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SELECTION OF THE OPTIMUM NDT METHODS FOR DETERMINATION OF STEAM BOILER REMAINING LIFE

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ABSTRACT

During the lifetime of any industrial equipment, including steam boilers and pressure vessels, it may be required, for various reasons, to estimate its remaining service lifetime. The operation of steam boilers is a complex process resulting in metal fatigue due to temperature cycling and pressure fluctuation, as well as in erosion and chemical depositions. Thus, during boiler operation, various flaws appear, such as cracks in locations of high mechanical stress and wall thickness reduction due to corrosion or erosion. This work aims to assist the engineering consultant to select the best available non-destructive technique (magnetic particles, X-rays, ultrasonics etc.) to estimate the remaining life of steam boilers. The methodology chosen for this purpose should cause as little process disruption and downtime as possible, while it must not affect the physical integrity and mechanical strength of the boiler.

***Keywords**:* Steam boiler

1. Introduction

There are several standard NDT (Non Destructive Testing) methods to examine the quality and condition of materials and joints at the stage of new pressure equipment manufacturing as well as during the operational lifetime of any industrial pressure equipment. However, while in new pressure equipment the methodology is well defined, in existing pressure equipment the methods to be used are dependent on various factors as: acceptable outage of the equipment, kind of process supported by the pressure equipment, type of equipment or item to be examined, fuel used, short term (daily) cycling, etc.
This work aims to assist engineering consultants dealing with pressure equipment to decide which method should be used at each specific case, to achieve best diagnosis on the equipment damage and, thus estimate the remaining life of the boiler and its components and prevent possible accident.
The examination gives two types of information:

- Global or large scale reduction of wall thickness – this is the critical factor determining the remaining life, as in case of reduced thickness the only two options are either de-rating the equipment (in terms of pressure and temperature) or scrapping.
- Localized flaws (cracks in welded joints, erosion of individual tubes etc). They affect currently the safe operation, but usually can be repaired.

The methodologies described here apply to standard industrial equipment. Special equipment in nuclear power service is tested at regular intervals according to well-defined, strict procedures and is not considered in this presentation.

2. Methodology and planning

The main parameters that affect selection of testing methods for existing operational equipment are:

- Limited accessibility inside most types of equipment. Manholes do exist in shells and drums but they are often too narrow (typical size of 300x400 mm) and obstructed.
- Limited local accessibility at specific critical locations of the equipment.
- Limited available time, if the equipment is in regular service.
- External metal surfaces are usually insulated and the owner is unwilling to remove the insulation, if it has not deteriorated.
- Exposed external metal surfaces are usually covered with a few layers of protective paints.
- Radiography and, especially, isotope γ-ray radiography, is not acceptable for boilers in the food, drinks and tobacco industries.
- The cost of in site NDT must not be very high.

The most used NDT methods are radiography (RT), either X-ray tubes and γ-ray isotopes, magnetic particles (MT), liquid penetrants (PT) and ultrasonic thickness (UT) measurement.
Of these methods, radiography (and lately some types of ultrasonic equipment) produce records for later reference, whereas ultrasonics, magnetic particles and liquid penetrants methods provide only temporary indications and they are very much dependent on the inspector's experience.

3. Personel skills

Most NDT methods are heavily dependent on personnel skill, training and experience, therefore, personnel conducting NDT methods should be well trained. It is recommended that personel involved in the assessment is also independently certified, preferably according to EN 473, by an accredited certification body. Personnel training and certification is usually described as Levels I, II or III. Maintaining a pool of trained and certified personnel (with 2 to 5 methods per person) is the major cost for inspection bodies in small markets.
Typically engineers are expected to be certified at Level III for radiography interpetation plus one of the other methods. Each technician is expected to be certified to Level II for 2 to 5 methods. The combined skills of all personel should cover the scope of methods required for these tests.

4. Recommended Methods and Procedures

Different NDT methods are recommended for sheet metal, tubes and welds. A very important factor in the choice of NDT method is accessibility of the exact location under investigation for testing personnel. An overview of the recommended methods is shown in Table 1. Of course, in all cases, visual examination is always used extensively, although it is often neglected in the documentation (bids, quality plans).

Table 1: Application of NDT methods to steam boiler testing.

PART	*EXPECTED FLAWS*	*RECOMMENDED NDT METHODS*
Shells, Flat parts, Steam drums	*Near uniform, medium scale corrosion and erosion*	*Visual, Ultrasonics*
	Localized high corrosion, pitting	*Visual, Ultrasonics, Radiography*
	Weakened welded joints, propagating fatigue cracks	*Detection of acoustic emissions, liquid penetrants, magnetic particles*
Tubes	*Near uniform, medium scale erosion*	*Visual, Ultrasonics*
	High temperature creeping	*Surface examination (replicas), Calculation EN 12952-4*
	Localized high erosion, thinning, pitting	*Ultrasonics*
Welding of tube to tubesheet	*Cracks after repeated stress cycling*	*Liquid penetrants, magnetic particles, radiography*
	Localized corrosion, hidden cracks	*Ultrasonics with angle probe*
Welded (gusset) stays of tubesheet	*Cracks after repeated stress cycling*	*Liquid penetrants, Magnetic particles*
Staybolts	*Cracks after repeated stress cycling*	*Visual, acoustic emission*

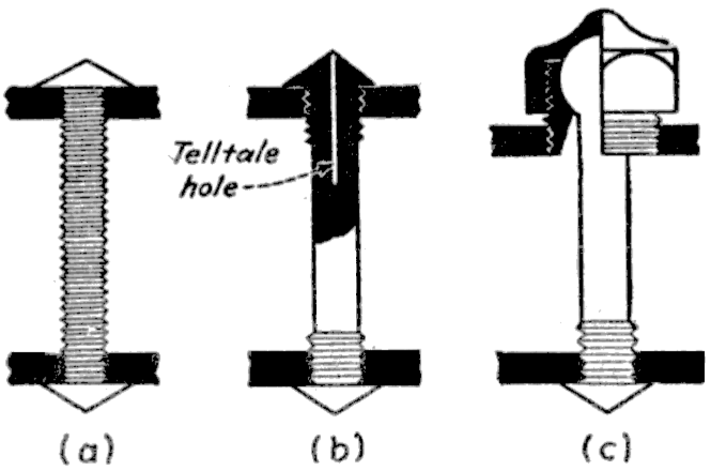

Fig. 1: Special technique to detect cracked staybolts [10].

Tubes and sheet metal usually are subjected to various modes of corrosion and erosion which reduce wall thickness, so the remaining wall thickness may be lower that the calculated for the design pressure of the equipment. Material loss may be relatively uniform or very localized. Locations of increased corrosion include the water-steam interface line and the locations near the flue gas outlet, were condensation of acidic liquid takes place.

Ultarsonics is the best method for the determination of actual (remaining) wall thickness for large areas of tubes and sheet metal. The method is fast and requires relatively low cost equipment [3, 4]. The operator must scan the whole area under test taking 1 or 3 measurements near each point of an imaginary grid. The grid must be denser at locations of suspected localized erosion. Afterwards the results can be presented in tabular form or be visualized by different colors on a drawing of the equipment.

A reference thickness must be established in some cases, when drawings and equipment specifications are not available. This is a common problem with Simple Pressure Vessels (air compressor tanks) and LPG tanks, but not very common with steam boilers. In this case, the reference thickness is obtained by UT sounding at intact spots.
Most defects in butt-welded joints appear during manufacture, with the exception of corrosion at the welded joints of some stainless steels like AISI 304 by seawater. These are, of course, repaired before the equipment is delivered. Another cause of cracks in welded joints, which takes place during normal operation, is cycling of mechanical stresses caused by pressure or temperature cycling. These cracks show up at locations of permanent or transient stress intensification due to geometry or differential thermal expansion. The likely locations of these defects are:

- Welded joints of fire-tubes or smoke-tubes to the tubesheets in shell boilers.
- Welded joints of tubes and pipes to steam drums of water tube boilers.
- Welding of tubes to collectors and distributors.
- Welding of stays and other support structures to drum shells and heads.

The tube to tubesheet welding process can be the source of many hidden defects, some of them caused by inadequate design or manufacture and other to operating conditions. In recognition of the special requirements at these locations, the new "EN ISO" family of welding procedure specification and qualification standards includes a special part on this subject [14].
While radiography and ultrasonics can often be used at these locations as well (with the special angle probe), they can be very time consuming and difficult in application, given the limited accessibility and unfavorable geometry. The methods of magnetic particles and liquid penetrants, applied to the external side only, give good results in most cases. Some liquid penetrants techniques can be used on large surfaces in very short times. Using these two methods, possible cracks can be easily detected by trained personnel. Photography can be used in many cases to provide a permanent record. The main drawback of these two methods is that they detect only cracks that extend to the visible surface of the metal.

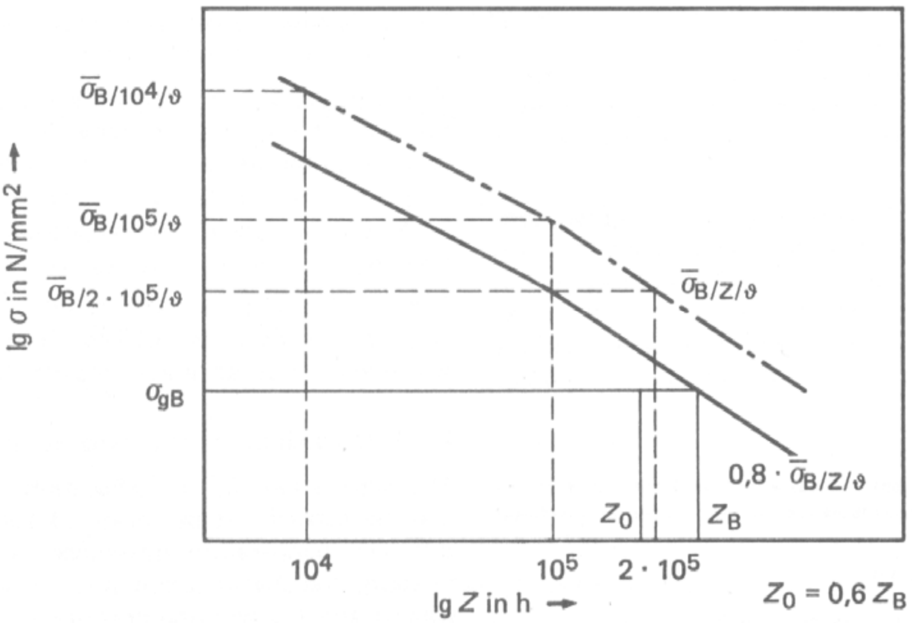

Fig. 2: Long term high temperature creeping stress values – TRD 801 Anl. 1 [7].

A special type of flaw appears at the hottest parts of the steam boiler, mainly the superheater and reheater tubes. The flaw consists of plastic deformation that occurs over a long time interval after application of the load and is described as "high temperature creeping". All boiler design codes (including EN 12052-3) pay special attention to this problem and specify additional strength

calculations. Types of steel used for boiler construction (boiler plate to EN 10028-2, tubes to EN 10216-2 and EN 10217-2) have specified high temperature creeping characteristics. These characteristics (stress for creep failure after 10000, 100000 or 200000 hours) can be used to calculate the remaining life of the boiler, based on its record, i.e. the length of time it has operated at a given pressure induced stress. The procedure is detailed in EN 12952-4. Briefly we present the qualitative diagram from TRD, which gives a qualitative view of the allowable stress for prolonged high-temperature service as a function of expected operational time (Figure 2).
If the available data do not allow a reliable calculation of the remaining time using this method, the alternative is a metallographic examination of the tubes exposed to very high temperatures. Instead of cutting off a part of a superheater tube, a replica of its surface is produced [11, 12, 13] and subsequently sent to the metallographic laboratory. It is frequently expected that the superheater tubes are changed after about 15 years of service, while colder parts of the boiler can operate up to 30 years or more.

5. Case study

The current presentation was inspired from an order given from a tobacco company to assess the remaining life of their existing water-tube boiler and decide whether to transfer the boiler to the new company's premises, located some 90 km from the old factory, instead of procuring a new shell (flame-tube) boiler. In contrast to standard practice in Greece, the boiler is installed on the roof of a multistory industrial building in downtown Piraeus, so removal of the boiler intact is very expensive.
The existing old steam boiler at G. Keranis Tobacco S.A., Piraeus is a special type of water tube boiler with vertical tubes (Rheinstahl – Henschel IK 5-12 IS). Its basic configuration is shown in Figure 3.

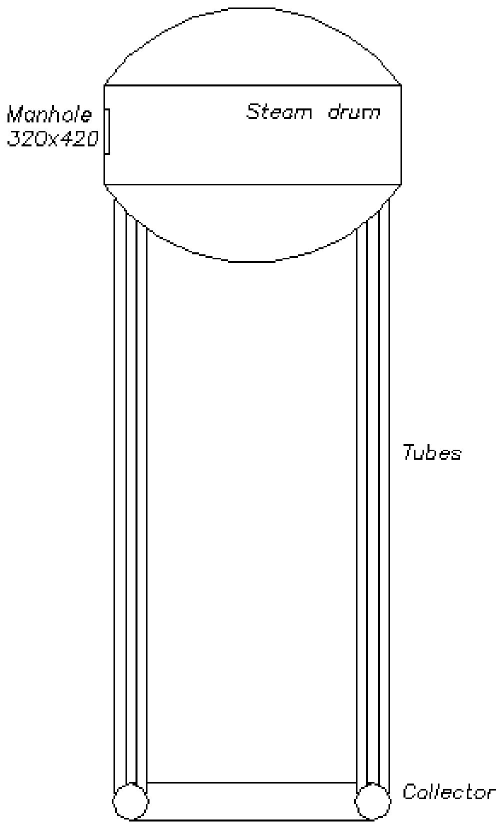

Fig. 3: The Rheinstahl – Henschel IK 5-12 IS boiler.

Boiler specification is 5 t/h of saturated steam at 12 bar(g). The tubes are arranged in two concentric rings and are made of St 35.8 steel (DIN 17175). The space between the two rings and between the outer ring and the insulated wall is not accessible. The tubes support the cylindrical drum at their top. Water is fed to the tubes by natural circulation.

This project was a special case with the following specific problems:

- Limited access to parts of the flame and flue gas space
- Usage of radioisotopes was out of question and X-ray undesirable
- The installation was run on high sulfur heavy fuel oil for the first 15 years of its operational life
- Some tube welding is not accessible, as it is located under refractory material
- Disruption of production was not acceptable.

The solution chosen was the following:

- All tests were scheduled for only one day (Sunday)
- The burner was removed.
- The water space was emptied and left to drain out and dry.
- All accessible steel surfaces were visually inspected in order to identify signs of erosion and corrosion.
- The wall thickness of each water tube of the inside ring was determined at three locations with ultrasonics (Figure 4).

Fig. 4: Ultrasonics thickness measurement of tubes.

Fig. 5: Examination of tube-to-drum joints using magnetic particles.

- The wall thickness of water tubes near the flue gas outlet was also determined with ultrasonics.
- The welded joints of the water tubes to the steam drum were examined with magnetic particles (Figure 5).
- The welded seams of various nozzles at the top of the steam drum were examined with liquid penetrants.

The measurements of tube wall thickness (a total of 144 individual measurements) were imported to a spreadsheet for statistical calculations and production of graphs.

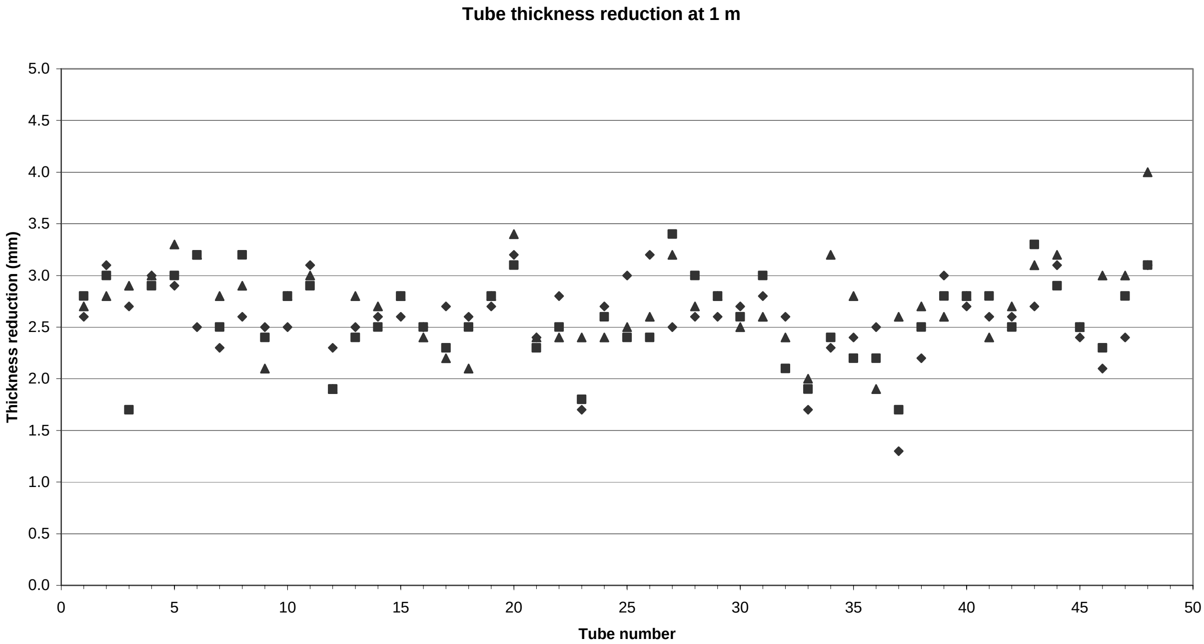

Fig. 6: Tube thickness reduction at 1 m above collector.

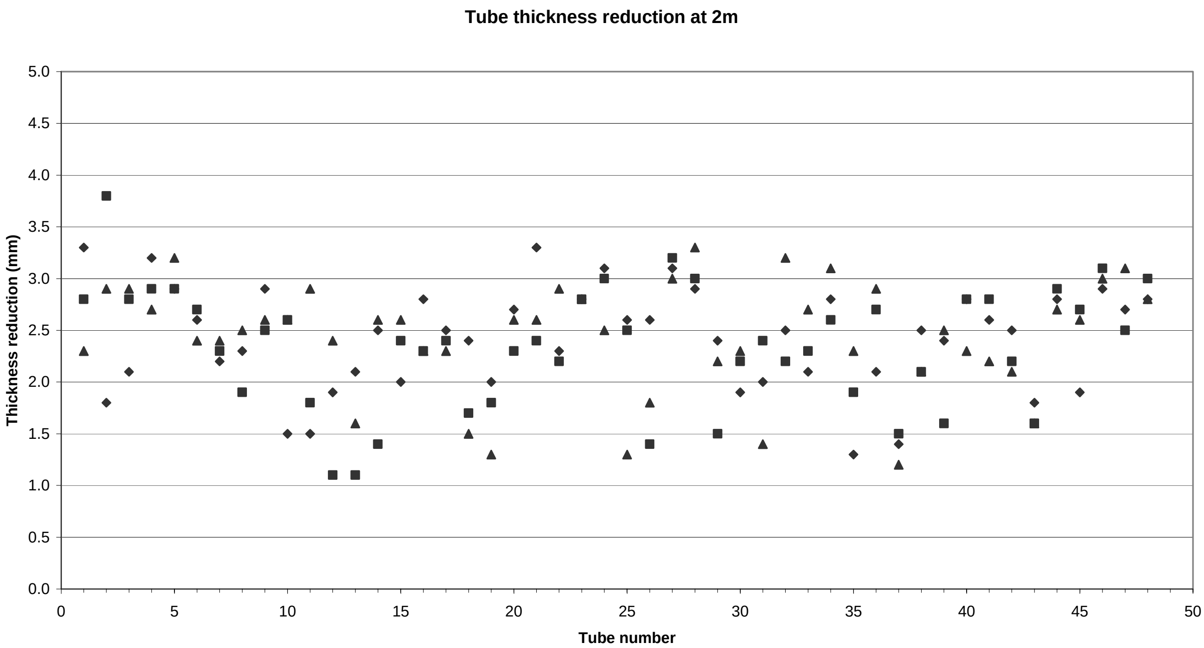

Fig. 7: Tube thickness reduction at 2 m above collector.

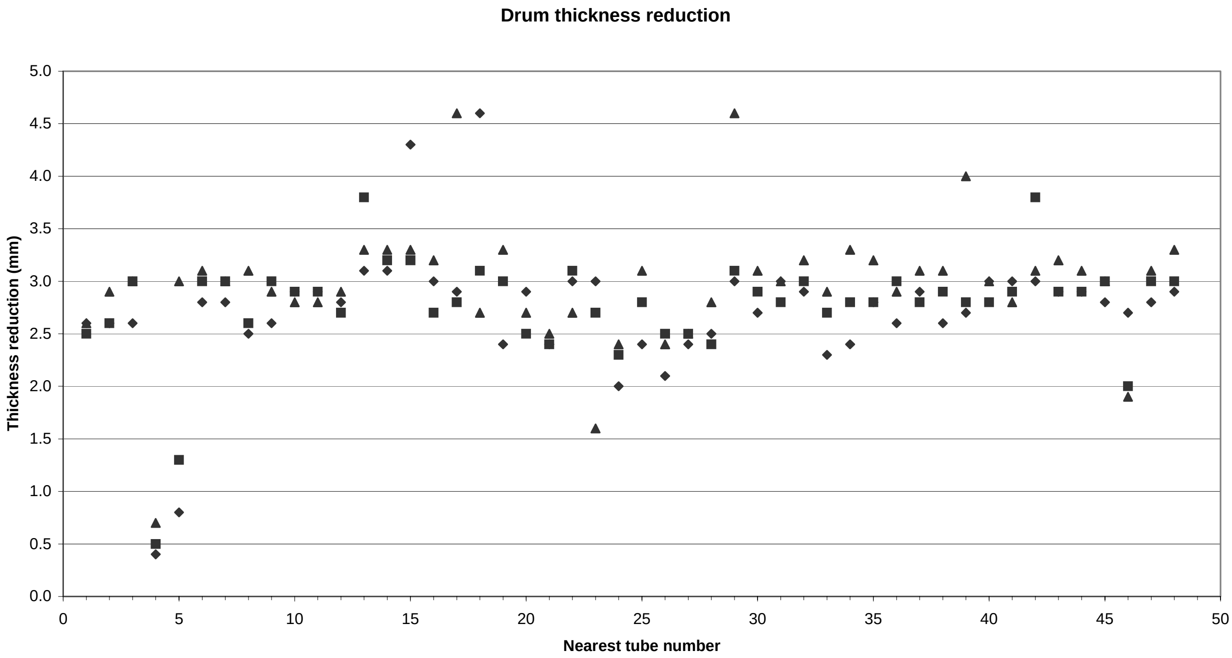

Fig. 8: Drum thickness reduction.

6. Conclusions

The NDT and the analysis of its results showed that:

- All welded seams (including 104 joints of tubes to the steam drum) were in perfect condition after 27 years of operation including daily cycling.
- The tubes of the inner ring had suffered from uniform corrosion and erosion of about 38% their initial thickness (Figures 6 and 7).
- The tubes of the outer ring near the flue gas outlet had suffered from intense corrosion and at some locations the thickness loss was over 50%. This effect was attributed to the high sulfur content of the fuel during the early years of operation
- The remaining life at de-rated pressure of the boiler was estimated to 5 years.

On the basis of these results and by taking account of the high removal and transport cost, it was recommended to the owner of the equipment to scrap the existing boiler and replace it with a modern shell (flame-tube) boiler.

7. References

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