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Liner Drilling Options Can Significantly Reduce Well Construction Times in Deepwater Operations

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Abstract

There are three main areas driving up the cost of deepwater well construction: 1) BOP maintenance and testing downtime; 2) narrow mud weight window operations and ECD control; and 3) excessive reaming and well conditioning for liner operations. One strategy to address narrow mud weight windows and formation stability is to design wells with close tolerance casing sizes. This requires an under-reamer operation. While it is usually part of the primary drilling operation, the associated tripping and conditioning of the hole for the liner run has led to the point where these operations can exceed the time needed to drill the original hole. Hole preparation and liner running operations used to be 30% of section drilling time. Close tolerance liner sections can now take up to five times longer (500%) in preparation and running than drilling.

Liner drilling has several advantages, one of which is the "smear effect". While there is much discussion on this, one unarguable point is the fact that there is no preparation and liner running time when drilling a section with liner drilling techniques. The biggest problem with liner drilling in deepwater well construction is that it has only been deployed for short sections, while normal sections are 2000 to 5000 feet. This necessitates retrievable liner drilling techniques. This paper describes the two types of systems that have been developed over that past ten years: 1) retrievable liner directional drilling (RLDD), and 2) close-tolerance liner drilling (CTLD) and their implications on future deepwater well construction strategies.

Introduction

Casing drilling is adding a bit to a string of casing and rotating the casing at the surface to drill ahead. The casing is used as the drill string. This involves rig modifications, primarily the addition of a casing drive system to rotate the "string". There are also well control and BOP issues to resolve. Liner drilling is adding a bit to a shorter length of casing that has a modified liner hanger and running tools on top of it and continuing with drill pipe to the surface. Liner drilling does not require rig or BOP stack modifications.

There are two major benefits to casing and liner drilling. First, upon reaching section TD, the casing is, by definition, set. Thus, all the hole problems encountered in drilling the section that are aggravated with conditioning the hole for tripping out and then setting casing are greatly reduced if not completely eliminated. This is estimated to be 40% of the NPT problems in drilling. Second, while drilling with casing, a stressing or strengthening of the wellbore wall appears to take place. This is called the smear effect. The smear effect is the mechanical plastering of particles into the wellbore wall that effectively increases its strength or stability. Evidence for the smear effect remains anecdotal; that is, there are stories attributed to it in successfully drilling sections with substantially reduced problems. It remains un-quantified and, thus, techniques to enhance it with additives to mud systems remain unproven. But it is widely accepted as effective across a large range of wellbore stability problems often with surprising results.

Casing and liner drilling had a ten year development spurt from 1998 to 2008 [1, 2, and 3]. The ability to retrieve drilling bottom hole assemblies (BHA) was developed during this time. Operator and service companies learned how to directionally drill with both casing and liner strings and drill up to 7000 ft sections at hole inclinations approaching horizontal. Then, as happens in evolution, a plateau was reached.

Casing and liner drilling is a substantial process change in well construction operations. The engineering design and execution requirements are significant. Expertise might be better deployed on more standard well designs. Horizontal shale wells were booming in North America. There were few options in casing sizes available limiting well design. A pause was called for.

Casing and liner drilling have continued in their simpler non-retrievable BHA form [4 and 5]. This is sometimes called "Level 2". The ability to rotate casing strings while running in the hole and cementing after a section is drilled with drill pipe is the basic casing or liner "drilling" operation. This is called "Level 1". The more complicated retrievable operations; retrievable casing drilling or "Level 3" and retrievable liner drilling, "Level 4" retreated to niche markets or were packed into deep storage. Liner drilling has continued in deepwater in the simpler Level 2 form.

Level 4 liner drilling for deepwater applications has two forms; 1) retrievable liner directional drilling[6] (RLDD) or

Steerable Drilling Liner[7] (SDL) as it is sometimes called, for standard casing sizes, specifically 9 5/8-in. and 13 3/8-in. and 2) close tolerance liner drilling[8] (CTLD) with 11 ¾-in. casing. CTLD was a joint initiative developed by ConocoPhillips, Tesco, and Baker Hughes to address the deepwater strategy of using under-reamers and half step downs in casing sizes to extend larger hole sizes deeper in these wells. Specifically, under-reamer operations allowed the addition of an 11 ¾-in. liner string between a 13 3/8-in. and 9 5/8-in. liner in well designs. The group developed and tested an 11 ¾-in. CTLD system in 2003, but the project languished after the operator moved out of directly operating in Gulf of Mexico deepwater wells.

The use of under-reamers to allow additional liner strings in deepwater well designs is an interesting development and a competing technology to liner drilling. The narrow mud weight window resulting from two pressure gradients (seawater and formation) in deepwater requires more casing strings to “stair-step” between the pore pressure and fracture pressure gradient sides of the window. Drilling a hole section with a bit that can pass thru the most recently set liner and an under-reamer that can open up larger than the internal diameter of this liner enables the next liner size to be larger than if the new hole was drilled without the under-reamer. The typical example is that a 12 ¼-in. bit is used to drill a new hole out of a 13 3/8-in. liner. The pass-thru internal diameter of 13 3/8-in. liner is slightly larger than 12 ¼-in. Later 14-in liners were used. Typically 9 5/8-in. casing is set in 12 ¼-in. hole. An under-reamer that, when closed, can pass through 13 3/8 or 14-in. liner and then open up to 14-in. allows an 11 ¾-in. liner to be set next. This type of operation can then be used in the 11 ¾-in. liner ultimately allowing twice as many liners to be used in a well design.

The development of multiple under-reamer size configurations has effectively allowed more difficult, narrow-mud-weight windows to be addressed. Liner drilling and the smear effect was and probably still is a good strategy to address this issue. Substantial development allowed the under-reamer approach to solve more difficult mud weight window problems. This lessened the motivation to develop liner drilling capabilities.

Everything has its costs. The use of under-reamers in BHA’s can cause problems in maintaining a gauge hole. A “go/no-go” decision must be made in the commitment to run a liner. Once that decision is made, it would be very difficult and time consuming to pull a liner that cannot make it to bottom. Drilling engineers were adding more and more reaming or conditioning runs to operations after TD of a section to help ensure that the liner would make it to bottom. Meanwhile outside considerations such as BOP tests complicated well operational planning. What once was a single operation, running a liner, has turned into a multi-step sequence. Liner runs typically took 30% of the time it took to drill a section. If drilling took nine days, the liner run was three days. A majority of liner running operations are now taking weeks. Deepwater well costs began to seem excessive, if not to skyrocket. There are multiple issues in deepwater well costs. A closer look at one aspect, the time in setting liners and how liner drilling might address that is the subject of this paper.

Deepwater Well Construction Liner Operations Performance

Deepwater drilling can be broadly defined as drilling operations that take place offshore in water depths more than 1000 ft from a rig that is dynamically positioned using a drillship or semi-submersible platform. The well control or BOP stack is on the seabed floor with a riser assembly extending to sea level. There are nine regions in the world where this takes place:

1) AFW – offshore west Africa
2) ANZ – Australia / New Zealand
3) ATL – the Atlantic offshore eastern North America (Canada)
4) FE – Far East
5) GOM – US Gulf of Mexico
6) LAM – Latin America (north)
7) LAS – Latin America (south)
8) MED -- Mediterranean Sea
9) NS – North Sea

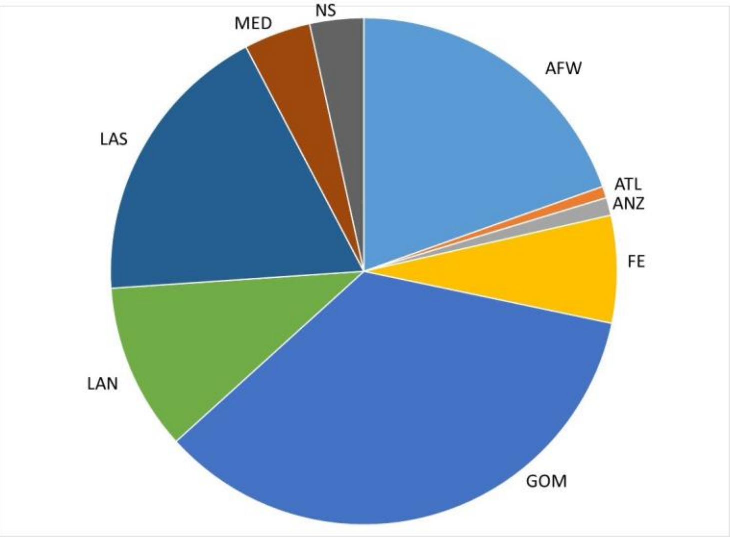

Figure 1. A pie chart showing the relative size by wells of the nine deepwater regions of the world.

This is just one way of describing deepwater deployment. Various databases have been analyzed to estimate the number of wells and liner sections drilled in these areas. Figure 1 shows a pie chart of wells drilled in these nine areas in the four years from 2012 to 2015. There were about 700 deepwater wells drilled per year during that time period. Each area is different. Limited time-depth data allows the construction of aggregate TD curves for each area. These are shown in figures 2 thru 9.

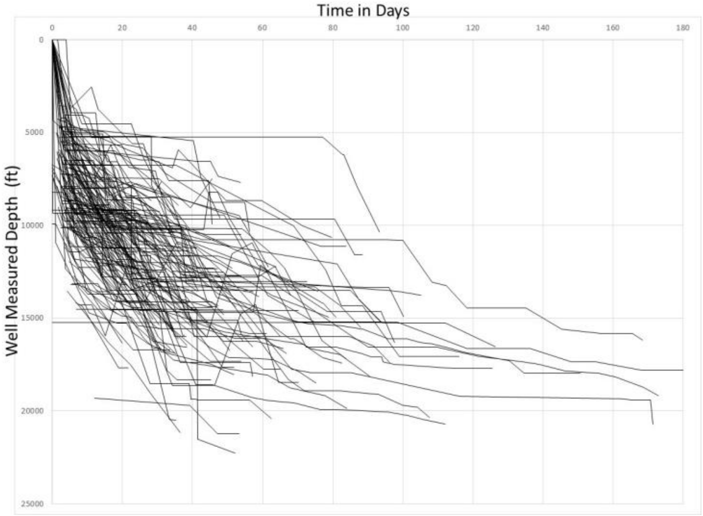

Figure 2. Drilling Time-Depth plots of deepwater wells offshore west Africa.

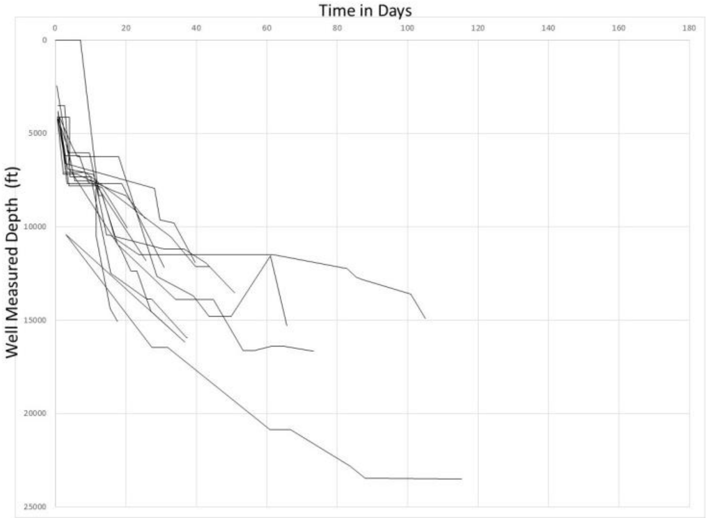

Figure 3. Drilling Time-Depth plots of deepwater wells Canadian Atlantic and Australia / New Zealand.

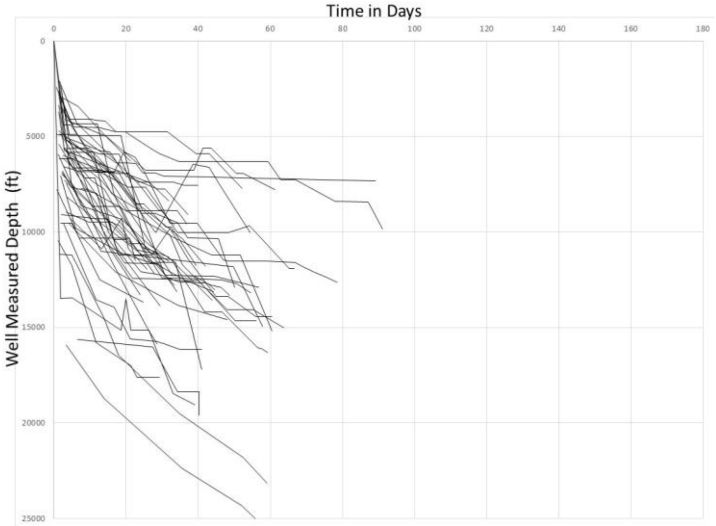

Figure 4. Drilling Time-Depth plots of deepwater wells in the Far East.

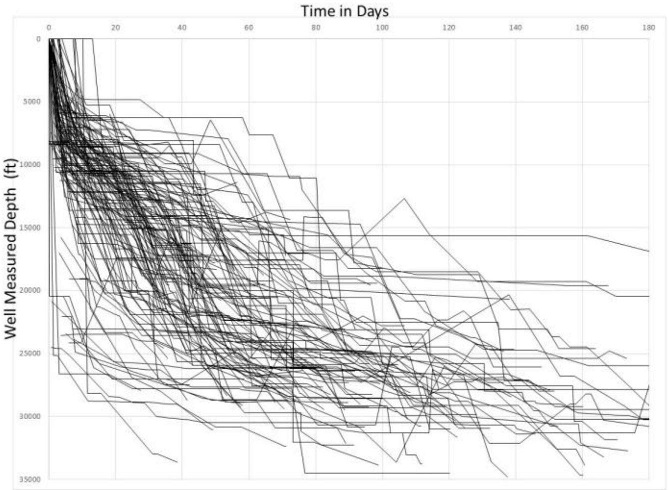

Figure 5. Drilling Time-Depth plots of deepwater wells in the US Gulf of Mexico.

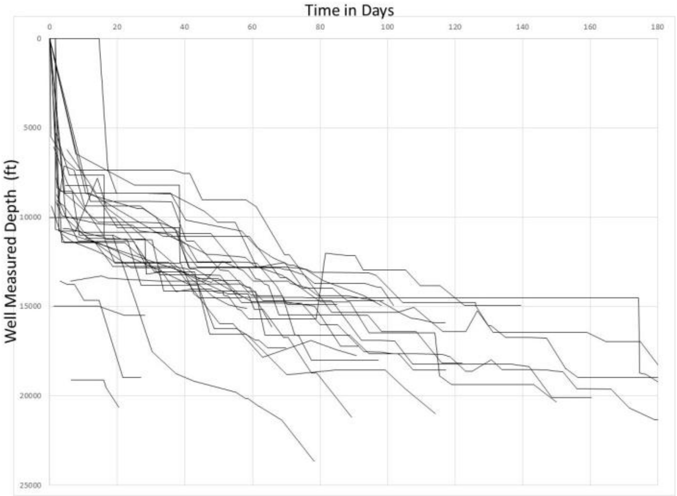

Figure 6. Drilling Time-Depth plots of deepwater wells in Northern Latin America.

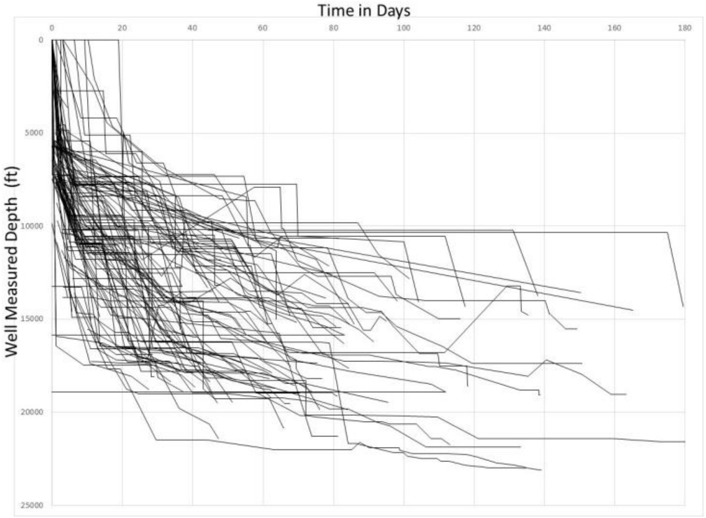

Figure 7. Drilling Time-Depth plots of deepwater wells Southern Latin America.

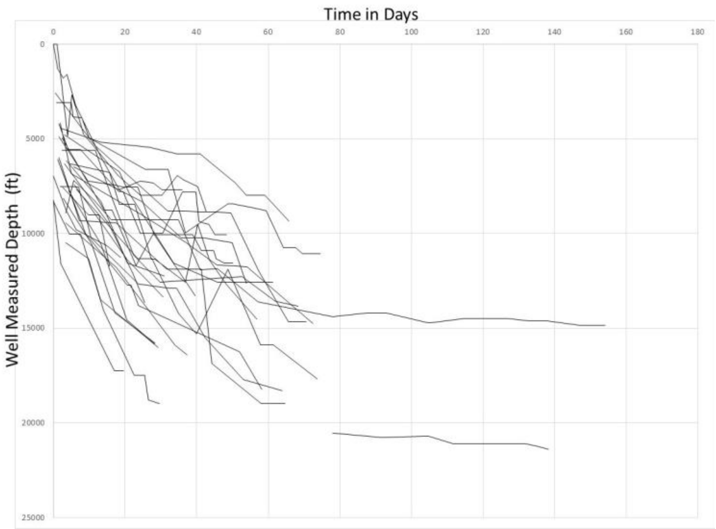

Figure 8. Drilling Time-Depth plots of deepwater wells in the Mediterranean Sea area.

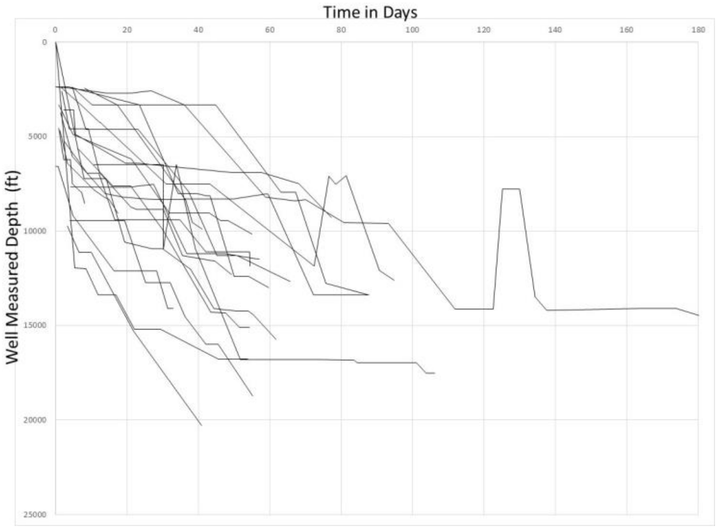

Figure 9. Drilling Time-Depth plots of deepwater wells in the North Sea.

Two basic observations are possible with these plots 1) the US GOM has substantially deeper wells than the other areas, and 2) there is a lot of flat time where liners are being run.

Looking at bit and liner size data, the following groupings of liner sizes can be made for organizational purposes:

1)	7	7 and 7 ¾-in liners
2)	9	8 5/8, 9 3/8, 9 5/8, 9 7/8, 10, and 10 1/8-in.
3)	11	10 ¾, 11 ¾, and 12-in.
4)	13	13 3/8 and 13 5/8-in.
5)	14	13 ¾ and 14-in.
6)	16	16 and 17-in.
7)	18	17 7/8 and 18-in.
8)	20	20 and 22-in.
9)	Surf	28, 30, 32, 36, and 42-in. surface liners

The surface strings can be considered in a different type of drilling operation than the smaller strings and these are sometimes set in batch operations making determination of liner setting times difficult. They are also not usually considered for liner drilling operations, though they could be in the future. The bar chart in figure 10 shows the estimated number of strings run from 2012-15 for the first eight groupings. This plot also allows for two basic observations; 1) the dominance of the US Gulf of Mexico, and the emergence of close tolerance drilling in the GOM with a high incidence of 14 and 11-in. liner groups. The other areas have more standard sequences of 16 (17-in.), 13 (13 3/8-in.) and 9 (9 5/8-in.) liners.

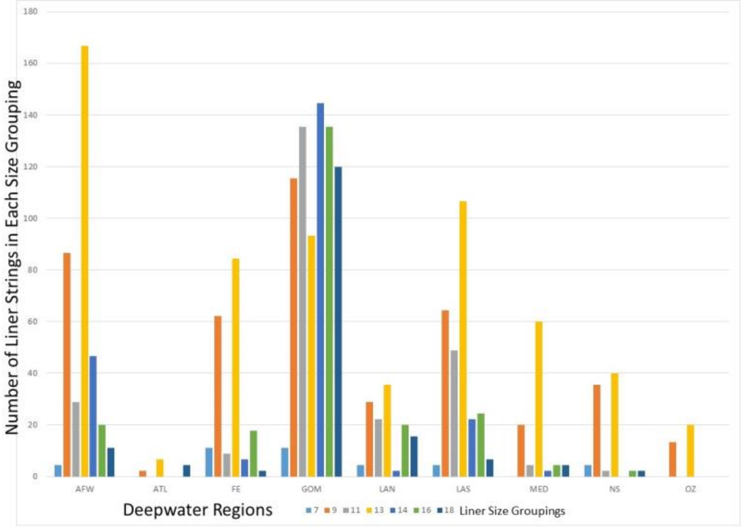

Figure 10. The number of liner strings run for each of seven size groups in the nine deepwater regions.

Taking a closer look at the data in these eight-size-sets, calculations can be made of 1) the time required to drill each section and 2) the flat time after drilling with reaming and conditioning runs and running of the liner. Cementing time is also included here as the data does not differentiate that before the next hole section is started. One would also speculate that down time for BOP tests is included here but these can be considered a fair part of the operation. A somewhat common metric, days per 1000ft, can be used here to compare multiple hole sections. The bar chart in figure 11 shows the drilling time in days per 1000ft of hole section and the overall liner operations time also in days per 1000ft of hole section for each of the eight liner size groups. On average liner operations take 77% of drilling operations. The major difference is the 7-in. group which is as expected and also statistically small.

Another way of looking at it is to extrapolate this data out to the 700 wells drilled in the nine regions. The bar chart in figure 12. There are 5200 drilling days and 4000 liner days in a typically-better deepwater year. These are most, if not all, of the productive below-rotary-table (BRT) days. The rest of the surface NPT is another issue. At a one million dollars per day spread rate, this liner time represents 4 billion USD per year of potential savings on deepwater operations with liner drilling.

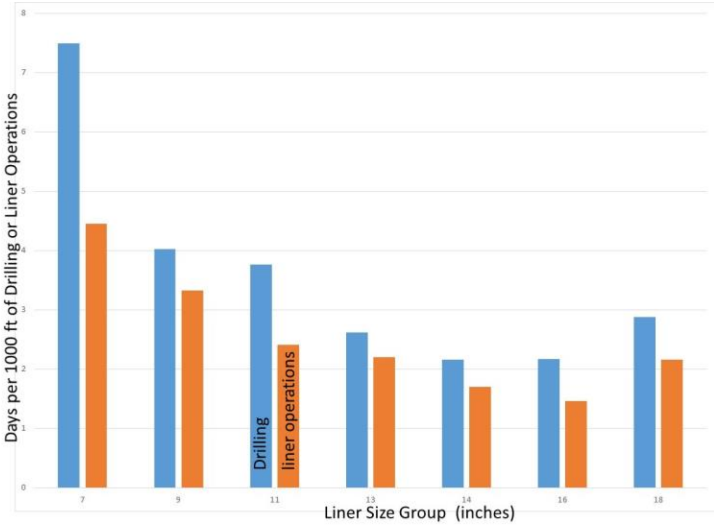

Figure 11. Bar chart of days per 1000ft for both section drilling and section liner operations time for the seven liner size groups.

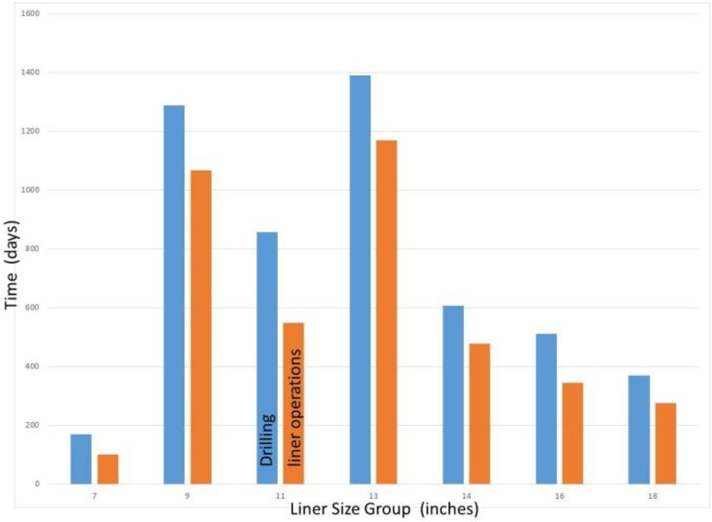

Figure 12. The total time spent in days both drilling and liner operations in an average year for the seven liner size groups.

Retrievable Liner Directional Drilling

Nearly all offshore and deepwater development wells are directional. Directional drilling requires measurement-while-drilling (MWD) and usually logging-while-drilling (LWD) tools as well as directional tools, typically rotary steerable systems (RSS). These tools must be retrieved as they are expensive and would prevent further progress if left in the hole. The high cost of deepwater operations have driven MWD, LWD, and RSS tool reliability to the point where a hole section can usually be drilled in one run without any tool failures or directional performance issues. Indeed, most of the runs in the 2012-15 data bear this out. Thus, retrievability can mean retrieve-once, at section TD. There are two commercially available RLDD systems, and they are shown in Figure 13. The Baker SDL system is effectively retrieve-once though it can develop further. Tesco developed a retrieve-on-demand system that was sold to Schlumberger in 2012. While, in general, retrieve-on-demand is a good idea, both are considered Level 4. But be clear! Level 4 RLDD is substantially more complex than Level 2 non-retrievable liner drilling. They are completely different drilling operations, and therein lies the problem. Level 4 is also twice as complicated as Level 3 retrievable casing drilling since two pairs of latching operations are in the retrieve and replace of liner drilling as compared to the single pair in casing drilling.

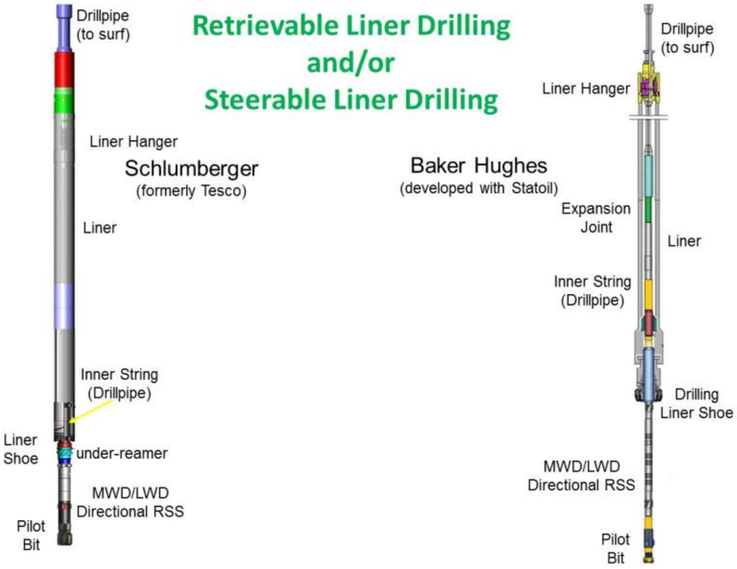

Figure 13. The two commercially available Retrievable Liner Directional Drilling or Steerable Liner Drilling Systems

RLDD strings have seven components:

1) bit and external BHA with RSS, MWD, and LWD tools
2) under-reamer or drilling shoe and internal BHA with liner centralization
3) internal drill pipe
4) internal latch or drive to liner and liner hanger
5) drilling liner hanger with multi-set slips
6) external liner
7) drill pipe to surface

Both retrievable and non-retrievable liner drilling systems result in no difference in surface appearance or operations once the systems are downhole. Thus there is no difference in BOP operations and well control sequences with liner drilling because there is standard drill pipe to the surface.

A retrieve and replace operational sequence is as follows:

1) use the multi-set slips in the liner hanger to “park” the liner in the previous liner
2) cycle the internal latch to disconnect the drill string from the liner hanger and liner
3) trip out of the hole and change the BHA as required

4) run back in the hole with the new BHA
5) cycle the internal latch to re-engage with the liner hanger and liner
6) re-set the multi-set slips to release the entire assembly from the previous liner
7) drill ahead

Only the first two steps are required upon reaching section TD.

Both commercially available RLDD systems have been tested and run in commercial wells. Both are reliable. There are limited configurations or liner sizes. There are development issues that remain. Under-reamer and cutting shoe structures have changed that may affect operations. The running of a cement float sub after reaching section TD is problematic as it typically must be pumped down. Hole cleaning above the liner hanger, where the annulus has a significantly larger cross sectional area is a problem. Bypass subs are in development to address this.

Liner drilling should be considered similar to running an intelligent completion. Liner drilling is effectively the combination of drilling and intermediate completion. Intelligent completions require system testing before running. Any new liner drilling size configuration is like a unique completion, it should be run in a “dress rehearsal” style in a test well. And like an intelligent completion, there is little motivation for service companies to develop a specific configuration for the upstream industry at large. There actually is not a lot of money in liner drilling for service companies. The MWD, LWD, and directional drilling service days are the same for drill pipe drilling operations and may even be less. A standard liner hanger is 500K to 800K USD. When it is ruggedized for drilling that might cost 600K to 1,000K USD. A back-up is required which may or may not be expended. Liner drilling services are 250K USD at a near maximum. This equates to 2 deepwater rig days. It costs more to trip liner drilling than the entire services. A different economic model may be necessary for liner drilling in deepwater.

Close Tolerance Liner Drilling

CTLD was developed to address squeezing an 11 ¾-in. liner in between 13 3/8-in. and 9 5/8-in. liner strings. While an 11 ¾-in. liner will pass through a 13 3/8-in. casing, the annulus is too narrow for effective hole cleaning during liner drilling. ConocoPhillips addressed this problem in 2003 for their Magnolia development. They coordinated this development with Tesco and Baker Hughes. The main premise was to utilize the inner annulus between the drill pipe and the liner, as opposed to the outer annulus between the liner and the parent casing for mud and cuttings flow (see fig14). A dynamic casing seal was designed and added to the liner near the liner hanger that would seal this outer annulus. An inner annulus valve was opened to allow mud/cuttings to flow up from the bit into the inner annulus. At the liner hanger the open inner annulus valve allowed the mud to enter the main annulus above the liner where there is a much larger flow area between drill pipe and the parent casing. A reversing port was put in the drill pipe near the liner hanger that diverted 5% of the mud flow from inside the drill pipe to the outer annulus. This mud flowed down (a reverse path) to the liner shoe where it co-mingled with the cuttings mud from the bit for the trip up the inner annulus. This 5% flow made sure that there was a positive pressure on the outer annulus so that no cuttings would filter up and lead to pack-off or sticking problems.

This retrieve-once 11 ¾-in. liner drilling system was designed for up to 5000ft of directional drilling at up to 5 deg/100ft curve rates. It would cut a 10 5/8-in. pilot hole with a 13 ½-in. under-reamer. MWD and LWD tools would be run in the pilot hole. The liner was a 65ppf with NOV (GrantPrideco) DWC/DS casing drilling connections rated for 40K ft-lbs drilling torque.

The system was built and drill tested on land but never used in a commercial deepwater well. ConocoPhillips sold their interests in Magnolia effectively ending the project in 2005. The development by Baker Hughes and Schlumberger (Tesco) of retrievable liner drilling systems and the deployment of motor assisted rotary steerable systems in casing and liner drilling occurred after this CTLD project. Those developments would enhance any revival of CTLD.

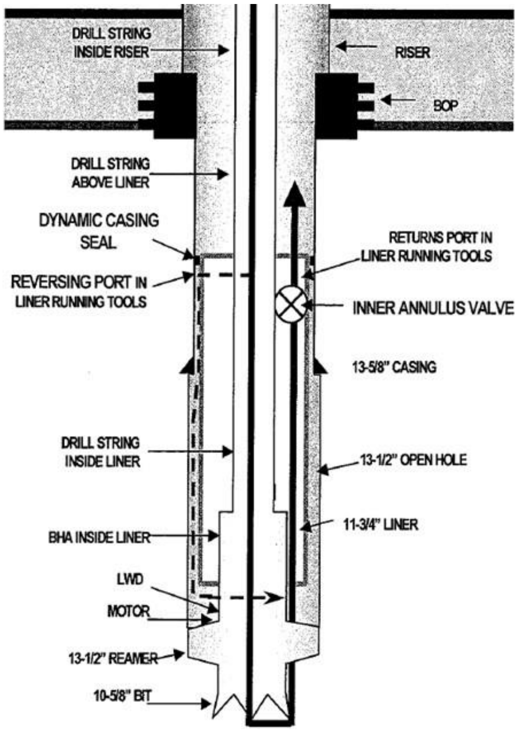

Figure 14. The Close Tolerance Liner Drilling (CTLD) system developed in 2003 (from reference 8).

The Smear Effect Revisited

The smear effect has been mentioned in many papers [9, 10, 11, and 12] and received credit for faster-than-expected casing drilling performance and higher quality wellbores as seen in cement job evaluation logs. But it remains un-quantifiable. There is not a way to calculate wellbore wall strengthening that could be equated into a widening of mud weight windows in a way that petrophysical log data can be used for formation strength calculations. Some estimations of losses reductions are possible, mostly from empirical data obtained from non-retrievable liner drilling (Level 2) projects in short depleted sand sections. It is generally accepted that casing and liner drilling is as fast as drill pipe drilling and maybe faster. This also can be credited to the smear effect. This does not mean that overall drilling will be faster since it must be assumed that system component reliability is less than the well vetted tools currently used in deepwater operations. Prudent well construction planning requires operators to treat any perceived benefits of smear as if it does not exist. One can speculate that when smear effect wellbore strengthening is quantified, close tolerance liner designs may not be needed. Since that is NOT the case, any utilization of liner drilling will require CTLD as well as RLDD systems. Smear effect or not, the fact that liner drilling eliminates the time required to condition a wellbore section and run liner as well as a host of associated non-productive time is undisputed.

Conclusions

This paper has reviewed the recent state of liner sections in worldwide deepwater well construction and liner drilling systems that might impact those operations.

1) There are an estimated 700 deepwater wells drilled every year and 4000 days spent to condition and run intermediate liners in these wells.

2) Non-retrievable liner drilling operations show that this time can be eliminated on short runs.

3) Retrievable Liner Directional Drilling and Steerable Drilling Liners have been developed, tested, and commercially run in a few wells by two different service companies with 13 3/8 and 9 5/8-in. liners.

4) A Close Tolerance Liner Drilling system was developed and tested with 11 ¾-in. liner.

5) Both RLDD/SDL and CTLD can eliminate liner conditioning and running time of the remainder of the longer sections with the addition of more liner size options.

6) The casing and liner drilling smear effects remains unquantified. When models are developed, close tolerance drilling may no longer be needed in deepwater operations.

7) A business model, similar one used with smart completions, may be a better approach to the next step in the evolution of liner drilling.

Acknowledgments

I would like to remember and thank all the developers and workers in casing and liner drilling, most of whom are retired.

Nomenclature

The following were used in this paper:

BHA = *Bottomhole assembly*
BOP =*Blow-out Preventer*
BRT =*Below Rotary Table*
CTLD =*Close Tolerance Liner Drilling*
DWC =*Drilling with Casing*
ECD =*Equivalent Circulating Density*
LWD =*Logging while Drilling*
MWD =*Measurements while Drilling*
NPT =*Non-productive Time*
RLDD =*Retrievable Liner Directional Drilling*
RSS =*Rotary Steerable System*
SLD =*Steerable Liner Drilling*
TD =*total depth*
USD =*US Dollars*

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