

Downhole Tubing & Casing Material Selection: Offshore Production Wells

Introduction

Wells can be organized into three primary categories: production, injection, and conversion/turn-around. Material selection must be tailored to each well type, as each offers unique challenges from a materials performance perspective.

Tubing and casing are critical to the production of oil and gas and well integrity. Reservoir fluids flowing through the production tubing are often corrosive, making necessary the use of corrosion resistant alloys (CRA) offshore. CRAs contain various quantities of Ni, Mo, Cr, Cu, and other elements for corrosion resistance, making them significantly more expensive than carbon steel (CS). Casing is primarily for structural integrity of the well and typically requires significantly larger diameters and heavier weights than tubing. Additionally, casing is generally not exposed to reservoir fluids, with some exceptions, so lower-alloy CRAs or carbon steel materials are often chosen to keep costs low. However, the materials used must still be carefully selected, as carbon steel may not be the optimum material for every use and the CRAs considered acceptable will vary based on the given environmental conditions.

Figure 1 shows two common well designs, one utilizing production casing and one utilizing production liner. While production casing ties back to the surface, production liner is instead suspended from a lower casing section. Both production liner and production casing are used to prevent well collapse and can act as backup containment in the case of a production tubing leak. Therefore, using carbon steel casing rated for use in sour service is considered a best practice for these applications. However, the use of carbon steel for casing may not be optimum for every well design.

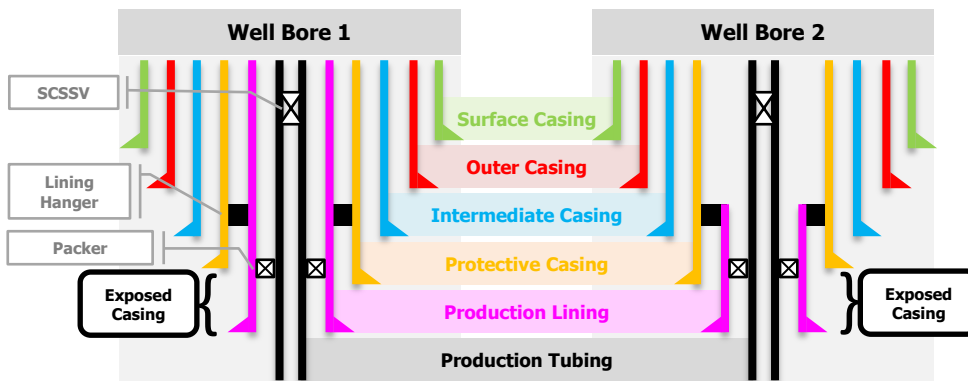


Figure 1: Schematic of Generic Well Bores

While nearly all casing and liners are carbon steel, there is a small section of casing that is exposed to reservoir fluids and should generally be made of the same material as that selected for the tubing. This section is referred to as 'exposed casing' or 'exposed lining' and is cemented in place for wellbore integrity in some well designs and also perforated and used for production in others. Surface, outer, and intermediate casing are used for structural integrity and are not expected to come into contact with the produced fluids.

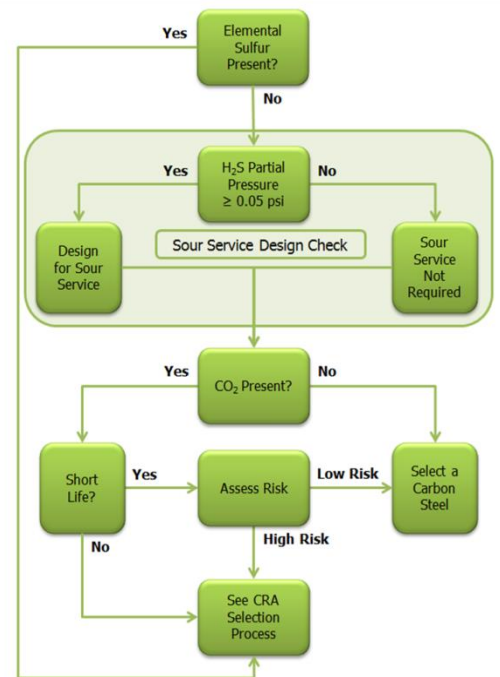


Figure 2: General Material Selection Process

General Location	Cost Per Day, Order of Magnitude	Example
Onshore – Accessible	\$10,000	West Texas
Onshore – Remote	\$100,000	North Slope of Alaska
Offshore – Accessible	\$300,000	Shallow Water Gulf of Mexico
Offshore - Remote	\$1,250,000	Deep Water Gulf of Mexico

Table 1: Approximate Workover Cost Per Day

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The primary focus of the material selection process is to identify materials which can be safely deployed. Selection is further refined by cost considerations in which capital expenditures (CAPEX) and operational expenditures (OPEX) are balanced to minimize total lifetime cost. Other considerations such as lead time, quality assurance, and schedule are also factored into the material selection process.

General Downhole Material Selection Process

Knowledge of a few specific parameters, such as the presence of CO₂ or the location, design life, or presence of elemental sulfur, is sufficient to determine whether a CRA is required, but these parameters are not sufficient to determine which CRA should be selected. Unlike carbon steel, CRAs are essentially resistant to corrosion due to CO₂ and thus CO₂ is the first indicator of whether carbon steel material can be successfully used for the production tubing. CO₂ partial pressure (as well as temperature) affects the rate of tubing wall loss and the subsequent frequency of tubing replacement by workover.

This information, when combined with well design life, will indicate the number of workovers expected for the well. Location heavily influences workover costs in cases where tubing replacement is required, as demonstrated by the generic location-based workover costs provided in Table 1.

This material selection process is illustrated in Figure 2, and should be evaluated separately for upper and lower production tubing. By this process, carbon steel tubing with downhole corrosion inhibition can often be used in lieu of a CRA, but corrosion inhibition is OPEX intensive and considered a high risk operation when used offshore. Regardless of offshore location, the presence of elemental sulfur will immediately require the use of CRA tubing due to sulfur's inherent high corrosivity. Ultimately, location is often the most significant driver in materials selection because of the consideration of workover cost.

Corrosion Resistant Alloy Selection

CRAs are almost always used for offshore production well tubing due to design life requirements and OPEX associated with workovers. Exposed casing will usually be constructed of the same material as the production tubing, as this material will be exposed to the same corrosive environment as the production tubing.

CRAs can be roughly divided into four categories (families) in order of general ascending corrosion resistance and cost: Martensitic stainless steel (MSS), duplex and super duplex stainless steels (DSS and SDSS), super austenitic stainless steels, and high Nickel Alloys. With the exception of the API 5CT L80 13Cr steel, all other CRA casing and tubing alloys are proprietary.

The CRA family is chosen based on the presence of elemental sulfur and a combination of H₂S partial pressure, chloride concentration and temperature. Other environmental parameters are then factored in, along with any specific usage history or available data, and the choice is assessed. Figure 3 shows the CRA family selection process.

Detailed material selection will ultimately be determined by parameters associated with the production and shut in environments: temperature (e.g., bottom hole and shut in), pH, chloride concentration, and H₂S partial pressure. The necessity to differentiate between the various temperatures is important. Bottom hole temperature (BHT) is often the most common driver for material selection. However, potential changes in the corrosive nature of produced fluids at the top of the well during shut in, when the well has cooled to the seafloor temperature, may indicate the need for a different material in the upper part of the well.

Additional parameters/requirements can necessitate revisiting the materials selection. These relate more to schedule, materials properties, and commercial considerations.

While materials can be selected based on the process described, fitness for service testing is an acceptable method to prove a material can work in a given environment, and is required if no data is available to confirm the alloy is acceptable. Common fitness-for-service test methods are as follows:

- Specific Corrosion Rate Testing
- Sour Service Compliance Tests
- NACE Method A Cracking Tests
- NACE TM 0177 Method C Tests
- NACE TM 0198 Slow Strain Rate Tensile Tests



Figure 4: Micrograph of the Weld & Heat Affected Zone of a C-Ring Specimen

Conclusion

Material selection is a nuanced process. A primary assessment based on environmental and operating conditions enables identification of outright inappropriate materials and allows a general selection to be made. Often, however, a multiplicity of acceptable options may exist and the ultimate decision will be decided by risk-assessment, where a balance between tolerable risk and acceptable cost must be achieved.

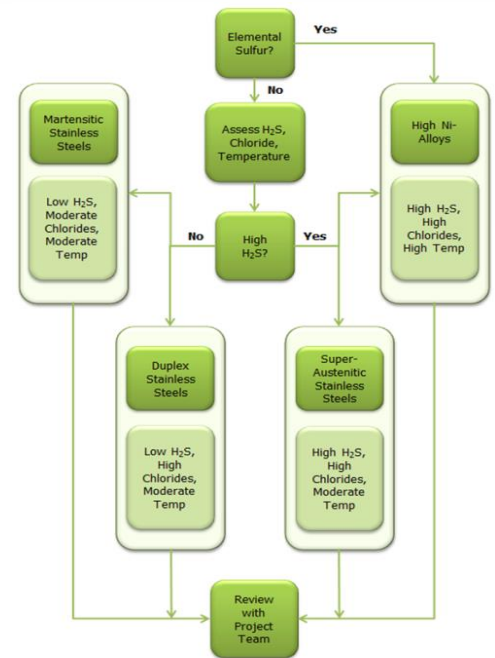


Figure 3: CRA Selection Process

References

1. Caldwell, E., et al., *A Selection Methodology for 13Cr-Type Alloy Oil Country Tubular Goods*. SPE 169633-MS, Aberdeen, UK, 2014.



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