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TECHNOLOGY****WELL CONTROL STRATEGY PLAN FOR BLOCK VIII, DINDIR – SUDAN****Ahmed A. Ibrahim, Shazaly S. Ahmed and Fatima A. Eltigani**Sudan University of Science and Technology, Faculty of Petroleum Engineering and
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ABSTRACT

Well control problems plagued the petroleum industry since it is infancy and known as losses of valuable resources, costs increasing, environmental damages, personnel casualties. The objective of this research is to develop well control strategy for block-8 depending on Twakul-1 well analysis of control problem occurred. Studying the wire line data to determine high pressure regions then confirm the pressure points data using well test data. Wire line data have been matches with each other justifying normal trend lines exist in subnormal region. Based on pressure analysis resulted balanced and safe mud weights were illustrated. Volumetric stripping method has been applied to kill the well. It is a complex technique combining volumetric method and stripping operation. It is worth mentioning; this method not common in the oil industry and is the first time to be applied in the Sudan. Well control strategy has been developed to help prevent and ease of dealing with such problems in future for Block-8, Dindir - Sudan. This well control strategy include four sections as equipments, alarms, procedures and training at rig site. **Finally**; it is a future prospective to have Sudanese well control, blowout and fire fighting strategies.

KEYWORDS: Well control, volumetric stripping, equipments, alarm, procedures and training.**INTRODUCTION**

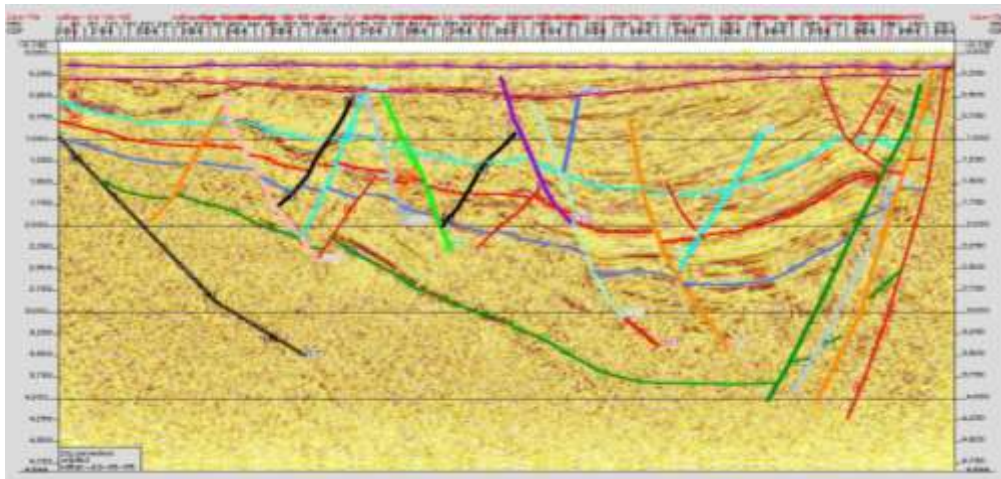
Strategy, a word of military origin, refers to a plan of action designed to achieve a particular goal, therefore our goal is to complete wells drilling operation safely without the occurrence of blow out problems. This aim can only be achieved if control of the well is maintained at all times to avoid losses of valuable resources, decrease drilling costs, avoid environmental damage, decreased regulations, avoid personel injuries and safe employees life (Robert; 1994). The understanding of pressure and pressure relationships is important in preventing blowout by experienced personnel's that are able to detect the well is kicking and take proper and prompt actions to shut-in the well. In some well control situations if drill string is not on bottom hole, neither the drill pipe or the casing pressure gauges are a reliable guide to bottom hole pressure. Without a good knowledge of the bottom hole pressures it is possible to allow the formation to go under balance and flow to get a large Secondary influx. This problem can be avoided if the bit is returned to bottom before or while well killing. The technique that allows us to strip back to bottom whilst safely maintaining control of the well while keeping the BOP closed is called volumetric stripping method . Block-8 is located in the Eastern part of Sudan which was firstly explored by Chevron Company and drilling of Dindir-1 well in 1983. Chevron suspended the operation because of the security issues and had to depart Sudan; White Nile Petroleum Operating Company (WNPOC) took over and continued exploration drilling in the block. Nine wells were drilled and as a result major amount of gas was discovered in Hosan-1 and Tawakul-1 wells. Tawakul-1 is the Sixth WNPOC's wildcat well and is the subject of study concern. The well proposed to test the hydrocarbon potential of the Jurassic/Cretaceous petroleum system of the western slope of the basin as stated in prespud meeting. Sudan fields generally has low pressure and no many well control records, but up-to-date there were two kicks as stated in daily drilling report records (WNPOC, 2009B and WNPOC, 2009C). In block-8 out of the ten drilled explore wells which representing 20% of total wells. This study is working on determining the kick

root causes, data evaluation, and develops control strategy. Proactive measurements have to be done in order to avoid problem and determine killing calculation (if needed) to save personal, equipment and reduce well cost.

General Geological Description (Blue Nile Basin)

The Blue Nile basin originated in an area of Neoproterozoic rocks aged about 750Ma that had become a peneplain, possibly during the Paleozoic era (540 - 250Ma). The basin was formed due to rifting during the Mesozoic era (250 - 65Ma). Between the Triassic and early Jurassic, about 300m of fluvial sediments were deposited by rivers and streams. During the Jurassic (200 - 145Ma) the basin was twice covered by an arm of the Indian Ocean for extended periods, creating a lower limestone sediment 450m thick and an upper limestone sediment 400m. In the late Jurassic and early Cretaceous period the basin rose, and the 280m upper sandstone sediments are alluvial or fluvial. In total, about 1.4km of sediment was deposited over the basement rocks in this period. Later, the Afar mantle plume caused volcanic eruptions in the early and late Oligocene (34 - 23Ma), depositing volcanic rocks between 500 ~ 2000m thick, with further eruptions in the Quaternary depositing another 300m of rock (GANI et. al., 2008). Block-8 is a part of Blue Nile basin characterized by very complex geological structure, as stated in Seismic cross-sections for Block-8 area explain many major and minor faults, figure (1), (ZPEB Cooperation-Sudan, 2008)

Figure-1: 2D seismic section in block-8, (ZPEB Cooperation-Sudan, 2008).

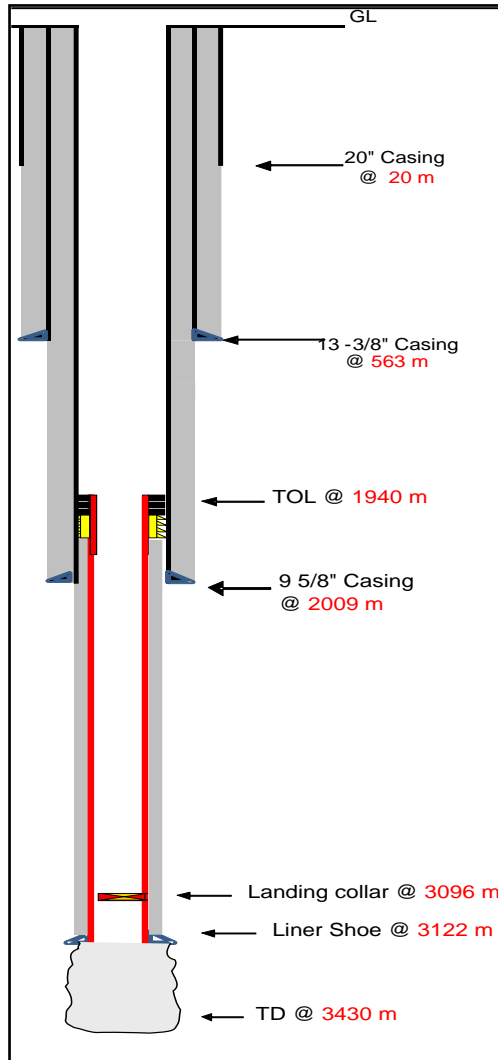


Tawakul-1 Well Data Acquisition

Casing Schematic: The casing schematic for tawakul-1 as stated in final well report (WNPOC, 2009A), figure (2) is acceptable because there are three stages: surface, intermediate and production sections feature makes drilling easier when moving from sand to clay layers. Present of long open hole sections for long time increase the probability of stability problems; also decreases trip time due to increase running speed in cased hole. However, there are some observations regarding completion to the production section with liner instead of normal casing especially call total depth to 3122m instead of 3430m. The well casing profile has the following characteristics:

- Conductor Casing: Size 20 Csg, Weight 68ppf and Grade K-55.
- Surface Casing: Size 13 3/8" Csg, Weight 68ppf, Grade K-55 and thread BTC.
- Intermediate Casing: Size 9 5/8" Csg, Weight 47ppf, Grade L-80 and Thread BTC.

- Production Casing: Size 7" Liner Csg, Weight 29ppf, Grade L-80 and Thread BTC.
- Figure-2: Tawakul-1 Casing Schematic (WNPOC, 2009A).**



Wire Line Data: Collected wire line logging (Resistivity, GR and Sonic) data were imported from the log lass file . These digits have to be frizzed and assured log operation quality by run of normal scale plotted as figure (3).

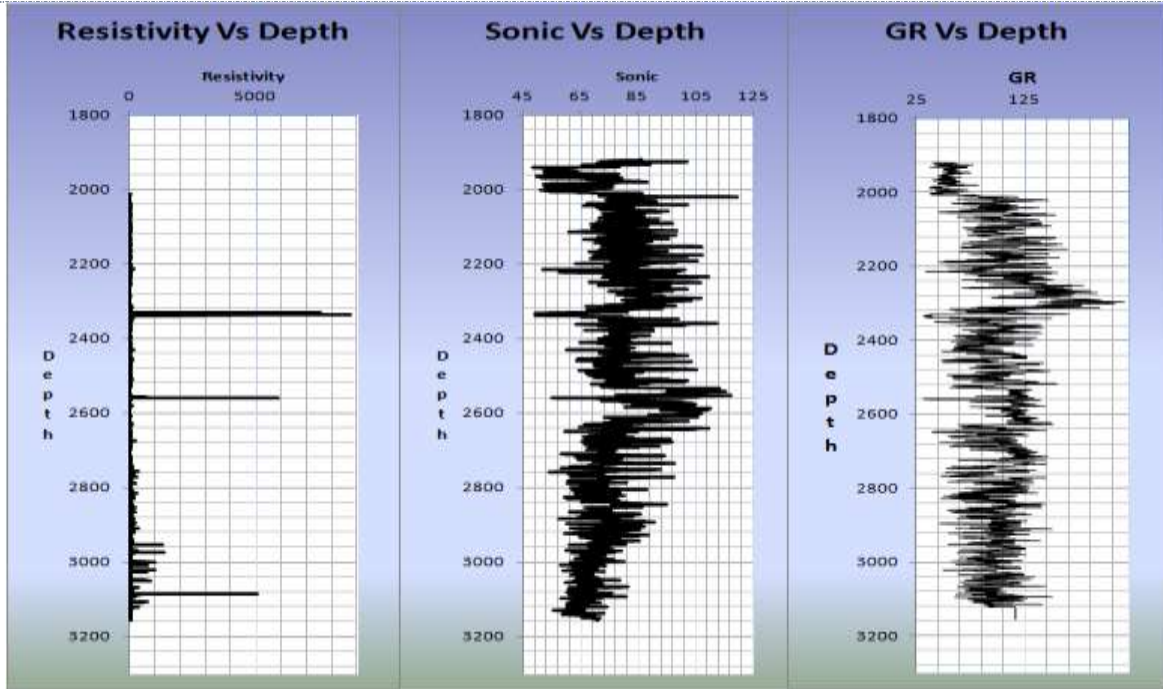


Figure-3: Wire Line Data (GR – Sonic and Resistivity) Vs Depth.

Formation Pressure: Formation pressure taken from wire line pressure test points XPT and MDT where the number of total points was 96 points, 66 pretests were valid, 21 tight, 5 lost seal, 3 dry and 1 super charged as stated in MDT and XPT wire line data. These digits have to be frizzed and assured the quality of log operation by normal scale plotted as figure (4).

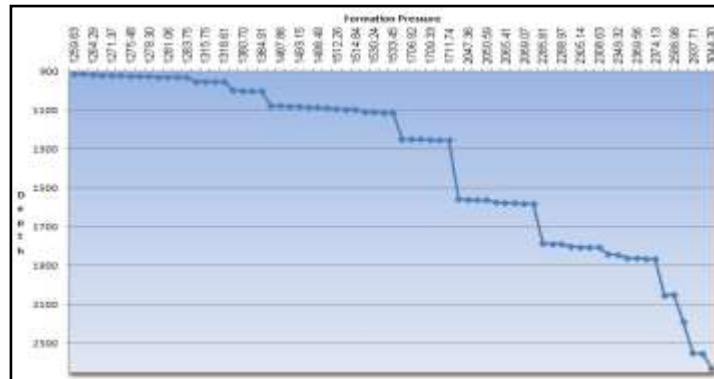


Figure-4: Formation Pressure Vs Depth.

DST Data: Originally two intervals were proposed to be tested; however due to low rate of the Drill Stem Test (DST#2) the test has to be redone as DST#2a. The build up period was selected from well testing data, which contains change in the time versus pressure during build up period as collected from build up period data sheet (2009) therefore these digital have to be frizzed and assure the quality of operation by normal scale plotted as figure (5).

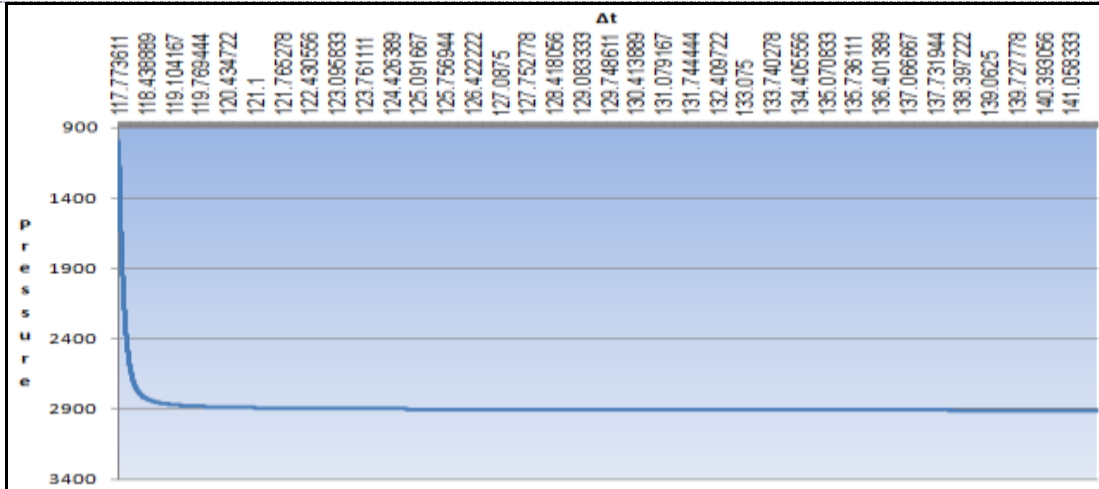


Figure-5: Time interval Δt Vs Pressure - Testing Data

This scheme does not lead us to any result unless it is done in Horner Plot to find initial reservoir pressure (Rajagopal,1993).

Above data have been applied to calculate safe mud weight and killing calculation through pressure analysis using wire line data to identify abnormal pressure zones, if any, and then calculate the safe mud weight. Figure (3), shows the information of GR, Sonic and resistivity for main hole were plotted in semi – log scale to identify areas of trend deviation from normal track line (Schlumberger, 1991). Correlation of the GR, Sonic and Resistivity trends identified there is a deviation of trend line at 2300, 2550 and 2600m depth to the left side for each of the GR and Resistivity graphs, and to the right in Sonic graph these findings indicated the presence of a high pressure zone.

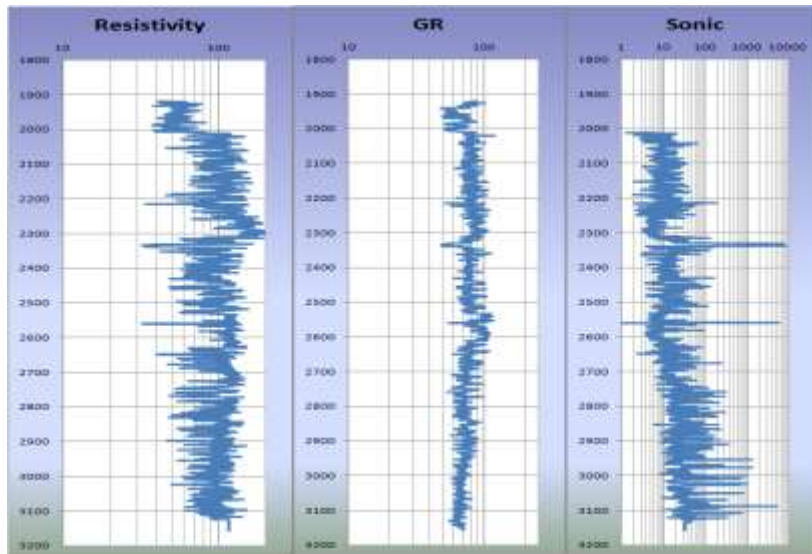


Figure-6 : GR, Sonic and Resistivity Vs Depth plotted in semi log Scale.

Horner and MBH method was used to correlate its outputs with the wire line logs as the following equation: $\text{Log}((t_p + \Delta t) / \Delta t)$ as t_p is production time and Δt is change in time during buildup period (Amanat, 2004); then the Horner Plot was illustrated as figure (7).

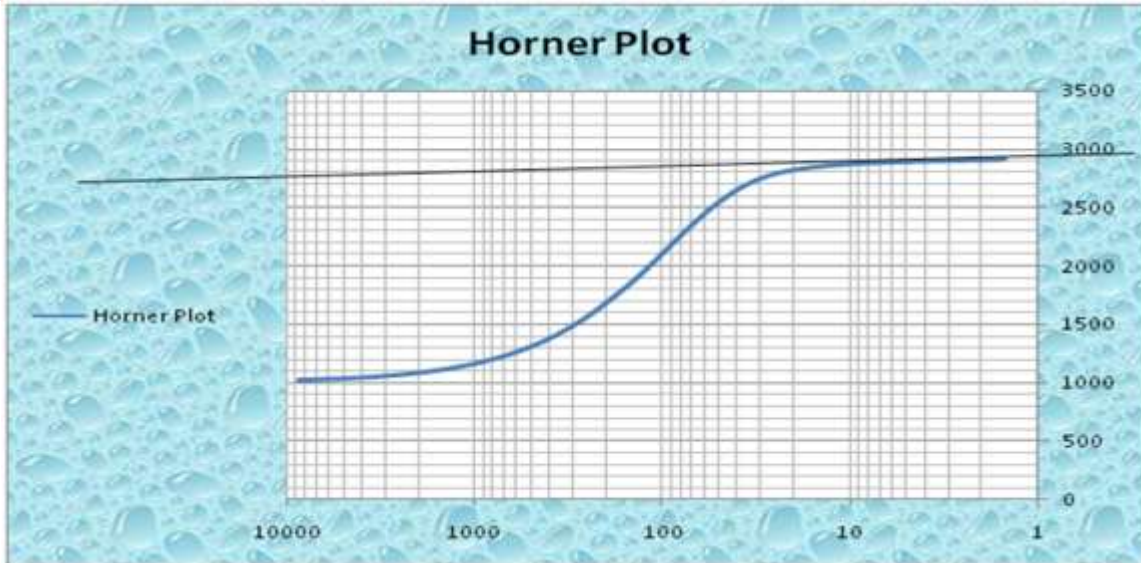


Figure-7: Horner Plot

For an infinite-acting reservoir, an estimate of p_t is obtained by extrapolating the straight-line section of the Horner plot to infinite shut-in time (obtained reservoir pressure equal 2920psi). Matching of results (well test and wire line data) indicated to almost same values considering depth different, as wire line logging value is 3044psi@2428m, while the pressure calculated from DST data is 2920psi@2414 – 2425m and 2449 – 2459m. As a trusted result, wire line data (XPT) have been taken as a reference to calculate safe mud weight, figures (8 and 9).

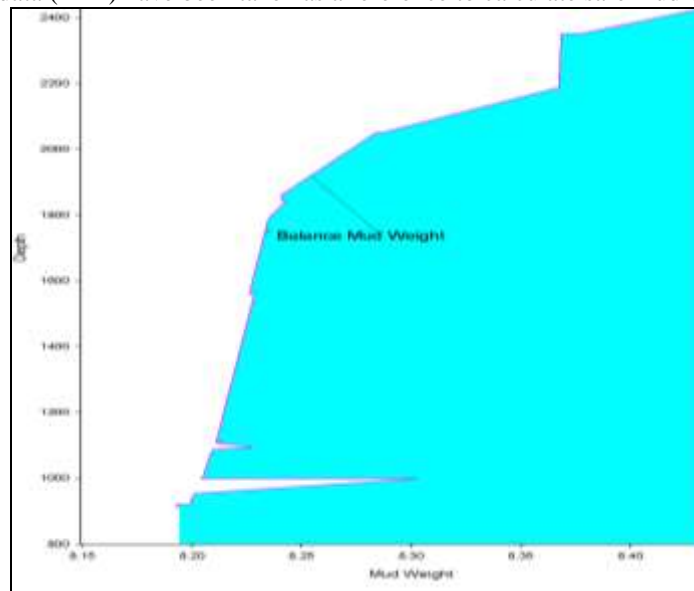


Figure-8: Balance Mud Weight Vs Depth

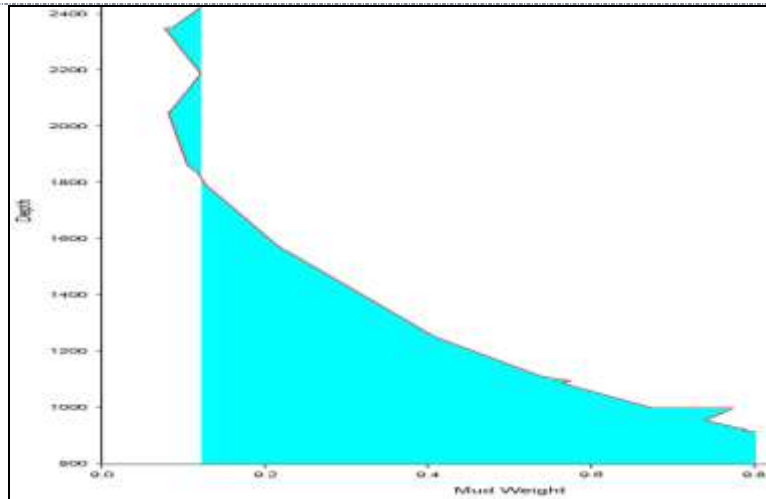


Figure-9: Safe mud weight Vs Depth

Obviously as figures (8 and 9) outcomes the pressure balance range from 8.433ppg@2428m to 8.193ppg@915m, accordingly, save mud weight range from 9.1ppg@2350m to 9.8ppg@911m. It seems presence of elevated pressure zones in wire line, while calculated mud weight values with in normal pressure range, as a result of pressure gradients the ranging were from subnormal to normal pressure (no abnormal pressure value encountered) . **log interpretation concluded to:** there was large amount of gas enter the well bore and/or back ground gas leading to kick situation due to large amount of micro de-bonding annulus and very bad cement quality as U-Suit log.

Volumetric Stripping Strategy

Operation background and assumptions: After setting the liner in Tawakul-1 well and pulling out of hole with 5"DP the driller noticed some bubbles increasing gradually, decided and continued pulling out of hole till surface, lay down liner running tool. As gas have been increased, started ran in hole with DP's using a float valve to 342m, the well start to flow. Shut the well in with 750psi as casing pressure (SICP) which increased gradually to 1600psi. The mud weight (MW) was 10.7ppg below top of liner and 8.6ppg above top of liner. The Hole diameter is 8.5in and the casing diameter is 7/6.184in. The previous hole diameter is 12.25in and casing diameter is 9.625/8.681in. The Hole measure depth (MD) is 11253.8ft, the total vertical depth (TVD) is 9485.4ft and the liner top at 6366ft (WNPOC; 2009C). Bit gain assumed to be 30bbbls as it is not available in all reports and influx considered as gas with gradient of 0.1psi/ft.

Pressure distribution and formation break down value: Once the height of the influx is known, shut in casing pressure stabilizes at 750psi and the rest of the well till top of liner is full of 8.6ppg or 0.4472psi/ft drilling fluid. Calculated bottom hole pressure is 3455psi is sufficient to keep the well under control as equivalent mud weight (EMW) 14.4ppg (max pressure 4767psi at shoe). The gas migration, shut-in casing increase gradually and accordingly casing shoe pressure (top of liner) increase with same amount till maximum SICP 2200psi which it is the formation break down value.

Volumetric Method: As initial shut-in the top of liner pressure was 3455psi (plus 50psi overpressure safety factor). Volumetric method excusion through reducing the hydrostatic pressure (100psi) through removing the equivalent height of mud (bleed off 16.4bbbls - 223.5ft of mud) and then close in the well to let gas to migrate and expand with casing pressure increase with 100psi as indicator with good control of the choke whilst bleeding off the mud to allow the bottom hole pressure to reduce by calculated amount. This process of allowing the casing pressure to build and then bleeding off the fixed volume whilst holding the casing pressure constant is repeated until the influx is at surface. It is important during all this to maintain a record of times, pressures and volumes, figures (10 and 11).

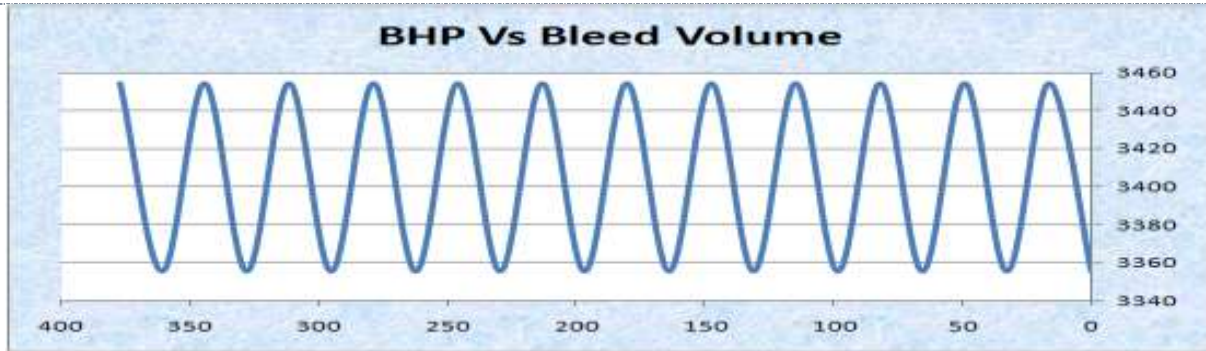


Figure-10 : Bottom hole pressure Vs Bleed Volume.

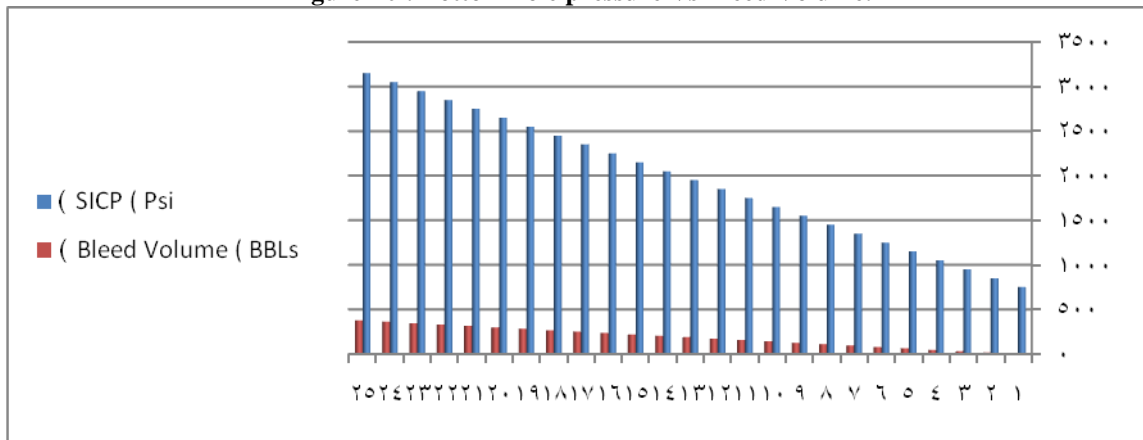


Figure-11: SICP and Bleed Volume.

Once the influx at surface it is not allowable to bleed off any further mud whilst holding the casing pressure constant (the approach has to change). The casing pressure must be maintained to keep the well under control. The pressure applied at the choke should now be replaced by mud hydrostatic. Again need to calculate the hydrostatic pressure supplied by the mud volume. The mud is allowed to fall through the gas in the well and any increase in casing pressure caused by the pumping should be noted. Once the mud has settled the casing pressure can be bled back to its previous value, prior to pumping the mud. It can then be further reduced by the hydrostatic pressure supplied by the mud pumped. If mud comes back whilst bleeding down the pressure then the well must be shut in. Further time should be allowed for the mud to fall through the gas. Loss of mud at this stage would reduce the hydrostatic balance and thus the bottom hole pressure. This process is repeated until the whole gas is bled. Then the control Cycle Hydrostatic Pressure per Barrel of mud pumped in upper annulus must be 6.1psi/bbl.

Combined Volumetric/Stripping Operation: Assuming a situation where whilst tripping out of the hole the well started to flow. Once the well was shut in, both with the annular preventer and an inside BOP, acting downwards to circulate out the influx. If the casing pressure increase with time then gas migration is happening. The pipes would be stripped in through the annular or two pipe rams. The casing pressure would be controlled. It would be held as close as possible to the shut in pressure assuring the hydrostatic balance was maintained. Whilst stripping in, the well is effectively a closed container. In order to maintain the constant casing pressure it should only be necessary to bleed off the closed end displacement of the drill pipe. If everything goes correctly, records should show that whilst maintaining the constant casing pressure the volume of mud returned is the same as the volume of the pipe stripped in.

In combined method Must Allow for gas migration, pipe volume and BHA to inter influx. This first approach to stripping operations has one major mistake, when the BHA enters the influx the height of the influx is changed and this affects the hydrostatic balance. This problem could be overcome if use the combined volumetric stripping technique. The combined method allows for both gas migration and the displacement of mud from the well by the drill pipe. In addition it anticipates the change in the hydrostatic pressures as the BHA enters the influx and

incorporates a simple safety factor to allow for this. Assess the situation at top of liner (6366ft) just before the BHA enters the influx during the stripping operation; assumed a ten barrel influx in the 9 5/8 in diameter cased hole section of the well and this would give an influx height of 410ft. Also assume that the influx is gas with a gradient of 0.1 psi/ft, can do exactly the same hydrostatic sum that in the above volumetric well control calculation to find the bottom hole pressure. Assessing the situation just after the BHA has been stripped into the influx and during this stripping operation the casing pressure is being held constant at 750psi. Not to mention that the open hole capacity was 0.0732 bbl/ft and the drill pipe annulus capacity is more than half (0.0665 bbl/ft), this means that when the influx goes below the collars it grows in height from 410ft to 451.2ft. The influx still occupies the same volume so its density remains unchanged. This means that even though the casing pressure held constant at 750psi the bottom hole pressure dropped by over 15psi.

Pressure Safety Factor (Psaf): Fortunately because the annular capacities and the volume of the influx were already known, thus safety factor (**Psaf**) has been calculated before kick happens to equal 0.0023psi by multiplying height different (0.0067ft) and gradient different (0.3472psi/ft).

Similarly volume of mud to bleed off to allow for the gas migration (Vstep) and pressure step increments (Pstep) has been calculated. According to rig pressure gauge configuration, Pstep has been chosen in the range 50 – 100 psi, considering the influx in the worst place, alongside the drill collar generally and in the top of liner in our case due to packer isolation failure. After the well has been shut in the rig must be prepared to implement the standard volumetric well control procedures. They can then decide whether or not combined volumetric stripping is possible. The weight of the drill string in the well must be greater than the upward force due to the SICP and the annular friction. The up force is determined from the area of the item in the BOP and the force acting on it. The diameter (Diam) of the item is used to find its area. The friction from the annular BOP is best determined from stripping drills. If combined volumetric stripping is not possible then the rig must continue with volumetric well control procedures. In this case mud report mentioned observed gas bubbles during pull out of hole with liner running tool but unfortunately do not mention the depth to determine string weight in the hole to decide which method can be applied.

Upward force has been calculated as 109296Ib

Single 5"HWDP Weight per meter	= 72.2 kg/m = 159.174 Ib/m
Single 5"DP Weight per meter	= 29.01 kg/m = 63.9561 Ib/m
5" HWDP length as per tally	= 213.5 m
5" HWDP weight	= 33984 Ib
Remaining weight to balance upward force	= 75312 Ib
Meters of DP to balance upward force	= 1178 m

Still have 1390m or more of string in the hole (Pull out of hole till 57 joints of drill pipe as per tally) when bubbles observed, it is strongly recommended to proceed with volumetric stripping method, but If pull out of hole with more than 57 joints of drill pipe it is recommended to proceed with normal volumetric well control method.

Well Control Equipments Strategy

Well control equipments include: type, arrangement, pressure rate and some practice to avoid same problem in future. Using graphics to illustrate the BOP's parts for each section, writing sizes and working pressure because the graphics more clarification than writing, especially in the equipments.

BOP Arrangement and specifications: The well control equipments required at the start of drilling the well or 17-1/2 inches diameter and because the weak formations at the beginning of the well, the well control instruments or system used are diverter system (To divert kick) instead of BOP's system. Generally proposed well head is slip lock type and firstly lay down first section spool (20in × 21.25in) and then install new well head (13-3/8in × 13-5/8in). It is very important that there be consistency between the values of pressure in the well head and BOP because it is usually use less working value as working pressure. Figure (12) shows the well control equipments required to drill main hole or 8-1/2in hole. It is a good practice to put one of pipe rams below spool and that in case of valves emergency maintenance in the kill or choke lines and also to give more options in case of stripping operation.

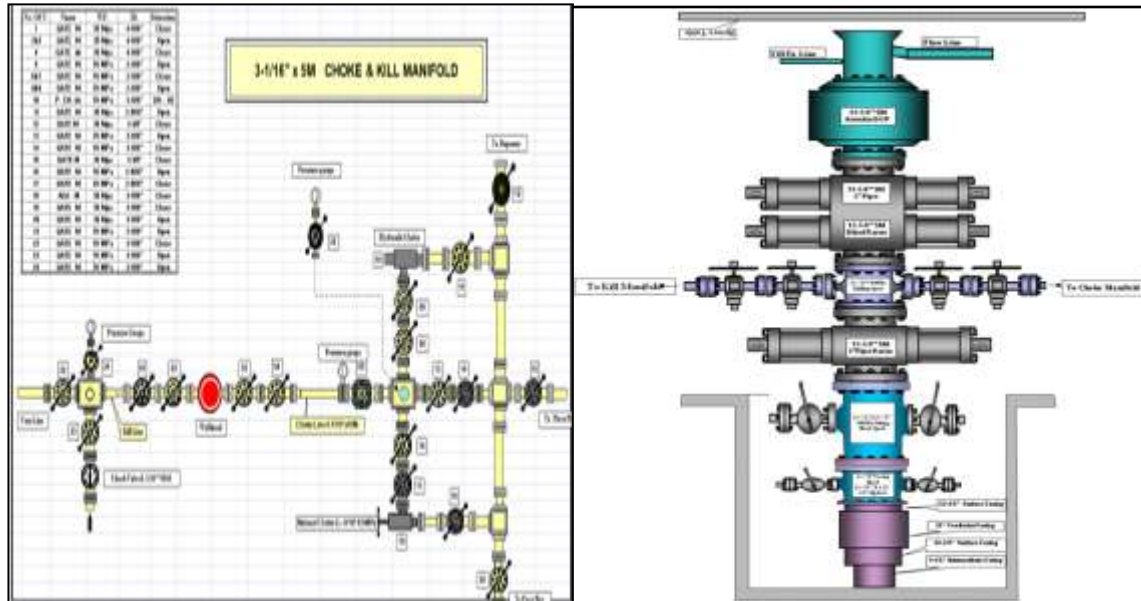


Figure-12: Proposed BOP Stack, Kill and choke manifold for 8-1/2in main hole.

Accumulator Unit: The purpose of an Accumulator Control System is to provide closing and opening power to the Blow-out Preventer Stack. The majority of systems are hydraulic. They are designed to close the Stack quickly and once closed to maintain closing pressure. Closing pressures can be adjusted according to type of equipment and operation in progress (Chevron Drilling Technology Center, 1994). API RP 53 recommends for Surface Stacks that a System should have capacity to (WITH PUMP OFF): Close annular, Close all rams, and Open one HCR. Remaining pressure shall be at least 200psi above pre-charge pressure. The volume of fluid stored in each 11 gallons accumulator bottles (10 gal nominal weight) calculated to be 6.6gal (3.4gal of nitrogen). The usable fluid to 1200psi should be 8.4 gal of Nitrogen and the remaining control fluid is 1.6gal. Therefore by subtracting the remaining control fluid from the stored fluid gives the usable fluid, which is 5gal noting that the 5gal of fluid is half total volume.

Mud Gas Separator Size: Three types of mud/gas separators commonly are used today: closed bottom, open bottom, and float types (MacDougall and Chevron Canada Resources Ltd, 1991). Float-type mud/gas separators are not recommended due to some inherent problems in the use, a closed-bottom separator is preferred and Open-bottom separators are acceptable. Maximum flow rate (Q_{max}) suppose to be handled by mud gas separator has been calculated as 6.8BBL/min depends on slow pump rate and pump out put values (598psi@55SPM and 0.1243BBL/Stk respectively); considering Separator Body initial a 36in diameter ID and 7in Vent Line ID consisting 200ft with 7in ID with three sharp right bends. Then the Gas Vent Line effective length should be 410ft (defined as total Vent Line plus equivalent length of corners, bends,....etc).

Peak Gas Flow rate calculation: Using driller method, max pressure of gas in upstream of choke have been calculated equal 1750psi and max gas volume for upstream equal 75.9bbls. The Time to pump gas out of the well will be 11.16 minutes, The Volume Of gas down stream of choke will be 9036bbls and then the Peak gas flow rate calculated 6549336ft³/day.

Vent Line Friction Pressure Calculation: Friction pressure losses has been calculated as 1.07×10^{-8} Psi

Mud Leg Calculation:

Assume all kick is dry gas, then the fluid gradient is 0.26psi/f which means that the minimum mud leg required (P_{ml}) will be 1.8psi, Where it is clear $P_{ml} > P_f$ ($1.8 > 1.07 \times 10^{-8}$) then blow-through condition will not exist. The minimum mud leg required has to be 4.115×10^{-8} ft and the minimum Separator ID 40.58in. Calculation included to use close bottom type separator, minimum body ID 40.58in, minimum Vent Line ID 7in and minimum mud leg or U-tube length to be three feet to be sufficient to handle worse-case kick properly in this area.

Well Control Alarms Strategy:

Well kick alarms which are installed to indicate the well is flowing are predominately fit. This is to inform the Driller and rig floor crew of a serious event occurring. These alarms initiate a sequence of actions (regarding the rig floor crews) are required to undertake in order to “secure” the well. In these situations time is of the essence, the alarm initiates actions immediately without further communication being necessary and can be as simple as a horn blowing on the rig floor (**Mud Flow Alarm, Mud Loss/Gain Alarm, Gas Alarm and General Alarms**).

Emergency Procedure Strategy:

Once there are any foreshows or signs of overflow, well kick or blowout by witness, report promptly the matters to driller on duty. The driller shall, in conformity to the well control regulations, sound a siren of well control. Any person on site hearing the sound of siren shall gather in a certain position specified in advance, and shall take due measures to control the wellhead under the sole instruction of the driller. After hearing the sound of siren, the emergency team shall run to well site as soon as possible to fulfill well shut-in and any other handling measures. All persons in camp shall get together at the specified place. Contractor head of emergency team on site shall report the situation to operator’s supervisor. Once blowout is out of control, staff on well site shall escape to safety area or Master point as figure (13). Inform the potentially threatened divisions or persons to evacuate from the potential dangerous area and report the serious situation to local authorities. After the blowout alarm is cleared, emergency team on site shall report to the site representative.

Note: Only key personnel (Drilling Supervisor, rig manager, on duty Tool pusher, on duty Driller, floor man, mud engineer and pump man) to be at the well area. Other non-essential personnel are required to assemble in the designated area downward of wind direction.

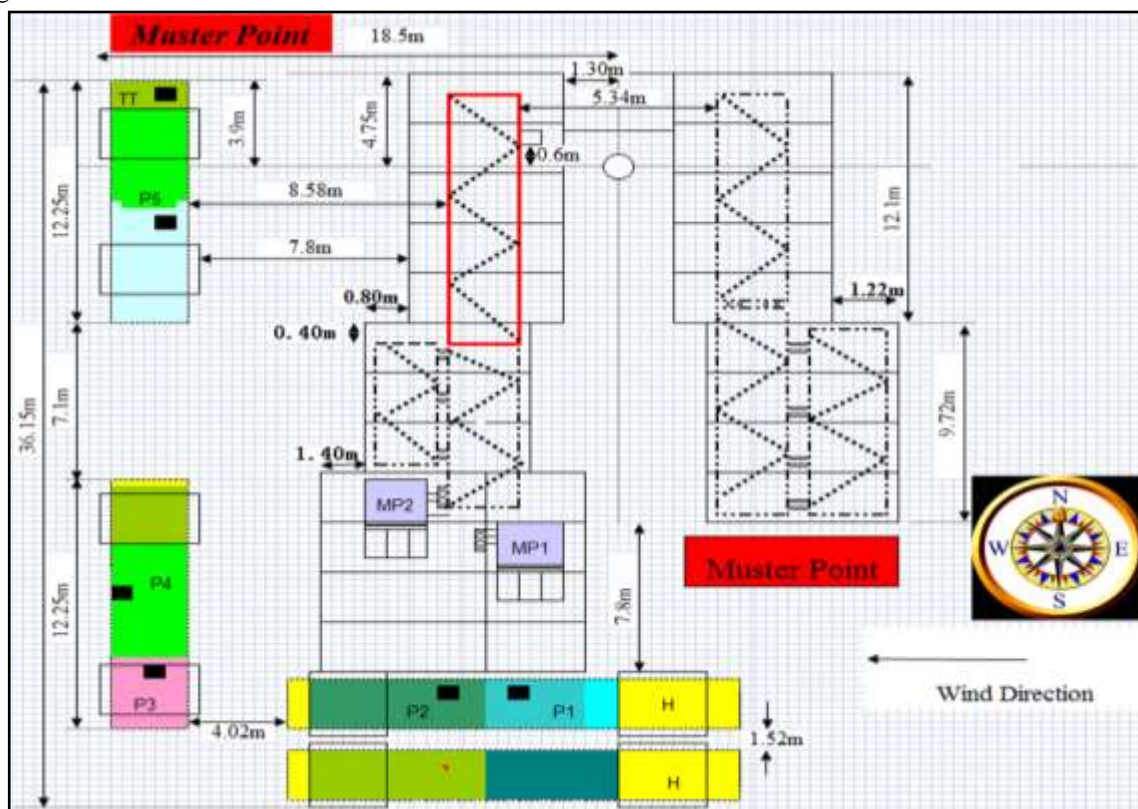


Figure-13: Well Site Lay out and Muster Points.

Emergency procedures of Hydrogen Sulfide (H₂S) on well site: In case H₂S detector or geological logging instruments give an alarm of H₂S, the operator of the instrument shall report this situation to the driller and sound the alarm. The driller, upon being reported the H₂S foreshow, shall stop any operation, and shall shut in well. All people except driller and bench worker with mask shall run to the up-wind direction. Emergency team shall run to well site to check H₂S content, head of the team shall report the same to supervisor of the operator at the same time. If the content of H₂S is below 10mg/l, Close observation shall be conducted regularly to decide whether the

production can be started. If however, that content is above 10mg/l, well shall be killed by circulation till H₂S gas invasion is under control; If the alarm of H₂S is cleared, team on site shall report to the site representative and render a final report.

Emergency Team and Evacuation Plan: Firstly Eestablish the emergency evacuation group as Group heads (Drilling Supervisor and rig manager) and Group members (Safetyman, Drilling engineer, Tool pushers, Campos's, Mechanic, Drillers, Data Engineer, First mud Engineer and Service companies Field Engineer).

Ensured measures:

1. All the vehicles on location should be in good condition, the diesel tanks should be fully filled and one barrel of spare diesel should be carried on the vehicles to ensure all the vehicles standby for 24 hours.
2. There should be enough emergency materials at campsite; the emergency materials should be kept and carried by special person.
3. All the staffs should know what the emergency signals mean by regular drills conducted.
4. All the personnel should listen to the designated person.
5. A red flag should be put up on the evacuation vehicle, every evacuation vehicle should be equipped with a radio so as to keep in touch with each other.
6. While evacuating, carry the radio, if attacked, stop any operation and fall down at muster point. Don't resist and keep communication as planned. If attacked at night, stop operation, turn off the derrick lights and make an alarm for 3 minutes.
7. If the condition permit, call for help and report to group heads.
8. Organize the staff to evacuate as pre-planned right away.
9. Rig Supervisor is the general responsible person at well site, evacuation should be under his command with cooperation with the rig manager.
10. All the people at well site should muster at the designated spot (as per figure 13) and count the number before evacuation.

Evacuation plan

1. Evacuation route : Location→Main camp→Dindir →Khartoum ;
2. The sequence of evacuation Supervisor car – rig manager car - rig's car (include bus-minibus and trucks if any) – service company car.
3. Personnel arrangement Supervisor car: driver, supervisor, geologist, mud engineer, all Data log guys.
4. Rig Manager Car: rig manager, safetyman, engineer and mechanic.
5. Rig car: driver, foreman, 2 electricians.
6. Bus: Campos's, cook, doctor, all shift members.
7. Minibus: driver, western cook, Sudanese cook, foods and water & all other employees.
8. SLB Car: SLB crew.

Well Control Training Strategy @ Rig Site

Pit Drill: The purpose of this drill is to reduce the time required for the Driller to detect and react. After the BOP is installed, this drill must be held with each crew until they are thoroughly familiar with the procedure and then regularly to increase the performance. This drill is training for emergency well control case. While drilling on bottom, without prior notice, the active pit level is to be gradually increased by manually raising the mud pit level float, or by pumping mud from the trip tank to the active system. The Driller, Drill Crew, and Mud Loggers should recognize a 10bbl pit gain within 1 minute and shut in the well within an additional minute by performing the following:

1. Detect the kick and sound the alarm.
2. Record the time to detect the pit level gain (goal is 1 minute or less).
3. Pick-up the drill string off bottom spacing-out the tool joint as required.
4. Shut down the pumps and check the well for flow.
5. If flowing, shut-in the well by opening the HCV valve and closing the Annular BOP in one motion. Make sure all valves downstream of the power choke(s) are closed.
6. Immediately notify Drilling Supervisor and Rig Manager.
7. Record SIDP and SICP and pit level gain.
8. Assess and review proficiency of drill with crew members.
9. Log drill and reaction time on the IADC and Daily Drilling Reports.

Trip Drill: The purpose of this drill is to reduce the time required for the Driller to detect and react to an influx while tripping. After the BOP is installed, this drill must be held with each crew until they are thoroughly familiar with the procedure. While tripping and after the drill string has been pulled into the casing, without prior notice, the apparent trip tank level is to be gradually increased by manually raising the mud level float, or verbally notifying the Driller from the Trip Tank Hand or the Mud Logging unit (if being used) that an increase in trip tank level has occurred. The Driller, Drill Crew, and Mud Loggers should recognize a 10 bbl trip tank gain within 1 minute and shut in the well within an additional minute by performing the following:

1. Detect the kick and sound the alarm.
2. Record the time to detect the trip tank gain (goal is 1 minute or less).
3. Space-out the tool joint as required and set the slips.
4. Shut down the trip tank pump and check for flow back into the trip tank.
5. Stab open safety valve onto the drill pipe and make-up hand tight, close valve.
6. Shut-in the well by opening the HCV valve and closing the annular BOP in one motion. Torque-up safety valve. Make sure the choke manifold valve downstream of the power choke is closed.
7. Immediately notify Drilling Supervisor and Rig Manager.
8. Record the time to shut-in the well after flow is detected (goal is 1 minute or less to minimize influx volume).
9. Make-up Inside BOP onto safety valve, open safety valve (optional step).
10. Record gain in trip tank and shut-in casing pressure.
11. Assess and review proficiency of drill with crew members.
12. Log drill and reaction time on the IADC and Daily Drilling Reports.

Conclusions and Recommendations

- ❖ GR, Sonic and Resistivity data have been subjected to a very careful evaluation and analysis; interpretation showed pressure zones indication were found to be at 2300, 2550 and 2600m.
- ❖ Correlating the Wire line (XPT) data to the direct method (DST), where Horner's method was used to give reasonable match. That was an excellent indicator of data quality and the possibility of using the information as reference.
- ❖ GR, Sonic, resistivity and XPT wire line data have been matches to each other to justify the conflict and correcting the errors, which concluded to trend line was move from sub normal to normal appear as abnormal pressure region.
- ❖ XPT wire line data analysis proved the absence of high pressure zones, these results have been confirmed by DST operation, where the operation discharge large amount of the water inside the tubing to create higher under balance.
- ❖ Balance and safe mud weight have been calculated based on wire line data and pressure analysis.
- ❖ Cement bond evaluation based on CBL-VDL-CCL and U-SUIT data determined the intervals of kick gas; unfortunately, the study was unable to determine exact formations or sources that was because of the long time between end of killing operation and acquired the log .
- ❖ Volumetric stripping method have been applied to kill the well, it is worth mentioning this method is not common in the oil industry and it is the first time to be applied in Sudan, it is highly recommended for any similar case in future as stated by Shazly (2011).
- ❖ There are some bad practice led to the aggravation of the problem and recommendations for future as the following:
 - i. It is important to reverse circulate with mud and pull out of hole with running tool, then run in hole with scraper after cement become hard (compressive strength). Displace the hole with brine and anti-corrosion to maintain hydrostatic pressure for worst case (kick with packer failure at the same time).
 - ii. Monitoring the well during pull out of hole with running tool and assure that the well if kept full all the time. The study showed even if the well was displaced with 8.6ppg mud weight and kept full with brine, hydrostatic pressure equal formation pressure may establish.
 - iii. Incorrect first Action When Encounter gas flow, where the decision is to continue pull out of hole to lay down running tool. It is well control basics to go back to bottom or top of liner directly after gas observation to circulate out the influx. Long time resulted in more gas to enter the well bore and pressure build up.

- iv. Correct action is to use volumetric stripping operation as explained in killing calculation section if string weight in the hole equal or more than upward force. Even if the upward force more than string weight in the hole the correct action was to use volumetric method directly after shut in the well.
- v. It is not recommended to dump Mud Directly after Cement Job before pullout of hole with running tool (Mud weight 10.6ppg). For gas well wait until cement compressive strength reached.
- vi. It is necessary to keep a suitable amount of Barite for an emergency and drilling supervisor should check the stock with mud engineer before spud the well as part of check list.

Well control strategy has been developed to help prevent and ease of dealing with such problems in future for Block-8, Dindir – Sudan.

Finally this study has covered many parts of the Tawakul-1 well control problem, but there are still some questions unanswered in this endeavor, such as large amount of gas was burned during the drilling with mud weight more than 10ppg not to forget the low formation pressure. The much important question **why operating company insist on the use of liner instead of normal casing in all well even in shallow wells?**

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