Coiled Tubing

Learning Objectives

- You will learn about types of coiled tubing rigs.
- You will learn best practices and techniques for conducting coiled tubing operations.
- You will learn the types of components for CT rigs, the tubing, strippers, rams, power packs, tools, controls, BOPs, and shear seal rams.
- You will learn how to handle common problems confronting coiled tubing operators.
Coiled Tubing

Overview

- The use of long lengths of small diameter pipe allows wells to be worked over economically.
- Lengths are coiled onto large reels for moving, storage, and work.
- CT units can rig up/down in a fraction of the time of conventional or workover units of similar capability.
- CT units can perform most operations required in normal workover and completion operations.
- CT units can work on live wells.
Full Bore Two-Way Valve

- New development of master valves subsea completions has led to the development of a full bore two-way sealing master valve.

- How are full bore two-way sealing valves used in workovers, completions, wireline, coiled tubing and snubbing? What advantages do they provide for the operator?

- They hold pressure from both directions. No need to install back pressure valves to pressure test the BOP stack in coiled tubing and snubbing.
Coiled Tubing Applications

- Coiled tubing had few applications when first introduced because of tubing limits.
- Tubing improvements and innovations in downhole tools have greatly enhanced coiled tubing applications and services.
  - Washing Sand and/or Fill
  - Tubing Scale Removal
  - Remedial Cementing
  - Thru-Tubing Fishing
Washing Sand and/or Fill

Packer
Casing
Tubing
Coiled Tubing
Thru-Tubing Fishing

- Shock Absorber
- Accelerator
- Jar
- Fishing Tool
Coiled Tubing

- Services include initiating well flow, pipeline and flowline cleaning, gas lift equipment services, shifting of sliding sleeves, BHP/BHT surveys, and services done by wireline. Other services include:
  - Setting Inflatable Packers
  - Drilling Composite Plugs
  - Setting/Retrieving Bridge Plugs
  - Reservoir Stimulation
Setting Inflatables

- Thru tubing straddlepack pack-off
Drilling Composite Plugs

- Drill Collars
- PDM
- PDC Drill Bit
- Bridge Plug
W I L D  W E L L  C O N T R O L

Bridge Plug

Setting Tool

Coil Tubing

Setting/Retrieving Bridge Plugs

Bridge Plug
Tubing
Packer
Casing
Coil Tubing
Acidizing Head
Coiled Tubing

Other Applications for coiled tubing:

- Siphon String Installation
- Coiled Tubing Completions
- Frac Packs
- Coiled Tubing Conveyed

Formation
- Drilling Data Acquisition
- Coiled Tubing Perforating
Coiled Tubing Installed as a Siphon String

- Packer
- Casing
- Tubing

Siphon String Installation
Coiled Tubing Completions

- Spoolable Completions

Tubing
Casing
Coil Tubing
Inflatable Packer
Frac Packs

- Diagram shows flowback to cleanup after a frac job.

Gravel Pack
Screen Liner
Stiff Wireline hidden inside Coil Tubing

Stiff Wireline BPV

TRT

Perforating Guns

Sump Packer
What the Coiled Tubing Can Do!

- Kill a well by forward circulation.
- Pump nitrogen to bring well in.
- Clean out sand.
- Stiff wireline sets bridge plugs or perforates.
- Run DST’s or production tests.
- Set straddle packers.
- Multiple trips in and out of well.
- Perform work without killing the well.
- Run spoolable completions.
- Run wireline operations: logs, surveys, etc.
- Dump or squeeze cement slurry
- Carry out drilling/milling operations.
Coiled Tubing Injection Head
Coiled Tubing Injection Head
Coiled Tubing Injector Chains

- Linear Beams
- Hydraulic Cylinders
- Roller Chain
- Gripper Chain
Unsupported Column Length

Coiled Tubing Buckling
Anti-Buckling Guide
Radius of tubing guide arch should be at least thirty times the specified OD of the coiled tubing.
Coiled Tubing Services Reel

- The Core radius should be at least twenty (20) times the specified coiled tubing diameter. The service reel, left photo, has a hydraulic swivel on front side; on rear side, some service reels have an electric swivel used with stiff wireline operations.
Coiled Tubing Services Reel

- Flange Diameter
- Core Diameter
- Turbine Counter
- Level Wind Assembly
- Drive System
- Reel Drive Motor
- Reel Brake
- Core Diameter
- Turbine Counter
- Level Wind Assembly
- Drive System
- Reel Drive Motor
- Reel Brake

Side View

Front View
Fluid Swivel and High Pressure Connection
Coiled Tubing Damage, Fatigue, Failure

Tubing degradation occurs when:

- **Corrosive fluids**, acids, are circulated through the tubing, or when the string is in a corrosive environment such as $\text{H}_2\text{S}$ or $\text{CO}_2$.
- **Abrasive fluids**, cement slurry or sand-laden fluid will erode the tubing on surface contact both inside and outside, and shorten its working life.
- **Tension** is the major stress factor once the coiled tubing is in the well.
- **Buckling** of CT strings occurs in highly deviated or horizontal wellbores.
Tension is the major stress factor once the coiled tubing is in the well.

- **Tension** is the major stress factor once the coiled tubing is in the well.
  - Tension, or hanging weight, occurs from the point of suspension, the chains, to the bottom of the string.
  - The tension load is affected by:
    - Hole angle.
    - Buoyancy of the fluid into which the tubing is run.
    - External versus internal pressures.
    - Wellbore obstructions, stuck pipe, and drag.

- If tension load exceeds tensile strength of tubing, pipe will part, usually just below the injector, where the greatest tension load occurs.
- Excessive tension contributes greatly to a decrease in collapse resistance.
Coiled Tubing Damage, Fatigue, Failure

- **Tubing degradation** includes buckling.
- **Buckling** of CT strings occur in highly deviated or horizontal wellbores.
  - String buckling starts when the natural radius of curvature is exceeded while the string is run in the hole.
  - The radius of curvature is the natural string bend from being stored on a reel.
  - In most coiled tubing sizes the radius of curvature is around 24 feet.
  - With the string in tension the radius of curvature disappears as the string straightens.
  - Completely relaxed tension loads allows the radius of curvature to be seen.
  - With the lower part of the string in compression, as in a deviated or horizontal well, the radius of curvature can be exceeded and the string gives way to buckling.
Coiled Tubing Failures

Field Coiled Tubing Failures 1994 - 1997

- Corrosion
- Field/Rig Damage
- Mfg Problem
- Wear
- Field Weld
- Temp
Coiled Tubing Failures

Sinusoidal Buckling of Coiled Tubing

- The force required to push the tubing string into a deviated or horizontal well increases with the length of tubing introduced into the deviated section.
- When the force reaches a certain level the tubing string will “snap” into a **sinusoidal** configuration.
- The period and amplitude of the wave is dependent on the dimensions of the coiled tubing and the tubing into which it is being run.
Helical Buckling of Coiled Tubing

- Increased length of tubing in the well leads to helical buckling.
- Once helical buckling takes place helical “lockup” is a real possibility.
- Helical lockup is where frictional forces by contact between the tubing ID and the coiled tubing OD exceed the pushing force.
- Now it is no longer possible to force any more coiled tubing into the deviated section of the well.
- More tubing can be further in at the surface resulting in a longer buckled section causing permanent damage or failure of the coiled tubing.
Coiled Tubing Failures

- Sinusoidal Buckling
- Helical Buckling
Coiled Tubing Failures

- **Ovality** is the degree to which the tubing is "out of round."
  - The percentage of ovality can be determined by taking random measurements of the tubing and performing the following simple equation:
    
    \[
    \text{% Ovality} = \frac{(\text{Max OD} - \text{Min OD})}{\text{Design OD}}
    \]
  
  - Using a machinist’s caliper, measure the maximum and minimum diameter and plug the values the formula with the design diameter.
  
  - The results yield a percentage of ovality. The smaller the percent ovality the better.
  
  - A small degree in ovality can mean a decrease in performance and collapse.
Coiled Tubing Failures

- **Notes on Ovality**
  - The easy place to measure is at the end of the tubing reel.
  - If the tubing end is OK, there’s no guarantee the entire reel is OK.
  - Coiled tubing manufacturers never guarantee round tubing due to:
    - The extreme stress the steel is subjected to during manufacturing.
    - The steel is initially in a flat state, shaped into a circle and welded to form the tubing, and lastly, is spooled onto a reel.
  - Stressing the steel in three dimensions will result in a reel of tubing that is not perfectly round in diameter.
  - Many assume that coiled tubing has at least a 5% ovality factor.
Coiled Tubing Failures

- Injector Gripping Forces
  - The *injector* damages CT when it grips and manipulates the CT.
  - Two opposing continuous chains with single links have gripper blocks.
  - The gripper diameters are sized per the coiled tubing used.
  - The gripping force, or chain tension is adjustable.
Coiled Tubing Failures

- Excessive forces in deep wells with severe hanging loads or misaligned chain blocks will cause pipe scaring and will greatly reduce the working life of the string.
- Hanging-off of the coiled tubing is done by means of slip rams.
- Slip rams have two opposing pieces that make contact with the pipe.
- Pipe scarring takes place when hanging-off. This promotes corrosion, and also weakens the pipe and shortens its effective life.
Coiled Tubing Failures

- Three types of **Cracks** occur in a string of coiled tubing.
  - They are first noticed as pinholes in the tubing string.
  - Without immediate attention they can develop into cracks that will lead to failure of the string.
  - The three kinds of cracks are shown in this illustration:
Coiled Tubing Failures

- **Pitting** of the tubing is usually associated with localized corrosion which can occur both internally and externally.
  - External pitting is caused by direct contact with corrosive wellbore or treatment fluids, atmospheric corrosion or can be a combination of both.
Coiled Tubing Failures

- Internal pitting is directly related to contact with improperly inhibited treatment fluids or failure to flush the coiled tubing following the use of a corrosive fluid.
- The weld bead is an electrolytic corrosive metallic cell.
Coiled Tubing Failures

- Slip Marks
- Injector Chain (repeating marks)
- Internal Weld Bead
- External Weld Bead
- Transverse Crack
- Longitudinal Crack
- Angled Crack

Wild Well Control
Damage because of the bending cycle
Bending Events During Coiled Tubing Operations

One Trip in/out

Bending Events 1 & 6

Bending Events 2 & 5

Bending Events 2 & 5
Pitting & Tensile Overloading Produce MOST Of The Coiled Tubing Failures

- Fatigue: 13
- Pitting: 26
- Corrosion: 8
- H2S Stress: 13
- Tension: 24
- Hel. Buck.: 5
- Mech. Damage: 3
- Welds: 8
• Abrasion decreases wall thickness and string performance.
  ▪ Round dents have little effect on string strength; but sharp scratches and gouges cause string corrosion.
  ▪ Localized abrasions are from direct contact with wellbore tubulars and associated with sinusoidal or helical buckling.
Coiled Tubing Failures

- Longitudinal scratches are the result of contact with sharp edges in the wellbore, BOPs, or the coiled tubing handling and spooling equipment.
Coiled Tubing Failures

- Other sources of damage:
  - Careless handling and inadequate maintenance.
  - Operations that present hazards to the tubing:
    - Spooling and unspooling.
    - Loading and offloading.
    - Handling on location.
  - A coiled tubing string allowed to become encrusted with rust will surely fail before one which is better maintained.
Coiled Tubing Failures

- **Balooning** and **necking** cause problems with handling equipment in the injector and chains, and with the pressure control equipment such as the stripper and BOPs.
  - Additionally, tubing performance (especially tensile and collapse) and tubing life can be affected.
Coiled Tubing Failures

- **Necking** is due to over-stressing a section of the string via tension loading.
- **Ballooning** results from cycling the tubing under pressure.
Strippers are primary barriers to wellhead pressure.

- The packing stack must be accessed from above.
- The energizing stripper applies pressure to lower bushing and compresses packing in an upward direction. Energizing stripper is called “packing.”
- When packed, wellbore pressure assists closing.
- Availability: 5M and 10M psi. WP
The Tandem Stripper is used in conjunction with a stripper as a backup in case of wear or failure.
Conventional Packing Arrangement

- Inserts may be urethane, nitrile, or viton elastomer depending on service requirements.
- Split inserts are replaceable with coiled tubing in place.
- Designs have three components:
  - Energizer
  - Packer insert
  - Non-extrusion ring
• The Side Door Stripper provides easier access to the packing element through the side door.
  ▪ Eliminates accessing the stripper from above.
  ▪ The side door stripper is available in two models.
Coiled Tubing Side Door Strippers

- Hydraulic Cylinder
- Securing Flange for Injector Head
- Body Side Door
- Locking Bolt
- Locking Doors
- Annulus Ports
- Body Side Door Quick Union

Unit w/ Doors Closed

Unit w/ One Door Open

Unit w/ Both Doors Open
Cylinder Sleeve Exposed

Unit w/ Piston at Top of Stroke - One Packing in Place & Coil Tubing

Cylinder Sleeve
Packing
M Seals
Lower Bushing
Tubing
Coil
Coiled Tubing - Radial Stripper

- Single piece body has few leak paths.
- Packer is accessible from the side.
- Packing elements fully retracted to clear oversized or upset tools
- Actuated radially.
- Stripper height is reduced.
Coiled Tubing Over-Under Tandem Stripper

• Industry recommends the use of a tandem stripper packer because it has two packing elements that can be activated individually.

• The life of the sealing elements is extended.
Coiled Tubing - Quad BOP

- BOP’s are “secondary” barriers in coiled tubing operations.
- Quad BOPs are arranged in this order (API RP 5C7) starting from top: blind ram, shear ram, slip ram then pipe ram.
Coiled Tubing - Quad BOP

- Equalizing ports are used to avoid opening blind rams or pipe rams under differential pressure.
- Rams are not designed to close when tubing is moving. The kill port allows pumping down annulus or down tubing after shearing.
“Combi” BOP’s have two main advantages over single function BOPs: less height and fewer steps for emergency shut-in procedures.

Most combination rams are designed to have wellbore pressure assist. They should not be opened until differential pressure is equalized.
Kill Port

- BOPs have a 2” OD kill nipple between the slip rams and shear rams.
- This enables the kill fluid to be pumped down the sheared tubing during emergency operations (and when pressure testing).
- Never use the kill port as a circulation line.
Shear/seal rams are “tertiary” barriers provide emergency shearing capability.

The shear blades are designed for minimum deformation to the tubing so kill fluid can be pumped through the suspended coiled tubing after the cut.

“Shear/Seal” BOP
BOP Closing and Equalizing Components

- The hydraulic actuator is used to open and close the rams.
- The hand wheel can be used to close only and also serves as ram lock.
- The weep hole and vent are used for detection and prevention of communication between the wellbore and hydraulic system.
BOP Closing and Equalizing Components

- The ram position indicator provides a visual indication of ram travel and position.
- An equalizing valve, left, is used to balance pressure across closed pipe, blind or combi rams before opening. The equalizing valve must be left in closed position during normal operations.
Quad BOP Ram Assemblies

- Shear rams are used to cut the coiled tubing in emergency situations, and serve as a “tertiary” barrier.
- The shear ram blades minimize tubing deformation – this allows an opening to pump kill fluids.
Quad BOP Ram Assemblies

- The blades are “case hardened” with softer inner cores to resist sulfide stress cracking.
- Blind rams seal the wellbore when no tubing is across them.
- Blind rams must be equalized before opening.
Quad BOP Ram Assemblies

- Slip rams used to close and hold tubing in place, are “bi-directional.”
- Slips hold coiled tubing in place against upward and downward forces.
- Replaceable slip inserts are machined to fit one size tubing only. Pipe rams seal around tubing.
- Pipe rams are wellbore pressure assisted.
- Pressure across them must be equalized before opening.
Combi BOP Ram Assembles

- Shear/seal rams are designed to cut tubing and seal the wellbore following the shear.
- Rams should be used only when it is not necessary for tubing to fall after cutting.
- They must be equalized before opening.
Combi BOP Ram Assemblies

- Pipe/slip Rams are used to seal the wellbore and to secure the tubing in place.
- Rams are wellbore pressure assisted.
- Pressure across them must be equalized before opening.
Power Pack

- Power pack supplies the hydraulic fluid to operate the coiled tubing unit including the injector and the BOPs.
  - Power packs include a diesel engine to power hydraulic pumps.
  - The system is regulated to a maximum pressure based on the job and wellhead pressure.
Power Pack

• Accumulators to power BOPs installed on the control cabin skid, used if a hydraulic power failure or if hydraulic fluid is not enough to run the BOPs.
• Accumulator contains a useable volume greater than is required to fully operate the BOPs and all associated valves.
Power Pack Marine Design
Coiled Tubing Control Console

- The control cab contains the control console which regulates every function of the coiled tubing unit.
Coiled Tubing Control Console

- The cab is lined up behind reel, in line with the wellhead. Some control cabs mounted on a hydraulic scissor lift so operator has clear view of the wellhead.
- It is advisable/mandatory that an ESD valve be installed in the control cab in case of emergency.
Coiled Tubing Console Control

- Well Control Stack Pressure Control
- Strippre Pressure Gauge
- Injector Pressure Control
- Reel Pressure Control
- Stripper Pressure Control
- Injector Hydraulic Pressure
- Reel Hydraulic Pressure
- Injector Speed (Hi – Lo)
- Injector Chain Traction Pressure
- Pumped Fluid Circulation Pressure
- Well Control Stag Ram Valves
- Injector Control
- Load Indicator
- Emg. Kill Switches
- Reel Controls
- Engine Throttle
- Wellhead Pressure
Coiled Tubing Hydraulic Controls

- Stripper systems are usually dual acting.
- Able to “pack” and “retract” hydraulically.
- Stripper hydraulic system pressure should be compatible with rating of stripper. Most capable of 5000 psi.
- All items MUST be Function tested after initial installation to ensure the correct connections made.
Coiled Tubing Hydraulic Controls

BOP systems usually require at least two (2) controls be shifted to actuate a ram to prevent accidental operation.

Hydraulic systems are equipped with an accumulator to allow several BOP operations without benefit of CTU power pack.
Coiled Tubing Grapple Connector

Coiled Tubing

Set Screw

Grapple

O-Ring
Coiled Tubing C.A.R.S.A.C.

• The combination anti-rotation self aligning connector (C.A.R.S.A.C.) is designed to assist with the tubing “make-up” where it is difficult to rotate the tools to engage threads.

• This tools allows a high degree of torque to be transmitted through it. This is achieved by the combination of a locking taper (which permits easy stabbing) and a self aligning anti-rotation connector.
The roll on connector is attached to the inside diameter of the coiled tubing being held in place by crimping the coiled tubing around the profile of the connector by a special crimping tool.

Pressure sealing is accomplished via the o-ring. This connector contributes to higher circulating pressures due to the internal restriction.
The **ball and seat check valve** is designed to allow pumping to be accomplished past the ball but prevents flow up the coiled tubing.
The flapper type check valve allows for pumping through the string of coiled tubing but disallows back flow through the tubing.

- Results in lower pump pressures due to the greater useable diameter of the flapper check.
- The flapper valve is the preferred type of BPV for CT operators.
Jetting and Circulating Subs

- Jetting subs and nozzles come in many designs and sizes based on the job at hand.
- Where return volume is the main concern, use a large port sub as shown in the top and middle diagrams.
- If turbulence at the sub is needed, the lower sub would be used.
The **release joint** allows the coiled tubing to be disengaged from the bottom hole assembly. The types of release subs are:

- Pressure activated
- Tension activated
- Combination pressure/tension

The pressure activated sub uses a ball pumped through the string and lands in the sub to seal.
Jetting and Circulating Subs

- Pump pressure then overcomes the friction bite of a collet and the string becomes free.
- The tension activated release joint relies on shear pins which must be failed for the string to become free of the bottom hole assembly.
- A fishing neck “looking up” allows the string to be reconnected with the appropriate fishing tool.
Horizontal Cable Installation

Requirements:
• Long Straight Location
• Wireline Unit
• Coiled Tubing Unit
• Pumping Equipment
Stiff Wire Line for Coil Tubing

- Wireline
- Pressure Bulkhead
- Electric Line to Collector on other CT axle
- Wire Line Collector
- CT Reel Isolation Valve
- CT to Inner Wrap on Reel
- CT Reel Rotating Swivel
- Reel Axle
CT - Vertical Cable Installation

Requirements:
- Cool Well
- Wireline Unit
- CT Unit
Coiled Tubing – Bottom Hole Connector

- CT Connector
- Coiled Tubing
- Swivel
- Cable Clamp
- Electrical & Pressure Bulkhead
- Flow Check Valve
- PEH-E
- PEH-A
- PEH-AB Head
- Standard Rope Socket Config.
Stiff Wireline Perforating

• The perforating gun is run below the packer with the coiled tubing.
Stiff Wireline Perforating

- Locates the interval to be perforated.
Stiff Wireline Perforating

- Gun is fired by electrical current.
Stiff Wireline Perforating

- Well bore is charged from the perforations by 5000 psi formation pressure.
Stiff Wireline Perforating

- Pressure from the formation returns and travels downwards and upwards.
Stiff Wireline Perforating

- Forces then rebound.
- Now calculate the force underneath the packer.
Stiff Wireline Perforating

Force = (ID, ins)^2 x 0.7854 x Pressure, psi

= (6.25)^2 x 0.7854 x 5,000

= 153,398 pounds force

Plus 50,000 pounds shock force (from firing perforating tool)

Total Force = 153,398 + 50,000 = 203,398 lbs
Stiff Wireline Perforating

- Force travels up:
  - Corkscrews tailpipe
  - Bursts casing at packer seal
Stiff Wireline Perforating

- Tubing is:
  - Corkscrewed
  - Packer is unseated, and blown up hole
Coiled Tubing Drilling

CT Unit on Location and Drilling Ahead
Coiled Tubing Drilling BOP Stack
The Titan Downhole CT Motor:

- Motor designed in response to current limitations found in CT motors.
- Rugged motor with very high performance. Motor has non-roller/ non-ball, lubricated bearing pack.
- Titan motor allows for very high jar loading. No traditional bearings to damage by impact.
- Strength enhancements in the drive shaft. Allows for greater side loading at the bit box.
Coiled Tubing PDC Bits and Mills

PDC Bits and Mills
Coiled Tubing Mill and PDC Bit

Mill and PDC Bit
Coiled Tubing Dual Circulation Sub

- The CT dual circulation sub provides a way to circulate the annulus when activated.
- The sub also has a rupture disc included.
- This sub may be used if no other way to circulate can be found.
Fishing Tools

Flow Activated HD Running/Pulling Tool

GS Type Pulling/Retrieving Tool With J-mechanism
Fishing Tools

Overshot

Spear
Shifting Tool

Shown activated >>
Fishing Tools

Accelerators

Jars
Wireline Guide for Coiled Tubing

- WL Guide For 1.25"
- Upper Interference Seal Ass.
- Slip & Bowl Assembly
- Lower Interference Seal Assy.
- Valve Removal Plug Preparation

- Slip Actuation Pin
- ½” NPT Grease Injection Port
- ½” Hyd. Injection Port
- ½” NPT Monitor or Chemical Injection Port
Coiled Tubing Tubing-Hanger
Coiled Tubing Packoff Installed
CT Gas Lift Installation

- 7-5/8” Casing
- 2-7/8” Tubing
- 1” OD Gas Lift Valves
- Coiled Tubing
- Landing Nipple
Spoolable-Completion Extension

- 7-5/8” Casing
- 2-7/8” Tubing
- Safety Valve
- Hanger Packer
- 1” OD Gas Lift Valves
- Coiled Tubing
- Landing Nipple
- Lower Sand
CT Gas Lift Mandrel with Connectors
Coiled Tubing Choke Manifold
Coiled Tubing Choke Manifold
Coiled Tubing

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