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COMPARATIVE ANALYSIS OF PUMP SPEED VARIATION IN WELL CONTROL PROCEDURE

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Abstract

The conventional constant bottom hole pressure methods are employed during well kill operations with the bit on bottom when the kick is taken. These methods allow for circulating out formation fluids influx without the need to shut-in the well by adjusting pump flow rate while monitoring and measuring the circulating pump pressure at a rate suitable for well control operations. Most operators recommend that when drilling several pump speed should be selected frequently enough so that an accurate value of the kill rate can be deployed when a kick occurs. This strategy however has some adverse effect on the formation as well as the well control equipment.

This paper therefore analyses the effect of varying the pump speed required to kill a well using the wait and weight method after shut-in casing pressure has stabilized by preparing and comparing kill sheets for selected kill rates and determining the amount of kill time needed to get the well under control again.

The results from analysis show that selecting between different pump speeds or kill rates affects significantly the bottom hole pressure but does not affect the number of strokes to bit because it depends only on the drill string volume and pump capacity. When considered based on kill time importance, the higher the pump speed the faster the time to kill the well. However, in selecting higher kill rates adequate attention must be paid to formation fracture pressure in the open hole so as not to damage the well.

Keywords: Kick, Pump speed, Pump pressure, Kill sheet, Kill time

Nomenclature

ρkill	Kill weight mud density, ppg
ρmud	Original mud density, ppg
Cds	Drillstring capacity, bbl/ft
Cdp	Drillpipe capacity, bbl/ft
CHWDP	Heavy weight drillpipe capacity, bbl/ft
Cdc	Drill collar capacity, bbl/ft
Cp	Pump capacity, bbl/stroke
lds	Length of drillstring, ft
ldp	Length of drillpipe, ft
lHWDP	Length of heavy weight drillpipe, ft
ldc	Length of drill collar, ft
Pp	Pump pressure, psi
Pci	Initial circulating pressure, psi
Pcf	Final circulating pressure, psi
Tbit	Time for Kill weight mud to reach the bit, minutes

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Abbreviation

		SStr
SPM	okes Per Minute	
		SSh
SIDPP	ut-In Drillpipe Pressure	
		SSh
SICP	ut-In Casing Pressure	
		SStr
STB	okes To Bit	

1.0 Introduction

In well control procedures the mud pump is used to circulate kick fluids out of the hole and to circulate kill mud into the hole, this makes it one of the basic tools of well control and the speed or rate at which the pump is run has significant effects on the pressure imposed on the formation and the overall success of the well control process.

Kicks are certainly inevitable while drilling but however, most scientific efforts have been on the prevention of kicks while drilling and only a few have focused on variables affecting kick control once they have occurred. Robert [1] asserted that since the fundamental goal of most well control procedure is to maintain a constant bottom hole pressure equal to or only slightly greater than formation pressure, accurate control of pump speed is necessary because small changes in pump speed can cause large changes in pressure at the bottom of the hole, where constant pressure is critical.

Karen [2] noted that to circulate out a kick from a well, most operators require that the pump rate be reduced to a speed below that used for normal drilling operation called the kill rate, this reduced pump speed affords several advantages to any well control method because it reduces strain on the pump and reduces circulating friction losses so that circulating pressures are less likely to cause excessive pressure on the exposed formation. The reduced pump speed also allows more time for the crew to react to problems (adding weighing materials to the mud) and allow the adjustable choke to operate within proper orifice range.

When the pump rate is reduced to the kill rate, circulating or pump pressure is also reduced. This reduced pressure is the kill rate pressure and it is obtained by pumping down the drillpipe and drill collars out of the bit nozzles and up the annulus, running the pump at the reduced speed and breaking circulation. While the kill rate pressure can easily be read on the standpipe gauge or the drill pipe pressure gauge, the relationship between the pump speed and pump pressure can be estimated by the equation;

$$P_2 = P_1\left[\frac{SPM_2}{SPM_1}\right]^2 \quad (1)$$

Where,

P_1= original pump pressure at SPM_1, psi

P_2 = reduced or increased pump pressure at SPM_2, psi

SPM_1 = original pump rate, strokes per minute (spm)

SPM_2 = reduced or increased pump rate, spm

The control and circulation of kicks from the wellbore can be enhanced by obtaining information on formation integrity, system pressure losses, drill string capacities and displacement prior to encountering the kick and performing certain calculations [3].

This study aims to investigate the effect of varying pump speed on bottom hole pressure while displacing a kick from a well by applying the descriptive and analytical approach in preparing kill sheets forsome selected and assumed pump speeds or rate.

2.0 Methodology

The wait and weight method of well control is applied in this study and it presents the most convenient way to contain a kick having shut-in the well. The influx is circulated out by pumping kill mud down the drillstring displacing the influx up the annulus. The kill mud is pumped into the drillstring at a constant pump rate and the pressure in the annulus is controlled on the choke so that the bottomhole pressure does not fall, allowing further influx to occur [4]. Although it is slightly more complicated to other available well kill techniques, but it offers some distant advantages. First, the well is killed in one circulation and the kill is achieved in half the time. In addition with modern mud mixing facilities, the time required to weight up the suction pit is minimized and the kill rate is not penalized and the annulus pressures are lowered [5].

The primary disadvantage with this method as presented by Yaun and Zeng [6] is potential for errors and problems while displacing the kill mud to the bit, stopping and starting the kill process is not easy especially during the period that the kill mud is being displaced to the bit.

We assume that the pump factor is unity (Pump factor = 1); the anticipated (or assumed) pump pressure at varying kill rate is P_p and the values are shown in figure 1.

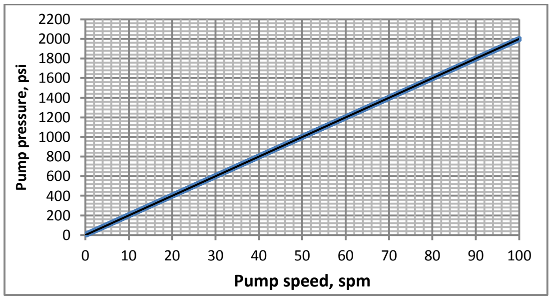

Figure 1 Assumed pump pressure vs. pump speed

The following are mathematical formulae utilized for the analysis of circulating pump pressure required to kill a well after shut-in and the corresponding stroke to bit (STB) in the wait and weight method of controlling a kick by using hypothetical well and kick data from literature [7].

Kill mud density, ρ_{kill}

$$\rho_{kill} = \rho_{mud} + \frac{SIDPP}{0.052 \times D} \quad (2)$$

Initial circulating pressure, P_{ci} at the kill rate

$$P_{ci} = SICP + P_p \quad (3)$$

Finalcirculating pressure (P_{cf}) at the kill rate with the kill mud at the bit

$$P_{cf} = \left[\frac{\rho_{kill}}{\rho_{mud}}\right] P_p \quad (4)$$

Number of strokes to bit, STB

$$STB = \frac{\text{Drill string Volume}}{\text{Pump Capacity}} \quad (5)$$

$$\text{Drill string volume} = C_{ds} l_{ds} = C_{dp} l_{dp} + C_{HWDP} l_{HWDP} + C_{dc} l_{dc}$$

$$STB = \frac{C_{ds} l_{ds}}{C_p} = \frac{C_{dp} l_{dp} + C_{HWDP} l_{HWDP} + C_{dc} l_{dc}}{C_p}$$

Time for kill mud to bit, T_{bit}

$$T_{bit} = \frac{STB}{SPM}, \text{min} \quad (6)$$

The pumping schedule over ten drillstring volume increments is assumedfor this analysis and so the drill pipe will change every $\left(\frac{STB}{10}\right)$ while the pressure reduction at each pump stroke increment will be$\left(\frac{P_{ci} - P_{cf}}{10}\right)$.

3.0 Analysis of Data / Result

The kill sheet presented in this study contains pre-recorded data (Table 1), a step by step calculation and a graph or other means (Table 2 and Figure 2) for determining the required pressures on the drill pipe as the kill mud is pumped for varying kill rates of 20spm and 40spm

Table 1 Kick Data for a Hypothetical Well

Wellbore Configuration	
Measured Depth	10,525 ft
Vertical Depth	10,000 ft
Surface Casing Information	
Description	9-5/8-in., 40.0-lbm/ft K-55 ST&C
Setting Depth	4,000 ft
Open Hole Diameter	8-1/2 in.
Drillstring Information	
Drill Collar Size	8.0 in. × 3.0 in.
Drill Collar Capacity	0.0087 bbl/ft
Drill Collar Length	360 ft
Heavy Weight Drillpipe	5.0 in., 49.3-lbm/ft

HWDP Capacity	0.00883 bbl/ft
HWDP Length	240 ft
Drillpipe Description	5.0 in., 19.5-lbm/ft
Drillpipe Capacity	0.01776 bbl/ft
Prekick Data and Mud Properties	
Mud Pump Description	7 in. × 12 in. Triplex @ 95% Efficiency
Pump Output	0.136 bbl/stroke
Mud Type	Water Base Mud
Mud Density	9.6 ppg
LOT with 9.0ppg Mud	1130 psi
Recorded Kick Data	
SIDPP	480 psi
SICP	600 psi
Pit Gain	35 bbl

3.1 Kill Sheet at 20spm

The pump pressure was set at 400 psi at an initial pump speed (or kill rate) of 20spm (Figure 1). The shut-in drill pipe pressure at the stabilized shut-in casing pressure of 600 psi is 480 psi (Table 1)

The required density of the kill mud, ρ_{kill} in pounds per gallon (ppg)

$$\rho_{kill} = \rho_{mud} + \frac{SIDPP}{0.052 \times D} = 9.6ppg + \frac{480\ psi}{0.052\ psi/ft\ (10{,}000\ ft)} = 10.52\ ppg$$

The initial circulating pressure, P_{ci}

$$P_{ci} = SICP + P_p = 600\ psi + 400\ psi = 1000\ psi$$

The final circulating pressure, P_{cf} at kill rate of 20spm with the kill mud at the bit,

$$P_{cf} = \left[\frac{10.52\ ppg}{9.6\ ppg}\right](400\ psi) = 438.3\ psi$$

Volume of the drill string (drill pipe, heavy weight drill pipe and drill collar) in bbl,

$$C_{ds}l_{ds} = (0.01776\ bbl/ft\ \times 9925\ ft) + (0.00883\ bbl/ft\ \times 240\ ft) + (0.0087\ bbl/ft\ \times 360\ ft) = 181.52\ bbl$$

The number of strokes to bit,

$$STB = \frac{C_{ds}l_{ds}}{C_p} = \frac{181.52\ bbl}{0.136\ bbl/stk} = 1335\ strokes$$

The time for kill mud to the bit,

$$T_{bit} = \frac{1335\ stk}{20\ spm} = 66.75\ mins$$

3.2 Kill Sheet at 40spm

We recall that the required density of the kill mud, ρ_{kill} and the number of pump strokes to bit, STB have been computed as 10.52ppg and 1335 strokes respectively.

The initial circulating pressure, P_{ci} at kill rate of 40spm

$$P_{ci} = 600\ psi + 800\ psi = 1400\ psi$$

The final circulating pressure, $P_{cf}$with the kill mud at the bit

$$P_{cf} = \left[\frac{10.52}{9.6}\right](800) = 876.67\ psi$$

Time for kill mud to the bit,

$$T_{bit} = \frac{1335\ strokes}{40\ spm} = 33.38\ mins$$

Table 2 Drillpipe pressure schedule

Pump strokes	Pressure @ 20spm	Pressure @ 40spm
0	1000	1400
134	943.83	1347.67
267	887.66	1295.34
401	831.49	1243.01
534	775.32	1190.68
668	719.15	1138.35
801	662.98	1086.02
935	606.81	1033.69
1068	550.64	981.36
1202	494.47	929.03
1335	438.3	876.7

The values in column 1 of table 2 are obtained over an assumed ten drillstring volume increments by addition of 133.5 strokes while values in column 2 and 3 are obtained from the corresponding pressure reduction at each pump stroke increase by 56.17psi and 52.33psi respectively.

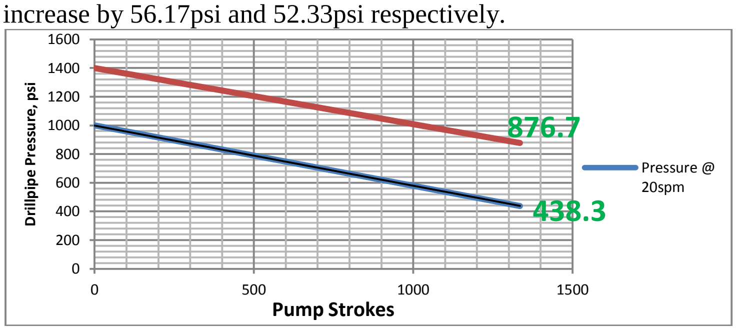

Figure 2 Drillpipe pressure corresponding to wait and weight method

4.0 Discussion

The result of selecting between the 20spm and 40spm pump speed at assumed or anticipated pump pressure of 400psi and 800psi respectively is expected at the bit on bottomhole. The pump speed of 20spm will cause a final pressure of 438.3psi to be felt at the bottom of the hole which is less than the stabilized shut-in is casing pressure of 600psi (shut-in casing pressure is equal to the formation pressure). The consequence of selecting this pump speed is a blowout scenario which may lead to loss of lives and equipment, damage to environment and additional cost of cleanups and compensations.

On the other hand, selecting a pump speed of 40spm will exert a final pressure of 876.67psi on the bit at the bottom of the hole. This pressure is greater than the shut-in casing pressure and when read at the surface; it indicates that the well is dead. This pressure should however not be allowed to exceed the leak-off test (LOT) pressure of 1130psi (table 1) because it could induce fractures in the formation thereby creating the possibility of an underground blowout.

The selected speeds both delivered kill mud weight to the bit with the same number of pump strokes of 1335 signifying that the stroke to bit for a drill string composed of one weight of drillpipe and one heavy-weight drillpipe or drill collar is independent of pump speed.

Similarly, selecting a kill rate of 40spm will deliver the kill weight mud to the bit in 33.38 minutes while the mud will reach the bit in 66.75 minutes for a pump speed of 20spm. This implies that higher values of kill rate or pump speed minimizes the kill mud weight response time at the bit.

5.0 Conclusion

This paper investigated the challenges of varying the pump speed so as to attain accurate values of the required kill rate for well control operations and provides a quick look approach to kill sheet preparation and well control analysis.

The results from analysis shows that either the pump speed at 40spm is kept constant or varied between higher values provided the formation fracture pressure is not exceeded by the final pressures felt at the bit on bottom.

It is recommended that care must be taken while selecting the intended pump speed to kill the well while using the wait and weight method because if an error is discovered after the kill mud is being pumped to displace the kick, stopping the process is quite difficult and resuming displacement is tasking.

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