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ANALYSIS OF SERVICE PROBLEMS OF CAUSTIC TANKS INSTALLED IN OIL AND GAS PLANTS

ANALIZA PROBLEMA U RADU REZERVOARA ZA NATRIJUM-HIDROKSID INSTALIRANIH U NAFTNIM I GASNIM POSTROJENJIMA

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Abstract

The paper deals with the one of the most general classifications of atmospheric tanks according to their roof type in oil and gas plants. An overview of recommended periods of inspection of storage tanks is given, together with their structural characteristics. Upon irregularities in the process of water purification, the caustic soda tank is prematurely open for inspection. Visual inspection of the major elements, ultrasonic thickness measurements, penetrant tests of welded joints, and checking the functionalities: cathodic protection system, level controller, electric heater, are performed on the tank. On that occasion, it is noticed that the electric heater is found distorted and inoperative. The damaged heater made of Incoloy 800 is carefully removed from its holder and a new heater is welded to the holder by GTAW procedure. The necessary NDE is performed and required electric parameters after repair welding are confirmed.

Izvod

U radu je prikazana jedna od najopštijih klasifikacija atmosferskih rezervoara prema vrsti njihovih krovova u naftnim i gasnim postrojenjima. Dat je pregled preporučenih rokova za inspekciju rezervoara u skladu sa njihovim konstrukcionim karakteristikama. Usled uočenih nepravilnosti u procesu pročišćavanju tehnološke vode, rezervoar za natrijum hidroksid, koji pripada rezervoarima sa konusnim krovom, je otvoren za pregled. Tom prilikom obavljen je vizuelni pregled, ultrazvučno ispitivanje debljina, penetrantsko ispitivanje zavarenih spojeva, funkcionalnost sistema katodne zaštite i regulatora nivoa, te je uočeno da je električni grejač vrlo oštećen i nefunkcionalan. Oštećeni grejač, izrađen od Incoloy 800, je odsečen sa držača, a novi grejač je zavaren na postojeći držač postupkom TIG. Sprovedena su potrebna IBR i potvrđena je električna funkcionalnost pre ugradnje u rezervoar.

INTRODUCTION

Storage tanks are used to store fluids such as crude oil, intermediate and refined products, gas chemicals, waste products, water/products mixtures. Important factors such as volatility of the stored fluid and desired storage pressure and temperature result in tanks being built of various types, sizes, and materials of construction /1/. Storage tanks (often called atmospheric tanks) in the petroleum industry are normally used for fluids having a true vapour pressure that is less than atmospheric pressure. Vapour pressure is pressure on the surface of a confined liquid caused by the vapours of the liquid. Vapour pressure increases with temperature. Crude oil, heavy oils, gas oils, furnace oils, naphtha, gasoline, and non-volatile chemicals are usually stored in atmospheric storage tanks. Many of these tanks are protected by pressure-vacuum vents that limit the pressure difference between the tank vapour space and the outside atmosphere to a few millibars (ounces per square inch).

Non-petroleum industry uses of atmospheric tanks include storage of a variety of chemicals and other substances operated in closed-loop systems not vented to atmosphere and with pressure control and relief devices as required. These tanks may be designed and operated as low-pressure storage tanks according to the requirements of API 620 standard /2, 3/. Other uses of atmospheric storage tanks can include liquid (both hydrocarbon and non-hydrocarbon) storage in horizontal vessels, storage of process liquids or granular solids in skirt-supported or column-supported tanks with elevated cone bottoms (non-flat bottom) and process water/liquids in open top tanks.

In general, there exist many classifications of storage tanks according to many criteria, such as their dimensions, shapes, materials, their working parameters, etc.

Nowadays, one of very often parameters for storage tank classification can also be the type (shape) of their roofs. According to the type of roof, storage tanks can be classified in the following types, as mentioned below, /2/:
- storage tanks with cone roof (Figs. 1 and 2), /4/;
- storage tanks with umbrella roof;
- storage tanks with geodesic dome roof;
- self-supporting dome roof tanks;
- pan type floating-roof tank;
- annular pontoon floating-roof tank;
- double-deck floating-roof tank;
- cable supported internal floating roof tank;

- plain breather roof tanks;
- balloon roof tanks;
- tank with vapour dome roof;
- welded horizontal tank supported on saddles;
- plain hemispheroidal storage tanks;
- noded hemispheroidal storage tanks;
- plain spheroidal storage tanks;
- plain hemispheroidal with knuckle radius storage tanks;
- noded spheroidal storage tanks, /2/.

Between previously mentioned types of storage tanks, the most common used type of atmospheric tank in oil and gas plants is the storage tank with cone roof primarily due to its simplicity of construction. These types of tanks have many purposes in the process industry and one of these purposes is for caustic soda storage. The fact that problems of tanks used for caustic soda storage in available literature have not been sufficiently researched is the main goal of the paper, particularly problems appearing in these tanks to be recognised at the right moment and properly analysed.

Figure 1. External view of tank with cone roof.

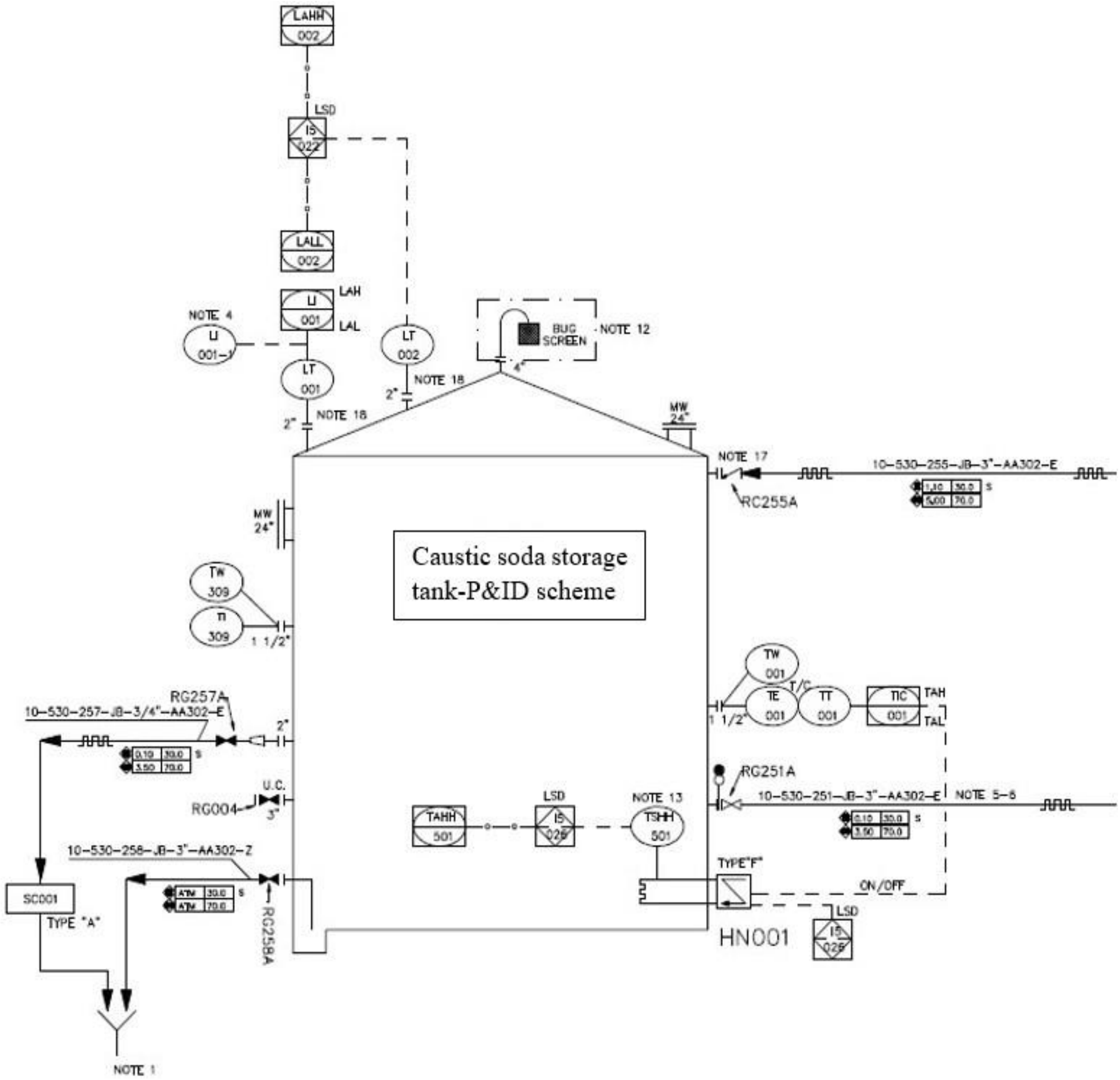

Figure 2. Piping and instrumentation diagram (P&ID) of operating caustic tank.

USE OF CAUSTIC TANKS IN OIL AND GAS PLANTS AND REASONS FOR INSPECTION

Generally, in most process plants technological water is used for cooling or heating appropriate process fluids. For that occasion, in the sense of avoiding limescale on internal piping surfaces, pressure vessels, storage tanks, and heat transfer surfaces of heat exchangers (that sometimes can lead to clogging of the tubes, or stopping water flow in tubes), clean and softened water is used. Additionally, it should be highlighted that practically in all plants, especially older process plants, adding of water take places permanently. Having this in mind, a unit is installed in most oil and gas plants used as a regular leading process of water preparation in a long time period obtaining desired quality. Usually, this unit is a demineralisation unit where water is usually treated by osmosis processes, diffusion processes, or by caustics water treatment or process streams. In this paper, we limit ourselves to the part of the unit in which water preparation by injecting caustic takes place for softening. Within the framework of this unit a cylindrical tank is installed (with a cone roof) where preparation of 50 % caustic solution takes place. Namely, through the nozzle on top of the tank, the caustic solution of around 40 % is introduced and is heated to a required operating temperature in the range 30-40 °C, followed by introducing a higher strength solution for obtaining the required caustic solution of 50 %. Heating of the solution is provided by an electric heater installed at the bottom of the tank. The electric heater is made of Incoloy and consists of three independent U-shape heaters. Usually in the winter all three heaters work continually, while in the summer, especially in the morning hours, one heater is in service. The prepared solution is drained through the nozzle at the bottom of the tank and is further distributed to other tanks and the basin for further use in the water purification process. Solution flow is provided by caustic pumps located outside the tank bank in a separate curbed area connected to the appropriate neutralisation basin.

DAMAGE MECHANISMS

The most common damage mechanisms in metal tanks used for storing caustic (alkaline) solutions such as NaOH and KOH are caustic corrosion and caustic stress corrosion cracking.

Caustic corrosion is usually manifested as localised corrosion due to the concentration of caustic solutions, and/or corrosive salts from these solutions that usually occur under evaporative or high heat transfer conditions (commonly called caustic gouging). Also, corrosion resulting in general thinning can occur at elevated temperatures, depending on the alkali or caustic solution strength.

Commonly alkaline corrosion attacks carbon steel, low alloy steels, and 400 series stainless steel, but here we highlight that carbon steel is the material most commonly used in situations where caustic soda is of concern. Caustic gouging is typically characterised by localised metal loss that may appear as grooves or locally thinned areas under insulating deposits. Corrosion of carbon steel in the high-concentration caustic at elevated temperatures will be generalised but likely confined to the location of high temperature such as areas near high heat transfer and poor water circulation.

On the other side, caustic stress corrosion cracking (CSCC) is characterised by surface-initiated cracks that occurs in piping and equipment exposed to caustic (alkaline hydroxide) solutions at elevated temperature, primarily adjacent to non-post weld heat treated welds. It is a form of alkaline caustic stress corrosion cracking. The temperature above which CSCC occurs depends on the concentration of the caustic solution. Usually CSCC attacks carbon steel, low-alloy steels, and 300 series stainless steel. Susceptibility to caustic SCC in caustic soda (NaOH) and caustic potash (KOH) solutions is a function of caustic strength, metal temperature, and stress level.

CSCC can occur in non-stress relieved piping and equipment that handles caustic, including H_2S and mercaptan removal units, as well as in equipment that uses caustic for neutralizing in sulphuric and HF alkylation units. In addition, we highlight that CSCC can occur in equipment as a result of steam cleaning after being in caustic service.

Caustic SCC typical propagates parallel to the weld adjacent to the base metal. i.e., in the zone of highest welding residual stress, but can also occur in the weld deposit, or HAZ, and can be transverse to the weld.

The pattern of cracking observed on the steel surface is sometimes described as a spider web of small cracks that often initiate at, or interconnect with weld-related flaws that serve as local stress risers.

Here also should be highlighted that cracks sometimes must be confirmed through metallographic examination. Cracks are typically branched and predominantly intergranular. Cracking that occurs in as-welded carbon steel typically appears as a network of very fine oxide filled cracks, /5-6/.

INITIAL INTERNAL OVERVIEW INTERVAL

Most commonly used standards in the industry for the design of storage tanks are API 620, API 650, and EN 14015 standards. The most often standards and the guides for tank examination are API 575, API 651, API 652, API 653, and EEMUA publication 159. It should be mentioned that API 651 standard gives recommendations for cathodic protection, and API 652 gives recommendations related to linings of above ground storage tank bottoms. Both of these items are included in the calculation period for inspection which is in detail described in the API653 standard. The interval from initial service date until the first internal inspection shall not exceed 10 years unless a tank has one or more of leakage prevention, detection, corrosion mitigation, or containment safeguards listed in Table 1. The initial inspection overview date shall be based on incremental credits for the additional safeguards in Table 1 which are cumulative. The initial overview interval shall not exceed 20 years for tanks without a release prevention barrier, or 30 years for tanks with a release prevention barrier.

As an alternative to establishing the initial interval in accordance with the previously mentioned, and to Table 1, the initial internal examination and reassessment can be established using RBI inspection assessment, /7-8/.

Table 1. Calculation of tank inspection intervals according to tank additional protection.

No	Tank additional protection	Add to initial interval
1	Fiberglass-reinforced lining of the product side of the tank bottom installed per API 652	5 years
2	Installation of an internal thin-film coating as installed per API RP652	2 years
3	Cathodic protection of the solid-side of the tank bottom installed, maintained, and inspected per API RP651	5 years
4	Release prevention barrier installed per API 650, Annex I	10 years
5	Bottom corrosion allowance greater than 0.150 inch	(Actual corrosion allowance-150 mils) /corrosion rate*
6	Bottom constructed from stainless steel that meets requirements of API 650, Annex SC, and either Annex S or Annex X; and internal and external environments are determined by a qualified corrosion specialist to present very low risk or cracking or corrosion failure	10 years

* Corrosion rate to be 15 mpy, or as determined from Annex H, Similar Service.

STORAGE TANKS EQUIPPED WITH LININGS AND/ OR CATHODIC PROTECTION SYSTEMS

The mostly used standards in industries related to cathodic protection systems are ISO 12473, ISO 12696, ISO 12954, BS-EN 14505, ISO 15589, EN 16299, IS8062-2 DNV-RP-B401, BS 7361, SP 0408, AWWA-D106-20, AMPP 21520: 2023, API 651, ASTM-G97-18, AZ/NZS-2832-1. Taking into account that the caustic tank is installed in an oil and gas plant, our further analysis is based on the main principals mentioned in the latest edition of API651 standard. Hence, when internal corrosion is experienced or expected, tanks can be lined with a variety of corrosion resistant materials such as coatings of epoxy or vinyl, fiberglass poured or sprayed concrete, alloy steel, aluminium, rubber, lead, synthetics as HDPE or Hypalon, and glass.

Cathodic protection (CP) systems are often provided for control of external bottom corrosion, and combined with internal linings, may also be used to protect the tank bottom internally, /1/. CP is a technique for preventing corrosion by making the entire surface of the metal to be protected as a cathode of an electrochemical cell. There are two systems of cathodic protection - galvanic anode and impressed current cathodic protection. A general scheme of a cathodic protection system with impressed current is shown in Fig. 4, /10/.

In addition, cathodic protection systems with impressed current generally can be classified according to the depth of installation of sacrificial anodes such as shallow anode bed installation and systems with deep anode bed. These systems are presented in Figs. 5 and 6, /12/.

DESIGN DATA AND DIMENSIONS OF CAUSTIC TANK

Caustic tanks belong to the group of storage tanks with cone roofs of carbon steel. Review of design data, main sizes and materials from which tanks are fabricated are presented in Tables 2 and 3, /4/.

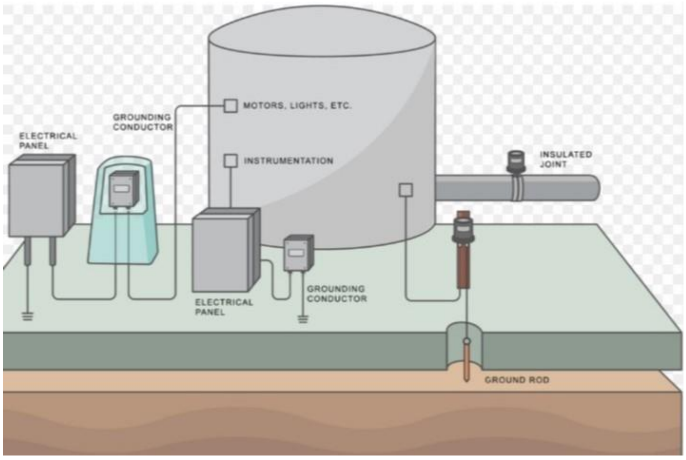

Figure 4. Cathodic protection system with impressed current.

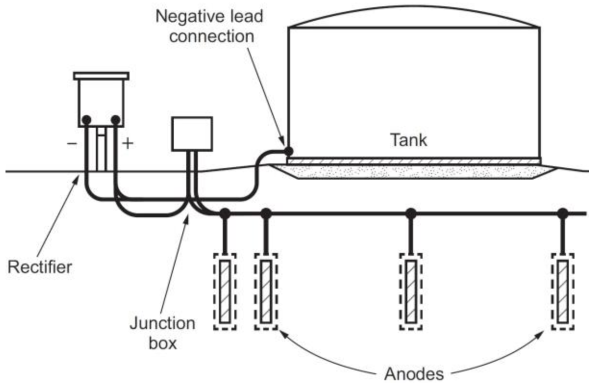

Figure 5. CP-systems with shallow anode bed.

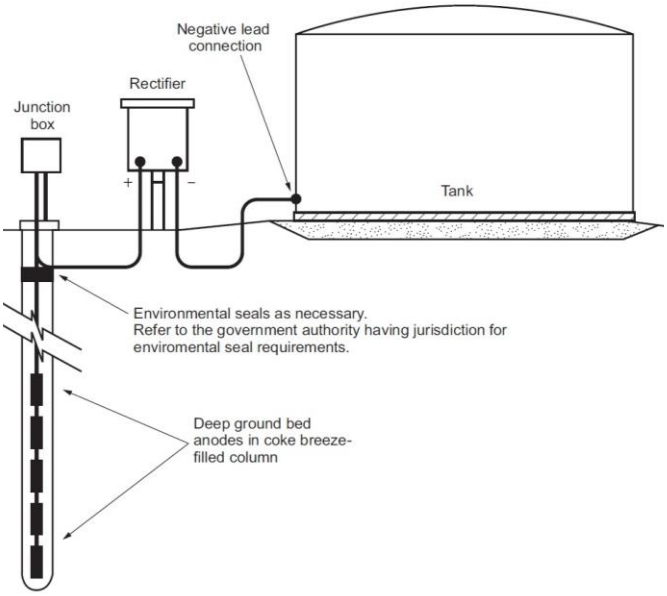

Figure 6. CP-systems with deep anode bed.

Table 2. Design data of the caustic storage tank.

No	Item	Value	Parameter
1	Geometric capacity	34.0	m^3
2	Network capacity	20.0	m^3
3	Tank inside diameter	3000	mm
4	Tank height	4800	mm
5	High high level	4225	mm
6	High level	4025	mm
7	Low level	1225	mm

8	Low level	1025	mm
9	Concentration of content	50.0	%
10	Operating temperature	30.0	°C
11	Specific gravity	1.560	-
12	Operating pressure	Atmospheric	-
13	Design temperature	70.0	°C
14	Design pressure	+35/-25	mmAq
15	Pumping rate-in	10.0	m^3/h
16	Pumping rate-out	10.0	m^3/h
17	Tank-corrosion allowances	3.00	mm
18	Roof type	Cone roof	-
19	Bottom slope	1/100	Cone up
20	Seismic factors	Z=0.15, I=1.25	-
21	Design wind velocity	145.0	m/h
22	Painting (exterior)	yes	-
23	Lining (interior)	no	-
24	Design standard	API 650	10^{th} ed.

Table 3. Design data at the storage tank.

Item	Design material	Design thickness
Roof plates	ASTM A36M	8.00 mm
Shell (Course number 2)	ASTM A36M	5.00 mm
Shell (Course number 1)	ASTM A36M	5.00 mm
Bottom plates	ASTM A36M	9.00 mm

INSPECTION OF THE CAUSTIC TANK

Periodic in-service inspection of tanks shall be established after installation of equipment on appropriate position in the plant. The purpose of this inspection is to assure continued tank integrity. The initial external/internal inspection and the interval between inspections is usually determined according to the requirements of relevant standards (such as API 575 and API 653) that should be determined by its service history unless special reasons indicate that an earlier inspection must be made.

In addition, jurisdictional regulations in some cases control the frequency and interval of inspections. Regulations may include vapour loss requirements, seal condition, leakage, proper diking, and repair procedures. Knowledge of such regulations is necessary to ensure compliance with scheduling and inspection requirements. If any provision of this standard presents a direct or implied conflict with any statutory regulation, the regulation shall govern. However, if requirements of this standard are more stringent than the requirements of the regulation, then requirements of this standard shall govern.

The caustic tank whose integrity is analysed in this paper has been put to service before 19 years, and initial internal inspection interval is calculated according to the requirements of API653. Hence, the calculated internal overview interval (IOI) from initial service (taking into account values from Table 1):

- Design code: API Standard 650-10^{th} Ed.
- Working medium properties: high corrosive and toxic
- Release barrier: no; Lining interior: yes
- Cathodic protection system: yes
- Bottom plate thickness: 9.0 mm = 0.354 inch
- So, credit for initial bottom thickness when the thickness is higher than 0.25″ will be: (0.354 – 0.250)/0.015 = 6.93 years.

Finally, the internal overview interval (IOI) from initial service: IOI = 10 years (initial) + 2 years (internal thin film) + 5 years (cathodic protection system) + 6.93 years (credit for initial bottom thickness) = 23.93 years.

Taking into account requirements of API 653 for storage tanks without release barrier, the maximal interval for initial internal inspection is 20 years, this value was adopted as the main value, /10/.

Although initial internal inspection is planned after 20 years after putting the tank in service, observed irregularity in the process, such as limescale on some heating surfaces of the shell and tube heat exchangers (manifested as increased pressure drop, especially in the winter period), and on the piping in the cooling tower, required premature opening of the tank for detailed inspection, /10/. This inspection included: external and internal visual inspection of main metal elements, ultrasonic thickness tests, penetrant testing of welded joints, functionality of the cathodic protection system, functionality of level controller and checking the electric heater functionality. Within the frame of visual examination, external and internal metal surfaces were checked, and the status of instrumentation equipment. On that occasion caustic rust (corrosion) was observed in its initial phase (Figs. 7 and 8).

Figure 7. Caustic corrosion observed in the initial phase.

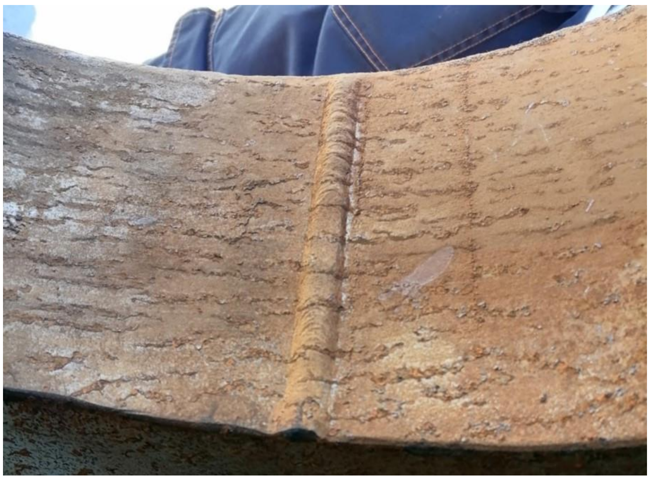

Figure 8. Caustic corrosion observed in the initial phase.

Also, considering the fact that these welded joints are prone to CSCC, cleaning and penetrant testing of welded joints was performed. Fortunately during this research, cracks have not been noticed (Figs. 9 and 10).

Figure 9. T-welded joint after cleaning and preparation for PT.

Figure 10. T-welded joint after developer spraying (no cracks).

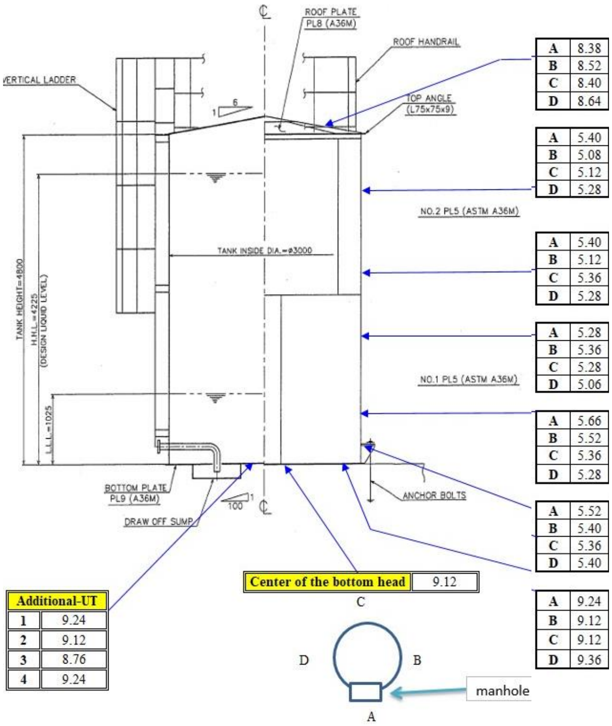

Figure 11. Scheme of performed ultrasonic measuring.

Further analysis included performing ultrasonic thickness measuring by flaw detector. Here it should be highlighted that calibration of the flaw detector is conducted by using carbon steel step wedge with the range 0-25.0 mm in steps of 6.25 mm. Ultrasonic measuring is conducted according to the previously prepared measuring scheme respecting the positions of internal elements (Fig. 11). A reduced thickness in the tank bottom, in area near draw off sump was noticed. Based on that, CR (short time) corrosion rate is calculated and the appropriate remaining life of storage tank, /10/:

- CR(ST) = $(i_{initial} - t_{actual})$/(years in between) (1)
- Remaining life = $(t_{actual} - r_{required})$/Relevant(CR) (2)

For our case:

- CR(ST) = (9.0 – 8.76)/(6 years) = 0.04 mm/year
- Remaining life = (8.76 – 6.0)/0.04 = 69.0 years.

The following part of tank inspection also included examination of functionality of the cathodic protection system. On that occasion, the functionality of junction boxes and measuring devices for electric parameters in the cathodic protection - cabinet was checked.

The insight into the condition of the main elements and the checking of parameters in the cabinet has concluded that the cathodic protection system is still working properly.

Based on the previous readings of electric parameters has led to the conclusion that the remaining life of sacrificial anodes is still long. During tank inspection, also checking of instrument equipment functionality was performed. Taking into account that caustic soda is very aggressive and that its leakage can have large consequences on the people occupied and around equipment, the level controller functionality was especially checked. The level gauge was raised/ lowered and electric parameters on screens for confirming appropriate functionality were simultaneously checked in the control room. It is highlighted that storage tanks for storing aggressive substances are usually equipped with two level gauges for needs of providing the exact level of substance in each moment, in the sense of avoiding leakage into the environment (Fig. 12).

Figure 12. Level gauges in the caustic tank.

Further analysis for determining the root cause of problems with the water purification process included inspection of the electric heater, used for heating caustic soda solvent to a proper temperature and its injection in the process piping in the sense of softening the water and avoiding creation of limescale on internal surfaces of processing equipment. The electric heater, fabricated from INCOLOY 800 material, is found distorted and inoperative, while checking the electric parameters (Fig. 13).

Figure 13. Electric heater found distorted and inoperative.

RESTORING THE INCOLOY800 ELECTRIC HEATER

After a detailed checking of relevant electric parameters while the electric heater was installed on the tank, it was removed and in a free position, electric resistance measurements were performed. On that occasion, the measured value was around 0.0 MΩ, so it led to conclude that the electric heater is totally inoperative, and the distortion of the heater led to internal ceramic breaking, being an integral part of the heater. Therefore, the electric bundle was removed from the holder by cutting. Considering the fact that caustic soda is a very aggressive substance and spilled from the tank is catastrophic to the surrounding concrete, equipment, and people, a detailed visual and penetrant inspection of the holder was performed in the sense of finding potential irregularities and caustic soda stress corrosion cracking. After a confirmation that cracks have not been detected, a new electric bundle is introduced and welded to appropriate spacers. Regarding that the electric heater is fabricated from Incoloy 800 and that the ceramic shell thickness is 1.50 mm, the GTAW welding procedure was selected, (Fig. 14).

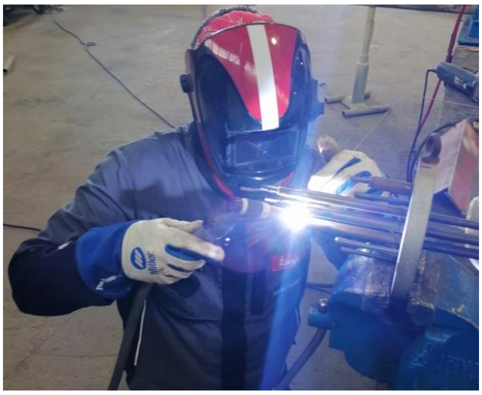

Figure 14. Repairing of the electric heater.

The GTAW welding procedure is selected in the sense of avoiding burn through of Incoloy 800 and fracture (cracking) of internal ceramic due to high temperature, because of the low heat input. After completing the connection of electric heater to the holder, the penetrant tests of the fabricated welded joints were performed, and the leak test (Fig. 15).

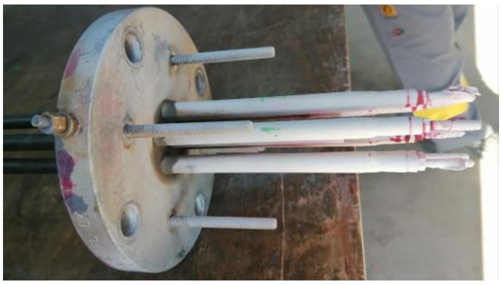

Figure 15. Penetrant test of electric heater.

The leak test was performed to confirm 100 % sealing of heater in the holder. Electrical resistance measurements of electric bundle confirmed heater functionality.

CONCLUSIONS

The paper deals with problems related to the long time service storage tank for caustic soda solvent. Due to appearance of limescale on internal surfaces of process equipment and increased pressure drop at heat exchangers, it was observed that the demineralisation unit for water purification is not working properly, especially in winter. Hence, in the sense of finding the root cause for observed process problems, the caustic tank was opened prematurely for inspection. Apparently, visual inspection, ultrasonic thickness measuring, penetrant testing in the sense of CSCC, and functionality checks of the main instrument equipment and electric heater, were performed. On that occasion it was noticed that the electric heater made of Incoloy 800 was found distorted and inoperative, being the main cause of the irregularity in the process of water purification. The existing electric bundle was removed from the holder and a new Incoloy 800 electric bundle was welded to the holder by GTAW. After repair welding, penetrant tests of welded joints, leak tests, and tests of the electric heater functionality were performed. Measured values of electric resistances of individual bundles confirmed the success of repair welding activities.

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