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Geothermal Well Controls: What are the indicators? – A Case Study in Producing Fields

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ABSTRACT

The common drilling positive kick indicators are: flow when pumps are off, increase flow during normal drilling and circulation, and pit gain. These indictors cannot be relied solely drilling through geothermal reservoirs when circulation is lost or when using aerated drilling fluid system.

This paper will present alternative and current practices being used by Chevron Geothermal and the industry in general to ensure well control events are handled safely and effectively. It is also the intent of this paper to differentiate well control monitoring that the geothermal industry is using to that of oil and gas that take into account the uniqueness and the difference in the drilling environments and hazards.

This paper will also present statistical analysis of well control events in two Chevron geothermal assets in Indonesia to get better picture of what really happened. Field data will be used and analyzed to seek and provide consistent understanding of the events.

At the end, the geothermal community has to clearly differentiate well control indicators and well control approach to that of oil and gas and propose the best and proven methods to ensure safe and effective handling of well control events. An open discussion and feedback should enrich this effort.

GEOTHERMAL SYSTEM

Geothermal resources have been used for cultural purpose and mineral extraction for the last 2000 years. The first modern drilling to investigate the resources commenced at Larderello - Italy in 1856, and the first power generation began almost 50 years later in 1904. Relative to petroleum or groundwater resources, the development of geothermal resources that followed was slow.[1] It is not surprise where there were minimum reference in regard to specific topic such as geothermal well control as what we are trying to discuss in this paper.

The heat in geothermal system is propagated from its source through conductive and convective transfer so then it creates a geothermal reservoir. Hence, there are basic component of geothermal system: (1) an aquifer or fracture network containing hot fluid, (2) a path through which cold water can flow to recharge the system or an input of magmatic fluid, and (3) a source of heat.[1] There is a key word of fracture network that intentionally be looked for in a commercial geothermal reservoir. The consequence of penetrating of a fracture network then a condition where high possibility of total lost circulation is encountered during the process to open this reservoir through drilling activity. Hence, the total lost conditions is inherently associated with any effort to explore and exploit a commercial geothermal reservoir. If no lost circulation encountered, i.e. no fracture network, then there will be least possibility that the geothermal reservoir is commercially discovered.

John Finger and Doug Blankenship[2] provided empirical thesis that most geothermal fields are under pressured (pore pressure less than fluid pressure in a full wellbore). This concurred with existing Chevron's geothermal producing fields that the original reservoir pressure is below the water gradient, i.e. sub normal pressure. Figure-1 depicts the original pressure sample of some wells in four producing fields. These set of data indicates that the water gradient could overcome the reservoir pressure for being flowing into borehole as long as the column of water could be maintained.

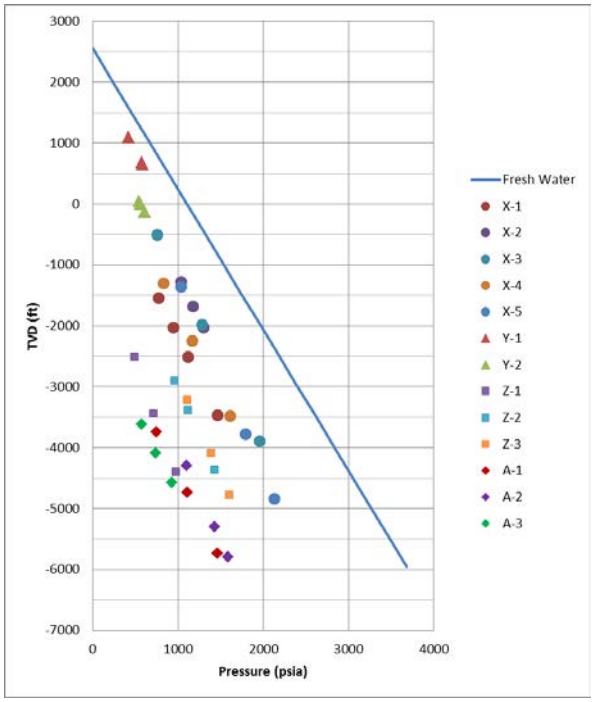

Figure-1: Original Reservoir Pressure of X, Y, Y and A Producing Fields

U-TUBE vs BROKEN U-TUBE

Accessing the reservoir for both oil/gas and geothermal resources shall use the common methodology which is through drilling a well. During the course of drilling operation the present of drilling fluid is required in order to ensure there will be minimum disturbances going down to the desire depth. To simplify the visualization, the drilling string and the annulus between drilling string and borehole can be depict as U Tube system. In common drilling process both legs will full with drilling fluid column, however in

certain circumstances where a lost return is encountered then a broken U-tube will be present as depict in Figure-2.

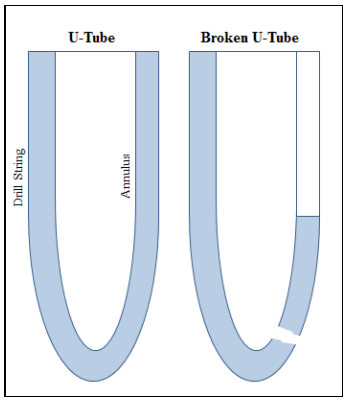

Figure-2: Visualization of drill string and annulus.

WELL CONTROL AND KICK DETECTIONS

Common oil and gas' well control practices are based on maintaining the bore hole pressure more than pore pressure of all formation exposed by the drill bit. An undesired well control event, which is called a well kick, occurs when the bore hole pressure inadvertently is allowed to fall below the pore pressure of a permeable zones and formation fluid begin to flow into the well.[3] In the common condition it is well-known the "three positive kick indication" they are: (1) flow when pumps are off, (2) increase flow during normal drilling and circulation, and (3) pit gain. Current rig equipment and instrumentation were built based on the most precise tools to identify those three parameters as early as possible. Flo-sho and Pit Volume Totalizer (PVT) are quite common to be employed in the rig unit for the above purpose. There are also know the "possible kick indication" they are: drilling break, increasing rotary torque, drill cutting change, and drilling fluid rheology change.

The above three positive well kick indication are easily be detected when the U-Tube is established between drill string and its well bore annulus, hence every single volume of reservoir fluid enter to the borehole then immediately one of the three positive well kick indication is happened and could be detected by the surface rig equipment. So then, the shut in well can be initiated timely in response for any reservoir influx. In the geothermal drilling environmental, where likely after penetrated the upper most commercial feed zone, then the circulation could not be establish, i.e. total lost circulation, where the drilling activity still progressing to the desire depth. During this course of "blind drilling", all those three positive kick indications are hard to be immediately recognized by the instrument or operation in the rig floor. If it is recognize, then it might be too late to handle the situation as the volume of reservoir influx might already been in the huge volume and the high temperature fluid already up to the surface where handling might be exposing safety concerns to the worker. The above description gives a contrast situation in both the U-Tube and broken U-Tube situation only for the well kick indication. In the analysis later on, we would like to introduce other methodology to at minimum providing an early alert of potential kick indication in the geothermal drilling operation.

Upon the well kick is recognized and the well shall be shut in for the killing process. Again, in the common well kill process almost all methods are using the concept of "Constant Bottom Hole Pressure". The Driller's method, Weight and Wait method, and Concurrence method are basically using the same concept. Well kill method using the constant bottom hole pressure only able to be established where the U-Tube of the system is established. Hence, we could maintain the drill pipe pressure and casing pressure using the choke manifold. In special circumstances, where the U-Tube is broken, then all the constant bottom hole pressure concept is no longer exist and those killing method are not applicable in the Broken U-Tube situation.

BOPE EQUIPMENT AND DRILLING PRACTICES IN GEOTHERMAL DRILLING ACTIVITY

In the drilling execution, we employed following Blow Out Preventer Equipment stack in order to ease the process of shut in the well after definite well kick indication is observed and for the further killing process. Figure-3 depicts the equipment schematic in order to aid the understanding of the process.

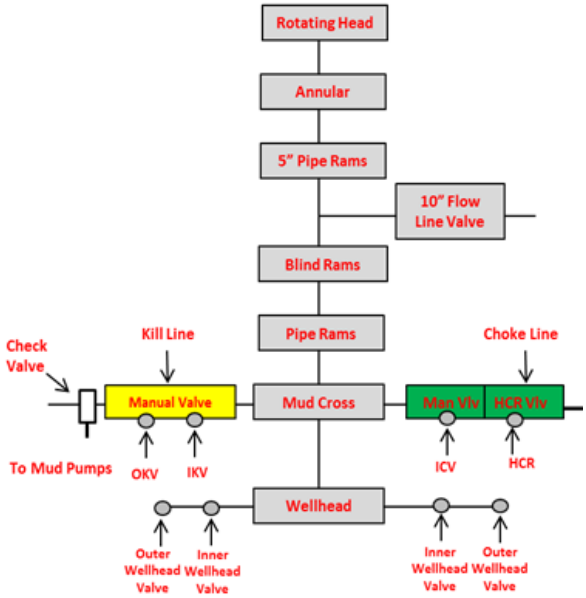

Figure-3: Typical BOPE Stack[4]

In order to prevent any drilling disruption so then, it is prepared in advance to use aerated drilling when encountered the feed zones and in order to minimize the risk of getting the drill string stuck. In addition to the flo-sho sensor in the flow line, it is also installed a temperature sensor in the up-stream of 10" flow line. This temperature sensor is introduced in order to observe the temperature trend during any activity. The production-liner section is commonly drills with aerated mud of 2500 SCFM and 700 GPM pumping rate of drilling fluid for 12-1/4" hole section. When a total lost is encountered, commonly when penetrate the upper most feed zone, adjustment of air rate is made in order to regain the circulation. When the circulation is fail to regain with maximum air rate, then the blind drilling is commenced. Any time where increasing flow line temperature is observed, then annulus pumping is introduced at lower rate i.e. 5 BPM in order to maintain the temperature stable. During this process, there were complex situation in the down hole: broken U-Tube, aerated mud (two phases), probable penetrating new feed zones, cutting transport, and maintain the well control. During the course of drilling a geothermal well, this phase probably the most complex and challenging section to accomplished safely. Hence, a lot of discussion and consideration of what have been done and what should be done must be opened widely to absorb any

applicable technology and practices in order to make the industry going to the safer and efficient conditions.

STATISTIC DATA ANALYSIS: WELL CONTROL POSSIBLE EVENT

Statistical data analysis was taken from the period since 2006 and involving about 52 drilling well activity. The preliminary screening based on the category of activity indicated of 19 events of possible well control related issues. We used term “possible” to indicate that further verification of this analysis might differ some of the list to different category.

Tabel-1 shows the hole section where the possible event are recorded. The 17.5” section is the production casing section, where there were not yet any anticipated feed zone penetrated, and the rest are the production liner section, where the anticipated feed zones are penetrated. There will be immediate challenge of the three events encountered during drilling the 17.5” section before even penetrating the geothermal reservoir? There always be a possibility of any leaks from the reservoir to the shallower zone. However, further analyze the data, it was indicated that during drilling on those three well, an aerated mud were used in order to regain the circulation. The air separation from the mud during no circulation (i.e. tripping out and operation idle) might induce a pseudo well kick. The flow line temperature has not been indicated any change on the temperature profile. Hence, it is suggested to consider the three events in 17.5 production casing are considered as system initiated event.

Hole Size (in)	Event
7	1
7.875	1
9.875	10
10.75	1
12.25	3
17.5	3
Grand Total	19

Tabel-1: Hole section of possible event.

When all the data are differentiated to its detail activity, there appears an interesting condition where the well control events majority happened during drilling and tripping activity. During drilling activity there should be active pumping of drilling fluid from the drill string and/or annulus; whereas during tripping activity there was only active pumping from the annulus. Based on those two thesis, it is suggested that the case might happened in any situation during the drilling activity. So then, early acknowledgement of the well control event is much important to handle the situation.

Activity	Event
Circulating	1
Connection	1
Drilling	5
Flushing well with Water	1
Monitoring Well	1
Reaming	2
Tripping	7
Wait On Cement	1
Grand Total	19

Tabel-2: Activity of possible event

Tabel-3 shows the circulation condition prior to the well control events. There is an interesting fact that three events occurred when there was a full circulation observed in the well activity prior to the well control. These crucial data point will dictate the industry that not in hundred percent cases that during penetrating the commercial feed zones, a lost circulation occurred during drilling operation. In other word, these events still able to establish the U-Tube condition to implement all method of constant bottom hole pressure to kill the well.

Status	Event
Return	3
Total Lost	16
Grand Total	19

Tabel-3: Status of circulation prior to event

Graphical plot is established to randomly point the time of well control events as depict in figure-4. There is no specific pattern of the timing such us day-time or night-time or crew-change that contribute such situation. This is to eliminate the human factor that in other situations becomes the initiator of unscheduled event like well control case.

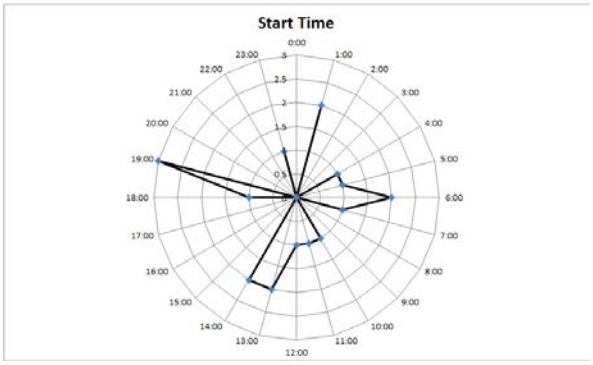

Figure-4: Time of events

FURTHER DATA ANALYSIS: CONTINUOUS FLOW LINE TEMPERATURE AND TORQUE

In order to identify with other parameter to early indicate the well kick event, a continuous flow-line temperature sensor is installed up-stream of the 10” flow line. During the total lost and blind drilling activity where a certain BPM of drilling fluid is pumped down into the annulus, the flow-line temperature sensor might only expose to the mist or vapor of hot fluid from the hole. As a result then it might give conservative information and shall be treated as changes of trend rather the exact data point. Hence, the continuous monitoring will play important role in this matter. Figure-5 shows some of normalized data to the time zero (t_0) of the well control events. The temperature data lines are not consistently following the unique pattern but an individual well could be detected as exhibiting of sudden increase of flow-line temperature and drop upon the action be taken to handle the situation. Though there was not definite trend can be drawn from this chart, however the writer still in strong argument that this piece of information will give a good signal of the well will behave. Further investigation on the type of temperature sensor and location of the sensor might be a good discussion for the industry.

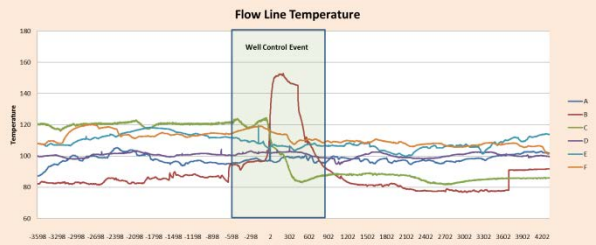

Figure-5: Flow line temperature vs normalized time

The continuous torque which is also commonly used in the industry is also plot with normalized time at the well control event. However, it does give also a consistent trend as an early indication.

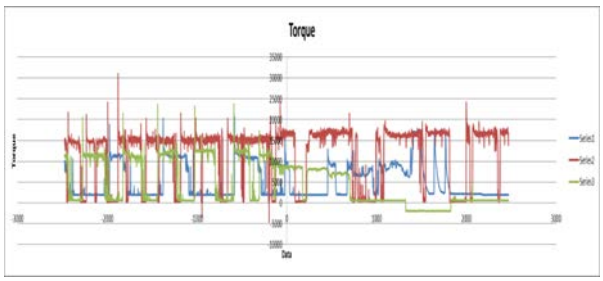

Figure-6: Rotary torque vs normalized time

SUMMARY AND CONCLUSIONS

- The common known three positive well kick indicators are not fully well-fit to geothermal drilling activity considering the nature of broken U-Tube when the drill bit penetrates commercial feed zones and blind drilling has to be taken to pursue the desire depth. This awareness shall drive the respective industry inhabitant to seek other method and associates instrument to support it.

- Introducing a continuous real-time temperature sensor located up-stream of the flow line becomes the primary kick indication in a geothermal drilling activity. The improvement of the sensor instrument and the location of the sensor will be the challenge for the industry to accurately provide the data in reliable outcome.

- The historical data advised that there were still possibilities of well control occurrence during the non-broken U-Tube situation, i.e. full circulation in a geothermal drilling activity. This will drive awareness that common three positive well kick indications might still be observed, as consequences its related equipment and sensor will be required to early detect the well control event. Further implication will apply that all well killing process using constant bottom hole pressure principles can be performed.

- Primary well control in a geothermal drilling activity will be fall in to the availability of cold fluid and its consistent deliverability to the well. This would be truly correct considering the empirical original reservoir pressure of commercial geothermal field is below water gradient i.e. sub normal. Pumping the cold water to kill a well control case in a geothermal drilling activity by means through both drill string and annulus will absorb the heat and condense the steam vapor to liquid and will establish the fluid column to overcome the reservoir pressure. Reservoir engineering work could assist to pre-calculate the maximum cold fluid requirement for a certain geothermal well/field.

- Other instrument for industry consideration is the real time annulus pressure monitoring while drilling. Though it will not provide direct indication by means of well kick occurrences, but it could provide the fluid column in the annulus at any time that play important role to keep the well in control.

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