Coiled Tubing - The Future of Underbalanced Drilling?

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ABSTRACT

Coiled tubing has been used with increasing frequency in some underbalanced drilling (UBD) situations because of perceived superiority to conventional jointed pipe drilling technology. Much of the success of an underbalanced drilling operation centres on the ability to maintain an underbalanced condition on a continuous basis, transmit effective survey and pressure data back to the surface in a unremitting fashion during the underbalanced drilling operation, clean the hole effectively and operate in a safe fashion with potentially high flow pressures at surface. Coiled tubing has distinct advantages in these areas over conventional jointed pipe due to the lack of requirements for connections, use of an internal wireline and capillaries for survey and geosteering purposes, and much higher operating surface pressure limitations than conventional jointed pipe.

Jointed pipe, however, is much less expensive to utilize and is readily available. Also, increasing experience and modifications in technology (such as EMT surveying tools) have reduced or eliminated many of the problems initially associated with its use for UBD applications. The common application of jointed pipe technology for drilling reduces problems associated with inexperienced crews implementing the relatively new technology of coiled tubing drilling. In addition, coiled tubing drilling technology is currently limited at 500-700 m of horizontal outreach and relatively small hole sizes in order to maintain sufficiently high annular velocity for adequate hole cleaning purposes. High frictional losses, associated with the necessity of injecting fluid through the entire length of the coiled tubing string at all times, may also be problematic.

This paper presents some of the advantages and disadvantages of coiled tubing and jointed pipe methods for underbalanced drilling, primarily from a reservoir and production optimization perspective, rather than from a simple mechanical or operational approach.

INTRODUCTION

What is Underbalanced Drilling? Underbalanced drilling is technically classified as any situation in which the effective circulating pressure of the downhole drilling fluid is less than the pore pressure of the adjacent formation (preferably over the entire length of the exposed open hole section of the pay). In some situations, where the formation has high natural pressure, an underbalanced condition can be generated quite easily using conventional unweighted type drilling fluids (clear brines or oils). This type of drilling is common in such places as the Austin Chalk in Texas and is often referred to as "flow drilling". In situations where the reservoir pressure is depleted, some type of non-condensible gas (either as a gasified fluid, mist or pure gas injection operation) is generally required to engender a sufficiently low equivalent circulating density to generate an underbalanced condition. The underbalanced drilling process is illustrated schematically as Figure 1 and has been discussed in detail in the literature[1].

Why Drill Underbalanced? A number of reasons are commonly provided as motivations for underbalanced drilling. These would include:

- reduced invasive formation damage resulting in higher production rates
- increased rate of penetration
- reduction in drilling problems such as lost circulation and differential sticking
- elimination of costly and exotic mud systems (and subsequent disposal of such)
- ability to flow test while drilling
- flush production during the drilling operation
- less environmental impact (generally no mud pits)

Not all reservoirs, however, are ideal candidates for underbalanced drilling and, if the technology is improperly applied, more formation damage may result than if a well designed and executed overbalanced operation had been utilized[2,3].

Nomenclature and Types of Underbalanced Drilling

There is often confusion as to different terms used when one refers to underbalanced drilling. To attempt to clarify these, the authors present the following definitions:

1. *Overbalanced Drilling.* A situation where, at all places in the exposed target formation, the circulating pressure of the drilling fluid is greater than the effective pore pressure of the formation, resulting in total containment of reservoir fluids, other than those produced by milling of the actual bit path itself.

2. *Near Balanced Drilling.* A situation where, at all places in the exposed target formation, the circulating pressure of the drilling fluid is greater than the net effective pore pressure. This results in a containment of reservoir fluids, as described in point 1 above, but attempts are made to reduce the magnitude of the circulating bottomhole pressure (generally by reducing the density of the circulating drilling fluid) to reduce the degree of overbalance pressure applied to the formation to some nominal value to increase ROP and reduce mud losses and invasive formation damage. In a horizontal well (or vertical well with significant open hole pay), the degree of overbalance pressure may vary along the length of the exposed formation face due to frictional pressure drop effects.

3. *Flow Drilling.* A situation which occurs when a conventional water or oil based mud system is used in a situation where high, naturally occurring, reservoir pressure is present. This results in an inherent underbalance pressure condition occurring in all, or a portion of, the exposed formation and results in flow of reservoir fluids to surface.

4. *"Artificial" Underbalanced Drilling.* This UBD technique has received much attention recently. In this situation, reservoir pressure is too low to allow an underbalanced bottomhole pressure condition to be established with conventional water or oil based drilling fluids. To reduce the density of the circulating mud column (and correspondingly the hydrostatic component of the circulating bottomhole pressure during the drilling process), a low density drilling fluid must be used. This is commonly achieved by concurrently injecting some type of non-condensible gas simultaneously with the drilling fluid (usually nitrogen, natural gas, air or oxygen content reduced air or flue gas), using pure gas or mist, foam or suspending solid hollow spheroids in the circulating fluid system. Typically, the return of excess formation fluids to surface during such a drilling operation is taken as evidence that an underbalanced condition has been obtained, but this does not necessary imply that an underbalanced pressure condition exists throughout the entire wellbore (which is the optimum desired scenario), only that an underbalanced pressure condition exists at some point within the exposed formation.

Jointed Pipe vs Coiled Tubing For Underbalanced Drilling

The vast majority of wells drilled using underbalanced technology have utilized conventional jointed pipe technology and rotary rigs. More than 85% of the wells drilled using the "artificial" underbalanced type technology in Canada have been drilled using conventional jointed pipe. The fraction is even greater if low head and flow drill applications are considered on a worldwide basis. Major advantages and disadvantages with respect to coiled tubing vs jointed pipe applications can be summarized into the following categories:

1. Safety and surface pressure control issues
2. Continuous BHP maintenance issues
3. Rate of penetration issues
4. Hole cleaning issues
5. Total drilling time issues
6. Continuous circulation issues
7. Mud spillage and environmental issues
8. MWD capabilities
9. Rig/site considerations, footprint
10. Surface hole/casing considerations
11. Hole size limitations
12. Depth limitations
13. Rotation issues
14. Torque, drag and weight on bit issues
15. Downhole motor issues
16. Tubing life limitations
17. Torque limitations
18. Flow hydraulics limitations
19. Orientation and steering difficulties
20. BHA considerations
21. Availability issues
22. Experience issues
23. Economics
24. Hybrid rig applications

Some of the more significant of these areas will now be discussed in more detail.

Safety and Surface Pressure Control Concerns

Safety and well control concerns are always a major issue in any underbalanced drilling operation, particularly in situations where high reservoir pressures or sour fluids exist. Due to the smooth and continuous surface of a coiled tubing string and the built-in stripping mechanism in the CT injection unit, this provides perceived superior safety when operating at high annular surface return pressures in an underbalanced drilling operation.

Considerable development work has occurred in the last few years in the development of a variety of different types of rotating control heads for similar control flexibility for operations using jointed pipe[4,5,6,7]. The new generation of control heads allows rotating operation at pressures of up to 2500 psi with a 5000 psi static pressure rating. The rotating working pressure is still less than for conventional CT, which may result in CT being a potential consideration for situations where sour fluids or high surface pressures are expected. Sour circulating fluids in the drill string, when connections are required for jointed pipe operations, may also aggravate safety considerations. CT drilling operations are also quieter than conventional jointed pipe operations, thus reducing noise concerns with drilling personnel and local residents.

If high surface injection pressures are required, CT may have a nominal safety consideration, due to the fact that the entire length of the high pressure CT spool is at surface in a location exposed to the rig crew and ongoing operations. The possibility of a leak or safety concerns is present, but appropriate monitoring of the fatigue and cycle life of the CT string should address many of these considerations.

Typically, jointed pipe underbalanced drilling operations have had an exceptional safety record when combined with properly designed surface control equipment and experienced drilling personnel. Hence, all factors being considered, for sweet, low surface pressure applications, CT does not exhibit any appreciable advantage with respect to safety considerations over conventional jointed pipe.

Continuous Maintenance of an Underbalanced Bottomhole Pressure Condition

One of the main motivations for underbalanced drilling, in many situations, is the elimination or minimization of invasive formation damage caused by fluid and solids losses to the formation under conventional overbalanced conditions. Much of this benefit is negated if the underbalance pressure condition is periodically compromised[2,3]. This phenomena is schematically illustrated as Figure 2. Coiled tubing has a major advantage over jointed pipe in this case, due to the fact that there is no necessity to break for connections. If standpipe injection of the non-condensible gas being used to generate an artificially generated underbalance pressure condition is occurring, this may result in bottomhole pressure fluctuations which may, if improperly handled, result in conditions of periodic hydrostatic overbalance pressure being encountered downhole. This may negate much of the benefit of the UBD operation (with respect to formation damage minimization). Damage may actually be worse in some cases in comparison to the same situation than if a well-designed overbalanced drilling fluid (which has the capability to form a stable and bridging and, hopefully, readily removable filter cake) had been utilized.

Bottomhole pressure fluctuations using jointed pipe can be minimized by making fewer connections (drilling with double or triple pipe stands - triples are becoming more common with the increasing use of top drive rigs for UBD jointed pipe applications), faster connections, circulating to pure gas to attempt to unload as much fluid from the horizontal and annular section as possible prior to making a connection, and leaving the annulus open during connections to allow bleedoff to prevent rapid fluid fallback in the vertical annular section of the wellbore. Bottomhole pressure fluctuations, however, in situations where significant volumes of liquid are being produced from the formation, can be minimized through application of these techniques but not totally avoided.

Alternate injection configurations, such a parasite tubing string or microannular injection techniques (see Figures 3 and 4) can provide stable and uniform bottomhole pressure profiles for jointed pipe operations similar to those seen during CT operations. These modified UBD operations increase expense of the well, however, both from an equipment perspective and also operationally due to the fact that more non-condensible gas is required to maintain the same bottomhole pressure in a concentric or parasite string application in comparison to a standpipe injection mode in the same situation.

Rate of Penetration (ROP) Issues

Generally, ROP is significantly increased by UBD operations. All factors being equal, ROP increases in CT vs jointed pipe operations are comparable, but this assumes that equivalent hole size, weight on bit, torque and drag considerations, etc. are present which is often not the case as will be discussed shortly. ROP may be compromised in some CT applications, particularly in extended reach applications, due to the fact that limited weight can be applied to the bit by the action of the CT injector at surface, and much of this force may be expended in drag effects as the CT string is forced around the horizontal bend and down the helical well path that is typically generated when attempting to drill horizontally with CT.

Hole Cleaning Issues

Hole cleaning presents a major problem in many UBD operations. Hole cleaning is affected by fluid rheology, cuttings size and concentration (which is in turn a function of bit type and ROP) and annular fluid velocity. The majority of CT operations are conducted using 2" or smaller CT strings, whereas hole size can be 6.25" or larger. This may result in high pump rates and frictional losses in the CT string being required in order to maintain sufficient annular velocity to maintain effective hole cleaning. Inability to rotate coiled tubing may further exacerbate the problems with hole cleaning. The use of larger CT strings (to reduce frictional drop in the string and increase corresponding annular velocity due to a reduction in annular size) may be useful. Increased use of aggressive bits (such as PDC's) to reduce cuttings size may also be useful, but may be offset by problems with torque generation and high amplitude torque variation.

The ability to continually or periodically rotate conventional jointed pipe may result in superior hole cleaning ability due to keeping a competent cuttings bed from forming. Working the CT string may also assist in hole cleaning ability in certain situations. Many CT applications for UBD are drilled slim hole which reduces the problems associated with low annular fluid velocities in the horizontal section, although problems may still be apparent in larger diameter uphole sections.

Total Drilling Time

Drilling times may be reduced using CT due to the fact that time for connections may account for up to 25% of the total drilling time (in soft formation applications) when drilling with conventional jointed pipe. Since connections are not required for a CT application, this represents direct reduced drilling time and cost savings for the drilling operation. CT can also be tripped much faster than conventional jointed pipe, which may also reduce on-site time if multiple trips are required in a particular job.

Continuous Circulation Issues

Due to the nature of coiled tubing, continuous circulation is possible both while drilling ahead, and also while tripping. The advantages of continuous circulation in maintaining a uniform BHP while drilling have been discussed previously. The ability to continuously circulate with CT while tripping, in general, reduces reaming requirements, allows for backreaming, while tripping out (if required) and allows the hole to be cleaned and maintained in a better condition.

Mud Spillage Issues

Generally, UBD operations have less environmental impact than conventional drilling, due to an absence of mud pits when a closed loop surface control type system is utilized. CT use in UBD further minimizes environmental impact as, once again, due to a lack of necessity for connections, mud spillage on the site during connections when jointed pipe is being used and the potential for contamination rising from such spillage is minimized.

Measurement While Drilling (MWD) Issues

The ability to MWD during an underbalanced drilling operation is essential, both from a geosteering and trajectory control perspective for a horizontal well, and also due to the fact that real time measurement of the BHP is essential to ensure the success of any underbalanced drilling operation.

In the early days of artificial UBD drilling, conventional mud pulsed telemetry was used. Since the presence of an incompressible fluid in the drill string is a pre-requisite for mud pulsed telemetry, this necessitates the cessation of non-condensible gas injection in order to allow the propagation of a successful suite of data to surface. This, of course, resulted in the application of full hydrostatic pressure to the formation and negated the underbalance pressure condition and, hence, most, if not all, of the benefits of underbalanced drilling with respect to formation damage mitigation were compromised. If a conventional mud system is used for a flow drilling application, this, of course, is not a problem as no non-condensible gas injection is required in this application and therefore conventional MWD technology can be used with no problems.

The advent of CT technology minimized some of the problems associated with downhole MWD technology since, due to the continuous nature of the CT string, a continuous trouble-free internal wireline approach could be used to directly transmit the data from the bottomhole MWD assembly back to surface allowing for continuous telemetry measurements while maintaining a continuously underbalanced condition.

The use of newer EMT technology[8] has allowed the successful application of MWD technology to jointed pipe applications with many of the benefits of a continuous wireline used in a CT system. With EM technology, an electromagnetic pulse is used to transmit the survey and pressure data directly through the ground back to a surface receiver. The technology has been used extensively and successfully in many UBD applications. Depth and temperature limitations are the major problems with this technique, as well as the inability of certain types of formations to effectively conduct the EM signal.

Rig/Site Considerations - Footprint

CT drilling has some advantages over a conventional jointed pipe rig with respect to site considerations in remote locations or sites with limited space. A CT unit is a smaller, more portable assembly than a conventional drilling rig, and typically requires only about 50% of the footprint space on site for operation in comparison to an equivalent system using jointed pipe technology. This lowers environmental impact on site (which may be critical in certain sensitive areas) as well as reducing site construction, use and abandonment costs).

Surface Hole Considerations

If CT is in use in a new drilling application, some adverse conditions may be imposed by the fact that a small conventional rig will generally be required in order to spud the well, run the surface and possibly intermediate casing or, in some cases, to pull the production equipment from an existing well. This, of course, may obviate some of the potential economic advantages of CT drilling since two complete sets of mechanical drilling equipment must be moved onto and off site with the economic and logistical hassles which this entails.

Hole Size Limitations

Although there are some reported cases of larger hole sizes being drilled with coiled tubing, the current conventional upper limit for CT drilling is presently about 6.25". Larger hole sizes, if required, typically tend towards using conventional jointed drillstring. CT drilling in the past has tended to be restricted to more slim hole applications and reentries, rather than large diameter new drill applications.

As CT drilling is extended to using larger diameter CT

FIGURE 1
THE UNDERBALANCED DRILLING PROCESS

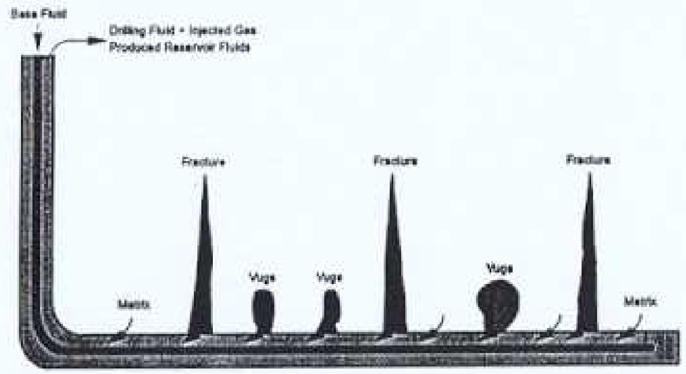

FIGURE 2
SCHEMATIC REPRESENTATION OF FLUID AND SOLIDS LOSS
IN OVERBALANCED UNDERBALANCED OPERATIONS

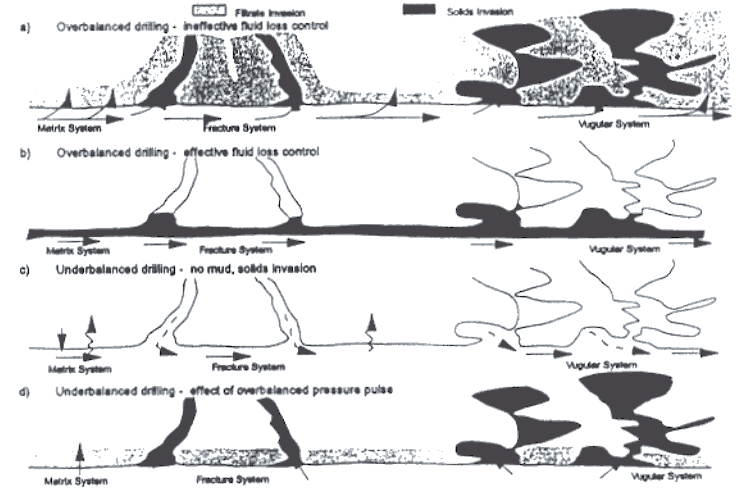

FIGURE 3
PARASITE STRING APPROACH FOR GENERATION OF THE UNDERBALANCED CONDITION

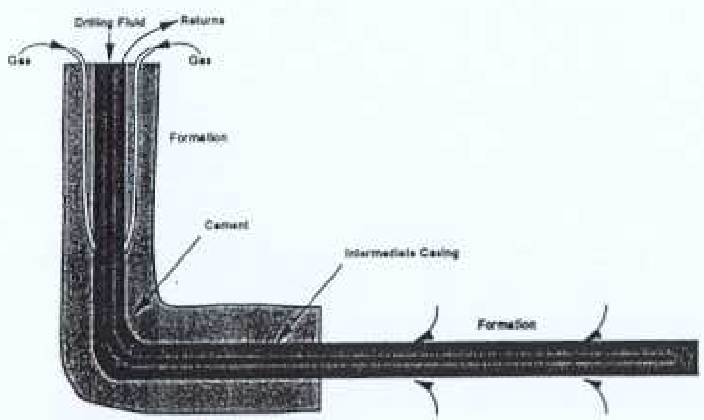

FIGURE 4
CONCENTRIC CASING STRING APPROACH FOR GENERATION OF THE UNDERBALANCED CONDITION