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Kick tolerance control during well drilling in southern Iraqi deep wells

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Abstract

The importance of kick tolerance in well operations has recently increased due to its implications in well design, in drilling and well control. To study a simple method for the application of kick tolerance concept in an effective way on the basis of field data, this research purpose is to improve knowledge about Kick Tolerance and represents a technical basis for the discussion on revision of standard procedure.

The objective of this work is to review and to present a methodology of determination the kick tolerance parameters using the circulation kicks tolerance concepts.

The proposed method allows to know, to evaluate and to analyze the kick tolerance problem in order to make the drilling execution safer and more economical by reducing the probability to have an incident.

The calculations of presented methodologies were based upon calculated input values such as p_{pore} and $p_{frac.}$ and not upon measured leak-off test and RFT (less accurate) input values as in traditional methods. The paper also analyses the calculations not with KT parameters only, but it has continued to give the killing operation procedure to such high pressure high temperature (HPHT) wells.

Key Words: gas kick, killing operation, kick tolerance, drilling control, casing setting depth.

Introduction

Kick Tolerance (KT) is commonly defined as the maximum volume of a given type of influx (typically gas), we mainly discuss gas kicks because gas is much more difficult kick fluid to handle than liquid. A small volume of gas at the bottom of a well is potentially dangerous because it expands when approaching the lower pressure near the surface. At low pressure it will expand and displace a corresponding amount of mud from the well, thus, reducing the bottom hole pressure which in turn allows more gas to flow into the well from the pores[7].

Another problem with gas kicks is that gas decreases mud rheology, especially in oil base mud, and Barite falls out. Barite must, by the way, be delivered from the supply base in adequate amount to increase the mud weight of the total active mud volume.

Many companies believe that KT calculations help to quantify safety margins that exist between expected wellbore conditions and incrementally higher well design limits. However, one big issue in the industry today is the lack of consistency about KT calculation, leading to significant confusion and increased risk [1].

There are two situations in dealing with gas kick, in the case of the open well, when the gas reaches the surface as it is circulated out of the hole its volume expansion can be calculated using Ideal gas law (Boyle's Law):

$$\frac{P1\,V1}{T1} = \frac{P2\,V2}{T2}$$

When gas is injected (from the formation) in to the closed well it will travel up the well with its pressure unchanged. In such well if gas expansion is prevented then hole will fracture when gas reaches the surface.

Hence when a kick is taken in a well, gas expansion must be allowed to take place to reduce well pore pressure. Kick tolerance is based on the fact that during a gas kick, gas is circulated out of the well at a controlled rate to reduce its pressure and to keep its expanded volume at surface to a manageable amount.

What Is Kick Tolerance

Many definitions had been given to explain KT, for practical purposes, kick tolerance may be defined as the maximum kick size which can be tolerated without fracturing the previous casing shoe. Kick tolerance may also be defined in the term of the maximum allowable pore pressure at next total depth or maximum allowable mud weight which can be tolerated without fracturing the previous casing shoe[2], [6].

Kick tolerance therefore depends on the maximum kick size, maximum formation pressure at the next total depth (TD) and the maximum mud weight which can be tolerated without fracturing the previous casing shoe (the weakest point in the open hole). Other factors which affect on kick tolerance include density of the invading fluid and the circulating temperature.

How to Calculate Kick Tolerance

Kick tolerance should be calculated prior to drilling ahead at intervals through the hole section to be drilled at the expected mud. If a factor such as mud weight or drill string geometry is changed, then the kick tolerance must be recalculated.

To determine the magnitude of kick tolerance, the parameters such as (pore pressure at TD, maximum mud weight to be used and fracture gradient at current casing shoe) are necessary to design influx volume that can be safely circulated out.

Kick tolerance should be calculated in terms of [1]:

- Kick volume which can be circulated out without fracturing the previous casing shoe.
- Additional mud weight over current mud weight.
- Drilling kick tolerance which is the maximum pore pressure which can be tolerated without need to exceed the maximum allowable mud weight.

The amount of influx volume that entering in well depends on:

- Underbalanced between mud weight and pore pressure
- Reservoir porosity and permeability
- Influx type
- Sensibility and reliability of detection equipment
- Reaction time of well control crew
- Type well shut in procedure

After closing the well, the pump seals the well at the drill string end, and at the other end by means of closed BOP (blowout pressure) and surface choke. Inside the drill string, the liquid composition is assumed to be uncontaminated, so that the new formation pressure [1], [5] becomes:

$P_{pore} = P_{SIDP} + \rho_{mud} .g.h_{well} = \rho_{kill} .g.h_{well}$ … (1)

Where:
P_{pore}: formation pore pressure at the next hole depth TD, psi.
P_{SIDP} : shut in pressure in drill pipe, psi.
h_{well} : true vertical depth of the well, ft.
ρ_{mud} : mud density in use at next hole, ppg.
ρ_{kill} : density of mud required to killing the well if necessary, ppg.
Then:

$P_{SIDP} = P_{frac.} - \rho_{mud} .g.h_{well}$ ... (2)

$P_{frac.}$: fracture pressure at the next hole depth TD, psi.

And the maximum allowable annular surface pressure (MAASP) is:

MAASP= $(\rho_{frac.} - \rho_2) .g.h_{csg.shoe}$ ... (3)

Where:
$\rho_{frac.}$: mud weight equivalent to fracture pressure in casing shoe, ppg.
ρ_2 : mud weight in annulus before shut in, ppg.
h_{csg} : well depth at casing shoe, ft.

Where:

$\rho_{frac.} = \frac{P_{frac,at\ shoe}}{g.h_{csg.at\ shoe}}$ ... (4)

If the surface pressure rises above MAASP, the formation below the casing shoe will fracture, and hence the required mud weight to balance the pore pressure:

$\rho_{kill} = \rho_{mud} + \frac{P_{SIDP}}{g.h_{well}}$ … (5)

When the gas reaches the shoe while being circulating, the pressure at the casing shoe is given by fracture gradient at shoe, and then the height of gas at casing shoe is:

$H_{sheo} = \frac{(h_{well} - h_{csg}) g * \rho_{mud} + (g * h_{csg} * F_G - P_{pore})}{g * \rho_{mud-G}}$ ... (6)

Where:
F_G : fracture gradient in casing shoe, psi/ft.
G: gradient of gas (0.05-0.15).

The volume of gas influx at casing shoe is:

$V_1 = H_{sheo} * C_a$ .... (7)

Where:
C_a: capacity between pipe & hole ($C_a = \frac{\pi}{4}(d_h^2 - d_p^2)$).
d_h: next hole diameter, in.
d_p: drill pipe diameter, in.

At bottom hole conditions the volume influx (V_2) is given by:

$\frac{P2\ V2}{T2} = \frac{P1V1}{T1}$

$V_2 = \frac{P1V1T2}{P2\ T1}$ ... (8)

Where:
P_1: fracture pressure at shoe, psi.
P_2: formation pressure at the next hole, psi.
T_1: temperature at shoe, F^0.
T_2: temperature at total depth, F^0.

The volume V_2 is the circulation kick tolerance.

$KT = (F_G - \rho_{mud})$ ... (9)

The volume at the kick zone, which will cause the pressure at the shoe to reach the maximum allowable value when the kick reaches the shoe, it is important to note that some sources stop calculations at this point and consider this the final value for kick tolerance. The allowable value when the kick enters the wellbore might be higher due to inclination or smaller due to the decrease in the annular capacity.

And from these the height of the kick at the kick zone isV_2.

$$H_{kick\ zone}=\frac{(h_{well}-h_{csg})g*\rho_{mud}+(g*h_{well}*F_G-P_{pore})}{g*\rho_{mud}-G} \quad ...(10)$$

Where:
F_G : fracture gradient at total depth, psi/ft.
Then the volume of gas influx at kick zone is:

$$V_3= H_{kick\ zone} * C_a \quad ...(11)$$

Where:
C_a: capacity of kick zone between drill collar & hole ($C_a=\frac{\pi}{4}(d_h^2-d_c^2)$).
d_h: TD hole diameter, in.
d_C: drill collar diameter, in.

Then
If ($V_3 \geq V_2$)
The kick tolerance = V_2
Else kick tolerance = V_3

The volumes are compared and the assumption is that the smaller value will create a more conservative, hence safer, kick tolerance.

It is conceptually wrong to neglect the BHA (bottom hole assembly) length [4]. If the kick will most likely not be circulated out of the wellbore, or it will create an unsafe and very hard task for the drilling crew, as it will reach the top of the drill collars with a kick height greater than H_{shoe} , which in consequence would induce losses at the shoe.

When BHA $\geq$ H_{shoe} some other calculations have to be performed in order to have a more accurate value for kick tolerance, where the calculations must be done for the volume across the top of drill collars.

V_3 must be taken to the bottom of the wellbore using Boyle's Law, so V_3 will calculate using equation (8).

In the above procedure, reality of the change in temperature will have effect in the mud rheology and gas density and hence on kick tolerance parameters have taken in calculation (equation 8).

Kick Tolerance Calculation in Southern Iraqi Deep Wells

In this research two abnormal deep wells data (with total depth reaches to 15000 ft and temperature reaches to 300F^0) are used to study KT. When drilling into area of overpressure with rapid pore pressure increase, and increasing mud weight to compensate, the KT (limited by formation strength at the previous casing shoe) calculations are made using predicted formation pore pressure, mud density and fracture pressure gradient which were calculating in a previous research[3], while methods introduced in literatures was define on the basis of shut in well pressure(measured pressure in shut in well, commonly called leak-off-test(LOT)).

For two abnormal deep wells in southern Iraq with three casing shoe-depths for each well, The input data for the studied wells have illustrated in table (1), KT is calculating in terms of maximum kick size (the smallest volume between V_2 and V_3, calculated using eq.8 or eq.11) at TD, shut in drill pipe pressure P_{SIDP} (calculated using eq.2), MAASP (calculated using eq.3), to be compared with surface pressure in order to know if the formation below casing shoe will fracture or not. And the density of mud required to killing the well if necessary (ρ_{kill}, calculated using eq.5) or in term of additional mud weight required to kill the well. All the above parameters are calculated and listed below in tables (2) and table (3) consequently for the two studied wells.

Results

To avoid kick we must keep the bottom hole pressure greater than formation pore pressure, to do this and for planning purposes, it is useful to construct a kick tolerance graph for each well as shown in figure (1) and figure (2). In that figures, the kick volume is plotted on X-axis (point 2), and the SIDPP is plotted on Y-axis. (Point 1) is the maximum SIDPP that was calculated using equation (2). (Point 2) is the maximum kick volume as obtained by equation (8) for zero initial drill pipe shut in pressure. The straight line joining points 1 and 2 is called the kick tolerance graph. All points to the top and right of the line represent internal blow out and lost circulation conditions (due to formation fracturing). Points below the line represent safe conditions and give kick tolerance for any combination of kick size and drill pipe shut in pressure (SIDPP).

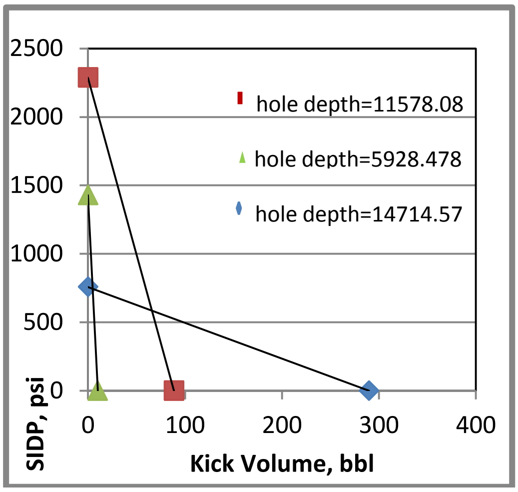

Fig. 1, Kick Tolerance Graph for the Well A

Table (4) and table (5) listed the expected SIDPP for each calculated kick volume. For the studied well, well control could be lost due to:

- High pressure zone not detected.
- Mud density too low due to gas cut.
- Lost circulation due to P_{well} > $P_{fracture}$.
- Not keeping annulus fill with mud during tripping.

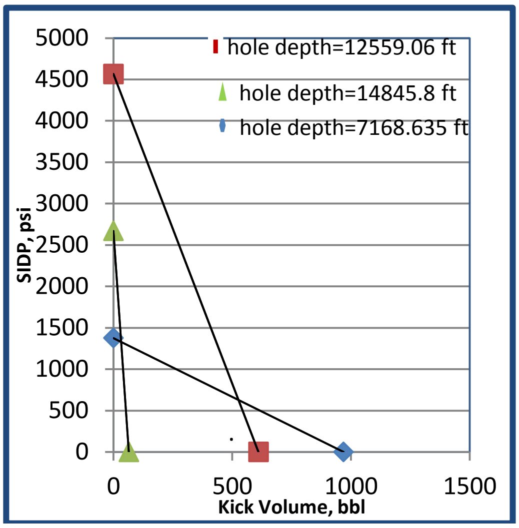

Fig. 2, Kick Tolerance Graph for the Well B

For any calculated kick size use figure 1 and 2 to predict the drill pipe shut in pressure P_{SIDP}.

Figure 3 to figure 4 shows the effect of the initial kick volume at the casing shoe setting depth using the proposed method. These results were obtained using the parameter BHA length (difference between TVD and casing shoe depth) shown in table.1 and kick volume in table 2 and 3. It is important to emphasize that the casing setting depth analysis was performed from the bottom of the well to the surface (from bottom to top). Having this in mind, it can be observed in Fig. 3 that an increasing kick volume requires the casing to be set closer to the final depth of the well. This point can be explained by the fact that the casing shoe position need to find higher fracture pressures (this is achieved by going deeper and closer to the final depth) to tolerate increasing kick volumes.

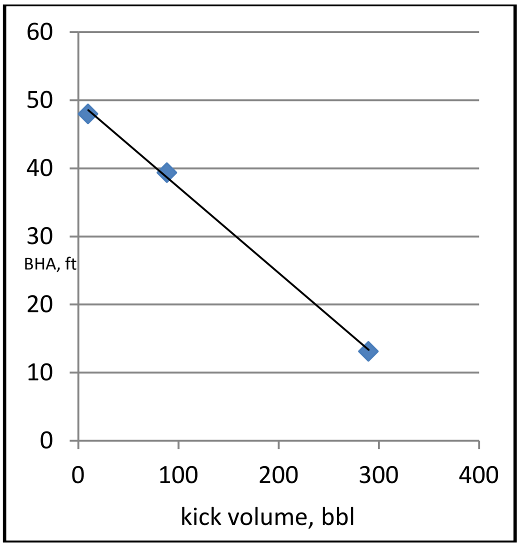

Fig. 3, Kick Volume and Open Hole Lengths For The Well A

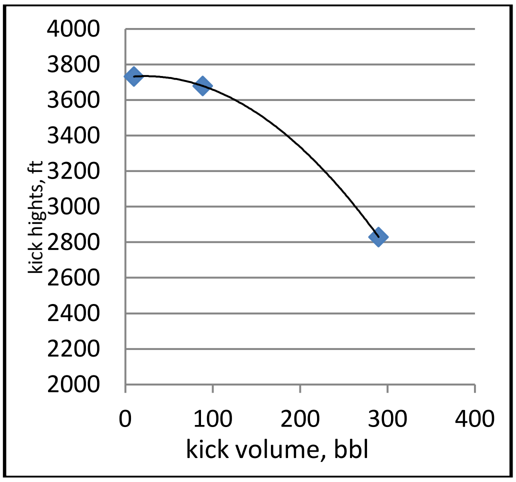

Fig. 4, Kick Volume and Kick Height H_{kick} for the Well A

Concluded Killing Procedures for the Studied Wells

There exist a number of different killing methods [(1)], the two main methods are the Driller's and the Engineer's Method. The Engineer's Method is also called the Wait & Weight Method (W&W). The most common method of restoring an overbalanced situation after a kick has occurred is the Driller's Method.

Once a kick has been detected, and the well has been closed, it is time to start planning the killing of the well. First deciding what circulation rate should be used to kill the well (ρ_{kill}, shown in table 2 and 3 as an additional mud weight). In the Driller's Method the pore fluid is displaced before kill mud is injected. This simplifies the operation but also induces higher pressure in the incased annulus, and the choke nozzles erode quicker. This could also lead to fracturing the casing shoe.

If the surface pressure rises above the Maximum Allowable Annular Surface Pressure, MAASP (shown in table 1 and 2), then the formation below the casing shoe will be fracture.

Table 1, Input Data in Kick Tolerance Calculations

	Well depth(TD), f	Casing shoe depth, ft	Fracture gradient at shoe, ppg	Mud weight, ppg	Hole diameter, in	Drill pipe diameter, in	Drill coller diameter , in	BHA length, ft
Well A	5928.478	5915.354	13.46154	10.9956	12.25	5	6.75	13.124
	11578.08	11538.71	14.80769	10.9956	8.375	5	6.75	39.37
	11530.08	12992.13	16.53846	14.42308	5.875	3.5	4.75	48
Well B	7168.635	7125.984	13.46154	9.7461	17.5	5	8	42.7
	12559.06	12486.88	17.69231	10.6624	12.25	5	8	171.2
	14845.8	14839.24	19.03846	15.5771	8.5	5	6.75	6.6

Table 2, Calculated Parameters of Kick Tolerance for the Well A

Well. A					
Estimatd			Kick tolerance		
TVD, ft	Mud weight, ppg	Pore pressure, ppg	Kick volume, bbl	Add. Mud weight, ppg	MAASP, psi
5928.478	10.9956	9.615385	289.7607	2.465938	1183.071
11578.08	10.9956	12.26	88.62963	3.812092	3115.453
14714.57	14.42308	15.96154	9.915399	2.115385	2468.504

Table 3, Calculated Parameters of Kick Tolerance for the Well B

Well. B					
Estimad			Kick tolerae		
TVD, ft	Mud weight, ppg	Pore pressure, ppg	Kick volume, bbl	Add. Mud weight, ppg	MAASP, psi
7168.635	9.7461	9.615385	968.4887	3.715438	1425.197
12559.06	10.6624	13.26923	610.8042	7.029908	2996.85
14845.8	15.5771	16.92308	64.93105	3.461362	1929.101

Table 4, Calculated SIDPP for Each Expected Kick Volume for the Well A

kick volume, bbl	Well. A	SIDPP, psi
100	TD=5028.475 ft	1020.20
200		1281.90
300		1543.60
400		1805.30
450		1936.15
50	TD=11578.08 ft	3577.30
100		4867.30
150		6157.30
3	D=14714.57 ft	1861.30
10		2870.00

Table 5, Calculated SIDPP for Each Expected Kick Volume for the Well B

kick volume, bbl	Well. A	SIDPP, psi
50	TD=7168.6 ft	4726.50
100		6783.00
150		8839.50
200		10896.0
20	TD=12560 ft	4713.46
40		4862.92
60		5012.38
80		5161.84
100		5311.30
120		5460.76
20	D=14846 ft	2698.42
40		2726.84
60		2755.26

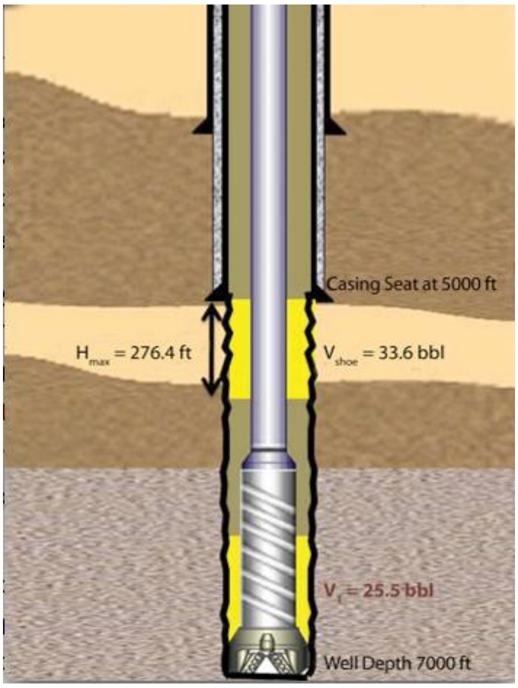

Fig. 5, Kick Volume (At the First Total Depth and the First Casing Depth) for the Well A

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