Finding ways to improve UBD hole cleaning

By Lei Zhou, Scandpower Petroleum Technology Inc

The test facility simulates conventional and UB drilling operations at downhole conditions.

UNDERBALANCED Drilling (UBD) is growing in popularity and is suggested as the solution to many drilling problems that the drilling industry will face in coming years. Depleted and low productivity reservoirs are examples of areas where UBD can be applied. Several common drilling problems can be avoided and lead to improved drilling performance in an optimally designed underbalanced drilling operation.

Although there are many advantages with this technique, there are also challenges. It is more difficult to design the operation. Control of bottomhole pressures require that the multiphase flow in the wellbore can be modeled accurately. **Scandpower Petroleum Technology** has been developing dynamic wellbore flow models with high accuracy and has, through the Drillbench suite, an excellent tool for integration with new technology such as the cuttings transport module.

HOLE CLEANING IN UBD

Compared with conventional drilling, additional equipment and procedures are required before, during and after a UBD operation. Furthermore, very little is known about the hydraulic properties of UBD fluids, and even less is known about their hole-cleaning capabilities. Hole cleaning is a major factor affecting cost, drilling time and safety of oil and gas well drilling. Inadequate hole cleaning can result in expensive drilling problems such as differential sticking, premature bit wear, slow drilling, formation fracturing and high torque and drag.

INDUSTRY EFFORTS

Oil companies and the US Department of Energy have funded JIP projects to study the complex problems related to hole cleaning in UBD conditions. Since 1999, a total of $5.97 million (75% from DOE, 25% from the industry) has been invested in the University of Tulsa Drilling Research Project (TUDRP). Probably the largest flow loop of its type in the US, the facility is designed to simulate conventional and underbalanced drilling operations at downhole conditions (elevated pressure and temperature). Several papers have been published based on experimental studies at this facility, which has generated a lot of valuable data and unique mechanistic models.

BHP PREDICTIONS

Estimation of bottomhole pressure is one of the most important tasks during UBD. Accurate prediction of BHP is the key to successful underbalanced drilling operations. However, in the inclined or highly deviated wellbore section, cuttings tend to deposit and form a stationary bed. As a result, in-situ concentration of cuttings in the wellbore is not equal to the concentration near the drill bit. Similarly, in-situ gas mass fraction is not the same as the injection gas mass fraction. Two of the most important parameters in BHP calculation, annular frictional pressure loss and mixture density, are very difficult to evaluate due to multiphase flow behaviors, where gas, liquid and solids flow simultaneously with different flow rates. Introducing a gas phase into the flow system creates more dynamic cuttings transport characteristics. The liquid portion of the mixture provides cuttings moving capacity and ensures that cuttings travel at the liquid velocity if they are not in the cuttings bed. Multiphase hydraulic circulation systems (as one has in UBD operations) may be simplified to a 2-phase flow system in which only a mixture of liquid and gas flows and with or without a stationary cuttings bed at the bottom of annulus. The most common flow regimes for possible effective cuttings transport are slug flow and dispersed-bubbly flow. Cuttings beds form when the fluid flow rate in the annulus can not prevent cuttings from deposition. As bed thickness grows, annular velocity and frictional pressure loss increase due to narrowed flow area, until an equilibrium condition is reached, if the operation conditions are not changed (pump rate, mud properties etc). Most cuttings transport models and correlations are established under equilibrium conditions or so-called steady-state condition.

CUTTINGS TRANSPORT MODEL

A new mechanistic model for cuttings transport is developed to predict minimum annular velocity (U_{MIN}) for hole cleaning in horizontal and inclined wellbore geometry. U_{MIN} is the velocity that will keep a nearly cleaned wellbore. The model combines 2-phase hydraulic equations, turbulent boundary layer theory and particle transport mechanism. If pump rate is less than U_{MIN}, cuttings will deposit in the annulus. The cuttings bed thickness can be estimated by this model. The new mechanistic model can be used to evaluate the hole-cleaning effect of liquid flow rate, gas injection rate, cuttings size and density, temperature, bottomhole pressure, inclination angle and rheology properties of drilling mud. The model is validated by available experimental data.

GAS INJECTION EFFECT

Studies have found that injection of gas has relatively small effect on an air-water system. For a low viscosity fluid like water, the system is sufficiently turbulent without introducing gas into the system. That may explain why the gas phase has minor effect on cuttings transport with water. However, in non-Newtonian mud/gas systems, it seems as if gas injection is playing a more important role. The turbulence created by the gas phase allows faster redistribution of the liquid phase in the annulus (high speed liquid slugs).

The model has been applied on a sample case with a 6x3.5-in. horizontal annulus with air and power law mud (n = 0.67, k = 0.335 $Pa.s^n$). U_{MIN} is sensitive to the changes of gas injection rate, and an increase of gas injection can apparently help hole cleaning. The effect of gas liquid ratio (GLR) on cuttings transport appears sensitive to other flow parameters as well, and it is highly influenced by the liquid flow rate.

MUD AND CUTTINGS DENSITY

The increase of mud weight has a positive effect on cuttings transport. U_{MIN} decreases as mud density increases. Moreover, increasing cuttings density seems to have less effect. Increased cuttings density will make hole cleaning more difficult. The simulation of an 8x4.5-in. annulus, 45° inclined from vertical and with k = 0.335 $Pa.s^n$ and n = 0.67 shows that to completely remove 2.61 sg density cuttings (average diameter size = 3mm) from this annulus using 1.08 sg density mud, nearly 500 gal/min pump rate is required.

It has been reported that larger cuttings are more difficult to transport at all angles of inclination if using low-viscosity fluids. However, it is easier to transport cuttings at low angles (0° to 60° from vertical) using high-viscosity fluids. When cuttings decrease to 0.5 mm and are nearly horizontal, it is much more difficult to move the small particles. The model shows that when cutting size is near to 0.5 mm, it will require much higher velocity (80% increase) to remove the cuttings, compared with 5-mm cuttings.

HOLE ANGLE

Increase in hole angle significantly decreases cuttings transport efficiency. 45°-60° from vertical was found to be the most difficult angles for hole cleaning. For muds with both high and low viscosity, increasing of inclination from vertical required a dramatic increase in minimum annular velocity to remove the cuttings. Maximum concentration was found in hole angles higher than 45°. When hole angle is 60° to 90° from vertical, it has minimal effect on cuttings transport. For a 6 x 3.5-in. annulus, the maximum U_{MIN} occurs at 60° and drops dramatically when hole angle approaching vertical position. In the range of 150-170 gal/min, the cuttings are effectively transported regardless of inclination angle.

PRESSURE AND TEMPERATURE

The pressure and temperature effects on cuttings transport are very complicated. As most fluid properties are function of P and T, the effects of P and T can be followed through the change of n, k and density of mud and gas.

As described previously, gas phase will be compressed under high pressure and could lead to dissolution into the liquid phase, which in effect will cause the gas superficial velocity in the lower section of the hole to be much smaller than in the upper section. As a result, it may cause a decrease of cuttings transport efficiency.

It has been reported that cuttings transport efficiency decreases as temperature increases. Up to 30% increase of the cuttings volume fraction in a 6x3.5-in. horizontal annular section is accurately measured while all other operation parameters are unchanged. It is important to recognize this negative effect, especially when drilling HTHP wells.

These results are now applied in new software models that can be integrated with the underbalanced drilling applications in Scandpower's Drillbench suite. This will result in better modeling and design of UBD operations in horizontal or high-angle wells. ■