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COMPUTER PROGRAM TO ANALYZE MULTIPASS PRESSURE-TEMPERATURE-SPINNER SURVEYS

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ABSTRACT

A computer program has been developed to analyze multipass pressure-temperature-spinner surveys and summarize the data in graphical form on two plots: (1) an overlay of spinner passes along with a fluid velocity profile calculated from the spinner and (2) an overlay of pressure, pressure gradient, and temperature profiles from each pass. The program has been written using SmartWare II Software. Fluid velocity is calculated for each data point using a cross-plot of tool speed and spinner counts to account for changing flow conditions in the wellbore. The program has been used successfully to analyze spinner surveys run in geothermal wells with two-phase flashing flow.

INTRODUCTION

Flowing pressure-temperature-spinner (PTS) surveys are run in geothermal production wells to identify production zones. The spinner is a wireline tool with a small propeller that spins when fluid flows past the tool. Revolutions of the propeller in a fixed period are counted and recorded at the surface. Commonly, one continuous pass over the length of the wellbore is made at a constant speed, and then stationary stops may be made at locations between inflow zones. Spinner counts are proportional to the velocity of fluid in the wellbore, provided fluid density is constant. If wellbore diameter is constant, then the difference of spinner counts above and below an inflow zone is proportional to the production rate from the zone. This method works in geothermal wells that produce a single phase liquid, provided the water does not flash to steam in the producing interval of the well. Other factors that can complicate spinner interpretation are: uneven borehole size, thief zones, surging flow, and flow reversals.

Flowing PTS surveys are run frequently in production wells in the Coso Geothermal Field to identify the best depth for injection of an inhibitor to prevent calcium carbonate scale. The pressure data from a PTS survey can be used to determine the depth at which geothermal fluids begin flashing to steam in the wellbore. In general, it is desirable to inject scale inhibitor below the flash depth, because calcium carbonate scale often forms when geothermal fluids flash to steam. However, in some wells the flash depth is at or below the deepest inflow. In other wells, thief zones may draw off fluids coming from deeper producing zones, or they may cause downflow of fluids from shallower producing zones. In such cases, inhibitor injected below the flash depth may not be carried up the wellbore where it is needed to prevent scale. The spinner data from a PTS survey is then critical to determine the velocity and the direction of fluid flow so that the inhibitor tube can be installed at the optimal depth.

All the complicating factors for spinner interpretation listed in the above discussion have been seen in one or more production wells in the Coso Geothermal Field. The frequency of PTS surveys and the interpretation difficulties prompted development of a computer program to analyze the surveys and produce a graphical output that summarizes all of the data on two graphs. The automated interpretation has also been useful for diagnosing mechanical problems in production and injection wells.

MULTIPASS PTS SURVEYS

Multipass PTS surveys are usually run in wells at Coso because the single-pass survey described in the introduction is inadequate to resolve complicated flow situations. Four passes of the PTS tool are made through the completion interval of the well at different cable speeds. (The completion interval is the slotted portion of the production liner.) Usually one down-pass at 200 feet per minute (fpm) is made from the surface to the bottom of the well. Then an up-pass is made, at 200 fpm, from the bottom to the top of the production interval. Two more passes over the production interval are made at 100 fpm, down and up. The four spinner passes allow tool response to be calibrated for each location in the wellbore so that fluid velocity can be calculated as fluid density changes above the flash depth. Multiple passes of pressure, temperature, and spinner are also useful for identifying tool glitches, surging, and transient effects.

The spinner response is calibrated by a crossplot of spinner counts versus cable speed, with up passes having a negative cable speed. (Figure 1, See reference 2 for a derivation of the crossplot method.) Ideally the points plot in a straight line, and the spinner response is the slope of the line that goes through the points. If the tool moves at the same speed as the fluid, spinner counts will be zero, so fluid velocity is equal to the cable speed where the

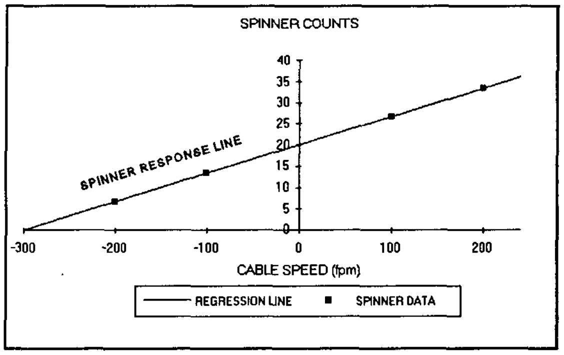

Figure 1. Crossplot of Spinner Counts and Cable Speed.

spinner response line intercepts the cable speed axis. In wells with single phase flow, there are usually several intervals of constant fluid velocity, separated by production zones and borehole diameter changes. Several crossplots, one for each interval, can be constructed by hand. However, flashing flow in a geothermal well causes velocity to increase continuously as it flows up the wellbore, and intervals of constant velocity do not exist above the flash point. The best way to view spinner data from a geothermal production well with a deep flash depth is as a continuous velocity profile. This requires many crossplots to determine spinner response as the two-phase fluid density changes. The crossplot process can be automated by a computer program and summarized graphically along with the pressure and temperature profiles.

The data in Figure 1 would be produced by an ideal frictionless spinner in an ideal nonviscous fluid. Real spinners deviate from the straight line of Figure 1 in several subtle ways. There is a threshold fluid velocity below which the spinner counts are zero. Two-phase flow will cause a nonlinear response at low spinner count rates due to liquid hold-up. (Liquid hold-up refers to the difference between liquid velocity and gas velocity in two-phase flow.) Because of viscosity effects, the actual fluid velocity is slightly offset from the intercept of the spinner response line and the cable speed axis. When the fluid velocity reverses direction relative to the tool, the spinner response curve will have a slightly different slope. For the analysis of spinner surveys from geothermal production wells, the nonlinear effects can usually be ignored because velocities are high and instabilities in two-phase flow cause variations that are much larger than the nonlinearities of the tool response. The exception would be for spinner measurements that are below the flash depth and below all major entries, where flow is single phase and fluid velocity is low.

AUTOMATED ANALYSIS METHOD

The PTS survey analysis program reads the PTS survey data into a spreadsheet, analyzes the data, and prints out two plots that summarize the raw data and the results of the analysis. Operator input is required at several steps in the process to adjust for variations in the data, to make analysis decisions, and to produce the most useful output. The spinner analysis is programmed in SmartWare II Software because SmartWare provides a compiled programming language for rapid calculations and high quality graphical output controlled by the program.

The PTS survey data is read from floppy disks provided by the survey company. The data can be in ASCII text or spreadsheet format. The best analysis is produced if pressure, temperature, spinner counts, and cable speed (or time of measurement) are available at each depth for each pass. A static pressure and temperature survey can also be included for reference. However, the minimum data required for a spinner analysis are depth, spinner counts and an average cable speed for each pass. As the data is read, it is filtered to remove sections where the tool slowed down, reversed direction or sped up. A pressure gradient is calculated from depth and pressure differences over an interval above and below the data point. The differences between passes of the average cable speeds divided by the differences of the average spinner counts, over several intervals, are calculated and the median is used as a starting estimate for the spinner response slope calculation.

To process the data in the spreadsheet, the measurement points for all the passes are sorted by depth, and calculation of fluid velocity starts with the deepest data point. The fluid velocity for the deepest data point is calculated using the spinner response slope estimated during data input. Fluid velocity (*VA*) is equal to the spinner response slope (*BA*) times the spinner counts (*SP*) minus the cable speed (*CS*).

$$VA = BA * SP - CS \qquad (1)$$

Spinner response slope (*BA*) in this analysis is defined as Δcable speed/Δspinner counts. Then the next data point is analyzed. The spinner response slope can be calculated when there is data from more than one pass. A least squares linear regression of the data points (one data point from each pass) provides fluid velocity and spinner response slope using: sum of spinner counts (*SSP*), sum of cable speed times spinner counts (*SCSP*), sum of cable speeds (*SCS*), sum of spinner counts squared (*SSP2*), and number of data points summed (*N*).

$$VA = \frac{SSP * SCSP - SCS * SSP2}{N * SSP2 - SSP^2}$$
$$BA = \frac{SCS + N * VA}{SSP} \qquad (2)$$

Each data point in the crossplot is replaced when a new data point for that pass is read. The calculated slope is averaged with previous slopes to adjust the spinner response as the analysis proceeds up the wellbore.

The crossplot is also used to set the sign of the spinner counts and to check the validity of the data. Most spinner surveys do not record the direction of spin but this can be determined from the crossplot. Figure 2 shows the crossplot that results when there is no fluid movement. Spinner counts going up hole are the same as spinner counts going downhole at the same speed. To

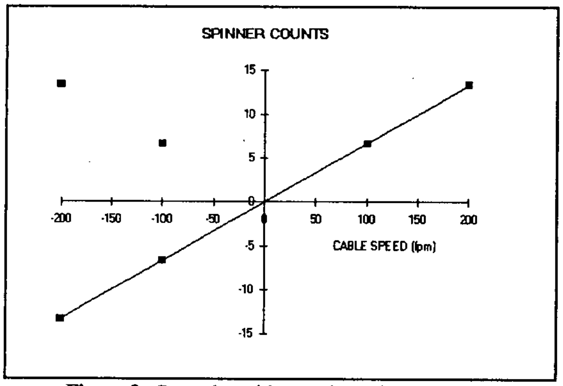

Figure 2. Crossplot with negative spinner counts.

form a straight line, the spinner counts must be negative for cable speeds of -100 and -200 fpm. When fluid velocities are low, spinner counts can be negative on up passes. When fluid movement is downward, as in an injection well, spinner counts can also be negative on down passes. When a data point is read, its sign is checked with a crossplot of the data points from the other three passes. The data point is given a positive or negative sign depending on which fits the crossplot best. If the fit is within data quality criteria, another crossplot is made using all four passes. The resulting fluid velocity is recorded, and the spinner response slope is averaged with the previous slope.

When all of the spinner data has been processed, a menu allows the operator to choose from several tasks that allow the results to be viewed, modified, or recalculated.

- A plot of pressure, pressure gradient, and temperature profiles can be viewed.
- A plot of spinner counts and fluid velocity profiles can be viewed.
- The pressure-temperature plot and spinner-fluid velocity plot can be printed in color or black and white.
- Wellbore data can be input to place a wellbore flow area profile on the spinner plot.
- A symbol can be placed at the depth of mud loss zones, steam entries, or altered zones.
- A footnote can be entered to print at the bottom of the plots.
- Adjustments to the spinner interpretation can be made.
- The fluid velocity can be recalculated using the adjustments.
- Sign of the spinner counts can be set manually.
- Spikes in the pressure and temperature data can be deleted.
- Plot scales can be modified.

The adjustments to the spinner interpretation allow the operator to compensate for many flow situations and poor data quality.

- The initial guess for the slope of the spinner response line can be changed.
- The number of slopes to average together can be increased to stabilize the slope of the spinner response line or decreased to allow more variation.
- The tolerance for slope data quality control can be tightened or loosened.
- A depth can be entered to exclude distant data from the crossplot.
- The tolerance for spinner counts data quality control can be tightened or loosened.
- Minimum counts can be set to eliminate small or zero spinner counts that are below the spin threshold.
- Maximum counts can be entered to eliminate spurious data.
- The spinner default sign, for data where a crossplot is not available, can be set to positive for production wells and negative for injection wells.
- The sign can also be set positive or negative for all spinner data, it can be set to use the previous sign for the same pass, or it can be left unchanged so that spinner signs set manually will not change.

EXAMPLE SURVEYS

This program has been used to analyze 137 PTS surveys from 58 different production and injection wells from late 1991 through the end of 1993. Most of the surveys provided useful information and many provided insight into the flow mechanics of geothermal wells. The program allowed extraction of necessary information from surveys with poor data quality. Some peculiar phenomena have been observed that might be blamed on tool malfunction, except that they occur in similar situations in more than one well. The following six example plots illustrate the most important flow patterns observed at Coso.

The PTS survey from Well 1 is typical of surveys run in Coso production wells (Figure 3). One major inflow at 3200 feet is represented by a step-increase in fluid velocity. This is in single-phase liquid as indicated by the pressure gradient of 330 psi/1000ft. Moving up the wellbore, the pressure gradient begins to decline, indicating that the flash depth is at 3050 feet. Fluid velocity decreases slightly just above the flash depth and then steadily increases while pressure, pressure gradient, and temperature decrease up to the top of the liner at 1200 feet. The increase in flow area above the liner top allows fluid velocity and pressure gradient to drop. Then the increasing velocity and decreasing pressure and temperature continue to the wellhead. The slow zone just above the flash depth has been seen on surveys in many wells, even when the flash occurs in blank pipe. Liquid hold-up in deviated wellbores is thought to be the cause of the slow zone. The spinner tool lies in the slower moving liquid on the low side of the wellbore while the small amount of steam flows along the high side of the wellbore at a higher velocity. Flash fraction and velocity increase farther up and greater turbulence causes the velocity to become uniform across the wellbore.

Well 2 has flashing fluid to the bottom of the wellbore (Figure 4). The pressure gradient is 210 psi/1000ft at the bottom of the well and is less than the liquid gradient of 330 psi/1000ft as seen in Well 1. There are three production zones represented by fluid velocity increases at ~3000 feet, ~2650 feet, and ~2150 feet. The static pressure profile shows that static liquid level is at 2800 feet so the reservoir is two-phase or vapor dominated at 2650 and 2150 feet. Production from the two-phase or vapor dominated portion of the reservoir is unlikely to cause scale in the wellbore. However, the entry at 3000 feet produces from a liquid zone, so there is a potential for scaling. The scale will tend to form in the formation, where the flash occurs. We can only hope that it is deep in the formation where it will not reduce productivity. If the productivity of the well declines and there is no scale in the wellbore, an acid job will be performed to remove the calcium carbonate scale from the formation. The overlay of the four spinner passes shows how the slope of the spinner response line can change. The spread of the spinner passes is 50 counts below 2500 feet, but above 2000 feet the spread is only 30 counts. The cable speeds were constant so the change in the spread of spinner counts indicates a change in the slope of the spinner response line.

The flash depth in Well 3 is below the major entries (Figure 5). Single-phase liquid up to 5600 feet is indicated by a pressure gradient of 330 psi/1000ft. Flashing flow is represented by the declining pressure gradient above 5600 feet. The fluid velocity profile indicates a small upflow from 6500 feet and major production zones at 4900 feet and 4100 feet. From the flash depth at 5600 feet up to 4900 feet, the spinner profiles are irregular but the peaks and valleys repeat on all four passes. The irregular spinner profile is typical of flashing flow, and the repeat of irregularities has been seen on many wells including Well 2, Well 4 and Well 6. This phenomenon may be due to washouts but, it occurs most often in the two-phase region, so it may be a characteristic of two-phase flow. Scale inhibitor can be injected below the flash depth in this well because there is some upflow, but the well must be watched to make sure that the inhibitor continues to be carried uphole.

There are two flash depths in Well 4 (Figure 6). The pressure gradient is ~320 psi/1000ft up to 4900 feet where it begins to drop off indicating flash. At 4650 feet a cooler inflow, represented by a step down on the temperature profile, raises the pressure gradient back up to 320 psi/1000ft. At 4400 feet it drops off again, indicating another flash depth. The fluid velocity calculated from the spinner survey indicates an inflow at 5500 feet. Then the velocity drops off at 5000 feet, probably due to flashing at that depth. There is a very small increase at 4650 feet where the temperature profile indicates an inflow, and then velocity increases above 4400 feet. The double flash zones have been seen on several surveys run in this well.

Production from Well 5 is disturbed by severe surging (Figure 7). The surges are most evident on the pressure gradient profiles as large spikes at periodic intervals. The overlay of pressure and temperature profiles shows variations that are due to the surging, and the four spinner passes do not line up parallel as they do in stable wells. The flash depth is at 4600 feet, as indicated by a decline in pressure gradient above that depth. The fluid velocity profile shows a small flow from near bottom and a significant inflow at 6050 feet. There is a slow zone at 4500 feet, probably due to the flash at that depth. Another production zone is indicated at 4400 feet where the fluid velocity increases again. Scale inhibition in this well was complicated by the surges, which diluted the inhibitor below the necessary dosage.

Well 6 had a downflow and thief zone when this survey was run (Figure 8). The downflow is represented by a negative fluid velocity from 3000 to 2600 feet. The flash depth is at 2900 feet, as indicated by a decline in pressure gradient above that depth. The fluid velocity indicates flow from near the bottom of the well that continues up to 3100 feet where it drops off to zero and then goes negative up to 2600 feet. The fluid velocity jumps up at 2600 feet and, except for a dip at 2400 feet, continues to increase up the wellbore. Scale inhibition in this well was not successful because inhibitor injected below the flash depth was lost to the thief zone. A workover was performed to plug the thief zone with cement and subsequent surveys did not show a downflow.

CONCLUSION

Multipass PTS surveys, analyzed with the aid of a computer program, have provided much useful information on wells in the Coso Geothermal Field. The results of PTS survey interpretations have been valuable in choosing depths at which to hang tubing for the inhibition of calcium carbonate scale. The surveys have some interesting characteristics that have not been investigated in depth but may be due to two-phase flow effects. Refinement of the PTS survey analysis methods, such as accounting for nonlinear effects, could improve the accuracy of the results. Other methods of investigating wellbore flow can clarify some ambiguities of PTS surveys. Dye tracer has been injected down the inhibitor injection tubes at Coso to measure the quantity and timing of returns to the surface. It is planned to summarize the results of the dye tracer testing in a subsequent paper.

ACKNOWLEDGEMENTS

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1. Dresser Atlas, *Interpretive Methods for Production Well Logs*, Third Edition, 1982.

2. Peebler, Bob, *Multipass Interpretation of the Full Bore Spinner*, Schlumberger Well Services, 1982.

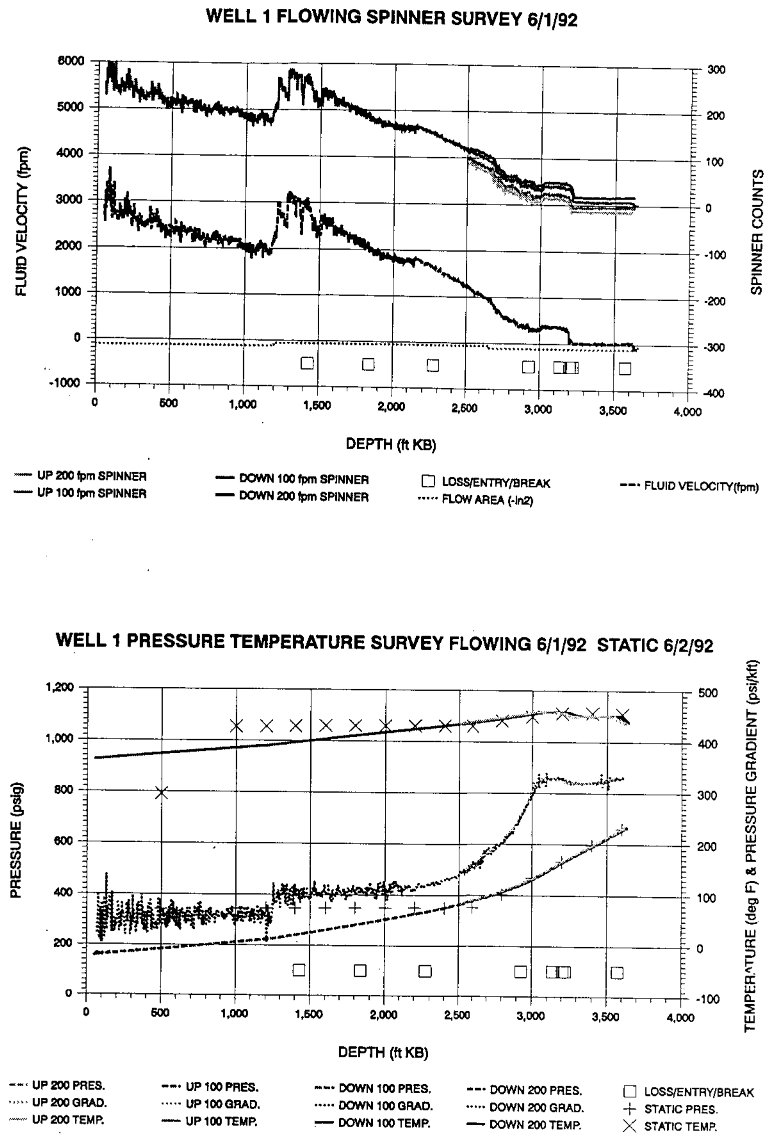


Figure 3. Pressure-Temperature-Spinner Survey from Well 1.

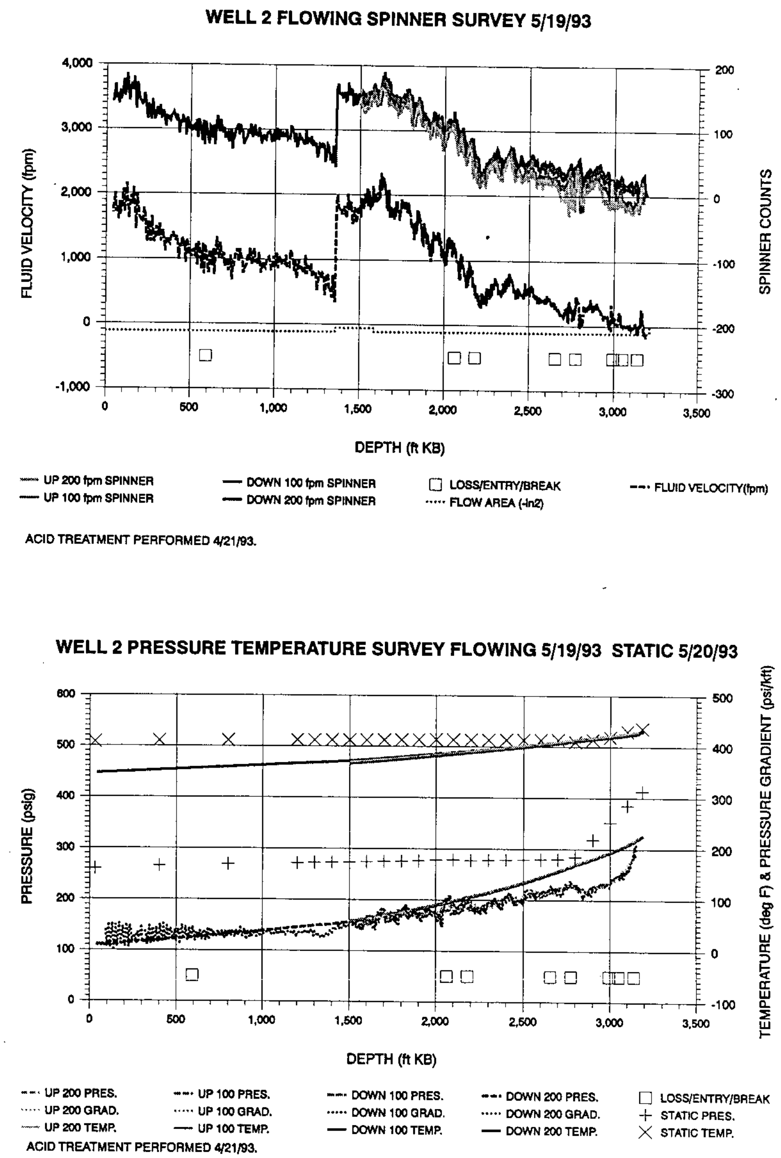
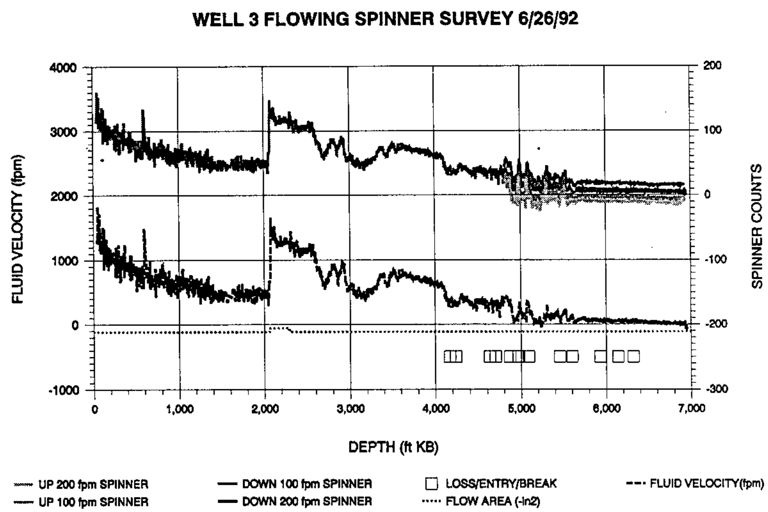
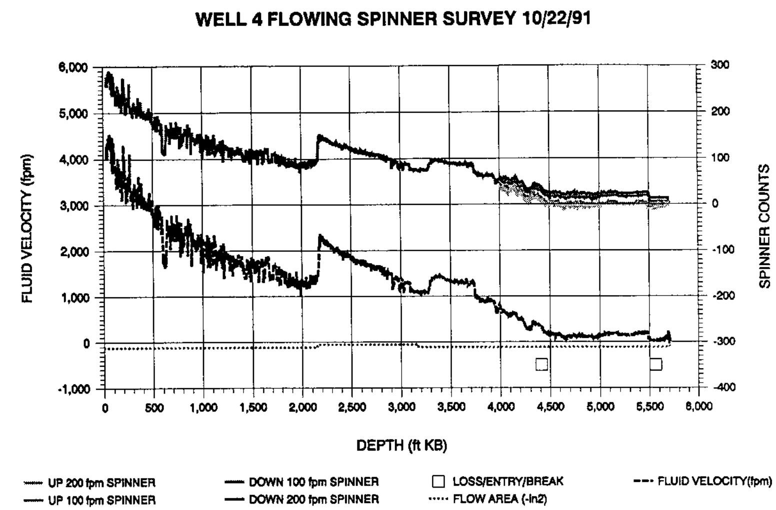


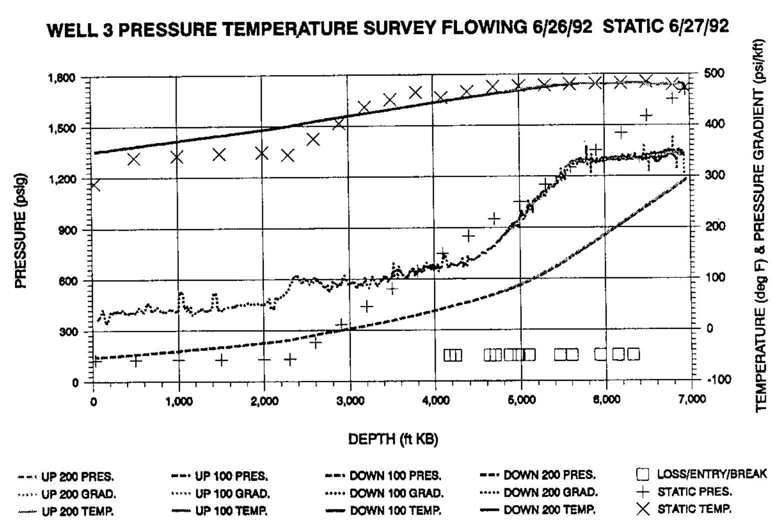
Figure 4. Pressure-Temperature-Spinner Survey from Well 2.



WHP = 150 psig during flowing survey.

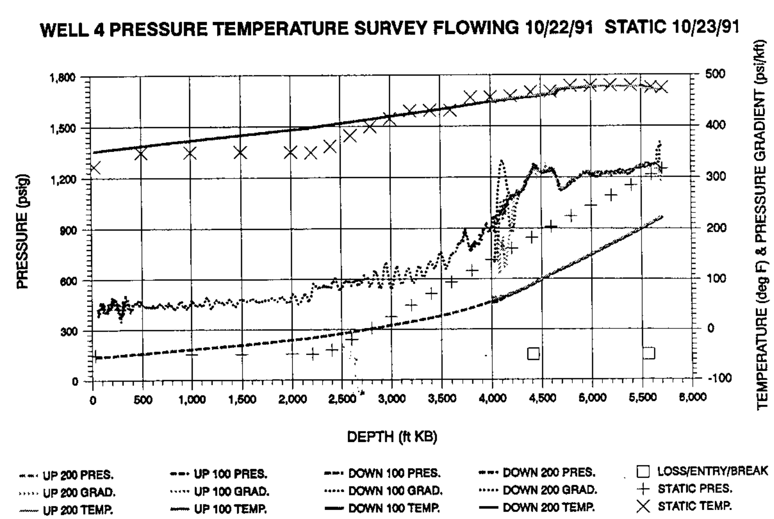


CLEANED OUT SCALE 3173 TO 3213 FEET. TUBE WAS AT 5500 FEET.



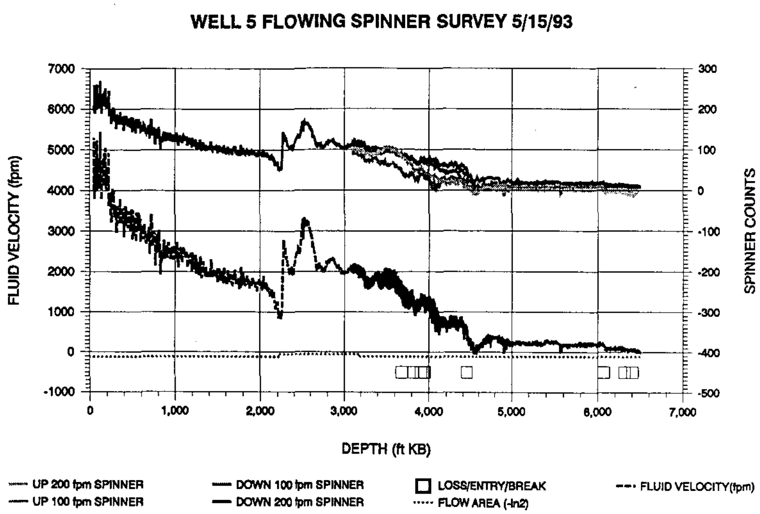
WHP = 150 psig during flowing survey.

Figure 5. Pressure-Temperature-Spinner Survey from Well 3.

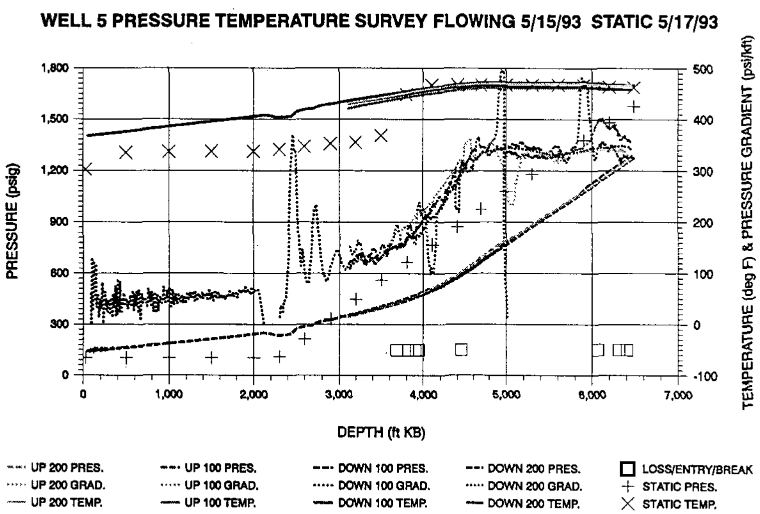


CLEANED OUT SCALE 3173 TO 3213 FEET. TUBE WAS AT 5500 FEET.

Figure 6. Pressure-Temperature-Spinner Survey from Well 4.

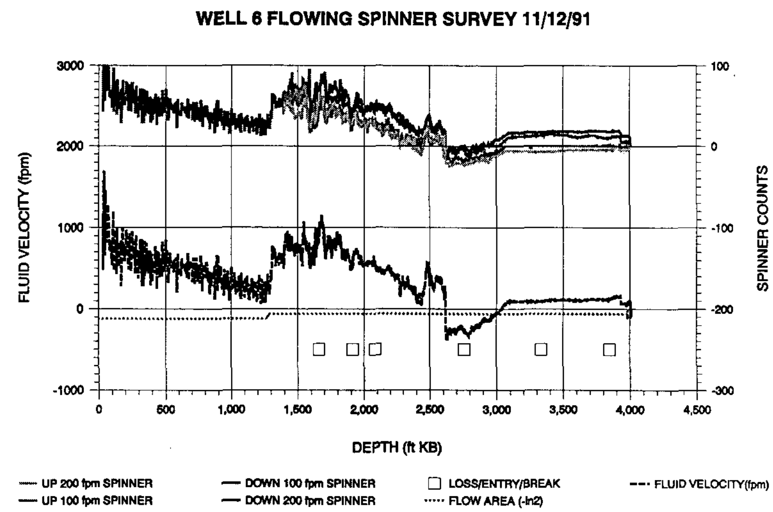


Inhibitor tube was at 5000 ft. Cleaned out scale; med. hard 2853 to 3710, hard 3710 to 3740, med. hard 3740-4711 & 4947 to 5162 ft.

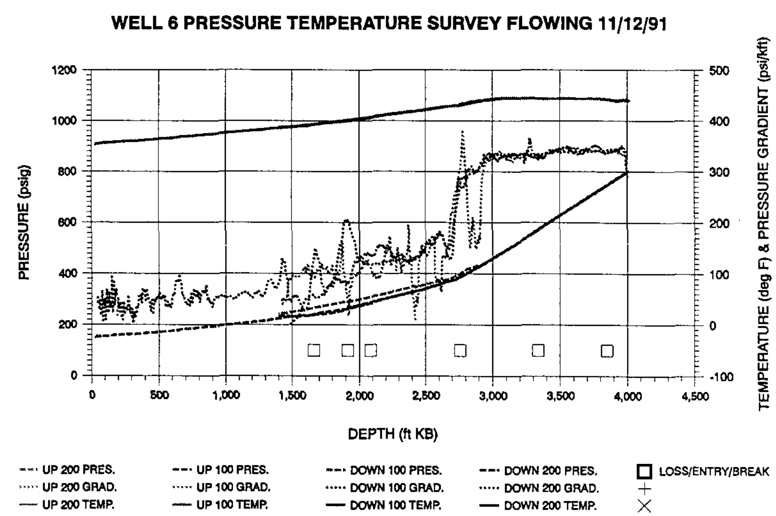


Inhibitor tube was at 5000 ft. Cleaned out scale; med. hard 2853 to 3710, hard 3710 to 3740, med. hard 3740-4711 & 4947 to 5162 ft.

Figure 7. Pressure-Temperature-Spinner Survey from Well 5.



WITH SCALE BEHIND SLOTS



WITH SCALE BEHIND SLOTS

Figure 8. Pressure-Temperature-Spinner Survey from Well 6.