Preface

Modeling & Simulation in Drilling and Completion for Oil & Gas

Modeling & Simulation is an indispensable tool in petroleum engineering, in which petroleum engineers must make comprehensive use of a variety of engineering sciences, including mechanics, electromagnetics, multiphase flows, etc., to study the behavior of down-hole tubulars, rock-fragmentation, fluid flows, etc. Thus, the tubular mechanics, multi-phase fluid mechanics, and the rock mechanics all under down-hole constraint conditions, must be researched by using a variety of methods, such as theoretical analysis, experimental studies, numerical simulations, down-hole information measurements & processing, and so on. For example, down-hole tubular strings such as drilling strings, casing strings, tubing strings and coiled tubing are operating in various long & narrow boreholes, filled with the working fluid and subjected to axial & lateral loads, drag & torque, interaction with fluid & rock, high temperature & high pressure, and so on. Thus their mechanical behavior is very complicated under the down-hole operation conditions, and must be studied by specialists with rigorous training in both mechanics and other engineering sciences. In petroleum engineering, research on down-hole mechanics is necessary to understand the instability mechanisms in the down-hole operation process, and provide a scientific basis for developing down-hole control techniques for improving the operational efficiency & performance in petroleum engineering.

There is a research group directed by Deli Gao, who is a professor of petroleum engineering, at the China University of Petroleum-Beijing, China. This group is committed to research on down-hole mechanics & control techniques, in the drilling & completions of critical wells including horizontal & complex-trajectory wells, deep-water wells, sub-salt wells, deep or ultra-deep wells and so on, for oil & gas. Analogous to the oil-spill incident which occurred in the Gulf of Mexico, also in deep-water drilling & completion, the critical wells pose severe challenges to petroleum engineers all over the world. The collection of papers in this special volume presents some of the results which are achieved by this research group in 2012. The following innovative results can be found in these papers:

1. Buckling of down-hole tubular strings has significant effects on many operations in petroleum engineering. The research on this topic will help us not only to understand the mechanics of the down-hole tubular buckling, but also help us devise approaches to reduce or mitigate such buckling in petroleum engineering. The analytical solutions for the down-hole tubular buckling equations, for sinusoidal and helical tubular configurations, are ob-

tained by the Galerkin method and the nonlinear scaling method and are in good agreement with the numerical results. The critical loads for the sinusoidal buckling and the helical buckling of down-hole tubular string are determined by using the constraint conditions under which the contact forces are nonnegative. Thus, the post-buckling behavior of the tubular strings with different configurations, in an inclined wellbore is determined by an analytical method. In another paper, advanced calculation models for predicting the down-hole drag & torque have been established, by considering the effects of tubular buckling behavior, fluid buoyancy, mechanical resistance, friction reducers and so on, to improve the calculation accuracy of prediction of down-hole drag & torque, which are verified by the field data and are very useful for engineering design and operations in horizontal, extended-reach and complex-trajectory wells.

2. In deep-water wells for oil & gas, the subsea wellhead structure is special, and the annular pressure cannot be released after the casing hanger is set. The pressure changes in the casing annuli, caused by a temperature change during the drilling and production process will increase the risk of failure of the casing. Therefore, an interaction model for the casing/cement/formation-system is established by considering the thermal loading in a perfect well section. The casing displacement function, as related to the temperature and the internal pressure in the casing, is obtained through a theoretical derivation. A theoretical model is thus established, which can be used to predict the annular pressure buildup caused by thermal expansion of both the casing and the annular fluid. This research shows that the annular pressure caused by temperature change can lead to a failure of the casing, when the average temperature change is high enough. Therefore, the effects of temperature and pressure should be taken into account specially in casing design for deep-water well engineering.

3. In oil & gas drilling engineering, both the efficiency of rock-breaking and the trajectory control of the well, should be quantitatively and correctly described by an ideal triaxial rate of penetration (ROP) model, along with the variations of objective and subjective factors. However, the existing ROP models fall short of achieving this goal, because the unloading effect is not taken into account in these models so that their applications are limited, especially in situations of underbalanced drilling (such as air drilling and foam drilling, etc.). Based on a rock-bit interaction model, a new triaxial ROP model related to unloading has been developed, in order to illustrate the effect of the bottom-hole differential pressure on the formation forces. This new model is successfully applied to predict the well-trajectory and the ROP

of two deep wells in Sichuan oilfield, China. In another paper, a mathematical model describing the crush of the rock- and earth-cuttings in gas drilling is established by coupling the two-phase-flow of gas & solid, with the failure mechanics of the rock. The numerical simulation thus developed can be used to study the distribution of the particles of the cuttings during the process of the transport in the annulus, in gas drilling

4. The bottom-hole pendulum assembly (BHA) for the hole deviation control is widely used in drilling engineering. The tilt-angle and the side -force of the drill bit are obtained by BHA analysis, based on the method of weighted residuals. Using this analysis, the effects of the drill bit anisotropy on the hole deviation control, is illustrated by case study, which shows that the BHA should be matched with the drill bit, with the side and short gauge protection. In another paper, the method of weighted residuals and Newton-Raphson iteration are used to calculate the nonlinear effects of BHA deformation to demonstrate that the effect of the axial displacement in the governing equation on the bit side force may be ignored, in an actual BHA analysis.

5. 3D FE models created by using the commercial finite element software (ABAQUS/Explicit) are used to perform the simulations for two key stages of the milling process, including the starting stage of the milling of the casing, and the stage of full-gauge milling of the casing-window. These models incorporate the effects of main drilling parameters, such as the reaction force, the torque, the speed, the feed rate per revolution, and the milling angle. The computed results verify the capability and advantages of 3D FE simulation for the process of milling of the casing-window.

6. In another study, a type of a three-electrode-array is first used in the development of a detection-tool, for connecting a relief-well to the blowout-well, in order to greatly increase the detection range and effectively reduce the requirements for the sensitivity of the sensors. Based on the strength of the magnetic-field detected by the sensor, a formula has been derived to calculate the distance between the relief-well and the blowout- well. In addition, the effects of some parameters, such as the length of the three-electrode array, on the strength of the magnetic-field, have been illustrated. In another paper, a new electromagnetic ranging system, called the solenoid assembly ranging system, is presented as a technical invention for determining the distance and direction from one wellbore to another nearby target wellbore.

7. Based on the characteristic of an inverse-proportional function, a new type of well profile is proposed, for extended-reach well engineering, which is called

the inverse proportional curve profile. Through an example, this new profile is compared with the existing well profiles, including a circular arc, catenary, sideway catenary, modified catenary, parabola and cycloid, in some aspects such as hook load, the maximum hole curvature, wellbore length, down-hole drag & torque and so on, in order to show that the inverse proportional curve profile has many advantages, including the smaller hole curvature, its steady change, a smaller down-hole drag & torque, and the shorter wellbore length. Therefore, it is expected that this new profile would be used in the design of extended-reach wells in the future.

8. A model for computing the radius of curvature and the length of coiled-tubing (CT), wound around the reel, has been established by analyzing the geometrical parameters of the reel system. It can be used to calculate the flow resistance in the CT wound around reel (CTFR), by combining with Dean-number and power-law fluid state equation, which may be useful for the selection of parameters related to CTFR in microhole drilling.

9. Also, using the law of conservation of mass, the Z12V190 diesel tail gas flow rates (DTGR) are calculated, by analyzing the Z12V190 diesel exhaust composition and calculating O_2 mass percentage (OMP). Based on the minimum kinetic energy method, the minimum gas injection rate (MGIR) formulae have been updated and illustrated by using case studies. The research results show that DTGD (*Diesel Tail Gas Drilling*) is suitable for low pressure shallow wells and deep wells under the condition that OMP in DTG must be less than 12%.

10. The PEBI (*Perpendicular Bisector*) grid node generation technique, and the process of treatment for the grid nodes at the junction of fracture and wellbore or the edge of fracture is proposed for a fractured horizontal well, and the PEBI grid node is successfully constructed on the basis of the Delaunay triangulation. This method is successfully used to solve the technical problems such as variation of angle between fracture and wellbore, complicated fluid flow at edge of fracture, and so on. Compared with the Cartesian grid, PEBI grid is more flexible, as it can be used to distribute the grid nodes appropriately, following the horizontal-well-trajectory and the fracture shape, so that the complicated requirements of the Cartesian grid method can be avoided for describing the shape of fractured horizontal well.

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