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Applications and Limitations of Coiled Tubing Technology: A Glance

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Abstract: Coiled tubing technology has revolutionized various operations in the oil and gas industry. This paper provides an overview of the applications, advantages, and limitations of coiled tubing technology. Starting with its historical development and basic components, the paper delves into the diverse applications of coiled tubing, including horizontal drilling, hydraulic fracturing, well cleanout, acid stimulation, and rigless completions. The advantages of coiled tubing, such as its ability to operate in pressurized or producing wells, quick deployment, and suitability for horizontal or deviated wells, are highlighted. The importance of coiled tubing cycles and fatigue analysis is discussed in detail to ensure safe and effective operations. The downhole equipment used in conjunction with coiled tubing is also explored, covering connectors, release joints, centralizers, nozzles, impact tools, under reamers, retrieving tools, check valves, and packers/plugs. Furthermore, the paper addresses the dimensions and specifications of coiled tubing, emphasizing its versatility and customization potential for various projects. It showcases the significance of coiled tubing in rigless deep-water applications and its role in cost-effective well intervention, drilling, completion, and well maintenance operations. Despite its numerous benefits, the paper acknowledges the limitations and challenges associated with coiled tubing technology, including safety considerations, costs, and equipment limitations. The conclusion highlights the ongoing efforts to improve coiled tubing technology, making it a valuable and indispensable tool in the oil and gas industry's future endeavors.

Keywords: Coiled Tubing, Horizontal Drilling, Hydraulic Fracturing, Unconventional Shales, Rigless Completions

1. Introduction

Although the idea of a coiled pipe or conduit to move tools downhole in oilfield operations goes back much further, with patents on the subject in the 1920s and 1930s, coiled tubing as it is known today dates back to the 1960s. For the British PLUTO ("Pipelines Under the Ocean") to construct petroleum supply pipes beneath the English Channel to serve Allied Forces during World War II, continuous flexible pipe was first successfully manufactured in 1944. These innovations served as the basis for the creation of contemporary coil tubing machinery.

A continuous reel of pipe that is coiled up is thin enough to slide through the top of a Christmas tree. Although composite and corrosion-resistant alloy models have been constructed, the tube is normally made of steel. It is fabricated in long strips, rolled cylindrically, and longitudinally welded. Although sizes up to 4 12" are available, diameters between 34" and 1 12" are more common. The system is made up of the reel itself, a blow-out preventer stack (BOP) to regulate well pressure, an injector head that directs tubing through a gooseneck and moves it into and out of the well with hydraulic motors, and other ancillary equipment like a power unit, crane for the surface assembly, control cab, and a transport system (i.e. – trailer, barge, or service boat).

Coiled tubing units can operate on pressurized or producing wells because of this assembly and the operator's ability to maintain continuous circulation without having to make or break connections between rigid pipes. They can also carry out the majority of tasks more quickly than a typical workover rig. Coiled tubing units provide a number of significant advantages in addition to their ability to swiftly and continuously circulate when working on active wellbores. Since the tubing is rolled out from the reel while activities are underway, the machine can deploy and rig up quickly. They also require little people to operate and have a small surface footprint. The use of coiled tubing units in the industry has grown as a result of all of these benefits. Expanding beyond their initial well cleanout and acid stimulation applications, they are now used to circulate or run bits and tools during drilling, completion, and workover operations throughout the life of the well. They are uniquely suited to horizontal or deviated well applications, since the steel tubing enables an operator to push tools beyond the reach of wireline and work past a curve unlike straight pipe.

One of the main advantages of CT is that it can be inserted into a well without the need for drilling a new hole. This allows for cost-effective and efficient well intervention, as well as the ability to access difficult-to-reach areas of the well. Additionally, CT is typically smaller in diameter than conventional jointed pipe, making it ideal for use in horizontal and deviated wells. CT is deployed into a well using a coiled tubing unit (CTU), which is a specialized piece of equipment that includes a reel, injector head, and control system. The CT is uncoiled from the reel and fed into the well through the injector head, which applies tension to the CT and controls its movement into and out of the well.

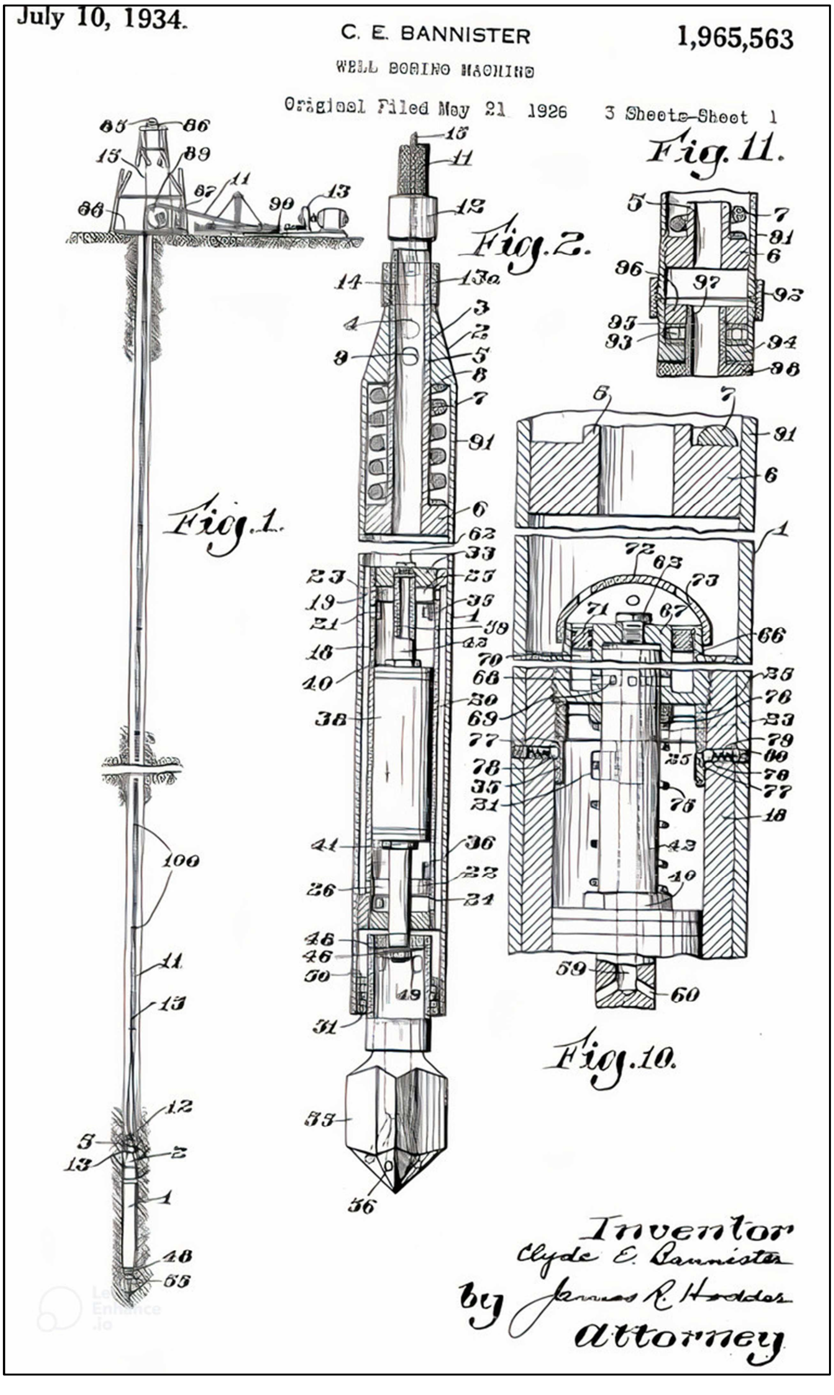

Figure 1. *First sketch of coiled tubing unit [1].*

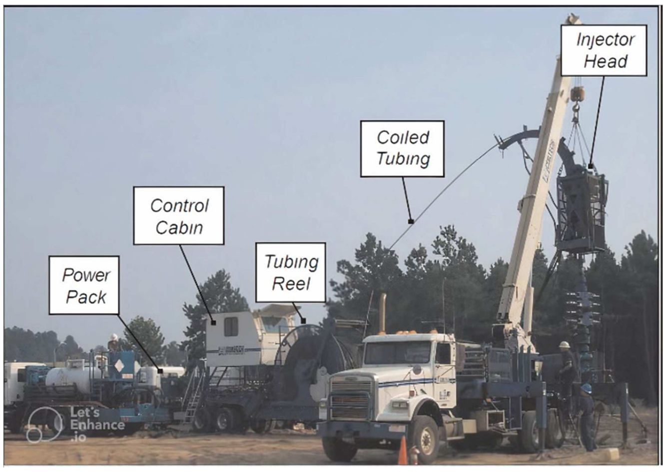

Figure 2. *Trailer mounted CT unit and crane [2].*

2. Coiled Tubing Applications

Once the CT is in the well, it can be used for a variety of operations. For example, CT can be used to drill a new wellbore by injecting drilling fluids and rotating a small drill bit at the end of the CT. CT can also be used for well stimulation, such as acidizing or fracking, by injecting fluids and/or proppant down the CT and into the well. Additionally, CT can be used for wellbore cleanout, such as removing debris or scale from the well, by running a specialized tool on the CT. The properties of CT that make it attractive for use in well intervention and completion operations are its strength, flexibility, and small diameter. The steel or composite material used to make CT is strong enough to withstand the high pressures and temperatures found in wells, while its flexibility allows it to navigate through deviated and horizontal sections of a wellbore. The small diameter of CT allows it to be run into wells that have small-diameter casing or tubing, which is common in horizontal and deviated wells. Another advantage of CT is that it can be easily removed from the well, allowing for quick and efficient intervention operations. This can be done by reversing the injector head, which applies tension to the CT and pulls it out of the well.

2.1. Drilling Applications

During the drilling portion of the well coiled tubing can be used to evaluate the reservoir, pushing logging tools far beyond the reach of wireline tractors. This technology is being utilized much more today due to the shale drilling revolution with long lateral intervals, and it enables the operator to precisely choose the best place to perforate and frac, increasing productivity while saving time and money. Coiled tubing can be used to drill as well deepening or under-reaming the wellbore. This can save both a great deal of time and money. Coiled tubing units are much quicker to deploy and there is no need to pull and re-run the completion tubing enabling the well to come on-line much quicker and expedite production.

We can list some current applications of coiled tubing drilling as follows.

A study [3] compares Underbalanced Coiled Tubing Drilling (UBCTD) with conventional drilling and stimulation in a carbonate target in Saudi Arabia. Biosteering in UBCTD shows superior performance compared to geosteering in conventional drilling, resulting in higher footage in the target zone and increased production. However, the slim-hole nature of UBCTD limits the use of logging while drilling (LWD) technologies for reservoir characterization and development planning.

Wiranata et al. [4] discusses the use of coiled tubing drilling (CTD) and the challenges encountered when the wireline inside the coiled tubing becomes disconnected from its bottomhole assembly (BHA) anchor. By utilizing a CT integrity monitoring system based on magnetic flux leakage (MFL), it was determined that the coiled tubing experienced linear plastic elongation, resulting in the wireline disconnection. The paper provides an analysis of the CT elongation growth and emphasizes the importance of accurate slack calculation and proper slack management practices to prevent such issues in future operations.

Guizada [5] discusses the use of underbalanced coiled tubing drilling (UBCTD) as a suitable approach for developing heterogenous deep carbonate reservoirs. Conventional strategies may not be optimal for such reservoirs, and the application of new technologies, such as UBCTD, can help optimize reservoir development. The UBCTD technique involves drilling with a lower fluid pressure than the reservoir pressure, minimizing formation damage, and allowing natural flow during drilling. The author presents a successful field case that demonstrates the effectiveness of UBCTD in maximizing reservoir contact, increasing well productivity, and provides an overview of the technology and its application.

2.2. Completion/Intervention Applications

Coiled tubing is used extensively during completion and intervention operations. One of the primary advantages of coiled tubing is that it allows tools to be introduced/operations performed on the well, while leaving the production tubing in place. This in a huge advantage as it saves a great deal of time and enables operations to be performed that would be otherwise impossible (due to its ability to push tubing down a live well, similar to a snubbing unit).

Pressure pumping is one of the primary uses of coiled tubing. Nitrogen lift is a common operation: during this operation the coil is run in hole while pumping nitrogen, which decreases the weight of the column of heavy completion fluid used to control the well. This enables the formation to overcome the hydrostatic pressure and helps to well back on production. Care must also be taken to monitor the pumping rates and returns from the well to ensure that the fluid is being pushed up to the surface and not down into the formation. Coiled Tubing is also used for stimulation: many times (especially on loosely consolidated sands) a “pill” must be pumped to control losses during completion activities. The same way this “pill” limits completion fluid from entering the formation it limits formation fluid from entering the wellbore. The most effective way to remove this pill is by spotting acid through coiled tubing.

Similar to spotting acid, coiled tubing can also be used to spot or wash with other chemicals (xylene, methanol, low dose hydrate inhibitor) for scale, hydrate, or asphaltene removal. As a well is depleted, the flowing tubing pressure falls below the asphaltene onset pressure and asphaltenes will begin to fall out of the fluid. This creates a restriction and can severely limit production; however, by doing a light intervention with coil tubing many of these issues can be corrected.

In the loosely consolidated sands that much of the world's oil is produced from, sanding of the tubing is often a problem. This is particularly difficult to deal with since due to the sand plug communication with the reservoir cannot be obtained. This prevents hydrocarbons from being produced while preventing the operator from properly killing the well. In these situations, coiled tubing is typically employed to circulate fluid on top of the sand plug and "wash-out" the sand, which can be a very risky operation depending upon the pressure below the sand plug. Many times, once the sand plug is washed if the circulating fluid is not correctly weighted the well will begin producing, rapidly carrying all of the sand to surface, and washing out surface equipment.

Coiled tubing can also be used to spot cement in a similar fashion. Coiled tubing is an effective way to introduce tools to the well, velocity strings, ESPs, and other things can be run on coil tubing in wells where it would not be possible to use slickline or wireline due to weight or deviation restrictions. As previously mentioned, coiled tubing can be used for stimulation purposes both acid stimulation and fracture stimulation: this enables an operator to frac a higher zone without pulling the production tubing or exposing their downhole equipment to proppant. Coiled tubing is often a contingency plan due to its range of abilities. It has a greater pulling capacity than wireline or braided slickline, which makes it ideal for heavy fishing operations. It also allows a great deal of weight of bit to be applied if the need to mill an obstruction arises. On US land with the long horizontal completions, coiled tubing is employed every day on hundreds of wells to mill the plugs which isolate one zone from the other; without coiled tubing for this application, many of these wells would not be economical. The ability to wash, mill, fish, and cement make coiled tubing one of the primary tools used in "P&A" or plugging and abandonment work. This is generating much more attention especially in the U. S. due to the BSEE push for a large number of plugged well to be permanently abandoned in the wake of the BP Macondo incident. Coiled tubing uses and applications are being expanded daily as operators look for ways to save rig time, and service companies' look to increase their range of services and increase the demand for their product. Service companies have begun running perforating guns on coiled tubing, which can enable higher zones to be brought into production without the added downtime of pulling and re-running production tubing. Many times, these wells must be perforated on tubing due to an underbalance leaving coiled tubing the most viable option.

Similar to the need to run formation logging tools on coil tubing during drilling operations, production log equipment is run on coiled tubing increasing as the number of the number of horizontal wells increase pushing far beyond the limits of wireline tractors. Schlumberger has even performed well tests using coiled tubing. Using this technology, operators can quickly and effectively perform a short well test to determine the initial skin. This abbreviated program can give them valuable insight when planning the best form of field development and can be done on land where the costs are relatively small or offshore where costs are high.

2.3. Rigless Deep-Water Applications

For land operations, one of the appeals of coiled tubing has always been that it does not require a rig to perform operations on the well. The opposite is true for offshore applications where a rig is required for any work. However, some operators have been pushing coiled tubing to its limits doing work off of intervention vessels, or even work boats. For wells with horizontal subsea trees, an intervention vessel will be used and instead of running a full-bore BOP stack on riser, a reduced bore (6 to 7 inch) BOP will be run without casing merely on a landing string. This is much quicker and provides a platform for medium to light intervention using coiled tubing. Many of these vessels do not have drilling capabilities and as such receive a reduced day rate. Coiled tubing has also been deployed from work boats with subsea injector heads, which can be done on wells with vertical subsea trees and is a very quick and efficient method for light workovers such as pumping acid. Ocean engineering advertises that they have the capability to perform rigless stimulation using coiled tubing deployed from a work boat in depths up to 10,000 feet.

We can list some current rigless coiled tubing applications as follows.

The Allegretti et al. [6] discusses a methodology for performing a challenging rigless fishing job to restore production in wells with limited accessibility. By combining conventional fishing tools with a coiled tubing (CT) anchor and electrical line (EL) cutting tools, the fishing operation successfully recovered a significant portion of the stuck CT pipe, leaving only a small section remaining. The innovative approach reduced the need for a costly rig operation and prepared the well for a simpler workover activity.

Dornan et al. [7] discusses the installation and application of the Access ESP system, also known as a rigless ESP system, in a well with a history of sand and solids production. The paper focuses on the retrieval and replacement of the rigless ESP through live well intervention using slickline and coiled tubing units for cleanout operations. The use of the rigless ESP system provides significant benefits, particularly for wells requiring frequent interventions, high rig costs, or limited rig availability. The paper confirms the feasibility of accessing the lower completion and performing well work interventions using the rigless ESP system.

3. Coiled Tubing Dimensions and Specifications

Coiled tubing is a long, thin pipe that is wound onto a large reel. It is typically made of steel or aluminum and can range in diameter from 1/8 inch to 2 inches. The length of coiled tubing can vary, but it is typically between 5,000 and 15,000 feet. Coiled tubing is used in a variety of applications, such as drilling, well maintenance, and completion operations. It is also used in the oil and gas industry for well intervention, including stimulation, sand control, and logging. Coiled tubing is typically manufactured to industry standards such as API 5CT [8] and API 5B [9]. These standards specify the material, wall thickness, and tensile strength of the tubing. The typical weight per foot of coiled tubing is around 1.5-2.5 lb./ft.

Coiled tubing is used in drilling operations to provide a flexible and cost-effective alternative to traditional drilling methods. It is also used in well intervention operations to perform tasks such as stimulation, sand control, and logging. Coiled tubing is inserted into the well and can be used to perform multiple operations, including drilling, fishing, and milling. Coiled tubing is also used in completion operations to provide a cost-effective alternative to traditional completion methods. It is used to run completion strings, such as sand screens and inflow control devices, into the well. It can also be used to run wireline logging tools [5] and other instruments into the well. Coiled tubing is also used in well maintenance operations to perform tasks such as acidizing, fracturing, and cleaning the wellbore. It is also used to run wireline logging tools and other instruments into the well. Coiled tubing is generally constructed of alloy steel, carbon steel, and aluminum. The tubing is typically coated with a corrosion-resistant material to prevent rust and other forms of corrosion. The tubing is also typically coated with a lubricant to reduce friction and wear during operations. Coiled tubing is typically transported to the well site on a large reel. The reel is mounted on a truck or trailer and transported to the well site. The tubing is then uncoiled from the reel and inserted into the well. Coiled tubing operations are typically performed by specialized service companies that have the equipment and personnel to perform the operations safely and efficiently. These companies generally have a fleet of coiled tubing units, which are specially designed trucks or trailers that are equipped with the necessary equipment to perform coiled tubing operations.

Overall, Coiled tubing is a versatile and cost-effective tool that is used in a variety of drilling, completion, and well maintenance operations in the oil and gas industry. It is typically made of steel or aluminum and can range in diameter from 1/8 inch to 2 inches, with a typical length of 5,000 to 15,000 feet. It is manufactured to industry standards and transported to the well site on a large reel, then uncoiled and inserted.

4. Downhole Equipment (BHA's) of Coiled Tubing

Coiled Tubing Operations can have simple or complex tools for the Bottom Hole Assembly (BHA). The tools vary depending on the operation, Drilling, Perforating, Logging, Completions, Fishing, Production, etc. In general, tools can include Connectors, Release Tools, Centralizers, Nozzles, Impact Tools, Under reamers, Retrieving Tools, Valves, and Packers.

4.1. Connectors

Also known as the Tubing End Connectors (TEC) are used connect various tools with the end of the Coiled Tubing. There are various connectors, which may be used at CT operations. A few examples of common connector types can be seen in the Figure below and include a grapple connector, dimple connector and roll-on connector.

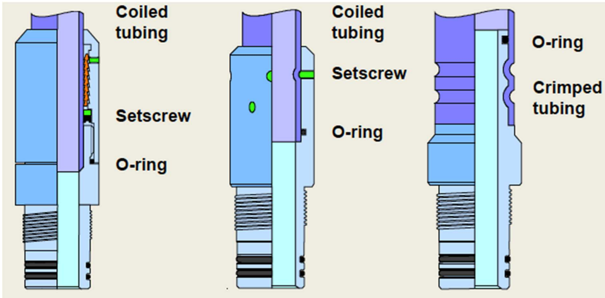

Figure 3. *Grapple connector, Dimple connector, Roll-on connector [10].*

The Grapple Connector is a tool, which is usually used during milling, fishing, or heavy-duty operations. The tool attaches itself on to the coiled tubing by biting on the tubing. The connection gets stronger as the coiled tubing is pulled on which increases the strength of the bite. The number of slots in a grapple connector varies which each company. This tool increases the outer diameter of the CT, which makes it impossible to run it through the injector. The grapple is usually associated with an overshot, which is discussed later in this paper. The Dimple Connector is an internal or external connector, which connects the coiled tubing to the drilling string by sliding inside the coiled tubing. This tool has larger through bore than the standard Roll-on Connectors. These tools can withstand tension or torque and are used in high-vibration and impact applications. The Roll-on Connector is a tool with threads on the end, which connects the CT with a tool string and is generally used to connect the CT with smaller tool strings. This tool is commonly used in non-torsional, non-vibrational and non-jarring operations.

4.2. Release Joints

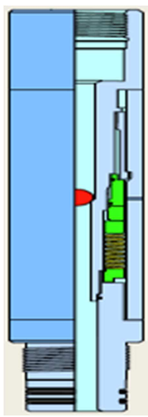

Figure 4. *Release joint [10].*

CT release joints are tools, which are used to easily separate the coiled tubing from the rest of the tool string. These tools allow easy connection and disconnection of the CT. The release joints are available as; Pressure-activated release joint, Tension-activated Release Joint, and a combination of both types.

4.3. Centralizers

These tools are used in CT when there are centralization problems within the well-bore. These tools provide centralization and stability while the operations are progressing. There are three popular types of centralizers (seen in the figure below): Fluted Centralizer, Flow activated Bow Spring Centralizer and Slip over Centralizer.

Figure 5. *Fluted centralizer, Flow act. spring centralizer, Slip-over centralizer [11].*

4.4. Nozzles and Jetting Subs

These tools are placed at the downhole end of the Coiled Tubing BHA. The sizes and the positions of the nozzle port vary depending on the desired jetting action. There are two types of jetting subs: Circulating Subs and Jetting Subs. Circulating subs are tools that help circulate fluids without jetting. These tools require large port area, and the port area may be either several small ports, which will help increase the turbulence or a few large ports may be used with little pressure drop across nozzle. Jetting Subs are tools used when jetting is required during a CT operation. The Sub requires a small port area, which is composed of several smaller ports for the jetting action.

4.5. Impact Tools

These tools are used in conditions such as high temperature, high pressure, or where corrosive fluids would significantly reduce the life cycle of a regular drilling or workover tool. Impact tools are preferred in these conditions because they can reliably perform. The impact tools have advantages such as not operating until they contact resistance and operating at high temperatures.

4.6. Under Reamers

These tools are designed to pass through restrictions downhole, or to open up and clean out the restriction to full hole size. These restrictions are the remainder of tools left from production, completion accessories and mostly cement from perforations.

4.7. Retrieving Tools

Retrieving tools, as seen in the figure below, are tools used to retrieve or "fish" lost tools and components in the wellbore. In many CT operations, it is recommended that releasable overshot are used. The releasable overshot operate while allowing fluid circulation, they come with the bowl/ grapple assembly and contain a catch and release mechanism.

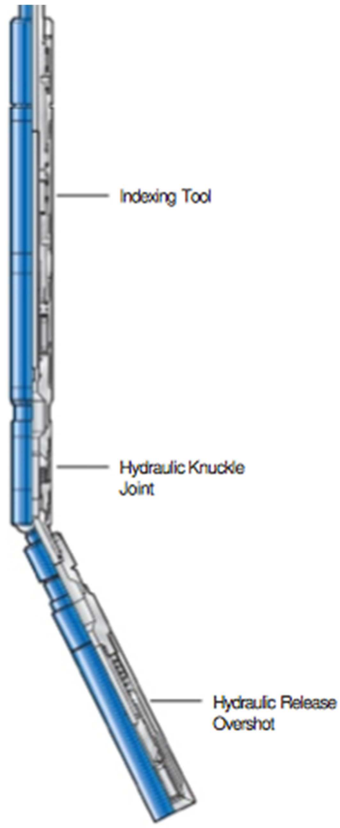

Figure 6. *Retrieving tool [12].*

4.8. Check Valves

Valves important parts of CT tools string because they help control flow. Several types include Check valves, flapper check valves, and ball/seat check valves. These valves are attached to the CT connector at the end of the CT string to help prevent backflow of the formations fluids to maintain a secure and stable well. Valves are used in most CT operations but may be excluded when reverse flow is required. A flapper check valve and ball/seat check valve can be seen in the figure below.

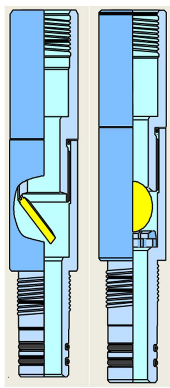

Figure 7. *Flapper check valve assembly, Ball and seat check valve [10].*

4.9. Packers/Plugs

Packers or plugs run on CT are easy to operate and can be permanent-set (drillable) or multiple set/release tools. The latter is easily released by a mechanism actuated from the surface. These tools are short and compact and contain an adjustable emergency shear release option.

5. Coiled Tubing Reels

Coiled Tubing (CT) has been defined as any continuously milled tubular product manufactured in lengths that require spooling onto a take-up reel, during the primary milling or manufacturing process. The tube is nominally straightened prior to being inserted into the wellbore and is recoiled for spooling back onto the reel. Tubing diameter normally ranges from 0.75″ to 4″, and single reel tubing lengths in excess of 30,000 ft have been commercially manufactured. Common coiled tubing steels have yield strengths ranging from 55,000 psi to 120,000 psi. A coiled tubing unit is comprised of a complete set of equipment to perform standard continuous-length operations in the field. The unit consists of four basic elements: reel, injector head, control cabin and power pack. Reel, for storage and transport of the coiled tubing; Injector Head, to provide the surface drive force to run and retrieve the coiled tubing; Control cabin, from which the equipment operator monitors and controls the coiled tubing; and the power pack- To generate hydraulic and pneumatic power required to operate the coiled tubing unit.

Coiled tubing reels are designed to optimize tubing capacity in the smallest possible envelope dimensions. With today's demands for longer, heavier, and larger diameter tubing, a full range of reels are supplied and built to fit different applications. Coiled tubing sizes range from 1.25 to 2.375 in, working pressure up to 15,000 psi and tubing capacity of up to 25,000 ft. Example of a coiled tubing can be seen in the figure below.

Figure 8. *Coiled tubing reel, 22,000 ft. to 2 inches [13].*

6. Importance of Coiled Tubing Cycles

In order to analyze the effect of cycling coiled tubing, it is necessary to do an analysis of the fatigue of the tubing. The fatigue analysis considers the geometry of the coiled tubing, material properties, and the equipment used. In addition, corrosion, stress concentrations, and statistical reliability of the empirical data are also considered. Coiled tubing goes through several plastic deformation cycles through its usage in and out of wells. The first deformation cycle takes place as the coiled tubing leaves the reel, where the coiled tubing is deformed from being bent to being straight. Next are two cycles of deformation while going through the gooseneck, straight to bent and bent to straight. These cycles are experienced both ways, i e., when going into the well and when pulling out of the well. Thus, the total number of cycles of plastic deformation will be six.

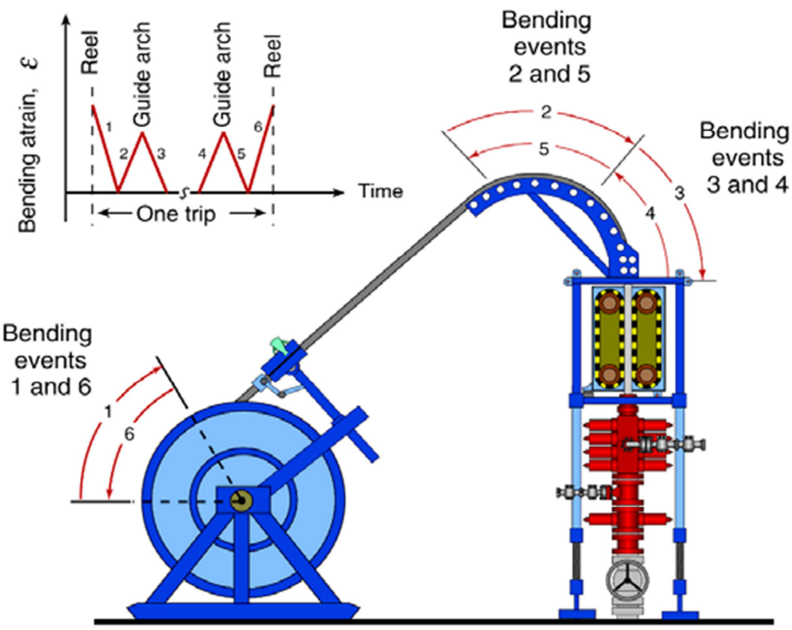

Figure 9. *Coiled tubing deformation cycles [15].*

During a coiled tubing job, the coiled tubing is further cycled by the operators, when performing a pull test, for example. But some of these may work part of the coiled tubing over the gooseneck only and other parts that may have left the reel would go back on the reel but do not reach the gooseneck. Thus, to have an accurate record of the cycles, knowledge of the distance between the reel and the gooseneck is required. The above is only concerned with plastic deformation of the coiled tubing due to axial loading and unloading. The axial forces impose axial stresses that are in excess of the material minimum yield stress. However, the main concern is total stress and not just axial stress. Thus, internal pressure, corrosion, and stress concentration due to welds and/or presence of H_2S sour gas all become pertinent. A special technique is utilized to account for each of these effects. The internal pressure will change the hoop and radial stresses, and these can be simply calculated and thus the total stress computed accordingly.

Corrosion and stress concentrations are more difficult to account for. Corrosion will normally reduce the wall thickness of the coiled tubing, and yet we do not have an exact measure of how much wall thickness is lost and until such measures become known, we have to make some assumptions to account for the loss of wall thickness. Clearly, the wall loss will reduce the coiled tubing cross- sectional area thus increasing the stresses due to the same load being applied. Commercial software is available to account for coiled tubing fatigue, one of the most popular is FACT by MEDCO [14].

7. Conclusion

Coiled tubing technology is a powerful tool that provides many benefits for the oil and gas industry. Its compact size and flexibility make it an ideal solution for a range of applications, from drilling and completion to rigless deep-water operations. This versatility is further enhanced by the wide range of dimensions and specifications available for coiled tubing, allowing it to be customized to meet the specific needs of different projects.

The use of coiled tubing is accompanied by specialized downhole equipment, which plays a critical role in ensuring the safe and effective operation of the technology. The coiled tubing reels themselves are also an important component of the system, providing a convenient and efficient way to store and transport the tubing. Another key factor that must be considered when using coiled tubing technology is the importance of coiled tubing cycles. This refers to the repeated deployment and retrieval of the tubing, which is a crucial part of the process. The efficiency and effectiveness of these cycles can have a significant impact on the overall success of the project and must be carefully considered when making decisions about the use of coiled tubing. While coiled tubing technology offers many benefits, it is not without its limitations. Factors such as safety, cost, and the limitations of the technology itself must be taken into account when deciding whether to use coiled tubing for a specific project. Despite these challenges, however, coiled tubing remains an important and valuable tool in the oil and gas industry and is likely to continue to play a significant role in the years to come.

In conclusion, coiled tubing technology is a versatile and powerful tool that offers many benefits for the oil and gas industry. From its wide range of applications and dimensions to its specialized downhole equipment and the importance of coiled tubing cycles, coiled tubing continues to be an area of active research and development, with ongoing efforts aimed at improving its capabilities and expanding its range of applications.

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