UBD With CT Has Plusses, Minuses

By D. Brant Bennion

CALGARY, ALBERTA, CANADA–Coiled tubing has been used with increasing frequency in under-balanced drilling (UBD) situations because of perceived superiority to conventional jointed pipe drilling technology.

Much of the success of an under-balanced drilling operation centers on the ability to maintain an under-balanced condition on a continuous basis, transmit effective survey and pressure data back to the surface in an unremitting fashion during the under-balanced 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 because of the lack of requirements for connections, the use of an internal wireline and capillaries for survey and geosteering purposes, and higher operating surface pressure limitations than conventional jointed pipe.

Jointed pipe, however, is much less expensive to utilize, and it is readily available. Also, increasing experience and modifications in technology such as electromagnetic (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 limited at 2,000-2,500 feet of horizontal outreach and relatively small hole sizes in order to maintain sufficiently high annular velocity for adequate hole cleaning. 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.

Under-Balanced Drilling

What is under-balanced drilling? Technically speaking, UBD is 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).

The under-balanced drilling process is illustrated schematically in Figure 1. There are a number of motivations for under-balanced drilling. They include:

- Reduced invasive formation damage, which results in higher production rates;
- Increased rates of penetration;
- Reduced drilling problems, such as lost circulation and differential sticking;
- Eliminating costly and exotic mud systems (and their subsequent disposal);
- The ability to flow test while drilling;
- Flush production during the drilling operation; and
- Less environmental impact (generally no mud pits)

Not all reservoirs are ideal candidates for under-balanced drilling, and if the technology is improperly applied, more formation damage may result than if an over-balanced mode of operation had been utilized.

CT Versus Jointed Pipe

The vast majority of wells drilled using under-balanced technology have utilized conventional jointed pipe technology and rotary rigs. In fact, more than 85 percent of the wells drilled using the "artificial" under-balanced type of technology in Canada have been drilled using conventional jointed pipe. The percentage 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 versus jointed pipe applications can be summarized into categories relating to 24 distinct issues:

- Safety and surface pressure control;
- Continuous bottom-hole pressure maintenance;
- Rate of penetration;
- Hole cleaning;
- Total drilling time;
- Continuous circulation;
- Mud spillage and environmental;
- MWD capabilities;
- Rig/site considerations, footprint;
- Surface hole/casing considerations;
- Hole size limitations;
- Depth limitations;
- Rotation;
- Torque, drag and weight-on-bit;


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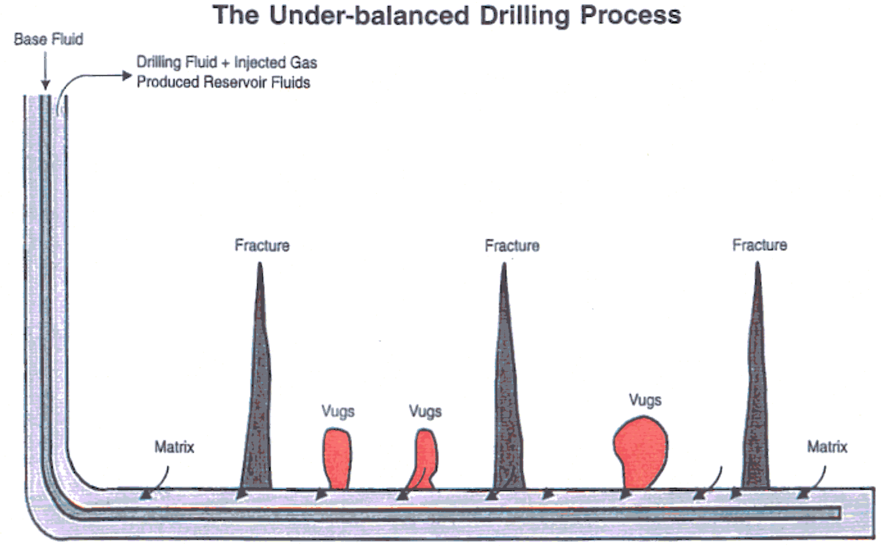
FIGURE 1

The Under-balanced Drilling Process



- Downhole motor;
- Tubing life limitations;
- Torque limitations;
- Flow hydraulics limitations;
- Orientation and steering difficulties;
- Bottom-hole assembly (BHA) considerations;
- Availability;
- Experience;
- Economics; and
- Hybrid rig applications.

Safety Issues

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

Considerable development work has occurred in the last few years in a variety of different types of rotating control heads for similar control flexibility for operations using jointed pipe. The new generation of control heads allows rotating operations at pressures up to 2,500 psi with a 5,000 psi static pressure rating. The rotating working pressure is still less than for conventional CT, which potentially may result in CT being considered 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, reducing noise concerns with drilling personnel and local residents.

If high surface injection pressures are required, CT may have a nominal safety consideration, owing 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 under-balanced drilling operations have had an exceptional safety record when combined with properly designed surface control equipment and experienced drilling personnel. Therefore, when all factors are considered, for sweet, low surface pressure applications, CT does not exhibit any appreciable advantage with respect to safety considerations over conventional jointed pipe.

Major Advantage

In many situations, one of the main motivations for UBD is eliminating or minimizing invasive formation damage caused by fluid and solids losses to the formation under conventional over-balanced conditions. Much of this benefit is negated if the under-balance pressure condition is periodically compromised. This phenomena is schematically illustrated in Figure 2. Coiled tubing has a major advantage over jointed pipe in this case, because there is no necessity to break for connections.

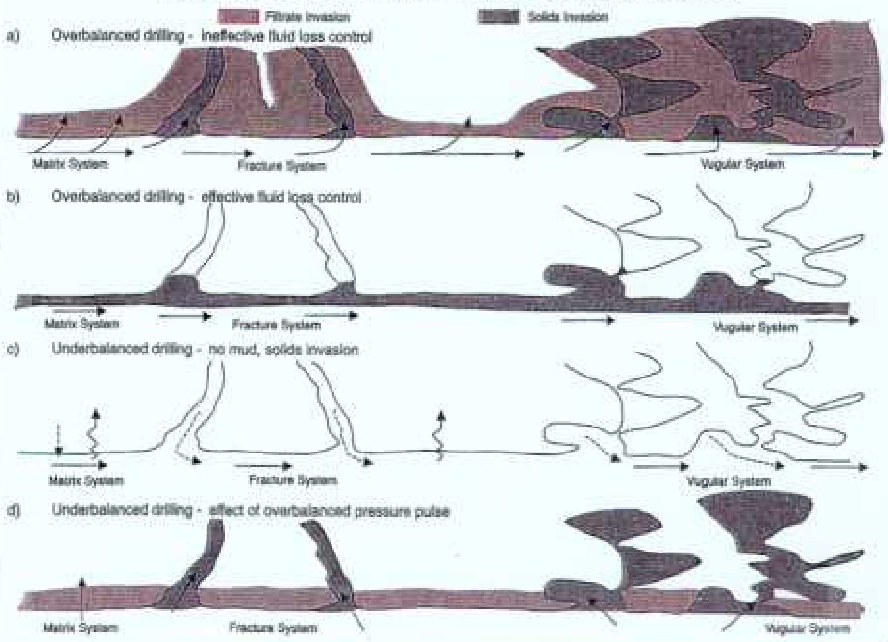
If standpipe injection of the non-condensible gas being used to generate an artificially generated under-balance pressure condition, it may result in bottom-hole pressure fluctuations during connections. This may, if improperly handled, result in conditions of periodic hydrostatic over-balance pressure being encountered downhole, which can negate much of the benefit of the UBD operation (with respect to minimizing formation damage). Damage may actually be worse in some cases in comparison to the same situation using a well-designed over-balanced drilling fluid (which has the capability to form a stable, bridging, and–hopefully–readily removable filter cake).

Generally, rate of penetration is significantly increased by UBD operations. All factors being equal, ROP increases in CT versus jointed pipe operations are comparable, but this assumes that equivalent hole size, weight-on-bit, torque and drag considerations, etc. are present. That is often not the case. ROP may be compromised in some CT applications, particularly in extended-reach operations, because of the limited weight that can be applied to the bit by the action of the CT injector at surface. 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

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 2.0-inch or smaller CT strings, whereas hole size can be 6.25 inches or larger. This may result in high pump rates and frictional

FIGURE 2
Schematic Representation of Fluid and Solids Loss in Over-balanced Under-balanced Operations



losses in the CT string in order to maintain sufficient annular velocity to maintain effective hole cleaning.

The inability to rotate coiled tubing may further exacerbate problems with hole cleaning. Using larger CT strings to reduce frictional drop in the string and increase corresponding annular velocity by reducing annular size may be useful, and a number of 3.5-inch CT drilling rigs are coming into use in the market. The increased use of aggressive bits such as PDCs 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 by keeping a competent cuttings bed from forming. Some new CT rig variants allow slow rotation of the CT string to combat the problem, but the technology remains somewhat new and unproven. 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 sections up hole.

Drilling times can be reduced using CT because of the fact that time for connections may account for 25-30 percent of total drilling time 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.

Because of its nature, continuous circulation is possible both while drilling ahead with coiled tubing, and while tripping. The ability to continuously circulate with CT while tripping helps reduces reaming requirements, permits back-reaming while tripping out (if required), and allows the hole to be cleaned and maintained in a better condition.

Generally, UBD operations have less environmental impact than conventional drilling because of the absence of mud pits when a closed-loop surface control type system is utilized. Using CT in UBD further minimizes environmental impact because the potential for contamination arising from mud spillage while connecting jointed pipe is eliminated.

Measurement While Drilling

The ability to measure while drilling during an under-balanced drilling operation is essential, both from a geosteering and trajectory control perspective for a horizontal well, and also because real-time measurement of bottom-hole pressure is essential to ensure the success of any UBD 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 prerequisite for mud-pulsed telemetry, this necessitated the cessation of non-condensible gas injection in order to allow the propagation of a successful suite of data to surface. This resulted in the application of full hydrostatic pressure to the formation and negated the under-balance pressure condition–as well as compromising most, if not all, of the benefits of UBD with respect to mitigating formation damage. Of course, this is not a problem if a conventional mud system is used for a flow drilling applications because no non-condensible gas injection is required, allowing conventional MWD technology to be used.

The advent of CT technology minimized some of the problems associated with downhole MWD technology since a continuous, more reliable internal wireline approach could be used to directly transmit data from the bottom-hole MWD assembly back to surface, allowing for continuous telemetry measurements while maintaining a continuously under-balanced condition.

The use of newer EMT technology 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 EMT, 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 electromagnetic signal.

Rig 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 and more portable assembly than a conventional drilling rig, and typically requires only about half the footprint space for operation as an equivalent jointed pipe system. This lowers environmental impact on site (which may be critical in certain sensitive areas), as well as reduced site construction, use and abandonment costs).

In regard to surface hole considerations, if CT is used 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, 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 on and off site with the economic and logistical hassles that entails. Hybrid rigs that incorporate both CT and conventional jointed pipe technology are in the evolution process, and are being seen more in the industry.

In terms of 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 6.25 inches. Larger hole sizes, if required, typically tend to use conventional jointed drill string. In the past, CT drilling has tended to be restricted to more slimhole applications and re-entries, rather than large-diameter new drill applications. As CT drilling is extended to using larger-diameter CT strings, the possibility of larger hole diameters in the future becomes more feasible.

Both depth and horizontal outreach also presently limit coiled tubing, because of the inherent helical buckling characteristics and limited power of the surface injector heads. Maximum horizontal outreach with today's technology is in the range of 2,500 feet (although some applications at greater lengths have been recorded), which severely limits the use of CT applications in many horizontal situations where extended-reach wells are required because of reservoir or surface location considerations and constraints.

On-going research in using CT tractor units, which can be used to apply weight to the bit in CT drilling applications, and using larger CT strings may extend the reach capability of CT in the future, but this remains one area in which conventional drill pipe exhibits considerable advantages over CT.

The amount of weight on bit that can be applied in vertical work is limited by the fatigue life of the tubing. The amount of force at the bit for directional or horizontal work is limited by the buckling point of the coiled tubing and associated frictional drag considerations. Jointed pipe obviously has advantages in these situations.

Downhole Motor

CT drilling obviously requires the use of a downhole motor. Because of the hole diameter associated with CT drilling, this necessitates the use of small-diameter motors that have generally had a less reliable performance history than do larger-diameter motor assemblies. In some cases, expenses associated with downhole motors, tripping and motor replacement have accounted for up to 25 percent of a job's cost.

With respect to tubing life issues, a typical CT string may be plastically deformed multiple times during a typical drilling operation. There is a limited cycle life for a typical CT string, after which safe usage for a drilling application is no longer feasible. This may significantly affect the economics of CT drilling, particularly for larger-diameter CT strings. New technology for the way CT is used has significantly reduced the number of plastic deformations required in a given operation, and will likely lead to a trend of significantly enhanced CT life and more cost-effective use.

The torque limits imposed by the CT string often limit the type and size of motor assembly that can be used in a given situation. In addition, for a CT application, torque wind-up may have an adverse effect on directional tool face orientation.

CT drilling may also have significant adverse flow hydraulics limitations with respect to conventional jointed pipe operations. These limitations include:

- A CT string of sufficient length to reach total depth must be brought on site for use in the drilling operation. Injecting the drilling fluid for the entire drilling operation must occur through the entire length of the CT string. This is in comparison to a jointed pipe operation, where a variable length of pipe corresponding to the depth of the current drilling location is used. This results in considerably more horsepower being required continuously for the entire length of the CT drilling operation.
- High pressures at the injection point of the CT string are required continuously to maintain flow, and the entire volume of the pressurized CT string is exposed at surface at the beginning of the drilling operation.
- Using small-diameter CT strings limits the flow rates to be used for a drilling operation because of excessive frictional pressure drops resulting in high surface pressures, which may negate safe and economic CT drilling.

Orientation and steering issues come into play because CT drilling requires the use of an orienting tool to steer the BHA for directional or horizontal work. This is newly developed technology with associated problems. A muleshoe sub is usually required to ascertain toolface orientation.

CT drilling also necessitates using a shear sub in the event that the BHA becomes stuck during the drilling operation. A coiled tubing adapter suitable for drilling induced stresses to connect the CT string to the BHA is required. This assembly is generally purpose built to allow encapsulated insertion into an under-balanced well.

Constraints And Economics

In many cases, using CT drilling technology for an under-balanced drilling operation is desirable, but operators encounter a shortage of suitable CT units for their particular applications, as compared to the availability of conventional jointed pipe rigs. This results in many applications of jointed pipe technology where CT may have been superior simply because of availability constraints. As more CT drilling units become available, this issue may become less problematic.

Although there are many experienced coiled tubing operators, there are few highly experienced CT drilling operators, especially for UBD applications. This results in problems in many applications with under-trained crews attempting to operate equipment in a highly non-standard situation, and may mean less-than-optimal performance and results. Once again, as more CT drilling units come into the market and the number of CT drilling operations increases, the mean expertise level of CT drilling crews will increase correspondingly.

A combination of high-demand, new (non-paid out) equipment and the limited life of CT strings may adversely affect the economics of a CT drilling application in comparison to conventional drilling with jointed pipe. The large number of depreciated and readily available land rigs that can be used for UBD operations may make CT an uneconomic alternative in many cases. An increased number of CT units will foster a more competitive market with more depreciated equipment that may aid in reducing costs and improving the economics of CT drilling as compared to jointed pipe.

There has been interest in the development of hybrid drilling rigs that incorporate the desirable features of both jointed pipe and CT drilling applications into a single unit. This is particularly appealing in some offshore applications where very limited footprint size is available for a given drilling operation. Once again, the cost of development and construction of hybrid rigs may make their initial use prohibitively expensive except in certain special applications.

Applications favoring CT

Selecting CT drilling over conventional jointed pipe for an UBD operation is not a specific one, and depends strongly on the specific set of reservoir, drilling, site and economic considerations of a given situation. However, coiled tubing drilling may be favored in applications where:

- Small-diameter holes (less than 6.25 inches) are required;
- Short-radius re-entries are required;
- Limited horizontal outreach is necessary (less than 2,500 feet);
- Sour gas/oil exists;
- High expected surface return pressures are anticipated;
- Difficulty in MWD is expected with current EM technology; and
- Maintaining a continuous under-balanced condition to mitigate formation damage is essential.

CT drilling in the under-balanced market is expected to occupy an increasing niche technology position. Because of some of the economic and technical limitations of current CT technology, CT drilling is not expected to replace, but rather impact the number of wells drilled under-balanced with jointed pipe in the near future. Operating improvements in using jointed pipe for UBD operations have removed many of the drawbacks associated with its use in the early application of UBD technology.

Today, CT occupies a 10-15 percent share of the Canadian artificial UBD market. That market share is expected to increase significantly over the next few years, to perhaps 25-30 percent of the total UBD market. However, jointed pipe will remain the dominant drilling technique for the near future. ❐