

THE STUDY OF WELL PLANNING USING THE KICK TOLERANCE CONCEPT

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Abstract. As the petroleum industry advances into deep and ultradeep water exploration, special problems surge, as: low fracture gradients, high pressure loss in choke lines, overbalance drilling due to a riser safety margin, and narrow drilling window due to the existing pore pressure and fracture gradients. As a result, the well planning has to be improved. Recently, the kick tolerance concept has been used during well design to determine casing setting depths. Due the application of this concept, well control considerations have been included in the determination of casing setting depths, making the drilling operation safer. This work presents three iterative algorithms to design setting depths of casing strings in oil wells using the kick tolerance concept. They compare the fracture pressure curve with the pressure generated inside the wellbore during a well control operation to estimate the shallowest casing shoe setting depth. This comparison is made in three ways: (1) the pressure is calculated at the time of the well closure, (2) the pressure is calculated during the kick circulation out of the well using a single bubble kick simulator to predict the pressure inside the wellbore, (3) the pressure is calculated at the time of the well closure and during the kick circulation, then these pressures are compared and the highest pressure is compared with the fracture pressure. The algorithms were implemented in softwares and examples were elaborated to show the application of these algorithms.

Keywords: kick tolerance, well planning, well control

1. Introduction

The deep water scenario presents especial aspects such as: low fracture gradients, high pressure loss in choke lines, overbalance drilling due to a riser safety margin, and narrow drilling window due to the existing pore pressure and fracture gradients. As a result, new techniques should be developed to assist in well design criteria.

This paper shows the application of well control considerations in determination of casing setting depths using the shut-in kick tolerance and the circulation kick tolerance concepts. The application of these concepts makes the drilling operation safer.

The objective of this work is to review and to present methodologies of determination of casing setting depths using the kick tolerance concepts. The presented methodologies were implemented in softwares and examples were elaborated to show the application of these algorithms. The paper also analyses the effect of the initial kick volume at the casing shoe setting depth.

2. Kick Tolerance Concept

The kick tolerance concept has been source of many discusses in the petroleum industry and there are many definitions for this concept. The original definition is: "difference between mud weight in use and formation pressure (expressed as mud weight equivalents) against which the well could be safely shut in without breaking down the weakest formation" (Ohara and Bourgoyné Jr., 1998).

According to Santos *et al.* (1995) kick tolerance can be understood as the capability of the wellbore to withstand the state of pressure generated during well control operations (well closure and subsequent gas kick circulation process) without fracturing the weakest formation.

And the definition adopted in this work is: "Kick tolerance is the maximum formation pressure, expressed in terms of equivalent density, such that, after a kick of a certain volume has been taken at formation depth and with the existing mud, the well can be closed and circulated without fracturing the weakest formation normally considered at casing shoe" (Santos and Barragan, 1998).

Based on this definition and assuming that gas occupies the annular space as a continuous slug, the kick tolerance when the well is shut in can be expressed as:

$$\rho_{kt} = \frac{D_{cs} \cdot (\rho_f - \rho_m)}{D} - \frac{L_k \cdot (\rho_m - \rho_k)}{D} + \rho_m \quad (1)$$

Where ρ_{kt} is the kick tolerance, D and D_{cs} are the well and the casing shoe setting depths, respectively, ρ_f is the fracture pressure at D_{cs} (expressed in equivalent density), ρ_m and ρ_k are the mud and the kick densities, respectively and L_k is the kick length.

Equation (1) is used if the kick top is below the casing shoe when the well is shut in. If the kick top is above the casing shoe the following expression is used:

$$\rho_{kt} = \frac{D_{cs} \cdot (\rho_f - \rho_k)}{D} + \rho_k \quad (2)$$

3. Methodology

The kick tolerance concept can be used to determine the setting depths of casing strings in two different ways: (1) at the time of well closure (shut-in kick tolerance) and (2) during the kick circulation (circulating kick tolerance). In situation (1) the procedure calculates the pressure inside the wellbore when the well is shut in. In (2) the procedure uses a kick simulator to calculate the pressure inside the wellbore during the kick circulation.

Three iterative algorithms for determination of casing shoes setting depths using the kick tolerance concept are presented in this section. The first algorithm uses the shut-in kick tolerance, the second one uses the circulating kick tolerance and the third one uses the shut-in and the circulating kick tolerance to determine the shallowest depth for the casing shoe. In the three methods the casing shoe setting depth is calculated from the bottom to the top of the well.

3.1. Shut-in Method

In this method is assumed that the most severe conditions at casing shoe occur by the well shut in. Rearranging the Eq. (1) and (2), the pressure at casing shoe, expressed in terms of equivalent density, can be defined as a function of the casing shoe depth by the Eq. (3) and (4):

$$\rho_{cs} = \frac{D \cdot (\rho_p - \rho_m)}{D_{cs}} + \frac{L_k \cdot (\rho_m - \rho_k)}{D_{cs}} + \rho_m \quad (3)$$

$$\rho_{cs} = \frac{D \cdot (\rho_p - \rho_k)}{D_{cs}} + \rho_k \quad (4)$$

Where ρ_{cs} is the pressure at casing shoe and ρ_p is the pore pressure at the final depth (D) of a certain phase of the well (expressed in terms of equivalent density). Equations (3) and (4) are used whether the kick top is below or above the casing shoe when the well is shut in, respectively.

A minimum safety margin should be added to the pressures evaluated by Eq. (3) or (4) to determine a curve of the pressure at casing shoe as a function of its setting depth. The maximum pressure allowable at the casing shoe is the formation fracture pressure in this point, then the shallowest casing shoe setting depth for a certain phase of the well can be defined by the intersection point of the casing shoe pressure curve and the formation fracture pressure curve.

This methodology was introduced by Santos e Barragan (1998) and can be described by the following steps:

1. for a final depth of a certain phase of the well (D), find the pore pressure and define the mud weight, the kick volume and kick density;
2. guess a casing setting depth (D_{cs}) - starting with the final depth of the phase;
3. calculate the kick length from the kick volume and annulus capacity;
4. use Eq. (3) or (4) to determine the pressure at the guessed D_{cs} ;
5. add the minimum safety margin to the value calculated in step 4;
6. find the formation fracture pressure at the guessed D_{cs} ;
7. compare the values calculated in steps 5 and 6. If they are equal, the guessed value for D_{cs} is the shallowest casing setting depth. If not, repeat the procedure from step 2 guessing a shallower D_{cs} .

3.2. Circulating Method

This method assumes that the most severe conditions at casing shoe occur during the kick circulation. A kick simulator is used to calculate the pressure behavior at casing shoe setting depth during the kick removal process. This method is similar to the shut-in method, although the pressure at the guessed casing shoe setting depth is calculated using a kick simulator. This value is the highest pressure evaluated at the casing shoe during the kick circulation and occurs when the kick top reaches the casing shoe.

3.3. Optimized Method

This method is an association of the two methods shown previously. In this procedure the pressure at the guessed casing shoe setting depth is calculated at the time of the well closure and during the kick circulation. Then, the highest pressure calculated in these two situations is the considered pressure at the guessed casing shoe setting depth.

4. Results of numerical simulations

The three algorithms shown and a kick simulator were implemented. The most important assumptions adopted in the development of this kick simulator are:

1. The kick is a real gas and occupies the annular space as a continuous slug;
2. The displacing fluid has the same density as the drilling fluid originally in the well (driller's method);
3. The gas slip velocity is not accounted for;
4. The gas expansion is considered;
5. The bottomhole pressure is kept constant and equal the formation pressure during the circulating;
6. Frictional pressure losses are considered in the mud regions and considered negligible in the gas region.

This kick simulator was used to predict the pressure behavior at casing shoe in the circulating and optimized method. The software presented by Santos (2003) uses a more realist kick simulator and could be used instead of the developed simulator.

Figure 1 presents the pore pressure and fracture pressure gradients curves for a deep water well drilled in Brazilian coast area presented by Lage *et al.* (1996) and the curves of pressure at casing shoe evaluated by the shut-in and the circulation methods. These two curves were calculated for the 7" casing using the parameters shown in Tab. 1.

Table 1. Parameters used in the simulations.

Final Depth of the Phase [m]	4500
Initial Kick Volume [bbl]	35
Kick Specific Gravity ⁽¹⁾	0.7
Mud Density [lb/gal]	11
Mud Viscosity [cP]	10
Drillpipe OD [in.]	5
Wellbore Diameter [in.]	6 1/4
Mud Flow Rate [gpm]	250

⁽¹⁾: relative to air

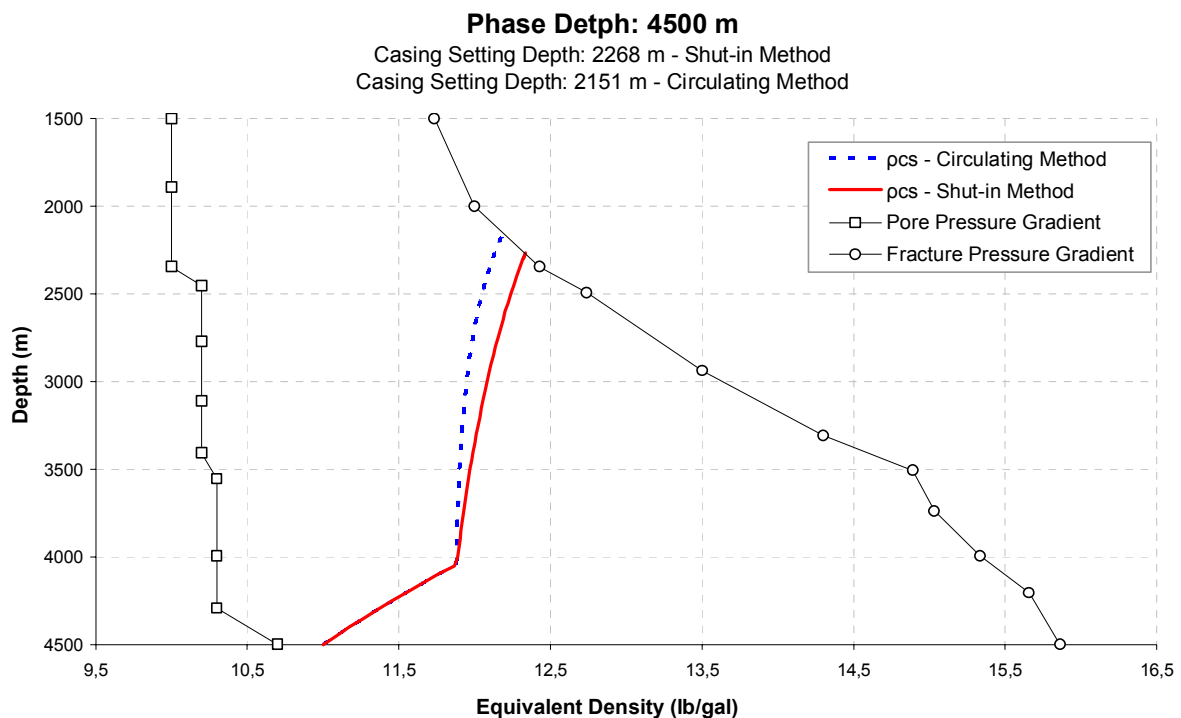


Figure 1. Determination of casing shoe setting depth using the shut-in and the circulation methods.

Figure 2 illustrates the application of the shut-in and the circulation methods to define the setting depth of the 16" casing. The parameters used are shown in Tab. 2.

Table 2. Parameters used in the simulations.

Final Depth of the Phase [m]	4100
Initial Kick Volume [bbl]	35
Kick Specific Gravity ⁽¹⁾	0.7
Mud Density [lb/gal]	10
Mud Viscosity [cP]	10
Drillpipe OD [in.]	5
Wellbore Diameter [in.]	14 3/4
Mud Flow Rate [gpm]	250

⁽¹⁾: relative to air

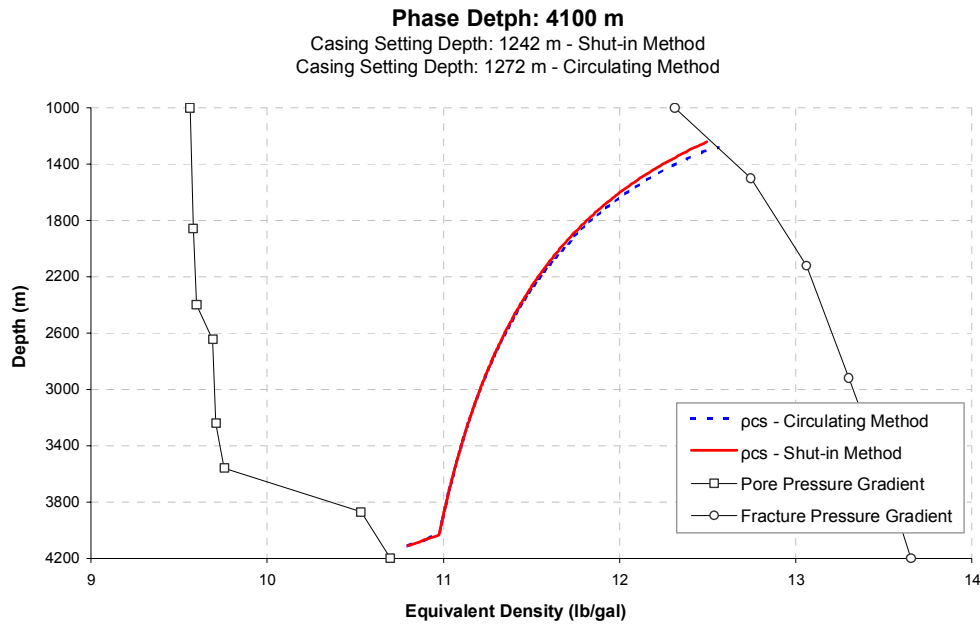


Figure 2. Determination of casing shoe setting depth using the shut-in and the circulation methods.

In situation shown in Fig. 1 the pressure at casing shoe evaluated by the shut-in method is higher than this pressure evaluated by the circulation method and in situation shown in Fig. 2 the pressure at casing shoe calculated using the shut-in method is lower than the one calculated using the circulation method. Thus, it is not possible to predict whether the pressure at casing shoe will be higher at the time of well closure or during the kick circulation, so the optimized method should be used.

Figure 3 and Tab. 4 show the application of the optimized method to design a well to be drilled in 2000 m water depth using the parameters shown in Tab. 3. Note that the curve of the pressure at casing shoe for the conductor 16" casing do not intercept the curve of fracture pressure gradient. Thus, other aspects should be considered in the determination of this casing setting depth as the amount required to prevent washout of the shallow borehole when drilling to the surface casing (13 3/8" casing) and the resistance of the soil (Bourgoyne *et al.*, 1986).

Table 3. Parameters used in the simulations.

Parameters	7" Casing	9 5/8" Casing	13 3/8" Casing	16" Casing
Final Depth of the Phase [m]	5700	5429	4827	4112
Initial Kick Volume [bbl]	35	35	35	35
Kick Specific Gravity ⁽¹⁾	0.7	0.7	0.7	0.7
Mud Density [lb/gal]	18	17	15.5	10
Mud Viscosity [cP]	10	10	10	10
Drillpipe OD [in.]	5	5	5	5
Wellbore Diameter [in.]	6 1/4	8 1/2	11	14 3/4
Mud Flow Rate [gpm]	250	250	250	250

⁽¹⁾: relative to air

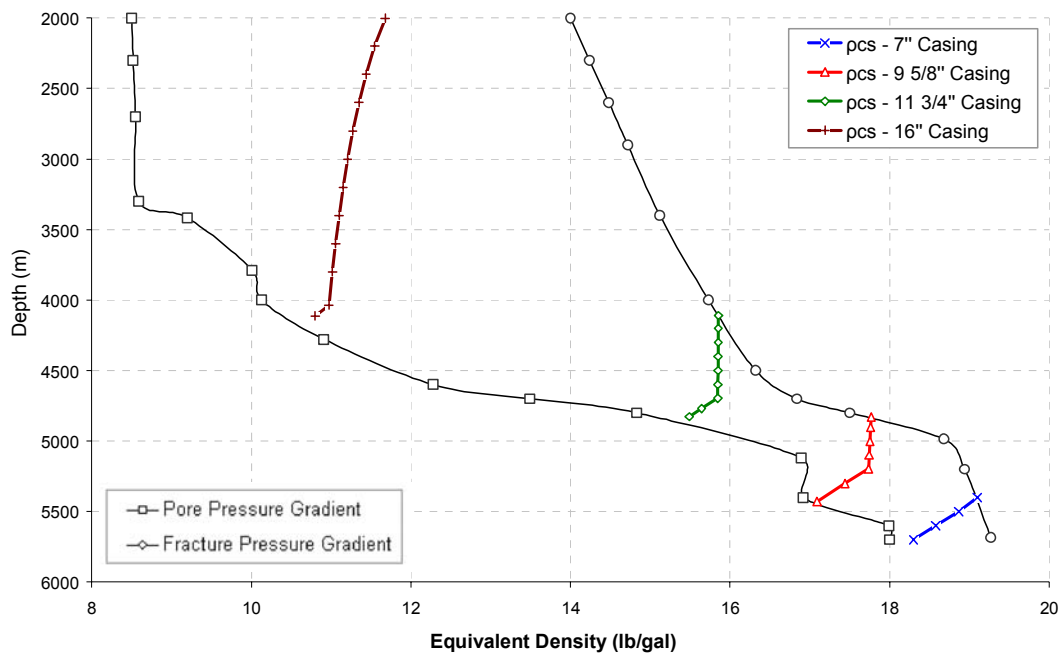


Figure 3. Well design using the optimized method.

Table 4. Casing setting depths.

7" Casing setting depth [m]	5429
9 5/8" Casing setting depth [m]	4827
11 3/4" Casing setting depth [m]	4112

Figure 4 shows the effect of the initial kick volume at the casing shoe setting depth using the optimized method. These results were obtained using the parameters shown in Tab. 1. 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. 4 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.

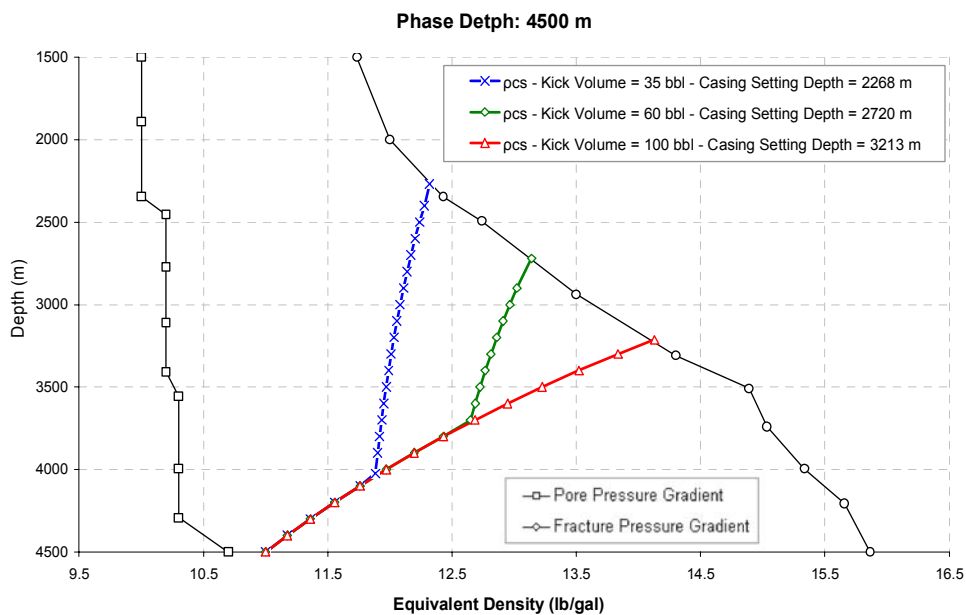


Figure 4. Effect of initial kick volume at the casing setting depth.

As observed in Fig 4, bigger kicks cause deeper casing shoe settings depths. Although, over certain kick volume, the casing shoe setting depth remains constant, as presented in Fig. 5.

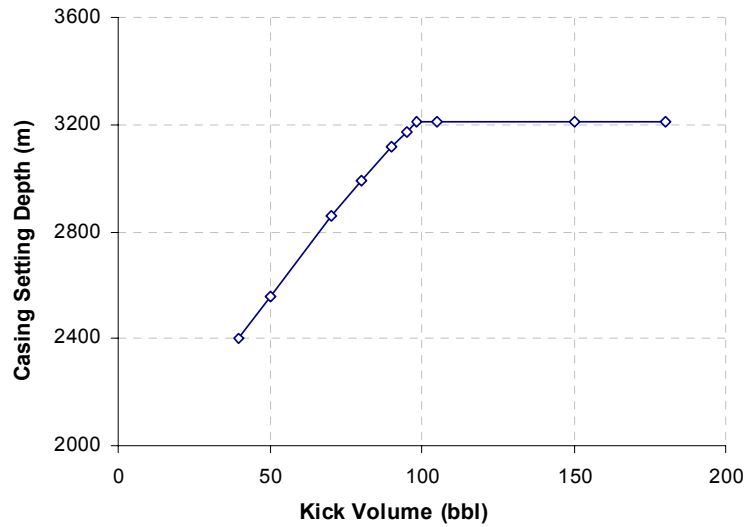


Figure 5. Effect of initial kick volume at the casing setting depth.

The casing shoe setting depth remains constant after the top of the kick reaches the calculated casing shoe setting depth because the maximum pressure at this depth was achieved. Fig. 6 shows this behavior, where the open hole length is the difference between final phase depth and the calculated casing shoe setting depth.

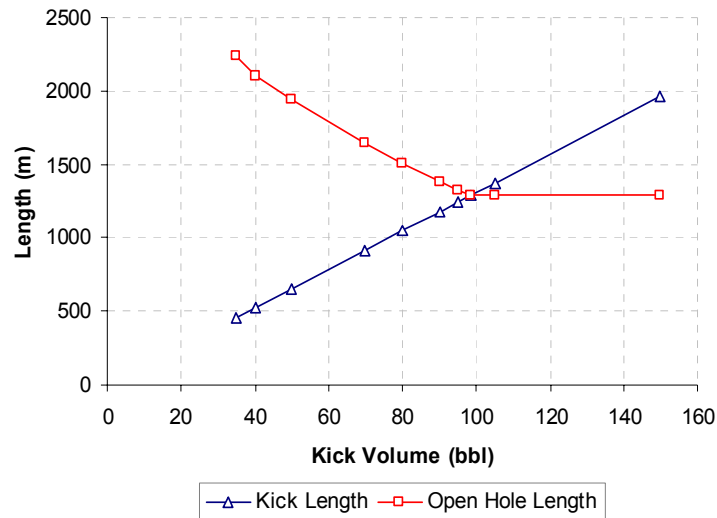


Figure 6. Intersection point of kick and open hole lengths curves.

5. Conclusions

The kick tolerance concept has been shown to be a powerful tool that can be used during well design. The casing shoe pressure behavior during well control operations – well closure and kick circulation – has been considered in the well planning with the application of the shut-in kick tolerance concept and the circulation kick tolerance concept.

Based on these concepts softwares were developed to provide the driller engineer with a convenient tool to be used in the well planning. These softwares make the selection of casing shoe setting depths fast and accurate.

The presented examples have shown that it is not possible to predict whether the pressure at casing shoe will be higher at the time of well closure or during the kick circulation, so the shut-in and the circulating kick tolerance concepts should be used together in the determination of casing setting depths.

The analysis of the effect of the initial kick volume has been shown that the bigger kicks cause deeper casing shoe setting depths. Although, over certain kick volume, the casing shoe setting depth remains constant.

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