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## **Thirty Years of Successful Coiled Tubing Re-Entry Drilling to Enhance Production in Mature Assets**

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### **Abstract**

Many oil and gas fields are approaching the end of their productive life. Production rates are declining, forcing operators to decide whether to shut down production and plug and abandon (P&A) the wells or explore cost-effective revitalization methods instead of drilling new wells.

Coiled Tubing Drilling (CTD) has been used for over 30 years to improve production rates in aging fields. This technology has evolved in response to changing operational objectives and increasing technical requirements, becoming a robust and reliable solution for enhancing production in mature fields.

Today, most operators are reviewing their existing, aging assets and evaluating solutions to revitalize fields while maximizing the recovery factor. CTD has emerged as a preferred method for re-entering existing wells and accessing undrained reservoir sections at a fraction of the cost of drilling a new well.

This paper examines the evolution of CTD technology, drawing insights from past lessons and technological advancements. It covers the progression from the first-generation CTD bottom hole assembly (BHA) in the 1990s, to the second generation with enhanced measurement capabilities and higher build rate performance, and finally, to the latest advanced high-temperature version. The development of these technologies is analyzed in correlation with evolving market requirements.

Different regions have specific CTD applications and operational constraints. The Middle East, for example, has utilized CTD since 1998 and has been a key driver in the development of high-temperature-rated and H<sup>2</sup>S-resistant BHAs. Examples of successful longterm projects, spanning 15 to 20 years, will be presented to demonstrate the technical and economic viability of CTD for field redevelopment.

Recently, the increasing demand for longer wells and more precise well placement has driven innovations in rib-steered motor technology. The first-generation rib-steered motor was designed to drill straight, long lateral sections, effectively mitigating early lockup issues experienced with conventional orienter-steered BHAs. The second-generation rib-steered motor introduced significantly higher build rates, making it suitable for both lateral and build sections. Future developments will continue to optimize these tools, particularly for high-temperature applications in the Middle East.

Additional and optimized Logging While Drilling (LWD) services like Gamma and Resistivity which can measure into different directions will enhance reservoir placement and Geosteering capabilities for Coiled Tubing Drilling in the future.

## Introduction

Coiled Tubing Drilling (CTD) has become a key solution for maximizing the potential of mature assets. Many aging fields suffer from depleted zones, resulting in declining production. As a result, many operators are actively seeking cost-effective methods to reverse this trend.

CTD enables re-entry into existing wells—in many cases, even without pulling the production tubing. Drilling new laterals from existing wells unlocks previously untapped reserves, extending field life and increasing recovery.

The applications for coiled tubing drilling today include drilling single or multi laterals through tubing. The ability to mitigate the use of expensive work over methods to pull completions equipment helps reducing cost. Also, CTD enables higher dogleg severity compared to conventional drilling, thus allowing for deeper sidetracks and drilling within the reservoir sections. CTD complemented with underbalanced drilling provides a safe closed system to flow the well while drilling, thus mitigating any formation damage. In some of the CTD operations, the well continues to flow to the production facility during drilling operations reducing time on existing production. The application of CTD in mature oil and gas fields has allowed the repurposing of these fields into gas storage. In offshore applications, slot recovery or pulling completions can be expensive. If the bypassed reserves are marginal or small pools, economics may not justify the spend for slot recovery or pulling completions to initiate new sidetrack. In such cases, CTD has been a game changer in the late life field development by allowing through tubing sidetrack and access to small, bypassed reserves.

Coiled tubing drilling technology and techniques have evolved significantly over the past three decades. The technology originated in the early 1990s with simple pendulum BHA designs and quickly advanced to more sophisticated solutions. Today's third-generation CTD BHAs integrate advanced rib-steered motors for enhanced steering precision, gamma and resistivity measurements for improved well placement, and highly ruggedized electronics engineered to withstand harsh drilling conditions at temperatures reaching up to 175°C.

## History of Coiled Tubing

Coiled Tubing Drilling is not new to the industry. A flexible spooled pipe was first introduced in a different application during the Second World War. Operation PLUTO (Pipeline Under The Ocean) used a flexible, subsea spooled pipe to supply the Allied troops with fuel for their tanks across the English Channel. A total of 651 million liters of fuel were pumped through the pipeline until the end of the war ([Wikipedia, 2025](#)).

The first Coiled Tubing unit for the oil and gas industry was patented in 1959 and used for clean-out operations (Skinner, 2016). Such units were frequently used for workover and acid stimulation in the early 1970s. Over the decades, coiled tubing technology evolved in response to fatigue failures caused by straightening and bending of the pipe while running in and out of the hole. Metallurgy and welding processes required enhancement before Coiled Tubing could be used for drilling applications in the early 1990s.

The first field trial for Coiled Tubing Drilling (CTD) was performed in the Paris Basin in 1991 and 1992 ([Traonmilin, 1992](#)). Traditionally, low-carbon steel alloys have been used to manufacture coiled tubing strings. These alloys come in different material yield strengths. To improve corrosion resistance, strength-to-weight ratio, and erosion and abrasion resistance, Titanium and composite (lightweight) coiled tubing strings have been introduced.

## The first ten year of CTD

Starting in 1991/92 with the first field trial in the Paris Basin, a very simple pendulum drilling BHA with no directional control was used. Two single-shot measurements confirmed that the BHA did not build an angle. Traonmilin ([Traonmilin, 1992](#)) lists the BHA components as follows:

- PDC bit
- Positive Displacement Motor (PDM)
- Cross-over
- Drill collar
- Cross-over
- Disconnect sub
- Double flapper check valve
- Wear sub
- Grub screw connector

CTD technology, like coiled tubing units and CTD bottom hole assemblies (BHA), rapidly improved in the following years, allowing the drilling of not only vertical wells but also deviated and horizontal wells.

In 1994 ([Eide, 1994](#)), a more advanced coiled tubing drilling system was used for re-entry into a depleted, water-flooded reservoir in Barenburg, Northern Germany. In the years before, many wells in this area had been plugged and abandoned due to uneconomical production. Coiled tubing re-entry drilling was seen as an economical, cost-effective solution to keep the wells in production. Another argument for using CTD was its lower environmental footprint, as it used existing production facilities and required less surface disturbance. The BHA used for CTD was specifically designed for re-entry operations and was already more advanced than the one described by Traonmilin ([Traonmilin, 1992](#)) two years prior.

A special Measurement While Drilling (MWD) tool was used, which included directional and pressure sensors. Power and communication were supplied by a wireline inside the coiled tubing, simplifying operations and reducing the number of components needed in the BHA. Since coiled tubing drilling is a non-rotational service, an electro-hydraulic orienter was implemented to rotate the bent motor to the desired direction. Due to limited push-pull forces on a coiled tubing string, a reliable release tool was essential. Since the presence of a wireline cable inside the coiled tubing prevented the use of a conventional ball-drop mechanism, a two-stage mechanical release system was developed. The first stage used a mechanical shear pin system, while the second stage was hydraulically activated. ([Eide, 1994](#)) The following BHA was used for the Barenburg deployment:

- 3 1/8" Navi-Drill motor
- Mechanical release tool
- Orienting tool
- MWD
- Quick connect to coiled tubing

In other deployments, a weight on bit sensor and a gamma ray sensor were added to the BHA.

Nitrogen injection was used in two different methods to drill the well at balanced and underbalanced conditions in a depleted, low- pressure reservoir. The first method, shown in [Figure 1](#), used a parasitic string

and a diffuser tube to perform nitrogen injection into the mother bore. The second method, shown in Figure 2, involved injecting nitrified fluid through the coiled tubing string.

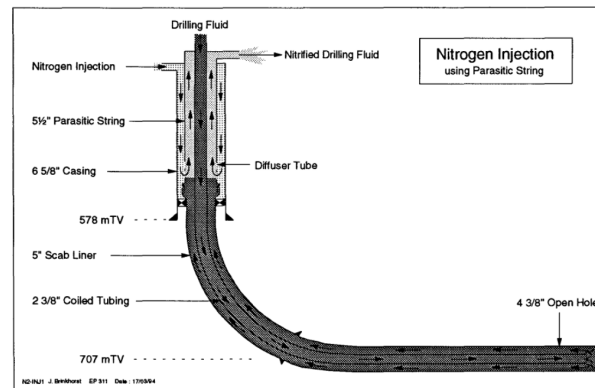


Figure 1—Nitrogen injection using parasitic string (Eide 1994)

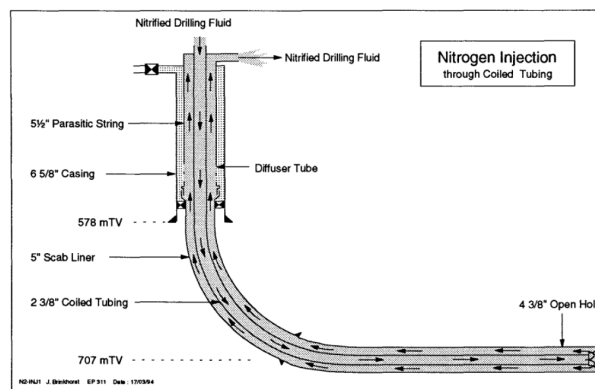


Figure 2—Nitrogen injection through coiled tubing (Eide 1994)

In the mid-1990s, specialized reeled systems were developed for CTD. They specifically addressed through-tubing re-entry for deviated and horizontal wells, allowing for underbalanced drilling if needed. These hybrid rigs enabled multiple well interventions, including drilling, logging, fishing, and completion, using a single system. They were capable of handling both coiled tubing and jointed pipe. The first two reeled systems, Copernicus and Galileo, were commissioned in 1996. (Young, 1997)

Copernicus was designed for land-based and offshore (fixed platform) CTD operations. It was also capable of completion tasks, making it ideal for re-entry coiled tubing drilling operations. (Young, 1997)

Galileo was designed primarily for onshore operations but was also suitable for offshore applications on both floating and fixed platforms. The system could be used for re-entry coiled tubing drilling, recompletions, and grassroots drilling. Grassroots drilling refers to the drilling of new wells, where coiled tubing is used to deepen or sidetrack a new preset well. (Young, 1997)

After the first field trials in the United States, the Galileo rig was shipped to the Netherlands, where it was used for underbalanced coiled tubing drilling (UBCTD). Koper (Koper, 1999) describes the steep learning curve experienced with the Galileo rig during its first three wells drilled in the Netherlands. Net operating time increased from less than 30% on the first well to almost 80% on the third well. He also describes the world's first through-tubing double casing exit.

The second Galileo rig was used in Lake Maracaibo, Venezuela, in 1997/98. It was mounted on a barge and moored at a water depth of approximately 30 feet. The first generation of CTD BHAs were used to drill underbalanced wells in depleted reservoirs (Offshore Magazine, 1998).

One major CTD project, involving a total of 28 wells, started in the Middle East at the end of the 1990s. The first generation of custom- built CTD BHAs was deployed on the hybrid rig Galileo3. Drilling operations were frequently performed underbalanced after setting the whipstock and milling the casing window. Typically, a 3 3/8" horizontal hole section was drilled into the reservoir and completed with a 2 7/8" perforated liner (Krueger, 2001).

The first commercial CTD geosteering service was introduced in this project in 1999. A 3 1/8" Ultra Slim Multiple Propagation

Resistivity (USMPR) tool was used, operating at broadcasting frequencies of 2 MHz and 400 kHz and measuring phase difference and attenuation.

The first-generation drilling BHA had a nominal outer diameter of 3 1/8" and 3 3/8" and was temperature rated up to 150°C, with a maximum build rate of 35°/100 ft (for the 3 1/8" OD BHA).

The main BHA components included:

- Bit (PDC or Tricone)
- NaviDrill motor
- Mechanical Release tool
- Electro-hydraulic orienter
- Gamma unit
- MWD unit (directional measurements and pressure)
- Communication sub
- US MPR (starting in 1999)
- Quick connect
- Coil connector

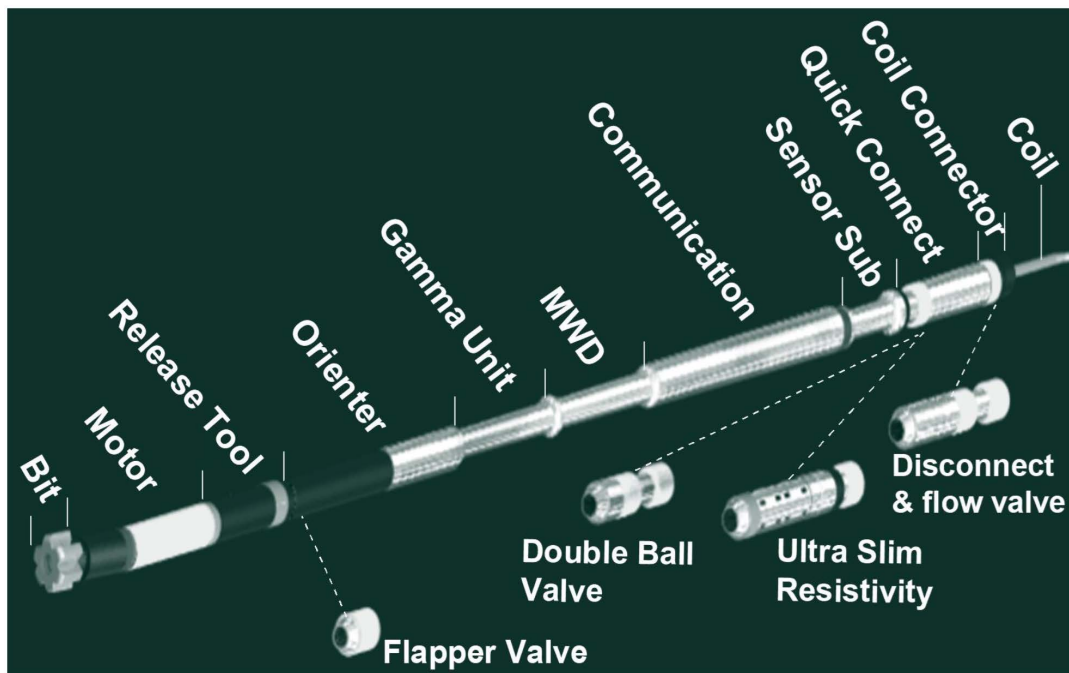


Figure 3—Example of first generation CTD BHA (courtesy of Baker Hughes)

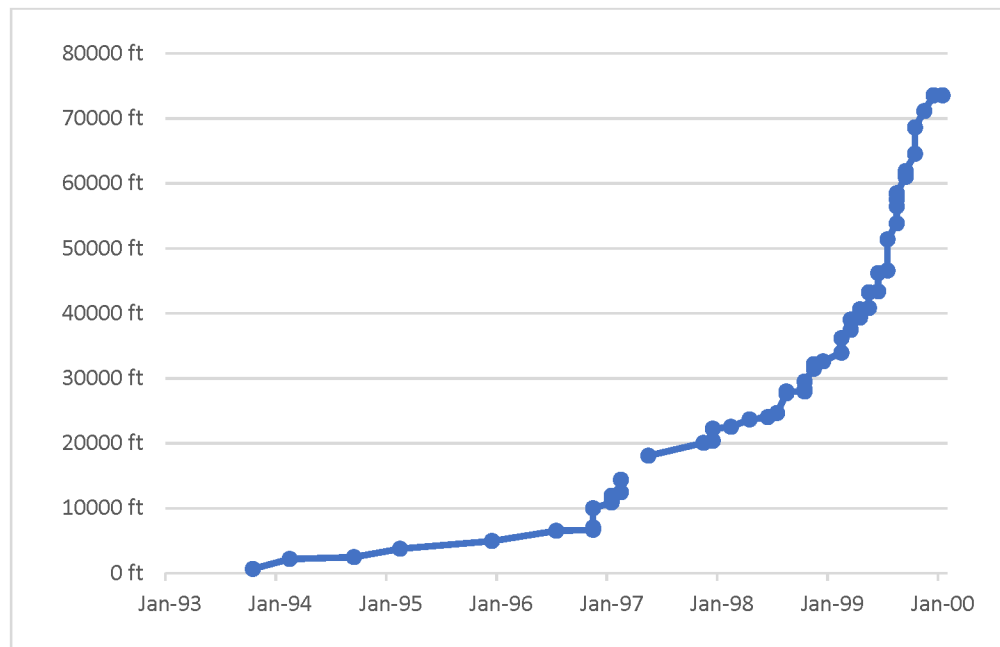


Figure 4—Total number of feet drilled with the first generation CTD BHA (courtesy of Baker Hughes)

## The second decade of CTD

The increasing complexity and challenging environment required mayor improvements to the BHA and the development of additional BHA components. The first big step was already made with the development of the US MPR which was released for commercial use in 1999. Additional improvements followed in the early 2000<sup>th</sup> with the introduction of the second generation of CTD BHA. While the 3 1/8" BHA was downscaled to 3.0" the need for an even smaller BHA to re-enter 3 'f' production tubing led to the development of a smaller 2 3/8" coiled tubing drilling BHA.

The mechanical release tool had reliability issues and limited the overpull of the CTD BHA due to the implemented shear pins. Its position had to be below any electrical connection and was therefore limited to placement right behind the motor. For the second- generation BHA, a new electrical disconnect was developed, which could be placed anywhere below the quick connect system. This upgrade allowed for greater flexibility in BHA design. The disconnect is activated with an electrical signal from surface and does not rely on any pressure drop or overpull. An additional circulation port was integrated into the disconnect to allow higher flow rates for hole cleaning without spinning the motor and bit. This is particularly important when circulating inside the casing while tripping in and out of the hole. The e-line connection to the surface allows a multi-cycle real-time control of all BHA components, including the electrical disconnect and circulation ports.

Below is a list of standard second-generation CTD BHA components and features. They are described in more detail, with different BHA variants outlined by Krueger (Krueger, 2016).

- Drill bit (PDC, straight or bi-center bit)
- Positive Displacement motor (PDM)
- Float valve - safety back pressure valve
- Electro-hydraulic orienter (HOT) - turns the AKO motor into the desired direction
- Rib steered motor (RSM) - optional, to replace PDM and HOT
- Directional Gamma Sub (DGS) - Directional and Gamma sensors

- Drilling performance sub (DPS) - including weight-on-bit (WOB), string and annular pressure, vibration and stick-slip
- Ultra slim multiple propagation resistivity (USMPR) (optional) - allows geo-steering capabilities
- Gyroscope (optional) - directional measurement when kicking off from near vertical casing exits
- Double ball valve (DBV) (optional) - well control for deployment into live wells
- Power and Communication Sub (PCS) - includes casing collar locator (CCL)
- Electrical disconnect and circulation sub (EDC) - emergency release and circulation while tripping
- Quick connect system - provides electrical and mechanical connection between coil and e-line to the BHA
- Coil connector - connects the whole BHA system to the coil and routes the e-line trough

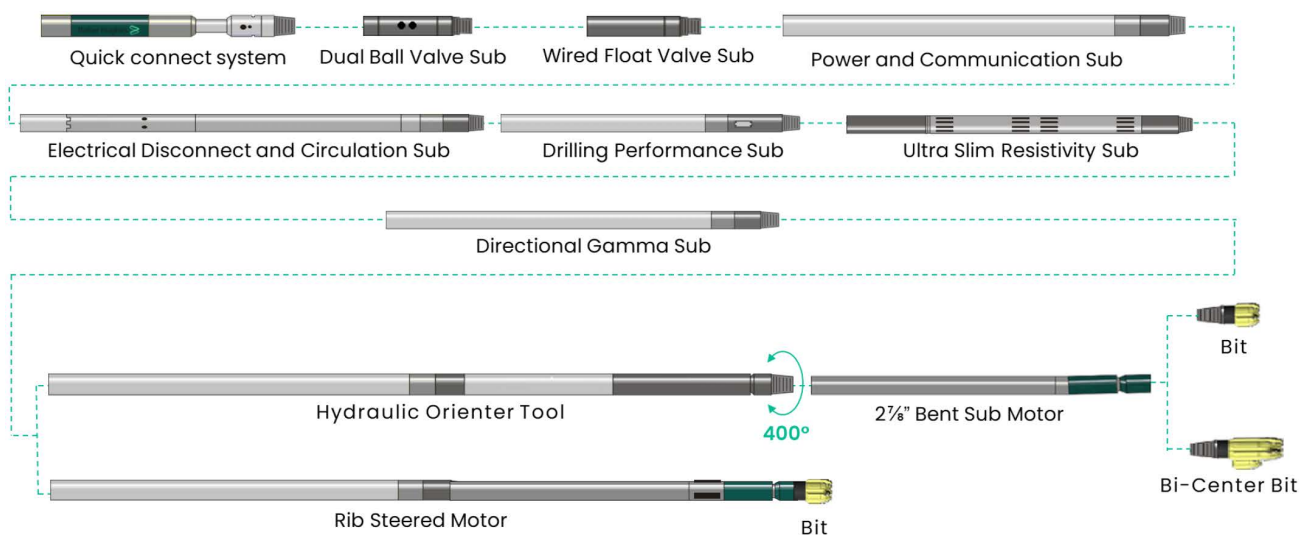
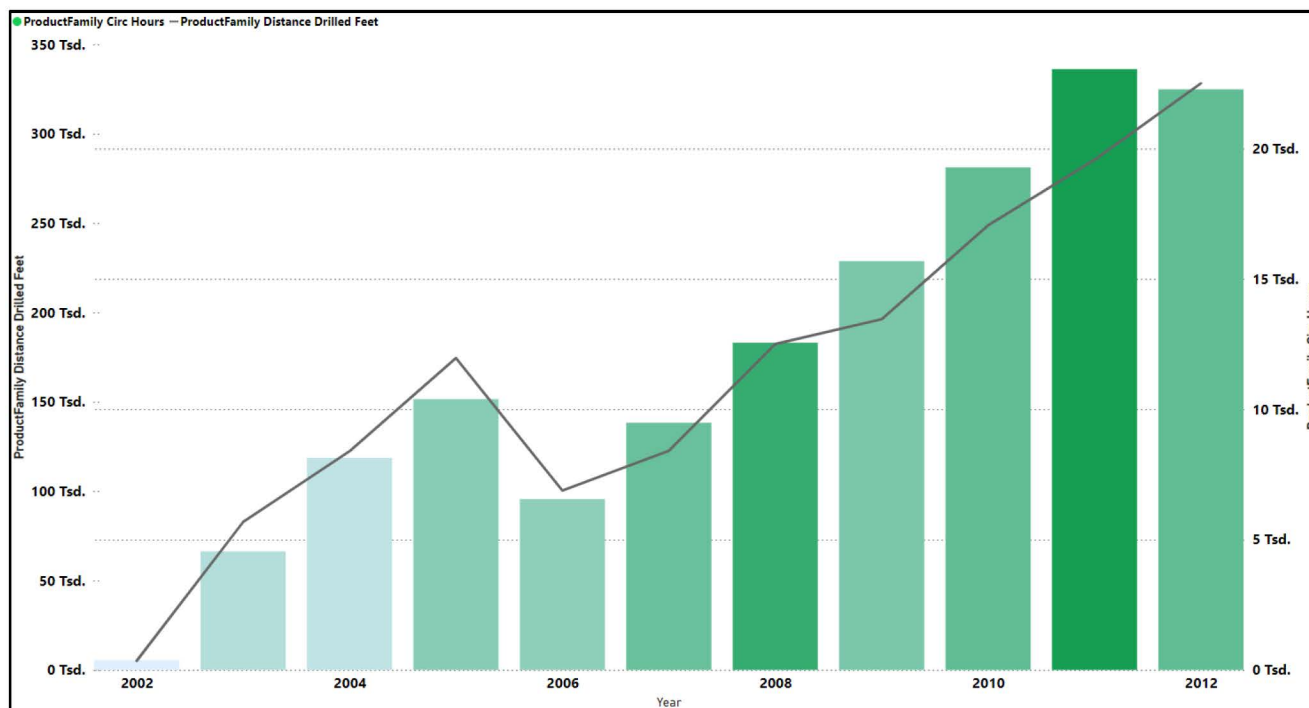


Figure 5—Typical 2<sup>nd</sup> generation CTD BHA set-up

The new, integrated, and modular BHA concept enabled greater customization of BHA configurations for specific applications and reservoir conditions. With the evolution and performance increase of the CTD BHA the surface equipment, including CTD units, tower rigs, and underbalanced drilling (UBD) packages were upgraded and tailored to specific operational requirements.

With the introduction of the optimized second generation of CTD BHA in 2002, CTD adoption saw a sharp increase, as shown in Figure 6, which illustrates the footage drilled (green bars) and circulation hours (black line) between 2002 and 2012.



**Figure 6—Total number of feet drilled with the second generation CTD BHA between 2002 and 2012 (courtesy of Baker Hughes)**

The Middle East played a critical role in driving CTD technology advancements. After the aforementioned major project in Oman, which was still utilizing the first-generation CTD BHA, the second major project in the Middle East started in Sharjah Emirate in 2002/03. This was the first project utilizing the second-generation BHA. A tower rig set-up with the latest UBD equipment allowed drilling underbalanced while simultaneously producing gas. Drilling was performed in high H<sub>2</sub>S formations with temperatures up to 160°C. Between 2003 and 2006, 40 wells with a total of 141 laterals were drilled in a 3 %" hole size. The next major project in the Middle East was in Dubai, with comparable conditions to the Sharjah field. Lessons learned and best practices from Sharjah were leveraged to enhance operational efficiency and mitigate risks in Dubai's drilling campaign in 2006 and 2007 (Krueger, 2011).

In 2008, the first pilot project started in the Kingdom of Saudi Arabia (KSA) to increase gas production in mature fields. This 6-well campaign required drilling of 3 5/8" multi-lateral re-entry wells from existing 4 'f' tubing. After the successful completion of these wells, the operator moved into a long-term, integrated project, which is still ongoing today. An integrated project means that all services are executed or subcontracted by one service company as a single point of contact (Krueger, 2011).

Another major, still ongoing project started in the second decade of coiled tubing drilling in Alaska. This marked a significant step in CTD applications for oil production. Starting in 2001 with the first generation of CTD BHA, the service company quickly transitioned to the second generation of CTD BHA in 2002. In fact, CTD in Alaska had already begun in the early 1990s. Many lessons learned from previous CTD deployments in Alaska were applied to optimize this major project. The application in Alaska differs from that in the Middle East. The main driver for CTD in Alaska is accessing bypassed pay zones in oil reservoirs. A typical application is re-entry of 4 'f' completions to drill 3 %" holes or re-entry of 3 'f' completions with 3.0" holes. The latter application was the driver behind the development of the world's smallest CTD BHA, with a 2 3/8" nominal outer diameter (OD). This enabled access to tighter restrictions in tubing or wellbores. All BHA components for a 3.0" BHA are also available for a 2 3/8" BHA. Pressure and temperatures at the North Slope are considered very moderate compared to the conditions in the Middle East. Therefore,

the performance and reliability of CTD BHAs have always been considered best-in-class when utilized in Alaska

## The third decade of CTD

CTD was first implemented at the start of the third decade by Petronas Carigali in 2011 over a 3-year pilot campaign (Zhon, 2016). The objective for CTD included re-entry into slim 3  $\frac{1}{2}$ " completions using a rigless drilling method to access marginal bypassed reserves that would otherwise be uneconomical to develop using conventional drilling. The second phase of CTD was developed two years later in 2013 using a Self-Elevating Workover Platform Vessel (SEWOP). SEWOP was used to assist operations due to the platform's limited space and deck loading capacity. Complex operations, such as re-entry drilling through a dual tubing completion and targeting different reservoirs, were successfully executed. A dual casing exit through 3  $\frac{1}{2}$ " tubing followed by a 9  $\frac{5}{8}$ " casing was also achieved in this project. Technologies such as reservoir navigation using geosteering with ultra-slim resistivity and gamma ray, managed pressure drilling, and rib steer motor significantly optimized CTD performance. In the first pilot, CTD restored three idle wells with a production of 1,400 barrels of oil per day (BOPD) (Zhon, 2026). The second CTD project restored three idle wells with a production of 2,400 BOPD (Zhon, 2026). In both projects, a 2  $\frac{3}{8}$ " slim hole bottom hole assembly was used with 2" e-line coiled tubing.

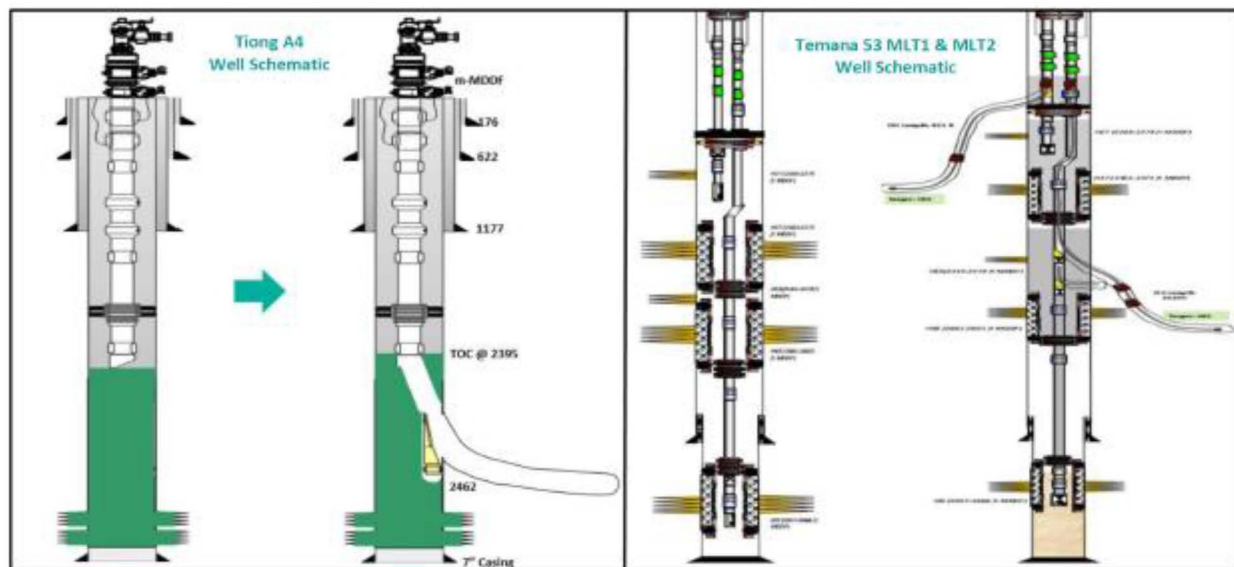


Figure 7—Comparison of CTD well design in Pilot project vs. CTD Phase II (Zhon, 2016)

During this decade, two major, continuously ongoing CTD projects in Alaska and Saudi Arabia dominated the industry, highlighting the diverse challenges and solutions required for CTD deployment in different environments.

Cold weather conditions in Alaska have been advantageous for the longest ongoing CTD operation globally. High-temperature reservoirs, one of the biggest challenges in the Middle East, are not an issue in Alaska. The main application in Alaska involves drilling into depleted and heavily faulted sandstone oil reservoirs. Typically, a thru-tubing whipstock is used to exit the casing through the existing 3  $\frac{1}{2}$ " or 4  $\frac{1}{2}$ " tubing. Multiple laterals are drilled from this single casing exit and completed with a slotted liner. Today, more than 3 million feet have been drilled with the second generation of CTD BHA in Alaska. Most of the global CTD drilling records have been set in these wells:

- Longest lateral: 8,153 ft

- Deepest kick-off: 21,500 ft
- Deepest total depth: 22,461 ft

Both sizes of drilling BHA, 2 3/8" and 3.0", are frequently used to meet the operators' requirements. Over decades of CTD operations in the North Slope, invaluable lessons have been learned. These insights are applied daily to enhance performance, optimize procedures, and advance the technology used in the region.

However, technology development for new and advanced downhole equipment has been primarily driven by the challenging environment and complex well designs in Saudi Arabia. To date, almost 2 million feet have been drilled with CTD in Saudi Arabia. Starting in 2008 with the pilot campaign of six wells and one discrete contract (each service contracted individually), CTD is now operated as an integrated project. In an integrated project, the operator has a single point of contact, with all services subcontracted and managed under a unified structure. The number of active CTD drilling rigs has steadily increased over the years.

The first five to six years of CTD operations in KSA focused on low- to mid-range temperature and H<sub>2</sub>S concentrations. However, as conditions evolved, the standard second-generation BHA began to reach its operational limits. In 2016, the BHA was upgraded with enhanced materials to withstand higher H<sub>2</sub>S content. The electronics were also upgraded, increasing the temperature limit from the initial 150°C to 160°C. However, this proved to be only a short-term solution, as temperatures frequently exceeded 160°C. A complete redesign of the downhole drilling BHA was required, incorporating a new sensor and electronics architecture to withstand extreme conditions.

The electronics in the first- and second-generation CTD BHAs were based on Printed Circuit Board Assembly (PCBA), which did not perform reliably at temperatures above 160°C. A new Multi-Chip Module (MCM) technology was introduced, consisting of hermetically sealed ceramic boards with non-organic components. Specialized high temperature (HT) electronics, combined with new sensors, internal electronic motors, advanced sealing systems, and improved hydraulic mechanisms, increased the reliability of CTD downhole equipment at temperatures up to 175°C. This upgrade not only improved performance in high-temperature environments but also enabled drilling in harder, more abrasive formations (Krueger 2020).

Different drive mechanisms were introduced to mitigate vibration challenges in such environments. Alternative motor designs with various rubber types were tested to optimize both performance and reliability. Bussy (Busy, 2020) describes new turbines that enhance drilling in highly abrasive sandstone formations and high-temperature environments while operating in underbalanced conditions. The 2 7/8" turbines, which do not require any rubber components, are particularly suited for high-temperature and two-phase gas injection applications. These turbines are compatible with all BHA generations, including the latest high-temperature version. Depending on the specific application and challenges, operators can now choose between different motor types and turbines.

Using either a mud motor or a turbine in standard coiled tubing drilling runs, directional control is achieved by an orienter. Because coiled tubing cannot be rotated from surface, the bent motor or turbine must be rotated downhole to achieve directional control. For drilling a straight lateral well, the motor or turbine must be continuously turned and oriented. A specialized control algorithm is implemented in the hydraulic orienter of the second and third-generation BHAs to maintain the drilling BHA on the planned trajectory. However, continuously rotating the orienter and drive mechanism will cause the well to be drilled in a spiral trajectory, increasing drag forces and ultimately limiting well reach. This will lead to suboptimal well placement and challenges when attempting to run a liner.

A solution to improve wellbore geometry and ultimately extend well reach is outlined by Ross (Ross, 2012), who describes the introduction of a rib-steered motor (RSM) in Alaska. The RSM concept is based on Rotary Steerable System (RSS) technology, which is widely used to drill complex 3D well paths. Lessons learned from RSS designs were applied to slim-hole motors, enabling precise control of well trajectory.

Three steering ribs are implemented at the bearing section of a straight slim-hole mud motor. The RSM provides steering modes like standard RSS systems:

- **Ribs-off mode** - ribs are fully retracted for tripping in and out of hole
- **Inclination hold mode** - steering ribs are controlled to maintain inclination
- **Steer mode** - An internal algorithm will control azimuth and inclination to drill to target
- **Center mode** - all ribs are equally pressurized to centralize the RSM

The RSM is available for both BHA sizes, 2 3/8" and 3.0".

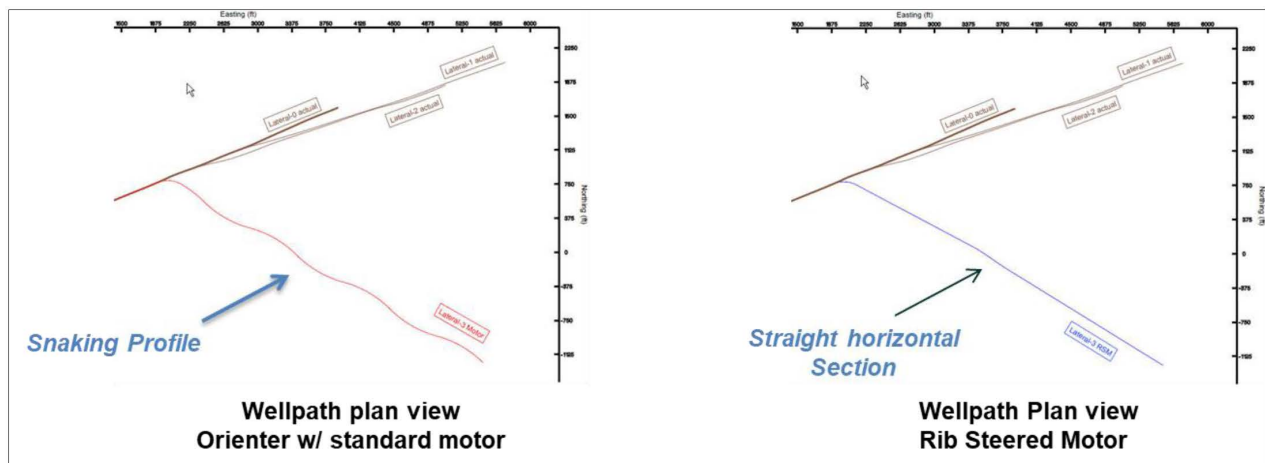


Figure 8—Difference between "snaking" orienter drilled well path (left) vs. a straight well path drilled with rib steered motor (right) (Krueger, 2011)

CTD units in mature CTD projects have become fit for purpose for the long-term applications. The lessons learned on the project have allowed for continuous improvement in design of the new units allowing for benefits such as precise drilling controls, minimizing the surface footprint and faster rig moves between wells. These enhancements in surface equipment are beyond the subject of this paper.

## The next (forth) decade of CTD

The two previous generations of CTD BHAs have established a proven track record of reliability and efficiency. However, based on lessons learned during past deployments, there are also opportunities for improvement. For instance, despite the many advantages outlined above, the rib-steered motor (RSM) has not been utilized as extensively as initially expected. A survey conducted with major operators identified key challenges associated with the first-generation RSM. The survey asked the following questions:

- What is the utilization of the RSM in your fields?
- What are the main benefits?
- What should be improved in the future?

The main answers are:

- Limited build rate (10°/100ft)
- Limited temperature rating (150°C)

- Limited reliability in harsh drilling conditions.
- High maintenance cost

Based on these findings, a product development initiative was launched to design and enhance the next generation of RSM technology. Currently, two new versions are under development. The second version, RSM2, is undergoing field testing. Its build rate capability has been improved to 25°/100 ft, while its electronics and hydraulic system have been upgraded to operate reliably at temperatures of up to 160°C. Additionally, enhanced components and an extended service life will contribute to reducing the overall maintenance costs compared to the first-generation RSM.

Figure 9 illustrates a cut view of a sandstone block tested with the RSM2, demonstrating its ability to achieve an open-hole sidetrack with a build rate of 27°/100 ft. Two recent field tests confirmed that the RSM2 successfully followed a predefined well path with a build rate of nearly 20°/100 ft at steering forces between 50% and 60%.



Figure 9—Cut view of a sandstone block showing an open hole sidetrack with an RSM2

Further field tests and qualifications will be conducted before the RSM2 is released for commercial use. Simultaneously, the third version, RSM3, is under development. This model represents a high-temperature upgrade of the RSM2 and will integrate all the recently implemented improvements while further enhancing its build rate capability, overall reliability, and temperature rating—pushing the operational limit to 175°C. The RSM3 will be aligned with the third-generation CTD BHA, incorporating Multi-Chip Module (MCM) electronic technology for enhanced performance in extreme environments.

Today, Logging While Drilling (LWD) capabilities in CTD applications remain limited to bulk gamma and resistivity measurements. However, surface logging techniques, such as biofossil analysis and detailed elemental and mineral composition qualification using X-ray Diffraction (XRD) and X-ray Fluorescence (XRF), are frequently used to enhance reservoir navigation, enabling operators to remain within thin target layers. (Alsaud, 2024) Additionally, resistivity inversion techniques are applied to improve geosteering accuracy in CTD operations. Despite these advancements, many operators worldwide have emphasized the need for azimuthal resistivity and gamma measurements to enhance well placement accuracy. Azimuthal Resistivity and Azimuthal Gamma measurements will significantly enhance reservoir navigation for slim-hole CTD applications.

As CTD services grow in complexity, the number of BHA components will continue to increase, potentially leading to longer tool configurations. This trend presents new challenges, particularly when deploying BHAs into live wells. Pressure deployment in multiple stages is highly time-consuming and should be minimized wherever possible. To address these challenges, ongoing research is focused on the miniaturization of electronics, hydraulics, and mechanical components to ensure that even fully assembled BHAs can fit within a lubricator.

CTD is typically operated using an e-line, which enables direct and rapid two-way communication between the surface system and the BHA. This characteristic makes CTD an ideal candidate for process automation. With the increasing digitalization of drilling operations, remote real-time access to BHAs allows for advanced monitoring, data-driven decision-making, and ultimately, remote operation.

## Conclusion

Coiled Tubing Drilling (CTD) has evolved significantly over the past 30 years, solidifying its status as an advanced and proven methodology for enhancing production in mature fields. The latest-generation CTD BHAs offer exceptional steering accuracy, leveraging Gamma and Resistivity measurements enhanced with inversion techniques to remain within the optimal reservoir interval.

A rib-steered motor (RSM) ensures well trajectory remains precise and straight within the designated corridor, while state-of-the-art electronics and hydraulic systems enable reliable performance in harsh environments, including high-temperature reservoirs.

Looking ahead, future developments will focus on further enhancing the RSM, incorporating azimuthal gamma and resistivity measurements for superior geosteering, and optimizing BHA length to streamline pressure deployment. These innovations will improve operational efficiency, reduce risk, and enable greater adaptability across diverse drilling environments.

The CTD market is currently expanding rapidly and is projected to double within the next two years. This strong industry growth is driving continuous advancements in CTD technology, further optimizing drilling procedures, and reinforcing CTD's role as a critical tool for unlocking additional reserves in mature fields.

## Acknowledgments

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