Today's complex drilling operations demand sophisticated well-control modeling tools

Ole B Rygg, Well Flow Dynamics AS

THE COMPLEXITIES OF today's drilling operations including deepwater drilling, shallow water or gas flow problems, HPHT wells and multilateral drilling operations demand modeling tools to be able to accurately plan and predict these types of operations.

The challenges facing a well control intervention task force will be even more substantial for all these types of operations and a significant effort should therefore be placed on up front risk reduction measures.

The hydraulic modeling tools required for risk reduction measures are indeed available today for these types of operations both to be used in contingency planning and during a well control incident.

Flow diagnostics and hydraulic operational design drives the strategy for response. This includes what kind of equipment and tools to use, which intervention method to use as well as how the operation should be controlled.

The same driving elements are also evident in the contingency planning process. The focus is then on being able to respond to a hypothetical well control incident, or even as importantly how to reduce the risk of the drilling operation.

This could, for example, include influence on well design and operational procedures.

WELL CONTROL DESIGN

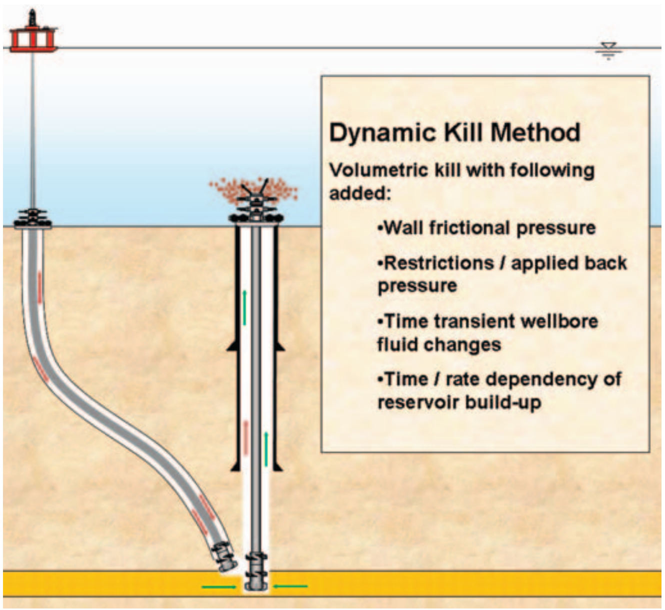
A successful well control operation to regain control of, for instance, a blowout well consists of three equally important phases:

- The analyzing phase;
- The planning phase;
- The execution phase.

In all three phases the well control modeling plays an important part and drives the decision making towards a successful operation.

ANALYZING THE INCIDENT

When facing a well control incident the first challenge is to analyze the ongoing situation thoroughly. It cannot be stressed enough how important this first phase is. Several incidents in the past have worsened due to planning and execution based on limited and wrong assumption about the ongoing situation.



Direct intersection options are dependent upon a ranging target such as casing or tubing and are the preferable and most used option for relief well intervention.

In the analyzing phase, a well control simulator should actively be used to predict the current flow situation in the well including well pressure, temperatures, fluid types and rates. Furthermore, modeling should be used to recapture the situation in the well prior to the incident and as such enhance the understanding of the problem encountered.

PLANNING THE OPERATION

When the well situation is fully understood, the detailed well control planning can be initiated.

During the planning phase the modeling tools should be used to simulate the different intervention options. Based on the results, the experienced well control engineers can decide on the best way forward and further estimate the resources required to perform the plan.

EXECUTION OF THE OPERATION

When the operation to regain control begins the modeling tool should be converted to an "online" simulator following the operation carefully in order for the engineers to continuously update their plans. If changes have to be made during the operation, the effect of the changes can be tested in the models before the well control task force take the appropriate action.

CONTINGENCY PLAN

In evaluation of emergency response for a drilling operation, onshore or offshore, one essential element is the pre-evaluation of the possibility of regaining control of a blowing well. Even though the probability of a blowout might be small, the consequences with respect to safety, cost and pollution could be catastrophic.

A contingency plan will focus on the ability to regain control. The plan could also evaluate the current level of technology and operational expertise available for a blowout intervention operation. Shortfalls can then be identified and appropriate action taken to reduce the deficiencies early in the planning phase.

A contingency plan will typically include the following parts:

- Define worst case scenarios based on the drilling and development plan;
- Calculate maximum blowout rate for the defined scenarios.
- Evaluate potential kill options;

- Calculate required kill rates and volumes;
- Identify and check relief well locations;
- Identification of drilling rigs for relief well drilling;
- Investigate the practicality of the chosen intervention operation;
- Investigate blowout probability and blowout frequencies for the planned operations.

BLOWOUT SCENARIOS

Evaluating the well configuration, completion program and planned operational aspects, worst case scenarios for blowouts should be selected.

These would typically include:

- Blowout through the drillpipe;
- Blowout through seabed or surface for flow in annulus;
- Blowout through open hole. Pipe pulled out of hole;
- Blowout through production tubing;
- Underground flow.

For worst case simulations, all of these scenarios assume a total loss of control and unrestricted flow to seabed or surface. Sensitivity on outflow restrictions should also be evaluated.

BLOWOUT INTERVENTION

Several methods can be considered in order to control blowouts. The actual method to be used for a particular blowout intervention operation will need to be decided by the blowout control task force at the time of an actual occurrence.

RELIEF WELL INTERSECT

Direct intersection options are dependent on a ranging target, such as a casing or tubing, and are the preferable and most used option for relief well intervention.

After dynamically killing the well with mud, the required mud density to statically balance the well should be pumped. When the well is sufficiently stable, cement can be pumped for final static control.

The theoretical and operational aspects of dynamic kills have been extensively covered in several technical discussions. The original work on dynamic kills with water was made by **E Blount** et al. of **Mobil Oil**, for their Arun blowout in Indonesia. They describe dynamic kill as a technique utilizing flowing frictional pressure drop to supplement the static pressure of the kill fluid being injected up the blowing well. Water flowing up the blowing well at a given rate can as an example cause the same total pressure difference between the reservoir level and the wellhead as a static mud column balancing the reservoir pressure.

Seawater may be used to evaluate communication path and pumping plant initially for some cases, but can also be used to kill the well for low rate flow, low pressure blowouts or blowouts with restricted flow area.

The casing design of a relief well could differ from a conventional well in the same area to ensure sufficient pumping capacity down the relief well. It is therefore essential that the pumping operation is modeled correctly and all aspects and potential shortfalls are investigated up front.

DYNAMIC KILL SIMULATIONS

Results of the dynamic kill simulations are usually given as the minimum required pump rate to stop further reservoir inflow.

The pump power requirements reflect pumping down the relief well annulus assuming pumping against a reservoir pressure. The kill requirement is based on the ability to achieve a minimum pressure in the flowing well to stop further reservoir inflow and consequently kill the well.

The calculated total volume of kill fluid required to kill the well consists of:

- Mud volume required to fill up relief well including wellbore annulus, kill and choke lines and optional flexible line;
- Required pump rate times the time to stop inflow (Flowing bottomhole pressure exceeds reservoir pressure);
- Two hole volumes of the blowout well ensuring two proper "bottoms up" circulations.

WELL CONTROL MODELING

Well control models available today can be divided into three different categories:

- Steady state models;
- Semi transient simulators;
- Full transient simulators.

The steady state models are available in various level of sophistication both with respect to fluid handling and user interface. These models can be used to get a rough estimate of maximum flow rates for a blowout as long as the fluid properties and reservoir inflow are taken care of correctly.

The semi-transient models are a next step development from the steady state models. The models estimate transient effects based on predicting steady state situations at various guessed rates and combination of fluids.

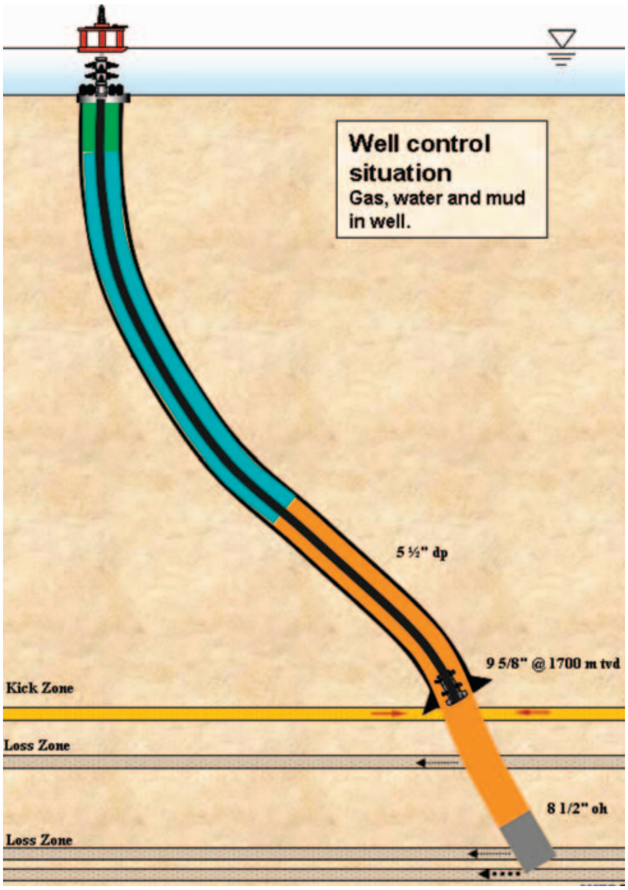
Since there are no direct coupling to the rest of the wellbore in time these models can only be used for boundary estimation with respect to kill rates for a well control operation. Volume estimation can for most cases not be estimated at a required level of accuracy.

The full transient well control simulators can be divided into two categories:

- Two-phase flow models;
- Three phase flow models.

Both of these types of models can be used to predict a well control situation with respect to transient wellbore temperatures and pressures, kill rate estimation and volume requirements. The three phase models are preferable over the two-phase models since they can handle the different fluids more accurately.

In addition to the base core multiphase physics the simulators needs to be able to handle the fluid properties in the well both with respect to pressure and temperature variations. Equally important are the boundary conditions to the environment including inflow from the reservoir and critical choke handling effects.



After temporarily plugging the bottom of the well by pumping cement, the plan to alleviate massive losses was to circulate the upper part of the well free of reservoir fluid.

To model all the transient effects during a complicated dynamic kill operation a network model is required. The network configuration will be able to include the effects of varying fluid mixtures, back flow and multiphase slugging effects that can be present in a dynamic kill operation.A fully transient simulator that could model all these parts of a dynamic killing process was first introduced by Rygg and Gilhuus in 1991.

For simulation of blowouts and kill interventions presented herein the Olga-Well-Kill simulator has been applied. The simulator is tailor-made for well kill simulations and has been used in a number of on-site applications for blowout and well control. The core code in the simulator is the OLGA2000 three phase flow model, which is the industry standard for transient simulations of flow in pipelines and wells.

The basic principles of the Olga model can be found in a paper by Bendiksen et al. The development and applications of the Olga-Well-Kill simulator are extensively described in several papers.

WELL CONTROL INCIDENT

While drilling from a semisubmersible rig into a mature reservoir a kick was taken followed by massive losses. The open wellbore consisted of a kick zone and loss zone. All available mud on the rig was pumped followed by seawater.

After temporarily plugging off the bottom of the well by pumping cement, the plan was to circulate the upper part of the well free of reservoir fluid. Fear of losing mud while circulating demanded a thorough analysis of the situation.

Simulations were performed with variable loss rate and used as guidelines in order to be able to analyze the situation. The successful circulation was proved by the perfect match with the predictive simulations.

The well control modeling played and integral part in all phases of this well control operation by analyzing the current downhole situation, planning the well control pumping operation and monitoring the final successful kill and plugging. ■