

USE OF SPINNER TOOL IN CAPACITY MEASUREMENT OF GEOTHERMAL WELLS DURING HOT INJECTION

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ABSTRACT

Actual capacity measurement of geothermal injection wells operated by PNO-C-EDC were conducted using the newly acquired spinner tools from Hot Hole Instruments. Multi-pass measurements were done inside the production casing while the wells were online and injecting brine at temperature of up to 185°C.

Each measurement is completed in relatively short time and data obtained are always in good agreement. Loss of injected brine due to damage in the casing was identified and quantified in one well. The spinner tool was also used in the identification of inflow zone in the open hole section. It shall also be used in the classification of scale deposition inside the casing.

INTRODUCTION

The well logging group of PNO-C-EDC now uses high temperature spinner tools for downhole fluid measurement in geothermal reinjection wells. The tool were acquired from Hot Hole Instruments of Los Alamos, NM.

Unlike the previous tools that PNO-C-EDC used for flow measurements, these new tools also give the direction of the impeller rotation and hence are useful in the identification of upflow or downflow zones.

The spinner system consists a of downhole flow sensing probe with a set of impellers of varying degrees in pitch ranging from 30 to 75 degrees, a spinner chassis which receives and conditions the signal from the downhole probe, a depth encoder with quadrature outputs for depth and logging

direction generation, and an IBM-PC compatible computer with a special interface card for decoding the spinner and depth signals. A dot matrix color printer with graphics capability outputs a hardcopy both in real time and after data processing. All of the hardwares are driven by a software specially developed to control the whole system.

The data recorded on the computer while logging are: spinner response in revolutions per second (rps), logging speed in m/sec, spinner direction represented by plus (+) and minus (-) signs, and time in seconds from midnight. These data are generated once every second.

SIMULTANEOUS DOWNHOLE CALIBRATION AND FLOW MEASUREMENT

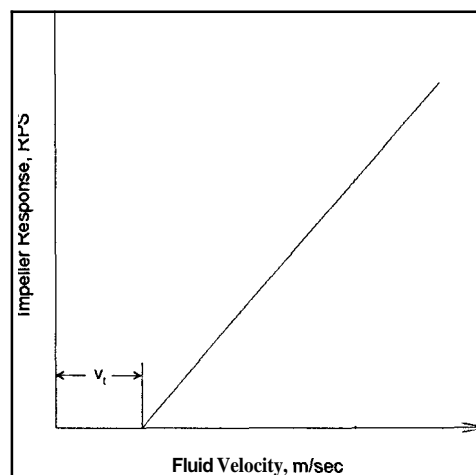


Fig. 1. A Typical Flowmeter Response Curve

To be able to quantify the results of measurement into flowrate, it is necessary to relate the impeller frequency to fluid velocity. This relationship is

called the tool's *response curve*. Simultaneous downhole calibration and flow measurement depend upon the tool's response curve. A typical response curve is a plot of impeller (RPS) against changing fluid velocities with the spinner stationary in moving fluid as shown in *Figure. 1*. V_t , (or threshold velocity), represents the fluid velocity necessary to start the rotation of the impeller and is largely dependent on bearing friction. A similar response curve can be generated by taking measurements in at least three constant spinner velocities while the well is at constant flowrate. This is, however, not a true response curve but an rps-cable velocity relationship, although the plotted points will produce a line of the same slope and can be applied in the computation of fluid velocity as will be shown later.

Threshold Velocity (V_t) Determination

The spinner's impeller will start rotating only when the force generated by fluid velocity surpasses the friction on the bearing of the impeller's shaft. The *threshold velocity*, V_t must be determined for each impeller type, shaft, and bearings. A typical response curve and consequently threshold velocity measurement is shown in *Figure. 2*. This plot is generated by logging while the spinner passes through a desired measuring point inside the well, at various constant velocities and at a stable flowrate. The flowrate is chosen such that a practical logging speed is attainable in order for the impeller to reverse direction while running in the same direction of the fluid flow.

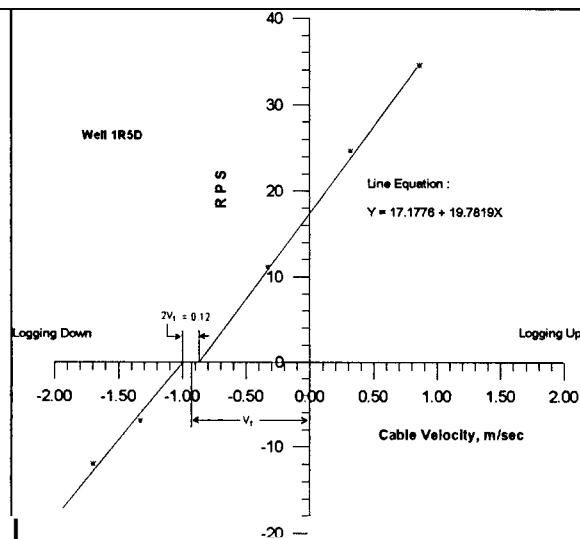


Fig. 2. A Typical RPS vs Cable Velocity Plot

As shown in *Figure. 2*, the RPS value increases proportionately with the increase in cable velocity (logging speed) as the tool moves in the opposite

direction of the fluid flow. However, when the tool is moving in the direction of the fluid flow, the RPS value decreases proportionately with the increase in cable velocity. The value will decrease to zero and will remain at zero for an interval of cable velocities that is twice as much as the value of V_t ($2V_t$). As the cable velocity is sufficiently increased in the direction of the fluid flow, the direction of the impeller rotation will go in the opposite direction and the RPS value will increase negatively. Detection in the reversal of the impeller's rotation for the HHI tool is conveniently incorporated in the design of the tool. For the data to be valid, the readings obtained should produce a linear relationship between RPS value and cable velocity. Linear regression lines were fitted on the points treating the positive RPS values separately from the negative RPS values to produce two lines of roughly the same slope but with different *x-intercepts*. The difference of these *x-intercepts* is equivalent to twice the threshold velocity ($2V_t$).

Note also from *Figure. 2* that it is possible to determine the maximum fluid velocity, V_f during the course of measurement. V_f is equal to the absolute value of the *x-intercept* of the positive rotation line plus the value of V_t .

Fluid Velocity Calculation

The response curve for a station fitted with linear regression is defined by the equation:

$$RPS = a + (m * V_c) \quad \text{Eq. 1}$$

where

- RPS = impeller response, revolutions/sec
- a = y-axis intercept
- m = slope of regression line
- V_c = cable velocity

For a reinjection well where the fluid flows toward the bottom of the well at a rate greater than V_t , the tool's response curve will always produce a positive *y-axis intercept* (+RPS) and a negative *x-axis intercept* ($-V_c$). From Equation 1, the *x-axis intercept* may be defined as

$$x_{int} = -V_c = \frac{a}{m} \quad \text{Eq. 2}$$

the negative (-) sign of V_c denotes that the tool is moving down with the direction of fluid flow.

As shown in *Figure. 2*, the maximum fluid velocity V_f may be computed as

$$V_f = |x_{int}| + V_t \quad \text{Eq. 3}$$

Substituting Equation 2 to Equation 3, we will have

$$V_f = \frac{a}{m} + V_t \quad \text{Eq. 4}$$

The impeller response when the tool is stationary is a more accurate measure of flowrate inside the wellbore. Theoretically, the stationary reading denoted as RPS, should equal the computed y-axis intercept a . In fact, the variation between RPS_o and a can be used as a gauge on the accuracy of the response curve. It is thus advisable to use the stationary reading RPS, in the computation of maximum fluid velocity.

Therefore, Equation 4 may be rewritten as

$$V_f = \frac{RPS_o}{m} + V_t \quad \text{Eq. 5}$$

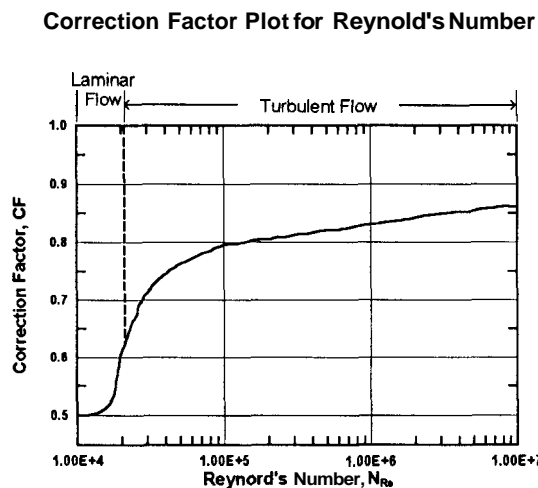


Fig. 3. Correction Factor Plot for Reynold's Number. (Atlas Wireline Services, 1982)

Based on experience of other well logging entities, the flowmeter measures fluid flow very satisfactorily when the fluid is in single phase and turbulent fluid flow occurs. These conditions are satisfied in almost all reinjection conditions. As the spinner is centralized in the hole, it is bound to measure the maximum fluid velocity, which is at the center of the hole for both laminar and turbulent flows. Thus, it is necessary to apply a certain correction to the fluid velocity so that volumetric flows are computed from average fluid velocities in the wellbore. This is accomplished by a correction factor empirically derived from the computed Reynold's Number of the

flow (Atlas Wireline Services, 1982). For most turbulent flows in a well, this factor is about 0.83. However, its value may also be estimated from the plot shown in Figure 3.

Figure 4 shows velocity profiles an both turbulent and laminar flows. Note that velocity at the center of the pipe is greater than the velocities away from the center, this difference is more pronounced in laminar flows.

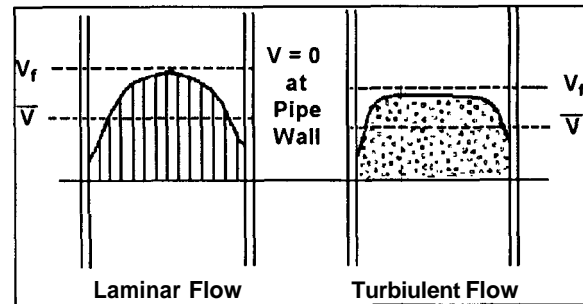


Fig. 4. Fluid Velocity Profiles for Both Laminar and Turbulent Flows. (Atlas Wireline Services, 1982)

A widely used index to check for turbulence is the Reynold's Number, N_{Re} .

$$N_{Re} = \frac{\rho VD}{\mu} \quad \text{Eq. 6}$$

where

- ρ = fluid density
- μ = fluid viscosity
- V = average fluid velocity
- D = inside pipe diameter

If the value of N_{Re} is 3000 or more the flow is turbulent and laminar for N_{Re} values less than or equal to 2000. N_{Re} values between 2000 and 3000 indicates either laminar or turbulent flow depending on well condition.

The corrected maximum velocity is

$$V_{fc} = V_f * \text{correctionfactor} \quad \text{Eq. 7}$$

To compute for volumetric flowrate Q ,

$$Q = V_{fc} * A \quad \text{Eq. 8}$$

where,

A is the cross-sectional area of the hole where measurement is done.

The volumetric flowrate may be converted to massflow (in kg/sec).

$$MF = \rho Q \quad \text{Eq. 9}$$

MF = massflow

This method of calibration and flow measurement does not rely on constant hole diameter, if hole diameter varies, the depths where variations occurred should be defined as separate measuring stations. Separate response curve for each station should be established. Response curves at stations of the same hole diameter would be parallel, when variations in hole diameter occur individual response curves must be used in the computation of flow rates breach section.

RESULTS OF AP SURVEYS

Surveys were conducted in some reinjection wells in Leyte Geothermal Power Project, and Soberano Geothermal Project in the Philippines. A characteristic spinner log for the surveys is shown in Figure 5. A response plot used for the computations of flowrates is shown in Figure 6.

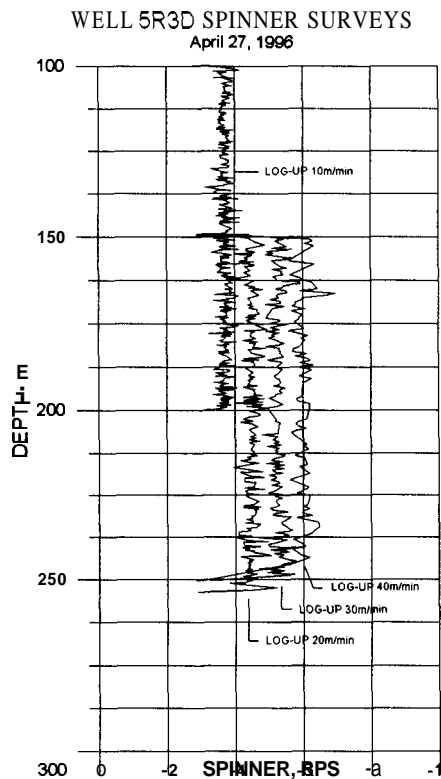


Fig. 5. A Spinner Log of Well 5R3D

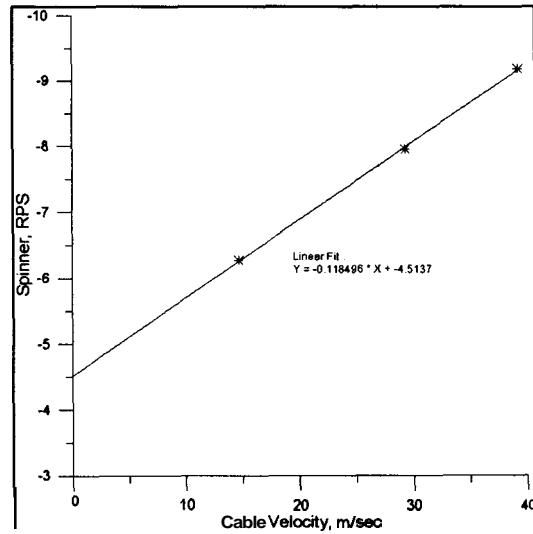


Fig. 6. RPS vs Cable Velocity Plot (Well OK-7)

A computer program was developed in-house to automate massflow calculations from the spinner measurements. This software prompts the user for inputs to compute for massflow. The prompt screen looks like the one shown in Figure 7. The software gives an output to the screen similar to the one as shown in Figure 8.

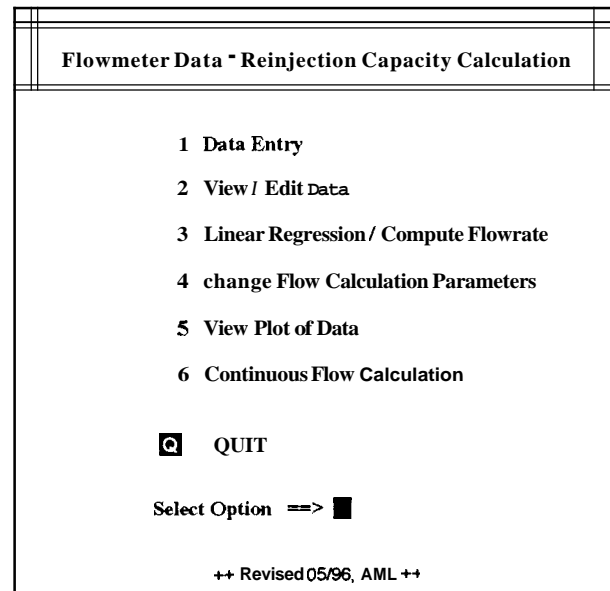


Fig. 7. Prompt Screen for Massflow Computations

The value of V_t for the spinner tool used however, was only assumed to be 0.06 m/sec which was the value established in one of PNOC's older flowmeter tools. The specific threshold velocity for the tool that was used was not established because the conditions of the wells i.e., flowrates, would not allow a logging speed that could induce a reversal in

pinner direction while running in the direction of he fluid flow. Also it could be seen in the alculations that the assumed V_i will not ignificantly affect the computed massflow. The V_i or the new spinner tool must be less than the ssumed value as manifested physically.

Massflow (kg/s) = 16.59622
 Volumetric Flowrate (cu.m/s) = 1.871262E-02
 Fluid Velocity (m/s) = .6948576
 Corrected Fluid Vel. (m/s) = .5767318

Hole Diameter (in.) = 8
 Cross-sectional area (sq. m) = .032
 Reynold's Number = .83
 Threshold Velocity (m/s) = .06
 Fluid Density (kg/cu. m) = 886.9

Intercept Used = 4.5137
 Computed Intercept = 4.5137
 Slope = 7.109784
 Number of data pairs = 3

Press any key to continue...

Fig. 8. Output Screen for the Automated Computations

The new tool is sensitive such that even a slight airflow can start the impeller turning which was not the case with the old flowmeter tool where the value was derived. Hence the assumed threshold velocity is safe enough for computations since it will not substantially affect the calculated massflow. However, the true threshold velocities for the different impeller shafts shall be obtained when logging conditions would allow.

Prior to each measurement, the branchline pressure (BLP) and wellhead pressure (WHP) are sufficiently stabilized to make sure the well is at maximum stable flow when the survey is conducted. Injection fluid temperature is always known from pre-set separator conditions or periodic temperature surveys.

The cross-sectional area of the hole where the measurements are done will influence the volumetric flow calculation to a large extent. For reinjection wells, it is assumed that scale deposition around the

well pipe is minimal. In this case, the original inside diameter of each well's 9-5/8" production casing is used, which is also a reasonable assumption for most wells with minimal scales deposition. It is

nevertheless ideal to periodically conduct a caliper log to check the casing wall condition.

LOST BRINE DUE TO CASING DAMAGE

One other application of the spinner tool is the identification and quantification of lost brine due to casing damage as in the case of Well 5R4D in Leyte Geothermal Field. Figure 9 shows a log of the well with significant change in spinner response starting at around 580m, which is still at the cased section of the well. The logging speed was practically constant at this depth. It can be inferred here that there was a casing break and that fluid was being lost at that point. By measuring the spinner responses at the points before and after fluid was lost, and calculating the equivalent massflows, the lost fluid can be quantified as the difference of the two. By plotting the spinner response curves as shown in Figure 10 and using the procedure previously described, the massflows are computed as 127.5 kg/s and 107.9 kg/s above and below the casing break respectively. Hence the fluid being lost due to casing break was 19.6 kg/s.

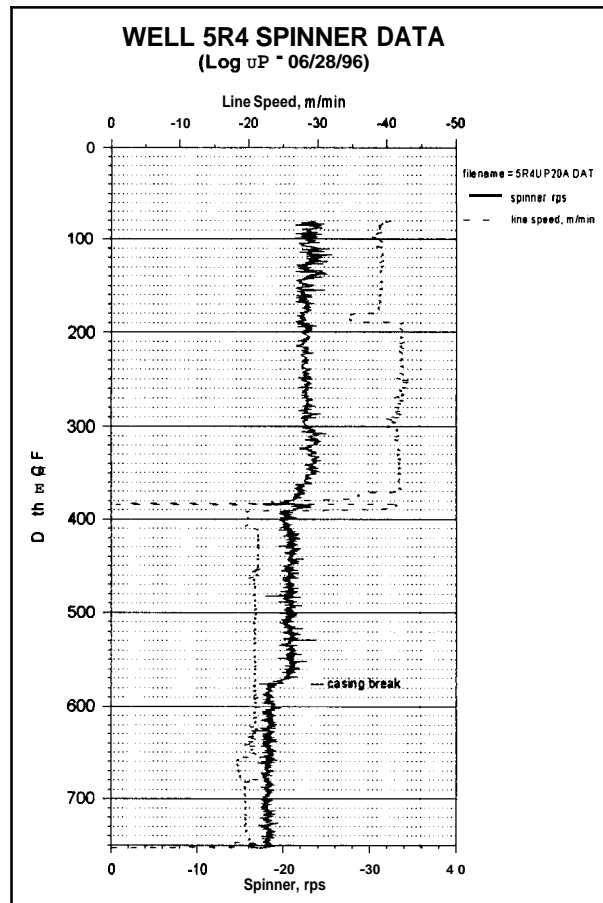


Fig. 9. Spinner Log of Well 5R4 Identifying a Break in the Casing.

ATION OF FLO ZONE

we sample logs that show spinner responses due to the presence of downflow are zone is shown in figures 11 and 12. The logs were conducted on Well PN-29D in PNOG's Palinpinon Geothermal field. The well was surveyed shut, with a WHP of 0psig.

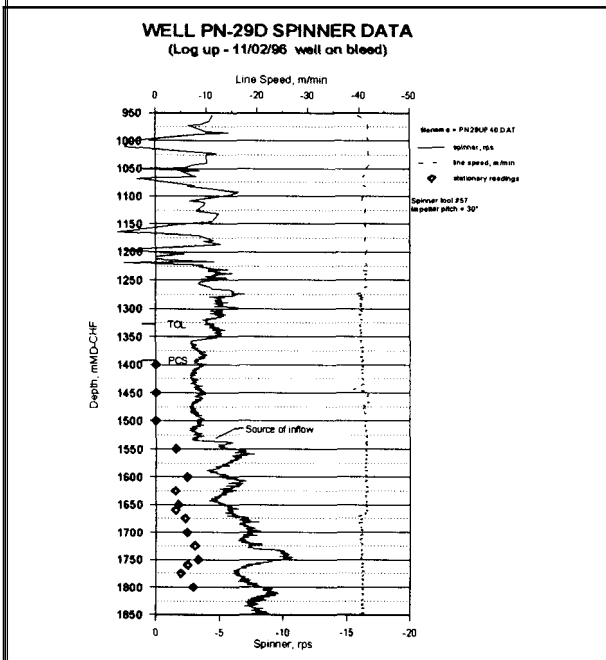
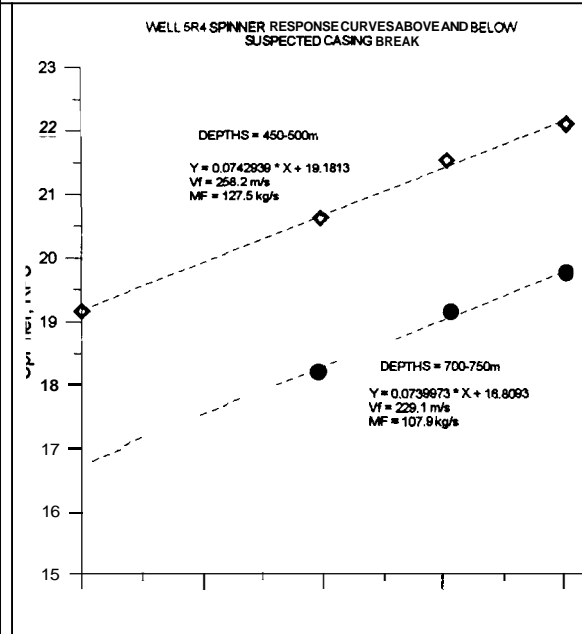


Fig. 11. Spinner Log of Well PN-29D at Line Speed of 40m/min. Showing the Presence of an Inflow Zone.

The logs were done at two (2) logging speeds of 40 and 30m/min. respectively. Based on these logs the inflow is at about 1535 mMDC. Stationary spinner readings confirm fluid entry into the wellbore between 1500m and 1550m.

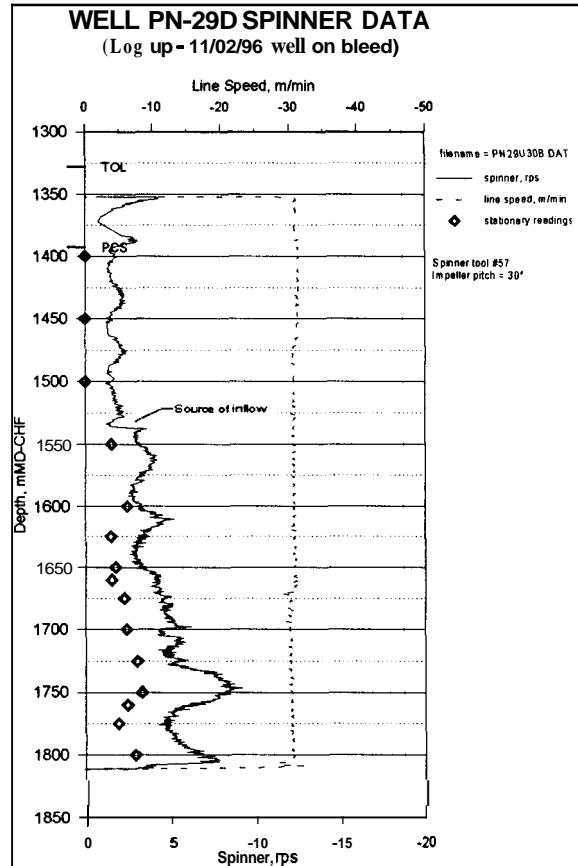


Fig. 12. Spinner Log of Well PN-29D at Line Speed of 30m/min. Showing the Presence of an Inflow Zone.

CONCLUSIONS

Capacity measurement of geothermal injection wells operated by PNOG-EDC is now routinely conducted using a high temperature spinner tool. The digital data are immediately processed using a computer hence results are readily obtained.

Casing anomalies such as breaks and casing depositions can be identified using the same tool, with the fluid lost due to casing break easily quantified.

The spinner tool can also be used to detect the presence of an inflow zone, the location of which can be distinctively marked as has been shown.

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