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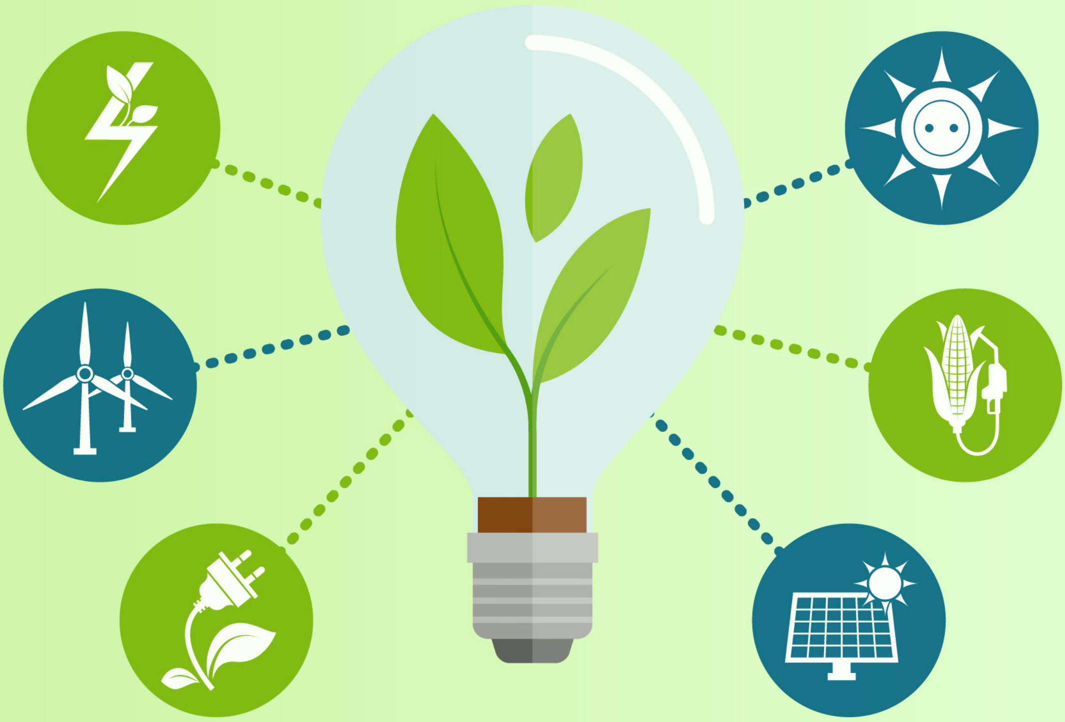

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Hydrodynamic Techniques in Well Control: In Professional Point of View

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ABSTRACT

The purpose of hydrodynamic methods is to understand the motion of fluids. The field of hydrodynamics has expanded widely in the petroleum industries and takes into account the energy of a fluid - the effect of pressures - the continuous matter, in short. Hydrodynamic theory deals with solving problems in oil and gas fields. Well control techniques focus on not losing control of the well in the first place. Because it is one of the most important aspects of drilling operations. Kicks can lead to explosions with potential loss of life and equipment. Choosing the right way to kill the well is very important and protects against human and equipment losses. Therefore, this study will choose the appropriate method for killing the well based on which conditions and characteristics of the well from a professional and safe point of view. In this study I used Kill sheet Excel model to compare the killing methods in terms of speed, efficiency, ambient environment, and well characteristics. Findings showed that the concurrent method is the best way to kill thr well if all resources and equipment are available at the drilling site, After that comes the engineer's method if the calculations were done correctly. Because it saves time with only one cycle and reduces casing pressure. Finally, the Driller method because it consumes more time and more circulation which leads to an increase in casing pressure. Thus, it can be said that this study enables us to choose the appropriate method for killing the well from a heuristic point of view.

INTRODUCTION

Well control is the technique used in oil and gas operations such as drilling, well work over and well completion for maintaining the hydrostatic pressure and formation pressure to prevent the influx of formation fluids into the wellbore. This technique involves the estimation of formation fluid pressures, the strength of the subsurface formations and the use of casing and mud density to offset those pressures in a predictable fashion. (R. D. Grace, 1997)

The aim of oil operations is to complete all tasks in a safe and efficient manner without detrimental environmental effects. This aim can only be achieved if well control is maintained at all times. The understanding of pressure and pressure relationships are important in preventing blowouts by experienced personnel who are able to detect when the well is kicking and take proper and prompt actions. (Well Control Training Manual 2002). There are two ways to prevent unwanted fluid to flow (Primary and secondary control).

In our study we will focus on Hydrodynamic method (Primary control) by ensuring that the pressure due to the Colom of mud in the borehole is greater than the pressure in the formations being drilled i.e. maintaining a positive differential pressure or overbalance on the formation pressures. (E.M.Eller 1956). A well kill is the operation of placing a column of heavy fluid into a well bore in order to prevent the flow of reservoir fluids without the need for pressure control equipment at the surface.

It works on the principle that the hydrostatic head of the "kill fluid" or "kill mud" will be enough to suppress the pressure of the formation fluids. Well kills may be planned in the case of advanced interventions such as work overs, or be contingency operations. The situation calling for a well kill will dictate the method taken. (H. Rabia, 1985)

Well control in general is an extremely expensive and dangerous operation. Extensive training, testing, proof of competence, and experience are prerequisites for planning and performing a well kill, even a seemingly simple one. Many people have died through incorrectly performed well kill. (J. N. Howell, 1967)

And as solutions to that problems we must Monitoring the indicators that indicate the flow permanently, which are Increase in pit gain volume and Increase in flow rate and Flowing well with pumps off

And drilling crow must have valid IWCF licenses And grant Well Control courses to the workers continuously

Finally, all the necessary resources and equipment inside the Rig site must be provided.

Objectives

This study aims to achieve these goals

1. Understand the basic principles of hydrodynamics of oil and gas
2. Provide a recommendation on the best well killing methods that are suitable for each type of well
3. Saving time, reducing costs, and preserving the safety of people and equipment
4. Analyzing the risks of controlling wells and hazard preventing in the future
5. A comparison of the most common methods of killing in terms of advantages, disadvantages and efficiency

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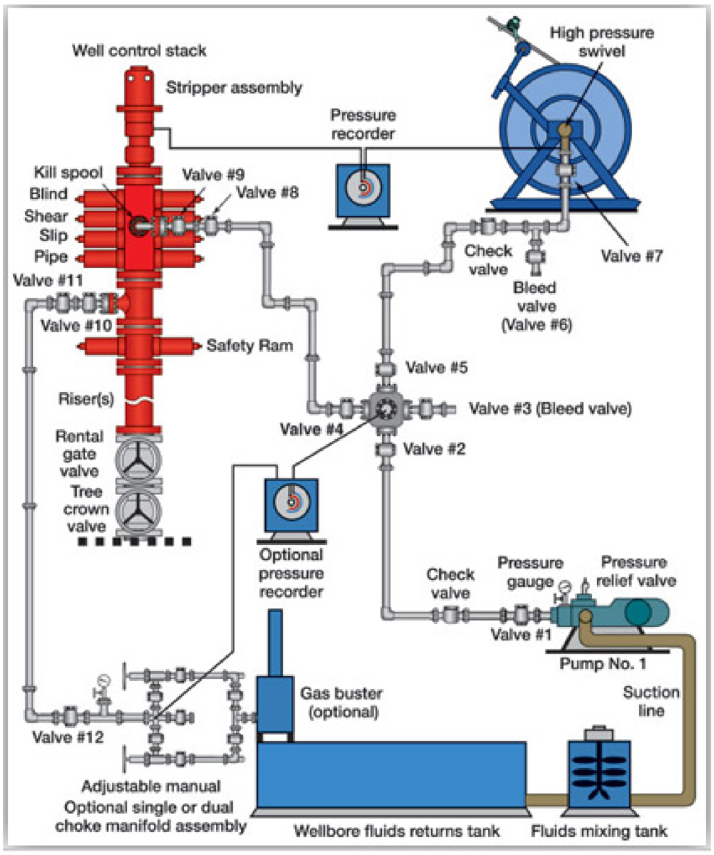


Figure 1: Categories of well control (primary and secondary)

METHODOLOGY

In this section, I will talk about the procedures for securing the well when a kick occurs and calculating the density and pressure of the killing mud using the well control formula, after which a comparison is made between the killing methods and choosing the best depending on Data and conditions

Well Control Procedures

In this section, we will get acquainted with the procedures for controlling the wells from the beginning of the kick event and choosing the appropriate method for controlling until the well is killed.
This will be done by building an Excel model using the well control formulas and comparing these methods based on efficiency, performance, speed, and completion.

Well Control Background

There are basically two ways to control the wells. Primary Control by ensuring that the hydrostatic pressure is greater than the formation pressure. Secondary Control by closing off the BOP valves at surface to stop the flow of fluids (P. L. Moore, 1974)

Shut-in Procedures

A hard shut-in is a technique where the BOPs are closed on the well with the choke in the closed position, whereas a soft shut-in entails closing the BOPs with the choke open, and then shutting in the well by closing the choke. The main concern with these methods is formation damage and added time for influx entry [R.D.Grace 2003]

Killing well methods

After having shut-in the well, the next step is to safely circulate the kick out of the well. Many different techniques have been used throughout the years, Driller's Method , Engineer's (W&W) Method and Concurrent Methods.(N. Adams & L. Kuhlman,1994)

Well Control Formula

1. Hydrostatic Pressure (psi)
   Mud Density (ppg)×0.052×TVD (ft)
2. Pressure Gradient (psi/ft)
   Mud Density (ppg)×0.052
3. Drilling Mud Density (ppg)
   (pressure (psi))/(TVD (ft)×0.052)
4. Formation Pressure (psi)
   Hydrostatic Pressure in Drill String (psi)+SIDPP (psi)
5. Pump Output (bbl/min)
   Pump Displacement (bbl/stroke)×Pump Rate (SPM)
6. Annular Velocity (ft/min)
   $$\frac{Pump\ output\ (bbl/min)}{Annular\ capacity\ (bbl/ft)}$$
7. Equivalent Circulation Density (ppg)
   $$\frac{Annular\ pressure\ loss\ (psi)}{capacity\ (bbl/ft)} + Mud\ Density\ (ppg)$$
8. New pump pressure with new pump rate (psi) approximate

$$Old\ pump\ pressure(psi) \times \left(\frac{New\ pump\ rate\ (spm)}{Old\ pump\ rate\ (spm)}\right)^2$$

9. New pump pressure with new pump density (psi) approximate

$$Old\ pump\ pressure(psi) \times \left(\frac{New\ pump\ density\ (ppg)}{Old\ pump\ density\ (ppg)}\right)^2$$

10. Maximum allowable mud density (MAMD) (ppg)

$$\frac{surface\ LOT\ pressure\ (psi)}{Shoe\ TVD\ (ft) \times 0.052} + LOT\ Mud\ Density\ (ppg)$$

11. Maximum Allowable Annular Surface Pressure (MAASP) (psi)

$$[MAMD(ppg)\text{-}current\ \ mud\ density(ppg)\ ] \times 0.052 \times Shoe\ TVD$$

12. Kill mud density (ppg)

$$\frac{SIDPP\ (psi)}{TVD\ (ft) \times 0.052} + Original\ Mud\ Density\ (ppg)$$

13. Initial circulation pressure

$$Kill\ rate\ circulation\ pressure\ (psi) + SIDPP\ (psi)$$

14. Final circulation pressure

$$Kill\ rate\ circulation\ pressure\ (psi) \times \frac{kill\ Mud\ Density\ (ppg)}{Original\ Mud\ Density\ (ppg)}$$

15. Shut in casing pressure (psi)

$$[MAMD(ppg)\text{-}current\ \ mud\ density(ppg)\ ] \times 0.052 \times Shoe\ TVD$$

Killing well procedures

Driller's Method

After shutting in the well, and checking for flow, the surface pressures are increasing. After a while, they start to stabilize, and Shut-in casing pressure (SICP) and shut-in drill pipe pressure (SIDPP) are recorded for kick calculations. The Driller's method, along with the Wait and Weight method, is a procedure that is based on monitoring the drill pipe pressure (DPP). This technique uses two circulations to kill the well: One to circulate the kick to the surface, and another one to circulate kill fluid to kill it. (R. Kastor & S. Letbetter, 1974)

1. The well is closed in with hard shut in procedure or soft shut in procedures and the information recorded
2. If a slow circulating rate pressure, PSCR, has been taken, then calculate the pressure required on the Drill Pipe for the first circulation of the well.
3. Open the choke about one quarter, start the pump and break circulation; then bring the pump up to the KILL RATE.
4. While the Driller is bringing the mud pump up to the KILL RATE, the choke operator should operate the choke so as to keep the casing pressure at or near the SICP reading.
5. Once the pump is up to the KILL RATE, the choke operator should transfer his attention to the Drill Pipe pressure gauge and adjust the choke to maintain the ICP on the drill pipe pressure gauge.
6. The last step on well control driller's method is helding the ICP constant on the Drill Pipe pressure gauge by adjusting the choke throughout the whole of the first circulation, until all of the Kick fluid has been circulated out of the well. The pump rate must also be held constant at the KILL RATE throughout this period.
7. Once the Kick is out of the hole, Shut the well in and mix up the kill mud weight required

Advantage	Dis Advantage
Minimum Arithmetic	More time
Circulation can be started almost immediately	Minimum of two circulations
Minimum Information Required	More wear on choke and gas handling machinery
Simplest to teach and understand	Higher annular pressure in gas kick
Doesn't require special consideration and modification in directional wells	Higher casing shoe pressure in long open hole section

Engineer's Method (W&W)

The main difference between the Driller's method and the Engineer's method is that the kill is executed in one circulation. When the kick has been detected, verified, and shut-in, the crew immediately starts weighting up the mud in the tanks to kill weight mud.

When the KWM is ready, the kick is circulated out by directly displacing the OWM and kick with KWM. The Wait and Weight method is a big more complex than the Driller's method, as circulating out the kick and killing the well is done simultaneously. (S. Devereux, 1999)

1. Calculate Kill mud weight
2. Initial Circulating Pressure
3. Once the pipe capacity of the Drill String is calculated, it is possible to draw a graph showing how Drill Pipe pressure varies as Kill mud is pumped down to the Drilling Bit
4. The choke is cracked open, the pump started to break circulation, and then brought up slowly to the Kill Rate, While that keep the casing pressure as near as possible to the SICP reading.
5. When the pump is up to the Kill Rate, the choke operator transfers to the Drill Pipe pressure gauge.
6. As the Kill mud proceeds down the Drill Pipe, the Drill Pipe pressure is allowed to drop steadily from the Initial Circulating Pressure to the Final Circulating Pressure, by choke adjustment. (through the table you have already done)

   i. Where the Kick is a small one, at or near the bottom of the hole, the Drill Pipe pressure tends to drop of its own accord as the kill mud moves down. Little or no choke adjustment is required.

   ii. Only in cases of diffused gas Kicks with gas far up the annulus will significant choke adjustments be needed during this period.
7. In Wait & Weight Kill Method, and after kill mud

Advantage	Dis Advantage
Minimum time , only one circulation	Losing time to mix mud
Less wear on choke and gas handling machinery	Requires the longest non circulating time while mixing heavy mud
Lowest casing pressure	More Arithmetic
Lowest casing shoe pressure	Require special consideration and modification in directional wells

has reached the Drilling Bit, the Drill Pipe pressure is maintained at the Final Circulating Pressure until the kill mud returns to the surface

Concurrent Method

The concurrent method is a way of gradually increasing the mud weight while circulating out the kick. It is more complex than both the Driller's method and the Engineer's method and does not always reduce the kill time. According to Watson Etal.; the concurrent method has previously also gone by "Circulate and Weight" or "Slow Weight-up" method.. (J. J. Schubert 1995)

1. Shut-in well after kick
2. Record kick size and stabilized SIDPP and SICP
3. ASAP start circulating original mud (fluid) by gradually bringing the pump up to the desired kill rate while using the choke to maintain constant casing pressure at the shut-in value.

(Pump pressure should be equivalent to calculated ICP. If not equivalent, investigate and recalculate if necessary)

4. Mixing operations begin and pits are slowly weighted up and each unit of heavier fluid reported.
5. Each interval or unit of increased fluid density is then noted and
6. Recorded with the pump stroke count at that time

6.1. The change in circulating pressure for the different density is calculated

6.2. Once this fluid reaches the bit lend of tubing, circulating pressure is adjusted with the choke by that amount.

7. The kick is circulated out and the fluid in the well continues to be gradually increased.
8. Once the kil fluid is consistent throughout the well, shut down pump and check for flow.
9. Close choke, shut well in and check pressures.

Advantage	Dis Advantage
Minimum of non-circulation time	Arithmetic is More complicated
Excellent for large increases in mud weight (underbalanced drilling)	Required more on-choke circulating time
Less casing pressure than driller methods	Higher casing pressure than W&W
Can easily switched to engineers method	Higher casing shoe pressure than W&W

Calculation and Results

Table 1: Well and Kick Data

Formation Data		Kick Data	
Data	Value	Data	Value
Total Depth	11700 Ft	Pump Out Put	0.7 Bbl/Stroke
Casing Shoe Depth	7142 Ft	Mud Weight	9.1 Ppg
Leak-Off-Test	2050 Psi	Sidpp	410 Psi
MW At LOT	9.7 PPG	SICP	525 Psi
Formation Pressure	2250 Psi	Bit Gain	3 Bbl
Mud Weight	9.1 Ppg	Dynamic Loss	370 Psi
Kill sheet calculations Result (by using Well Control Formula)			

Table 2: Driller method

Data	Value
Maximum Allowable Density	15.2 ppg
Initial MAASP	2273 psi
Kill Fluid Density	9.77 ppg
Kill Fluid Gradient	0.51 psi/ft
Initial circulation pressure	Pump1 = 960 psi - pump2 = 1030 psi
Final circulation pressure	Pump1 = 591 psi - pump2 = 666 psi
Pressure loss	40 psi/100 strokes

Table 3: Engineers Method

Data	Value
Maximum Allowable Density	15.2 ppg
Initial MAASP	2273 psi
Kill Fluid Density	9.77 ppg
Kill Fluid Gradient	0.51 psi/ft
Initial circulation pressure	Pump1 = 960 psi - pump2 = 1030 psi
Final circulation pressure	Pump1 = 591 psi - pump2 = 666 psi
Pressure loss	40 psi/100 strokes

Concurrent Method

First of all calculate Mud Mw increase in 4 stages (9.77-8.33)=1.44, now (1.44/4)=0.36 ppg in each stage. By calculation i have this result.

Table 4: Concurrent Method

Stages	Mw Current Ppg	Mw Kill Ppg	Maasp Psi	Icp Psi	Fcp Psi
1	8.33	8.69	1687	960	574
2	8.69	9.05	1594	574	573
3	9.05	9.41	1500	573	572
4	9.41	9.77	1407	572	571

IWCF Surface BOP	KILL SHEET	1 of 2

WELLNAME: NC-115 UNITS: US DATE: 9-Feb-23
DEPT: 11750

FORMATION STRENGTH DATA:

SURFACE LEAK-OFF PRESSURE FROM FORMATION STRENGTH TEST (A) 2050 psi

DRILLING FLUID DENS. AT TEST (B) 9.7 ppg

MAX. ALLOWABLE DRILLING FLUID DENSITY =

(A) psi / 0.052 / Shoe TVD + (B) ppg = (C) ppg

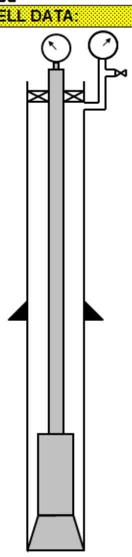
2050 / 0.052 / 7142 + 9.7 = (C) 15.2

INITIAL MAASP =[(C) ppg - Curr Dens] x Shoe TVD x 0.052

= 15.2 - 9.1] x 7142 x 0.052

= 2273 psi

CURRENT WELL DATA:



DRILLING FLUID DATA
DENSITY 9.1 ppg
GRADIENT 0.4732 psi/ft

CASING & SHOE DATA
SIZE 9.625 in
M. DEPTH 7142 ft
T.V. DEPTH 7142 ft

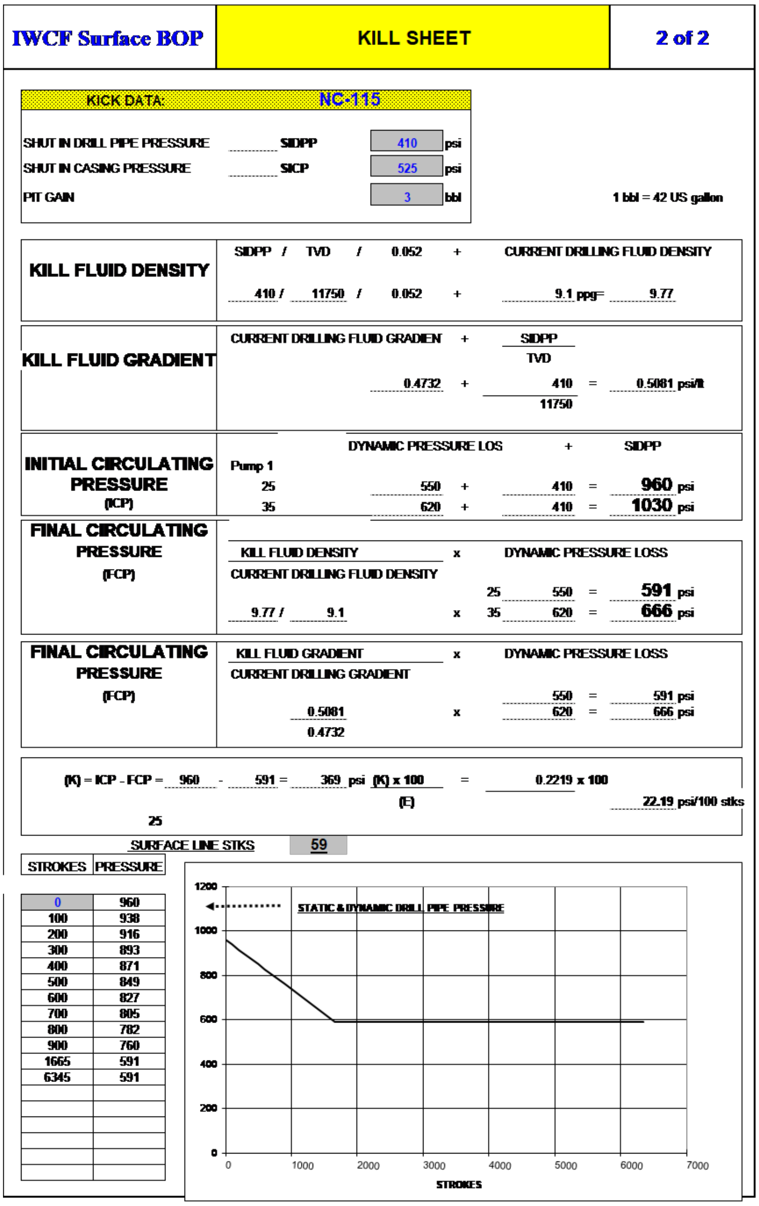
HOLE DATA
SIZE 8.5 in
M. DEPTH 11750 ft
T.V. DEPTH 11750 ft

PUMP No. 1 DISPLACEMENT	PUMP No. 2 DISPLACEMENT
0.119 bbl / stk	0.119 bbl / stk

SLOW PUMP RATE DATA	DYNAMIC PRESSURE LOSS PUMP No. 1	DYNAMIC PRESSURE LOSS PUMP No. 2
25 SPM	550 psi	550 psi
35 SPM	620 psi	620 psi

PRE-RECORDED VOLUME DATA:	LENGTH ft	CAPACITY bbl/ft	VOLUME bbl	PUMP STROKES strokes	TIME minutes
DRILL PIPE 5"	10600 x	0.01776 =	188.3		25
HWDP 5"	910 x	0.00874 =	7.956 +	VOLUME / PUMP DISPLACEMENT	PUMP STROKES / SLOW PUMP RATE
DRILL COLLAR 6.5"	240 x	0.00803 =	1.927 +		
DRILL STRING VOLUME		(D)	198.1 bbl	(E) stks 1665	67 min
DP/HWDP x OPEN HOLE	4368 x	0.0459 =	200.5 +		
DC x OPEN HOLE	240 x	0.02914 =	6.994		
OPEN HOLE VOLUME		(F)	207.5 bbl	1744 stks	70 min
DP x CASING	7142 x	0.04892 = (G) +	349.40	2936 stks	117 min
TOTAL ANNULUS VOLUME	(F+G)=(H)		557 bbl	4680 stks	187 min
TOTAL WELL SYSTEM VOLUME	(D+H)=(I)		755 bbl	6345 stks	254 min
ACTIVE SURFACE VOLUME	(J)	1000	bbl	8403 stks	
TOTAL ACTIVE FLUID SYSTEM	(I+J)		bbl	14748 stks	
SURFACE LINE VOLUME			7 bbl	59 stks	

CALCULATIONS CAN BE MADE USING EITHER DRILLING FLUID DENSITY OR DRILLING FLUID GRADIENT.



IWCF Surface BOP | KILL SHEET | 2 of 2

KICK DATA: NC-115

SHUT IN DRILL PIPE PRESSURE	SIDPP	410	psi
SHUT IN CASING PRESSURE	SICP	525	psi
PIT GAIN		3	bbl

1 bbl = 42 US gallon

KILL FLUID DENSITY: SIDPP / TVD / 0.052 + CURRENT DRILLING FLUID DENSITY
410 / 11750 / 0.052 + 9.1 ppg= 9.77

KILL FLUID GRADIENT: CURRENT DRILLING FLUID GRADIEN + SIDPP / TVD
0.4732 + 410 / 11750 = 0.5081 psi/ft

INITIAL CIRCULATING PRESSURE (ICP): DYNAMIC PRESSURE LOS + SIDPP
Pump 1
25: 550 + 410 = 960 psi
35: 620 + 410 = 1030 psi

FINAL CIRCULATING PRESSURE (FCP): KILL FLUID DENSITY / CURRENT DRILLING FLUID DENSITY x DYNAMIC PRESSURE LOSS
9.77 / 9.1 x 25: 550 = 591 psi
35: 620 = 666 psi

FINAL CIRCULATING PRESSURE (FCP): KILL FLUID GRADIENT / CURRENT DRILLING GRADIENT x DYNAMIC PRESSURE LOSS
0.5081 / 0.4732 x 550 = 591 psi
620 = 666 psi

(K) = ICP - FCP = 960 - 591 = 369 psi (K) x 100 / (E) = 0.2219 x 100 = 22.19 psi/100 stks
25

SURFACE LINE STKS 59

STROKES	PRESSURE
0	960
100	938
200	916
300	893
400	871
500	849
600	827
700	805
800	782
900	760
1665	591
6345	591

Figure 2: IWCF Surface BOF (Kill Sheet)

CONCLUSION

type of well control method depends on a various considerations.

as the pressures do the kick give on surface, competence do the workers have, Available equipment and resources, type of mud is used

Time it takes to perform all preparations and operational phases for the kill operation

Driller Method

The Driller method provide some advantages over the Engineers and Concurrent method. cause those methods may be useful for achieving lower shoe and surface pressure in some cases. However, these advantages are often exaggerated, and in fact, we may not see a significant reduction due to gas transmission So if the drill pipe pressure schedule is not calculated and followed correctly. we cant reduction the pressure

Engineers Method

It can be difficult to properly follow the W&W method in complex and deviant wells. And it will be more complicated in the case of using the simultaneous method that needs more equations

Therefore all resources must be available at the drilling site And the calculations must be very accurate in order for this method to succeed and take into consideration the time spent in preparing the killing fluid.

Concurrent Method

Due to the low level of experience of existing drilling personnel, and limited field practice with well control methods the simultaneous method may not offer significant advantages. It may be the best method if all resources are available such as professional crew, chemicals needed to kill, and efficient circulation system

RECOMMENDATIONS

1. Driller's Method is a logical, simple, practical, adequate and often superior approach to kill majority of the wells we drill
2. I recommend using the driller's method in deviant wells because it does not need many calculations like the engineer's method
3. I recommend using the engineer's in case of hige casing shoe and surface pressure because its useful for achieving lower shoe and surface stresses.
4. I recommend using the engineer's method for solid layers that can withstand high hydrostatic pressure
5. I recommend using The concurrent method in case of limited of circulation system
6. I recommend using The concurrent method in case of all the capabilities and materials necessary to deal with such a situation must be available
7. I recommend to Monitoring the indicators that indicate the flow permanently, which are as follows
   a. Increase in pit gain volume
   b. Increase in flow rate
   c. Flowing well with pumps off
8. The time it takes to perform the killing process should be as low as possible, so we always recommend doing BOP Drill at least once a week to get used to the killing process
9. The drillers must have valid IWCF licenses And grant Well Control courses to the workers continuously

Nomenclature

BHP	Bottom hole pressure, psi
BHA	Bottom hole assembly
BOP	Blowout preventer
EOB	End of build point
FCP	Final circulating pressure, psi
FP	Formation pressure, psi
HCR	High closing ratio gate valve placed before the choke
ICP	Initial circulating pressure, psi
KOP	Kick off point
KMW	Kill mud weight, ppg
MD	Measured depth of any point, ft
MW1	Original mud weight before kick occurred, ppg
MW2	Kill mud weight, ppg
OMW	Original mud weight, ppg
RRCP	Reduced rate circulating pressure, psi
SB	Strokes from surface to bit
SICP	Shut-in casing pressure, psi
SIDPP	Shut-in drill pipe pressure, psi
SCP	Slow circulating pressure, psi
STB	Total number of strokes to bit
TDMD	Total depth point measured depth, ft
TVD	True or total vertical depth, ft
TMD	Total measured depth, ft
W&W	Wait and Weight method of well control

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