DISPLACEMENT OPERATIONS

# Software assists wellbore cleanup

**A new computer program predicts pumping pressure and equivalent circulating densities (ECDs) and explores the advantages of using new tools like a circulating sub for completion fluid displacement operations.**


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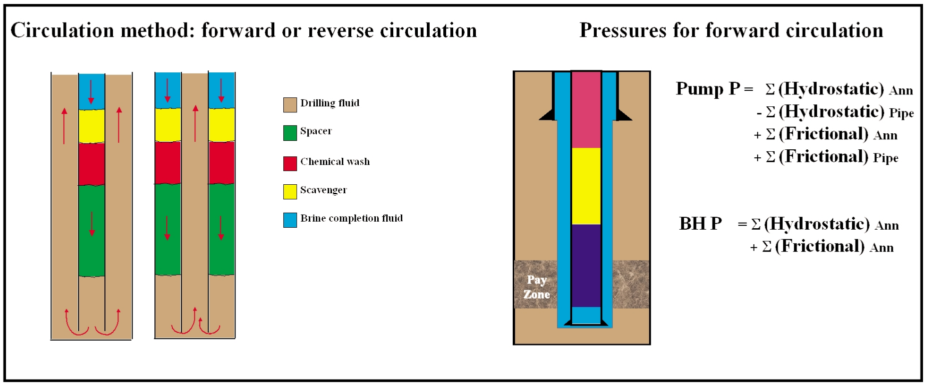



**Figure 1. When multiple fluids are sequenced in either forward or reverse circulation mode to clean out a well prior to completion, it becomes difficult to model the resulting pressures and hydraulics.**

Drilling mud displacement has become an important step in the well construction process for high-rate, high-productivity wells. Many consider that the first step to ensure an optimum completion is to remove leftover drilling fluid residue and casing debris after running casing. Or in the case of an open-hole completion, make sure that the well bore is completely free of adhering debris before proceeding with completion operations. This requires that the mud used during drilling operations be changed out with various types of solids-free completion fluids.

While drilling hydraulics is well addressed in drilling industry, completion fluid displacement is seldom studied or modeled. However, careful planning of the wellbore cleanup operations can help ensure both job success and well productivity.

**A clean wellbore is good**

Benefits from cleaning the wellbore include:

- increased productivity and mud recovery;
- reduced rig time;
- reduced filtration time and expense;
- maintained integrity of the completion fluid;
- fewer mechanical failures of downhole equipment; and
- reduced corrosion pitting.

To clean a wellbore after drilling, teams use:

- mechanical tools such as casing brushes, casing scrapers, circulation tools, jetting tools, filters, and combinations thereof; and
- chemical procedures using pills containing solvents, wetting agents or demulsifiers.

These two methods together usually are used during cleanup.

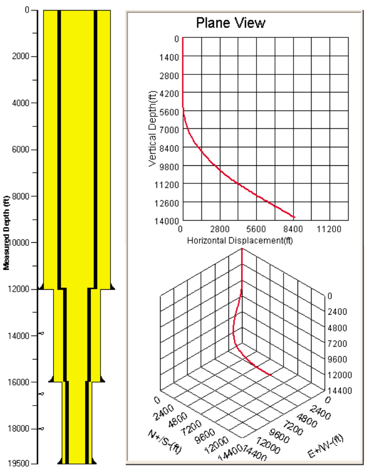
**Multifluid hydraulics**

Unlike drilling hydraulics, in which only one fluid is circulated throughout the well bore, completion fluid displacement has more than two and sometimes as many as nine or more fluids in circulation. Not only the leading edges of fluids, but also the flow rates at each time step are changing continuously, imposing difficulties in determining the pump pressure and bottomhole ECD.New technologies such as the circulation sub or reverse circulation can help the success of the operations greatly, thus new methods are needed to analyze their impacts on pump pressure requirements and bottomhole pressure (BHP).

Whether forward or reverse circulation methods are used for a mud displacement operations (Figure 1), several technical concerns require analysis:

- displacement hydraulics in the 3-D wellbore;
- pump pressure and horsepower requirements;
- rheology for each fluid involved;
- flow pattern (plug, laminar or turbulent);
- ECDs at various depths of interest;
- dynamic annular pressure profile; and
- impact of tools such as circulation subs.

These concerns can be analyzed best using a computer model that lets engineers see the effects of different design parameters prior to the job. Potential problems can be identified and




**Wellbore intervals (from top down)**

| # | Description | ID | MD |
|---|---|---|---|
| 1 | Casing 9.875" | 8.625" | 12000' |
| 2 | Casing 7.000" | 6.004" | 16000' |
| 3 | Casing 4.500" | 3.826" | 19500' |

**Pipes (from top down)**

| # | Description | OD | ID | Length |
|---|---|---|---|---|
| 1 | Drill Pipe | 5.000" | 4.276" | 11950' |
| 2 | Drill Pipe | 3.500" | 2.764" | 4000' |
| 3 | Drill Pipe | 2.875" | 2.151" | 3550' |

**Fluid properties**

| # | Fluid | Weight (ppg) | PV (cP) | YP (lbf/100ft2) |
|---|---|---|---|---|
| 1 | Mud | 17.50 | 37 | 17.0 |
| 2 | Push pill | 18.00 | 55 | 18.0 |
| 3 | Surface wash | 8.50 | 1 | 0.5 |
| 4 | Viscous sweep | 11.60 | 21 | 4.0 |
| 5 | Completion fluid | 17.80 | 3 | 2.0 |

**Fluid pumping schedule**

| Fluid | Vol. (bbl) | Pump Rate (bpm) | Stage Time (min) |
|---|---|---|---|
| Push pill | 50 | 3.00 | 16.7 |
| Surface wash | 50 | 3.00 | 16.7 |
| Viscous sweep | 50 | 3.00 | 16.7 |
| Completion fluid | 350 | 3.00 | 116.7 |
| | 75 | 3.50 | 21.4 |
| | 650 | 7.00 | 92.9 |

**Figure 2. Shown are the data used for the case studies with and without a circulation sub.**

appropriate modifications can be made before the pump even starts. A new computer software program called Cleanup models the displacement hydraulics of completion fluids and aids in the design of optimum mud displacement jobs.

**Case without circulation sub**

Using the data in Figure 2 without considering a circulation sub, a team ran the Cleanup software to analyze the results. Figure 3 shows that pump pressure exceeds the maximum allowable pressure. Meanwhile, the ECD at the well depth also exceeds the formation s fracture gradient.

Figure 4 shows the annular pressure profiles before and after completion fluid enters the top annular section. As soon as the completion fluid enters the top annular section, the cleanup procedure designer increases the pumping rate to increase the annular velocity there because the hydraulic diameter in that annular section is large. Therefore, the BHP jumps from 13,953 psi to 17,793 psi, exceeding the fracture limit at well total depth. Figure 5 shows the 2-D visualization of the displacement process with various zones of interest indicated by red triangles.

Another consideration for well bore cleanup operations is the annular contact time for certain fluids. The purpose is to allow adequate time for chemicals to take effect to remove the mud cake or residue on the rock face. Figure 6 shows the resulting annular contact time for all the fluids involved in the circulation except the native mud.

**Same case with circulation sub**

One of the reasons for the excessive pump pressure and BHP in the case above is that the well has a low annular clearance between the 4.5-in. casing and the 2.875-in. drill pipe. Given this situation, the cleanup team can try one or more of the following measures to reduce the pump pressure and BHP:

- reduce fluid density;
- reduce fluid viscosity;
- use different pipe sizes;
- reduce flow rate; or
- place a circulation sub on the pipe on the top of low annular clearance section.

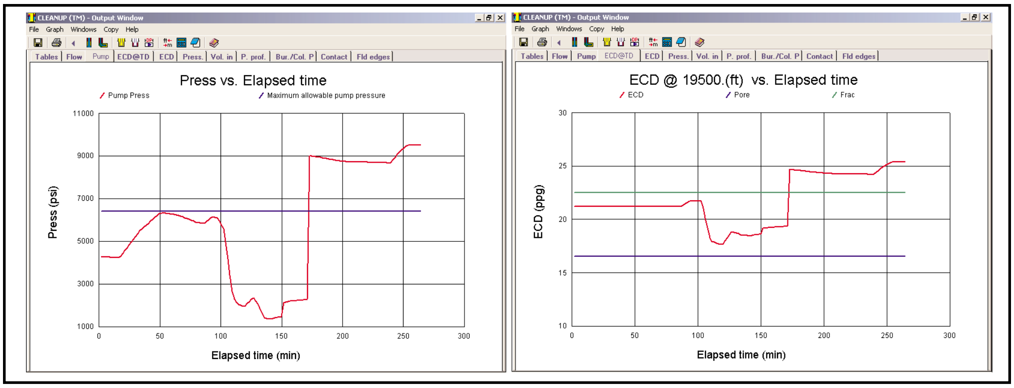



**Figure 3. Without a circulation sub, the pump pressure required will exceed capacity, left, and the ECD at total depth will exceed the formation fracture pressure.**

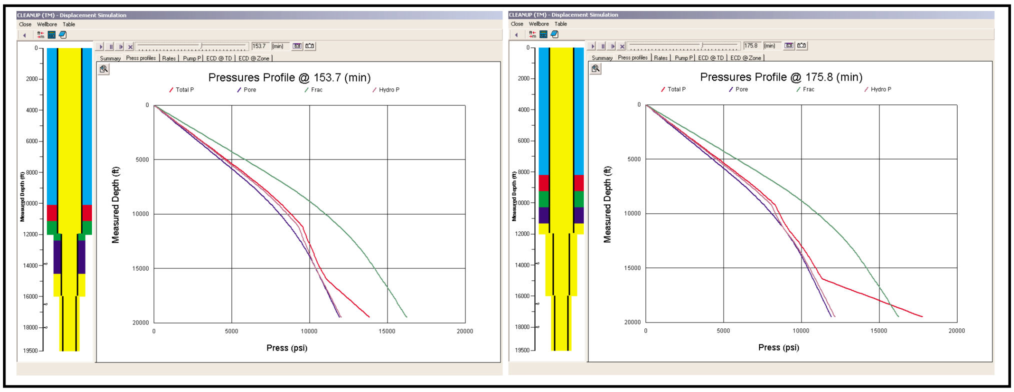



**Figure 4. As soon as the completion fluid enters the top annular section, pump rate must be increased to maintain the annular velocity there because of the large annular diameter. Bottomhole pressure (red line) jumps from 13,953 psi to 17,793 psi, exceeding the fracture limit (green line) at well total depth.**

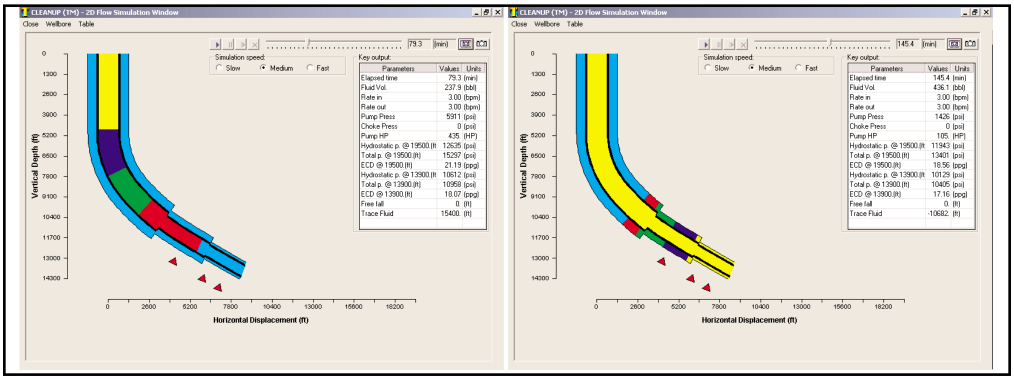



**Figure 5. The Cleanup program enables 2-D visualization of the fluid displacement while monitoring conditions at the zones of interest (red triangles).**

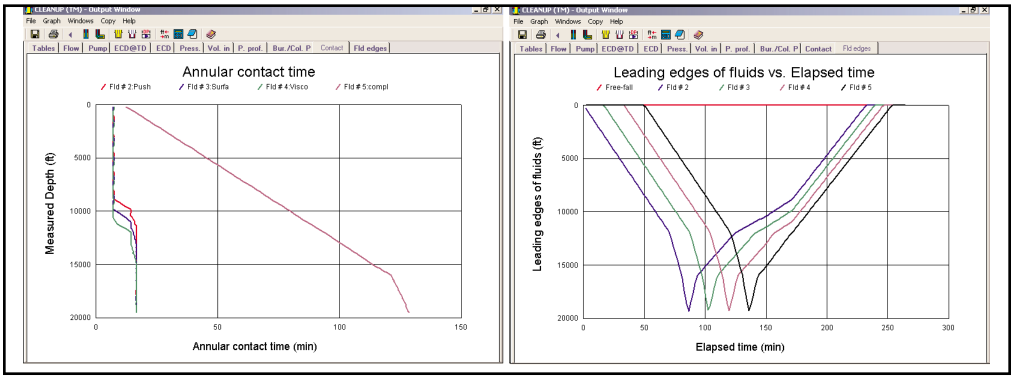



**Figure 6. Program outputs include annular contact time for each fluid, left, and a trace of elapsed time for the leading edge of each fluid, right.**

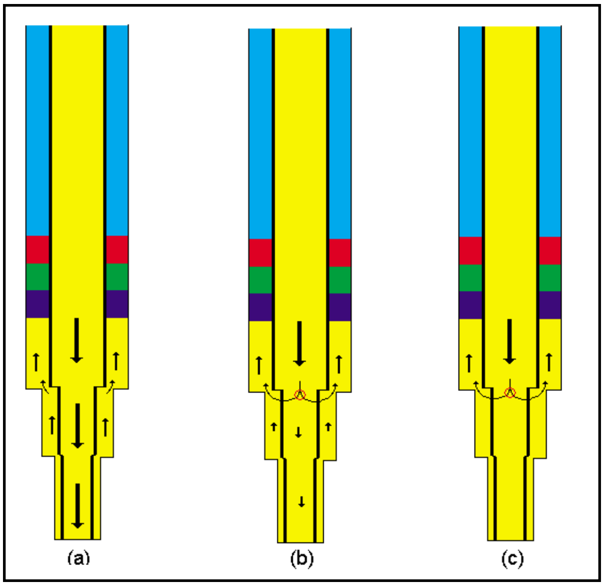



**Figure 7. This diagram shows the fluid flow without any circulation sub (A), with a circulation sub that allows some downward flow (B), and with a sub that makes all the fluid flow through the bypass (C).**

Designers have developed a new tool, commonly called a flow bypass tool or circulation sub, for well bore cleanup operations. This tool, on drill pipe immediately above the liner, has ports open to the drill pipe annulus. These ports allow the fluid to bypass from the narrow drill pipe interior to the larger annulus between drill pipe and casing. They enhance well displacement operations by providing optimum annular velocities throughout all annular configurations. Especially, it allows high circulation rates above liner tops.

Several open and close mechanisms are used in these circulation subs:

- drop a ball to activate;
- cycle open and close positions repeatedly by stopping and starting flow again; and
- picking up or slacking off the work string.

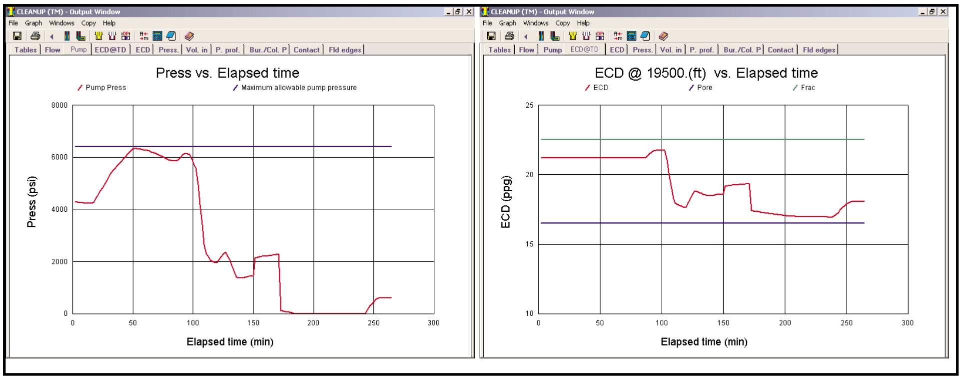



**Figure 8. The same case history as Figure 3 was run, this time using a circulation sub. Pump pressure and ECD at total depth are within acceptable limits.**

Figure 7 illustrates the different circulation subs for flow bypass. Type B allows some downward flow. In this case, displaced fluid is seeking the least resistant path to flow. Type C, once open, forces all fluid to go through the bypass. Therefore, there is no flow downward inside pipe past the circulation sub location. These types help reduce the bottomhole and pump pressures depending on the well bore configuration and location of the bypass tool.

For this case study, the team considered placing a Type B circulation sub on the pipe at 11,900 ft (3,630m). The plan was to open the circulation sub once the leading edge of the completion fluid passed the circulation sub in annulus. Figure 8 shows both the pump pressure and bottomhole ECD have decreased to within the acceptable range because flow bypassed through the sub, decreasing frictional pressure drop inside pipe and in the low annular clearance sections.

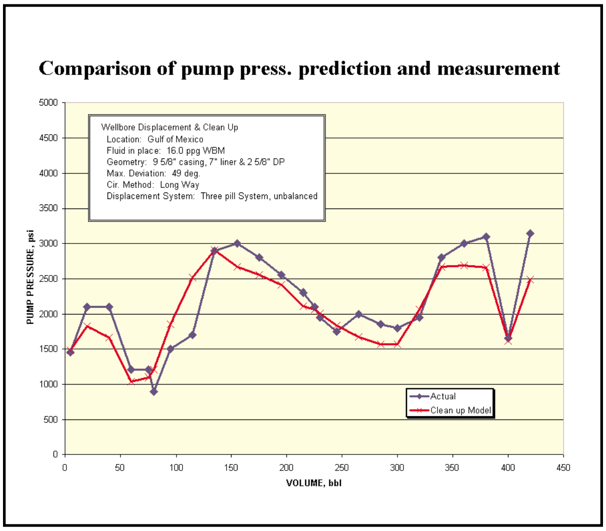



**Figure 9. In a Gulf of Mexico well, pump pressure predicted by the Cleanup program closely matched that actually observed in the field.**

## Comparison with field data

One service company conducted a comparison of field-measured data with pump pressure predicted by the Cleanup program. The well was drilled in Gulf of Mexico with a mud weight of 16 lb/gal water-based mud. The wellbore had a 9 5/8-in. casing with 7-in. liner and 2 5/8-in. drill pipe inside. Maximum hole deviation was 49°. These recorded data as well as drill string configuration, fluid properties and pumping schedule were used as input into Cleanup, while the recorded pump pressures were compared to the pump pressures calculated by the program. Figure 9 shows the good agreement between calculated and field-measured pump pressures.

## Displacement simulator

Cleanup, an engineering design and analysis simulator, has been developed to describe the flow dynamics of mud displacement. It can:

- optimize pump rates for maximum displacement efficiency by calculating the highest allowable pump rates without breaking down the formation;
- predict ECDs and pressure profiles at any time and depth;
- be used for forward and reverse flow, free-fall or back-fill, as well as with circulation subs;
- calculate minimum pump rates for turbulent flow;
- help engineers identify problems and optimize mud displacing operations; and
- display in 2-D the mud displacing flow pattern and resulting pressure profile during the job.

Using this software, engineers can avoid potential problems, resulting in a higher percentage of successful wellbore cleanup operations, particularly in extended-reach wells, slim holes and deep offshore wells. **E&P**

## Acknowledgment

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