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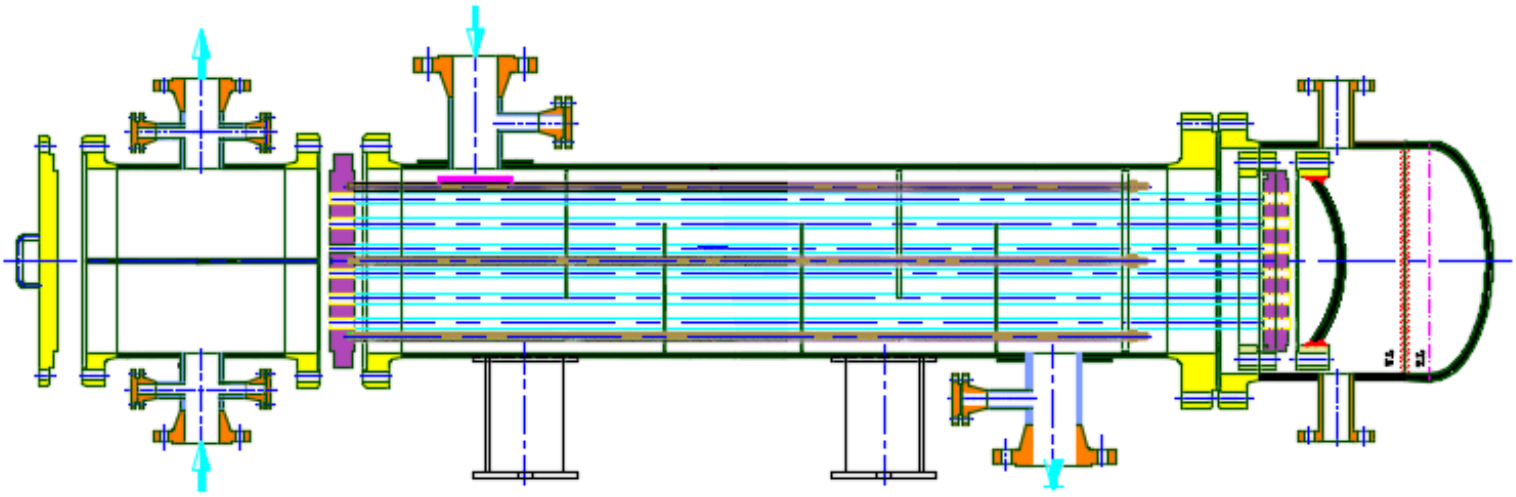
How to avoid internal bolt failure and fluid contamination in Shell & Tube Heat Exchangers used for sour service?



Typical Floating Head Heat Exchanger

In addition to various other configurations of Shell and Tube Heat Exchangers (Fixed & U-Tube), Floating Head type is the most widely used type heat exchanger for heating & cooling in the refinery process units. Floating head exchangers are configured very sophistically to accommodate the Thermal expansion / Contraction caused by the difference in temperature of Shell side & Tube side fluids. One side of the Tube-sheet is fixed between Girth Flanges and other side is fixed between Floating head assembly as shown in (Figure-1). This assembly allows free movement of fluids caused due to Thermal Expansion, hence the name Floating head Heat Exchangers.

Typical Floating head Shell and Tube Heat Exchanger can be designed as per ASME Codes & TEMA Standards. The material of construction of shell and tube side component including stud and bolt can be selected based on various process parameters such as pressure, temperature, material properties, corrosion allowance, stream composition etc...

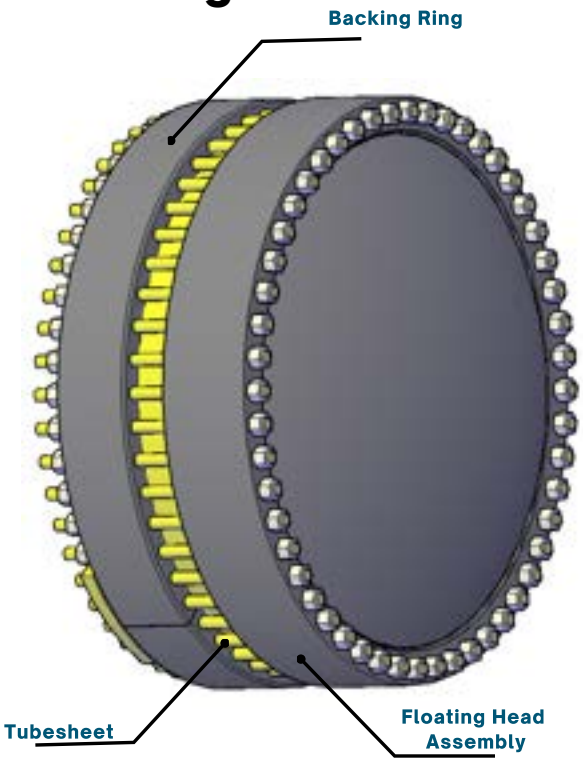
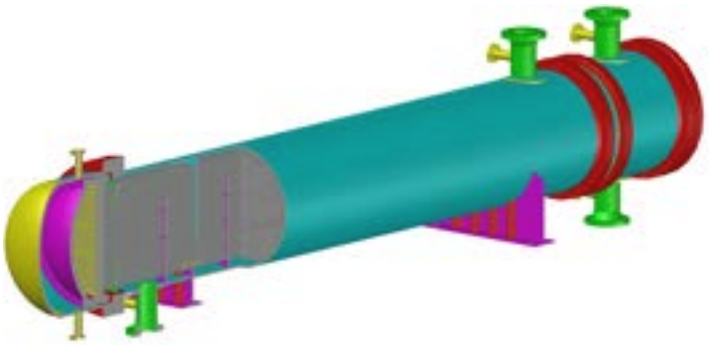


Figure-1

Often ASTM A193 Gr B7 bolts and ASTM A194 Gr 2H nuts are used in carbon steel shell and tube side components. In order to avoid bolt failures in wet H2S environment, ASTM A193 Gr B7M bolts and ASTM A194 Gr 2HM nuts are used in floating head flange, especially for sour services. The penetration of atomic hydrogen into the susceptible material could cause wet H2S damage. Further, the stream parameters such as pH, H2S concentration & its partial pressure, temperature, toxic contaminant like cyanide in the stream could cause potential damage to the fasteners. Also, metallurgical properties such as strength, hardness, and susceptible microstructure, steel cleanliness (inclusions and laminations) accompanied with residual and/or applied stress are the critical factors, which can contribute to the failure in wet H2S environment.

In AES shell/tube heat exchanger, floating head bolts are in contact with shell side stream. As mentioned above, the unfavorable environmental condition will crack the high strength bolts leading to cross contamination of shell and tube streams which also results in equipment outrage. Atmospheric distillation column overhead condenser in crude distillation unit, stripper overhead condensers in hydrotreater and hydrocracker, main column overhead condenser in fluid catalytic conversion unit are some of the exchangers designed with ASTM A193 Gr B7M bolts on floating head due to sour environment in its shell side. ASTM A193 Gr B7 bolts are used for floating head where H2S is not anticipated in the shell side stream.



AES Heat Exchanger

Case Studies

The following are the Case studies in refineries on failure of ASTM A193 Gr B7 floating head bolts in the past three years:

Case 1: Stabilizer Overhead condenser bolt failure in Diesel Hydro treating (DHDT) unit

DHDT unit stabilizer column overhead condensers are stacked AES type exchangers. Leak was suspected in floating head cover flange and hence, shell cover was dropped. Water filling was carried out in tube side pressurized. Leak was noticed (as shown in the figure-2) from the floating head flange due to shearing of B7 bolts (4 nos). Mix up of two grades was evidenced. ASTM A193 Gr B7 bolts were found in place of ASTM A193 Gr B7M bolts and hence, all Gr B7 bolts were replaced with Gr B7M bolts. Also, the gasket was replaced and tube and shell side hydro test was carried out and taken into service.

Figure-2

Case 2: Stabilizer overhead condenser bolt failure in Crude Distillation unit

During plant operation, traces of hydrocarbon (shell side fluid - LPG) were observed in cooling water (tube side fluid). On opening the shell cover, one ASTM A193 Gr B7 bolt was found cracked which paved way for LPG to cross contaminate with cooling water. Hardness of the failed bolt was measured to be 300 BHN (maximum). ASTM A 193 Gr B7M bolts were replaced with ASTM A193 Gr B7M and gasket was also replaced and ,hydrotested and equipment was taken online.

Case 3: Propane condenser bolt failure in Propane DeAsphalting (PDA) unit

Propane De-Asphalting (PDA) unit has propane condensers to condense propane vapor in De-Asphalted oil recovery section. Considering absence of H2S content in propane, AES S&T condensers were designed with ASTM A193 Gr B7 floating head bolts as mentioned in Bill of Materials (BOM) of exchanger general arrangement drawing. Yet, floating head bolts were sheared in-service. It was analyzed and found that H2S slippage in to shell side stream had caused the brittle failure of high hardness bolts (As shown in figure-3&4). All Gr B7 bolts were replaced with Gr B7M with new gasket, and equipment was hydro-tested and taken into service.

Figure-3

Figure-4

ASTM A193 Gr B7 vs ASTM A193 Gr B7M:

Chemical composition, Mechanical Properties and Heat treatment are compared in the following tables

Grade	ASTM A193 Gr B7	ASTM A193 Gr B7M
wt %		
C	0.37 min - 0.49 max	0.28 min - 0.49 max
Mn	0.65-1.1	0.65-1.1
P	0.035	0.035
S	0.04	0.04
Si	0.15-0.35	0.15-0.35
Cr	0.75-1.2	0.75-1.2
Mo	0.15-0.25	0.15-0.25

Properties	Size: M64 and below		Size: Above M64 to M100	
	Gr B7	Gr B7M	Gr B7	Gr B7M
Tensile strength, min, Mpa	860	690	795	690
Yield strength, min, Mpa	720	550	655	550
Elongation in 4D, min, %	16	18	16	18
Reduction in Area, min, %	50	50	50	50
Hardness (HB)	321 max	235 max	321 max	235 max

Grade	ASTM A193 Gr B7	ASTM A193 Gr B7M
Minimum Tempering temperature (°C)	593	620

The differences are highlighted and discussed as follows:

- Carbon content in Gr B7M can be as low as 0.28 wt% to achieve desired low hardness whereas in Gr B7 minimum carbon content shall be 0.37 wt%.
- Maximum Hardness permitted for Gr B7 is 321 HB whereas it is restricted to maximum of 235 HB for Gr B7M
- Irrespective of bolt size, Gr B7M can have minimum tensile strength 690 Mpa. However, Gr B7 minimum tensile strength shall be 860 Mpa for size M64 and below and 795 Mpa for size above M64 to M100. Most of the floating head bolt size in AES type exchanger is less than M64. Hence, B7M minimum UTS is 690 whereas Gr B7 minimum UTS is 860 Mpa.
- In Quenching and Tempering heat treatment operation, Tempering temperature for Gr B7M is 27'C higher than the minimum tempering temperature of Gr B7. The desired low hardness value in Gr B7M is achieved by higher tempering temperature.
- Also, for B7M, tempering heat treatment shall be final activity. All kind of Machining and forming activities shall be completed strictly prior to heat treatment operation as laid down by ASME procedure.

Recommended Practice:

The following are the recommended practices in Refinery Process units to avoid wet H2S cracking of floating head flange bolts in AES configured S&T heat exchanger

- To avoid mix up of Gr B7 and Gr B7M materials during routine maintenance of heat exchangers, separate lot for Gr B7M bolts shall be maintained in warehouse for floating head flanges and workmen shall be informed about the importance of using Gr B7M in floating head cover flange.
- Usage of ASTM A193 Gr B7M bolts as per drawing shall be ensured by 100% visual inspection during tube hydro-testing of AES type heat exchanger.
- Considering the possibility of H2S slippage into Shell side stream, it is wise to consider the usage of ASTM A193 Gr B7M bolts for all floating head in hydrocarbon service AES type exchangers even though ASTM A193 Gr B7 bolts are mentioned.
- During procurement of ASTM A193 Gr B7M bolts, Quality Assurance Plan shall insist upon Stage wise inspection of Hardness testing, Tensile testing, product marking etc and witness by Third party inspector in addition to in-house quality control team. It shall also be ensured that no machining and forming operation including cutting, thread rolling are carried out after heat treatment operation for Gr B7M.
- 100% Hardness testing for Gr B7M is supplementary requirement as per ASTM A193 standard specification. Considering the criticality, 100% hardness testing by Indentation method shall be made mandatory in the stage of procurement. The same shall be distinguished by bolt manufacturer in product marking by having a line under the grade symbol as B7M as mentioned in ASTM A193 standard.

Authors

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Hope you enjoyed the news letter and please stay safe !!