Investigating the Effect of Nozzles on the Rate of Penetration in Drilling Geothermal Wells - A Case Study of Menengai Geothermal Field

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Keywords

Geothermal, bits, nozzles, hydraulics, penetration

ABSTRACT

We examine the change in rate of penetration (ROP) by incorporating nozzles onto the bit by analyzing wells located in Menengai Geothermal Field in Kenya.

Two pair of wells located on the same well pads were taken as samples for the case study because they had similar formation characteristics. The well denoted `A' after a numeral being directional whilst the ones with only numerals being vertical wells. The wells studied were: MW-09, MW-09A, MW-20 and MW-20A. For the sake of this study we assumed the pairs of wells studied were vertical and have the same formation and drilling characteristics. The maximum inclination of the directional wells in Menengai geothermal field is about 22^0 hence the assumption of all the wells being vertical is acceptable. All other factors that affect Rate of Penetration were assumed to be constant while drilling and the incorporation of nozzles considered being the cause in change of ROP for the pair of wells being compared.

1. Introduction

Drilling fluids circulate through a drill string to nozzles at the bit and back to the surface via the system annulus. They provide three crucial functions to drilling; namely cleaning of the cutting structure, cuttings removal from the hole bottom efficient cuttings evacuation to the surface, lubrication, cooling the bit and obtaining down hole data

2.1 Literature Review

The hydraulic energy that causes fluid circulation is one of only three variable energy inputs (weight on bit, rotary speed, and hydraulic flow) available on a drilling rig for optimization of drilling performance.

Hydraulic performance can be optimized by roller-cone bit options, such as: Nozzle selection, flow tubes, vectored flow tubes, center nozzle ports.

These features provide alternatives for precise placement of hydraulic energy according to well bottom needs.

Generating cuttings is the first step needed to achieve high rate in penetration; cleaning those cuttings from the cone and hole bottom and lifting them through the annulus to the rig surface is the remaining part of a hydraulic solution. Efficient velocity profiles deliver hydraulic energy to the most needed points, even in cases for which drilling flow rates are compromised.

Energy is the rate of doing work. A practical aspect of energy is that it can be transmitted or transformed from one form to another (e.g., from an electrical form to a mechanical form by a motor). A loss of energy always occurs during transformation or transmission. In drilling fluids, energy is called hydraulic energy or commonly hydraulic horsepower.

The basic equation for hydraulic energy is

$$H= (pq)/\ 1{,}714 \tag{1}$$

Where H = hydraulic horsepower, p = pressure (psi or kPa), q = flow rate (gal/min or L/min), and 1,714 is the conversion of (psi-gal/min) to hydraulic horsepower [or (kPa•L/min) = 44 750].

Rig pumps are the source of hydraulic energy carried by drilling fluids. This energy is commonly called the total hydraulic horsepower or pump hydraulic horsepower:

$$H_1= (p_1q)/\ 1{,}714 \tag{2}$$

Where H_1 = total hydraulic energy (hydraulic horsepower) and p_1 =actual or theoretical rig pump pressure (psi). (See prior equation for metric conversion.) Note that the rig pump pressure (p_1) is the same as the total pressure loss or the system pressure loss. H_1 is the total hydraulic energy (rig pump) required to counteract all friction energy (loss) starting at the Kelly hose (surface line) and Kelly, down the drill string, through the bit nozzles, and up the annulus at a given flow rate (q).

Bit hydraulic energy, H_b, is the energy needed to counteract frictional energy (loss) at the bit or can be expressed as the energy expended at the bit:

$$H_b= (p_bq)/\ 1{,}714 \tag{3}$$

The general formula for fluid velocity is

$$V= (q/A)\ldots \tag{4}$$

Where v = velocity (m/min), q = flow rate (L/min), and A = area of flow (m^2).

The average velocity of a drilling fluid passing through a bit's jet nozzles is derived from the fluid velocity equation:

$$v_j = (0.32086q)/ A_n \tag{5}$$

Where v_j = average jet velocity of bit nozzles (m/s) and A_n = total bit nozzle area (in^2).

Nozzle sizes are expressed in $^1/_{32}$-in. (inside diameter) increments. Examples are $^9/_{32}$ and $^{12}/_{32}$ in. The denominator is not usually mentioned; the size is understood to be in 32nds of an inch. For example, $^9/_{32}$- and $^{12}/_{32}$-in. nozzles are expressed as sizes 9 and 12.

3. Methodology

Data was collected from a comprehensive review of drilling log data of MW 20 and MW 09, vertical wells done in 2013 and 2012 respectively. This data was to be compared to that of MW 20A and MW 09A which are directional wells done in 2013 and 2014 respectively.

4. Results

4.1 MW-09

It is the sixth well to be drilled in the Menengai prospect. Its aim at confirming the extent of the resource to pave way for drilling of production wells.

The well was spud in on 17th July 2012 at 1500hrs and completed on 31st October 2012 at 1800hrs. It took 107 days to complete. 90 days were spent on drilling operations while 17 days was due to downtime.

The surface hole was drilled to a depth of 61.5m with total loss of circulation being encountered from a depth of 20 m to casing depth. The 20″ surface casing was set at 58.69 m. Cementing of the well was done immediately thereafter. Cement was received on the surface after 16 backfills. A total of 180.34 tons of neat cement were used for cementing the 20″ 94 PPF BT casing.

The 17½″ hole was drilled to a depth of 355 m with the anchor casing being set at 351.30m. A total of 110.75 tons of cement was used to cement the 13⅜″ 54.5 PPF BT casing. Again this section was characterized by circulation losses.

The 12¼" hole was drilled to a depth of 870.3m with the 9⅝″ 47 PPF BT production casing being set at 867.56m.The production casing hole was drilled with aerated water and foam thus achieving continuous circulation with minimal intermittent losses. A total of 57 tons of cement were used to cement the well.

The 8½" hole was drilled to a depth of 2088m. A decision was made to terminate the well at this point after total loss of circulation was experienced for 13 hours. Attempts to regain circulation proved futile. This measure was taken to avert possible drill string sticking.

26 PPF 7 inch liners landed on bottom on 28th October 2012 at 1900hrs. 108 slotted and 4 plain liners were run in hole. Well logging followed immediately thereafter. A class 600 expandable master valve was installed on 31st October 2012 at 1800hrs.

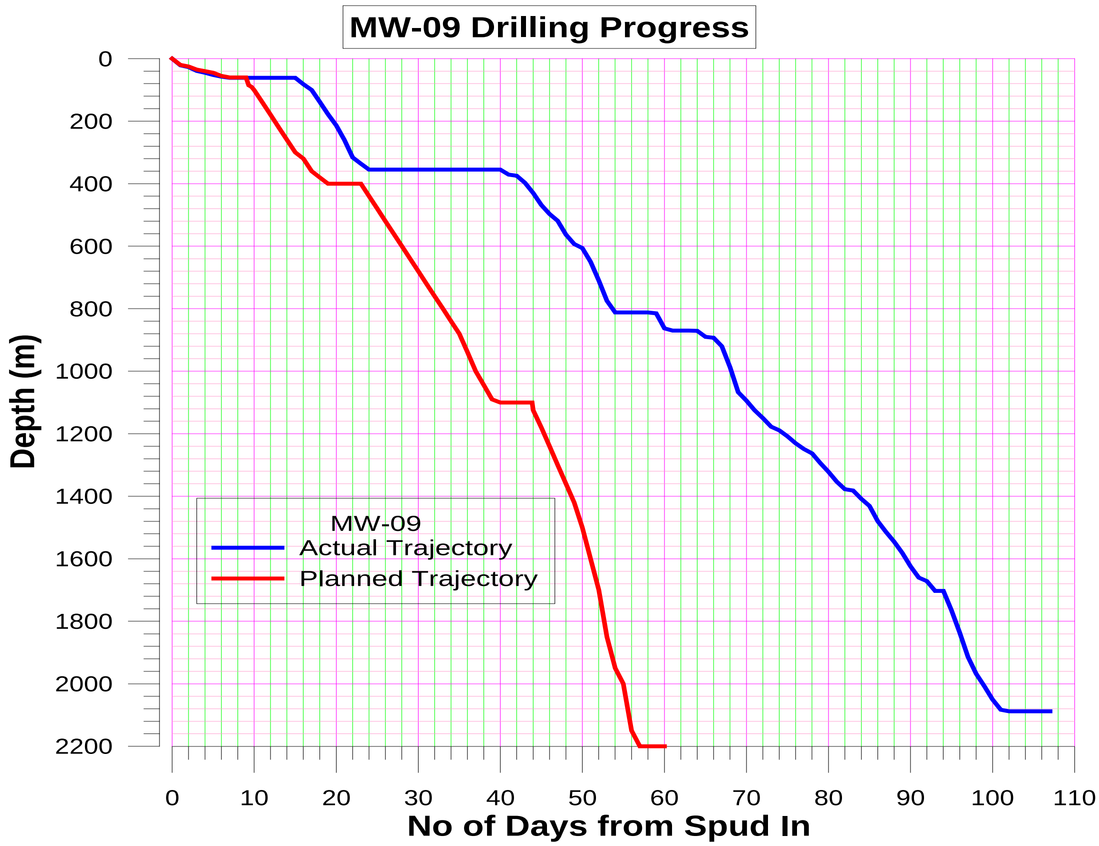

Fig 1: Daily drilling chart of MW-09

4.2 MW-9A

This project was intended for drilling a directional production well as part of the steam production for the 100MW power plant under the Menengai Geothermal Development Program. The well is located in Menengai crater geothermal field. The project was assigned to GDC Kifaru 2 drilling rig.

The project commenced on 16th May 2014 when the rig started moving to the site. Rig up of the equipment took 14 days. The well was spudded on 1st June 2014 at 2130 hours and completed 146 days later on 27th October 2014.The project had been scheduled to end in 100 days. The schedule overrun was largely due to down time and intrinsic Non Productive Time (NPT).

The well was terminated at 2131m, which was short of the planned target depth of 3000m by 869m. This was attributed by getting stuck at 2131m due to suspected magma encounter. Backing off of the drill string commenced after which all the 5” drill pipes, 5” heavy weight drill pipes and 6$^1/_2$” drill collars were recovered leaving only the 8$^1/_2$” bit, bit-sub and 8$^1/_2$” near bit stabilizer in hole.

The well was fairly completed to specifications. The well integrity is assured despite the challenges while drilling. Drilling this well was made difficult by several factors including; lack of drilling water, severe lost circulation, lack of drilling mud, string twist off among others.

These factors made it difficult to execute the drilling program effectively leading to cost and schedule overruns.

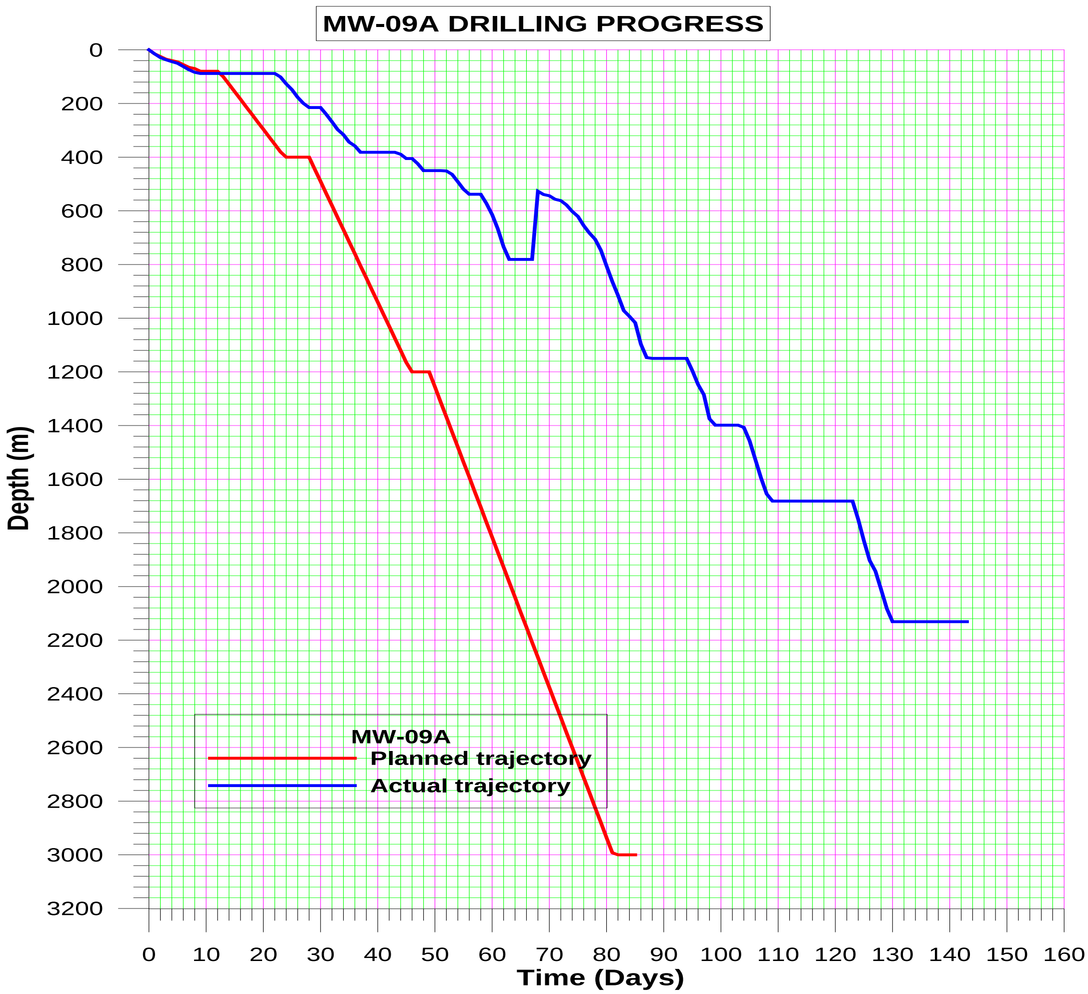

Fig 2: Daily drilling chart of MW-09A

4.3 MW-20

It is one of the production wells aimed at providing steam for the 90MW power plant. The well was spud in on 7th October 2013 at 0400hrs and completed on 3rd February 2014 at 1500hrs. It took 119.46 days to complete. 95.93 days were spent on drilling operations, 2.16 days in well logging while 21.37 was downtime.

The surface hole was drilled to a depth of 64.00m with returns. The 20″ surface casing was set at 56.88 m. Cementing of the well was done immediately thereafter. Cement was received on the surface after primary cementing. A total of 21.27 tons of neat cement was used for cementing the 20″ casing.

The 17½″ hole was drilled to a depth of 382.00m with the anchor casing being set at 372.53m. A total of 107.30 tons of cement was used to cement the 13⅜″ casing. This section was characterized by circulation losses occasioning blind drilling with water and gel sweeps in the better part of the section.

The 12¼" hole was drilled to a depth of 1211.00m. The 9⅝″ production casing was set at a depth of 1190.22m.The production hole was drilled by water complimented by high viscosity gel sweeps with returns on the surface. A total of 184.59 tons of cement was consumed in this section.

The 8½" hole was drilled to a depth of 2461m. While drilling at this depth, the drill string got stuck. The string was freed 7 hours letter following spirited effort in working the string. A decision was therefore made to complete the well at this depth.

7'' liners landed on bottom on 30th January 2014 at 2000hrs. 109 slotted liners and 2 plain liners were run in hole making a total of 111 joints. A 10 inch class 900 master valve was installed on 3rd February 2013 at 1500hrs

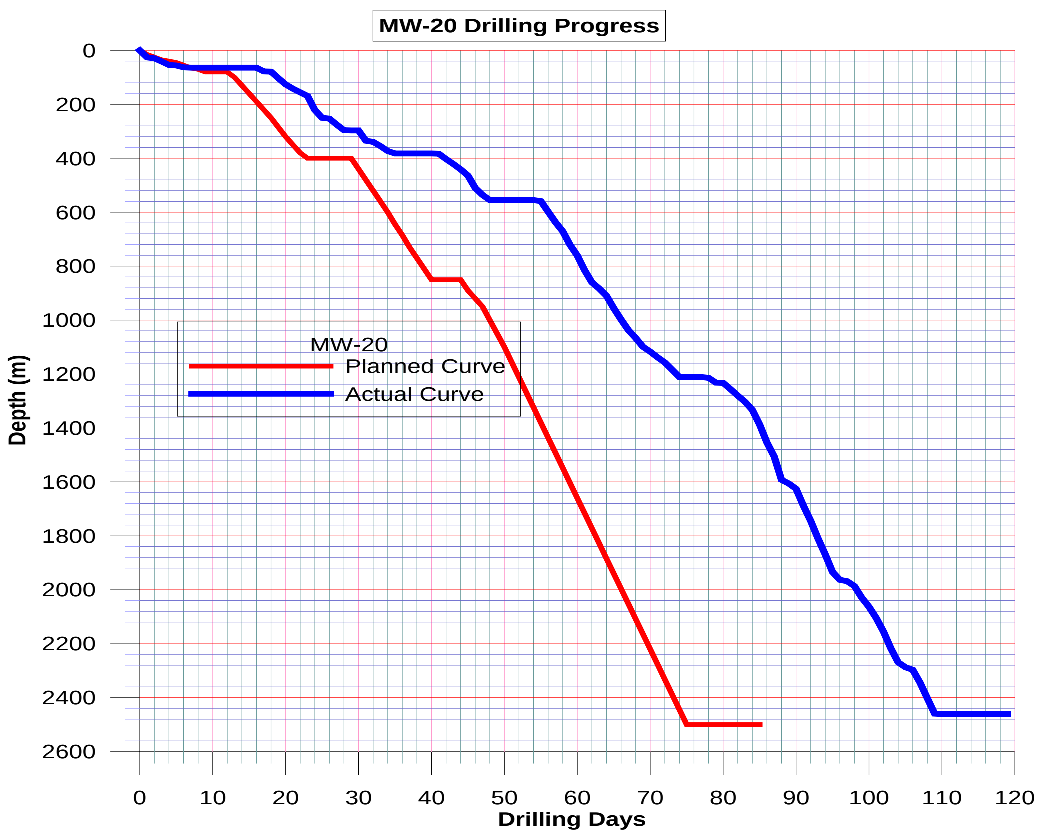

Fig 3: Daily drilling chart of MW-20

4.4 MW20A

It was drilled as a directional well, and as part of steam production for the 100MW power plant programme. The well is located in Menengai crater geothermal field. The project was assigned to GDC Kifaru 1 drilling rig.

After successful rig move and rig up, from MW 10A, the well was spudded on 21st July 2014 and completed 108 days later on 5th November 2014.The well had been scheduled to be drilled in 85 days. The schedule overrun was largely due to wait on fuel delivery among other internal and external factors.

The well was drilled to a depth of 2219M in 108 days instead of a planned duration of 85 days. The actual overrun is 23 days. Out of this, 21.63 days was due to wait on fuel delivery, 5.05 days wait on repairs, 0.21days wait on mud motor delivery and 2.42 days wait on water. The well was fairly completed according to specifications and earlier than planned active days, 6 days less. The well integrity is assured despite the challenges while drilling. Drilling this well was made difficult by several factors including; wait on fuel, wait on drilling water and wait on repairs. These factors made it difficult to execute drilling programme effectively leading to cost and schedule overruns.

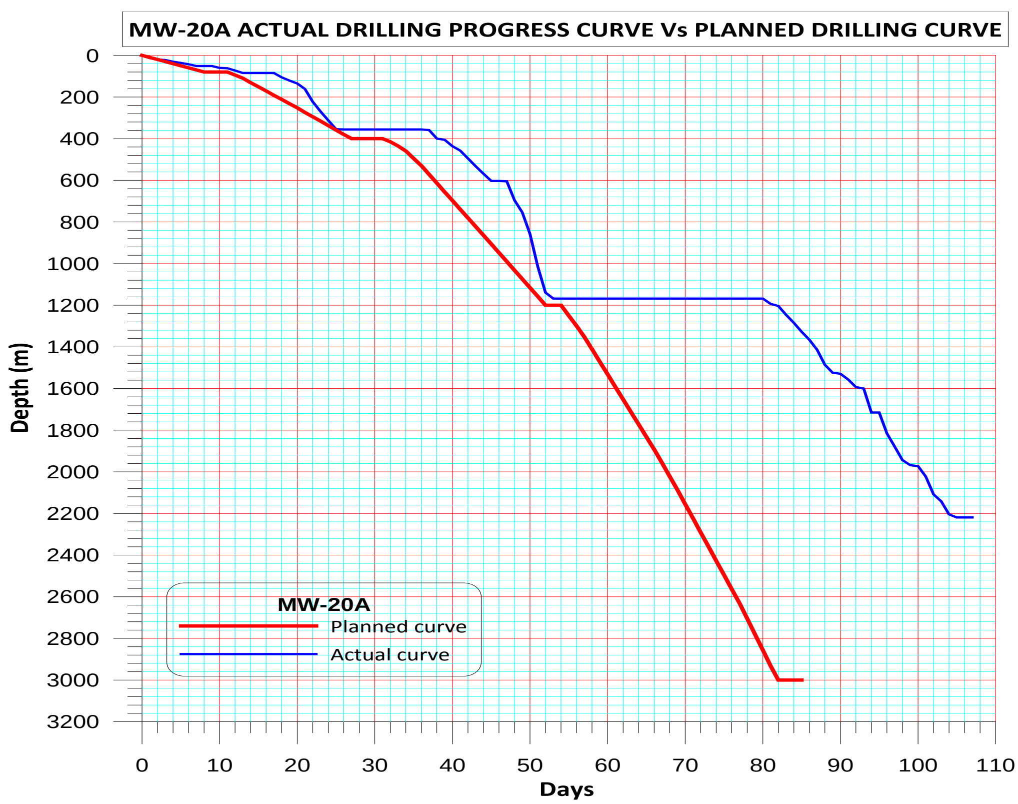

Fig 4: Daily drilling chart of MW 20A

5. Discussion and Data Analysis

From the table above, the rate of penetration was calculated and the results tabulated

$$Rate\ of\ penetration\ (ROP) = \frac{Drilled\ Depth}{24\ hours} \quad (6)$$

$$\text{ROP} = \frac{31m}{24} = 2.5833\text{m/hr} \quad (7)$$

$$\text{ROP} = \frac{40m}{24} = 1.6667\text{m/hr} \quad (8)$$

With above formular, the rate of penetration was calculated for each day and graphed.

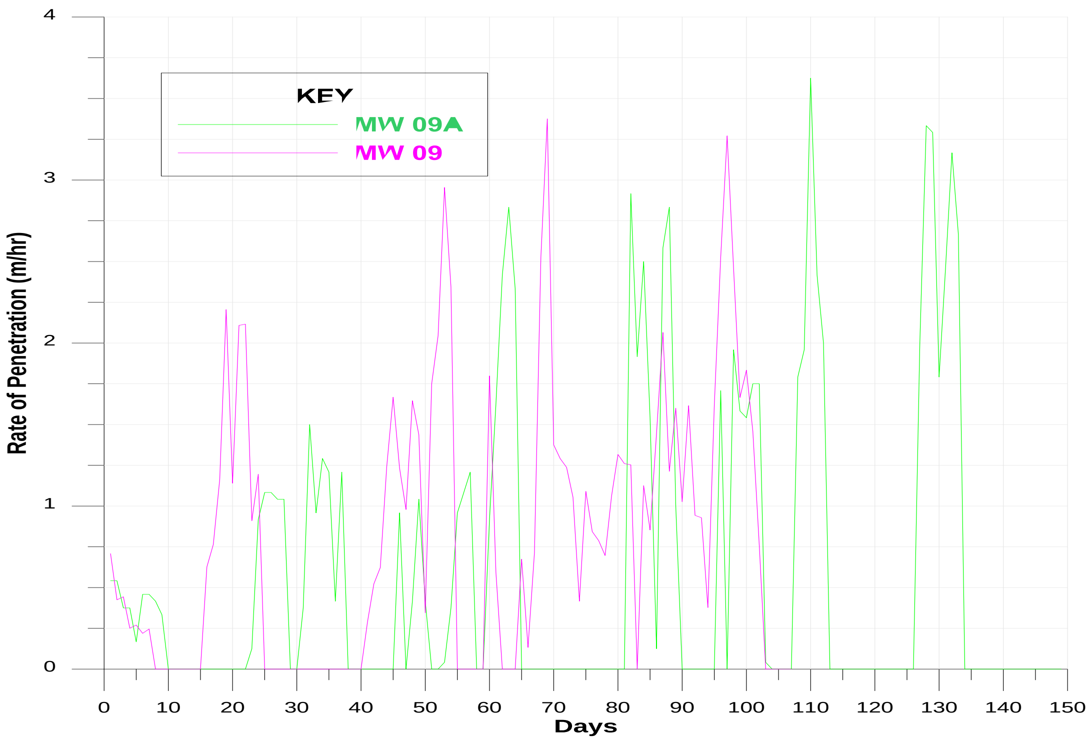

Fig 5. Rate of penetration of MW 9 and MW 9A.

Results showed that some directional wells took longer but that was caused by major downtimes during its operation but achieved much higher rates of penetration. MW 09A achieved a depth of 2131m after 149 days but with a downtime of 64 days whilst MW 09 took 107 days with a downtime of 17.2 days. That means MW09A took 85 days to reach 2131m and MW 09 took 89.8 days to reach 2088m.

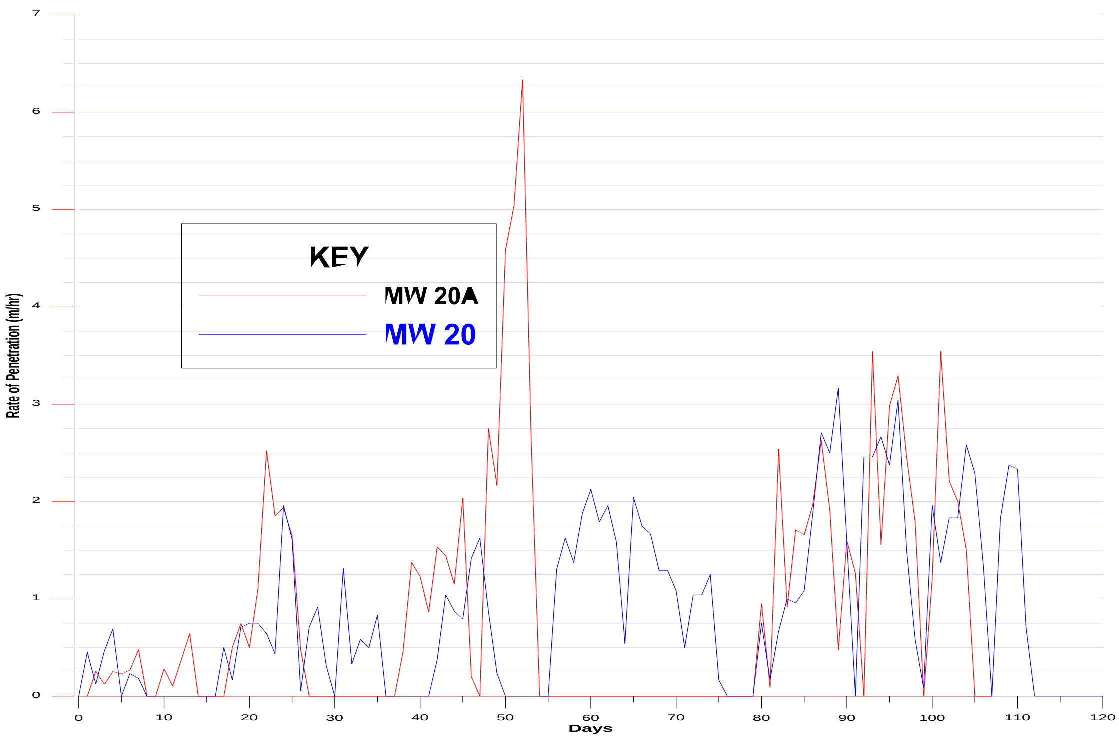

Fig 6: Rate of penetration of MW20 and MW 20A

MW 20A took 108 days to reach 2219m with a downtime of 29.31 days whilst MW 20 took 119.46 days with a downtime of 23.53 days. That calculates to 78 days compared to 95.93 days.

This shows that the rate of penetration of the MW 09A and MW 20A was higher compared to MW 09 and MW 20 and this proves that the addition of bit nozzles increased the drilling rates. The bit nozzles that were incorporated onto the drill bit increased the bit's hydraulic energy. This enabled better bottom hole characteristics.

From the results, the average rate of penetration was calculated to be 1.07m/hr, 1.2m/hr, 0.97m/hr and 1.24m/hr for MW 09, MW 09A, MW 20 and MW 20A respectively. This was calculated after omitting the downtime.

5.1 Assumptions

This study assumes that both pairs of wells were vertical, the same bottom hole assembly (BHA) was used in both pair of wells, all data recorded was correct and the driller's procedures on day of drilling were the same i.e.; weight on bit, pump strokes.

6. Conclusion

The rate of penetration obtained by a bit fitted with nozzles was found to be higher than the rates of an open bit. This was achieved due to better characteristics created by incorporating the nozzle that improved the rate of rock cutting, improved hydraulic dynamics and increased bit cooling.

7. Recommendation

The nozzles are recommended for ongoing use in drilling operations as they have demonstrated an increase in rates of penetration compared to bits without nozzles.

Further studies should also be carried out to compare vertical wells using the same bottom hole assembly (BHA)..

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