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Comparative Study of Drilling Fluid Impact on Well Controls Methods For Deviated Wells, Gulf Of Suez, Egypt

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Abstract

This study aim to present comparative results between most common well control methods of actual case studies for various deviated wells at Bahar and Gulf of Suez fields and discuss the selection of well control methods. Beside all of previous the study will highlight comparison between previous well control methods in case of changing base fluid of the used drilling fluid from WBM to OBM in same wells with proven type of influx fluid (Oil/Gas) by using drilling simulator DS-20. The simulation give results for OBM impact on well control parameters and monitoring the effect of changing parameters on warning signs and kick detection and chock performance to re-evaluate the kick control procedures, In addition to present the practical recommendations for various well control scenarios to improve awareness for personnel and equipment safety to reduce the risk of blowout incidents.

Keywords: *Water Base Mud; Kick, Oil Base Mud; Wait and weight method; Driller's method; Gas solubility and Well Control.*

1. Introduction

In February 2015, drilling team initiate in drilling for first exploration well with directional drilling application at Behar field to maximize and develop the oil production in this area, which located in Gulf of Suez.

This well gives us opportunity to study and deal with the well control issues for first time in this field. As we know, uncontrolled influx of a well is considered abnormal situation during drilling operations that may take place in the hydrocarbon fields. There are many reasons that can lead to this situation like decreasing in mud weight, insufficient hole fill with mud, swab-bing or surging pressure which resulted by pipe movement speed in small clearance in well bore and loss of mud circulation [1].

Gas cut mud considered the worst scenario in case of drilling with oil base mud due to the ability of gas to be soluble in oil phase and lead to some problems in control operations during kick circulated out to surface [2-3].

The main objective of well control is to keep the bottom-hole pressure constant based on U-tube pattern to prevent further kick, These two techniques are very widespread as standard methods. Wait and weight (engineer / one circulation) method requires less circulation time and it decreases well bore pressures when heavy mud reaches annulus before influx circulated out and lower annular pressure rather than any other well control method but this method has limitation in gas expansion during weighting up the mud and preparing kill fluid with high weight could be get lack of chemicals additives on small land rigs or work over rigs [4-5].

On the other hand, Driller's method needs longer circulation time (at least complete two cycles of circulation) with simple calculations with no delaying time for mud preparation with high weight than existed in wellbore but has some limitations like long time to circulate the influx and force it out the well bore and poor chock controlling performance especially in case of O.B.M masked with gas influx further lead to washing out in chock assembly [6].

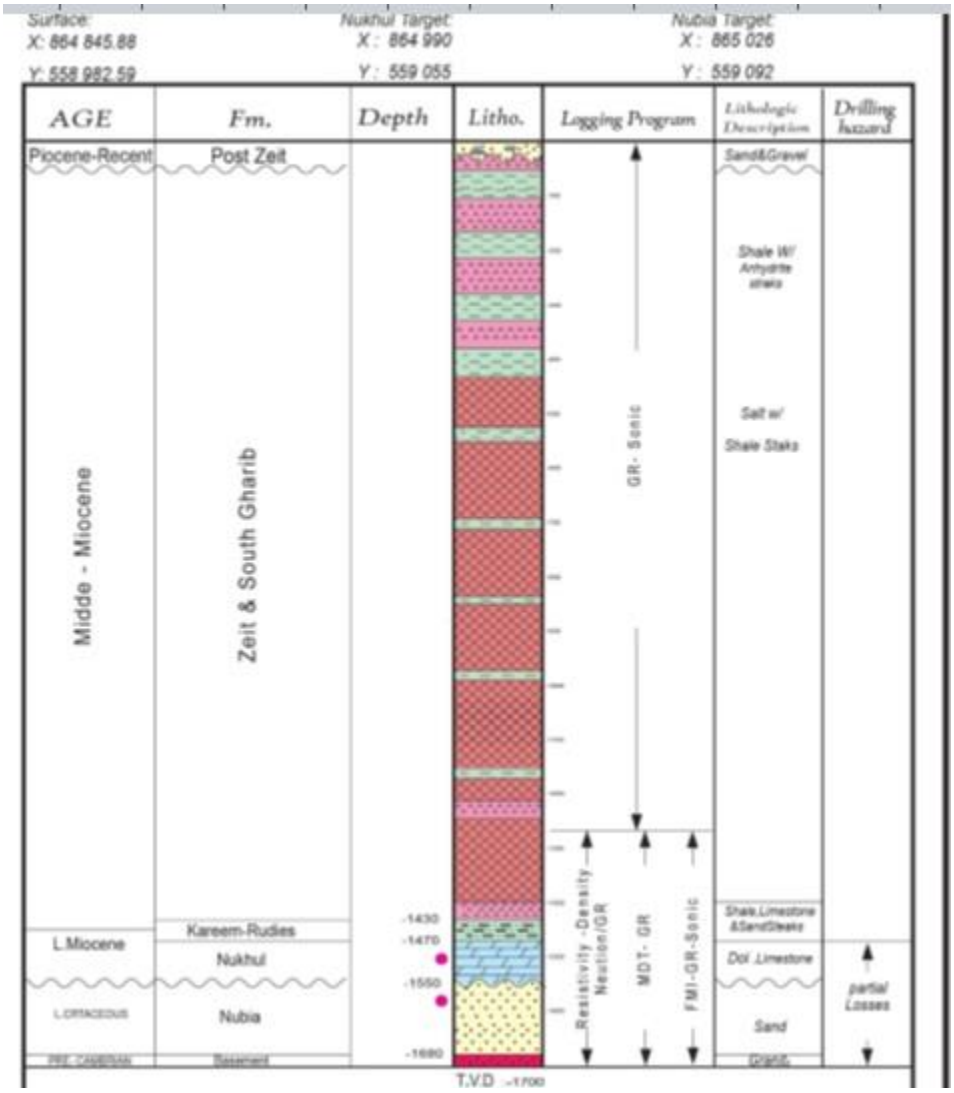

Figure 1. Predicted stratigraphic sequence of Behar Field

In proposed field study we drilled hole section with water base mud and faced well control issues with pit gain around 15 Bbl. in Kareem Formation at Behar Field, One of the fields in Gulf of Suez which most of oil production in this field comes from carbonate reservoirs, Kareem formation is considered one of these formations formed at Middle-Miocene age which consist of two members Shagr and Rahmi as shown in Figure 1, containing mainly lime stone with shale and sand streaks [7].

Like these zones could lead us face more complicated drilling problems like pipe sticking or well logging tool sticking problems, Sometimes drilling design consider these problems and try to handle it in developed wells in same field by switch over drilling fluid type from WBM to OBM for getting solutions to these problems which could result in suspend drilling operations time or lost down hole equipment, hence spending high financial cost if we take decision to perform fishing operations or P&A proposed well in worst cases.

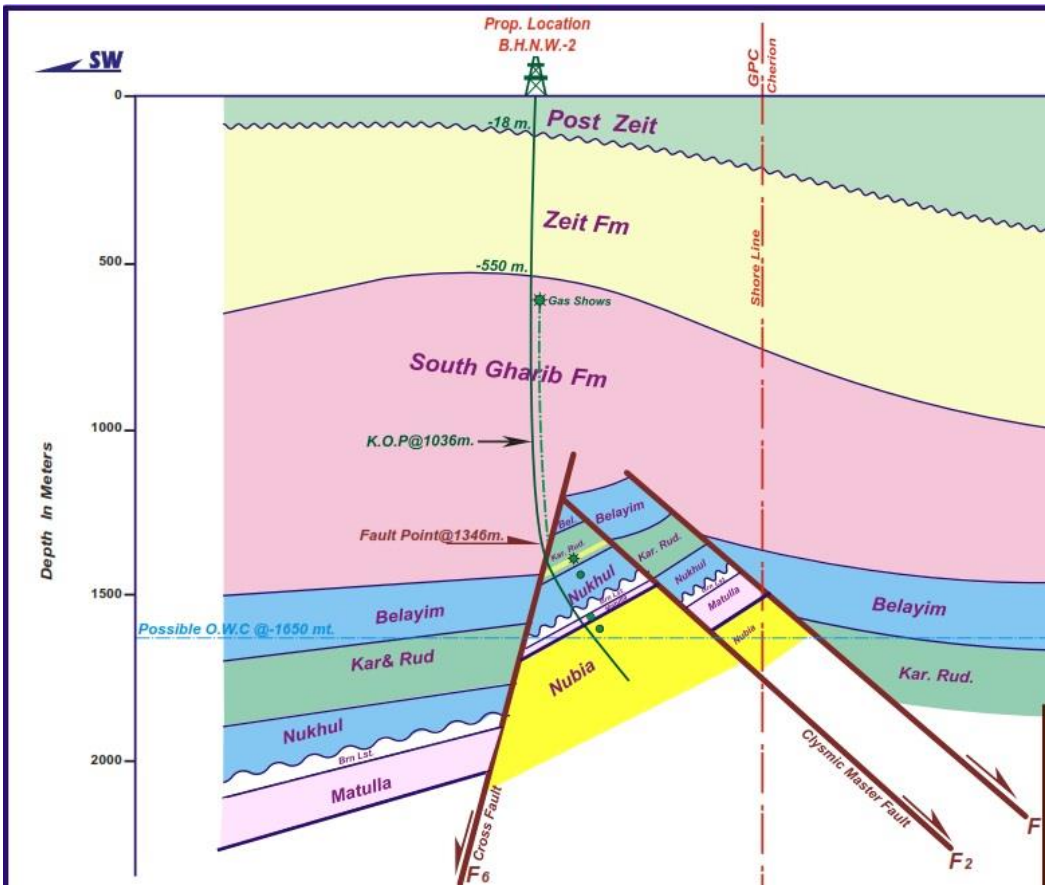

Figure 2. Geoseismic cross-section for proposed well.

Oil based mud as a term was firstly used as drilling fluid in 1920s, and in 1980s, OBM is optimized to synthetic based mud to minimize environmental impacts especially in offshore [8]. Oil based mud as a drilling fluid has many benefits compared with water-based mud like as follow:

1- Preventing clay content swelling and hydration and provide shale inhibition.
2- Reduce the formation damage if we reach targeted pay zone.
3- Support the well bore stability in case of directional angle building in deviated wells.
4- Improve drilling performance which can give high rate of penetration
5- Minimize corrosion factors like bacterial creation, which effect on down hole tubular.
6- Prevent stuck pipe, which occurred resulted from shale movement, due to continues phase is very high so minimize active shale exposure to dispersed phase (water) [9

Moreover some limitations must be take it strictly, we talk about oil as a flammable fluid which has low flash point as example for diesel 140^{O}F and exposure with hydrocarbon can be raise flash point degree to 200^{O}F then lead to initiate any fire at location if we didn't have any facilities to deal and handle this issue[1,9].

Shale inhibition is important target while penetrate active shale streaks due to ability of clay for sloughing and result in drill pipe sticking, The Idea from using OBM to support stability is make coating to shale particles and prevent it to face direct contact with water and dispersed water phase in oil can adjust salinity to minimize osmotic effect by equalize salinity of brine with formation water salinity and lead to good gauge bore hole, Meanwhile that must know how we can control the well and monitor chock performance during gas influx circulated out of the well [9].

2. Previous studies

The previous investigations show the difference between wait and weight method and driller's method which has gas influx in deviated and horizontal wells, well control methods

studies and simulations shed light on the problem of gas solubility and gas migrations as wait and weight method could be used to deal with gas migration with high influx volume compared with driller's method [10].

The problem of gas existing in well bore as influx is considered as gas has tendency to be soluble in oil phase with completely miscibility in drilling fluid and many previous studies are concerned this phenomena and one of this studies found a relationship between pressure and gas solubility, which has a linear increasing with moderated pressures [11].

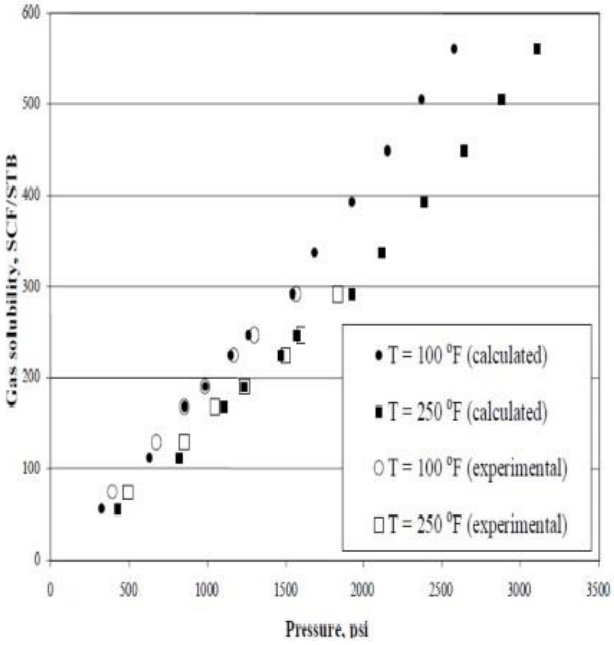

Figure 3. Gas solubility in oil based mud at moderate pressures

The studies give us a perfect relations between gas soluibilty with different oil phases, oil minerlas, diesel and synthetic oil, like parrafine based fluid has higher solubilty tendency related to easter based fluid and the last one used for offshore operations due to the low toxic and environmental impacts, therefore the effect of gas solubility in oil based mud is different dependet on the type of continous phase, Then with phase fluid has high solubility effect result in hard detect for gas influx and the polarity of continous phase play role to decrease this effect like easter based mud (synthetic fluid), So kick detection for gas influx is sensitive to type of contionous phas and that lead to chose optimum well control method for influx handling [12].

3. Methodology simulation study

This study will clarify comparison between well control behavior either using WBM or OBM with constant well control data for same well bore scheme, The main objective is simulate well control situations which occurred with WBM and compare with same conditions in case of OBM which need it in some cases to handle and solve other associated problems in drilling operations like prevent pipe sticking and support shale inhibition or optimize well bore stability and shed light on gas influx behavior difference between two well control methods with changed type of drilling fluid, and this paper is considered a primary step for mapping best recommendations for well control methods in case of need to change type of drilling fluid in same field and describe the gas behavior and its impact on well control operations.

3.1. Well bore date for proposed well

In this part we show well bore data for proposed well we had gas influx caused gas cut mud weight and lead to decrease in mud weight and lost in first barrier (hydrostatic pressure), and from this point we will simulate well control operation to overcome gas influx till reach to surface.

Table 1. Well bore configuration with gas kick scenario

Drill pipe (O.D * I.D)	5 × 4.276 IN
Drill collar (O.D * I.D)	6.75 × 2.875 IN
Previous casing	9.625 × 8.835 IN
Casing shoe depth	4550 FT
Hole depth	4690 FT
Fracture gradient	0.89 PSI/FT
Bit diameter	8.5 INCHES
Bit nozzle	6 X 13/32
Mud density	11 PPG
Kill mud weight	12.5 PPG
Pit gain	15 BBL
Pump displacement	0.011 bbl./strokes
SICP	440 PSI
SIDPP	400 PSI

Case 1#: Driller method (water-based mud)

In this real situation we have taken gas kick during penetrate Kareem formation in proposed well, we get gas cut mud and notice that decreasing in mud weight which out from the well 9 PPG, We stopped drilling operation and took precautions to investigate if the well is flowing or not and found by flow check the well is flowing, First step stopped the mud pump and shut in the well to record and stabilized after 25 minutes on x-axis SIDPP and SICP as shown in Figure 1.

We recorded drill pipe pressures at slow circulation rate (SCR) 30 strokes per minutes, Driller method consist of at least two circulations cycles, First cycle we started circulation with minimum SCR to overcome gas influx during well control operation and controlled casing pressure via remote chock (chock size around 0.25 inches), Prevent getting second influx during gas influx trip out to surface by chocking the well and maintain BHP (Rose curve) above kick zone curve (yellow line), Second cycle we prepared kill mud weight as related to kill sheet was 12.5 PPG and started pumped down with step down rates to overcome any trapped pressures to continue drilling operations.

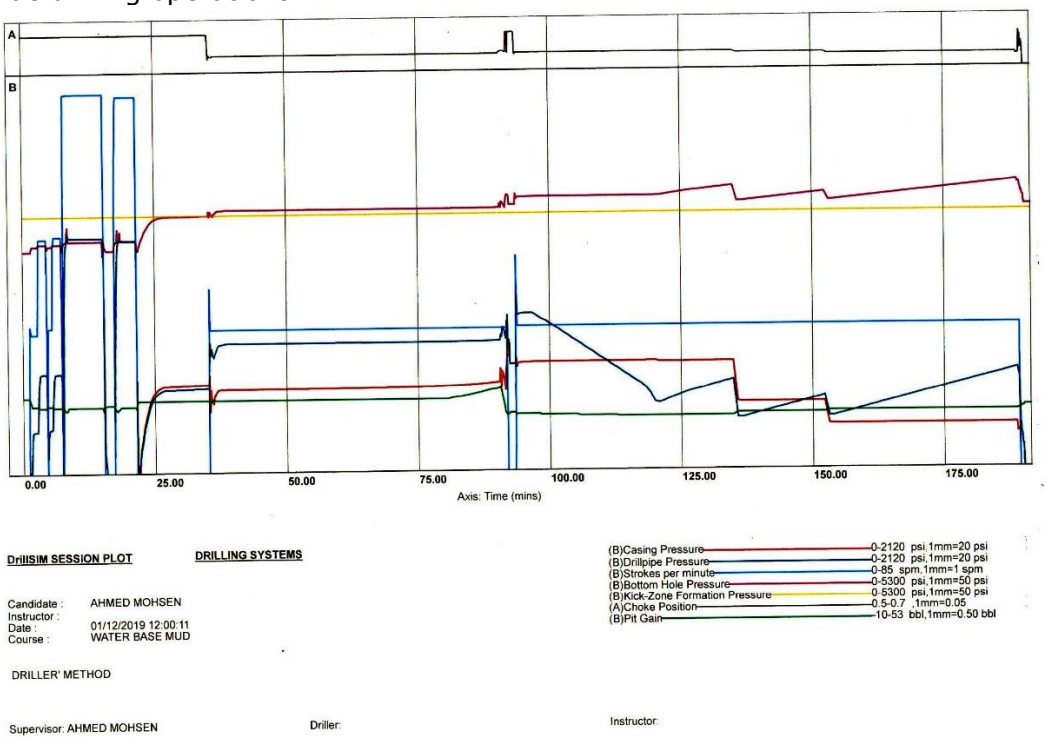

Figure 4. Driller method in case of using water-based mud in well bore

During pumping kill mud weight we observed decline in drill pipe pressure(Blue line) till KMW reached to bottom followed decreasing in casing pressure (Red line) till reached to surface and in this part we have to observing any increasing in casing pressure and vent any higher pressure to avoid KMW break down open hole zone beneath casing shoe depth.

Case 2#: Wait and weight method (water – based mud)

In this case, we simulate another scenario, previously Rig facilities did not provide any chemicals to prepare and pump kill mud weight rapidly so we simulate if we have chemical stokes and initiate in mixing KMW what would happened, During simulated drilling operation with constant parameters and simulate get same value of influx and record same SIDPP and SICP, We will shut down the well and start in KMW pumping with step down rate reached bottom (bit depth) and observed decreasing in drill pipe pressure, we have to maintain BHP at satisfied value above kick zone pressure and observe drill pipe pressure to maintain it at constant value till gas kick reached surface and observe decreasing in casing pressure till lowest value till KMW reached to surface, as well control rule of thumb we need to reach both of drill and casing pressure to same value (zero pressures while shut down pumping kill fluid) and with monitoring casing pressure value to ensure there is no any additional trapped pressure.

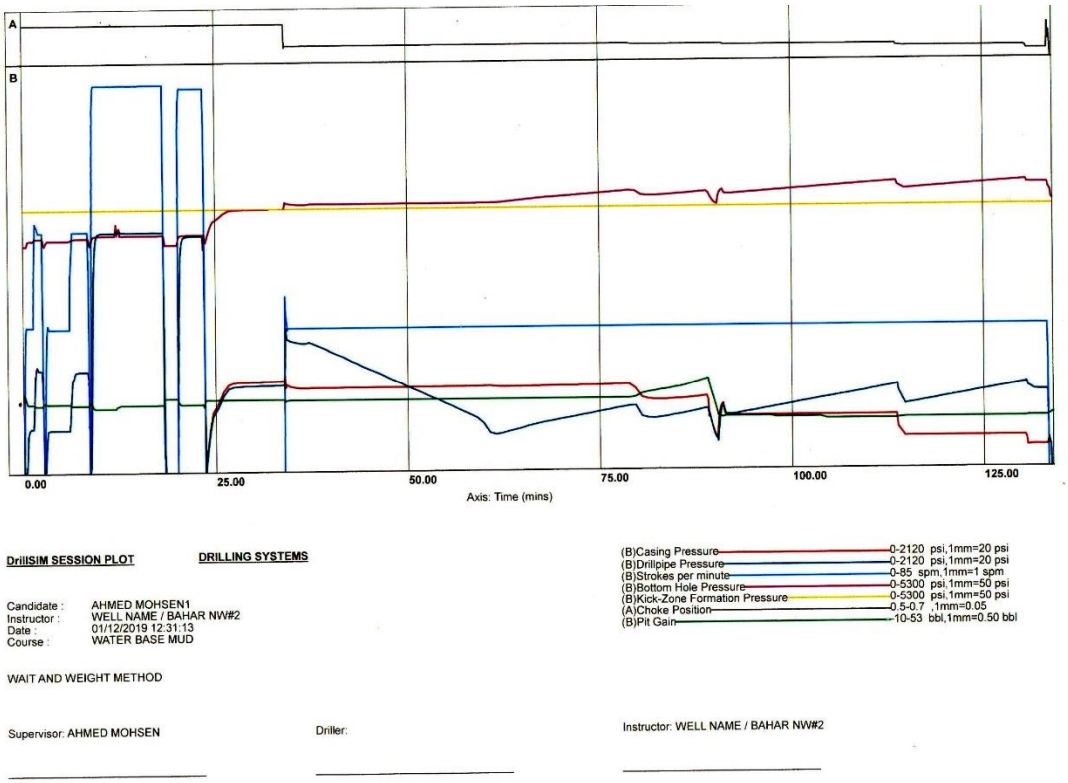

Figure 5. Wait and weight method in case of using water-based mud in well bore

3.2. Oil-based mud data

In this part we state clearly in details and simulate well control operation in case of using oil based mud, Kareem formation has shale streaks as shown in stratigraphic column Figure 1. and experienced hole problems like pipe sticking and wire line sticking in open hole log operations especially when penetrate the well with high build angle reached to 70° and by using oil base mud system would overcome with 90 % from these problems, Any way the concept behind that simulation is if we get gas influx in case of drill Kareem formation and get same influx how should we do in this case and what will be gas migration behavior in case of using

oil – based mud, Oil-based mud data and weighted materials CACL2 to raise weight for mud system used in proposed field as follow:

Table 2. Oil-based mud data for proposed well

Mud weight	11 PPG
Funnel viscosity	60 sec/ qrt
PV	25 cP
Yield Point	18 LB / 100 ft2
Low shear yield point (LSYP)	16 LB/ 100 ft^2
Lime content	6 PPB
Calcium chloride (CACL2)	14 %
OIL/WATER ratio (OWR)	90/10
Primary emulsifier	4 Drums
Secondary emulsifier	8 Drums
Wetting agent	8 Drums
Filtration control agent	80 sacks
Viscosifier	120 sacks

Case 3#: Driller's method (oil-based mud)

In case of using oil-based mud, we will simulate get gas influx at same depth (Kareem formation) which hole depth at 4690 feet, Stopped drilling operations and check flow from well bore found dynamic, after 50 minutes on x-axis Observed increasing slightly casing pressure but without stabilized value actually simulator experienced in this case and show fluctuation in recorded SICP and SIDPP.

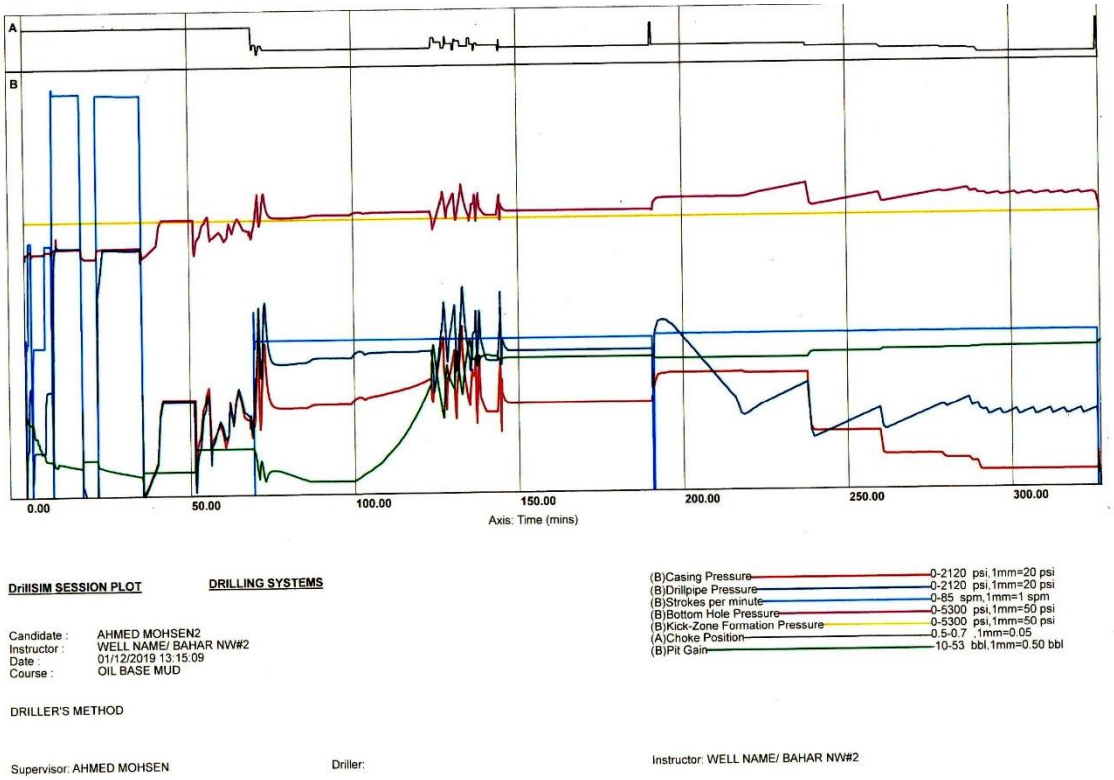

Figure 6. Driller's method in case of using Oil-based mud in well bore

Whatever we recorded and prepared kill sheet with maximum recorded reading which was SICP= 530 PSI and SIDPP = 490 PSI, Meanwhile closing the well we found unstable recording shut in casing pressure and drill pipe pressure, Started first circulation with minimum slow circulation rate 30 Strokes per minute, we tried to control the well via remote chock (chock size 1/8 inches), Observed increasing rapidly in casing pressure during first circulation that

lead to hesitate action with chock partially and save kick tolerance at low limits till gas influx reached surface and get unstable conditions and lost bottom hole pressure rapidly which responsible for overcome formation pressure resulted in take fast action and close the chock size completely for minutes to maintain bottom hole pressure and avoid lost overbalance condition during gas influx circulated out from the well.

Started second circulation with pumping KMW 13 PPG and observes decline in drill pipe pressure, after kill mud weight has been reached beneath bottom drill pipe the casing pressure was stabled and did not decrease that lead to opened chock partially to keep bottom hole pressure at satisfied values and avoid break formation.

Case 4#: Wait and weight method (oil-based mud)

In case of this simulated scenario, Shut in the well and started to raise density for mud weight to prepare KMW 13 PPG and started circulate the well and get control on gas influx which found path to mud column in annuli.

Recorded SICP 530 PSI and SIDPP 500 PSI after long time related to previous cases, circulate the well with minimum slow circulation rate and with step down rate for kill mud weight we monitored SICP to avoid any sudden increasing in casing pressure, but we did not get any unrespectable increasing value or observe any gas expansion while KMW circulation and continued circulation till gas influx reached surface and proceed further steps till stabilized and confirm there was no any additional gain from formation

Opened partially chock size around 0.25 inches and noticed stabilization in chock size through circulate KMW that due to absence high gas expansion but we kept monitoring to avoid increasing in well head pressures during kill mud weight circulated in annuli till reach surface and observe decline in casing pressure till ensure get well controlled to proceed drilling operation.

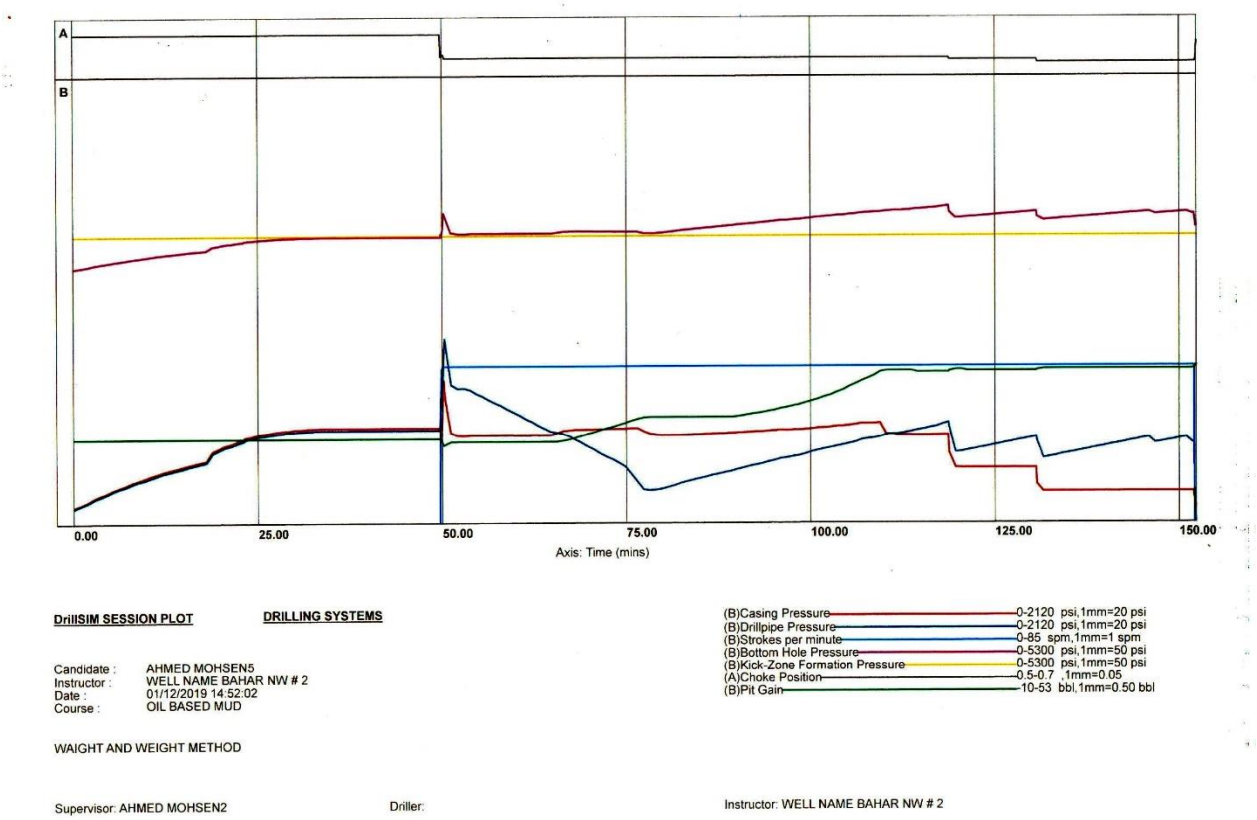

Figure 7. Wait and weight method in case of using Oil-based mud in wellbore

4. Results and discussion

From previous cases, we experienced various scenarios for well control operation and differentiate with simulated cases (Case # 2, 3 and 4) with real scenario Case #1 to show gas influx behavior in case of changing drilling fluid from water based mud to oil based mud as follow:

4.1. In case of using water-based mud (Case #1 and Case #2)

Driller's method "CASE #1" known as fast decision way to get control and let gas gain out the wellbore before let gas migrates through mud column in case of waiting for mixing or add salts to raise density to mud system, Using water-based mud and due to low compressibility force of water phase that resulted in stabilization in killing operation in first circulation trip till gas out the well, chock size is almost constant around 1/4 inches along killing operation time, the only limitation for this way is take long time to complete two circulation cycles and waste time of drilling rig due to take long time to complete killing operation in two cycles of mud circulation, However this method very effective to minimize chance drill string stuck because you expose drill string to mud circulation instantly which we could face it in Kareem formation caused by active shale streaks existence.

Wait and weight method "CASE #2" as shown in simulated scenario lead us to ensure this method give us lowest stresses on equipment of drilling rig while killing operations due to present stabilizing in well bore pressure related to driller's method in case of using water-based mud related to Case #1, SO from previous discussion we observe there is no preference between two methods in case of using water-based mud for same wellbore configuration except driller's method will give us low probability to drill string stuck in this zone due to fast action for mud circulation.

4.2. In case of using oil-based mud (Case #3 and Case #4)

From previous output data in simulated Driller's method "CASE #3" chart give us some complicated scenarios may be face drilling supervisor during killing operation and get back well control in case of using oil-based mud as follow:

a) First in the beginning well control operation with constant slow circulation rate 30 strokes per minutes we chocked the well lower than any cases around 1/8 inches
b) We get more fluctuations in casing pressures records and increasing rapidly after sort of stabilizing records in well head pressures (drill pipe and casing) while gas influx circulated out that resulted from insoluble gas in mud column became in free pattern and that happened when we reach bubble point pressure then observed increasing in casing pressure instantly before total gas influx reached surface.
c) Delay in response time for chocking the well that lead to high probability to get additional influx while first circulation period.
d) Maintain bottom hole pressure overbalanced which needed to control the well is very hard in case of using Driller's method, actually bottom hole pressure lost around 150 psi during first circulation period.
e) Second in case of gas influx out to surface, decreasing in bottom hole pressure was rapidly that led us to shut in the well completely with continued pumping rate with slow circulation rate for minutes to get back overbalance the well at satisfied values and prevent get high additional influx.
f) We took excessive time around 50 minutes on scale x-axis and pumping one more cycle with same mud weight above first circulation cycle in case of **CASE #3**. Even total gas influx circulated completely out the well to ensure there was not additional undetected influx, then continued initiation in second circulation cycle with kill mud weight higher than existed in wellbore.

In case of simulated scenario **Case #4** wait and weight method there was not distinguished differences related to same method in case of using water-based mud **CASE#2** and kill mud weight reached bottom well bore and support overcome and controlled the well in 75-100

minutes interval on scale x-axis as shown Figure 7. Before gas insoluble in mud column get free under bubble point pressure and that give us preference to control the well with stabilized records for wellhead pressures.

Hence, Wait and weight method is preferred and had priority in case of using oil-based mud as drilling fluid, Driller's method in case of oil-based mud need well-trained operators to handle gas influx precisely.

Table 3. Comparison between well control methods in different drilling fluid types

	Case #1	Case #2	Case #3	Case #4
Chock size, inches	¼	¼	1/8	¼
Time for well control, Minutes	150	100	275	150
Overbalance during killing operation, PSI	50	50	50-250	50

5. Conclusion

As previous study we recommend during well planning take precautions to clarify some points to choose type of drilling fluid and what will depend on choosing if we face well control issues especially in proposed zone may be face other problems like pipe / wire line stuck in open hole zone.

As long as drill the well with water-based mud, there is no difference if we use driller's method or wait and weight method except driller method is considered fast action to prevent any additional problems and the difference in killing operation time is better than in wait and weight if we managed and provide supported chemicals to mix kill mud weight in short time.

As long as drill the well with oil-based mud, there is distinguished differences and hard to get control if we kill the well by Driller's method and it will take long time to get back stabilization and control the well that will expose more stresses to equipment and failure in chock, It will need high qualified personals to take decision and good monitoring for recorded pressures to avoid get additional gas influx or formation breaking, Wait and weight method is better than Driller's method and preferred in this situation, It will give us stability in fast time and lower annular pressure, So we recommend that while drilling design and mud design program for developed well in same field to avoid associated hole problems in this zone like pipe stuck in open hole.

Nomenclature

WBM	*Water-based mud*	*Bbl.*	*Barrels*
OBM	*Oil-based mud*	*KMW*	*Kill mud weight*
P&A	*Plug and abandon*	*PPG*	*Pound per gallon*
SICP	*Shut in casing pressure*	*PSI*	*Pound per square inch*
SIDPP	*Shut in drill pipe pressure*	*I.D*	*Inside diameter*
BHP	*Bottom hole pressure*	*O.D*	*Out diameter*
SCR	*Slow circulation rate*		

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