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An Experimental Investigation of Kicks When Gases Are in Solution: The Dormant Kick Story

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Abstract

The current drilling activities are relying on the safety mechanism to shut down the well in case of a kick and restore the safety for the rig and crew. Kick detection is a very important aspect of daily rig activities and nowadays has been highly improved through computer-aided solutions. Some of these solutions include highly advancements in wellbore models and sensors, while the newest ones have based their solution through machine learning applications. Kick detection is important because it is a time sensitive process, which means that if delays occur in the decisional process, this may lead to catastrophic incidents. To better understand the nature of kick detection when gas kicks are soluble in drilling mud (for example oil base mud and methane) a small blowout simulator have been developed and two simple experiments have been conducted: water and air that mimics water-based mud and methane and water and CO_2 which mimics the solubility of methane in oil-base mud.

The experiments have shown that in the case of soluble kick situation a delay in detecting the pressure increase at surface exists, resulting in a wrong interpretation of the bottom hole situation. The experiments have shown a time increase to detect the surface kick pressure with up 600% from 3 minutes to 20 minutes. We called this a dormant kick.

Keywords: Kick detection, gas kicks, blowout simulators, CO_2, drilling mud, dormant kick

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Introduction

Conventional drilling methods use weighted drilling mud to prevent fluid (oil, water, gas) kicks. During drilling operations, certain formations can cause a kick with excessive pressure leading to a wellbore wall collapse and lost circulation. A kick is an unexpected influx of fluid from a permeable formation into the borehole, where it will be transported with the drilling fluid toward the surface. Every drilling operation carries the risk of a kick. However, a situation where the migration of uncontrolled formation fluids like oil, gas, water or mixture from the wellbore to the environment can be termed as a Blowout. Blowouts can be avoided, and the consequence of well control events can be minimized by timely detecting and killing kicks.

The world has observed well blowout calamities claiming many lives and causing environmental damage from Santa Barbara well control event to a gas explosion in Oklahoma (Tamin, 2019). When gas enters the wellbore, it mostly remains dissolved in oil-based drilling fluid due to high pressure. But with drilling fluid traveling upwards to a lower pressure zone, gas progressively starts to come out of the solution and starts expanding. Gas remaining dissolved for a significant portion of the flow path is a major challenge for early detection of gas kicks, making it very critical to pick any weak signals or differential parameters to allow maximum time for kick handling. Leading indicators can be used to assess the safety performances and vulnerabilities of a system. The use of leading indicators-based process safety approaches can provide important information on the efficiency of well control barriers to avert blowouts (Mannan et al. 2016).

The objective of this study is to model and carry out kick situations experimentally. Following the public data analysis, a scaled 20-feet high model was built in the Well Construction Technology Center (WCTC) to experimentally simulate the blowout. The goal of the experiment was to determine the pressure influx that led to an equivalent percentage of liquid displacement, which for our experiments was considered to be 10%. Tests on the water filled column were conducted with air and carbon dioxide to simulate water and oil-based muds, respectively. The PIPESIM analysis demonstrated the inflow and outflow performance relationships to mimic the experimental setup conditions.

In what follow we will define the term dormant kick as a kick that occurs in a very slow manner, meaning that the differential pressure on bottom will change from overbalance to underbalance situation within hours. This slow tendency will have a bigger impact when the drilling fluid and kick are miscible, hence the gases can easily enter into solution at small differential pressure on bottom.

To demonstrate this, a scaled model at the WCTC facility was designed to simulate a dormant and dynamic kick. The dormant kick study demonstrated the safety hazard of entrained gases within oil-based mud. In contrast to non miscible conditions, the dissolved carbon dioxide took longer to build up pressure, but eventually increased tremendously over a short period of time. This emphasizes the importance of observing pit gains, utilizing the blowout preventer, and circulating entrained gas out of the mud column during drilling operations since a well may seem to be killed or not flowing but actuality, the pressure could be building up.

Methodology

Laboratory scale setup:

A scale model was developed based on the generated results from PIPESIM model. The setup will not only simulate a dynamic blowout, but also a slow release -dormant kick- to analyze the dissolvability of gas in oil-based mud. Furthermore, the setup model will also accommodate water-based mud simulations for future research. To meet these objectives, several ideas were brainstormed to create an accurate model at an affordable budget and available supplies.

In order to simulate a well blowout incident, several key assumptions were made. Various investigated wells were using oil-based drilling fluid when the gas kick occurred, so to simulate this given the constraints, water was used as the drilling fluid and CO_2 as the gas influx. CO_2 was used because it is highly dissolvable in water and this is representative of the dissolvability of natural gas in the oil-based drilling fluid. The conceptual simulation setup is illustrated in Figure 1 with the end goal being a fully representative of a well without drill string model with the adaptability for other applications in the future.

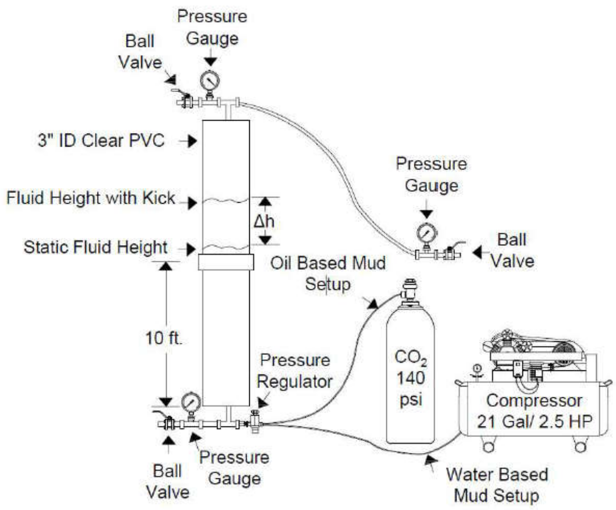

Figure 1 - WCTC blowout simulation design concept.

The developed model utilizes two 10-ft PVC pipes with 3” inner diameter along with several pressure gauges and valves to monitor the change in pressure over time. There is also the ability to use a CO2 tank as the gas for oil-based mud simulations or use an air compressor for water-based mud experiments. The setup is rated for 90 psi maximum pressure due to the limit of the couplings and PVC. The maximum pressure was well within the target experimental procedure, so it did not limit the analysis in any way. The change in the fluid height during the dynamic kick experiment is representative of the volume increase caused by the kick volume.

Experimental Procedure for Dormant and Dynamic Kick Determination

- ***Dormant Kick***

To simulate the dormant kick with water-based drilling fluid, air and water were used. The air compressor was set to 80 psi allowable pressure and the pressure regulator was used to adjust the valve. The regulator was set to the minimum pressure that caused bubbles in the fluid column to occur. The top-side ball valve was then closed and the pressure gauge at the top was read every 30 seconds until it reached equilibrium and the results were recorded. This same procedure was repeated with CO_2 and water which represents oil-based drilling fluid.

- ***Dynamic Kick***

Simulating the dynamic kick involved measuring the height of the fluid level before and after the pressure influx occurred. This procedure was completed for both water-based and oil-based drilling fluid simulations. To begin, the ball valve at the end of the hose was opened and the starting height of the fluid was measured. Next the compressor was set to allow 80 psi to the system. The regulator was used to adjust the pressure influx to the system in increments of 5 psig from 10-40 psig. At each pressure, the fluid level was measured ensuring that the fluid height never completely filled the system. This procedure was then completed for the simulated oil-based drilling fluid with the same increments of pressure.

Results and Discussions

- ***Dormant Kick***

The results of the dormant kick experiment verified and validated the expectation that CO_2 would dissolve in water similar to oil-based mud and natural gas. As presented in Figure 2, the water-based mud (Air) simulation demonstrated a quick pressure build-up after only 3 minutes, whereas the oil-based mud (CO_2) simulation took 20 minutes. This shows that if this experiment were to be correlated to real life, a well can seem to be killed or not flowing with oil-based mud, but in actuality, it could be a dormant kick, which will leave little time to react once the pressure reaches the beginning of the quick build-up region designated by the black dotted line as shown the figure below.

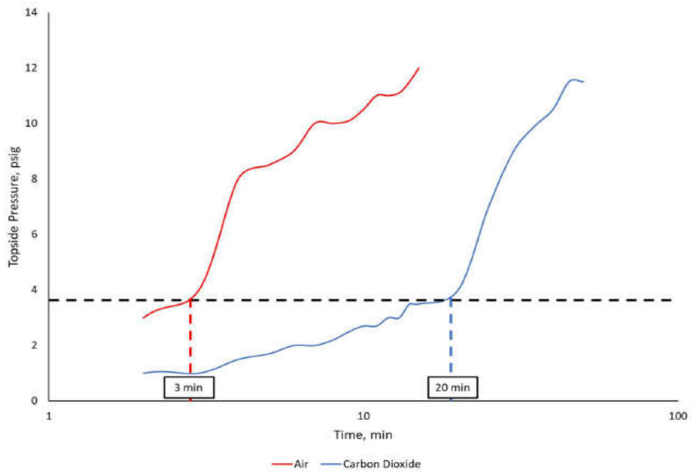

Figure 2- Plot of back pressure in relation to time for a dormant kick simulating oil-based and water-based drilling fluid.

- ***Dynamic Kick***

The dynamic kick experiment was used to simulate a rapid influx that the is considered a standard situation a well experienced during the blowout. Our target was to mimic an influx that will represent around a 10% increase in total volume in the wellbore. The results of the dynamic kick experiment showed that a 26-psi pressure influx represented a 10% volume increase for the oil-based mud simulation. This is slightly different than the water-based mud simulation, which required 29 psi in order to experience a 10% volume increase in the water column. This difference in the required pressure influx is most likely due to the solubility of CO_2 in water. A summary of these results can be seen in Figure 3.

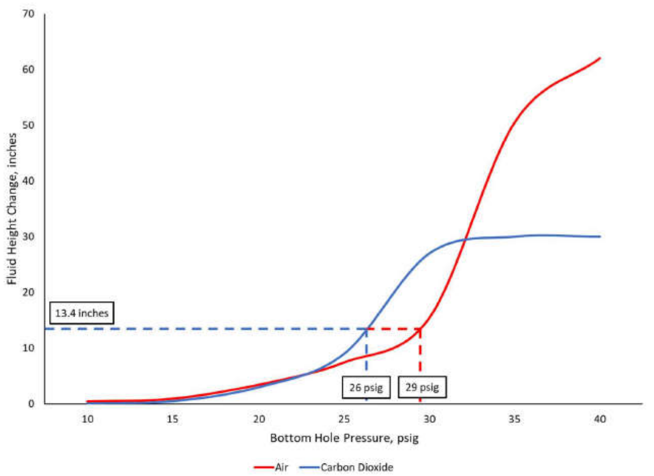

Figure 3- Height change in relation to pressure change simulating a Dynamic Kick with simulated oil-based and water-based drilling fluid

WCTC Setup Modeling and Simulation in PIPESIM Environment

Having determined the downhole conditions that led to the case study well, S-1 well blowout using PIPESIM simulation, a second simulation was performed on the WCTC scale model well. This second simulation was performed to determine the corresponding conditions which would best replicate the kick and blowout within the scale model well. The simulation for the scale model was performed using a methodology similar to that used in the first simulation. The PIPESIM schematic of WCTC scale model well is illustrated in Figure 4.

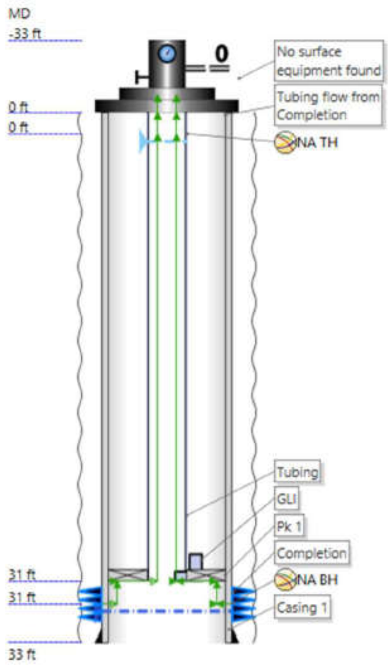

Figure 4- PIPESIM representation of WCTC setup

The scale model of the case study well was simulated as a roughly 30 ft. deep well producing water through a simple perforated-casing completion. The reservoir pressure was initially simulated at 140 psig. The PIPESIM model included a singular-point gas lift system to simulate the air and CO_2 injection system present on the actual scale model. The user defined PIPESIM fluid model for the gas lift (CO_2 injection) is presented in Figure 5.

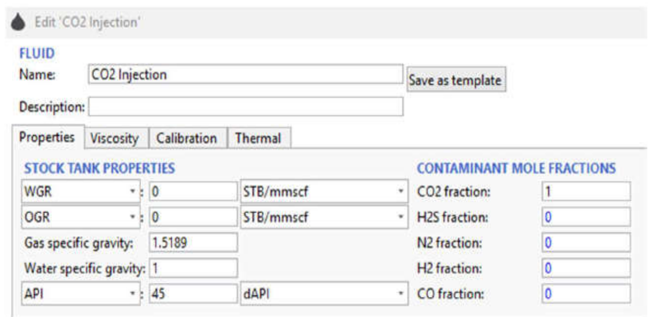

Figure 5- User defined fluid properties for the WCTC blowout model

The objective of this simulation was to determine the pressure at which gas needs to be injected into the model to displace about 10% of the water within it. With a 134” fluid column, gas needs to be injected at a pressure which raises the height of the water by 13.4". To find this pressure, a baseline was established for the scale model's VLP with zero gas injection. The same iterative process was applied to determine the flowrate at which a 10% fluid displacement would occur. For consistency, the factor of time was also considered during this simulation process. The iterative outcome is presented in Figure 6.

Future Utilization of WCTC Blowout Designed Model

The importance of the model designed at the WCTC is that it will be used for further research on blowout simulation and prevention. The model can be used to experiment with both water and oil-based muds by altering the gas injected. Dormant and dynamic kicks can be simulated, along with testing while the BOP is open or closed. The simulator is currently upgraded and can be used as training base for field engineers.

Conclusions

The analyzed and simulated blowout for two different cases: dynamic and dormant kicks. The result of this blowout shows how important it is to recognize a kick early on before it is too late, most especially alarm management for different drilling operating modes.

The conclusions can be drawn as follow:

- Drilling with oil-based mud poses a higher risk for a potential kick due to the high solubility of gas in oil.
- When a dormant kick occurs, the well can seem to be killed or not flowing but gas can be dissolving in the drilling mud and lead to a kick or even worst a blowout.
- The dynamic kick test showed a 26-psi pressure differential in the model, which equates to a BHP of 2,050 psi.
- The developed model at the University of Oklahoma's Well Construction Technology Center correlates to published data on well blowout incidents with 10% liquid displacement caused by the gas influx.

Acknowledgments

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Nomenclature

BOP - *Blowout Preventer*
ID - *Inside Diameter*
IPR - *Inflow Performance Relationship*
OPR - *Outflow Performance Relationship*
GOR - *Gas-Oil Ratio*
VLP - *Vertical Lift Performance*
PPE - *Personal Protective Equipment*
PVC - *Polyvinyl Chloride*

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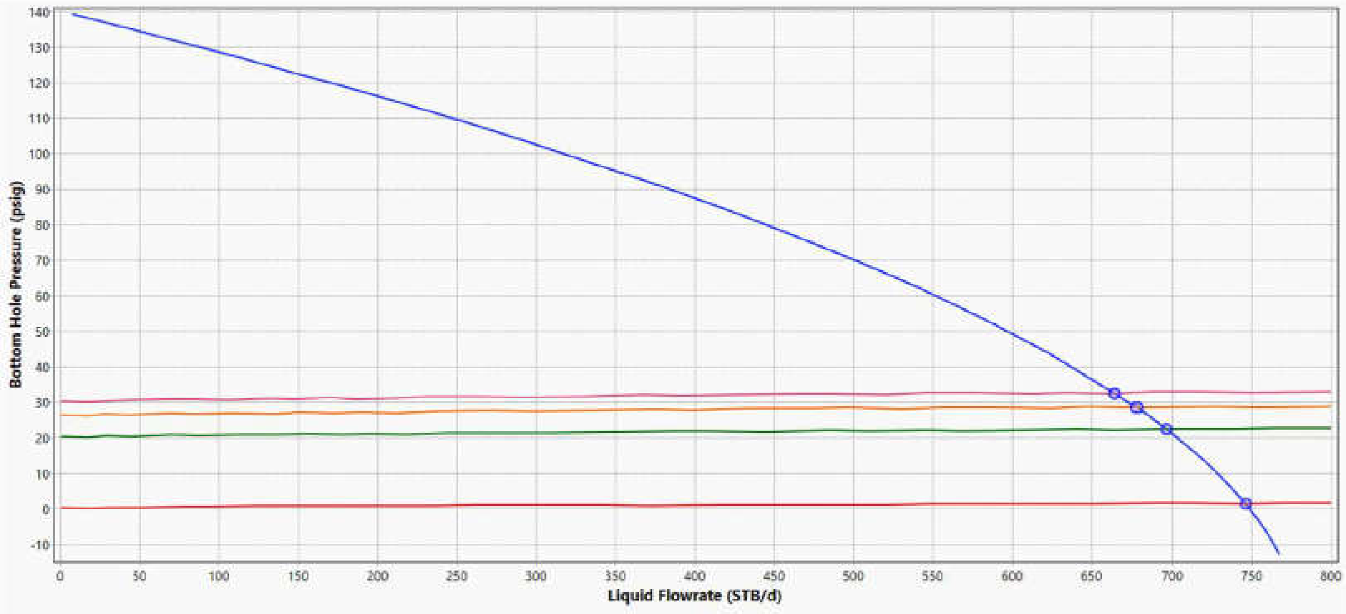

Figure 6- PIPESIM results for BHP that equates to a 10% volume increase. The green line represents 26 psig which was found to result in a 10% volume increase