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SEA-CURE®: the solution for the U.S. strategic petroleum reserve

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Plymouth Tube Co. supplied the chosen replacement tubing material SEA-CURE® for use in the Strategic Petroleum Reserve's heat exchangers.

The U.S. Department of Energy (DOE) stores crude oil for emergency supply for cases when the need arises in salt caverns along the Texas and Louisiana coastline. The process of withdrawal is later handled through a system of heat exchangers that cool the crude to suitable temperatures for transport to final storage destination. However, the harsh chemical makeup of the inter-costal water source causes severe corrosion to the tubing of the heat exchangers leading to tubing failure. As a result the SPR had to re-tube the oil coolers every six months. This article relates Plymouth Tube Co.'s introduction of SEA-CURE® tubing for the project – a superferritic stainless steel with high corrosion resistance to high chloride and brackish water conditions.

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The Strategic Petroleum Reserve (SPR) was created to allow access to oil in situations for which the United States is threatened or confronted with a disruption in oil supply. The Texas and Louisiana coastline, populated with salt caverns offered both an economical and logistical option for storage. Deep within the confines of these salt caverns storage sites were created. Some caverns are deep enough to hold the height of the Sears Tower, one of the world's tallest buildings with room to spare.

Salt caverns provide a safe, natural source for storage. Due to their depth and location adjacent to the Gulf of Mexico, oil could be stored without any environmental concerns. The walls of the caverns are considered "self-healing" and should any compromise of the structure occur, the caverns rock hard walls will close over time. Also, the environment within the caverns create a natural fluid circulation keeping the crude oil at a consistent quality and temperature.

However, when the oil is extracted from the depth, the crude temperature is too high to process and must be cooled. The process of oil withdrawal is handled through a system of heat exchangers that cool the crude to suitable temperatures required for transfer and final processing of the oil.

Crude is extracted by a process of pumping water into the bottom of the cavern. Since oil floats on water, this process

SPR stores the US supply of crude oil for energy access in situations of supply disruption. Photos courtesy of the U.S. Department of Energy

raises oil to the surface. This same water source is used within the heat exchanger process with the oil passing around the tubes within the outer shell of the cooler while water flows through inside the tubes to cool the crude.

When the SPR required access to the crude oil supply, it was discovered that the heat exchangers that were constructed largely with carbon steel (CS) tubing per ASTM A214A (Ref. [1]) or ASTM A179 (Ref. [2]) were subjected to severe corrosion, leading to tube fouling and failure of the heat exchangers. The harsh chemical makeup of the inter-coastal water source created a cocktail that was high in chloride, sulfate and calcium with a pH slightly above or at neutral. This brackish water combined with CS was ultimately causing the SPR to retube the oil coolers on average every six months.

Since the SPR was required to aid in cases of oil shortage emergencies, the chances that the crude oil extraction could be hindered by unreliable oil coolers was an issue the U.S. Department of Energy had to resolve. The DOE utilized their Management and Operating contractors, DynMcDermott to evaluate the CS tubing and test viable options for solution.

After extensive research regarding material selection, DynMcDermott provided the option of a superferritic stainless steel (SS), SEA-CURE® per ASTM A268 (Ref. [3]) as a replacement grade for the tubing due to its high corrosion resistance in high chloride, brackish water environments.

SEA-CURE® which is manufactured using UNS S44660 superferritic stainless steel is a brand of tubing offered only through Plymouth Tube Co.'s East Troy, WI facility. The tubing is manufactured using proprietary processes that ensure the

Oil cooler found at Strategic Petroleum Reserve is used to cool crude oil as it is extracted from the storage caverns. Photo courtesy of Sandia National Laboratories.

optimum high corrosion resistance and met the criteria as a suitable replacement in the DOE's oil coolers.

Following the identification of SEA-CURE® as a replacement for the existing CS tubing, due diligence required careful assessment of the current system as well as the proposed approaches to address this particular corrosion issue. With the assistance of scientists from Sandia National Laboratories (Ref. [4]), a research program was conducted which compared the relative performance of the current CS system and the SEA-CURE® replacement option with two corrosion mitigation strategies.[1]

The challenge of mimicking the environment and process of extraction from the SPR's oil coolers in the Sandia National Laboratories was a task in itself. Barrels of the water found at the Brian Mound and West Hackberry SPR's locations were shipped to the labs in the effort to best replicate the corrosive environment for which the heat exchangers were subjected. Test heat exchangers were designed to replicate the conditions of site heat exchangers. Tubing samples of the electric-resistance-welded (ERW) CS tube per ASTM A214A, seamless cold-drawn low-carbon steel tube per ASTM A179 and the superferritic SEA-CURE® stainless steel per ASTM A268 were tested under the conditions of the two SPR sites.

There were two proposals for addressing the corrosion and fouling issue. The need to compare the processing and corrosion of each was required for proper analysis. One proposed solution was to retube the oil coolers with the superferritic stainless steel SEA-CURE® that offered inherent traits of corrosion resistance. The other solution considered was the chemical moderation of the process using CS with the introduction of a corrosion inhibitor and deposit control agent. While the latter was a more economical solution, it posed a higher risk.

Extensive tests using both treated and untreated water were conducted using bounded heat exchanger temperature conditions and heat transfer rates observed at the SPR sites. CS and SEA-CURE® corrosion sensors were evaluated during and at the conclusion of the tests. Also, samples of the CS and SEA-CURE® tubing were cut into cross-sections and evaluated to see the effects of corrosion in the wall thickness of the material. The following summary and conclusions were confirmed.

While the inhibitor and deposit control solution did reduce the severity of corrosion on the CS, the localized attack and magnitude observed still indicated potential for tubing perforation and overall reduction in tubing strength.

The ERW CS was consistent with the seamless CS which exhibited pitting along the surface; however, the ERW also had increased amounts of localized attack along its entire weld root.

Under any of the conditions the superferritic stainless steel SEA-CURE® was tested during this study, no quantifiable corrosion was observed. The outcome of the evaluation suggested that SEA-CURE® was the viable replacement material for the heat exchangers.

When compared to CS and other possible alternatives, SEA-CURE® exhibits higher corrosion resistance in high chloride, brackish water conditions. SEA-CURE® is specifically designed for applications for which chloride induced pitting, crevice and stress corrosion cracking may be encountered. Based on the environment of the SPR sites, SEA-CURE® was chosen as the replacement material for the oil coolers. Plymouth Tube Co. shipped over 2,180,000 feet of tubing used to retube 34 heat exchangers supplied in various deliveries from 2002 to 2005. No reported issues of tube failures or fouling have been reported since replacement SEA-CURE® was utilized.

References

[1] ASTM A214/A214M-96, "Standard Specification for Electric-Resistance-Welded Carbon Steel Heat Exchangers and Condenser Tubes," Annual Book of ASTM Standards (West Conshohocken, PA: ASTM Intenational, 2001).

[2] ASTM A179, "Standard Specification for Seamless Cold-Drawn Low-Carbon Steel Heat Exchangers and Condenser Tubes," Annual Book of ASTM Standards (West Conshohocken, PA: ASTM Intenational, 2001).

[3] ASTM A268, "Standard Specification for Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service," Annual Book of ASTM Standards (West Conshohocken, PA: ASTM International, 2001).

[4] Enos, D.G., B.L. Levin, and T.E. Hinkebein (2005, September). Laboratory Evaluation of Corrosion Mitigation Strategies for Large, Once-Through Heat Exchangers. Materials Performance, pp. 36–41.

U-bending process of SEA-CURE® tubing supplied for the Strategic Petroleum Reserve oil cooler application. Photo courtesy of Plymouth Tube Co.

[1]Testing data reported by Sandia National Laboratories not intended to endorse any specific product or brand of material.