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Coiled Tubing Operations at a Geothermal Field in Kenya: Experience, Lessons and Challenges

Martin Rotich

Geothermal Development Company (GDC), Ltd.

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Coiled tubing, work over, well stimulation, geothermal, air-lifting, submergence

ABSTRACT

The coiled tubing unit is applied in multiple operations that include work over, well stimulation and drilling. Work over operations involve sand washing, well cleanout, drilling and milling, gas lifting and induced flowing, fishing, cement squeezing, drainage, cement plug drilling, wax removal and plugging removal. In terms of stimulation it is used in fixed point fracturing, separate layer fracturing, uniform acid distribution and dragging acidification while in drilling it is applied in slim hole drilling, under-balanced drilling, old well deepening and sidetracking of horizontal wells. In geothermal wells the coiled tubing unit is mainly used for well intervention services such as airlifting, scale removal and remedial cementing. The equipment mainly consists of power unit, compressor unit, well control equipment, coiled tubing and injector.

This paper highlights the experience, lessons and challenges while performing coiled tubing work in a geothermal field in Kenya. The coiled tubing team working to understand, service and operate every part of the coil tubing unit achieved a major milestone by successfully initiating discharge on two wells; MW-08 and MW-04A in November, 2020 in the Menengai geothermal field. A dummy run was first performed to determine clear well depth, water rest point and produce Pressure-Temperature (P-T) profile before running in coiled tubing. The tubing was run in and stationed below the water rest point and discharge initiated. A locally fabricated wash tool was used as the lead tool on the coiled tubing while running in hole.

1. Introduction

Coiled tubing is used for stimulating and testing geothermal wells that cannot be discharged by the traditional method of compressing. The air compression stimulation method involves injecting air through a valve on the well head depressing the water level. The cold water is pushed down into the hot part of the well to reach the formation temperature at that depth, eventually allowing the well to self-flow once the pressure is rapidly released and boiling in the water lifts the fluid to the surface (Jason, 2015). The use of the air compression method is limited by the pressure that can be achieved by the compressors. In air-lift pumping, coiled tubing is run into the hole from the well head to depths below the water level in the well. Compressed air or nitrogen gas is injected through the coiled tubing causing the water column in the annulus to bubble as the air flows back to surface. This decreases the density at the water/air column causing the aerated fluid to boil faster and rise to the surface. Gas-lifting has been attempted in the Philippines with success (Ishaan et al., 2020 and Buiiing et al.,1998) .Both air-lift pumping and air compression are used for wells that are not discharging due to water in the casing. The wells have cold water columns above the permeable zones which prevent the up flow of hot reservoir fluids from deeper sources.

The main objective is usually to unload the cooler water column in the cased part of the well so that the well can discharge from the bottom hot acquifers.It is anticipated that once the cooler fluid in the cased part of the well has been removed, the well could then initiate discharge from the bottom feed zones (Onacha,2020). Gas lifting is routinely used in the oil industry for producing wells that have stopped producing naturally because of severe pressure drawdown in the reservoir (Sarmiento, 2011).

In order to stimulate wells that could not self-discharge or discharge by air compression method, GDC in October, 2020 embarked on a campaign to airlift these wells using coiled tubing in its Menengai geothermal field. The team first started by operationalizing two of its coiled tubing units. Two candidate wells were then selected as they had shown promising indications from heat-up surveys and injectivity completion tests; MW-08 and MW-04A.The Menengai Geothermal Field is located in the southern part of the Kenyan rift in Nakuru County, (see figure 1 below). Candidate wells for air-lifting are shown in figure 2.

Drilling in the Menengai geothermal field started in February 2011 with the aim of harnessing steam for electric power generation. Several wells have been completed and tested, and a temperature of more than 300°C has been recorded at 2000m (Ofwona et al.,2011).The first few exploration wells were drilled vertically in Menengai. Directional drilling was later adopted after confirming the existence of the resource to take advantage of the benefits offered by directional drilling such as maximizing wellbore exposure through productive zones in the reservoir, enabling drilling to inaccessible locations like built up areas or beneath mountainous areas, sidetracking, minimizing environmental damage and is economical to drill several wells from a single well pad (Iglis, 1987).A number of wells drilled (both vertical and directional) could not self-discharge, hence the stimulation through air-lifting.

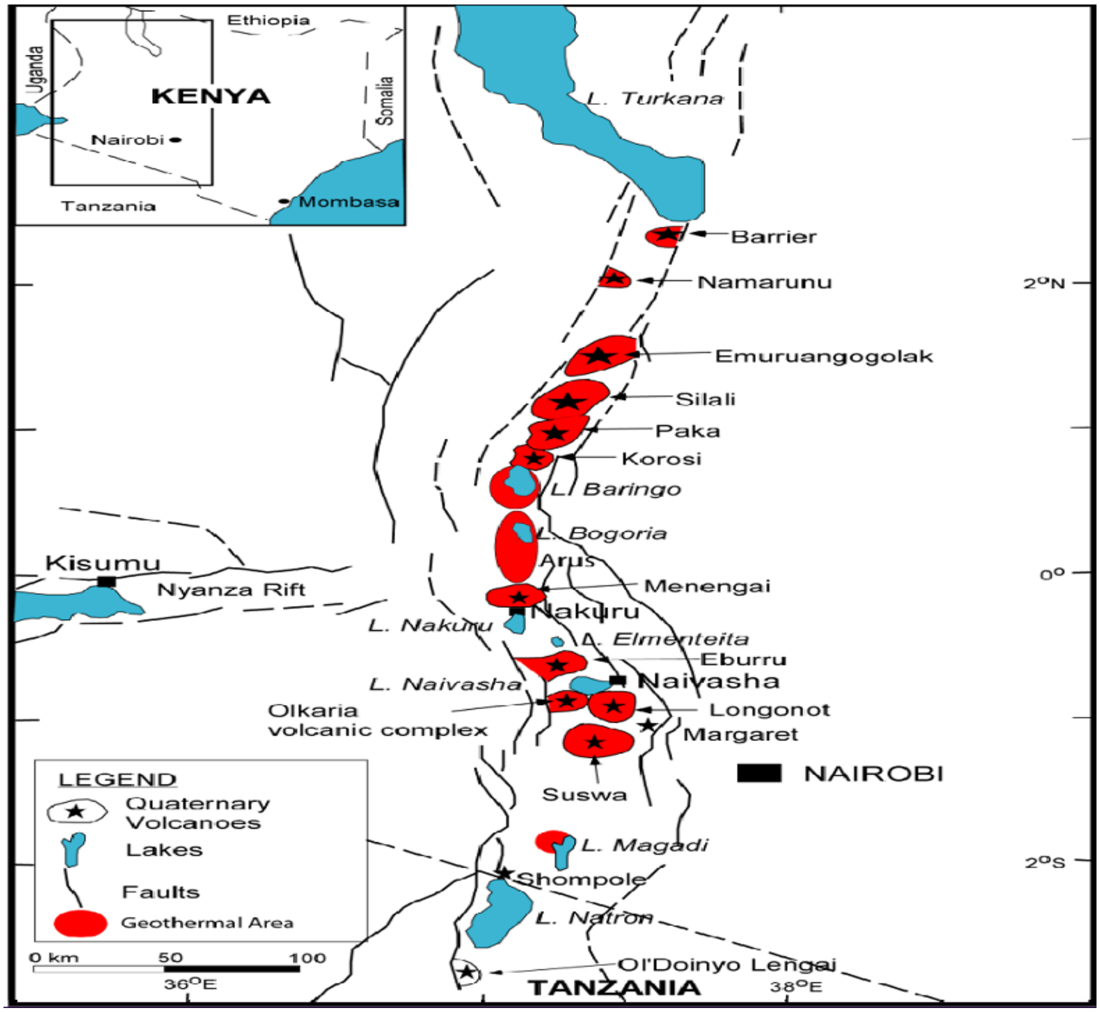

Figure 1: Locations of geothermal resources in Kenya. Menengai geothermal field located near L.Nakuru

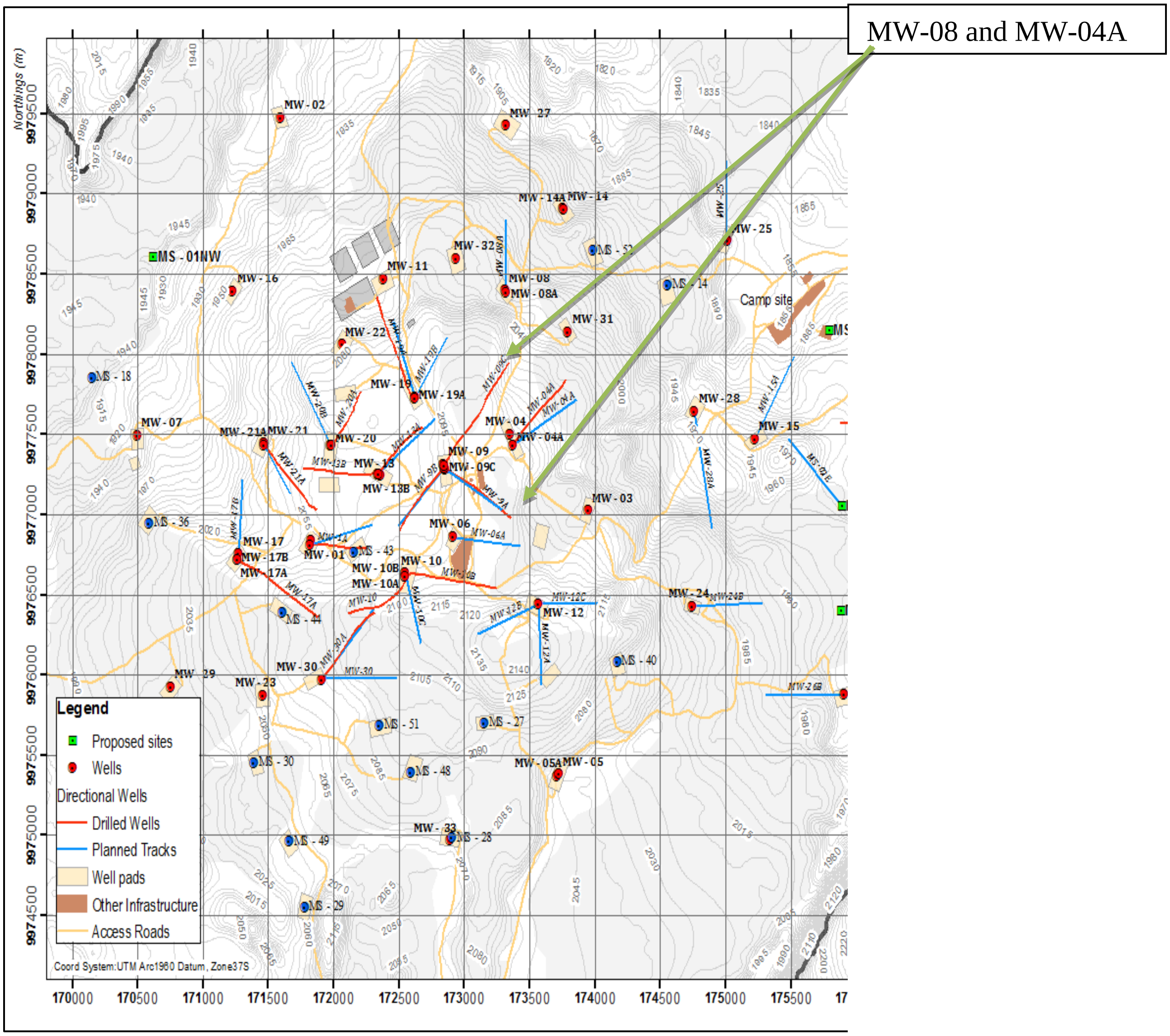

Figure 2: A map of Menengai Geothermal Field showing location of MW-08 and MW-04A (Air-lifted wells).

2. Coiled tubing equipment used

The coiled tubing unit used is a designed integral truck-mounted scheme; all equipment are integrated on a power chassis, and the main equipment comprises, air compressor, HPU, coiled tubing reel, coiled tubing, crane, injector, fluid pump, control console, quad BOP, stripper, lubricator and data acquisition system. It has compact structure, small volume and good transportability. The power of the chassis is output to chassis driving axle, air compressor and HPU, and then the HPU provides power for vehicular equipment (including injector, coiled tubing reel, crane, BOP, stripper and soap pump).

Figure 3: Coiled tubing truck with all equipment

Figure 4: Coiled tubing truck showing position of crane and control console

Figure 5: Coiled tubing assembled on the well head

Figure 6: Coiled tubing team during operationalization of coiled tubing equipment

2.1 Specification of main units

2.1.1 Injector

Max. out-hole power	30000lbs (133kN)
Max. in-hole force	15000lbs (67kN)
Max. out-hole speed	200ft/min (1 m/s)
Caliber clamping range	3/4"-2"
Diameter of gooseneck	72"
Weight	1650kg
Overall dimensions	40 ½"×46 ½"×69 ½" (without injector gooseneck)
	93 ¼"×46 ½"×138 1/16" (with injector gooseneck)

2.1.2 Air compressor

Max. output flow	600CFM (17M3/min/53 l/min)
Max. output pressure	2000psi (13.8MPa)
Cooling mode	five-stage air cooling
Working mode	continuous working state

2.1.3 Crane

Max. lifting mass	8000 Kg
Max. lifting moment	16 TM
Extension distance	9.75m (max.)
Rotation angle	360°

2.1.4 Fluid pump

Max. pressure	3000psi
Max. displacement	14gpm

2.1.4 Quad BOP

Drift diameter	78mm (3-1/16")
Rated working pressure	70MPa (10000Psi)
Hydrostatic test pressure	105MPa (15000psi)
Temperature grade	T-20 (-29 to 121℃)
Outside diameters of applicable coiled tubing	1-1/4" and 1-1/2"
Structural form	lateral horizontal movable type
Hydraulic control pressure	19.5-21 MPa (2,800-3,000 psi)Max
Top connection form	3-1/16"×10000psi API6A flange,
Specification of gasket ring:	BX154
Bottom connection form	3-1/16"× 10000psi API 6A flange,
Specification of gasket ring:	BX154
Connection form of side exit	2-1/16"× 10000psi API 6A stud,

Specification of gasket ring:	BX152 with flange and 2"FIG 1502 union joint
Specification of hydraulic control connection	1/2" NPT (with saver sub)
Height	1144mm (45 in)
Weight	1720kg (3800 lb)

2.1.4 Stripper

Drift diameter	78mm (3-1/16")
Rated working pressure	70MPa (10,000psi)
Hydrostatic test pressure	105MPa (15,000psi)
Temperature grade	T-20 (-29 to 121℃)
Dimension of applicable coiled tubing	1-1/4"
Structural form	side door opening type
Hydraulic operation pressure	34.5MPa (5,000psi) Max
Oil mass for closing rubber core	2.2L (0.58 Gal)
Oil mass for retracting rubber core	0.6L (0.16Gal)
Oil mass for closing side door	5.2L (1.37 Gal)
Oil mass for opening side door	1.4L (0.37 Gal)
Specification of hydraulic control connection	NPT 1/2 internal thread (with saver sub)
Test interface	NPT 1/2 internal thread (with saver sub)
Working media	Sulfurous natural gas, petroleum, drilling fluid and water
Bottom connection form	(Integral 6-5/16"-4 ACME-2G'B' Male hand Union) union joint
Overall dimensions	φ290mm×950mm (11.5in×37.5in)

2.1.5 Coiled tubing reel

Diameter of reel core	64" (1625.6mm)
Outside diameter of coiled tubing reel	106" (2692.4mm)
Inside width of coiled tubing reel	67" (1701.8mm)
Capacity of coiled tubing reel	5210m (1 1/4")
Tubing capacity	5200m (1-1/4" coiled tubing)
Driving mode of coiled tubing reel	direct driving by hydraulic motor
Caliber of applicable coiled tubing	3/4" to 1-1/2"
Torque	6750Nm
Let-right displacement distance	1500mm
Max. speed	12rpm
Weight	2.6T (without coiled tubing)
Max. working flow and pressure of motor	35L/min, 18MPa
Max. working flow and pressure of oil cylinder	25L/min, 16MPa
Min. opening pressure of brake	1.2MPa
Max. bearing pressure of brake	21MPa

2.1.6 Coiled tubing

Outside diameter (OD)	1 1/4"
Wall thickness	3mm

2.2 Airlifting BHA tool

The coiled tubing lead tool was adapted to the end of the coiled tubing through a threaded connection. The lead tool was fabricated from a local workshop in Kenya.

Figure 7: Air-lifting lead tool

Figure 8: Testing the lead tool before running coiled tubing in hole

3. Air-lifting of wells MW-04A and MW-08

3.1 Air-lifting of well MW-04A

Well MW-04A is a directional well drilled to a depth of 2240 metres. From the well temperature profile in figure 9, it can be seen that the well temperature at 700metres is 130°C .This depth was targeted for initial submergence level for air-lifting to provide faster boiling of the aerated fluid. The well had once been air-compressed and it discharged for a few hours but collapsed due to possibility of large cooler water column in the well or slow recharge from the reservoir.

For a successful air-lift the questions are, what submergence (distance below the water table) the coiled tubing is required, and what air-compressor rating (pressure and air flow) is necessary for a successful discharge? (Jason, 2015).In the case of MW-04A, the water rest level as inferred from the pressure profile in figure 10 is at 400 metres. The main objective was therefore to unload the cooler water column in the casing to a depth of 1200 meters (9 5/8" casing shoe) by air-lifting so that the bottom hot aquifers can discharge. The air-lift was designed to be carried out in regular depth intervals as shown in table 1 to achieve sufficient air flow and pressure output at the submergence level to initiate air-lift. Maximum compressor output flow is 600CFM (17m³/min) and maximum output pressure is 2000Psi (13.8MPa or 137.89 bar).The compressor was run at an output pressure of 1450 Psi (10MPa).Estimated flow rate at 10MPa is 435CFM.The rule of thumb is that for each 0.063 L/s (1 gpm) of water, the proper compressor capacity for air-lift pumping is to provide about 0.35 L/s (3/4 cfm) of air (Jason, 2015).

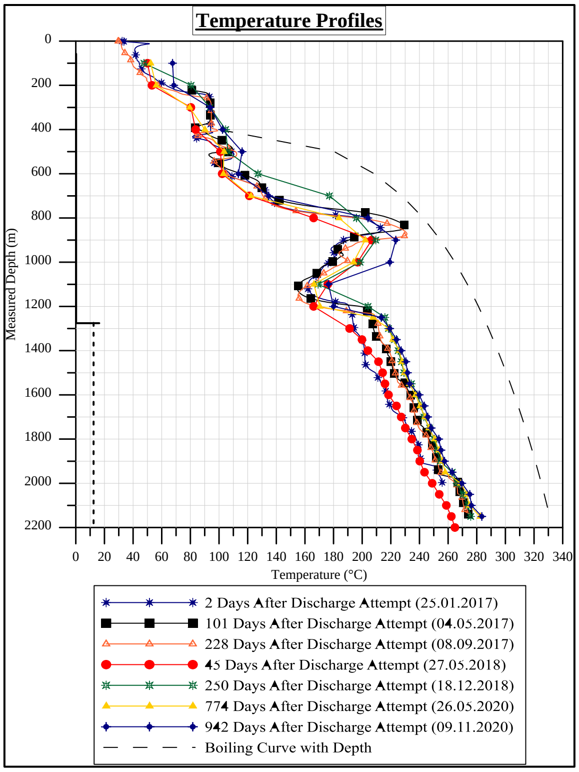

Figure 9: Temperature profile of MW-04A

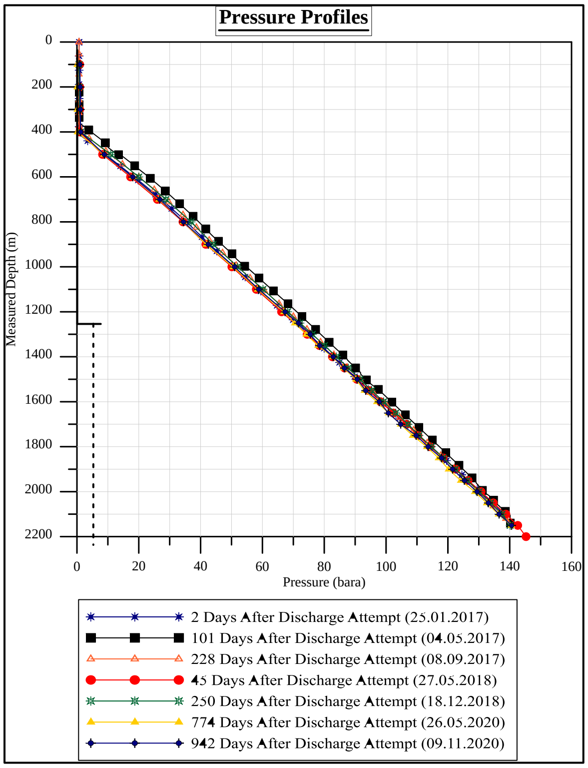

Figure 10: Pressure profile of MW-04A

3.1.1 Air-lifting plan

The minimum required pressure to start the air-lift at any submergence point is calculated from the formula:

$$\text{Minimum pressure requirement (bars)} = \frac{\text{density of water} * 9.8 * \text{depth of submergence}}{100{,}000}$$

Required injection pressure was determined by adding a safety factor of 25% to the minimum pressure requirement as table 1 shows. With the compressor being run at an output pressure of 1450 Psi, it was expected that air-lifting could be initiated at all selected submergence points.

Table1: Air-lifting plan for well MW-04A

Well depth (metres)	Depth of submergence (metres)	Hydrostatic pressure (Psi) at submergence	Required injection pressure (Psi)	Injection flow rate (cfm)
700	300m	428	535	400
1000	600m	854	1067	400
1300	900m	1281	1601	400

3.1.2 Observations

- When the coiled tubing was placed at submergence of 300m, and air-lifting attempted, the well discharged for 4 days and died down.
- Second air-lift was attempted at submergence of 600m.The well discharged for 2 days and also died down.
- The last air-lifting attempt was performed at submergence of 900m.The well discharged for a few hours and died down.

3.1.3 Inference

- Reservoir team concluded that the well has relatively good permeability but probable formation damage during drilling resulted in the well not recharging faster. That could be likely the reason why the well discharged longer during the first air-lifting attempt and collapsed much faster with subsequent air-lifting attempts due to slow recharge from the reservoir.

3.2 Air-lifting of well MW-08

This well was put on air-lifing program as a result of its inability to discharge by itself and even after air compression. Well MW-08 was drilled to a depth of 2300 metres with P-T profiles shown in figures 11 and 12 .The water rest level from the pressure profile is at about 400 metres. Air-lifting program similar to that of MW-04A was adopted as the two wells have comparable water rest levels and temperatures at initial air-lifting submergence.

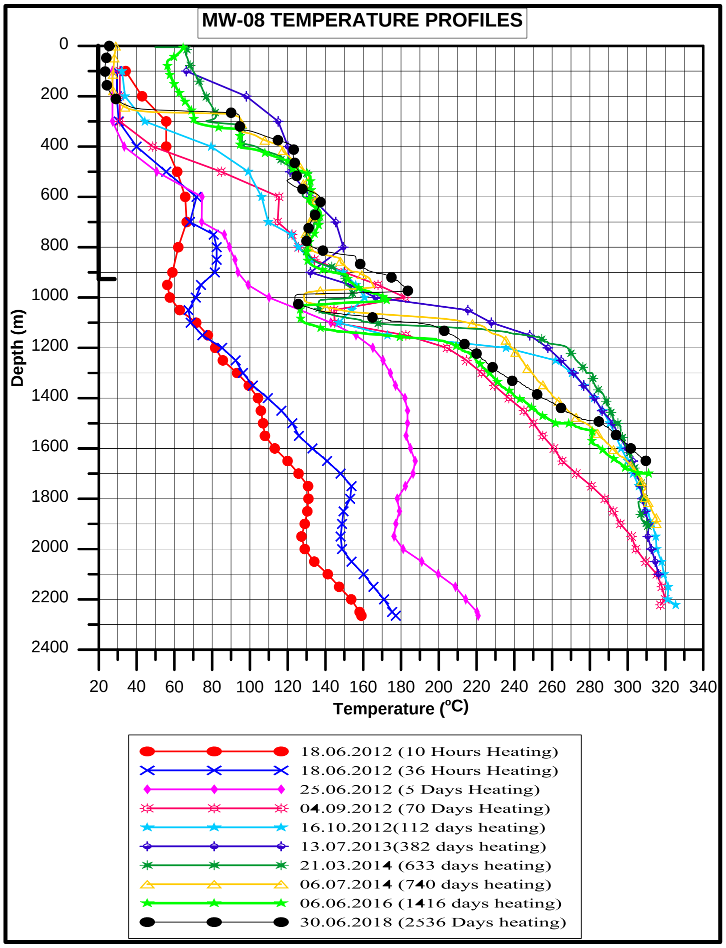

Figure 11: Temperature profile of MW-08

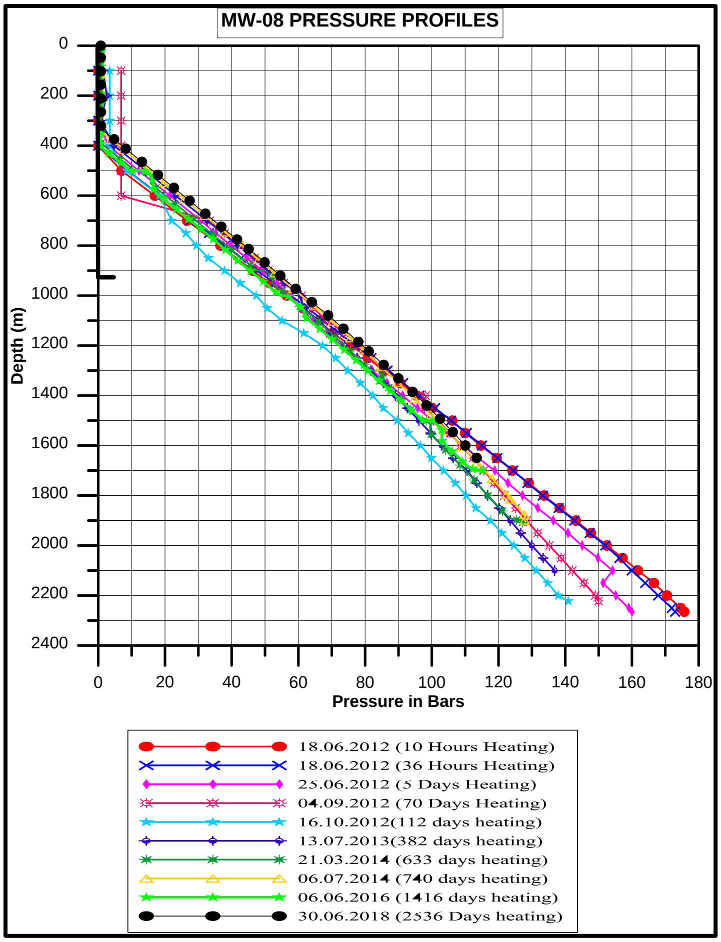

Figure 12: Pressure profile of MW-08

3.2.1 Observations

- When the coiled tubing was placed at submergence of 300m, and air-lifting attempted, the well discharged for a few hours and collapsed.
- Second air-lift was attempted at submergence of 600m one day after the initial air-lifting attempt. The well did not discharge.

3.2.2 Inference

- Reservoir team concluded that the well has high temperature but very tight permeability. The cold water with rest level at 400metres had taken some time to accumulate. That is why air-lifting at submergence of 600m did not yield anything. Hydro-fracturing could be attempted to improve on permeability.

Figure 13: MW-08 discharging during air-lifting

4. Conclusion

The coiled tubing team working to operationalize the coiled tubing equipment were successful. The team were able to understand, service and operate every part of the coil tubing unit and proceeded to air-lift target wells. The selected wells were successfully air-lifted but collapsed after few days/hours of discharging due to a number of reasons as inferred by the reservoir team from the discharge behavior of the wells during air-lifting. Tight permeability was suspected for well MW-08 since the well discharged only for a few hours and collapsed during the initial air-lifting attempt at submergence of 300 metres.It did not also discharge with subsequent attempt at 600 metres submergence. Hydro-fracturing could be attempted to improve on permeability of this well.

Well MW-04A showed promising results as it discharged well for 4 days before collapsing. It was concluded that this well probably suffered formation damage during drilling and thus detailed analysis of reservoir and drilling data should be done to ascertain formation damage by invasion of drilling mud and/or drill cuttings during drilling. Large doses of high viscosity mud injected in open hole to contain drilling loses may cause severe wellbore damage that constrains well productivity (David et al., 2000). If that is confirmed to be the case, acid stimulation treatment can be carried out for well MW-04A.

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