Journal of Trends in the Development of Machinery and Associated Technology
Vol. 18, No. 1, 2014, ISSN 2303-4009 (online), p.p. 91-94

INTEGRITY ASSESSMENT OF ABOVEGROUND OIL STORAGE TANKS DUE TO THE CORROSION METAL LOSS

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ABSTRACT
The corrosion is one of the major degradation mechanisms of aboveground oil storage tank steel structures. Therefore, for tanks in long-term service, a major issue becomes loss of thickness close to, or below, minimum acceptable values, as well as loss of sufficient stabilizing weight. Also, a required corrosion allowance for new designed tanks, as well as remaining corrosion allowance for existing ones, present important parameter. Of course, corrosion allowance is mostly limited depending on tank service condition and design service life or inspection intervals. In addition, installation of appropriate cathodic protection system plays significant role, both for new or existing tanks with extended service. Thus, the paper will show major corrosion degradation processes with some project samples on main aboveground oil storage tank components: bottom, shell and roof. Furthermore, the major aspects of integrity assessment procedure and acceptance criteria, based on recognized international standards, shall be discussed.

Keywords: keyword 1, keyword 2, keyword 3 (Times New Roman, 11-pt.)

1. GENERAL ABOUT OIL STORAGE TANKS

A vertical-aboveground oil storage tanks (OST) are major elements of any oil terminal (e.g. tank farm), and they are designed, fabricated and erected as welded structures in accordance to rules of various standards, codes or specification. Among several, to most used are American API 650 and European EN 14015. Beside various types and functional properties, a OST may have fixed or floating roof, or combination of two; or OST may work under atmospheric (close to 0 mbar) or increased design pressure (max. 172mbar, but not higher than 500mbar). However, precise definition are provided in reference design standards [1,2].

The main components of OST, as welded structure, are bottom, shell and roof. Of course, for proper functional and safe operation, a one OST must have installed other necessary items, such as processing nozzles, connecting pipework, fire-fighting system, various instrumentation and venting valves, stairways and handrails, and finally corrosion protection system. As base materials, carbon structural steels are predominantly used [1,2,3]. Of course, designer may select higher strength structural steel, particularly for shell, when technological and economic requirements dominate. When considered sizes, OST may have diameter over 60m, and height up to 20m, or nominal capacity even larger than 60.000m^3 which may require more than several hundred tons of as-build steel structure.

While considering design phase, OST designers must consider various type of loads, but most influential are hydrostatic and internal (vapor) pressure, wind load and seismic load [1,2,4].

Here, all checks to normal and emergency load combination include thickness of base material less any corrosion allowance (CA). Therefore, it is important to consider appropriate value of CA in [mm] for any part of OST structure in combination with predicted corrosion protection system (CPS) and type of stored product and environment condition. Of course, CPS consists of active and passive protection, e.g. cathodic protection and surface coating of welded structures. Therefore, complete CPS may guarantee reliable and safe exploitation life of OST; of course only based on corrosion degradation mechanism [1,2,5,6].
In addition, particular design issue presents provision of sufficient stabilizing (dead) weight of complete OST welded structure. Contrary, extreme load combination condition, represented with seismic and wind load, including internal pressure may destabilize OST by mean of overturning moment. Such load combination is conservative design assumption. Also, all required stability checks and condition consider base material thickness less any CA. Obviously, OST must have sufficient stability both in as-build (new) and in corroded condition. Thus, one of unfavorable condition for integrity assessment arises, if OST suffer more than predicted corrosion damage [1,5,6].

2. CORROSION OF TANK COMPONENTS

Corrosion of OST welded structures may appear in various types of mechanisms and intensity. Of course, for OST the most dominant are uniform and pitting corrosion (Fig. 1), beside some particular types related to stress corrosion and rather aggressive products (such as ones containing H_2S). Whatever, the major issues related to corrosion, regarding integrity of OST are [7,8]:

- Loss of sufficient material thickness and further rise of stress state as well as loss of stiffening.
- Appearance of holes and penetrations which further cause leakage and loss of product.
- Loss of sufficient stabilizing weight to resist overturning (wind and seismic) loads.

Appearance of complete tank corrosion (shell + roof)

Corrosion products as sign of bottom perforation

Pitting holes on roof plates close to bad welds

Pitting on shell support due to the bad welds

Figure 1. Typical smaples of corrosion degradation on OST

A most intense corrosion is found on OST areas where pure or insignificant CPS exists, or particularly where coating layers are damaged or totally absent. So, in extreme cases, where pure maintenance practice are applied, as-build OST of original 60 tons weight may loss up to 6 tons (10% of total weight) due to the corrosion degradation in exploitation period of 20-30 years, which may correspond to average 0,05-0,10 mm/year corrosion rate. Of course, it does not mean that CA for new tanks in similar condition should be high as 3 mm.

Regarding structural integrity of OST, the most dangerous are corrosion of shell and annular ring, while product leakage is mostly caused by corrosion of central bottom plates. Also, intensive corrosion may appear on roof plates (both internal and external) and on roof supporting structure or generally in vapor space. Here, roof plate corrosion does not need to be particularly related to structural integrity as it is rather an environmental issue. Of course this is not a case for roof supporting structure, which may loss sufficient load-caring capacity and possess serious threat to structural integrity. For some products which may contain impurities and water, an intensive corrosion may appear in bottom area, and which is even more dangerous in area of shell-to-bottom joint. Here, appropriate OST design solution should enable proper drainage of all non-product residuals [1,5,6,8].

3. MAJOR PRINCIPLES OF INTEGRITY ASSESSMENT DUE TO THE CORROSION

A detailed recommendation and guides to assess structural integrity of OST are provided in reference standards, such as API 653 and EEMUA 159 [5,6]. Here, user must distinguish between outside inspection (OST in-service), and combined outside + inside inspection (OST out-of-service). During such inspection activities, which is periodically required, a broad range of non-destructive testing (NDT) must be performed. The main goals of such NDT are:

- To determine remaining thickness, generally by mean of ultrasonic thickness measurement (UT), of main tank components (shell, bottom and roof).
- To assess tank components for any abnormal condition, such as appearance of cracks or other material imperfection, intense deformation, or foundation settlement.

Because, main problem related to corrosion is loss of sufficient thickness, a minimum acceptable values, as acceptance criteria, must be determined prior to inspection. Here, rules are similar such as for design principles. Generally, OST bottom consisting of annular ring and central bottom segment must have at least 4,5 mm and 2,5 mm plus any possible CA, respectively. Particularly for annular ring, sufficient thickness is also required to resist stresses due to the seismic loading. Further, OST roof plates must have at least 2 mm plus any possible CA, while 25% original thickness loss is maximum allowable for roof supporting structure [5,6].

Of course, the shell, as major part of OST must have sufficient thickness to resist hydrostatic loading. Therefore minimum allowable thickness, t_{min} [mm]; is determined based on product height (considering for each shell course), H [m]; OST diameter, D [m]; maximum allowable material stress, S [MPa]; product specific gravity, G [-]; internal design pressure, p [mbar]; also sometimes original joints efficiency, E [-]; and finally any possible CA [mm]; [6]:

$$t_{\min} = \frac{D}{20 \cdot S \cdot E}\left(98 \cdot G \cdot \left(H - 0{,}3\right) + p\right) + CA \qquad \text{... (1)}$$

Obviously, beside H, D, G and p which are well known for any OST, as well as generally E=1 for plates outside joints (e.g. welds), a major issues become knowing of base material, e.g. S, and proper selection of any possible CA. Actually if all other variables are known, CA should be selected based on OST service history, or as OST user (client) requirement, or just extracted as any possible value based on positive difference between average UT measured value, t_{av} [mm], and calculated, t_{min}, form term (1) (without CA). However, if t_{av} is less than t_{min}, beside there is no any possible CA, remaining shell course thickness is not acceptable.

In any case, proper selection of CA is required for “provision” of sufficient remaining life, RL [year], of OST component based on assumed corrosion rate, CR [mm/year]. Here, assumed CR must be based on OST previous service history and existing or new applied CPS. Also, RL must not be less than first predicted in-service inspection of repaired tank.

Of course, general recommendation of in-service and out-of-service inspections intervals are clearly provided in reference standards. Therefore, while routine in-service inspection, based on visual testing (VT) and proper UT, when required, should be every 3 months; a more detailed out-of-service inspection, based on VT, UT and additional particular NDT methods for OST interior (such as for tank bottom) should be every 1-20 year based on stored product and environmental condition [5,6].

Once the remaining thickness are evaluated, and in particular when they are accepted or selected for proper repair method, complete OST must evaluated for sufficient stabilizing weight, less any predicted CA for each OST component. Here particularly, sufficient OST weight is required to resist overturning moment due to the wind load, because worst case scenario is based on empty OST (without any product stored). Otherwise, OST must have proper anchorage. In addition, OST must be checked for sufficient stiffness due to the wind load. Here, a sufficient wind girders must be provided (either be mean of existing ones, or additional – new secondary wind girders).

Finally, all required evaluation steps and calculations may be iterative, as long as all required acceptance criteria and checks are fulfilled. Of course, repair methods for any OST component is based on reinforcement of loss thickness, either by build-up welding, patch plates welding, butt-weld insert plates, complete new plates reinstallation, or by mean of cold welding or build-up (such as metal particles reinforced epoxy). Which repair method should be selected depends on level of degradation, by mean of size, location and evaluated thickness loss [5,6].

4. FINAL REMARKS

Any readers must be aware that provided principles in this paper are general and for introduction only. Of course, detailed principles are provided in references technical regulations [5,6].

However, during its service life, OST may suffer from various degradation mechanisms, which among many, corrosion is most influential. Therefore, three major concerns related to corrosion arise for any OST: (1) increase of stress state, (2) loss of stiffness and (3) loss of sufficient stabilizing weight. Of course, once any OST is properly inspected and evaluated, a various repair methods are available, or as in most unfavorable case OST must "retired" (when complete repair cost is not economically beneficial).

For definition of any reliable remaining service life after repair, or interval of first out-of-service inspection of OST, a sufficient CA must be determined (or selected). Here, definition of CA is strongly dependent on existing or newly design CPS. Otherwise, if there is no possibility to extract or select any future CA for OST, there is no reasonable base for definition of any remaining life. Obviously, this is a fact which must be considered clearly within design of new tanks in combination with proper inspection and maintenance plans of any OST.

5. REFERENCES

[1] API 650, Welded Steel Tanks for Oil Storage, American Petroleum Institute, 2011.

[2] EN 14015, Specification for the design and manufacture of site built, vertical, cylindrical, flat bottomed, above ground, welded, steel tanks for the storage of liquids at ambient temperature and above, CEN, 2004.

[3] I. Hajro, D. Hodžić; Basic comparison of selected structural steel strength influence on total welding fabrication costs of oil storage tanks, Proceedings of 12th International research/expert conference on trends in the development of machinery and associated technology: TMT 2008, Istanbul, Turkey, 26-30 August, ISBN 9958-617-21-8, 2008.

[4] N. Dan Felician, P.M. Sabin, Material selection and corrosion resistant alloys for petroleum industry, Proceedings of 17th International research/expert conference on trends in the development of machinery and associated technology: TMT 2013, Istanbul, Turkey, 10-11 September, ISBN 9958-617-21-8, 2008.

[5] API 653, Tank Inspection, Repair, Alteration, and Reconstruction, American Petroleum Institute, 2013.

[6] EEMUA 159, Users' Guide to the Inspection, Maintenance and Repair of Above Ground Vertical Cylindrical Steel Storage Tanks, EEMUA - The Engineering Equipment and Materials Users' Association, 2003.

[7] API 575, Inspection of Existing Atmospheric and Low-pressure Storage Tanks, American Petroleum Institute, 2005.

[8] API 571, Damage Mechanisms Affecting Fixed Equipment in the Refining Industry, American Petroleum Institute, 2003.