



An integrated approach for drilling optimization based on Dynamic Multiphase Kick Tolerance Calculation

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Summary

Overpressure regime in deepwater formations pose drilling challenge with narrow stable mud weight window due to lower fracture gradient in relatively softer sediments as compared to onshore wells. In such scenario, casing shoe depth plays crucial role to manage proper hole condition. Apart from pore pressure analysis, assessment of kick tolerance plays critical role in designing such wells and is often misunderstood in the industry. Confusion and lack of standards regarding kick tolerance often prevents effective use of concepts to assess the risks while drilling.

In the oil and gas industry, simplified single bubble static kick model is mostly used which do not consider dispersion, solution and migration as well as the temperature effects of an influx into wellbore.

Optimizing drilling using advanced well control standards specifically by implementing dynamic multiphase Kick Tolerance estimation and measurements will be an added tool to reduce the exploration cost as well as to enhance maximum safe drillable depth by achieving targets which would otherwise be unachievable in the conventional world.

This study details the significance of dynamic Kick tolerance in getting the well to the prognoses depth at minimal cost with no major NPT and saving rig days.

Introduction

Real-time pore pressure monitoring using a combination of LWD services integrated with Kick modeling coupled with risk registers based on predrill pore-pressure model provides significant insight into wellbore management and allows for optimizing casing shoe depth. Thereby, Kick modeling and analysis provides value in safety and cost savings in

drilling industry. This is especially true for deep water wells where the overburden is reduced and the margin between mud weight and fracture gradient is minimized.

The large uncertainty bands of predicted pore and fracture pressures in HPHT exploration wells in Eastern Offshore had driven the casing design. Minimum requirement for Kick Tolerance based on corporate standards drove implementation of analysis using a dispersed model instead of a single bubble model to achieve more realistic Kick tolerance values.

Deepwater and HPHT operations are two areas where the use of sophisticated simulators (Drillbench™) can enable difficult processes and procedures to be broken down into individual identifiable contributions.

Methodology

This study has been carried out in a deep water well which has narrow drilling margin in deeper section, and safe drilling to reach the planned depth was expected to be difficult. Based on predrill pore pressure prediction and Kick tolerance analysis using single bubble model, intermediate hole section (12¼") was planned to split at a particular point (Casing seat) and allow the hole to be secured prior to drill further. To comply fully with the corporate standard of Kick tolerance volume, additional hole section and casing string would be required, adding further complexity, cost and risk to the well and the operations.

A dynamic well control simulation process had to be initiated as Kick tolerance with single bubble model was giving low values. Dynamic well control simulation is incorporated the influx properties like dispersion, solution and migration as well as the

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temperature effects therefore provided relatively higher Kick tolerance margin.

The Case

The subject well was drilled on a HPHT prospect on Offshore (**Figure.1**). The objective was to appraise the lower Pliocene equivalent of offset wells discovery sand in the same block.

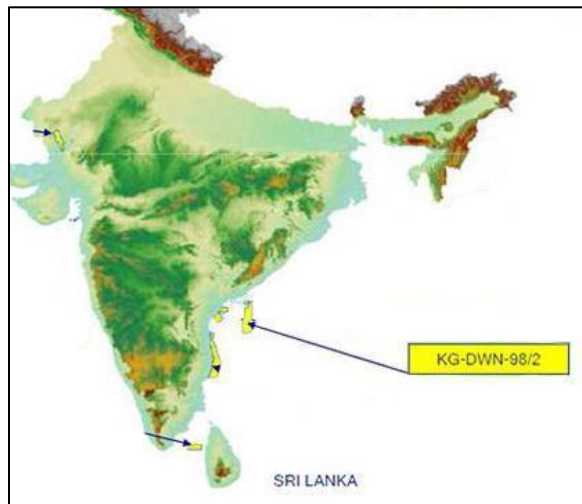


Figure 1: Eastern Offshore KG Basin, India.

The real-time use of data from the LWD formation pressure and sonic tools allowed the pre-drill velocity-to-pore-pressure transforms established during predrill modeling to be updated while drilling using the velocities from the sonic tool and pressures from LWD formation pressure tool. This calibrated transform was then applied (in this case) and continuously being revised the predrill pore pressure model while drilling, thus reducing the uncertainty in the pore pressure prediction ahead of the bit (**Figure. 2**). The well specific velocity information from LWD sonic was used to further define the geopressured predictions in shale and update the predrill model. The gamma ray tool assisted with lithology discrimination, while resistivity data was used for an independent pore pressure evaluation.

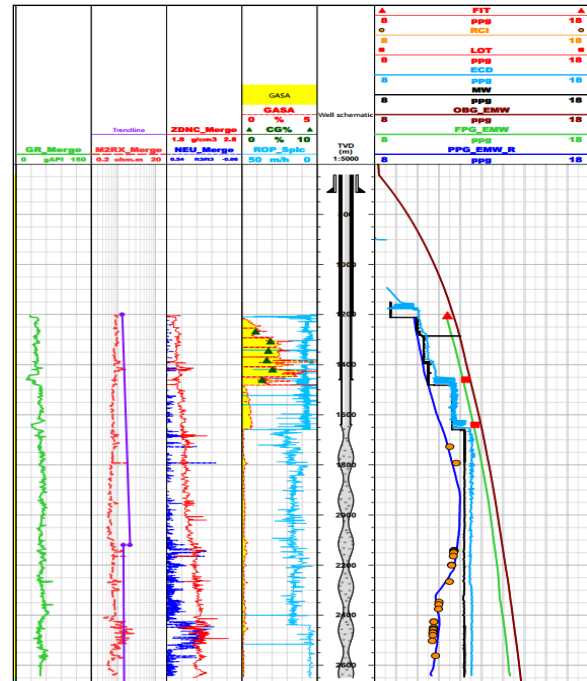


Figure 2: Post drill PPFG.

The casing design and shoe depth selection for the subject well was driven by the challenging pore pressure / fracture gradient (PPFG) profile as well as the wellbore stability issues observed in offset wells (**Figure. 3**). As seen in offset wells, pressure profile was characterized by a pressure ramp at around 1450m, where 16” liner planned setting depth, 9-5/8” casing planned setting depth was at 2450m at the end of pore pressure rise and production casing planned setting depth was at 2830m.

The setting depth of the 16” liner was driven by a minimum and maximum value of fracture gradient. A minimum fracture gradient was required to enable a manageable Kick tolerance for the most likely case in the 14¾x17½” hole, and a maximum fracture gradient was in fact driven by the burst rating of the 20” casing for the load case full displacement to gas, which is mandatory for exploration wells.

On this section, a very narrow mud window was expected at bottom of the pressure ramp. Subsequently, the aim was to set the 13-3/8” shoe at a sufficient depth to cover unstable formations thereby

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maximizing the probability of the 12¼” bottom hole assembly reaching planned section total depth (TD).

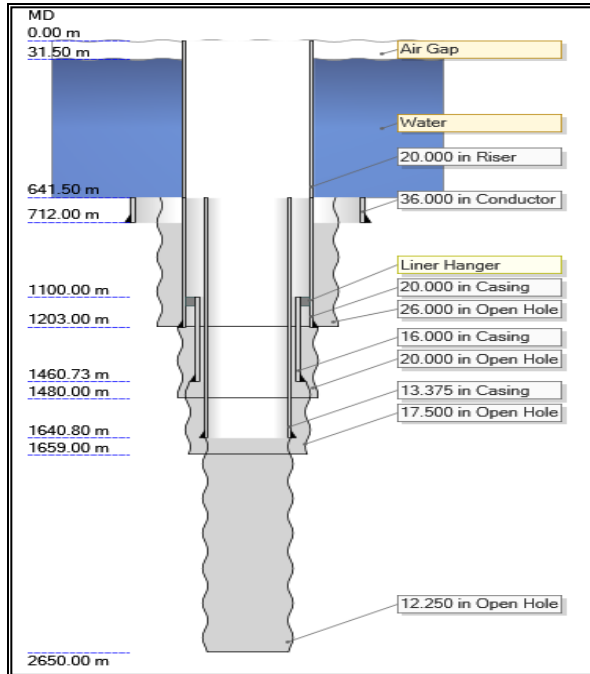


Figure 3: Well Profile.

As learned from offset wells incidents in same section, 16” liner was set above the high-pressure zone. Based on this and other offset well experience, the 16” liner was part of the base case plan for the subject HPHT exploration well.

The objective of 12¼” section, on the other hand, was to cover formations that were troublesome from a geomechanics perspective to set the 9-5/8” casing shoe above the first potential reservoir and, thereby, enabled the reservoir to be drilled in an 8½” section (Figure.3). But, the real-time data had given the possibility to extend the 12¼” section TD further deeper as compared to planned depth based on revised dynamic Kick tolerance and refined PPFG values.

Conventional Kick Tolerance approach

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. Quite often, but not always, that weakest point will be casing shoe.

At the design stage, the selection of a safe casing seat is, in part, determined by the calculation of Kick tolerance for a gas kick.

There are two values necessary to define a Kick tolerance:

- 1) Kick Intensity: This is difference between the pressure in the formation and the pressure in the well. In other words, the kick intensity defines the degree of underbalanced and thereby also defines the rate in which the kick is taken (Figure.4).
- 2) Kick Volume: This is the quantity of formation fluid to enter the well from the kicking formation.

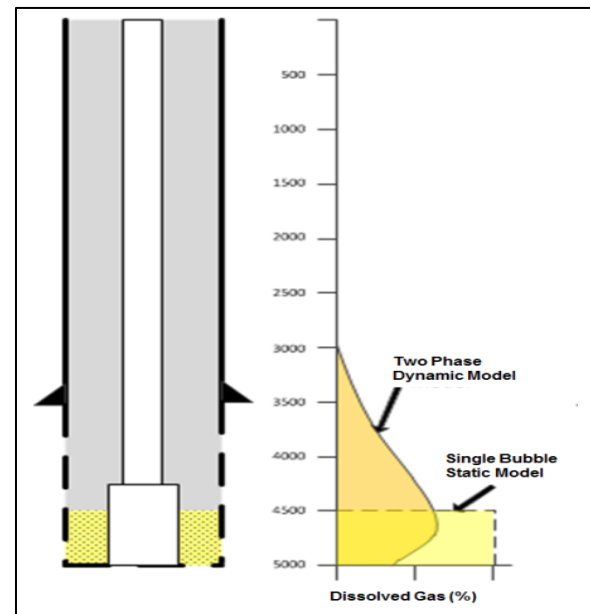


Figure 4: Comparison of influx distribution between single-bubble model and dispersed model.

The conventional single-bubble Kick tolerance calculation proceeds as follows: The first step of a simplified Kick tolerance calculation (constant temperature, constant density, no compressibility) is to define the maximum vertical height of a gas influx (H_{max}) at the casing shoe based on fracture gradient, mud weight, kick fluid density, predicted pore pressure and adjusted MAASP (Maximum Allowable Annular Surface Pressure).

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$$H_{max} = \frac{MAASP - 0.052 \times (PP - MW) \times TVD}{0.052 \times (MW - Kick\ Density)}$$

Volume of the influx at casing shoe,

$$V_{shoe} = H_{max} \times \text{Casing capacity.}$$

Then calculate volume of the influx on bottom (V_{btm}) is calculated using Boyle's Law.

$$V_{btm} = V_{shoe} \times \frac{P_{shoe}}{PP}$$

Limitations of Conventional approach

In a single-bubble model, the kick is considered to have entered the wellbore as a single, continuous phase, displacing the drilling fluid, and with a clean influx (gas) and mud interface. The single-bubble model does not account for influx distribution, gas dissolution in the drilling fluid, and multiphase behavior based on pressure and temperature of the influx and the mud system. These simplified assumptions can lead to an erroneous calculated Kick tolerance volume. The difference in distribution of the influx in the annulus is shown in **Figure.5**

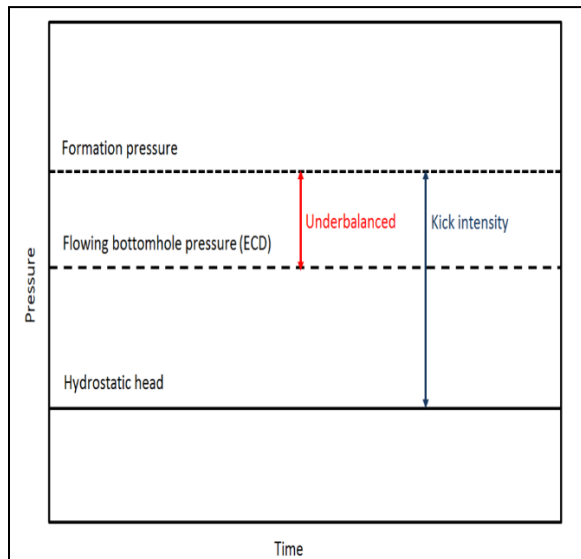


Figure 5: Definition of Kick Intensity.

Dispersed-bubble dynamic Kick tolerance approach

The dynamic simulations take influx, then follow the standard well control procedures of shutting down the pumps and closing the BOP's and allowing the bottom hole pressure to be balanced before circulating out the influx. By using the dispersed-bubble KT model, the full set of conditions and scenarios in a kick control situation could be simulated in the transient modeling software, allowing meaningful sensitivity analysis to be carried out, among others with respect to kick volumes, circulating rates, pit gain, crew reaction time, formation production potential, and choke operator error.

Using the dynamic Kick tolerance simulations several kick scenarios can be modelled, where a realistic distribution of the influx is accounted. The kick is then circulated out using Driller's method (or any other preferred method). The dynamic model calculates the pressure at the last casing shoe whilst keeping the bottom hole pressure constant during the circulation. The maximum pressure at the shoe is calculated as the top of the gas bubble reaches the shoe during well shut in and kick circulation. Gas expansion and breakout, and the specific interaction of the influx with the with the drilling fluid, which rheology is affected by pressure and temperature. The dynamic model provides a realistic kick margin when compared to the simplified single-bubble model for a drilled kick scenario and will often provide a better margin (**Figure.6**).

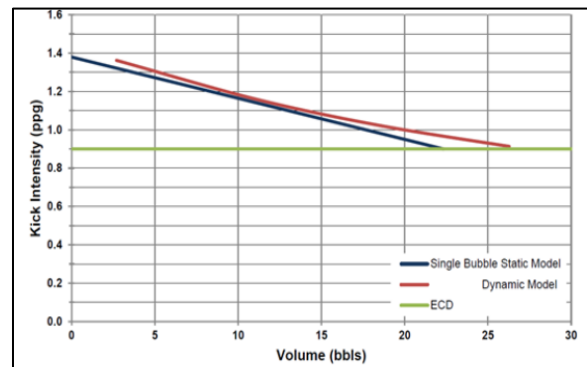


Figure 6: Comparison between single and dispersed bubble model Kick Tolerance.



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After the same analysis is done for all the well sections, an optimized casing design, setting depths and casing shoe characteristics will be available with the specific drilling. This in many cases results in the elimination of one or more casing strings from the original standard well design.

The Kick tolerance standard in the 12¼” hole for the subject well was 25bbl, and if single bubble kick tolerance calculation were to be used, it yielded Kick tolerance lesser than the required standard. Accordingly, during planning phase, the TD of 12¼” phase was planned as 2450m. In 12¼” section, dynamic Kick tolerance analysis were performed integrated with PPFPG updates as drilling progressed and (as shown in Fig.4) allowed the section to extend until 2650m where drilling was stopped and called as well TD. An extension of 200m was done without splitting the section thereby requirement of extra intermediate casing was eliminated.

Conclusions

Dynamic Kick modelling applications assesses the following not commonly assessed by the single bubble model: Gas solubility of SOBM, Gas migration in WBM, Frictional pressure in annuls, Mud compressibility. Dynamic models provide more accurate Kick tolerance values results in more precise well designs which increases safety and potentially saves money through fewer casing strings. It can monitor the effect of Kick tolerance by adjusting mud weights, casing setting depths, formation types, etc. Also, it can track the solubility of gas kick in NADF which result in more detailed insight to the Kick tolerance dynamics and during well control.

Dynamic multiphase Kick tolerance is proposed to display changing Kick tolerance values through the entire hole section. Multiphase dynamic kick models can simulate well control events much more realistically when compared to single bubble static models therefore allowing drilling to be accomplished efficiently.

Well control simulations are expected to enhance the drilling safety margins by appending them in to the drilling companies well control procedures. Dynamic well control simulations will provide a higher Kick tolerance margin in comparison to a conventional single bubble static model when the top of influx is at

the last casing shoe. This allows most of the time, the next casing to be set deeper than the conventionally defined target depth thus in many cases additional phases / casing will be eliminated. Dynamic Kick tolerance tools can better assess the risks associated with circulating out a certain amount of kick volume during well-control operations.

This case study showed the importance of real-time hydrodynamic monitoring and its respective realistic Kick tolerance estimations that comply customer standard, allowed drilling to proceed in the constraints of a very tight mud window, and pushed a 12¼” section deeper than planned. This eliminated an entire casing section and several rig days.

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