximum accuracy of the measured pressure data:

1. Shield pressure transducer from direct sunlight and rain. (Use insulating foam tube over transducer)
2. Protect transducer and cables from vibration or movement.
3. Do not permit cable connectors to become wet.
4. Use good quality batteries and maintain a good charge in the batteries

In very harsh environments (Canada, Siberia or tropics) it is advisable to put the well analyzer and the external battery within an insulating enclosure so as to protect them from extreme temperature or humidity.

For maximum accuracy use a pressure transducer with a full-scale range as close as possible to the maximum casing pressure expected at the end of the buildup test.

Data Processing

The program is designed for unattended operation of the Well Analyzer while acquiring data for an extended buildup or draw down test. Various flags, which can be reset during the test, control the type of test and the type of data that is acquired. Frequency of data acquisition is also controlled by the operator and can be modified during the test. Provision has been made to allow editing of the data as well as appending data in the event that the normal sequence of events has to be interrupted (loss of power, loss of gas pressure or mechanical malfunction) so that the overall result of the test is safeguarded. Although the program is primarily designed for use in conjunction with pumping wells it is applicable to flowing wells and gas lift where there is not a packer in the annulus or if there is a pack-off the measurements are made through the tubing.

The operation of the software is divided into a set-up phase, an acquisition phase and a data quality control and analysis phase. Various options are chosen from buttons and check boxes that are activated via the corresponding tabs.

Bottomhole pressure (BHP) determination is based on wellhead pressure measurement, determination of the gas/liquid interface pressure and calculation of the annular fluid gradients. In order to achieve the maximum accuracy in BHP it is necessary to account for temperature variations, acoustic velocity variations, and changes in composition of the annular fluid.

Temperature Correction

During the several days of the typical well test, the transducer's sensing element may undergo temperature variations of over 60 degrees F. Even though the transducer is built with integral temperature compensation this temperature change can cause considerable (+/- 2%) variations in the measurement of casing head pressure that are reflected in the BHP record. Additional correction is applied, by measuring the transducer temperature with a thermistor and computing the corresponding pressure deviation from calibration curves obtained for each individual transducer, to eliminate most of the interfering pressure oscillations.

Acoustic Velocity Variation

During the well test (buildup or drawdown) the pressure, temperature and component distribution of the gas in the annulus will undergo significant changes. These in turn will cause variations in the acoustic velocity of the gas. At any given time the average acoustic velocity is obtained from an automatic count of filtered collar reflections, when available, and the average joint length. For wells where the acoustic record does not show collar reflections, the variation of acoustic velocity is computed from the known gas gravity the average temperature and the measured pressure.

Experience indicates that pressure-dependent velocity variations occur gradually and continuously, as shown in Figure (3). The data reduction program interpolates between these points to calculate the depth to the gas/liquid interface from the measurement of the travel time of the liquid echo. If this variation were not taken into account and a single value for acoustic velocity were used in interpreting the travel time data a significant error in calculated BHP would be made.

Annular Fluid Composition

Several papers have been presented on the correct methods for calculation of bottomhole pressure from acoustic determination of annular liquid levels. The BHP is the sum of the casing head pressure and the hydrostatic column pressures due to the annular gas and liquid. The gas column gradient is calculated as a function of pressure, temperature and gas gravity. The liquid column pressure is a function of the composition of the liquids, and the in-situ water/oil ratio and gas/liquid ratio. Flowing conditions and well geometry determine the fluid distributions. For example for steady state pumping conditions the liquid above the pump intake is oil due to gravity segregation occurring in the annulus. When the well is shut in for a buildup the water cut remains essentially constant during the after flow period and a moving oil/water interface develops during the test. These factors are taken into consideration by the program in calculation of the bottomhole pressure. In-situ oil and water densities are calculated as a function of pressure and temperature using conventional correlations.⁶

When the producing bottomhole pressure is below the bubble point, free gas is produced from the reservoir and is generally vented from the annulus. This annular gas production reduces the liquid column gradient and thus has to be taken in consideration in the BHP calculation. Experience indicates that a gaseous liquid column can extend for a significant period of time after the well is shut in. A correlation derived from a multitude of field measurements of gaseous liquid column gradients³ is used to account for this effect. When a long annular gaseous liquid column is present in a pumping well, to obtain the most accurate results, it is recommended that before the initiation of the buildup test the liquid level be depressed to a few joints above the pump by increasing the casing head back pressure while maintaining a steady pumping rate. This is easily achieved by means of an adjustable backpressure regulator installed on the casing head valve that will maintain the casing pressure constant during the process of liquid level depression until stabilization. The result will be that at the end of the after flow period the height of the liquid column will be minimized and a major portion of the BHP will be provided by the surface casing pressure (that is measured very accurately) and the gas column pressure.

Best Practices

Running a pressure buildup test involves a major commitment of time and manpower as well as temporary loss of income while the well is shut-in. Therefore every effort should be made to guarantee that the final data is of sufficient good quality to yield an accurate representation of the formation permeability, skin and static reservoir pressure. The following recommended procedures provide guidelines to help reach that objective. Although the procedure makes reference to the Well Analyzer, it is understood that it is applicable to tests undertaken with other acoustic fluid level instruments.

Beam Pumped Wells

- 1- Obtain all necessary data for acquisition and pressure transient analysis. Review and update base well file. Obtain or draw a well bore diagram to identify all changes in annular cross section that could be used as down hole markers or that could interfere with automatic liquid level selection (liners, tubing cross-overs, etc.)
- 2- Prior to date of well test, perform acoustic measurements to determine normal producing conditions, acoustic velocity, casing pressure and existence of a gaseous liquid column. Perform dynamometer test to determine pump fillage and effective pump displacement.
- 3- If height of gaseous liquid column is significant perform a short duration (1hour) liquid level depression test (by closing the casing to flow line valve) to estimate the time required to depress the liquid level to the pump intake.
- 4- Inspect all well connections to flow lines, casing head, tubing head, stuffing box, condition of valves, leaks etc. and report any problems to the operator so that they may be fixed before date of well test. It is important that the SV is holding otherwise there will be excessive back flow of liquid from the tubing, during the early stages of the buildup and this will show up as additional after-flow.
- 5- Shortly before (24-48 hours) date of test put the well on a production test in order to determine the average 24-hour production rate, water cut and GOR.
- 6- Review and update all data and prepare test procedure and check list.
- 7- If gaseous liquid column depression is to be performed, install back pressure regulator on casing to flow line outlet (if possible) and start increasing casing head pressure while monitoring liquid level. Use the pressure transient module to monitor depression test). This may take several hours or days as estimated in step 3. This should continue until the fluid level is indicated to be about 60 feet above the pump intake. When this is reached the casing pressure should be stabilized to a constant value (+/- 5% of the measured value)
- 8- Make sure all batteries are charged before starting the test. On the day of the test after setting up the equipment take a fluid level to verify that all is normal. Take a dynamometer and verify that the pump fillage and operation is the same as was established in step 2 and agrees with the well test information. If the difference is more than 10% continue monitoring the dynamometer during 30 minutes to detect any abnormalities. If the pump operation is erratic, then postpone the test until the problem is fixed since it would be impossible to determine an accurate well flow rate that is needed for pressure buildup interpretation.
- 9- Verify that all connections between the gas bottle and the remote fire gun do not have any leaks. Check all electrical connectors for tightness and protect them from rain. Place a thermal insulating tube on the pressure transducer. Check connection to external battery and verify that the Well Analyzer (EXT BAT) light is on and the charger cable is connected to the laptop.
- 10- Start the TWM program and go through the Set Up procedure to get the zero offset of the pressure transducer. Select the Transient Test module and complete the test set up procedure. Use Logarithmic schedule unless there is a reason for selecting otherwise. Take a Pre-Shot and verify that the program is picking the fluid level correctly (adjust the signal window if necessary) and that the acoustic velocity and fluid level depth are computed correctly as established earlier (steps 7 and 8)
- 11- Start the buildup acquisition (START acoustic transient test) while the well is still pumping (first pressure value corresponds to PBHP). As soon as the program completes the processing of the first shot STOP the pump. Set brake and lock out the motor switch. Close tubing flow valve to prevent the well to flow as the pressure builds up during the test.
- 12- Monitor the progress of the test at least for 30 minutes and check that the fluid level is picked correctly and all the data is consistent (fluid level may rise or fall depending on well conditions) especially the casing pressure should show a consistent trend. Make any adjustments to obtain accurate time to liquid level as described in the TWM manual.
- 13- Determine the rate of casing pressure increase (psi/hour) to estimate the likely casing pressure for the time when you will return to the well to check the test progress. Set the regulator pressure to 200 psi above the estimated future casing pressure to insure that fluid level shots will be taken at that time.

- 14- Check that the EXT. POWER indicator is lit, check all connections before leaving the well. Check that the laptop power management has been set to NEVER turn off the laptop and that the laptop will stay ON even when closing the lid. Close well analyzer case and protect from the environment. Wait until a shot is taken automatically before leaving the site.
- 15- When returning to the well, open the Well Analyzer and the laptop. Check the Progress screen and verify when the last shot was taken, when the next shot is due, the presence of soft shots (S), the casing pressure, time to liquid, etc. Take a MANUAL shot and observe the liquid level pick and depth calculation. Check a time plot of Casing Pressure vs. time and observe if there are any anomalies (step changes of pressure or abrupt changes of slope) that may indicate the presence of leaks at the wellhead or transducer problems.
- 16- Make necessary adjustments to obtain accurate fluid level and depth values in subsequent shots.
- 17- Determine casing pressure increase rate and adjust regulator pressure. Check the pressure in Nitrogen bottle and battery voltage and replace them as necessary.
- 18- Copy all the data recorded to this point to a diskette, CD or USB removable memory as appropriate to the laptop in use. The objective is to transfer the data to an office computer for further analysis to determine if the test has run sufficiently for meaningful buildup interpretation or if the test should be continued.
- 19- If the test continues go back to step 14.
- 20- If the test is terminated, take a MANUAL shot and when the computer finishes processing the data select END Transient Test and exit the Pressure Transient Module.
- 21- Select the Acoustic Test module, select "shut-in" to indicate the well status and take an acoustic record to establish the present value of Static Bottom Hole Pressure in the well base file.
- 22- Select Dynamometer Test. Connect the PRT to the polished rod. Open the tubing valve to the flowline, release the brake and start pumping unit.
- 23- Make dynamometer measurements to determine that the pump is operating normally.
- 24- Open slowly the casing valve to the flowline to SLOWLY reduce the casing pressure to its normal operating value. See NOTE below for ESP wells.
- 25- After the casing pressure has stabilized, repeat dynamometer measurements to verify that the pump is operating normally. If not then notify the operator of the problems that may be indicated.
- 26- If all is normal, stop the pumping unit, disconnect dynamometer and remote fire gun. Transfer all data to external storage.
- 27- Start unit and verify that all is normal before leaving well site.

ESP and PCP Wells

For wells produced with ESPs or PCPs the steps related to dynamometer measurements are not relevant. For ESP wells it is very important to reduce the casing pressure very slowly since gas will dissolve in the down-hole cable's insulation as the pressure in the annulus increases during the buildup test. A rapid reduction of casing pressure will cause the insulation to swell and possibly damage the cable. A slow decrease in casing pressure allows the dissolved gas to evolve gradually without causing swelling of the insulation.

Gas-Lift Wells

Fluid level measurements are made through the tubing. Annular fluid level is monitored before shut-in and then periodically to observe any changes in pressure or fluid level during the transient test. After completing the fluid level test the remote fired gas gun is installed on the tubing, preferably above the swab valve (when present) after removing any needle valve and replacing it with a fully opening ball valve. Injection of the gas into the casing is stopped and the valve from the tubing to the flow line is closed. Acoustic single shots are taken manually at 3 to 5 minutes intervals until a clear fluid level echo is observed. Then the pressure transient module is used to set up automatic acquisition of the data from that point onwards.

Gas Wells

Wells that are producing gas through tubing with no packer in the annulus

Pressure transient measurements should be done in the annulus since there will be a minimum of liquid accumulated above the tubing intake. Fluid level measurements should be taken before stopping the flow from the tubing to establish the position of the liquid level in the annulus and to observe any variations during normal flowing conditions.

Wells that are producing gas through tubing with a packed-off annulus

Procedure is similar to that described above for Gas-Lift wells.

Wells that are producing gas through the annulus and dewatered through tubing

Procedure is similar to that recommended for pumping wells

Wells that are producing gas through both tubing and annulus

Preferred method is to undertake the pressure transient measurements through the annulus. These wells will exhibit a longer after flow and well bore storage effect than those wells producing through tubing and have a packed-off annulus.

Presentation of Results

At any time during and/or after the test it is possible to obtain graphical and tabular presentation of the data and the calculated results.

The type of presentation is selected from options in the data presentation menu. These include:

- Casing head pressure vs. time
- Bottomhole pressure vs. time
- Liquid level vs. time
- Transducer temperature vs. time
- Acoustic round trip time (seconds) vs. time
- Acoustic Frequency (Jts/sec) vs. time
- MDH—BHP vs. Log(time)
- Horner
- Log-Log analysis
- Liquid after flow vs. time
- Gas after flow vs. time
- Smoothed velocity vs time
- Battery voltage vs time

In all the transient plots, utilities are made available to aid in the interpretation. These include least square line fits of selectable portions of the data, unit slope and half slope trend lines, zooming to portions of the data and calculation of time derivatives.

The purpose of the pressure transient interpretation graphs is to provide a real time analysis to determine whether the test has been carried long enough to the point when interpretation of the data will yield accurate values of skin, permeability and reservoir pressure.

RESULTS OF FIELD TESTS

The Automatic Acoustic Bottomhole Pressure System has been used for many years and for a variety of situations and environmental conditions. Following are presented a selection of field data with the purpose to illustrate the variety and quality of the data that has been obtained.

Well A

Figures 4 (a-e) illustrate the data obtained during a seven-day pressure buildup test in a 4900-ft beam pumping well. Production prior to shut-in was 226 water, 36 oil in Bbl/D and 24 MSCF of gas. A total of 197 fluid level measurements were recorded. Data was appended one time. Figure 4a shows the measured casing head pressure increasing throughout the test caused by continued influx of gas. The pressure transducer temperature exhibits daily variations as large as 40 degrees F but temperature compensation and calibration eliminates any effect on the pressure data. Figure 4b shows the rise in liquid level of about 3000 feet experienced during the liquid after flow period that seems to end at about 5000 minutes where the liquid level stabilizes at about 1900 feet. Figure 4c shows the computed BHP that is used to generate the Log-Log plot shown in Figure 4d where the unit slope line and the derivative indicate that the well bore storage effect ends at about 20 hours. The corresponding Horner plot shown in Figure 4e shows a small skin of 0.8 and a $P^* = 2018$ psi.

Well B

Figures 5 (a-d) illustrate results of a 4-1/2 day buildup test in a PC pumped oil well producing 80 Bbl/D oil from a depth of 3150 feet. Data was appended 6 times due to poor external battery quality and a total of 136 fluid level

shots were taken. Figure 5a shows that liquid level increased by about 2600 feet and casing head pressure built by 380 psi during the test. The **x** points in the figure correspond to bad data due to occasional misfiring of the remote fire gas gun for lack of sufficient gas supply pressure or other problems. They are not included in the calculations but are a part of the permanent record and are shown for data quality control. The computed BHP and liquid after flow are plotted in Figure 5b that shows the leveling off of the after flow at about 48 hours and the corresponding near-stabilization of the BHP. The Log-Log plot in Figure 5c shows by the end of the test the radial flow period is just beginning and that probably the test was ended prematurely. The Horner plot in Figure 5d is characteristic of a severely damaged well with a skin near 9 and a $P^*=1306$ psi.

Well C

Figures 6a through 6c show the results of a buildup test extending 25 days and 17 hours. A total of 831 shots were taken and the data set was appended 61 times. The pumping well is completed with 7 inch casing and 2-7/8 inch tubing and was producing 16 Bbls/day oil from a 12 ft pay zone at a formation depth of 5379 feet. Figure 6b shows a very smooth decrease of the round trip travel time as the depth to the liquid level rises from 4998 feet at shut-in to 1916 feet at the end of the test. The bottom hole pressure increases from 168 to 1607 psi during the same time period. Figure 6c shows the Log-Log plot of the BHP data and indicates that the test was terminated prematurely since the derivative is changing and the radial flow period has not been reached in spite of the lengthy test.

Well D

Figures 7a through 7c show the results of a buildup lasting 3 days and 13 hours in a well producing 4 bbl of oil and 4 Mcf of gas per day from a 56 ft thick formation. A total of 235 shots were taken and the data was appended 4 times. Well bore storage effects are overcome and the radial flow period is reached after about 8 hours of shut-in but then there is an increase of the derivative as seen in Figure 7b, that indicates the presence of a boundary effect. Figure 7c shows that using the radial flow section of the data the skin is estimated at $S=2$ and P^* yields 102 psia.

Well E

In this well 13 MSCF/D of gas are being produced by flow through the casing annulus while 24 Bbl/day of water is pumped via the tubing. Figure 8a shows that the gas flow appears to continue throughout the test since the casing pressure continues to increase from 53 at the start to 252 psia at the end while the liquid level rises only 25 feet. The net result is that the computed BHP essentially mirrors the increase in casing pressure as seen in figure 8b. The noise from the gas flow and the fact that the liquid level stayed below the upper required manual analysis of several shots and the rejection of several points as indicated by the **x**'s in Figure 8a. The resulting bottom hole pressure vs. time is shown in Figure 8b and the Log-Log plot in Figure 8c shows that the test was carried out past the end of the well bore storage effects and into the radial flow region.

Figure 8d shows the corresponding Horner plot that yields a skin = -0.5 and a $P^* = 330$ psia.

This data set required some manual interpretation of the liquid level data due to the noise and interference from echoes generated by the perforations since the liquid level was primarily below the top perforations. Figure 8e is a plot of the RTTT to the liquid level as a function of time. It shows that several data points do not follow the decreasing trend corresponding to the rise in liquid level. The software allows manual interpretation of the acoustic record that is reproduced in Figure 8f and that corresponds to the data point flagged by the dashed vertical marker in Figure 8e. The record shows that the liquid level is not properly selected automatically by the software due to the presence of a signal (caused by the perforations) that precedes the arrival of the echo from the liquid level. Figure 8g shows how the liquid level marker is adjusted to the correct first break of the liquid level echo. After the correction is made, the data point in question now follows the expected RTTT trend as shown in Figure 8h. Similar corrections were carried out for the other outlying points prior to recomputing the final values of BHP.

Well F

This well is a low production well (4 bbl/day oil) from a shallow formation (1800 feet) with perforations over a 66 ft interval. The buildup test was carried out over 10 days and 22 hours. A total of 116 shots were taken and the data was appended 17 times since the Well Analyzer had to be used for dynamometer and fluid level measurements in other wells. Figure 9a shows a very smooth increase of casing pressure from 1.5 psig to over 65 psig during the buildup. The increase corresponds to continued gas after flow. Figure 9b shows a rapid increase in fluid level at the beginning of the test followed by a constant rate of liquid inflow that stops after about 5 days into the buildup. The resulting Log-Log plot shown in Figure 9c indicates a unit slope trend corresponding to a fractured reservoir. This is confirmed by the Horner plot shown in Figure 9d that gives a negative skin near -6 and a $P^* = 149.1$ psia.

Well G

This well is being produced with an ESP pump at a rate of 2211 Bbl/day water and 9 Bbl/day oil from a depth of 2900 feet completed with 5-1/2 inch casing and 2-7/8 tubing. The producing interval covers 400 feet. A total of 90 shots were taken and the data was appended once during the 26-hour buildup test. Figure 10a shows the variation of casing pressure (circles) and liquid level (triangles) that show a relatively rapid increase in liquid level from 2800 to 800 feet in depth. The Log-Log plot in Figure 10b shows a decreasing derivative that follows a brief radial flow period indicating there is a constant pressure boundary. The result of the Horner plot shown in Figure 10c indicates significant well bore damage with a skin $S = 8.44$ and a $P^* = 1040$ psia.

Well H

The buildup in this well is an example where the liquid level dropped to a deeper depth while the casing pressure increased during the test. The well was producing 1 Bbl/day oil, 18 Bbl/day water and 50 MCF/D gas from a depth of 5020 feet. A rod pump is set at the bottom of the producing interval at 5770 feet and initially the top of the gaseous liquid column is observed at 4800 feet corresponding to the relatively high flow of gas from the annulus. The collapse of the fluid column as the casing pressure increases is shown in Figure 11a. The corresponding BHP computed at 5020 feet is seen to mirror the increase of casing pressure in Figure 11b. The Log-Log plot in Figure 11c shows that the radial flow period may be just beginning. As such the test should have been continued. The Horner plot shown in Figure 11d indicates that there may be significant skin but it is not possible to quantify with the available data.

Well I

Figure 12a shows the variation in casing pressure and liquid level in a water well producing at a rate of 550 Bbl/day from a 10 ft formation at a depth of 1456 feet. Note the very rapid 700 ft increase of liquid level during the first hour accompanied by an increase in casing pressure from 0.1 to about 20 psi. The corresponding BHP mirrors the increase of liquid level as seen in Figure 12b. The resulting Log-Log plot shows that well bore storage effects are overcome after 2-1/2 hours of shut-in. The dip in the derivative indicates the possibility of a dual porosity formation. The Horner plot in Figure 12d indicates a very large skin $S = 41$ and a $P^* = 434$ psia.

SUMMARY

A digital pressure buildup data acquisition and processing system has been developed which uses an acoustic liquid level instrument to determine the annular or tubular fluid distribution while measuring the wellhead pressure. Unattended operation is made possible by the laptop computer that controls the progress of the test according to a predefined schedule, records and interprets the data and presents the information to the operator, in real time during the test. The advanced electronics and pressure sensors used in the hardware result in a very stable data acquisition system that operates reliably over extended periods of time. The software that controls the acquisition and monitors the test progress offers the option of interrupting data acquisition when the system is required for testing at other wells and provides a reliable means of appending new data to the saved test while maintaining the time relation to the beginning of the test.

The system has the overwhelming advantage over wireline-conveyed measurements that it does not require entering the well bore but is totally based on surface measurements. Real-time information regarding the progress of the pressure transient allows the operator to decide on the best course of action to insure that the test will yield accurate and complete data. Preliminary analysis of the data done at the well site can be followed up with detailed transient analysis by exporting the BHP data vs. time to other analysis software.

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Figure 1 – Acoustic Liquid Level Set-Up for Programmed Automatic Operation

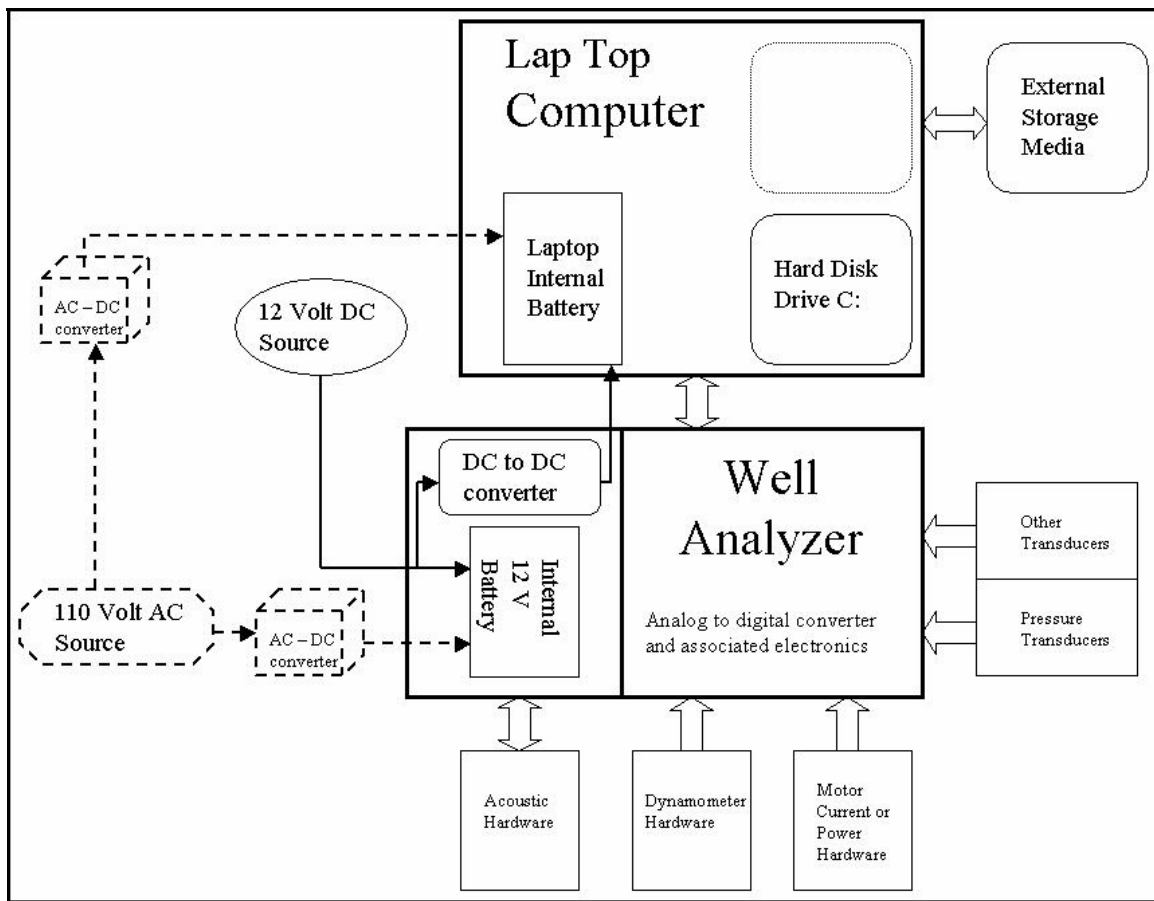


Figure 2 – Schematic Diagram Of Hardware Used For Pressure Transient Data Acquisition

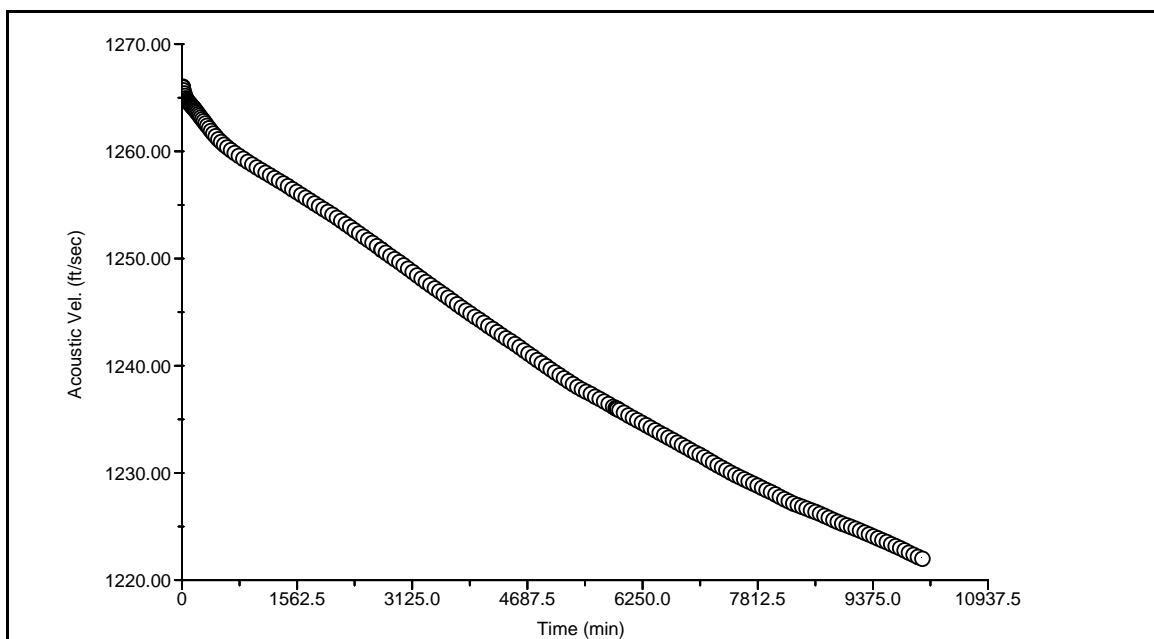


Figure 3 - Variation of Measured Acoustic Velocity During Pressure Buildup Test

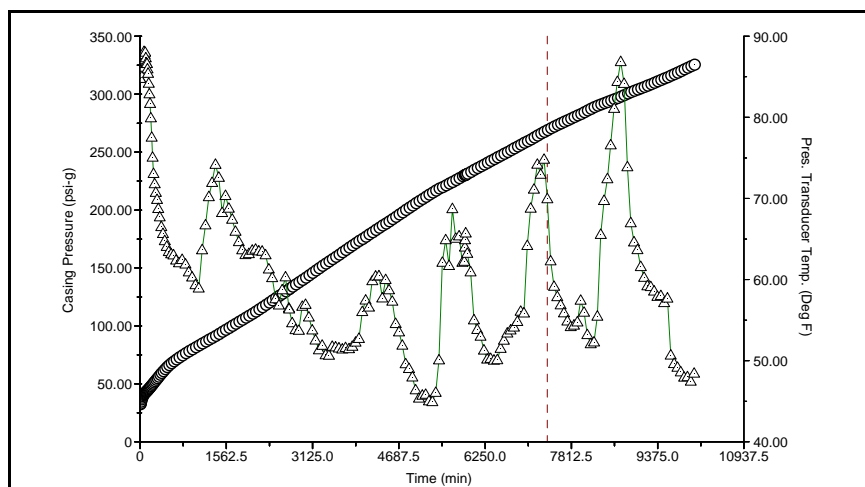


Figure 4a – Long Term Pressure Buildup Test Showing Casing Pressure (circles) and Transducer Temperature (triangles) as a function of elapsed time.

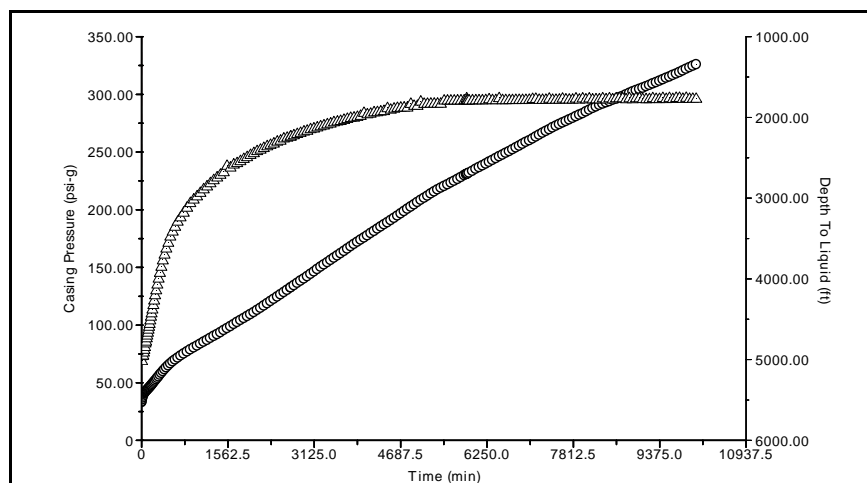


Figure 4b – Depth to Liquid Level (triangles) and Casing Head Pressure (circles) vs. Time

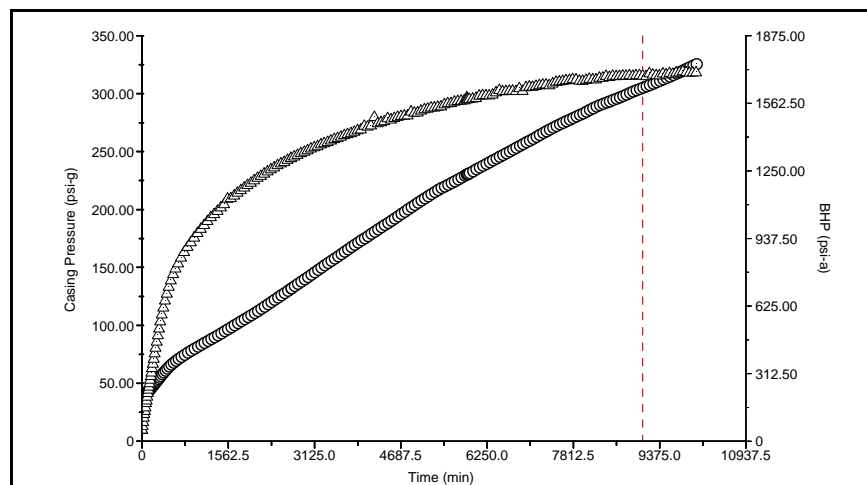


Figure 4c –Computed BHP (triangles) and Measured Casing head Pressure (circles) vs Time

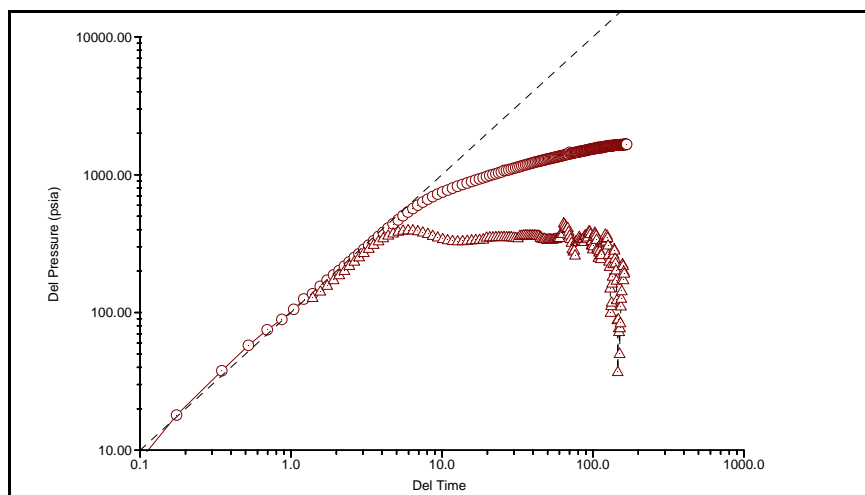


Figure 4d -Resulting Log-Log plot of Delta Pressure with Derivative vs. Delta time in hours

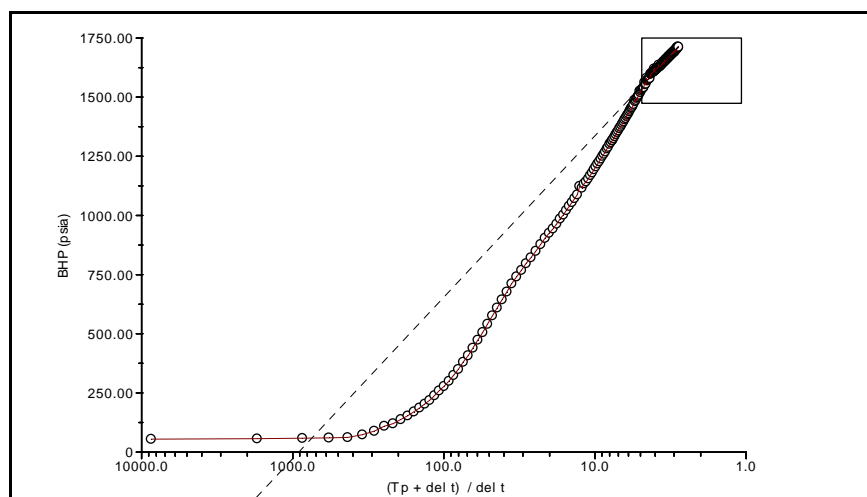


Figure 4e – Horner plot yields Skin= 0.8 and $P^* = 2018$ psi

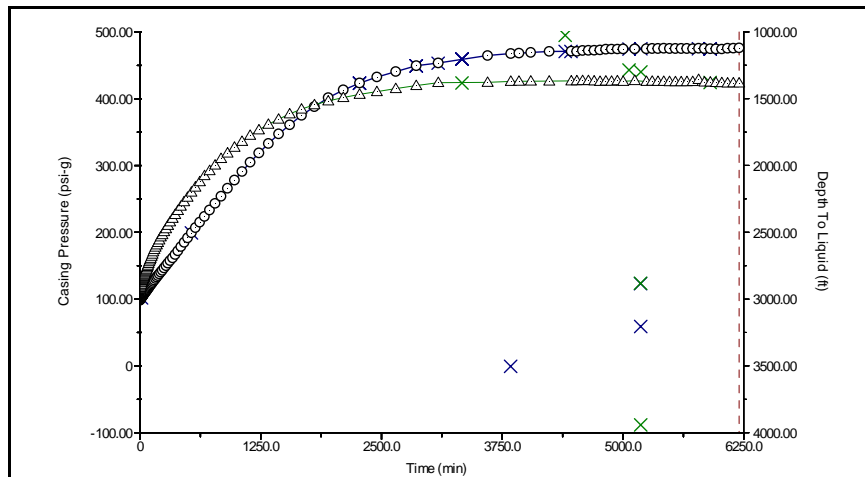


Figure 5a - Liquid Level (triangles) Increases 2600 Feet and Casing Pressure (circles) Builds Up 378 psi During 4-1/2 Days Test

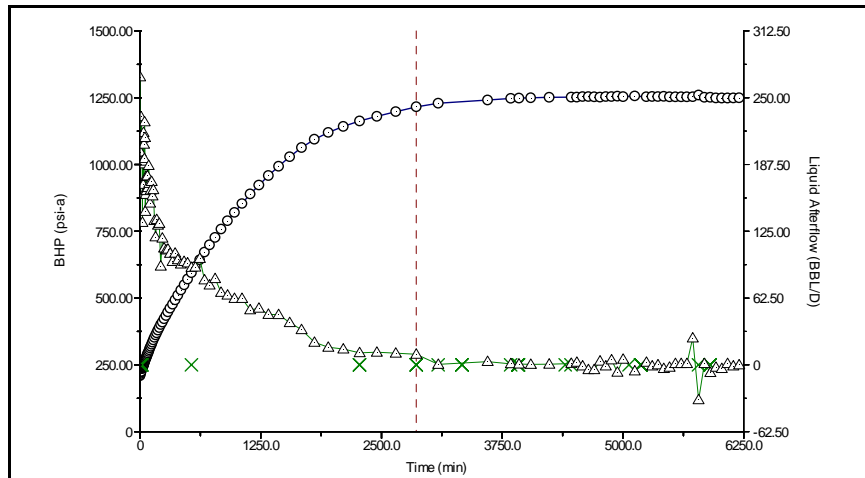


Figure 5b –BHP (circles) Levels Off and Liquid After Flow (triangles) Tends to Zero After About 48 Hours

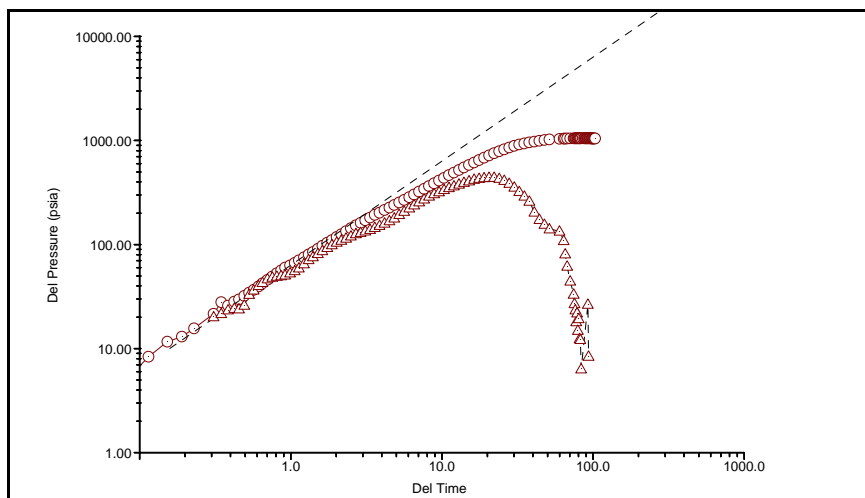


Figure 5c - Resulting Log-Log Plot of Delta Pressure with Derivative vs. Delta Time in Hours

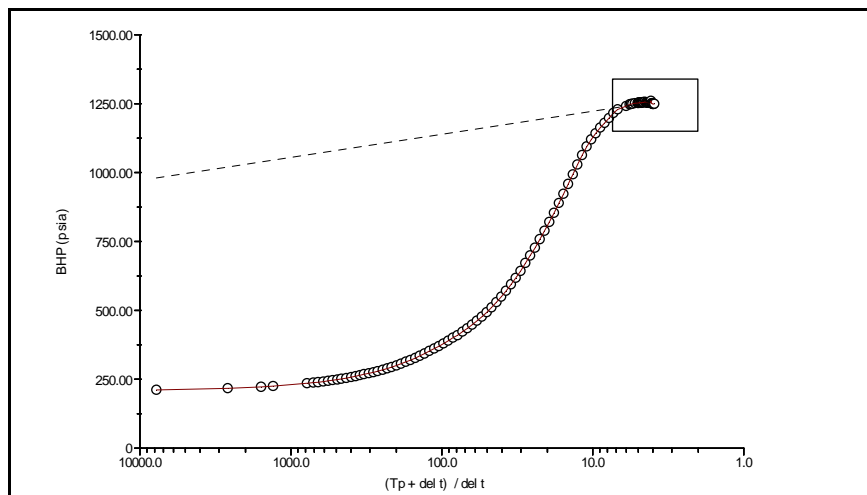


Figure 5d - Horner plot shows skin of 8.9 and $P^* = 1306$ psi

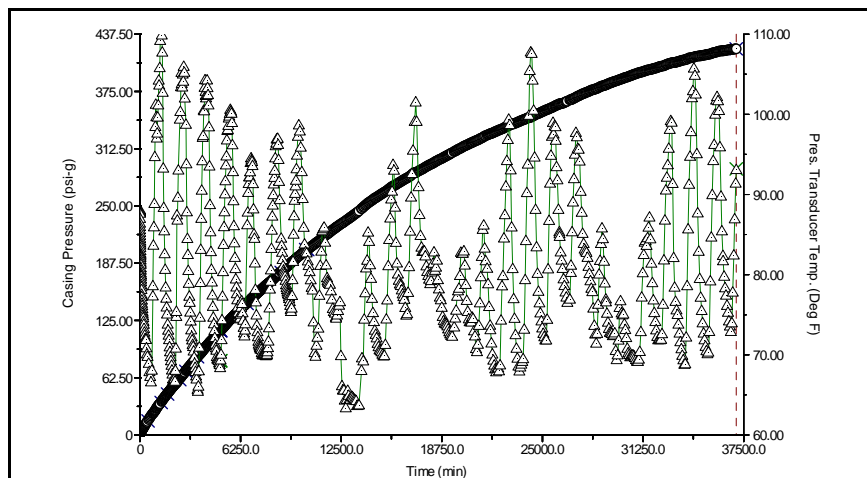


Figure 6a – Variation of Casing Pressure and Transducer Temperature (triangles) During 25 Days and 17 Hours Buildup Test

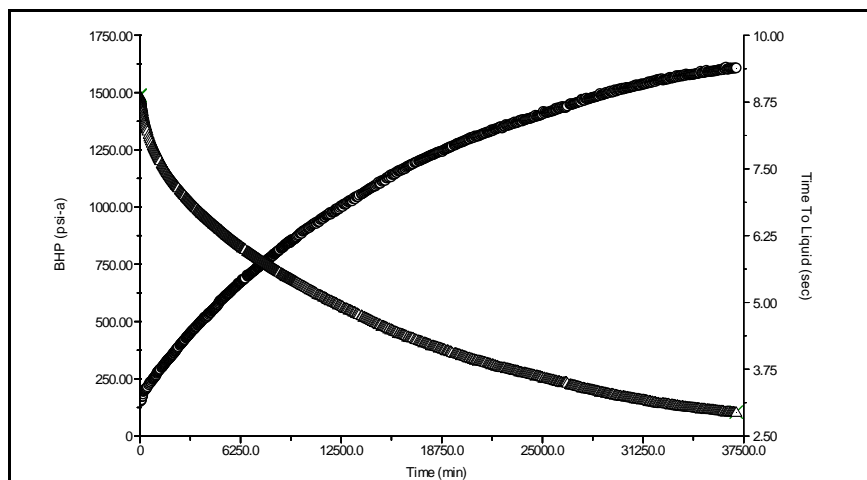


Figure 6b – Computed BHP (circles) Increases as RTT to Liquid Decreases When Liquid Rises

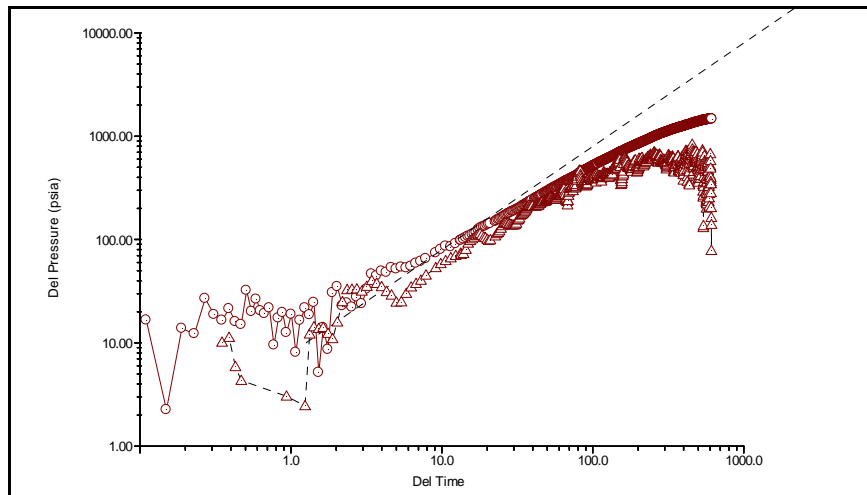


Figure 6c - Well Bore Storage is Just Beginning To Be Overcome and Radial Flow Period Start but Test was Terminated Prematurely

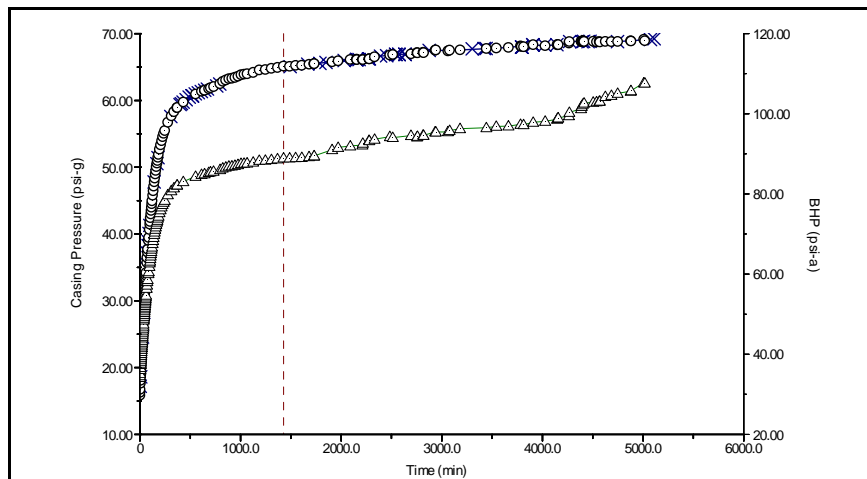


Figure 7a - Casing Pressure (circles) and BHP (triangles) During 3 Days and 13 Hours

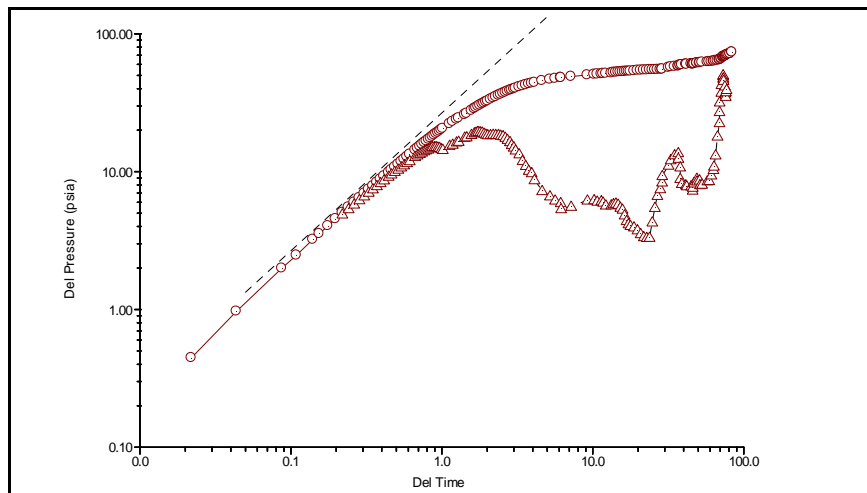


Figure 7b – Log-Log Plot Shows Boundary Effect After Radial Flow Period

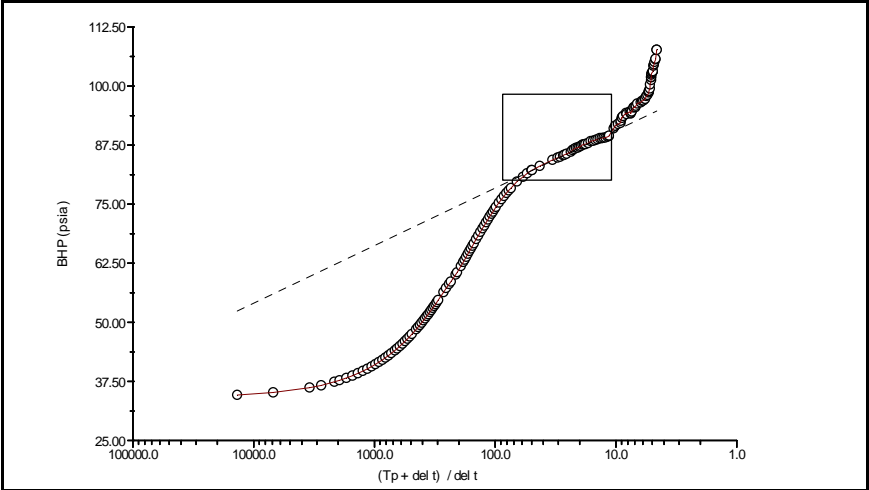


Figure 7c - Horner plot: skin= 1.7 and $P^* = 102$ psia

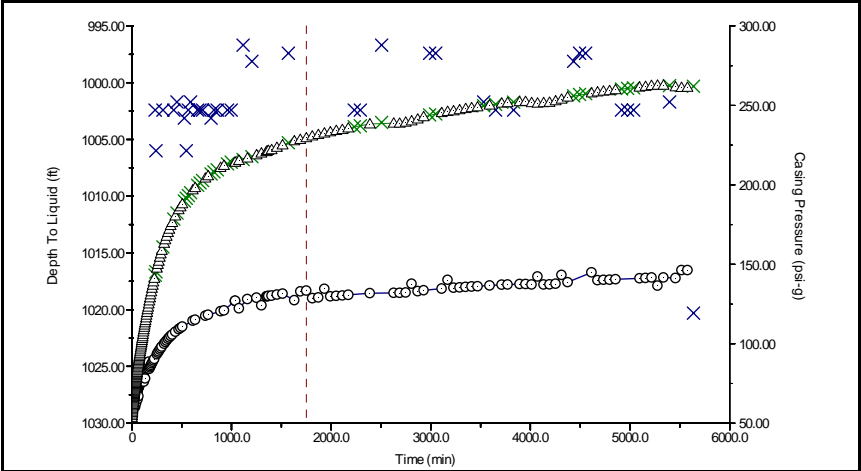


Figure 8a – Casing Pressure (triangles) and Liquid Level Depth (circles) During 3Days- 21 Hours Buildup Test

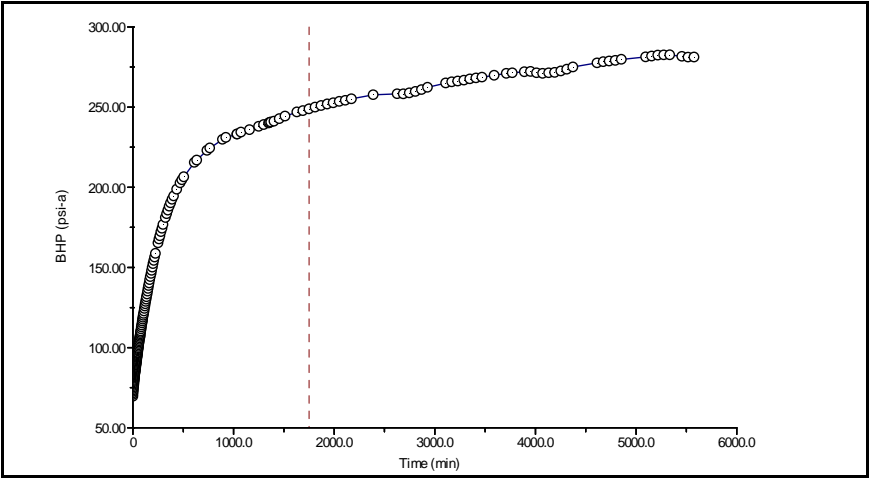


Figure 8b - BHP vs. Time

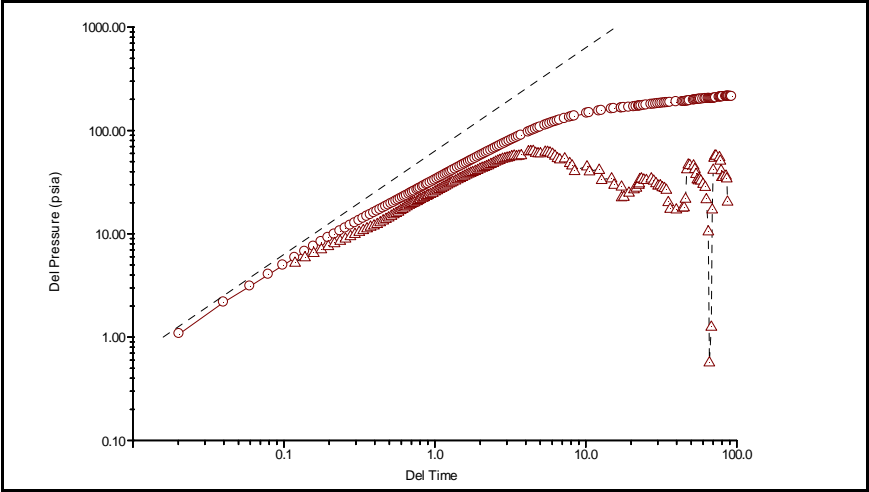


Figure 8c - Log-Log Plot Showing End of Storage Effects

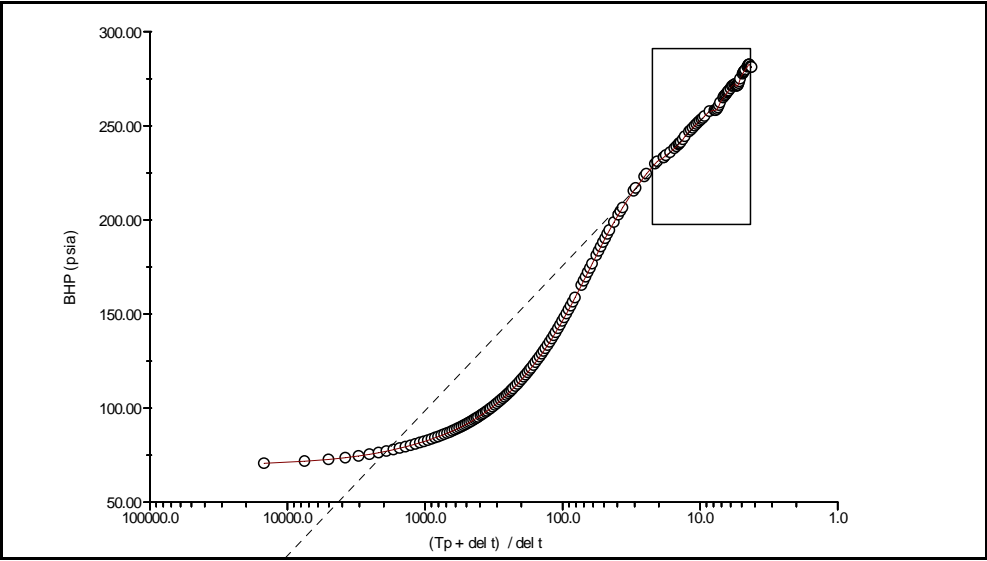


Figure 8 d - Horner Plot Estimates a Skin = -0.5 and $P^* = 330$ psia

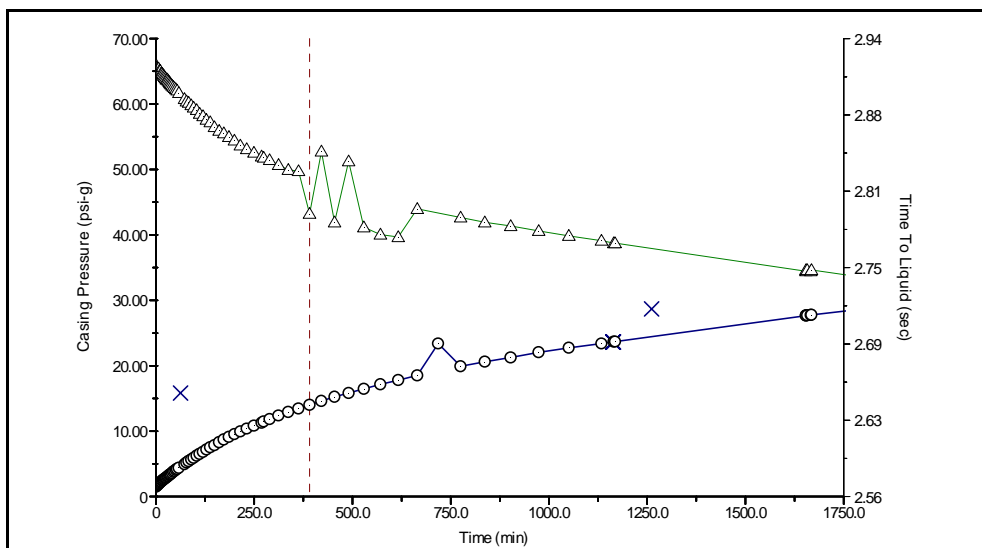


Figure 8e - LL Selection Correction Example

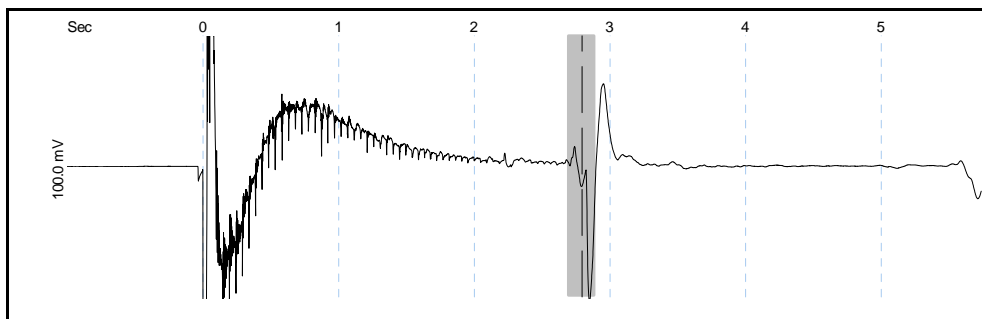


Figure 8f – Acoustic Record for the Data Point Flagged in Figure 8e

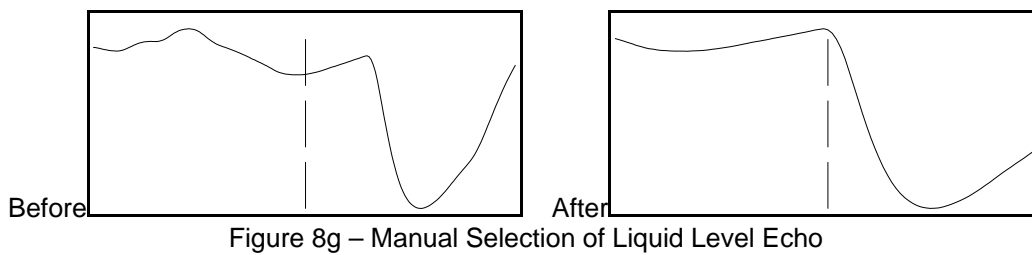


Figure 8g – Manual Selection of Liquid Level Echo

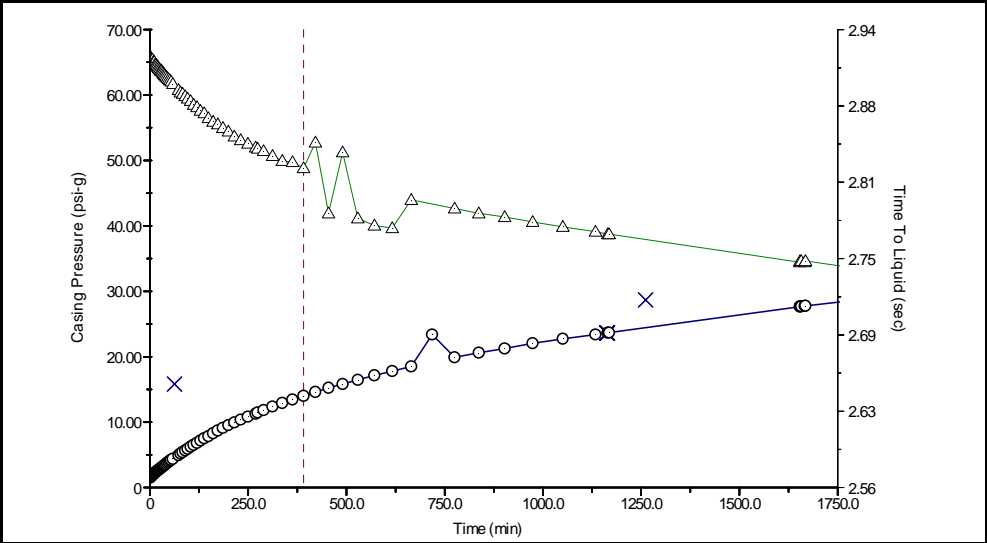


Figure 8h – Corrected RTTT Now Falls within the Expected Trend

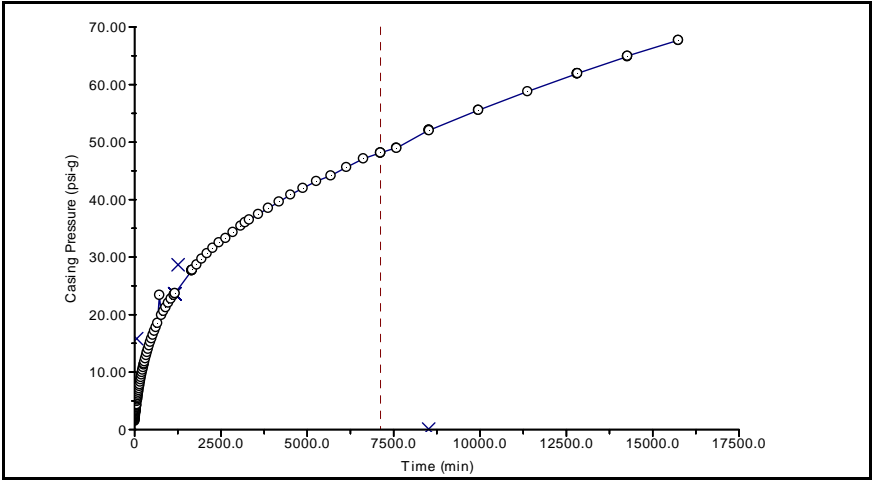


Figure 9a - Casing Pressure vs. Time

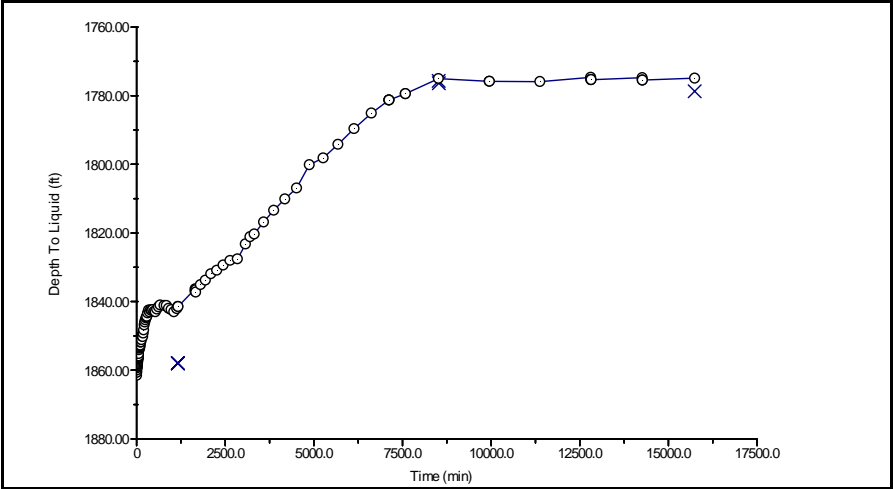


Figure 9b - Liquid Level Depth vs. Time

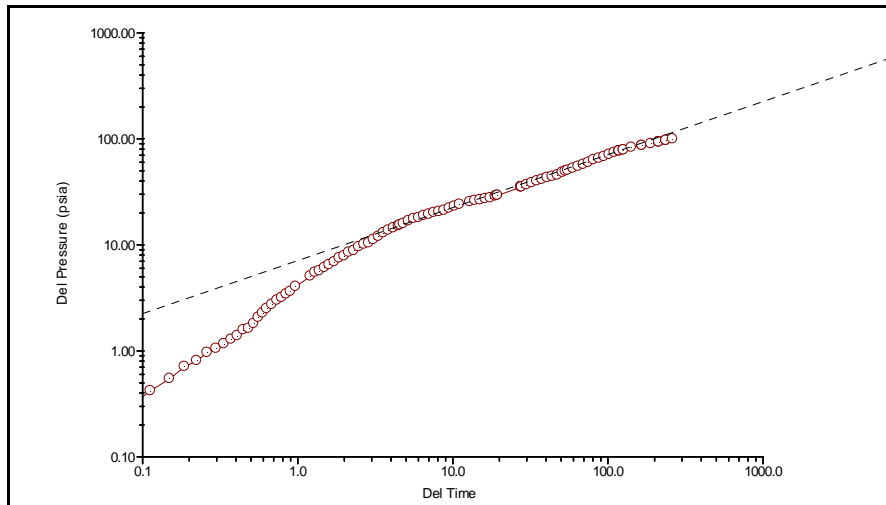


Figure 9c – Bottom Hole Pressure Trend Follows $\frac{1}{2}$ Slope in Log-Log Plot

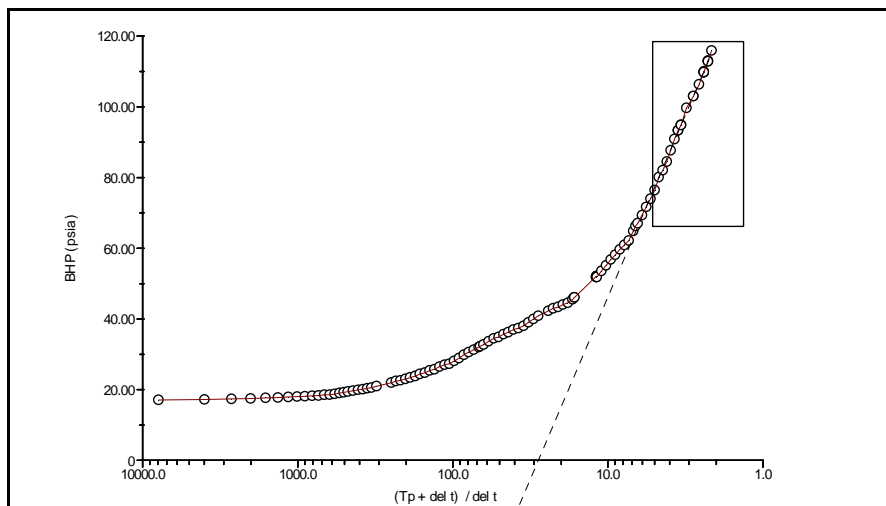


Figure 9d - Horner Plot: Skin = - 5.94 and $P^* = 149.1$ psia

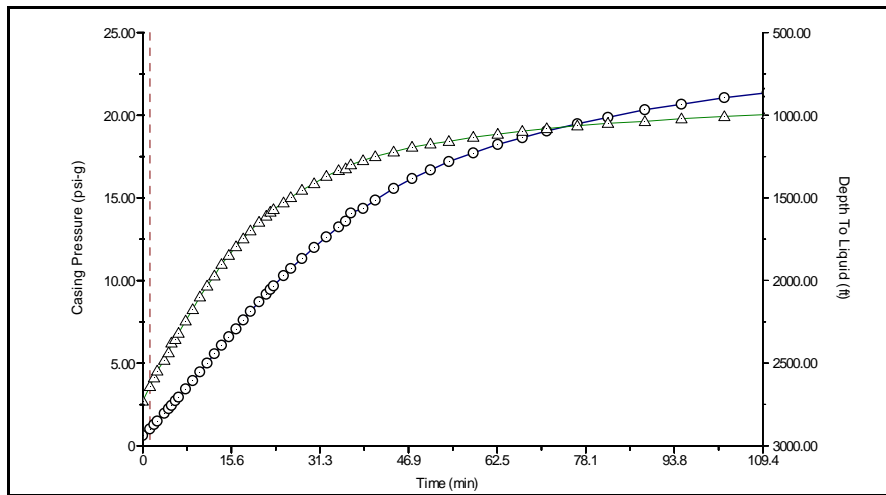


Figure 10a - Casing Pressure (circles) and Liquid Level (triangles) vs. Time

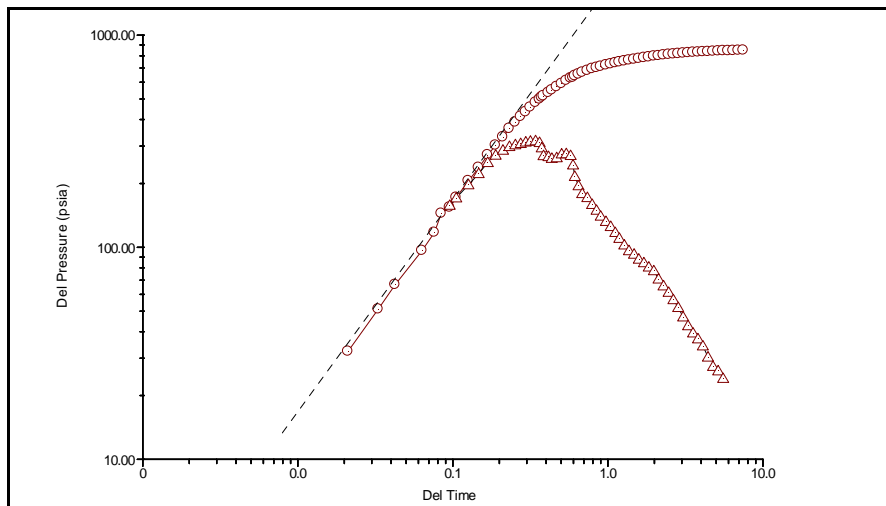


Figure 10b - Log-Log Plot with Unit Slope and Decreasing Derivative

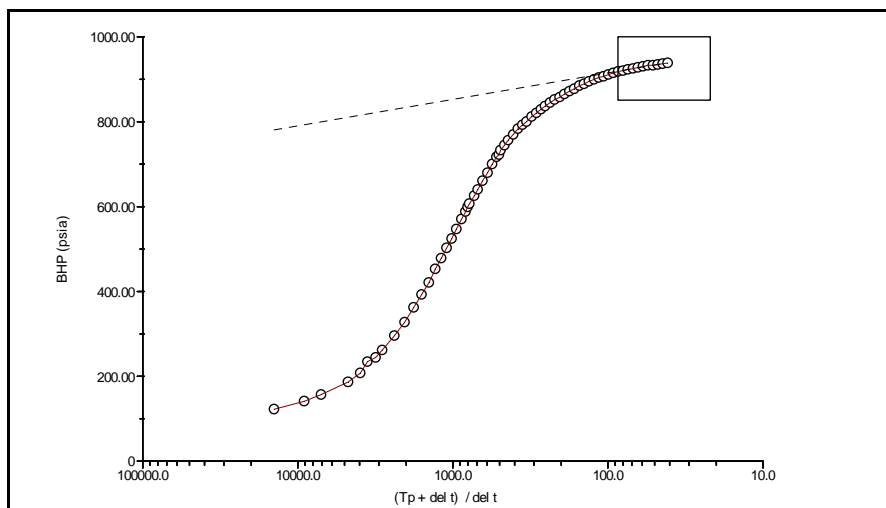


Figure 10c - Horner Plot $P^*=1040$ psia $S= 8.44$

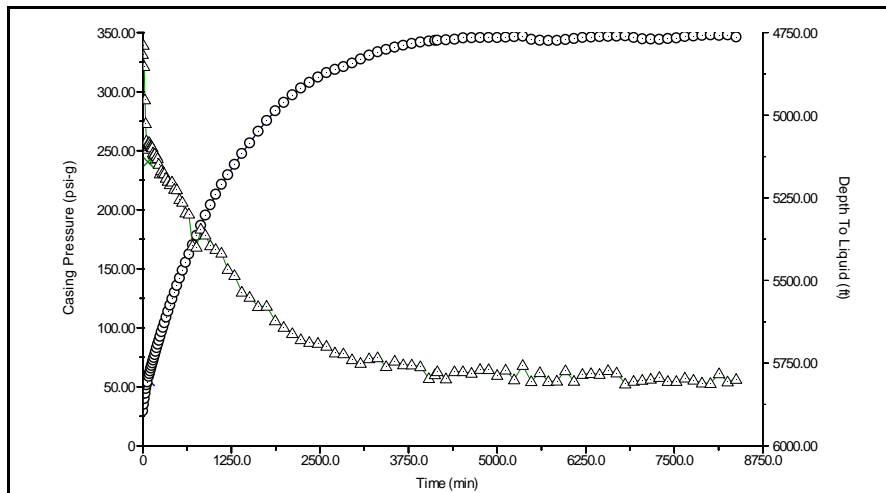


Figure 11a - Liquid Level (triangles) Drops as Casing Pressure Increases

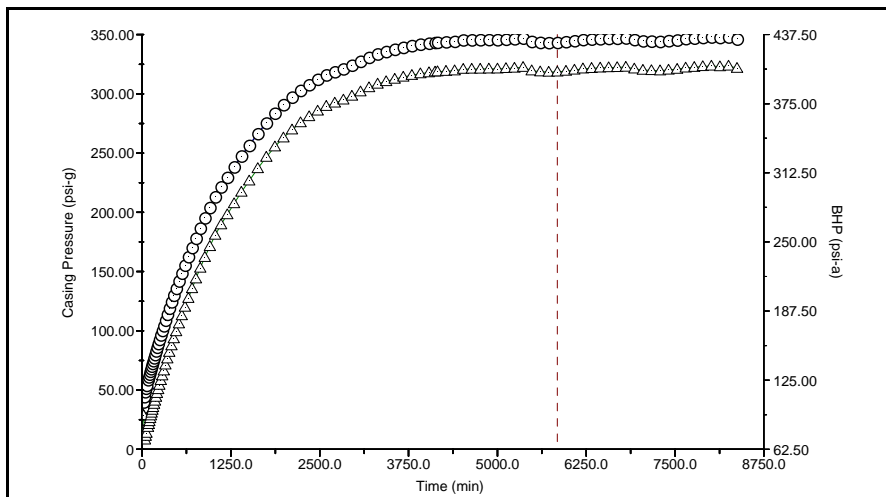


Figure 11b – Casing Pressure (circles) and BHP (triangles) vs. Time

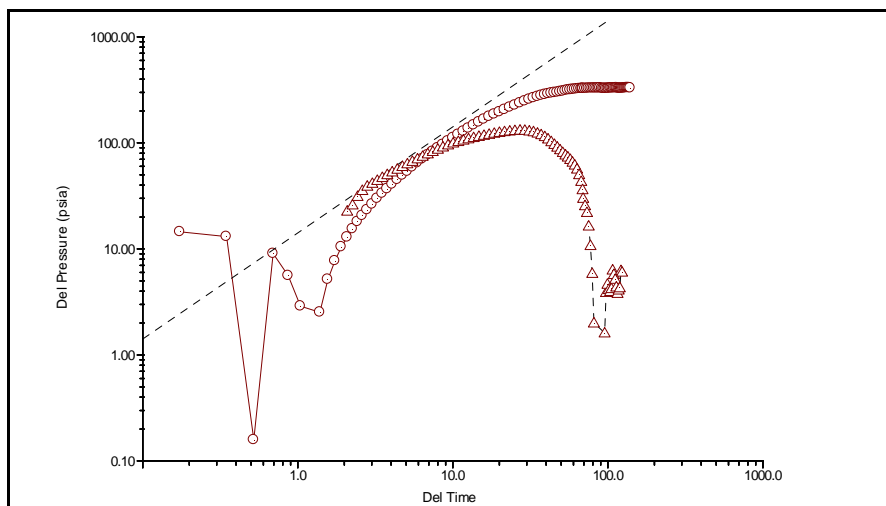


Figure 11 c - Log -Log Plot Shows Beginning of Radial Flow Period

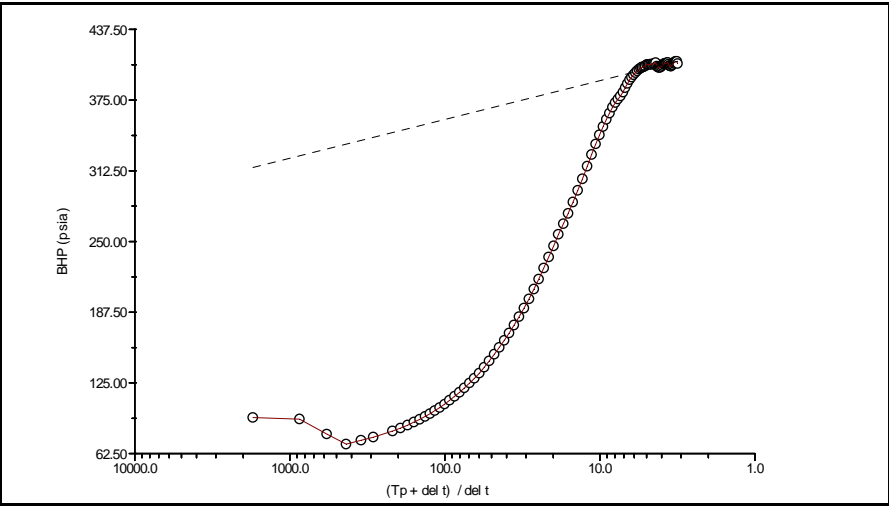


Figure 11d – Horner Plot Seems to Indicate Significant Skin

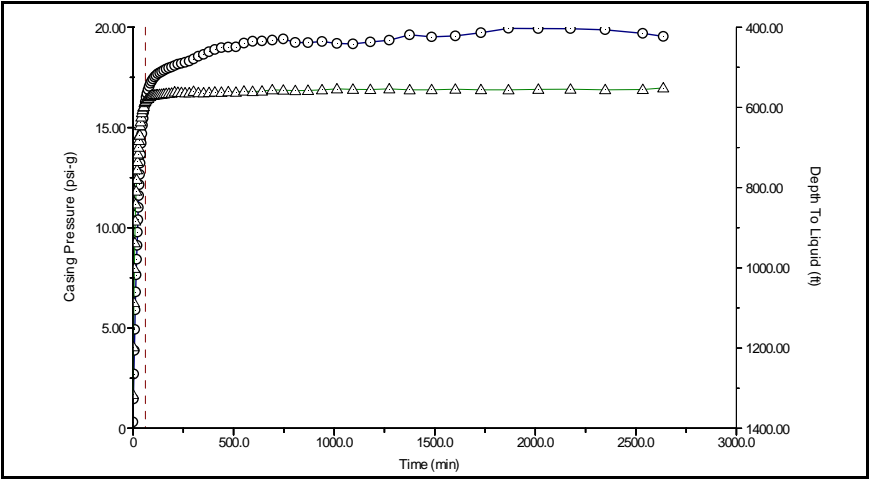


Figure 12a - Liquid Level (triangles) Rises 700 Feet in 1 Hour

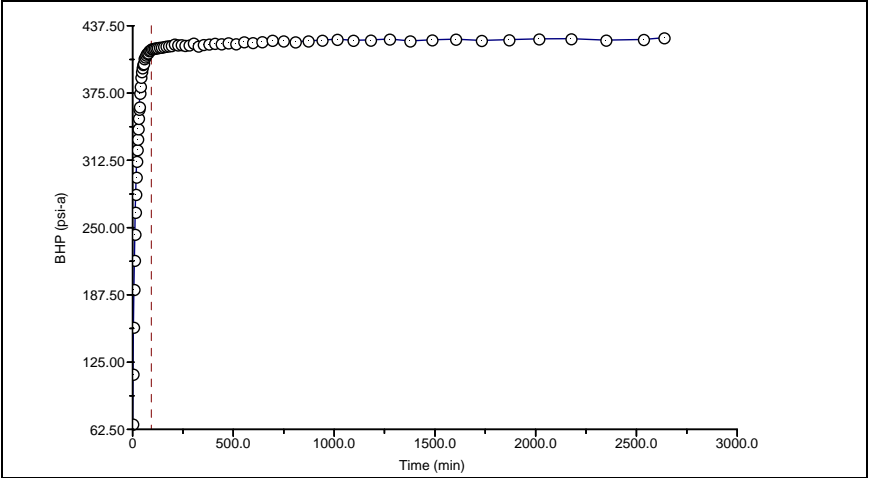


Figure 12b – Bottom Hole Pressure vs. Time

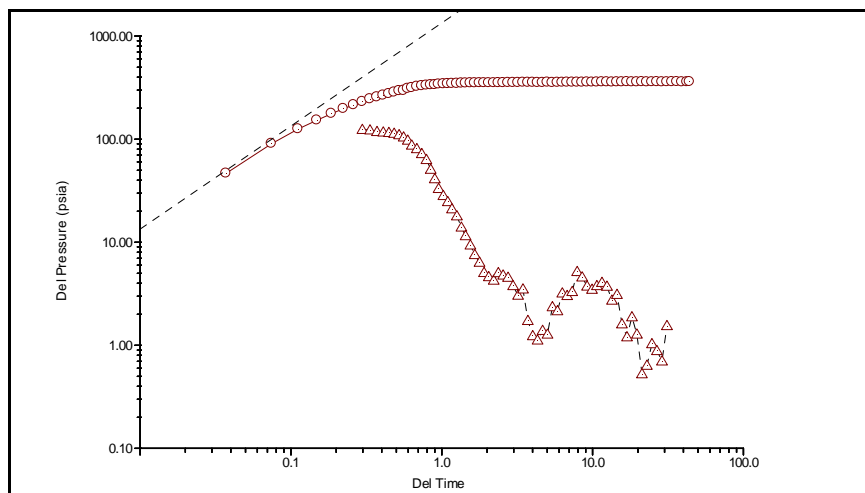


Figure 12c - Log-Log Shows Very Short Well Bore Storage Effect

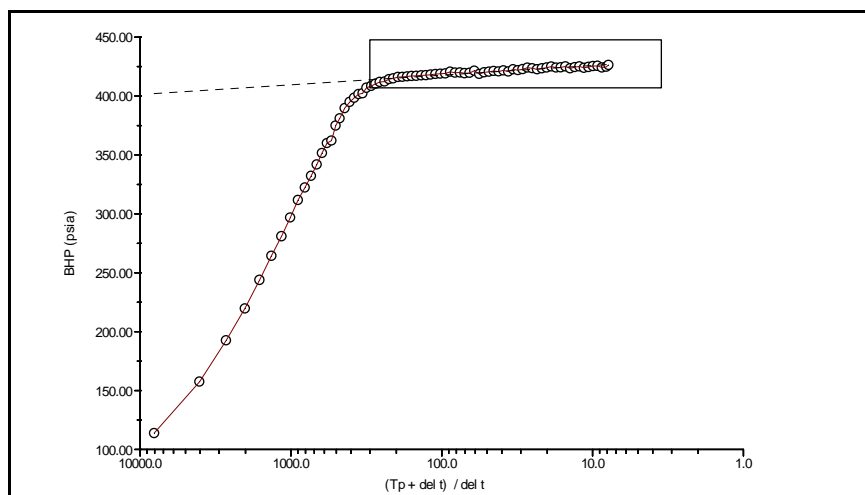


Figure 12d- Horner plot: $P^*=434$ psia $S=41$