Integrated Well Performance Analysis

A.L.Podio
University of Texas at Austin
J.N. McCoy
and Dieter Becker
Echometer Co.

Abstract

Computer acquisition, processing and analysis of acoustic, dynamometer and related data at the wellsite, offer new capabilities in analyzing a well's performance.

A powerful lap-top computer is used in conjunction with a compact analog to digital converter to acquire data from acoustic microphones, pressure transducers, load cells, accelerometers, motor current sensors, tachometers and other transducers to better analyze a pumping well's performance.

The acquired data is processed to obtain bottomhole pressures, gradients of gaseous annular liquid columns, casing annulus gas flow rates, surface dynamometer cards, downhole pump cards, permissible load diagrams, Horner plots, MDH plots and other diagnostic analyses so that the operator can better visualize the performance of the pumping system, the wellbore and the formation characteristics. All of the acquired data and diagnostic plots mentioned can be acquired and analyzed at the wellsite, using the one compact computerized system.

Introduction

Well performance addresses the complete well system including: the reservoir, the wellbore and the pumping components as shown in Figure 1. Visualization of well performance is defined as: the ability to understand how these elements interact to yield the present conditions of flow rates, loads, pressure,efficiency, etc.

This ability allows the production engineer to evaluate the effect of changes in the operating parameters such as speed, stroke, surface pressure, on/off time, etc. and/or changes in the well configuration such as pump depth, rod sizes, surface unit geometry, well stimulation, etc. on the overall performance of the well.

Acoustic Well Soundings

Acoustic echo-ranging techniques to generate well soundings have been in effect for over fifty years to aid in the analysis of pumping wells[1]. Early application was limited to determining the presence of liquid in the annulus above the pump. If liquid was found over the pump then the operator assumed that additional production was available if a larger pump was installed; or, if the pump were not operating properly, that the pump should be pulled and repaired. Engineering analysis and interpretation of the records yields additional information. In particular bottom-hole pressure is calculated from the summation of the surface casing pressure plus the gas column hydrostatic and the liquid column hydrostatic pressures.

This presumes knowledge of the density and distribution of the oil and water and gas in the annular column especially in the case of wells where relatively high fluid columns are observed.

Computer-based Acoustic Measurements

Digital signal processing, utilized so extensively by the geophysical industry, and the availability of small lap-top computers have resulted in significant advances and improvements in acoustic well sounding. Three important achievements are possible by utilization of a portable microcomputer. First, the computer can process the acoustic data digitally to obtain more accurate liquid level depths, automatically. Second, the determination of bottom-hole pressures from the acoustic liquid level measurement, the surface pressure, and properties of the produced fluids is automatically available. Third, the computer offers automatic operation of the equipment in that the computer can be programmed to perform well soundings and obtain casing pressure measurements on command, without operator attention.

The Well Analyzer's computer and A/D converter can be used in conjunction with any modern manually or remotely operated acoustic gas gun and microphone. The gas gun generates an acoustic pulse in the wellbore and the microphone converts the reflected acoustic pressure pulses to electrical signals. These signals are digitized by the analog to digital (A/D) converter at a rate of 1KHz and stored in the computer. The computer displays these signals and processes the data as instructed by software to automatically determine liquid level depth.

To calculate the producing bottom hole pressure the casing pressure is measured at the time of liquid level determination. When liquid is present above the formation and gas is flowing upward in the casing annulus, the casing vent valve is closed and sequential measurements of casing pressure are made for approximately 10-15 minutes so that an accurate casing pressure buildup rate can be obtained. The program uses this rate and the annulus void volume to calculate the casing annulus gas flow rate. This allows determination of the gaseous liquid column gradient from empirical correlations.

Detailed Acoustic Analysis of a Typical Well

When the acoustic liquid level is determined, the display, shown in Figure 2, is observed by the operator after an acoustic pulse has been generated at the surface of the well and reflected signals are received by the microphone. The dashed vertical line at the liquid level kick indicates the exact time which the software selected as the onset of the liquid level signal. The liquid level kick is at 7.575 seconds.

Automatic selection of the liquid level reflection is undertaken by a pattern recognition scheme that involves the amplitude, polarity, width and phase shift of the received signals.

The lower right hand inset shows the detail of the liquid level signal selected by the software. The two vertical lines shown in the main upper window at 3.9 and 4.9 seconds delimit data which are shown as raw signal on the lower left hand insert. The raw signal is processed to accent collar reflections and then is displayed immediately above the raw signal. The software determines an estimate of the total number of collars from the surface to the liquid level using the frequency of this processed signal as an average value of collar count per unit time. In general, software selection of the liquid level will correspond to the correct determination. However, if a tubing anchor, upper perforations, a paraffin ring or other obstructions exist in the annulus, the program may select one of these signals as the liquid level.

If the display of the processed signal showing tubing joints is not satisfactory to the operator, he has the option to request displays and/or printouts of the raw signal and processed signals including a band-pass filtered signal to accent the deep collars and a high-pass filtered signal to accent all of the tubing collars in the well. These displays allow the operator to perform a detailed study of variations in cross sectional area of the annulus, showing anomalies such as different tubing joints lengths, salt rings, paraffin deposits, submersible pump cable splices, casing holes, casing leaks, tubing leaks, multiple tubing strings, gas lift valves, upper perforations, changes in tubing and casing diameters, and any other condition which affects the area of the annulus.

Well Performance Analysis

Acceptance of the computer's interpretation of the acoustic data, results in the detailed well analysis screen display shown in Figure 3.

The objective of this display is to provide complete visualization of the wellbore conditions at the time of the measurement. The figure is divided in two sections: on the right is a schematic diagram of the wellbore and reservoir configuration, on the left are several blocks containing quantitative information about the well and its past performance.

The central block is used to present the results of well performance analysis based on a Vogel-type IPR relationship. This includes the current producing rate efficiency and the maximum potential production achievable by reducing bottom-hole pressure to a minimum value.

The well schematic includes important parameters such as tubing depth, perforation depth and other characteristics. The currently measured casing pressure, casing pressure buildup rate and the calculated casing annulus gas flow rate are printed opposite the gas portion of the well. Just below are printed the depth to the gas-liquid interface and the percentage of liquid present in the gaseous liquid column. At the bottom of the well are printed the calculated producing bottom-hole pressure (PBHP) and the most current value of static reservoir pressure (SBHP).

Every fifteen seconds during the time since the fluid level shot was fired, the computer automatically acquires the casing-head pressure to determine the annular gas flow rate.For this well an increase in pressure of 0.2 psi in 2.5 minutes corresponds to an annular gas flow rate of 7.3 MCF/D. From this, the gas fraction in the fluid column is then calculated using a correlation determined from numerous field measurements [2]

In this example, the 3259-ft fluid column above datum consists of a mixture of oil and gas with about 87% liquid. This column's hydrostatic, plus the annular gas hydrostatic and the casing-head pressure result in a producing bottom-hole pressure of 1082 psia.Considering that the stabilized formation pressure is 3000 psia, and using Vogel's IPR relation, the program determined that this well is being produced at 84% of the maximum producible rate.

This raises the question whether it is possible to increase the production rate in this well that exhibits a relatively high fluid column above the pump.The answer to this question can be obtained only by analyzing the performance of the pumping system and determining whether it is functioning at a reasonable level of efficiency.This analysis can be easily undertaken by switching the Analyzer's software to the Dynamometer analysis mode.

Dynamometer measurements

The Well Analyzer provides means to acquire data from load and position transducers in order to undertake conventional and/or advanced dynamometer analysis.

Polished Rod Load and Motion Measurement

The data accuracy needed for quantitative dynamometer analysis requires the use of calibrated transducers based on some form of strain gage measurement. The movement of the polished rod can be monitored in a number of ways.Traditionally its position is measured by means of a rotary displacement transducer connected to the carrier bar via a string and which yields a voltage output proportional to position[3,4].

The Well Analyzer on the other hand takes advantage of its high speed computing capability and senses the acceleration of the polished rod. This is done by a very compact integrated-circuit accelerometer that is built into the load cell, thus requiring a single connecting cable between the load/acceleration sensor and the computer.

Integration of the acceleration signal yields the polished rod velocity which when integrated again yields the position of the polished rod as a function of time.The constants of integration are determined from the boundary conditions that define the minimum, maximum and average position of the polished rod for a complete pump cycle.

Data Acquisition and Data presentation

Due to the speed of the lap-top computer, the dynamometer data is displayed in real time much like an oscilloscope. Figure 4 shows an example of load and acceleration data and the corresponding computed velocity and position as a function of time. The operator can select special portions of the data series for display in more detail so as to study special characteristics of the signal for one specific cycle. When the operator is satisfied with the dynamometer wave forms, he branches to the dynamometer visualization display which is shown in Figure 5. The principal objective of this display is to give immediate indication as to whether the pumping system is operating properly or not. The upper window shows the dynamometer card that corresponds to the data in Figure 4. The lower part of the display presents diagnostic graphs that include the polished rod load and the motor current as a function of time for a selected cycle on the left hand side. Observation of the electrical current gives indication of the unit balancing: uneven current peaks are an indication that the unit is either over or under balanced.In this particular example the indication is that more current is required during the upstroke than during the downstroke which is an indication that the rods are under balanced.

On the bottom, right hand side are plotted the surface dynamometer corresponding to the selected stroke and the computed down-hole pump dynagraph. This is obtained by digital solution of the wave equation using the exact rod string geometry described in the well data file and the load and acceleration data recorded by the computer.

In this particular example it can be observed that the pump dynagraph indicates that pump fillage is essentially 100% with minimal rod stretch. Overall this is an indication the the pump is operating at capacity. Before concluding that it may be possible to increase the production from this well it is necessary to determine that the pump valves are operating with minimum or no leakage. The program directs the user to undertake the appropriate valve checks by measuring the rod loads as a function of time with the unit alternately stopped during the upstroke and during the downstroke.

The conclusion is thus that in this well the relatively high fluid level is an indication that the current pumping rate is less than the flow capacity of the formation. Production could probably be increased either by modifying the pumping parameters (speed and stroke) or by increasing the pumping time if the well has been running on a time clock. Proper analysis may require using a pumping design program and for this reason the well Analyzer allows the operator to save the data and well parameters to a diskette in various standard formats for export to other PC-based pumping design and analysis programs [5,6,7].

Transient pressure analysis

The previous analysis presumes that we have some knowledge of the stabilized reservoir pressure and of the possibility of existence of formation damage.

Flowing bottom hole pressure surveys, pressure buildup tests, pressure drawdown tests are the principal tools available to determine reservoir pressure, formation permeability and skin factor. 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 installation of surface indicating bottomhole pressure gages have not become cost effective, nor have wireline measurements through the annular space.

Automatic Acoustic Pressure Transient Data Acquisition

The Automatic Acoustic Pressure Transient system, based on the Digital Well Analyzer[8] configured for long term unattended operation, provides a practical method for transient analysis of pumping wells.

This is implemented by providing a long term source of power and gas to the Well Analyzer as shown in Figure 1, and switching to software specially developed for pressure transient data recording and analysis. The computer program EBUP has the multiple functions of controlling the well testing sequence, acquiring, storing and analyzing the data and generating tabular and graphical outputs[9].

Since the bottomhole pressure calculation is based on wellhead pressure measurement, determination of the gas/liquid interface 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 duration, the transducer sensing element may undergo temperature variations of over 60 degrees F. Even though the transducer is temperature compensated this temperature change causes considerable errors in the measurement of casinghead pressure. Additional corrections are introduced by measuring the temperature with a thermistor and computing the corresponding pressure deviation from calibration curves obtained for each individual transducer and entered in the program.

Acoustic Velocity Variation

During the well test (buildup or drawdown) the pressure temperature and composition of the gas in the annulus will undergo significant changes. These in turn will cause variations in the acoustic velocity of the gas.[10,11] At any given time the average acoustic velocity is obtained from an automatic count of filtered collar reflections and the average joint length. 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[2,10,11,12]. The BHP is the sum of the casinghead 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. Pumping conditions and well geometry determine the fluid distributions. For example in 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 afterflow period. 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.[13]

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 gradients[13] is used to account for this effect. However when a long gaseous liquid column is present, in order 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 casinghead back pressure while maintaining a steady pumping rate. This is easily achieved by means of an adjustable back pressure regulator installed on the casinghead valve.

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:

* Casinghead pressure vs. time
* Bottomhole pressure vs. time
* Liquid level vs. time
* Transducer temperature vs. time
* Acoustic time (seconds) vs time
* Acoustic Frequency (Jts/sec) vs time

* MDH -- BHP vs Log(time)
* Horner
* Log-Log analysis
* Liquid Afterflow vs time
* Gas afterflow 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.

Sample transient well test

This test well was being produced with a casinghead pressure of 20 psig with gas being vented from the annulus. Initial conditions indicated that the well was essentially in a pumped-off condition with the annular fluid level near the pump intake.

Figure 6, is a complete listing of the well data. Figure 7 shows the casing pressure increase as a function of time for the 166 hour duration of the buildup test. The rate of pressure increase decreases with time and the overall change in casing pressure corresponds to 107 psi. Figure 8 shows the corresponding variation of the liquid level which rises fairly uniformly from a depth of 4674 ft to a depth of 4589 feet. This depth is calculated based on the measured travel time to the liquid level and the acoustic velocity in the annular gas. The liquid level and the casing pressure data are combined in calculating the bottomhole pressure variation during the buildup, which is presented in Figure 9.

The program permits exporting this bottomhole pressure data as a function of time to a disk file which can then be fed to commercially available transient analysis programs. It also provides means for analysis of the data so as to insure that the test will yield the information necessary to analyze the well's performance. Figure 10 shows the program's MDH analysis which is obtained by selecting (using operator controlled markers) the portion of the data in the rectangular window and fitting a least square line to the data.

Similarly Figure 11 shows the corresponding Horner plot which yields an extrapolated reservoir pressure pf 278 psia and a skin of -2.96.

Conclusions

A portable, compact and complete system has been developed for acquisition of acoustic well soundings, polished rod dynamometer data and transient well test data and for integration of this information in a series of coordinated graphic displays on a portable microcomputer. These displays allow the operator to visualize the current conditions and present performance of the well and to immediately identify existing or potential problems.

References

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13- Huddleston, K. L., et al.: "Application of Portable Microcomputers to Field Interpretation of Acoustic Well Surveys," SPE Computer Technology Symposium, Lubbock Texas, March 1985.

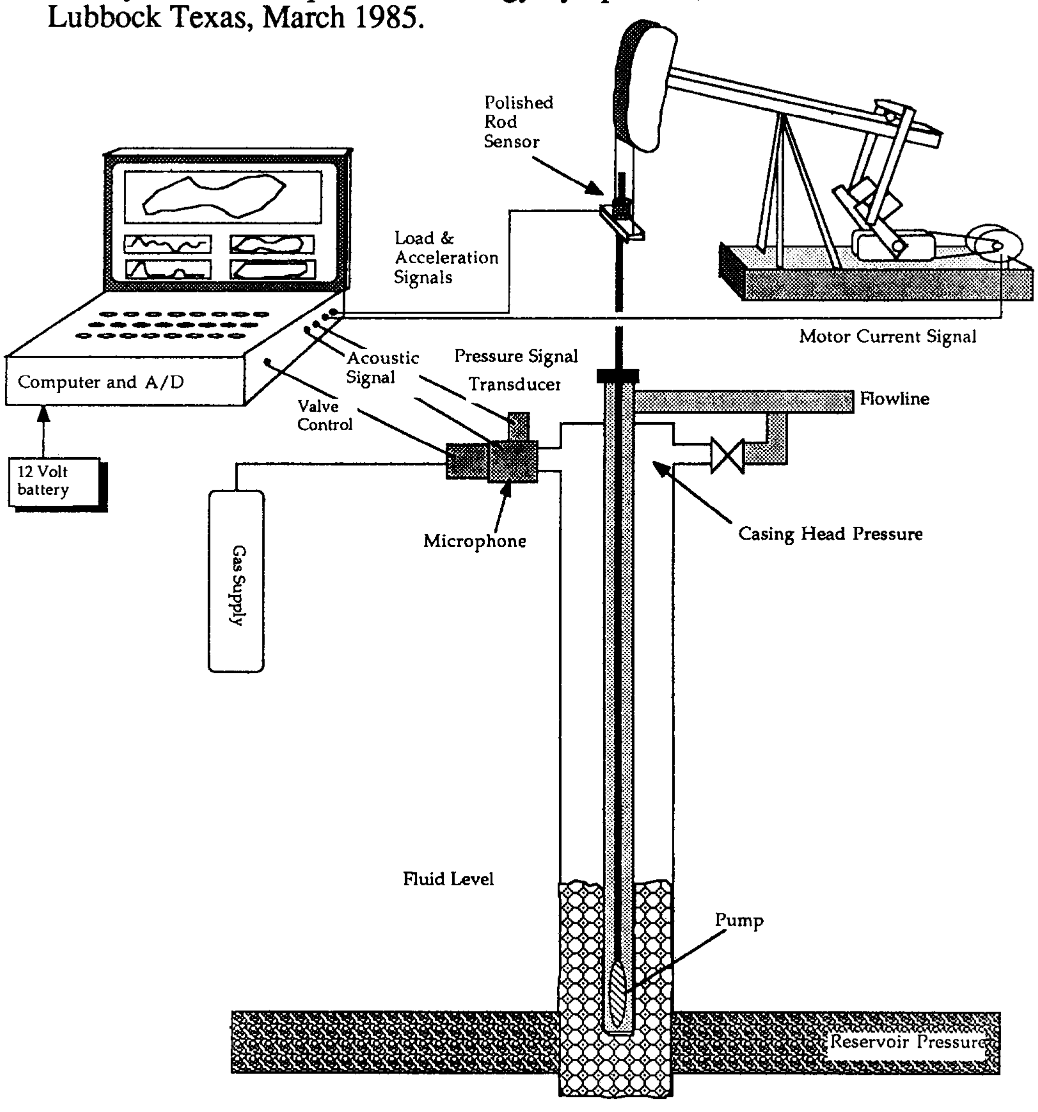


Figure 1 - Well performance analysis addresses the complete well system including the reservoir, wellbore, and pumping components

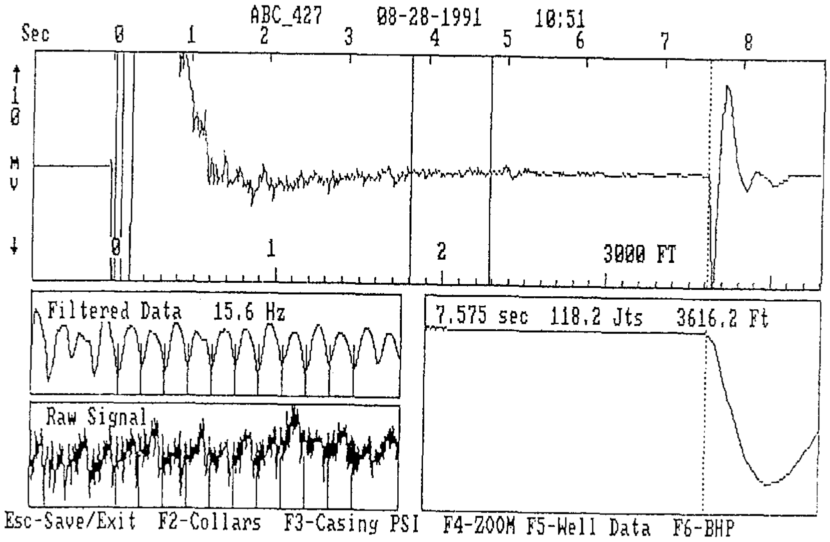


Figure 2 - The acoustic liquid level is determined after an acoustic pulse has been generated at the surface of the well and reflected signals are received by the microphone

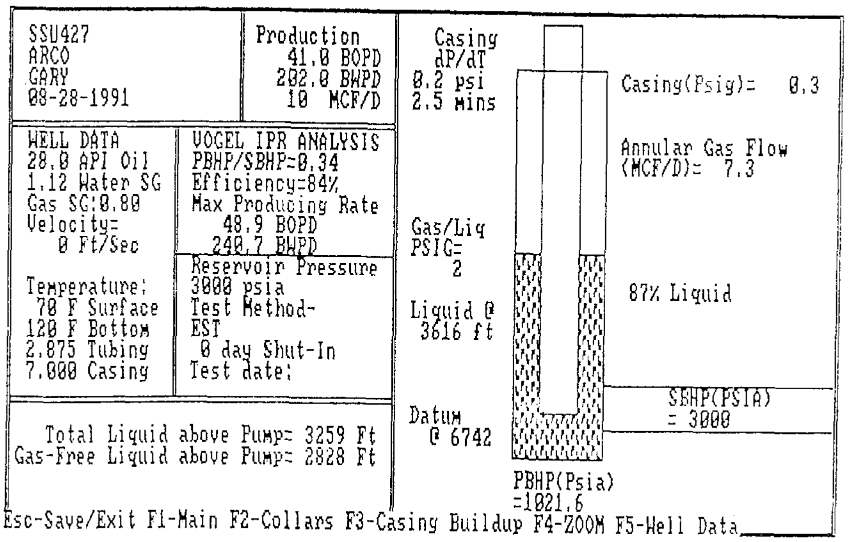
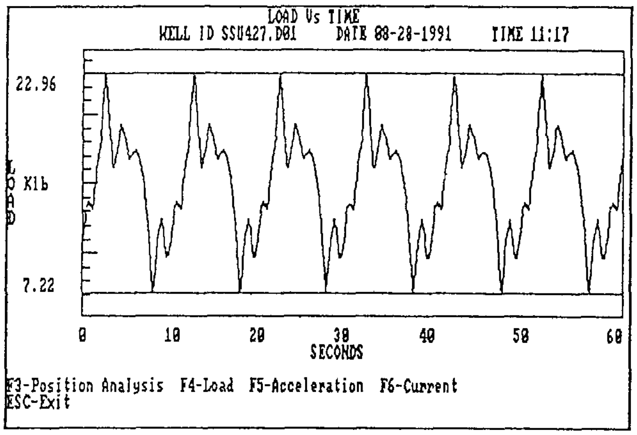
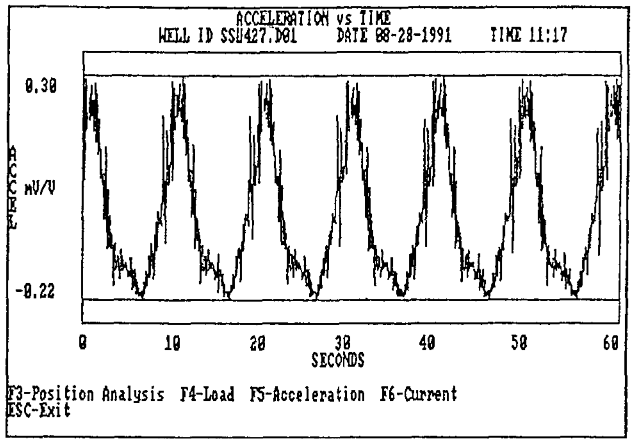
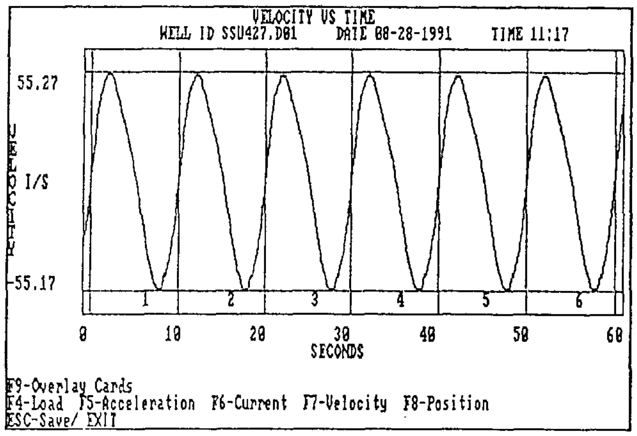


Figure 3 - A detailed well analysis display provides complete visualization of wellbore conditions at the time of measurement







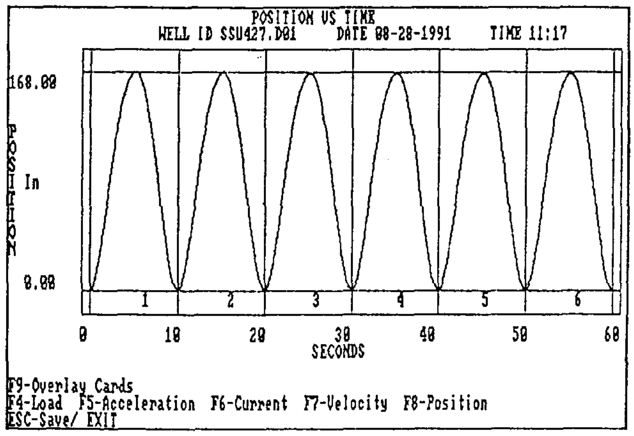


Figure 4

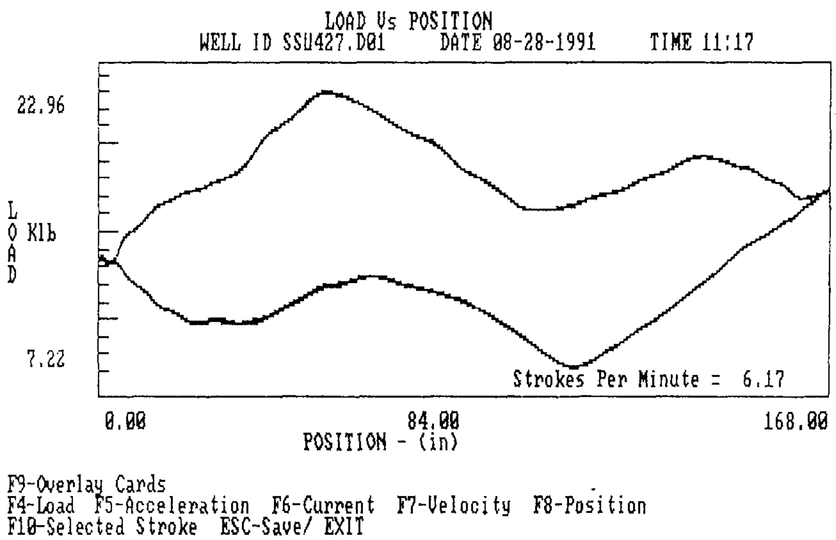


Figure 5 - Dynamometer visualization display

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Well Name: BIT76     Company: UT                Operator:

Formation Depth: 4730  [Ft]  Pump Depth: 4730  [Ft]

Average Joint Length: 31    [Ft]   BOPD: 10     BWPD: 1       MCF/D: 2

Surface Temperature: 76  [F]       Bottomhole Temperature: 166 [F]

Bo: 1.2  [Vol/Vol]   uo: 2    [cp]     Oil Gravity: 44    [API]
Bw: 1    [Vol/Vol]   uw: 0.7  [cp]   Water Gravity: 1     [SG]
Bg: 2.33 [RB/MCF]    ug: .011 [cp]     Gas Gravity: 0.75 [SG]

Net Pay(H): 15  [Ft]  Porosity: 0.28 [Fraction]  Horner Time(tp): 300   [Hrs]

Total Compressibility(ct): 376      [1E-6]   Drainage Area:  20  [Acres]
      Wellbore Radius[Ft]: 0.5
Casing, ID: 7      [Inches]   Tubing, OD: 2.5    [Inches]

  -Flag for Gaseous Liquid Correction [0-ON / 1-OFF]
  -Flag for Pressure Falloff Test  [1-ON / 0-OFF]

                    Hit Esc to Continue with the Test
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Figure 6 - Listing of well data

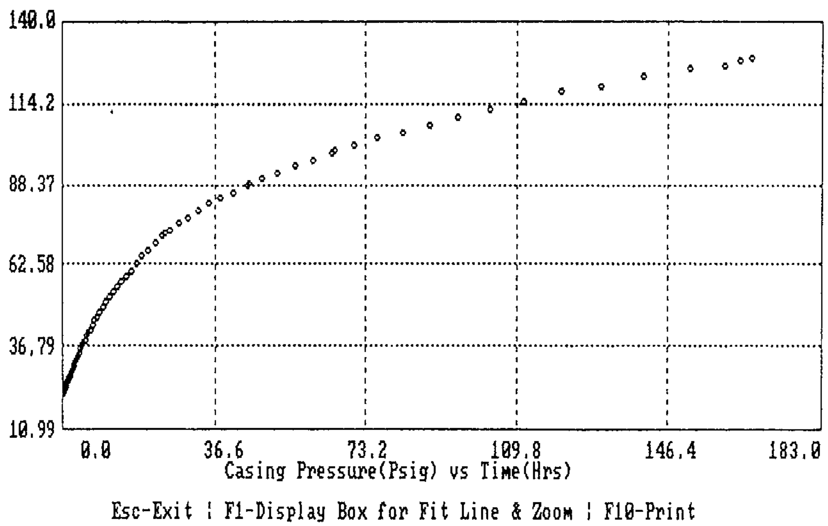

Figure 7 - Casing pressure vs. time plot

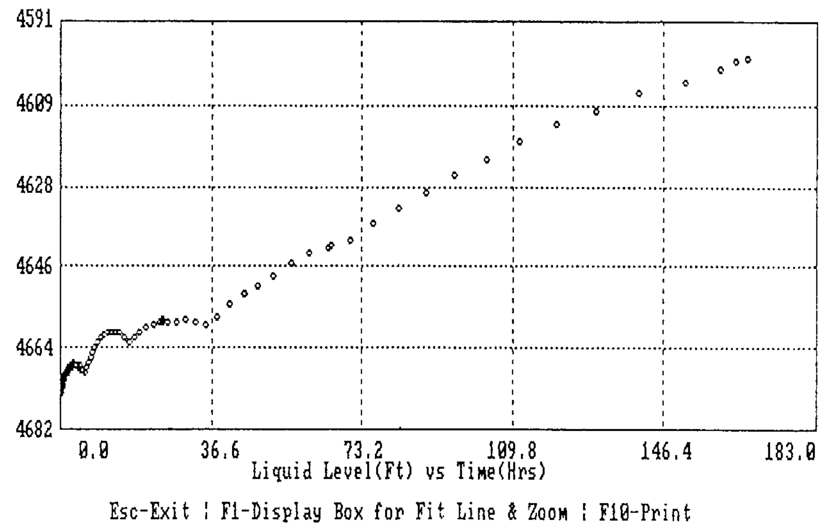

Figure 8 - Liquid level (ft) vs. time (hrs)

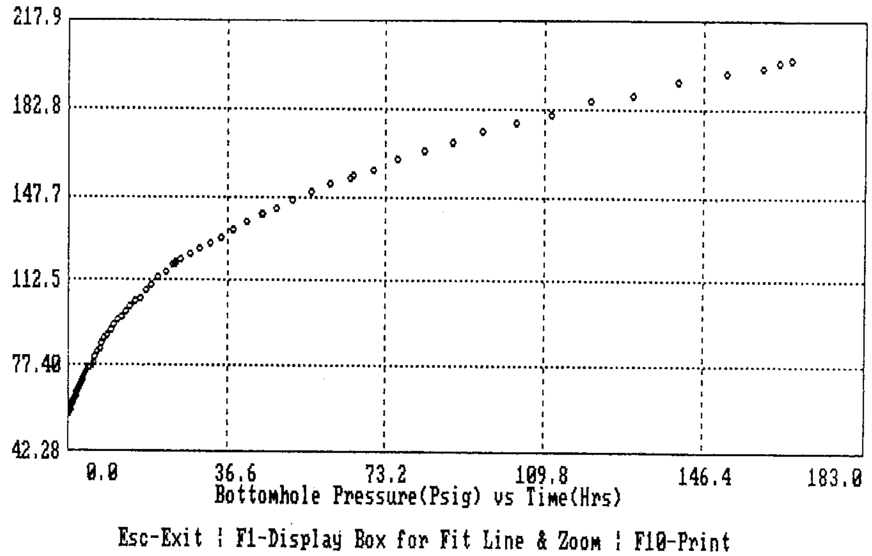

Figure 9 - Bottomhole pressure (PSIG) vs. time (hrs)

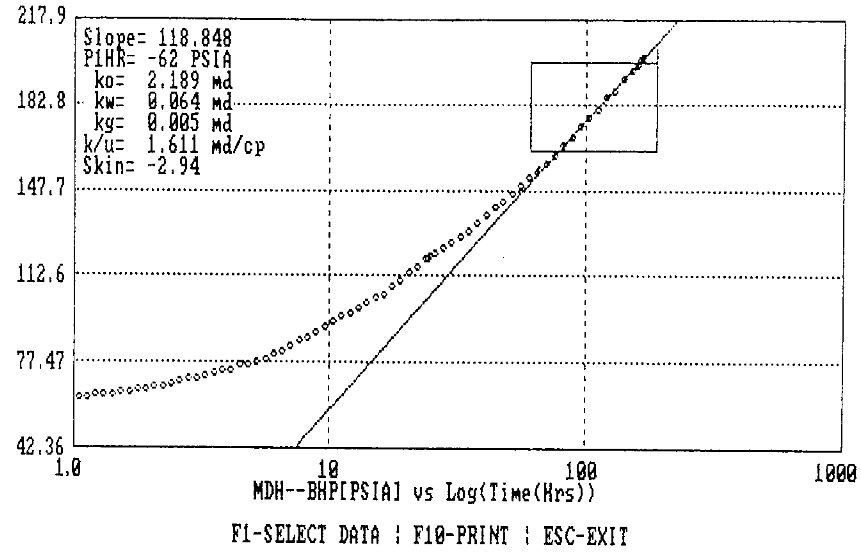

Figure 10 - MDH plot

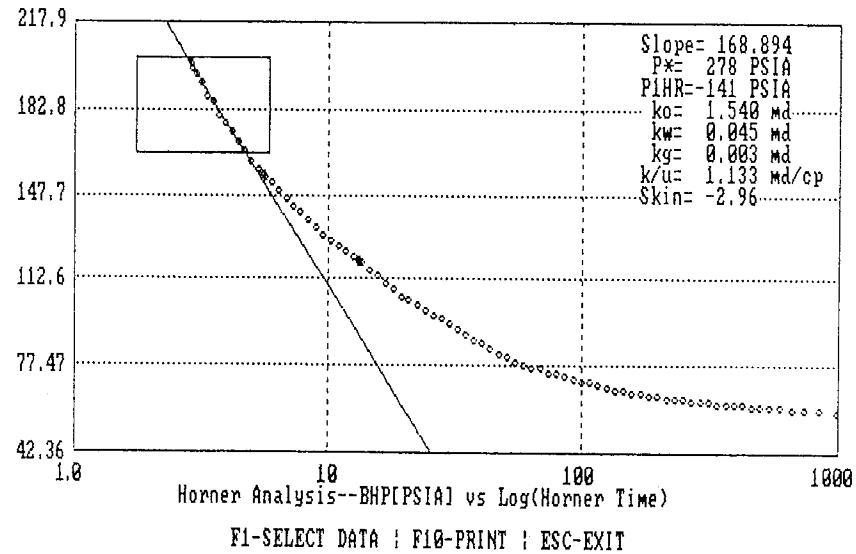

Figure 11 - Horner Plot