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Example Case of Geothermal Well Control Event

Tommy Souvanir, Redha B. Putra, Doddy Darmawan

[Star Energy Geothermal, Indonesia]

Tommy.Souvanir@starenergy.co.id, redhaputra@starenergy.co.id, doddy@starenergy.co.id

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ABSTRACT

Geothermal well control is an example of well control event in subnormal and under balance condition where formation pressure is lower than hydrostatic column in the wellbore. Well control event may occur in shallow section above the reservoir or in the reservoir. Those well control events have different cause mechanisms. The shallow well control may be caused by abnormal high formation temperature that exceeds saturation temperature while high temperature may occur due to natural heat flow path to surface through fracture or fault. Well control event in the reservoir section correlates with severe losses where hydrostatic column head in the annulus is lower than steam entry zone that allows steam flow to surface. To prevent those well controls, the prediction of pressure and temperature is crucial information in well planning phase and needs to correlate with losses prediction.

The estimation of continuous required water supply during losses condition is essential, as well as in worst well control event. The water supply must be tested to prevent the shortage. In execution stage, monitoring wellbore pressure and temperature closely is critical and in losses condition, back side pumping is required to prevent steam flow to surface. This paper will describe one case of geothermal well control event. In order to explain the sequence of well control event (from the normal condition to steam flow occurred), in that certain well the sensors must have been installed. Understanding the mechanism of well control event will provide safe practice in geothermal well. By preventing well control event, it will increase the efficiency of drilling process, as well as deliver environmental friendly operation.

1. INTRODUCTION

Wayang Windu Geothermal Field is one of the assets operated by Star Energy Geothermal (see Figure 1). It produces 227 MW and together with Salak and Darajat Geothermal Field, the company produces 875 MW of electricity. It makes Star Energy Geothermal the biggest geothermal producer in Indonesia. The first Unit (110 MW) at Wayang Windu was completed in 1999, and has been producing at full capacity since 2000. At the time of its installation, Unit 1 was the largest geothermal turbine in the world. On March 2, 2009, Wayang Windu Unit 2 was inaugurated, with generation capacity from a single turbine/generator, of 117 MW (Wayang Windu Geothermal Asset, 2019). Located at Pangalengan City, West Java Province, Indonesia, Wayang Windu Geothermal Field is hot water-dominated geothermal resource. Steam comes from production wells completed to about 4,700' - 8,000' measured depth (MD).

Wayang Windu Geothermal field just completed 2019 – 2020 Drilling Campaign in order to maintain full generation of unit 1 and unit 2 at 277 MW. Four new makeup wells drilled from two different pad, MBA pad and MBD pad, two wells drilled in each pad. Wayang Windu Drilling Campaign 2018-2019 achieved 69 kg/s out of 64 kg/s target steam production.

In this drilling campaign, some lessons learned identified, and one of them is well control event. From four wells drilled, two of them have well control event that occurred in different well and pad. The sequence of well control events are recorded and documented clearly from initial condition until well is safely secured, through combination of down hole pressure and temperature sensors installed in Measure While Drilling (MWD) tool as well as surface pressure, temperature and flow sensors installed in surface line.

Figure 1: Star Energy Geothermal operation field

2. GEOTHERMAL PORE PRESSURE AND FRACTURE PRESSURE

It is known that geothermal well extracts heat from reservoir fluid (either hot liquid or steam), that lead to deal with high temperature during drilling. Before discussing further about geothermal well control, it is good to know the concept of geothermal reservoir pressure and fracture pressure.

Simplifying the geothermal well pressure and temperature, it can be grouped into two sections, before entrance of the reservoir and at reservoir section. Figure 2 shows the plot of well pore pressure and fracture gradient. Above the top reservoir, normal pore pressure is water gradient and fracture pressure corresponds to overburden. After penetrating the reservoir, formation pressure is either hot fluid or hot steam, while fracture pressure can be ignored due to geothermal system is one single system and connected. Reservoir fluid is much lighter than normal water.

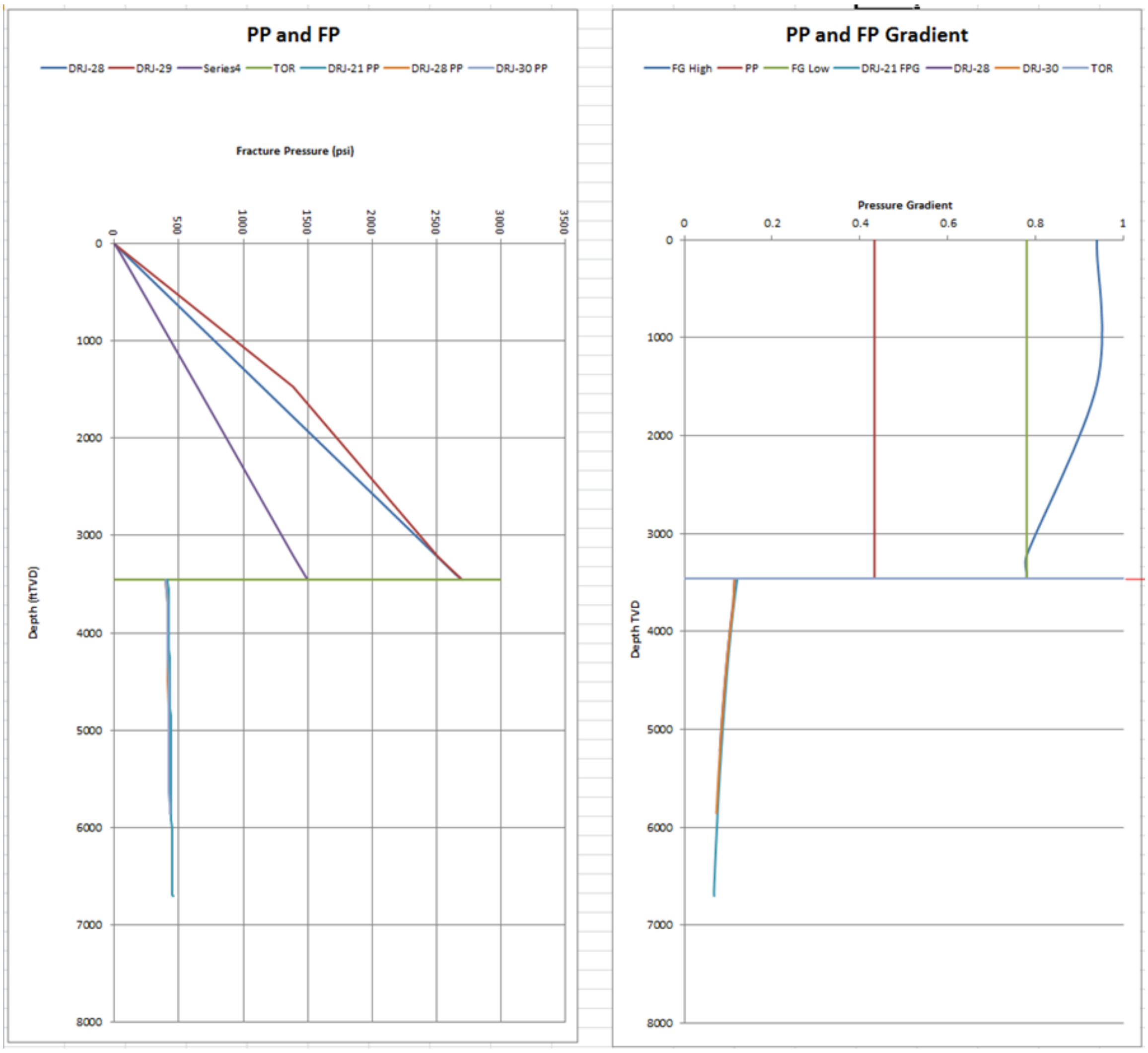


Figure 2: Pore pressure and fracture pressure gradient plot

3. GEOTHERMAL WELL CONTROL METHOD

Following the geothermal pore pressure and fracture pressure concept, well control method also divided into two types, circulation and bullheading. Circulation is the method before entrance of the reservoir section, if the influx occurred then it will circulate out and will be replaced by weighted fluid in order to continue drilling. In this condition, the hydrostatic is required at balance with pore pressure and slightly under balance from fracture pressure. In the event that hydrostatic pressure is lighter than pore pressure, it will trigger the influx while if hydrostatic pressure higher than fracture pressure, it will break the formation that leads to the losses.

Bullheading is the method after in the reservoir section. The reservoir is hot water or steam, created by formation temperature. In the reservoir, the wellbore is under balance. In the event that wellbore hydrostatic pressure is much heavier and cooler than reservoir fluid, then it will lead to losses condition where the wellbore fluid penetrates the formation.

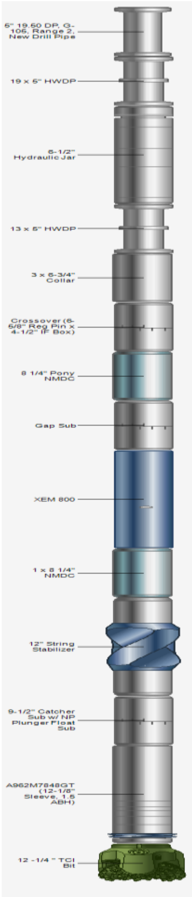
In losses condition, most of the time head of liquid column is too low and no longer overcomes the saturation pressure or prevent the flashing occurred. In order to control these conditions, pumping huge amount of cool fluid to wellbore is the only feasible method.

This paper specifically shares well control event after drilled into reservoir and in total losses condition.

4. PRESSURE, TEMPERATURE AND FLOW SENSORS TO MONITOR WELL

During drilling, the sensors are installed in order to monitor down hole and surface condition. In down hole, annulus pressure and temperature sensors installed in MWD tool regularly record and transmit to surface. In the surface, pressure, temperature and flow sensors were installed in the flow line with additional pressure and temperature sensors installed in the casing head. These surface sensors record circulating fluid continuously in order to observe any anomaly conditions of well control event. All sensors' information are processed in mud logging unit in order to be able to display in real time together with other drilling parameters.

Figure 3 shows 12-1/4" directional Bottom Hole Assembly (BHA) with MWD tool that has annulus pressure and temperature sensors. MWD tool distance is approximately 100 feet from the bit. This information is necessary in next discussion of the sequences of well control event.



Schlumberger

Field Name	WAYANG WINDU	Borehole Name	MBD-8 ST1	Hole Size (in)	12.250
Structure Name	MBD	BHA Name	MBD-8 ST1 BHA#3a 12.25in	Depth In (ft)	0.00
Well Name	MBD-8		Motor-XEM (ABH 1.5 for ST)	Depth Out (ft)	0.00

	Desc.	Manu.	Serial Number	OD (in) / ID (in)	Max OD (in)	Bot Size (in) / Top Size (in)	Bot Type / Top Type	Bot Gender / Top Gender	FN OD (in) / FN Length (ft)	Length (ft)	Cum. Length (ft)	Cum. Weight (1000 lbm)
				8.000								
1	12 -1/4 " TCI Bit	TBA		3.250	12.250	6.625	6-5/8 REG	Pin		1.08	1.08	0.3
				9.625		6.625	6-5/8 REG	Box				
2	A962M7848GT (12-1/8" Sleeve, 1.5 ABH)	Schlumberger		7.850	12.125	6.625	6-5/8 REG	Box		30.45	31.53	6.3
				9.563		6.625	6-5/8 REG	Pin				
3	9-1/2" Catcher Sub w/ NP Plunger Float Sub	Schlumberger		2.813	9.563	6.625	6-5/8 REG	Box		3.97	35.50	7.2
				8.250		6.625	6-5/8 REG	Pin				
4	12" String Stabilizer	Schlumberger		3.000	12.000	6.625	6-5/8 REG	Box		4.99	40.49	8.2
				8.250		6.625	6-5/8 REG	Pin				
5	1 x 8 1/4" NMDC	Schlumberger		2.813	8.500	6.625	6-5/8 REG	Box		29.53	70.02	12.9
				8.375		6.625	6-5/8 REG	Pin				
6	XEM 800	Schlumberger (Extreme Engineering)		3.250	8.375	6.625	6-5/8 REG	Box		33.46	103.48	17.5
				8.000		6.625	6-5/8 REG	Pin				
7	Gap Sub	Schlumberger (Extreme Engineering)		3.500	8.000	6.625	6-5/8 REG	Box		3.67	107.16	18.0
				8.250		6.625	6-5/8 REG	Pin				
8	8 1/4" Pony NMDC	Schlumberger		2.875	8.250	6.625	6-5/8 REG	Box		8.50	115.65	19.4
				6.375		6.625	6-5/8 REG	Pin				
9	Crossover (6-5/8" Reg Pin x 4-1/2" IF Box)	Rig DATI		3.000	7.625	4.500	NC50 (4 1/2 IF)	Box		3.67	119.33	19.7
				6.750		4.500	NC50 (4 1/2 IF)	Pin				
10	3 x 6-3/4" Collar (3 joints)	Rig DATI		2.875	6.750	4.500	NC50 (4 1/2 IF)	Box		89.57	208.89	28.6
				5.000		4.500	NC50 (4 1/2 IF)	Pin				
11	13 x 5" HWDP (13 joints)	Rig DATI		3.000	6.500	4.500	NC50 (4 1/2 IF)	Box		398.13	607.02	48.2
				6.500		4.500	NC50 (4 1/2 IF)	Pin				
12	6-1/2" Hydraulic Jar	Smith		2.750	6.500	4.500	NC50 (4 1/2 IF)	Box		30.74	637.77	51.1
				5.000		4.500	NC50 (4 1/2 IF)	Pin				
13	19 x 5" HWDP (19 joints)	Rig DATI		3.000	6.625	4.500	NC50 (4 1/2 IF)	Box		582.70	1220.47	79.8
				5.000		4.500	NC50 (4 1/2 IF)	Pin				
14	5" 19.50 DP, G-105, Range 2, New Drill Pipe (139 joints)	Rig DATI		4.276	6.625	4.500	NC50 (4 1/2 IF)	Box		4356.53	5577.00	182.3

Figure 3: MBD-8 well 12-1/4" directional Bottom Hole Assembly (BHA)

5. WELL CONTROL EVENT STEAM FLOW FROM ABOVE THE HEAD LIQUID COLUMN

This well control event occurred in MBA-6 well. Reservoir section drilled with 12-1/4" bit started from 2,581 feet by using aerated mud to prevent the losses. Partial losses encountered at 2,938 feet and followed by total losses at 3,159 feet. Blind drilling without backside pumping is continued with combination of 1,100 Gallon per Minute (GPM) mud pumping and 1,200 standard cubic feet meter (SCFM) air that increased gradually respond to decreasing down hole pressure. While working pipe prior to making connection at 4,716 feet, initial return is observed in the flow line sensor and then followed with flow line temperature and MWD – annulus temperature increasing.

Figure 4 shows MBA-6 parameters plots from initial condition of steam flow until well secured. Flow sensor in light blue line (GS_FOUTPDL) recorded initial return and jump up rapidly to full return, flow line temperature sensor in grey line (GS_TMPPH) increased after initial return observed and then climb up to maximum temperature at 144 ^{o}C while MWD – annulus temperature (ZTMP) sensor in pink line increased after the flow line jumping up. MWD – annulus temperature kept increasing to maximum temperature at 152 ^{o}C although the flow line temperature decreased.

In the surface, white steam started to flow from the separator and the flow rate increased rapidly along with flow line temperature and MWD temperature increased. Initial white steam started to change with dark brown steam carrying huge amount of drilling mud and cuttings. Figures 5 shows MBA-6 initial white steam started flowing from separator and the changed to dark brown steam.

Steam flowing for five minutes, then MBA-6 well shut in immediately by closing BOP – lower ram and then bullheading with combination of 920 GPM to the string and 800 GPM to the annulus. Wellbore vacuum within 15 minutes and then flow line temperature and down hole annulus temperature are back to initial temperature.

In this MBA 6 well control event, MWD – annulus temperature increasing is slower than flow line temperature increasing and it can be explained that the steam is flowing from above the head liquid column. After total losses occurred, head liquid column dropped continuously along with additional of hole depth. At some level, head of liquid column is lower than feed zone depth that allows saturation condition occurred and fluids flashing into steam. MWD – annulus sensor is far down below head liquid level and contacting with cool fluid from the string continuously that leads to MWD cooling. After flashing occurred, most of annulus liquid transform to steam and then the annulus temperature increased significantly. Cool fluid that pumped to string, in the middle of travel to bottom will contact with high temperature and then became hotter when it came out from the bit and contact with MWD – annulus sensors. These conditions explain that MWD – annulus temperature keeps increasing while flow line temperature decreased and the maximum temperature is higher than flow line temperature.

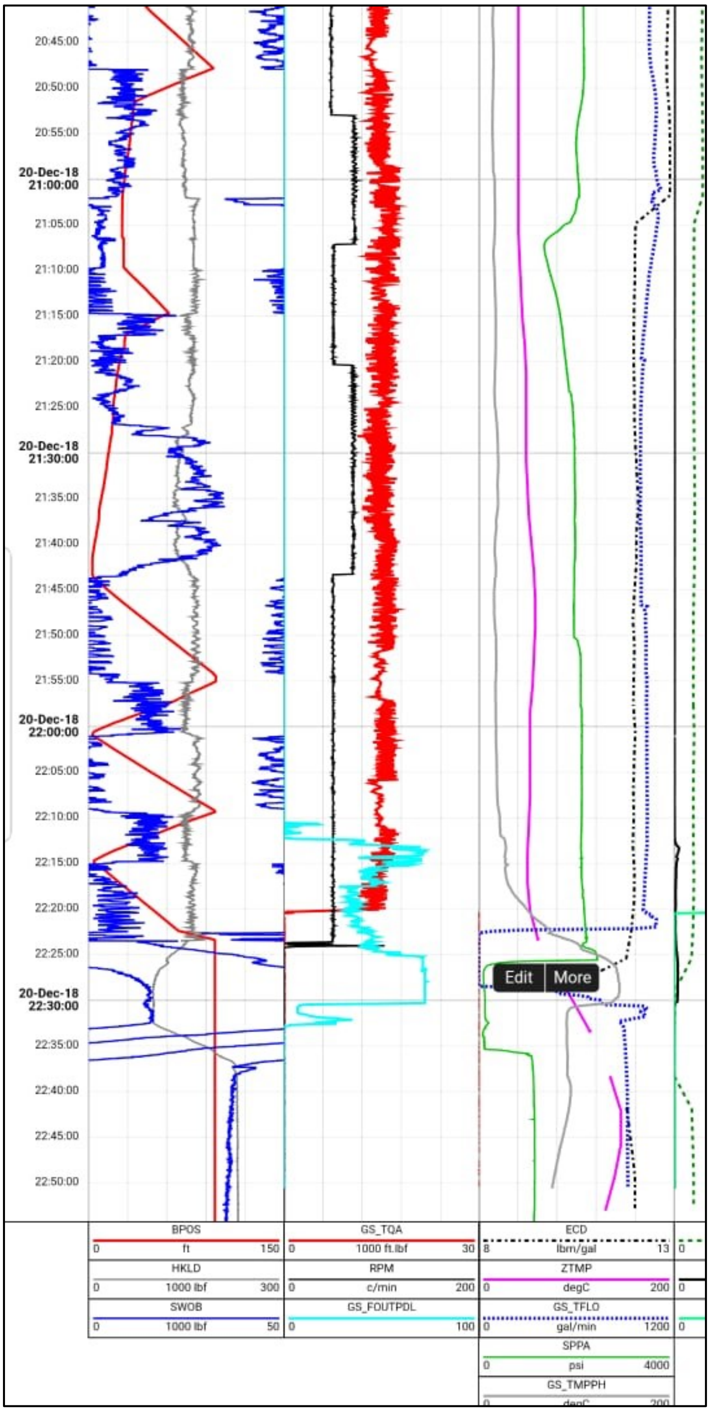


Figure 4: MBA-6 parameter plot from initial of steam flow condition until well secured

Figure 5: MBA-6 initial white steam started flowing from separator and the changed to dark brown steam.

6. WELL CONTROL EVENT STEAM FLOW FROM BELLOW THE HEAD LIQUID COLUMN

Wayang Windu's second well control event occurred in MBD-8 well. The event occurred in reservoir section and in total losses condition. Reservoir section drilled with 12-1/4" bit started from 2,449 feet. Partial losses encountered at 2,920 feet and followed by total losses at 3,188 feet. Blind drilling with no backside pumping continued to the depth of well control event at 3,565 feet with combination of 800 GPM and 14,000 SCFM to the string. While reaming up pipe, initial return observed and then down hole temperature and flow line temperature are increasing rapidly.

Figure 6 shows two well control events in MBD-8 parameter plot from initial condition of steam flow until well secured. For the first well control event, the full return at flow line follow by MWD – annulus temperature and flow line temperature increasing. Flow sensor in pink line (GS_FOUTPDL) start with no return and then full return shortly. Flow line temperature sensor in red line (Bloei line) reached maximum at 66 ^{o}C and MWD – annulus temperature (ZTMP) sensor in pink reached maximum at 97.6 ^{o}C.

Well was secured immediately by closing BOP – lower pipe ram and then bullheading with combination 400 GPM to annulus, 1,000 GPM to the string and air rate reduce from 1,400 SCFM to 1,300 SCFM . After wellbore vacuum, it is decided to continue drilling with backside pumping off in order to prevent cutting settling and stuck pipe.

After drilling continued to 3,586 ft with combination 830 GPM and 1,400 SCFM to the string, other well control event occurred. Initial condition and the parameters increasing are similar with previous event. Full return occurred rapidly and then flow line temperature reached maximum at 84 ^{o}C and MWD – annulus temperature reached maximum at 93 ^{o}C. Well is secured safely and back to vacuum by bullheading with combination 425 GPM to annulus and 985 GPM to the string, then the pumping is continued for one-hour to observe well vacuum was stable.

In those well control events, flow line temperature and MWD – annulus temperature are coincide increasing. It explains steam flow from below the head liquid column. After head liquid level column drops, wellbore hydrostatic pressure drops significantly that leads to condition at balance with formation pressure. The impact of hot formation temperature was the pumping fluid became lighter and then the formation pressure was not able to overcome that allows hot fluid circulate from deeper depth to the surface. When hot fluid migrate to surface, boiling and flashing occurred.

Figure 7 shows MBD-8 initial white steam started flowing from separator and changed to dark brown steam. The sequence is similar with MBA-6 steam flow, small amount of white steam started flowing in the separator and then the flow rate is increasing. After white steam at high flow rate and it changed to dark brown steam that consist of mixture drilling mud and cuttings. Well is secured safely, which indicated by the evidence that dark brown steam stopped flowing from the separator.

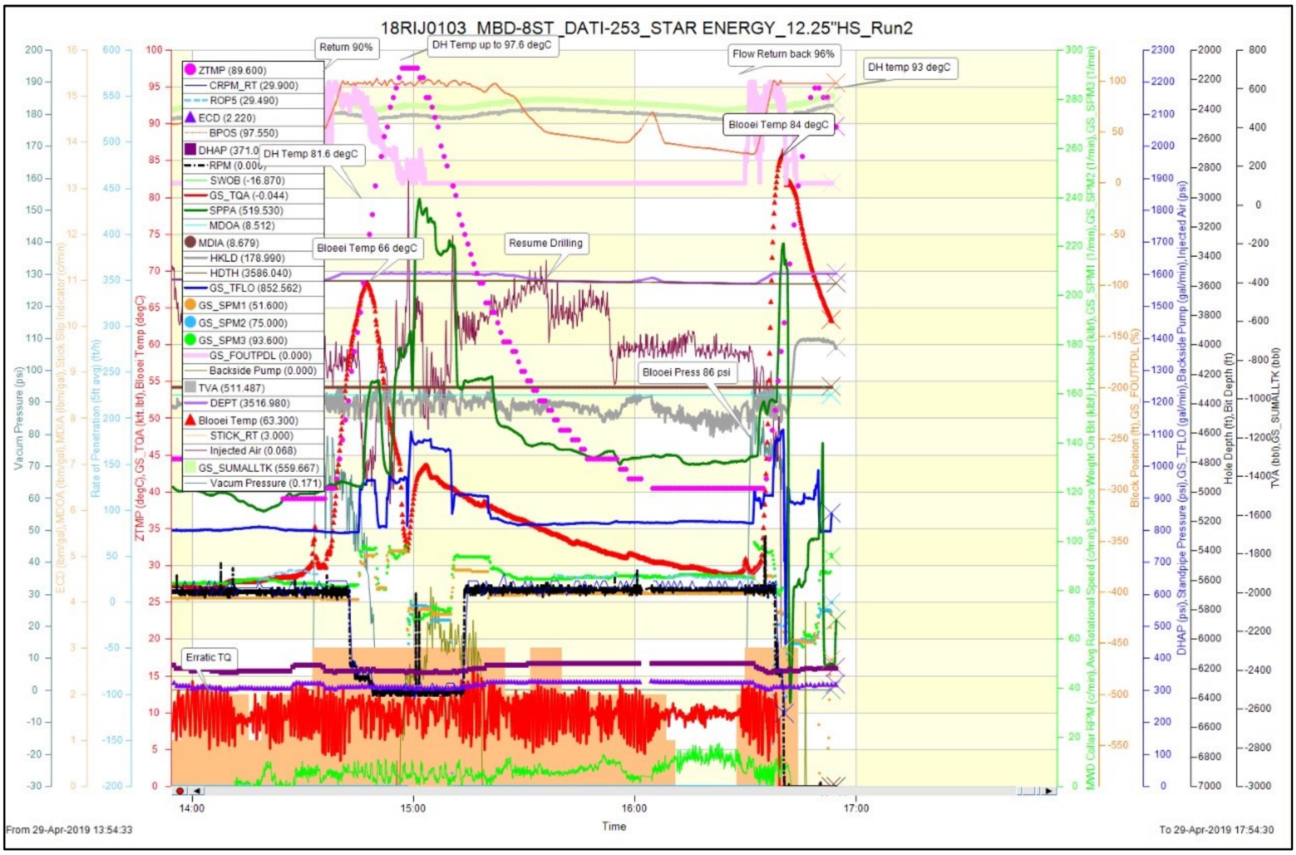


Figure 6: Two well control events in MBD-8 parameter plot from initial of steam flow condition until well secured

Figure 7: MBD-8 initial white steam started flowing from separator and changed to dark brown steam.

7. CONTINOUS ADEQUATE WATER SUPPLY SAFEGUARD FOR GEOTHERMAL WELL CONTROL

Continuous adequate water supply is the most essential for geothermal well drilling. In the absence of adequate water supply, drilling activity will not be able to proceed. It is common in geothermal drilling industry to suspend drilling operation while waiting for the water. In total losses condition, huge volume of water pumped into the wellbore in order to balance fluid loss to formation and maintain head liquid column as high as possible. In well control event under total losses condition, cool fluid needed to pump into the wellbore in order to prevent saturation condition and fluid flashing into steam occurred.

Rule of thumb in geothermal drilling operation, minimum range for water supply that shall deliver to drilling rig continuously is at 35 – 45 Liter Per Second (LPS). Besides the continuous water supply, usually back up water storage also prepared by either some additional tank or water pond. Rule of thumb for back up water storage in drilling rig is approximately 24,000 gallon (571 barrel) that allows two hours extra time of drilling operation before water run out.

In Wayang Windu drilling campaign, water supply was tested prior to well spud in. Minimum continuous water supply agreed by the team to supply to drilling rig is 32 LPS with back up water storage in the location, which was kept in full column all the time. These practices were proven to manage continuous water supply and no water shortage issue occurred during drilling campaign.

7. CONCLUSIONS

Advantages of parameters recorded in two well control events in Wayang Windu successfully improved the understanding of well control sequence (from the normal condition to steam flow occurred). Some of takeaways from well control events are as follows :

- In total losses condition, well control events can be grouped into two conditions, steam flow from above and below the head liquid column.
- Steam flow from above the head liquid column may occur due to the hydrostatic column drops below steam feed zone that allows saturation condition occurred and fluids flashing into steam.
- Steam flow from below the head liquid column may occur due to the wellbore hydrostatic pressure drops significantly that leads to the condition under balance with formation pressure. At this stage, formation pressure is not able to overcome that allows hot fluid circulation from deeper depth and flashing at surface.
- Continuous water supply is safeguard for well control risk and water supply shall be tested prior to spud in and maintain back up water storage full all the time.

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