

Recommended Practice for Coiled Tubing Operations in Oil and Gas Well Services

API RECOMMENDED PRACTICE 5C7
FIRST EDITION, DECEMBER 1996

REAFFIRMED, DECEMBER 2007



AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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Recommended Practice for Coiled Tubing Operations in Oil and Gas Well Services

0 Introduction

This recommended practice is provided to meet the need for design and operating recommendations covering the coiled tubing industry.

Coiled tubing operations and limitations are different in several ways from those for jointed tubing. The primary differences between coiled tubing and jointed tubing are that coiled tubing bends and lacks connections. As with all tubing operations, coiled tubing's effectiveness depends on good job planning and equipment design along with proper pipe handling, maintenance, and storage procedures.

1 Scope

1.1 MATERIAL COVERED

This recommended practice covers coiled tubing and associated equipment (see Figure 1) as well as applications (see 1.3). Coiled tubing sizes are specified by outside diameter (OD) and are currently available in 3/4-inch OD through 3 1/2-inch OD. Materials covered in this recommended practice are high-strength, low-alloy steels with specified yield strengths from 55 thousand pounds per square inch to 90 thousand pounds per square inch. Use of coiled tubing in onshore and offshore operations as well as critical and routine operations are discussed.

1.2 MATERIAL NOT COVERED

Due to the limited scope of this document, not all coiled tubing materials and applications are addressed here. Although some of the information presented could be relevant, alternate materials under development (such as titanium, corrosion resistant alloys and composite materials) are not covered. In addition, the applications listed in 1.4 are outside the scope of this recommended practice.

1.3 APPLICATIONS COVERED

Coiled tubing applications covered in this document are as follows:

- a. Cased hole workovers.
- b. Cased hole drilling.

1.4 APPLICATIONS NOT COVERED

Coiled tubing applications not covered in this document are as follows:

- a. Open hole drillings (balanced or unbalanced).

- b. Open hole workover operations.
- c. Pipelines and flowlines.
- d. Control line.
- e. Capillary tubing.

1.5 DOCUMENT ORGANIZATION

Material presented in this recommended practice is organized into five sections, including these general sections (1 through 4).

Section 5 covers design, care, and handling of coiled tubing as manufactured and prepared for delivery to the purchaser. The current processes of coiled tubing manufacture and high-strength, low-alloy steel materials used are reviewed. Mechanical and performance properties for new coiled tubing are also covered, along with a review of tapered string design and construction. Section 5 concludes with a review of the nondestructive inspection practices and tests commonly employed by coiled tubing manufacturers.

Section 6 addresses the serviceability issues related to performing coiled tubing operations, and offers recommended guidelines for coiled tube maintenance, record keeping, and derating. This includes a discussion of the unique characteristics of coiled tubing, such as fatigue, fatigue derating methods, changes in tube diameter resulting from bending while in service, derated collapse pressures due to ovality, and effects of corrosion and cracking of coiled tubing. This section concludes with a general discussion of the performance of welds in the coiled tubing string.

Section 7 addresses surface and downhole equipment used during coiled tubing operations. Equipment addressed includes coiled tubing injectors, tubing reels, hydraulic power supply (prime mover), tubing guide arches, well control components, riser stacks, high-pressure surface piping, and a review of tubing connectors for attaching tools to the coiled tubing.

Section 8 is a discussion of operational contingencies and suggested guidelines for performing coiled tubing services. Topics covered include pre-job preparation, rig up, entering the well, and potential operating concerns which may be experienced when performing various downhole services.

2 References

2.1 STANDARDS

Unless otherwise specified, the most recent editions or revisions of the following standards, codes, and specifications shall, to the extent specified herein, form a part of this standard.

API

- Spec 5CT *Specification for Casing and Tubing (U.S. Customary Units)*
- Spec 5L *Specification for Line Pipe*
- Spec 6A *Specification for Valves and Wellhead Equipment*
- Spec 6H *Specification for End Closures, Connectors, and Swivels*
- Spec 16A *Specification for Drill Through Equipment*
- Spec 16C *Specification for Choke and Kill Systems*
- RP 16E *Recommended Practice for Design of Control Systems for Drilling Well Control Equipment*
- RP 53 *Recommended Practice for Blowout Prevention Equipment Systems for Drilling Wells, 2nd Edition, May 1984*
- Bul 5C3 *Bulletin on Formulas and Calculations for Casing, Tubing, and Drill Pipe*

ANSI¹

- B1.20.1 *Pipe Threads, General Purpose*
- B3.1.3 *Chemical Plant and Petroleum Refinery Piping*

ASME²

Boiler and Pressure Vessel Code

ASTM³

- A370 *Mechanical Testing of Steel, Steel Products, Annex II—Steel Tubular Products*
- A450 *Standard Specification for General Requirements for Carbon, Ferritic Alloy, and Austenitic Alloy Steel Tubes*
- E18 *Standard Methods of Tests for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*
- E384 *Standard Test Method for Microhardness Testing of Materials*
- E144 *Hardness Conversion for Metals*
- E-94 *Guide for Radiographic Testing*
- E-140-88 *Standard Hardness Conversion Table for Metals*

NACE⁴

- MR-01-75 *Sulfide Stress Cracking Resistant Metallic Materials for Oil Field Equipment*

2.2 OTHER REFERENCES

1. S.M. Wilhelm, "Galvanic Corrosion in Oil and Gas Production, Part 1—Laboratory Studies," *Corrosion*, 1992, Volume 48, Number 8, p. 691.

2. M. Bonis and J.L. Crolet, "Practical Aspects of In Situ pH on H₂S Induced Cracking," *Corrosion Science*, 1987, Volume 27, Number 10.11, p. 1059.

3. A. Ikeda, et al, "Corrosion Behavior of Low and High Alloy Tubular Products in Completion Fluids for High Temperature Deep Well", *Corrosion*, 1992, Paper No. 46, NACE⁴, Houston, Texas, April 1992.

4. M.L. Walker and K.R. Lancaster, *Coiled Tubing Acid Related Corrosion Proceedings*, 3rd International H₂S Materials and Corrosion Conference, Corrosion Laboratories, Inc., Houston, Texas, May 1993.

5. T. Taira, et al, "Resistance of Pipeline Steels to Wet Sour Gas," *Current Solutions to Hydrogen Problems in Steels*, 1982, *American Society for Metals*, Metals Park, Ohio, p. 173.

6. T. Kushida and T. Kudo, "Hydrogen Induced Cracking Observed by the In Situ HIC Measurement Method," *Corrosion Engineering*, Volume 40, 1991, p. 711.

7. J.F. Bates, "Sulfide Cracking of High Yield Strength Steels in Sour Crude Oils," *Materials Protection*, 1969, Volume 8, Number 1, p. 33.

3 Coiled Tubing Advantages and Limitations

3.1 ADVANTAGES

The ability to deploy coiled tubing provides several advantages including the following:

- a. Work on live wells (pressure at surface).
- b. Efficient well entry.
- c. Quick rig up.
- d. Small surface footprint as compared to workover rig.
- e. Efficient offshore mobilization (modular components).
- f. Fast entry and withdrawal from wells.
- g. Continuous circulation of fluids throughout the well service.
- h. Performing work while the well is producing.
- i. No threaded connections to complicate pressure seals and well control during operation.
- j. Flush outside diameters.
- k. Ability to deploy many tools adapted from workover, drilling, and wireline operations.
- l. Adaptation to permanent completions.

3.2 LIMITATIONS

Growth in the coiled tubing industry has been facilitated by a better understanding of coiled tubing limitations and innovative adaptation of the technology. The bending radii and surface equipment used stress the coiled tubing beyond its yield strength, causing plastic deformation. This planned yielding of pipe is unique in oil-field operations. Limitations of current coiled tubing service operations include the following:

¹American National Standards Institute, 11 West 42nd Street, New York, NY 10036.

²American Society for Mechanical Engineers, 345 East 47th Street, New York, NY 10017

³American Society for Testing and Materials, 100 Bar Harbor Drive, West Conshohocken, PA 19428.

⁴National Association of Corrosion Engineers International, P.O. Box 218340, Houston, TX 77218-8340.

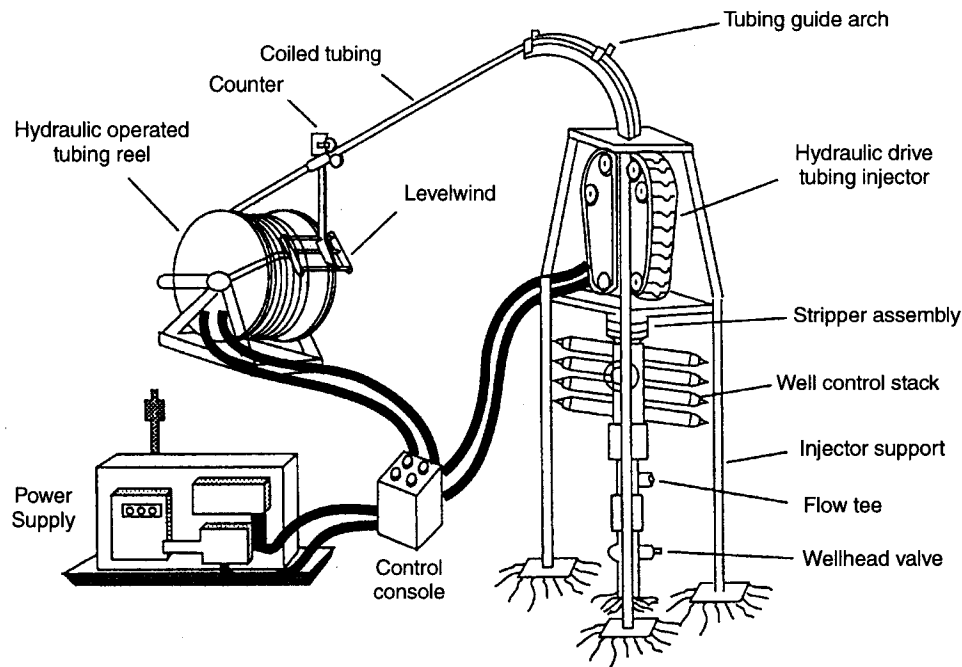


Figure 1—Typical Coiled Tubing Unit Modular Components

- a. Ultralow cycle fatigue cracking.
- b. Diametral growth (ballooning).
- c. Mechanical damage from handling and use.
- d. Environmental damage from acid, oxygen, or other substances.
- e. New pipe operational limits due to pipe strength in burst, collapse, tension, or buckling.
- f. Uncertainties in derating used coiled tubing.
- g. Difficulties in tube-to-tube butt welding.
- h. Operational limits of surface equipment for well control working pressure, push or pull loads, allowable pipe deformation, and tool lubricators.
- i. Downhole operational limits for pushing or pulling loads, frictional pressure losses through the tubing string, and collapse resistance due to ovality of the coiled tubing.

Failure modes and reasons for some past failures are as follows:

- a. Tensile yielding.
- b. Burst and collapse (wall loss or cracking).
- c. Fatigue cracking.
- d. Leaks (corrosion).
- e. Buckling.
- f. Ballooning (work hardening or softening).
- g. Plugging.
- h. Using tubing not fit for the service (improper working pressure ratings or excessive fatigue cracking due to bending/pressure cycles).
- i. Mechanical damage to the tubing (improper injection head procedures or downhole conditions).

- j. Inadequate welding practices or quality control.
- k. Lack of derating for field welds.

4 As-Manufactured Coiled Tubing

4.1 INTRODUCTION

Factors affecting coiled tubing performance are presented in this section. Particular topics include manufacturing, steel composition, properties and testing, and inspection. The information presented here is considered proven technology.

4.2 PROCESS OF MANUFACTURE

4.2.1 Description

Coiled tubing is electric-welded pipe manufactured in a tube mill with one longitudinal seam formed by high-frequency induction welding without the addition of filler metal. A flat strip is formed into a round shape in preparation for welding. The edges to be welded are mechanically pressed together, and the heat for welding is generated by the resistance to flow of electric current. Sizing to the final diameter is accomplished in the tube-forming line by slightly reducing the diameter after welding.

4.2.2 Length

The length of the flat strip material may be in excess of 3,000 feet and a spool of coiled tubing may be in excess of 20,000 feet. Long coiled tubing spools can be manufactured by welding the lengths of flat strip together prior to forming

the tube. Coiled tubing can also be tube-to-tube butt-welded to desired lengths.

4.2.3 Heat Treatment

Subsequent to welding, the coiled tubing should be heat treated by one or more of the following methods to achieve the final mechanical properties:

- a. The coiled tubing weld seam is annealed (minimum temperature of 1600°F) and stress relieved, typically in the tube mill line immediately after welding.
- b. The coiled tubing is full body stress relieved.
- c. The coiled tubing is quenched and tempered.

4.2.4 Tapered Strings

Tapered strings of coiled tubing can be manufactured by changing the wall thickness of the tubing within the length of a spool while maintaining a constant outside diameter. This is done to increase the performance properties of the coiled tubing in selected sections while minimizing the total weight of the string. Tapered coiled tubing strings are discussed in 4.8.

4.2.5 Spool Documentation

Spools of coiled tubing should be identified by a unique identification number which is assigned at the time of manufacture. Documentation for each spool of coiled tubing should include the number, outside diameter, grade, wall thickness(es), length, and weld positions. A spool of coiled tubing may be manufactured from one heat or a combination of heats that are selected according to a documented procedure.

4.2.6 Traceability

Traceability of coiled tubing should be maintained by the manufacturer throughout the manufacturing and testing process. Purchaser requirements often include traceability to the heat of steel.

4.3 COILED TUBING MATERIAL

4.3.1 Characteristics

High-strength, low-alloy steels are commonly used to achieve the desired weldability, corrosion resistance, fatigue resistance, and mechanical properties. The hot-rolled steels are manufactured using fine grain practices.

4.3.2 Ladle Chemistry

Commonly used ladle chemistries are modified ASTM A606 Type 4 and modified ASTM A607, as shown in Table 1. The ranges shown in Table 1 are a composite of the values offered by the manufacturers surveyed.

4.4 MECHANICAL PROPERTIES

Mechanical properties of coiled tubing should be provided for each spool of coiled tubing by the manufacturer. The mechanical properties reported are for the tubing prior to spooling or any service-induced cold work. Spooling and service conditions can alter the degree of cold work and hence the actual mechanical properties of a coiled tubing string. The minimum tensile properties for commonly used grades are shown in Table 2.

4.4.1 Yield Strength

The yield strength of new coiled tubing is determined by either the tensile stress at which the strain in the gauge length exhibits a 0.2 percent offset, or the tensile stress required to produce an extension under load of 0.5 percent.

4.4.2 Tensile Strength

The tensile strength is the tensile stress corresponding to the maximum load in a tensile test of the gauge section, and shall meet the manufacturer's written specification or the requirements of Table 2, whichever is greater.

4.4.3 Ductility

Ductility of coiled tubing is the percent elongation of a 2-inch gauge length in a tensile test. The minimum elongation required for each grade, weight, size (outside diameter), and wall thickness shall be in accordance with the manufacturer's written specification.

4.4.4 Hardness

The maximum hardness of coiled tubing is specified to reduce the susceptibility to sulfide stress cracking per NACE MR-01-75. The maximum allowable hardness is HRC 22 for standard coiled tubing grades as shown in Table 2.

4.4.5 Impact Toughness

Standard Charpy V-notch testing is not applicable to coiled tubing, due to the low thickness of the tubing. Toughness of the coiled tubing is enhanced by the steel manufacturing process. Typically, the steel is fully killed, made to fine grain practice, and the sulfur content is limited to 0.005 percent. These steps provide the steel with inherent toughness to resist brittle failure.

Other inspection procedures, (such as electromagnetic, radiographic, flaring, hydrostatic pressure testing, and coiling) are used to detect flaws in the product which could affect performance.

4.5 MECHANICAL TESTING PROCEDURES

Note: The mechanical properties do not necessarily remain the same after spooling.

Table 1—Common Ladle Chemistry for Coiled Tubing
(by Weight Percent)

Item	C	Mn	P	S	Si	Cr	Ni	Cu	Mo	Cb-V
Modified ASTM A606 Type 4	0.08–0.15	0.60–0.90	0.030 max	0.005 max	0.30–0.50	0.45–0.70	0.25 max	0.40 max	0.21 max	—
Modified ASTM A607	0.80–0.17	0.60–0.90	0.025 max	0.005 max	0.30–0.45	0.40–0.60	0.10 max	0.40 max	0.80–0.15	0.02–0.04

Note: max = maximum.

Table 2—Tensile and Hardness Requirements for
As-Manufactured Coiled Tubing

Grade	Minimum Yield Strength (ksi)	Minimum Tensile Strength (ksi)	Maximum Hardness (HRC) (Converted from Micro Hardness)
CT55	55	70	22
CT70	70	80	22
CT80	80	90	22
CT90	90	100	22

Note: ksi = thousand pounds per square inch.

4.5.1 Tensile Tests

Tensile properties are determined by tensile tests on a longitudinal full tube or strip specimen in accordance with the requirements of ASTM A370. Specimens are cut from each end of the spool at the time of manufacture and are tested at room temperature. Each test provides the tensile strength, yield strength, and ductility (percent of elongation) of the coiled tubing.

4.5.2 Hardness Tests

Hardness tests are performed on a tensile specimen prior to tensile testing, or on a specimen immediately adjacent to the test specimen in accordance with ASTM E384. Because of the thin wall of the coiled tubing, microhardness tests are typically performed and converted to the appropriate Rockwell scale. Hardness conversions are based on ASTM E144.

4.5.3 Flare and Flattening Tests

The manufacturer shall perform flare and flattening tests on each end of a spool of coiled tubing in accordance with ASTM A450. The acceptance criteria shall meet ASTM A450 requirements as a minimum, or the manufacturer's written specification if it is more severe.

4.5.4 Hydrostatic Pressure Test

Hydrostatic pressure tests are performed by the manufacturer on spooled coiled tubing. The test pressures specified herein are based on the following formula, and are rounded to the nearest 100 pounds per square inch gauge, but not to

exceed 10,000 pounds per square inch gauge. The minimum hold time at the hydrostatic test pressure shall be 15 minutes. Failure will be defined as pressure loss greater than 50 pounds per square inch gauge during the hold period or any visible fluid loss. The test pressure for a tapered coiled tubing string shall be based on the thinnest-wall segment of the string. See Equation 1.

$$P = \frac{2 \times f \times Y \times t_{min}}{D} \quad (1)$$

Where:

P = hydrostatic test pressure (pounds per square inch gauge).

f = test factor = 0.80.

Y = specified minimum yield strength (pounds per square inch gauge).

t_{min} = minimum specified wall thickness of the thinnest wall segment of tubing on the spool (inches).

D = specified outside diameter (inches).

Table 3 provides hydrostatic test pressures for various grades and sizes of spooled coiled tubing. Test pressures in excess of 10,000 pounds per square inch gauge shall be by agreement between the manufacturer and purchaser.

4.5.5 Toughness Tests for Coiled Tubing

Currently, no toughness testing exists for coiled tubing. The user may seek alternate methods of qualifying coiled tubing against failure by fracture. See also 4.4.5.

4.5.6 Sulfide Stress Cracking and Hydrogen-Induced Cracking-Resistance Tests

The typical 0.005 percent sulfur maximum limit in conjunction with the HRC 22 hardness limit provides compliance with NACE MR-01-75.

4.6 DIMENSIONS, WEIGHTS, AND TOLERANCES

Coiled tubing is furnished to the outside diameters, wall thicknesses, and weights shown in Table 3. Some applications may require special dimensions and weights as agreed upon by both the manufacturer and purchaser.

4.6.1 Diameter

Outside diameter is determined by a caliper-type measurement. Tolerances typically specified before spooling are ± 0.010 inch. Coiled tubing is spooled during manufacturing, which distorts the tube and may affect the outside diameter and ovality. The user should take such factors into account in the design and use of coiled tubing.

4.6.2 Wall Thickness

Each length of coiled tubing shall be measured for conformance to wall-thickness requirements. The wall thickness at any place shall not vary from the specified thickness, t , by more than the permissible tolerance specified below:

Wall thicknesses below 0.110 inch	-0.005 inch +0.010 inch
Wall thicknesses of 0.110 inch or greater	-0.008 inch +0.012 inch

4.6.3 Weight

Weights shall be calculated using the theoretical density of the steel, the specified wall thickness, and specified outside diameter of the tube. See Equation 2.

$$W = 10.68 \times (D - t) \times t \quad (2)$$

Where:

- W = plain end weight (pound/foot).
- D = specified outside diameter (inches).
- t = specified wall thickness (inches).

4.6.4 Length

Lengths shall be measured during manufacturing. Measuring instruments used in manufacturing should be accurate to ± 1 percent.

4.6.5 Weld Flash

The external weld flash on the coiled tubing is removed. Coiled tubing may be supplied with the internal weld flash removed, depending upon the manufacturer's capability and the purchase order. When the internal weld flash is not removed, the maximum height of the weld flash shall not exceed the value of the minimum wall thickness of the tube.

4.6.6 Capacity

Capacity (V_C) is the unit volume of fluid contained inside the coiled tubing. See Equation 3.

$$V_C = 0.0009714 \times d^2 \quad (3)$$

Where:

- V_C = internal capacity per foot (barrels/foot).

- $d = D - 2t$ (inches).
- D = specified outside diameter (inches).
- t = specified wall thickness (inches).

4.6.7 Displacement

Displacement (V_P) is the equivalent unit volume of fluid that will be displaced by the cross-sectional area of the coiled tubing body upon insertion into a filled well. See Equation 4.

$$V_P = 0.0009714 \times (D^2 - d^2) \quad (4)$$

Where:

- V_P = body displacement per foot (barrels/foot).
- D = specified outside diameter (inches).
- $d = D - 2t$ (inches).
- t = specified wall thickness (inches).

External displacement (V_E) is the equivalent unit volume of fluid that will be displaced by insertion of a closed-end string of coiled tubing into a filled well. See Equation 5.

$$V_E = 0.0009714 \times D^2 \quad (5)$$

Where:

- V_E = tube displacement per foot (barrels/foot).
- D = specified outside diameter (inches).

4.6.8 Drift Ball

When specified on the purchase order by the purchaser, the manufacturer should drift the coiled tubing to a specification agreed upon by the manufacturer and purchaser.

4.7 PROPERTIES OF NEW COILED TUBING

4.7.1 Collapse Pressure (Round Tube Without Axial Stress)

The collapse pressure (in the absence of axial stress and internal pressure), P_C , for as-manufactured coiled tubing is calculated using the appropriate formula of API Bulletin 5C3 for yield strength, plastic or transition collapse pressure. If the coiled tubing $D/t_{\min}$ ratio is less than the $D/t_{\min}$ ratio as shown in API Bulletin 5C3, Table 4, Column 2, then the collapse pressure can be estimated using Figure 2 as a function of $D/t_{\min}$ and minimum yield strength, Y . Cases where axial load is combined with external pressure, P , are discussed in 5.7.

4.7.2 Pipe Body Yield Load

The *pipe body yield load* is defined as the axial tension load (in the absence of pressures or torque) which produces a stress in the tube equal to the specified minimum yield strength (Y) in tension. See Equation 6.

$$L_Y = 3.1416 (D - t_{\min}) t_{\min} Y \quad (6)$$

Table 3—Coiled Tubing Specification Requirements and Performance Properties

Specification Requirements								Calculated Performance Properties ^a		
Specified Diameter Inch <i>D</i>	Plain End Weight (lb./ft. ^b)	Grade	Wall Thickness		Inside Diameter Inch <i>d</i>	Hydrostatic Test Pressure (psi) ^c	<i>D/t_{min}</i> Ratio ^d	Pipe Body Yield Load (lb.) <i>L_y</i> ^e	Pipe Internal Yield Pressure (psi) <i>P_r</i> ^e	Torsional Yield Strength (lb./ft.) <i>T_f</i>
			Specified Inch <i>t</i>	Minimum Inch <i>t_{min}</i>						
.750	.59	CT55	.083	.078	.584	9,200	9.62	9,060	11,440	138
1.000	.81	CT55	.083	.078	.834	6,900	12.82	12,430	8,580	268
1.000	.74	CT70	.075	.070	.850	7,800	14.29	14,320	9,800	316
1.000	.79	CT70	.080	.075	.840	8,400	13.33	15,260	10,500	332
1.000	.85	CT70	.087	.082	.826	9,200	12.20	16,550	11,480	353
1.000	.92	CT70	.095	.090	.810	10,000	11.11	18,010	12,600	376
1.000	.98	CT70	.102	.097	.796	10,000	10.31	19,260	13,580	395
1.000	1.04	CT70	.109	.104	.782	10,000	9.62	20,490	14,560	414
1.000	1.17	CT70	.125	.117	.750	10,000	8.55	22,720	16,380	452
1.000	.74	CT80	.075	.070	.850	9,000	14.29	16,360	11,200	361
1.000	.79	CT80	.080	.075	.840	9,600	13.33	17,440	12,000	379
1.000	.85	CT80	.087	.082	.826	10,000	12.20	18,920	13,120	403
1.000	.92	CT80	.095	.090	.810	10,000	11.11	20,580	14,400	430
1.000	.98	CT80	.102	.097	.796	10,000	10.31	22,010	15,520	452
1.000	1.04	CT80	.109	.104	.782	10,000	9.62	23,420	16,640	473
1.000	1.17	CT80	.125	.117	.750	10,000	8.55	25,960	18,720	516
1.000	.74	CT90	.075	.070	.850	10,000	14.29	8,410	12,600	406
1.000	.79	CT90	.080	.075	.840	10,000	13.33	19,620	13,500	426
1.000	.85	CT90	.087	.082	.826	10,000	12.20	21,280	14,760	454
1.000	.92	CT90	.095	.090	.810	10,000	11.11	23,160	16,200	484
1.000	.98	CT90	.102	.097	.796	10,000	10.31	24,770	17,460	508
1.000	1.04	CT90	.109	.104	.782	10,000	9.62	26,350	18,720	532
1.000	1.17	CT90	.125	.117	.750	10,000	8.55	29,210	21,060	581
1.250	1.03	CT55	.083	.078	1.084	5,500	16.03	15,800	6,860	440
1.250	.94	CT70	.075	.070	1.100	6,300	17.86	18,160	7,840	517
1.250	1.00	CT70	.080	.075	1.090	6,700	16.67	19,380	8,400	544
1.250	1.08	CT70	.087	.082	1.076	7,300	15.24	21,060	9,180	582
1.250	1.17	CT70	.095	.090	1.060	8,100	13.89	22,960	10,080	623
1.250	1.25	CT70	.102	.097	1.046	8,700	12.89	24,600	10,860	658
1.250	1.33	CT70	.109	.104	1.032	9,300	12.02	26,210	11,650	691
1.250	1.50	CT70	.125	.117	1.000	10,000	10.68	29,150	13,100	762
1.250	1.60	CT70	.134	.126	.982	10,000	9.92	31,140	14,110	799
1.250	1.82	CT70	.156	.148	.938	10,000	8.45	35,870	16,580	882
1.250	2.01	CT70	.175	.167	.900	10,000	7.49	39,770	18,700	944
1.250	.94	CT80	.075	.070	1.100	7,200	17.86	20,760	8,960	590
1.250	1.00	CT80	.080	.075	1.090	7,700	16.67	22,150	9,600	622
1.250	1.08	CT80	.087	.082	1.076	8,400	15.24	24,070	10,500	665
1.250	1.17	CT80	.095	.090	1.060	9,200	13.89	26,240	11,520	712
1.250	1.25	CT80	.102	.097	1.046	9,900	12.89	28,110	12,420	752
1.250	1.33	CT80	.109	.104	1.032	10,000	12.02	29,950	13,310	790
1.250	1.50	CT80	.125	.117	1.000	10,000	10.68	33,320	14,980	871
1.250	1.60	CT80	.134	.126	.982	10,000	9.92	35,590	16,130	913
1.250	1.82	CT80	.156	.148	.938	10,000	8.45	40,990	18,940	1,008
1.250	2.01	CT80	.175	.167	.900	10,000	7.49	45,460	21,380	1,079

Note: lb. = pounds; / = per; ft. = foot (feet); psi = pounds per square inch.

^aThe performance properties and hydrostatic test pressures shown apply to new pipe, and do not take into account additional deformation, axial load, residual stresses, or ovality caused by spooling or service cycling.

^bPipe weight in pounds/foot is based on specified dimensions of pipe.

^cBarlow's formula is used to calculate the internal yield pressure (Equation 7) and the hydrostatic test pressure (Equation 1). The minimum wall thickness, the specified minimum yield strength, and the specific outside diameter are used in the calculation. The effect of axial loading on internal yield pressure is not included.

^dThe calculated D/t_{min} Ratio as listed in Table 3 is based on the specified outside diameter and minimum wall thickness of the coiled tubing size shown.

^ePipe body yield load is based on specified outside diameter, minimum wall thickness, and minimum specified yield strength as seen in Table 2.

^fWorking pressure and working loads should be based on appropriate safety factors, taking into account the serviceability issues discussed in Section 5.

Table 3—Coiled Tubing Specification Requirements and Performance Properties (Continued)

Specification Requirements								Calculated Performance Properties ^a		
Specified Diameter Inch <i>D</i>	Plain End Weight (lb./ft. ^b)	Grade	Wall Thickness		Inside Diameter Inch <i>d</i>	Hydrostatic Test Pressure (psi) ^c	<i>D/t_{min}</i> Ratio ^d	Pipe Body Yield Load (lb.) <i>L_y</i> ^e	Pipe Internal Yield Pressure (psi) <i>P_r</i> ^c	Torsional Yield Strength (lb./ft.) <i>T_f</i>
			Specified Inch <i>t</i>	Minimum Inch <i>t_{min}</i>						
1.250	.94	CT90	.075	.070	1.100	8,100	17.86	23,350	10,080	664
1.250	1.00	CT90	.080	.075	1.090	8,600	16.67	24,920	10,800	700
1.250	1.08	CT90	.087	.082	1.076	9,400	15.24	27,080	11,810	748
1.250	1.17	CT90	.095	.090	1.060	10,000	13.89	29,520	12,960	801
1.250	1.25	CT90	.102	.097	1.046	10,000	12.89	31,620	13,970	846
1.250	1.33	CT90	.109	.104	1.032	10,000	12.02	33,700	14,980	889
1.250	1.50	CT90	.125	.117	1.000	10,000	10.68	37,480	16,850	980
1.250	1.60	CT90	.134	.126	.982	10,000	9.92	40,040	18,140	1,028
1.250	1.82	CT90	.156	.148	.938	10,000	8.45	46,110	21,310	1,134
1.250	2.01	CT90	.175	.167	.900	10,000	7.49	51,140	24,050	1,214
1.500	1.43	CT55	.095	.090	1.310	5,300	16.67	21,930	6,600	733
1.500	1.43	CT70	.095	.090	1.310	6,700	16.67	27,910	8,400	933
1.500	1.52	CT70	.102	.097	1.296	7,200	15.46	29,930	9,050	988
1.500	1.62	CT70	.109	.104	1.282	7,800	14.42	31,930	9,710	1,041
1.500	1.84	CT70	.125	.117	1.250	8,700	12.82	35,580	10,920	1,155
1.500	1.95	CT70	.134	.126	1.232	9,400	11.90	38,070	11,760	1,216
1.500	2.24	CT70	.156	.148	1.188	10,000	10.14	44,000	13,810	1,353
1.500	2.48	CT70	.175	.167	1.150	10,000	8.98	48,950	15,590	1,460
1.500	1.43	CT80	.095	.090	1.310	7,700	16.67	31,890	9,600	1,066
1.500	1.52	CT80	.102	.097	1.296	8,300	15.46	34,200	10,350	1,129
1.500	1.62	CT80	.109	.104	1.282	8,900	14.42	36,490	11,090	1,189
1.500	1.84	CT80	.125	.117	1.250	10,000	12.82	40,670	12,480	1,320
1.500	1.95	CT80	.134	.126	1.232	10,000	11.90	43,510	13,440	1,389
1.500	2.24	CT80	.156	.148	1.188	10,000	10.14	50,290	15,790	1,547
1.500	2.48	CT80	.175	.167	1.150	10,000	8.98	55,950	17,810	1,669
1.500	.43	CT90	.095	.090	1.310	8,600	16.67	35,880	10,800	1,200
1.500	1.52	CT90	.102	.097	1.296	9,300	15.46	38,480	11,640	1,270
1.500	1.62	CT90	.109	.104	1.282	10,000	14.42	41,050	12,480	1,338
1.500	1.84	CT90	.125	.117	1.250	10,000	12.82	45,750	14,040	1,485
1.500	1.95	CT90	.134	.126	1.232	10,000	11.90	48,950	15,120	1,563
1.500	2.24	CT90	.156	.148	1.188	10,000	10.14	56,580	17,760	1,740
1.500	2.48	CT90	.175	.167	1.150	10,000	8.98	62,940	20,040	1,878
1.750	1.68	CT55	.095	.090	1.560	4,500	19.44	25,810	5,660	1,026
1.750	1.91	CT70	.109	.104	1.532	6,700	16.83	37,650	8,320	1,462
1.750	2.17	CT70	.125	.117	1.500	7,500	14.96	42,020	9,360	1,631
1.750	2.31	CT70	.134	.126	1.482	8,100	13.89	45,000	10,080	1,721
1.750	2.66	CT70	.156	.148	1.438	9,500	11.82	52,140	11,840	1,928
1.750	2.94	CT70	.175	.167	1.400	10,000	10.48	58,140	13,360	2,092
1.750	3.14	CT70	.188	.180	1.374	10,000	9.72	62,150	14,400	2,197
1.750	1.91	CT80	.109	.104	1.532	7,600	6.83	43,020	9,510	1,671
1.750	2.17	CT80	.125	.117	1.500	8,600	14.96	48,020	10,700	1,864
1.750	2.31	CT80	.134	.126	1.482	9,200	13.89	51,430	11,520	1,967
1.750	2.66	CT80	.156	.148	1.438	10,000	11.82	59,590	13,530	2,203
1.750	2.94	CT80	.175	.167	1.400	10,000	10.48	66,440	15,270	2,391
1.750	3.14	CT80	.188	.180	1.374	10,000	9.72	71,030	16,460	2,511

Note: lb. = pounds; / = per; ft. = foot (feet); psi = pounds per square inch.

^aThe performance properties and hydrostatic test pressures shown apply to new pipe, and do not take into account additional deformation, axial load, residual stresses, or ovality caused by spooling or service cycling.

^bPipe weight in pounds/foot is based on specified dimensions of pipe.

^cBarlow's formula is used to calculate the internal yield pressure (Equation 7) and the hydrostatic test pressure (Equation 1). The minimum wall thickness, the specified minimum yield strength, and the specific outside diameter are used in the calculation. The effect of axial loading on internal yield pressure is not included.

^dThe calculated D/t_{min} Ratio as listed in Table 3 is based on the specified outside diameter and minimum wall thickness of the coiled tubing size shown.

^ePipe body yield load is based on specified outside diameter, minimum wall thickness, and minimum specified yield strength as seen in Table 2.

^fWorking pressure and working loads should be based on appropriate safety factors, taking into account the serviceability issues discussed in Section 5.

Table 3—Coiled Tubing Specification Requirements and Performance Properties (Continued)

Specification Requirements								Calculated Performance Properties ^a		
Specified Diameter Inch <i>D</i>	Plain End Weight (lb./ft. ^b)	Grade	Wall Thickness		Inside Diameter Inch <i>d</i>	Hydrostatic Test Pressure (psi) ^c	<i>D/t_{min}</i> Ratio ^d	Pipe Body Yield Load (lb.) <i>L_y</i> ^e	Pipe Internal Yield Pressure (psi) <i>P_r</i> ^c	Torsional Yield Strength (lb./ft.) <i>T</i> ^f
			Specified Inch <i>t</i>	Minimum Inch <i>t_{min}</i>						
1.750	1.80	CT90	.102	.097	1.546	8,000	18.04	45,340	9,980	1,781
1.750	1.91	CT90	.109	.104	1.532	8,600	16.83	48,400	10,700	1,880
1.750	2.17	CT90	.125	.117	1.500	9,600	14.96	54,020	12,030	2,097
1.750	2.31	CT90	.134	.126	1.482	10,000	13.89	57,860	12,960	2,213
1.750	2.66	CT90	.156	.148	1.438	10,000	11.82	67,040	15,220	2,479
1.750	2.94	CT90	.175	.167	1.400	10,000	10.48	74,750	17,180	2,690
1.750	3.14	CT90	.188	.180	1.374	10,000	9.72	79,900	18,510	2,825
2.000	2.20	CT70	.109	.104	1.782	5,800	9.23	43,360	7,280	1,956
2.000	2.50	CT70	.125	.117	1.750	6,600	17.09	48,450	8,190	2,189
2.000	2.67	CT70	.134	.126	1.732	7,100	15.87	51,930	8,820	2,314
2.000	3.07	CT70	.156	.148	1.688	8,300	13.51	60,280	10,360	2,605
2.000	3.41	CT70	.175	.167	1.650	9,400	11.98	67,320	11,690	2,839
2.000	3.64	CT70	.188	.180	1.624	10,000	11.11	72,040	12,600	2,990
2.000	2.20	CT80	.109	.104	1.782	6,700	19.23	49,560	8,320	2,235
2.000	2.50	CT80	.125	.117	1.750	7,500	17.09	55,370	9,360	2,502
2.000	2.67	CT80	.134	.126	1.732	8,100	15.87	59,340	10,080	2,645
2.000	3.07	CT80	.156	.148	1.688	9,500	13.51	68,890	11,840	2,978
2.000	3.41	CT80	.175	.167	1.650	10,000	11.98	76,930	13,360	3,245
2.000	3.64	CT80	.188	.180	1.624	10,000	11.11	82,340	14,400	3,417
2.000	2.50	CT90	.125	.117	1.750	8,400	17.09	62,290	10,530	2,814
2.000	2.67	CT90	.134	.126	1.732	9,100	15.87	66,760	11,340	2,976
2.000	3.07	CT90	.156	.148	1.688	10,000	13.51	77,500	13,320	3,350
2.000	3.41	CT90	.175	.167	1.650	10,000	11.98	86,550	15,030	3,651
2.000	3.64	CT90	.188	.180	1.624	10,000	11.11	92,630	16,200	3,844
2.375	2.64	CT70	.109	.104	2.157	4,900	22.84	51,940	6,130	2,831
2.375	3.00	CT70	.125	.117	2.125	5,500	20.30	58,100	6,900	3,181
2.375	3.21	CT70	.134	.126	2.107	5,900	18.85	62,320	7,430	3,371
2.375	3.70	CT70	.156	.148	2.063	7,000	16.05	72,480	8,720	3,815
2.375	4.11	CT70	.175	.167	2.025	7,900	14.22	81,090	9,840	4,177
2.375	4.39	CT70	.188	.180	1.999	8,500	13.19	86,890	10,610	4,413
2.375	2.64	CT80	.109	.104	2.157	5,600	22.84	59,360	7,010	3,236
2.375	3.00	CT80	.125	.117	2.125	6,300	20.30	66,400	7,880	3,635
2.375	3.21	CT80	.134	.126	2.107	6,800	18.85	71,220	8,490	3,853
2.375	3.70	CT80	.156	.148	2.063	8,000	16.05	82,840	9,970	4,360
2.375	4.11	CT80	.175	.167	2.025	9,000	14.22	92,670	11,250	4,773
2.375	4.39	CT80	.188	.180	1.999	9,700	13.19	99,300	12,130	5,043
2.375	2.64	CT90	.109	.104	2.157	6,300	22.84	66,780	7,880	3,640
2.375	3.00	CT90	.125	.117	2.125	7,100	20.30	74,700	8,870	4,090
2.375	3.2	CT90	.134	.126	2.107	7,600	18.85	80,120	9,550	4,334
2.375	3.70	CT90	.156	.148	2.063	9,000	16.05	93,190	11,220	4,905
2.375	4.11	CT90	.175	.167	2.025	10,000	14.22	104,260	12,660	5,370
2.375	4.39	CT90	.188	.180	1.999	10,000	13.19	111,710	13,640	5,673

Note: lb. = pounds; / = per; ft. = foot (feet); psi = pounds per square inch.

^aThe performance properties and hydrostatic test pressures shown apply to new pipe, and do not take into account additional deformation, axial load, residual stresses, or ovality caused by spooling or service cycling.

^bPipe weight in pounds/foot is based on specified dimensions of pipe.

^cBarlow's formula is used to calculate the internal yield pressure (Equation 7) and the hydrostatic test pressure (Equation 1). The minimum wall thickness, the specified minimum yield strength, and the specific outside diameter are used in the calculation. The effect of axial loading on internal yield pressure is not included.

^dThe calculated D/t_{min} Ratio as listed in Table 3 is based on the specified outside diameter and minimum wall thickness of the coiled tubing size shown.

^ePipe body yield load is based on specified outside diameter, minimum wall thickness, and minimum specified yield strength as seen in Table 2.

^fWorking pressure and working loads should be based on appropriate safety factors, taking into account the serviceability issues discussed in Section 5.

Table 3—Coiled Tubing Specification Requirements and Performance Properties (Continued)

Specification Requirements							Calculated Performance Properties ^a			
Specified Diameter Inch <i>D</i>	Plain End Weight (lb./ft. ^b)	Grade	Wall Thickness		Inside Diameter Inch <i>d</i>	Hydrostatic Test Pressure (psi) ^c	<i>D/t_{min}</i> Ratio ^d	Pipe Body Yield Load (lb.) <i>L_Y</i> ^e	Pipe Internal Yield Pressure (psi) <i>P_r</i> ^c	Torsional Yield Strength (lb./ft.) <i>T^f</i>
			Specified Inch <i>t</i>	Minimum Inch <i>t_{min}</i>						
2.875	3.67	CT70	.125	.117	2.625	4,600	24.57	70,960	5,700	4,793
2.875	3.92	CT70	.134	.126	2.607	4,900	22.82	76,170	6,140	5,090
2.875	4.53	CT70	.156	.148	2.563	5,800	19.43	88,760	7,210	5,789
2.875	5.05	CT70	.175	.167	2.525	6,500	17.22	99,450	8,130	6,365
2.875	5.40	CT70	.188	.180	2.499	7,000	15.97	106,680	8,770	6,744
2.875	5.79	CT70	.203	.195	2.469	7,600	14.74	114,930	9,500	7,167
2.875	3.67	CT80	.125	.117	2.625	5,200	24.57	81,100	6,510	5,478
2.875	3.92	CT80	.134	.126	2.607	5,600	22.82	87,050	7,010	5,817
2.875	4.53	CT80	.156	.148	2.563	6,600	19.43	101,430	8,240	6,616
2.875	5.05	CT80	.175	.167	2.525	7,400	17.22	113,660	9,290	7,274
2.875	5.40	CT80	.188	.180	2.499	8,000	15.97	121,920	10,020	7,707
2.875	5.79	CT80	.203	.195	2.469	8,700	14.74	131,340	10,850	8,191
2.875	3.67	CT90	.125	.117	2.625	5,900	24.57	91,240	7,330	6,163
2.875	3.92	CT90	.134	.126	2.607	6,300	22.82	97,940	7,890	6,544
2.875	4.53	CT90	.156	.148	2.563	7,400	19.43	114,110	9,270	7,443
2.875	5.05	CT90	.175	.167	2.525	8,400	17.22	127,870	10,460	8,183
2.875	5.40	CT90	.188	.180	2.499	9,000	15.97	137,160	11,270	8,671
2.875	5.79	CT90	.203	.195	2.469	9,800	14.74	147,760	12,210	9,215
3.500	4.82	CT70	.134	.126	3.232	4,000	27.78	93,490	5,040	7,736
3.500	5.57	CT70	.156	.148	3.188	4,700	23.65	109,100	5,920	8,836
3.500	6.21	CT70	.175	.167	3.150	5,300	20.96	122,410	6,680	9,750
3.500	6.65	CT70	.188	.180	3.124	5,800	19.44	131,420	7,200	10,357
3.500	7.15	CT70	.203	.195	3.094	6,200	17.95	141,730	7,800	11,038
3.500	4.82	CT80	.134	.126	3.232	4,600	27.78	106,850	5,760	8,842
3.500	5.57	CT80	.156	.148	3.188	5,400	23.65	124,680	6,770	10,099
3.500	6.21	CT80	.175	.167	3.150	6,100	20.96	139,890	7,630	11,143
3.500	6.65	CT80	.188	.180	3.124	6,600	19.44	150,190	8,230	11,837
3.500	7.15	CT80	.203	.195	3.094	7,100	17.95	161,970	8,910	12,615
3.500	4.82	CT90	.134	.126	3.232	5,200	27.78	120,200	6,480	9,947
3.500	5.57	CT90	.156	.148	3.188	6,100	23.65	140,270	7,610	11,361
3.500	6.21	CT90	.175	.167	3.150	6,900	20.96	157,380	8,590	12,536
3.500	6.65	CT90	.188	.180	3.124	7,400	19.44	168,970	9,260	13,316
3.500	7.15	CT90	.203	.195	3.094	8,000	17.95	182,220	10,030	14,192

Note: lb. = pounds; / = per; ft. = foot (feet); psi = pounds per square inch.

^aThe performance properties and hydrostatic test pressures shown apply to new pipe, and do not take into account additional deformation, axial load, residual stresses, or ovality caused by spooling or service cycling.

^bPipe weight in pounds/foot is based on specified dimensions of pipe.

^cBarlow's formula is used to calculate the internal yield pressure (Equation 7) and the hydrostatic test pressure (Equation 1). The minimum wall thickness, the specified minimum yield strength, and the specific outside diameter are used in the calculation. The effect of axial loading on internal yield pressure is not included.

^dThe calculated D/t_{min} Ratio as listed in Table 3 is based on the specified outside diameter and minimum wall thickness of the coiled tubing size shown.

^ePipe body yield load is based on specified outside diameter, minimum wall thickness, and minimum specified yield strength as seen in Table 2.

^fWorking pressure and working loads should be based on appropriate safety factors, taking into account the serviceability issues discussed in Section 5.

Where:

- L_v = pipe body yield load (pounds).
 Y = specified minimum yield strength (pounds per square inch).
 D = specified outside diameter (inches).
 t_{min} = minimum wall thickness (inches).

4.7.3 Internal Yield Pressure

The *internal yield pressure* is defined as the internal pressure which produces a stress in the tubing equal to the specified minimum yield strength (Y), based on the specified outside diameter and the minimum wall thickness, using Equation 31 from API Bulletin 5C3. See Equation 7.

$$P_r = \frac{2 \times Y \times t_{min}}{D} \quad (7)$$

Where:

- P_r = internal yield pressure (pounds per square inch gauge).
 Y = specified minimum yield strength (pounds per square inch).
 t_{min} = minimum specified wall thickness of the thinnest wall segment of tubing on the spool (inches).
 D = specified outside diameter (inches).

4.7.4 Torsional Yield Strength

Torsional yield strength is defined as the torque required to yield the coiled tubing (in the absence of pressures or axial stress) and is calculated as shown in Equation 8:

$$T_f = \frac{Y \times [D^4 - (D - 2t_{min})^4]}{105.86 \times D} \quad (8)$$

Where:

- T_f = torsional yield strength (pounds per foot).
 Y = specified minimum yield strength (pounds per square inch).
 D = specified outside diameter (inches).
 t_{min} = minimum specified wall thickness of the thinnest wall segment of tubing on the spool (inches).

4.8 TAPERED COILED TUBING STRINGS

4.8.1 Capabilities

Tapered coiled tubing strings are usually constructed with a uniform outside diameter and varied inside diameter to provide enhanced performance in services where the performance of single wall-thickness coiled tubing string is restrictive. The three common categories for the design of tapered coiled tubing string are seen in the following three paragraphs:

4.8.1.1 Extended Operating Depth

Tapered coiled tubing designs can increase the maximum operating depth of a string. By using thinner-walled tubing segments deep in the well and using thicker-walled segments shallow in the well, a tapered coiled tubing string of similar material strength can work at depths greater than a single wall thickness string of the same material strength.

4.8.1.2 Enhanced Stiffness

Another design of tapered coiled tubing string uses thicker-walled tubing segments on the lead portion of the string to provide enhanced stiffness and buckling resistance when snubbing into wellbores with high surface pressure. In addition, this type of taper design is used in services requiring the transportation and mechanical operation of downhole tools.

4.8.1.3 Well-Specific Designs

Numerous tapered coiled tubing strings are constructed to wellbore-specific design criteria (for example, horizontal borehole service) where the strength needs at specific locations along the length of the string are provided through use of tubing segments of different wall thicknesses.

4.8.2 Tapered Coiled Tubing String Construction

The construction of tapered coiled tubing strings shall conform with Section 4.2 of this recommended practice, with the following additions:

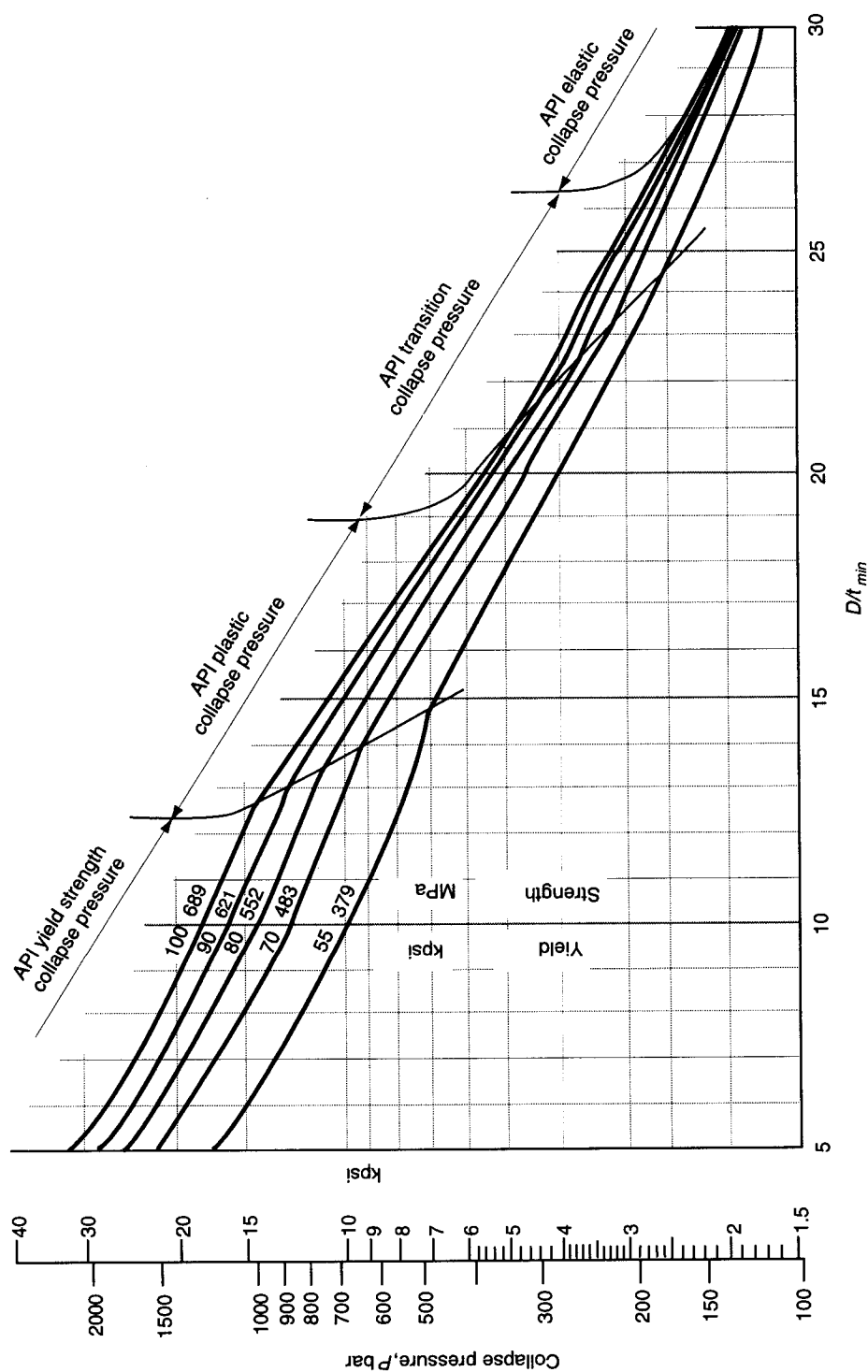
- The individual segments of the tapered coiled tubing string shall be of the same grade material with uniform chemistry and mechanical properties.
- The change in specified wall thickness, t , between the adjoining coiled tubing segments shall not exceed the values specified as follows:
 - 0.008 inch where the specified wall thickness of the thicker of the adjoining segments is less than 0.110 inch.
 - 0.022 inch where the specified wall thickness of the thicker of the adjoining segments is 0.110 inch or greater.
- The weld between adjoining coiled tubing segments may be bias welded in strip form (prior to the tube-forming process) or tube-to-tube butt welded (post tube-forming process).

4.9 NONDESTRUCTIVE INSPECTION (NDI) OF COILED TUBING

4.9.1 General Requirements

4.9.1.1 Accessibility to Purchaser

Where the inspector representing the purchaser desires to inspect this pipe or witness these tests, reasonable notice shall be given of the time at which the run is to be made.



Note: Not representative of coiled tubing in service conditions.

Figure 2—Calculated Collapse Pressure Ratings for Various D/t_{min} Ratios of As-Manufactured Coiled Tubing

4.9.1.2 NDI of Body of New Tubing

The entire body of the pipe shall be nondestructively inspected for material discontinuities by one or more of the following methods or methods which can be demonstrated to show equivalent sensitivity: (a) ultrasonic or (b) electromagnetic. The location of the equipment may be at the discretion of the manufacturer. However, at least one NDI method must take place at the end of the mechanical forming process.

4.9.1.3 NDI of Bias Weld

The weld which joins two strips together shall be inspected through its bulk by radiographic methods.

4.9.1.4 NDI of Electric Weld (EW) Seam

The weld seam of coiled tubing shall be inspected nondestructively full length by (a) the ultrasonic or (b) electromagnetic method. The location of the equipment may be at the discretion of the manufacturer. However, at least one NDI method must take place at the end of the mechanical forming process. If the flash is present, NDI may not be as accurate.

4.9.1.5 NDI of Tube-to-Tube (Butt) Weld

The weld which joins two tube ends together shall be inspected through its bulk using radiography.

The inspection of the bias weld, electric weld seam, and tube-to-tube butt-weld shall cover 100 percent of the weld area, and an area on either side which encompasses the heat affected zone.

Note: The same NDI equipment may be used for inspection of the coiled tubing body (4.9.1.2) and the electric weld seam (4.9.1.4).

4.9.1.6 Weld Location Record

The manufacturer shall provide the purchaser with a record of the location of the bias and butt-welds. This record may be obtained by visual and mechanical methods, or by nondestructive methods.

4.9.1.7 Tube Repair Record

The manufacturer shall provide the purchaser with a record of the locations of all repairs in the finished tube, including welding repairs and the removal of imperfections and defects.

4.9.2 Reference Standards for Nondestructive Inspection

4.9.2.1 Tube Body Inspection

A reference standard having the same diameter, wall thickness, and grade as the coiled tubing being inspected shall be used to demonstrate the effectiveness of the inspection equipment and procedures prior to each mill run. The reference standard may be of any convenient length as

determined by the manufacturer and shall contain a 1/32-inch diameter through-drilled hole as a test imperfection. The hole shall be drilled perpendicular to the surface of the reference standard.

As an option, when agreed upon between the purchaser and the manufacturer, additional reference standards containing the following machined flaws may be placed on the same reference standard and used in the inspection of coiled tubing:

- a. A machined notch placed on the outer surface of the reference standard comprised of the following dimensions:
 1. Length—0.5 inch at full depth.
 2. Depth—10 percent (± 15 percent) of the specified wall of the product.
 3. Width—No wider than 0.020 inches.
 4. Orientation—Longitudinal or, at the manufacturer's or customer's option, oriented at such angle as to optimize detection of anticipated imperfection.
- b. Where the inner diameter (ID) of the standard permits, a machined notch of the dimensions provided in 4.9.2.1, Item a may also be placed on the ID surface of the standard.
- c. A wall loss area 1.0 inch $\times$ 1.0 inch at 10 percent of specified wall thickness will be placed at a distance from the drilled-through hole, sufficient to produce two separate and distinguishable signals.

The inspection equipment shall be adjusted to produce a well-defined indication when the reference standard is scanned by the inspection unit.

In the event of more than one reference imperfection being placed in a test standard, the signals from the reference imperfections shall be clearly separated on the record obtained from the NDI equipment. Reference imperfection signals shall not overlap.

4.9.2.2 Bias Weld Inspection

The reference standard for determination of the sensitivity of the film radiographic technique shall be a 2T hole on an ASTM penetrometer, in accordance with ASTM E-94. The penetrometer shall be used on each weld to verify the effectiveness and procedures of the inspection.

The homogeneity of weld seams examined by radiological methods shall be determined by means of X-rays directed through the weld material onto a suitable radiographic film.

The weld area and heat affected zone shall be hardness tested, with the maximum hardness not to exceed HRC 22.

4.9.2.3 Tube-to-Tube (Butt) Weld

The same reference standard(s) as in 4.9.2.2 shall also be used to demonstrate the effectiveness of the inspection equipment and procedures for tube-to-tube weld inspection prior to each mill run.

4.9.2.4 Tube Electric Weld (EW)

The same reference standard(s) as in 4.9.2.a shall also be used to demonstrate the effectiveness of the inspection equipment and procedures for EW inspection prior to each mill run. If the flash is present, NDI may not be as accurate.

Note: The reference standards defined in the preceding are convenient standards for the calibration (standardization) of NDI equipment. The dimensions of the drilled hole or machined notches in these standards should not be construed as a minimum size imperfection detectable by the NDI equipment.

4.9.3 Nondestructive Evaluation of Body

4.9.3.1 Inspection

The body of coiled tubing shall be 100 percent inspected for defects to a written procedure after standardization of the inspection unit with the reference standard. The equipment used shall be capable of continuous and uninterrupted inspection of the tube body. The equipment shall be adjusted to produce well defined indications when the reference standard is scanned by the inspection unit in a manner simulating inspection of the product.

Regions from which defect indications originate shall be marked with an automatic paint-spraying device or other marking methods for further evaluation.

4.9.3.2 Drift

By agreement between the purchaser and manufacturer, a drift ball may be pumped through the entire spool of coiled tubing prior to shipment of the coiled tubing to verify drift. This process shall be performed to the manufacturer's written procedure with documentation provided to the purchaser.

4.9.4 Nondestructive Evaluation of EW Seam

The EW seam of coiled tubing shall be inspected for 100 percent of its length to a written procedure after standardization of the inspection unit with the reference standard. The equipment used shall be capable of continuous and uninterrupted inspection of the tube body, and shall be capable of inspecting an area of $\frac{1}{8}$ inch on either side of the weld. The equipment shall be adjusted to produce well-defined indications when the reference standard is scanned by the inspection unit in a manner simulating inspection of the product.

Regions from which defect indications originate shall be marked with paint or other marking method for further evaluation.

4.9.5 Imperfections and Defects in Finished Tubing

4.9.5.1 Imperfection

An imperfection is a material discontinuity or irregularity in the product detected by the methods outlined in this recommended practice or visual inspection.

4.9.5.2 Defect

A defect is an imperfection of sufficient magnitude to warrant rejection of the product.

4.9.5.3 Disposition of Imperfections and Defects

Any imperfection that produces a signal as great or greater than that of the reference standard shall be considered a *defect*. Coiled tubing imperfections and defects are categorized as follows, along with the recommended disposition:

4.9.5.3.1 An external imperfection may be removed by grinding or machining, provided the remaining wall thickness is not less than the minimum wall thickness, t_{min} . When the depths of the grind exceeds 10 percent of the specified wall thickness, t , the remaining wall thickness shall be verified with a calibrated compression wave ultrasonic wall thickness gauge. Where grinding is performed, generous radii shall be employed to prevent abrupt changes in wall thickness; the grind shall exhibit a high degree of workmanship; and the surface texture of the grind shall exhibit no transverse scratches.

The area from which the defect is removed shall be re-inspected by one of the nondestructive testing methods specified in 4.9.6 to verify complete removal of the defect.

4.9.5.3.2 Any imperfection on the inner or outer surface of the coiled tubing which reduces the thickness remaining at the root of the imperfection to less than minimum wall, t_{min} , but greater than 87.5 percent of the specified wall thickness, t , shall be identified by the manufacturer. The location of all imperfections on the inner or outer surface of the coiled tubing which reduce the thickness remaining at the root of the imperfection to less than minimum wall, t_{min} , but greater than 87.5 percent of the specified wall thickness, t , shall be clearly marked by the manufacturer, and the position of the imperfection on the spool will be recorded and supplied to the purchaser.

4.9.5.3.3 Any imperfection on the inner or outer surface of the coiled tubing which reduces the thickness remaining at the root of the imperfection to less than 87.5 percent of the specified wall thickness, t , shall be considered a defect and given one of the following dispositions:

- The section of the pipe containing the defect may be cut off within the limits of the requirements of the length and weld provisions of the purchase order.
- Repair of defects by welding shall be permitted only upon agreement between the manufacturer and the purchaser.*
- Rejected.

4.9.6 NDI Methods for Verifying Defect or Imperfection Removal

The area from which a defect or imperfection is removed shall be reinspected with any of the following techniques: (a) liquid penetrant inspection or (b) magnetic particle inspection.

4.9.7 NDI Indications Not Generated From the OD

Occasionally, NDI indications may be generated from mid-wall and internal surface imperfections and from weld bead droplets. These may be proved to written procedures using x-radiography, ultrasonic compression wave testing, or ultrasonic shear-wave testing.

4.10 CERTIFICATION AND DOCUMENTATION

The manufacturer shall provide certification and documentation for each spool of coiled tubing which includes, as a minimum, the following:

- a. Chemical composition.
- b. Heat number(s).
- c. Mechanical properties: hardness, tensile strength(s) and yield strength(s).
- d. Identification and position of various segments of coiled tube on the spool of different specified wall thicknesses (tapered string).
- e. Weld log including bias-weld and butt-weld locations
- f. Tube grade and serial number(s).
- g. Hydrostatic-test pressure including test duration, maximum pressure, minimum pressure, temperature, and test fluid.
- h. Drying procedure used if applicable (removing liquids from ID of coiled tubing using nitrogen).
- i. Nondestructive test methods performed on the spooled coiled tubing and welds and subsequent results obtained.
- j. Tube repair record.
- k. Details of drift ball pumping program if applicable.
- l. Record of the number of times the coiled tubing has been spooled and unspooled during the manufacturing and testing program.

5 Coiled Tubing String Design and Working Life

5.1 INTRODUCTION

This section includes topics on coiled tubing string design considerations, ultra-low cycle fatigue prediction methods, diametral growth, other OD anomalies, collapse derating, discussion on corrosion effects, and common weld survivability.

The useful working life of coiled tubing is limited by several factors, including the following:

- a. Fatigue.
- b. Diameter growth and ovality.
- c. Mechanical damage (kinks, surface anomalies).
- d. Corrosion.
- e. Welds.

All of the preceding factors, acting either singly or in combination, will contribute to eventual mechanical failure of the coiled tubing. Every effort must be made to avoid failure due to these factors during well site operations. A decision when to retire the workstring must be made based on its current condition and known service history. Except for severe mechanical damage, none of these factors can be precisely quantified or predicted. When derating coiled tubing for one or more of these effects, a compromise is required between the need to minimize well site failures and the need to obtain an economic working life from the string.

5.2 DESIGN CONSIDERATIONS OF COILED TUBING STRING

The design of coiled tubing strings shall be based upon the specified minimum yield strength, wall thickness(es) and outside diameters of the coiled tubing. Design criteria relating to the tubing weight, overpull, wellbore condition, and hydraulically applied loads, as defined in the following paragraphs shall be considered.

5.2.1 Weight

The weight of the coiled tubing string shall be calculated relative to a specific reference fluid(s) and shall be consistent throughout the string design calculations.

One of the two following conditions shall be used to define the weight of a coiled tubing string and reference fluid(s) in the design procedure for a specific coiled tubing string.

- a. Air weight: The weight of an empty (air filled) coiled tubing string in air.
- b. Buoyed weight: The weight of the coiled tubing string immersed in a fluid. The tubing may be gas filled (maximum buoyancy), filled with a reference liquid (conventional buoyancy), or filled with a heavier fluid.

5.2.2 Overpull

The tension load applied in excess of the buoyed load of the coiled tubing and tools hanging below the injector. Overpull loads are the combined loads resulting from tubing-to-pipe friction and anticipated downhole service pulling loads.

5.2.3 Wellbore Condition

The wellbore condition includes the following design concerns: