A math-based model for deep-water oil drilling

August 25 2011

Oil well control is one of the most important processes during drilling operations. In deepwater drilling, controlling pressure in the oil well is crucial, as excessive pressures in the drilled hole can result in blowouts, leading to disastrous events like the 2010 Gulf of Mexico Oil Spill.

The deeper the well, the higher the pressure, and the higher the risks associated with tapping oil from wells. During drilling, when the pressure applied to balance the hydrocarbon pressure in a well is not great enough to overcome that exerted by gas and fluids in the rock formation drilled, water, gas, oil, or other formation fluid can enter the hole. This is called a "gas kick," which in worst-case scenarios can lead to blowouts.

In a paper published earlier this month in the *SIAM Journal on Mathematical Analysis,* author Steinar Evje presents new analysis of a mathematical model that has applications to the study of such gas kicks in deep-water oil wells.

The use of mathematical models is important for the development of tools that can help simulate, and hence, increase control in deep-water well operations. "Various gas kick simulators are being developed for the purpose of studying well control aspects during exploratory and development drilling," says Evje. "Simulators have become an important tool for the development of new, more efficient and safer drilling methods."

"A simulator for drilling operations is composed of a set of nonlinear coupled partial differential equations that describe the simultaneous flow of hydrocarbons in a well. This mathematical model represents a 'virtual laboratory' where the finer mechanisms related to a number of different physical effects can be studied in detail," Evje goes on to explain.

The main challenge presented in many of these models is the precise prediction of the pressure profile in addition to liquid/gas volumes and flow rates at various points along the oil well. "This issue becomes even more critical as many drilling operations today involve long and deep wells with corresponding high pressures and high temperatures," Evje explains. Regions along the well that are open to crevices and deformities in the rock formations present specific challenges, as it is critical to maintain well pressure at these positions within certain limits. Thus, in the case of inflow of gas from surrounding rock formations, it would be important to safely transport this gas out of the well.

The starting point for Evje's proposed mathematical model is a one-dimensional two-phase model, which is often used to simulate unsteady, compressible liquid and gas flow in pipes and wells. Unlike previously analyzed models, in this gas-liquid model, the two phases may have unequal fluid velocity and a generalized term to jointly represent liquid and gas pressure.

This allows a model that can describe the ascent of a gas slug (conglomerate of high pressure gas bubbles) due to buoyancy forces in a vertical well. A gas-kick situation is usually accompanied by such a flow scenario.

In order to compute reliable solutions, it is crucial to have a model that is well defined mathematically. Mathematical methods are applied in order to derive upper and lower limits for various quantities like masses and fluid velocities, which provide insight into the parameters that are important for the control of these quantities. In addition, they allow proof of the existence of solutions for the model in a strict mathematical sense. In this paper, the author demonstrates that under certain assumptions, a solution exists.

Conditions are assumed to be isothermal, and relevant physical mechanisms are factored into the model, such as frictional forces, hydrostatic pressure, force of gravity, and compression and decompression of gas.

Such mathematical analysis is essential to optimize and evaluate drilling operations and well-control practices in order to minimize the possibility of oil well disasters, especially in deep-water wells. "The possibility of blowout occurrences needs to be mitigated in order to avoid human casualties, financial losses, and finally but not least, environmental damage," says Evje.

More information: Weak Solutions for a Gas-Liquid Model Relevant for Describing Gas-Kick in Oil Wells, Steinar Evje, *SIAM Journal on Mathematical Analysis* 43 (2011), pp 1887-1922. Online publish date: August 11, 2011

Provided by Society for Industrial and Applied Mathematics