CRA-Tubulars

Frequently Asked Questions. (FAQ)

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General Properties and dimensions.

Q1. In what API tubing sizes is CFST (Carbon Fiber available?

We currently provide 2 3/8”, 2 7/8”, 3 ½’, 4 ½” tubing (5” coming soon).

These tubing sizes have standard API ID’s. dimensions and tubing weight are as follows:

API size:	OD tubing	API size	ID	Weight	Thread type
Inch	mm	ID inch	ID mm	LBS/ft	
2.375"	60.325	1.995	49	~ 3.1	any
2.875"	73.025	2.244	57	~ 3.1	any
3.5"	88.9	2.795	71	~ 3.1	any
4.5"	114.3	3.724	94.6	~ 3.1	any
5"	127.0	4.408	111.96	~ 3.1	any

Tubing weight may vary slightly.

Only ID is provided and not drift.
API-5 allows for 12.5% wallthickness variation in metal tubing
Our manufacturing process has much tighter tolerance control, hence ID is between OD and drift

Q2.What is CFST made off?

CFST is composed of a corrosion-resistant liner made of Titanium ASTM Grade-2. The liner is then covered with several layers of Aerospace grade carbon fiber and high-grade epoxy resin. The Ti. liner gives corrosion resistance and prevents permeation of any hydrocarbons into the CF layer. The CF layer provides strength in the axial and radial direction.

Q3.Is CFST expensive?

CFST is economical from a lifecycle cost perspective. It outlasts any high alloy metallic tubing. Considering the cost of several workovers, new tubing, chemical treatment, and cashflow impact resulting from shut-in periods, the price is very competitive. CFST is more economical than 13Cr tubing and certainly a lot less expensive than Duplex or Inconel tubing. CFST is priced slightly above CR13 tubing but will last many times longer.

Q4.What is the expected delivery time of CFST?

CRA-Tubulars plans to manufacture tubing in-country or certainly within the region. In this model we expect to deliver a spool of CFST in under 1 month, combined with HWOU installation, our process can have your well back on production within 2 months. This is much faster than traditional jointed metal CRA completions. Delivery times of Duplex or Inconel are typically over 18 months.

Q5.What is the maximum pulling force?

CFST is slightly stronger in axial forces than metallic tubing is. Our prototype testing showed 240,000 lbs. before the tubing broke. Since it weighs only one-third of metal equivalent tubing, it is a much stronger downhole. Example: 10,000 feet of steel tubing weighs 92KLBS, and our tubing weighs only 30KLBS, so we would have ±62KLBS (92-30kLBS) more pulling force than metal tubing.

Q6.What are the maximum burst pressure and temperature rating?

CFST is provided in two grades: Burst and collapse 10KSI and the high grade >15KSI. Temperature is 180 degrees Celsius; this puts our non-metallic CRA comfortably in the HPHT range of applications. We have a high grade under development aiming to approach 200C.

Q7.Is the material brittle?

No, to achieve the highest possible temperature resistance we are using highly crosslinked thus brittle resins. Our combination of resin, fiber, and the liner however is not brittle. Microcracks do occur in the outer layer (none in the inner liner) as soon as the pipe is spooled on a reel this is normal and does not affect its performance in any way.

Q8.How will the CFST behave under an uncontrolled flow (blow-out) condition?

Since CFST is as strong as metal, the behavior is expected to be similar. During such conditions steel tubing, drill pipe, and collars have been seen expelled from the well. That will likely happen with CFST too. Will it happen sooner? Not sure, but even if the event fully escalates 50% faster than with metal, the consequences will not be different, only instead of say an hour, it might happen in 30 minutes. Nothing to avert the consequence of such an event can be done in that time frame. Steel pipe, casing, and tubing have been sand-cut in minutes resulting from the extreme velocities of the two mediums together. Similar expectations for CFST.

There is no reason, when looking at other Industries, to believe non-metallic composite is less strong than metallic are. Airplanes are made of carbon fiber (CF), F1 cars are accident impact strengthened with CF. They are all much stronger than metal equivalent material. The unique and extreme forces in an uncontrolled well flow cannot be counteracted by metal or non-metallic composites, they will perform similarly.

Q9.Can CFST resist collapse pressure?

Yes, there is sufficient safety on the collapse performance (radial hoop strength) to allow for safe installation and operation. Calculations have shown that with a tubing full of gas, zero pressure at the surface, an annulus with packer fluid, and max design pressure at the surface (i.e. MDASP) there is no risk of collapse.

Q10. What is the expected service life of a CFST completion?

In most of the corrosive well-operating environments, the expected life exceeds 20 to 30 years. Titanium is very durable, corrosion-resistant, and in other industries like seawater coolers in nuclear power plants and chemical industries, it is the metal of choice for high corrosion resistance.

Carbon fiber is strong and nearly inert to corrosion bar wet/temperature degradation over time. CRA-tubulars apply a safety factor to the operating envelope. The (initial) operating limits are the limits CF would have after degradation.

Q11. What OCTG treads and types can CFST be connected to in the completion string?

We use a propriety cross-over design from carbon-fiber composite to any metal CRA alloy matching any type of premium or non-premium thread required by the client.

Q12. What completion accessories can CFST be connected to in the completion string?

As mentioned, we can provide any available thread type. CFST can be connected to any off-the-shelf completion accessory.

Q13. In what length will the completion tubing be supplied and what is the maximum well-depth CFST can be deployed?

Our product is a reeled endless tubing and is delivered in this configuration. The maximum length depends on the number of completion accessories installed. It can be one length from hanger to the packer, or it can be in segments for instance, from hanger to SCSSV and then next to the packer.

Tubing stress analysis indicates that well depths over 6,000 meters are still well within the operating envelope of the tubing.

Rig and other means of deployment:

Q14. What are the deployment options available?

Our product can be deployed using a Hydraulic Workover Unit (AKA: Snubbing Unit). With the completion string weight being one-third that of a conventional metal string, a much smaller workover rig can be used. (think sucker-rod pulling or water well drilling rigs). Since these small rigs and HWOU have a much shorter mobilization time, there is a distinct advantage in reducing the shut-in time of the well from failure to repair. This has a very positive effect on cashflow.

Q15. Would Coiled Tubing deployment be possible?

Yes, it is for completions that have straight tubing from hanger to packer. The outside of the CFST is smooth enough not to create increased wear on the stripper rubber.

Q16. Can CFST be deployed under pressure?

It is recommended to be run in a lower pressure environment. Due to the low stiffness, there is a probability of buckling when deploying against pressure. This could happen in the well or above Coil Unit stripper of HWO stripper BOPs. We recommend running completions in conventional rig operation mode; well pressure controlled by fluid or unperforated casing.

Q17. Won't spooled tubing be very large and difficult to stock or place on the platform/well site?

Average spooling diameter for CFST	
Tubing diameter	spool diameter
(inch)	(ft.)
2 3/8th	14
2 7/8th	16
3 1/2	19

A spooled coil will have a similar footprint to a 20ft. container. It will be much taller to accommodate the reel. Our tubing does not need indoor storage, so height should not be an issue. In most cases, the tubing will not be stored for long periods but used immediately after production. On the wellsite, it does not take up more space on the pipe-rack as full completion length tubing, only higher.

Applications:

Q18. Can CFST be used as a Velocity string?

Yes, it is perfectly suited for velocity strings. Being non-metallic and corrosion resistant, CFST tubing is a life of the well solution. When a gas well starts cutting water, it usually results in sweet corrosion, sour corrosion, or a combination. Normal Velocity strings are made of carbon steel Coiled Tubing and will last a few years at most. Our CFST will last for the remainder of the life of the well, without any future changes or corrosion surprises from well effluent. Our tubing can be connected to any standard Industry velocity string hanger-seal or whatever required.

Q19. Can CFST be deployed in seawater injection wells or produced water disposal wells?

Yes, it is ideally suited for this purpose. Injection water almost always contains oxygen from exposure to the surface or by dissolved oxygen in seawater. The fluid typically has elevated temperatures which increase the challenge for most OCTG strings. CFST is built to manage these challenging installations. No expansive scavenging, no cooling to match the operating envelope of the metal CRA. CFST is the fit for purpose pipe for disposal wells.

Note: Some clients are interested in downhole and surface injection line applications. They have to dispose of water at temperatures over 120C and have to replace flowlines and completion as frequently as ± every year. Currently, there is no competition, metal, or non-metallic, that can manage this environment. CFST is the fit for purpose pipe for disposal wells.

Q20. Can CFST be deployed in Artificial lift designed completions?

Yes, However, some precautions in the design are required. Non-metallic centralizers on the sucker rods; for both beam pumping and PCP installations. A limited deviation would be an advantage and result in prolonged life. Soft start or VSD in ESP is a must as it will reduce residual torque on the composite tubing when starting the downhole motor. Gas lift completion is no different from metal tubing.

Intervention activities:

Q21. Are there any special Well Intervention restrictions or precautions?

CFST will in general be used in wells requiring a metal CRA tubing completion. However, the corrosive film on the Titanium liner is much harder than metal CRA alloy. Therefore, it will be much more difficult to damage that film contrary to Duplex or Inconel alloys. However, it is recommended to design and execute interventions similar to high Chrome, Nickel, or Inconel tubing. Carbon steel intervention tools can chip off steel splinters which could be embedded in the metal CRA tubing and give access to corrosion. If it is necessary to perform Interventions, non-metallic centralizers should be deployed, reduced running speed, especially in dry completions, like gas-wells. Intervention tools shall be selected new, burrs filed off. Plastic coated wire is a distinct advantage in both types of CRA tubing.

Q22. Can the same pipe cutting tools be used for carbon fiber as for conventional tubing?

Not all cutting tools are advisable. Obviously, chemical cutters will not work, similarly, they do not work on metallic CRA tubing. The electric pipe cutting tool from Sondex wireline has been successfully tested on these materials.

Q23. Can CFST be milled

Yes, it can be milled but requires modified tools and reduced milling rates/conditions, bit type rpm, etc. The cuttings from milling the tubing are very light, and even lightweight, low viscosity brine will carry it to the surface.

Q24. How will/can top of fish (TOF) on CFST be fished?

In the case of severed tubing, the fishing operation is similar to metal tubing. The TOF can be dressed, fished internally, or externally. A grapple overshot with slips engaging on the outside of the tubing and possibly a spear inside could work equally well as with traditional metal tubing fishing.

Q25. How stiff is the tubing when running into obstructions?

In the unlikely event that after a bit and scraper run the well is not fully accessible, the impact of CFST tubing weighing one-third of its metal competitor is low. Furthermore, CFST is as strong as metal, no issues.

Q26. Can “seating nipples” be installed CFST completion?

Yes, CFST tubing can be made-up to any standard, any manufacturer's accessory, as well as to nipples for plugs, standing valves, beam-pump seating nipples, etc. Any conventional completion design can incorporate CFST tubing.

Q27. Can a wireline deployed tubing punch be used in CFST completion?

At the moment this has not been tested, however, looking at a large number of available alternative options, mechanical or explosive, it should be possible.

Q28. How can CCL depth correlation be used in CFST completion?

By their nature, non-metallic composites do not react to magnetic fields, very much like metal CRA tubing. CRA-Tubulars has an option to install depth correlation points for intervention in case there is a need for more accurate in-depth control. They are installed at the client's request during the manufacturing of the tubing.

Q29. Can downhole power and/or fiber optic sensors be installed in CFST completion?

Yes, a hydraulic control-line can be incorporated into the outer layer. Using available SCSSV's and packer with integrated control-line options, it can be supplied. Similarly, fiber optic cable can be integrated. Existing technology allows for the cable to exit the tubing, bypass the accessory, and connect to the optic cable below again.

Power cable for ESP can be "wrapped" in the out layer, providing a sturdy and protected alternative to traditionally banding to the outside of the tubing.

Q30. How can we inspect the tubing in the completion?

In conventional metal CRA completion, monitoring of corrosion during the production life of the well is desired.

Can we inspect, and is that needed, in non-metallic CRA tubing?

Pulsed Eddy is a technology that could be tried on this new development. It makes non-magnetic elements slightly magnetic showing wall thickness reduction. It is a proven technology in measuring riser wall thickness and airplane structure inspection.

Downhole Video is a visual option to investigate the condition of the inside of the tubing.

CRA tubulars intends to further develop this requirement for those clients needing to comply with this requirement.

<u>Carbon Capturing and Storage application:</u>

Q31. How does CFST make such an interesting economic alternative to metal alloys in CCS wells?

Carbon Capture and Storage requires captured CO2 to be pumped as a liquid down old oil and gas wells. Pumping the liquid CO2 into an empty reservoir below hydrostatic pressures a well would allow the liquid to "evaporate" at the top of the well, resulting in a large temperature drop. This Joule Thompson cooling effect varies with the effective

remaining reservoir pressure. Over time this evaporation will reduce as reservoir pressure increases. CFST is designed with two unique components suited for this purpose, Titanium-Ti and Carbon Fiber-CF. Titanium has a track record as a storage vessel for liquid Helium and CF was used on NASA's Space Shuttle liquid Oxygen and Hydrogen tanks. These proven track records in extreme cold environments, exhibit fit for purpose application of CFST components. Kobe steel puts the minimum temperature limit of Titanium at minus -269 degrees Celsius (4 degrees Kelvin). Carbon fiber in the grade used in CFST can safely be applied to minus -40 degrees Celsius without losing its strength.

In comparison, (metallic-CRA-alloys) like Duplex or Super Duplex are limited at around minus -50 C and minus -100 degrees C respectively.

Additionally, prices of these (metallic-CRA-alloys) are much higher than CFST, making it a very interesting economical alternative in these applications.

Q32. What is the thermal resistance of the CFST?

The thermal resistance of carbon fiber (through-thickness) =0.8W/m-K.

The CFST total thermal resistance per length (1 meter) R=0.0339K/W

Q33. Why is the thermal CTE of CFST so much lower than metal CRA tubing?

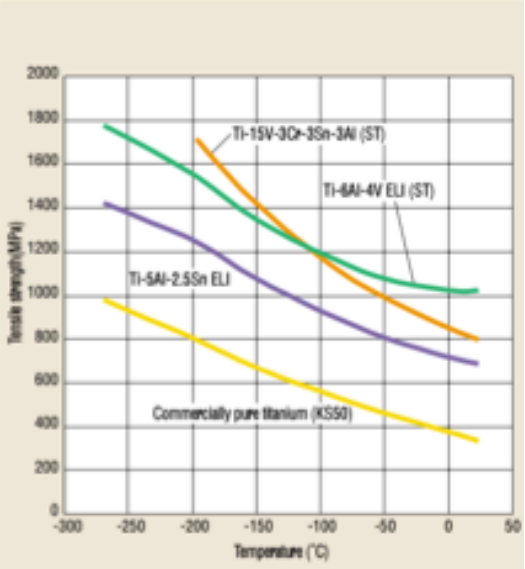
Carbon fiber has a negative Coefficient of Thermal Expansion (CTE) and since it is so much stiffer than the surrounding epoxy, the combined effect is dominated by the CF. Therefore, the Temperature Coefficient is between 1/3 and 1/2 of that of metal tubing.

Q34. What is the thermal conductivity of CFST?

This number will be derived from that of Titanium and carbon fiber and gives a thermal pipe resistance of R=0.0339K/W per unit length of 1 meter.

Q35. At what minimum temperature can CFST be used in CCS wells?

Titanium on its own is used for Helium storage vessels because of its extreme low-temperature capabilities. Carbon fiber on its own was used on the Space Shuttle liquid Oxygen and Hydrogen tanks. Both applications are low-temperature environments. The difference in the operating envelope in CCS wells and the aforementioned applications are the forces and stresses experienced in wells. However, Titanium shows an *increase in tensile strength* when cooled down (Source Kobe Steel).



Low temperature characteristics

Neither commercially pure titanium nor titanium alloys become brittle even at extremely low temperatures. In particular, commercially pure titanium and Ti-5Al-2.5Sn ELI can be used even at 4.2 K (-269°C). (Fig. 4)

Carbon fiber has a negative Coefficient of Temperature Expansion (CTE), reducing thermal effects and forces resulting from temperature fluctuations. Our resin used in

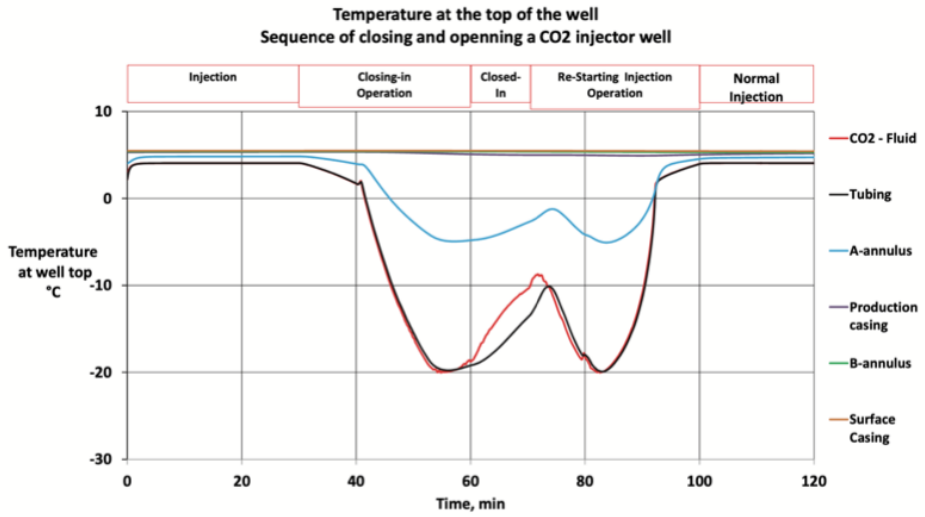


Figure 4. Temperature at different well elements in the top of the well for the sequence of closing-in a well after a long term injection period, well closed-in for a short period of time and re-starting injecting for a low reservoir pressure case (2750psi - ~ 190bar). CO_2 injection rates during the closing-in and the re-starting operations are proportional with time.

CFST can safely be exposed to minus -40 degrees Celsius. As can be seen from this temperature profile simulation illustrated, it would make CFST perfectly suitable for the large majority of CCS wells. It will only go below minus -20C in exceptional cases. At a price around 13Cr tubing, the Operator will get superior service to duplex or Inconel properties, low-temperature coefficient, and low tubing weight.

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