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NDE Techniques for Reliable Inspection of Carbon Steel Tubes

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Abstract

Ferromagnetic tubes in Heat Exchangers, Boilers, Air Fin Coolers are most common in the Petrochemical Industry. Carbon Steel, an inexpensive material has good mechanical properties and heat transfer capabilities. However, it is often employed in conditions where corrosion if it sets in, acts very fast. Over the years with shrinking maintenance budgets and longer intervals between plant shutdowns the need for reliable inspection of these units has increased. The advent of digital technology, several enhancements to the inspection equipment based on RFEC, Magnetic Flux Leakage, Ultrasonic IRIS have taken place. Each of these techniques has its own merits and demerits.

This paper presents an overview of the techniques available for carbon steel inspection discussing their merits and demerits.. It also presents a methodology of selecting the right combination of techniques to achieve reliable inspection results using practical case studies of field work carried out.

Keywords: *Heat exchanger tube inspection, Boiler tube inspection, RFEC, MFL, IRIS*

1. Introduction

Heat Exchangers, Air Fin Coolers and Boilers are critical components in any chemical processing operation. Tubes in these units are subject to process chemistry on both sides or to process chemistry on one side and water or steam on the other. The chemical fluids flowing through these tubes and heat transfer conditions contribute to accelerated corrosion of tube materials (Fig. 1). Carbon Steel, an inexpensive material which has good mechanical properties and heat transfer capabilities is commonly used in these units. However, they are often employed in conditions involving steam or water on one side of the tube which can lead to corrosion of the tubes if certain parameters are not maintained.

Fig. 1: Corrosion in Heat Exchanger, Air Fin Cooler and Boiler Tubes

In the past, and to some extent still, due to the low cost of carbon steel tubes, entire exchanger re-tubing was not an issue. These exchangers were still run until no longer serviceable. In today’s markets with restricted maintenance budgets, high costs of unscheduled shutdowns and longer shutdown intervals, the old practices are changing. It is becoming more necessary to be able to determine the damage in the tube material and be able to quantify this data as much as possible. It is therefore imperative that these components are examined periodically and their integrity maintained using demonstrated and reliable NDE Techniques.

Techniques available for Carbon Steel Tube inspection include the following:

1. Visual Inspection
2. Remote Field Eddy Current (RFEC)
3. Magnetic Flux Leakage (MFL)
4. Ultrasonic Internal Rotating Inspection System (IRIS)
5. Partial Saturation Eddy Current
6. Laser Optics (LOTIS)

These techniques differ widely from the commonly used Eddy Current technique for non-ferromagnetic materials and are very often misused due to poor understanding of their working principle and capabilities.

This paper presents a brief overview of the various techniques available for carbon steel inspection discussing their merits and demerits and presenting a methodology of selecting the right combination of techniques to achieve reliable inspection results.

2. Techniques Available for Carbon Steel Tube Inspection

2.1 Visual Inspection

Visual Inspection has come of age with the advent of modern video inspection tools that have advanced features. These video inspection tools allow image processing and inspection of wide range of tube sizes. They provide extensive information about the tube. However, the external condition of the majority of the tubes cannot be inspected. Even when inspected, quantitative data is marginal at best. This inspection method is slow, and depending on the remote viewing equipment, expensive. Inspection of a tube may take several minutes. If a small sample of data is indicative of the overall condition, this may be an adequate test.

2.2 Remote Field Eddy Current (RFEC)

RFEC is a low frequency inspection technique that allows accurate measurements of wall loss especially in Ferro-Magnetic Steel tubes. It uses a relatively simple instrument and is not affected by high magnetic permeability of the carbon steel tubes assuming that it is uniform in the length of the tube.

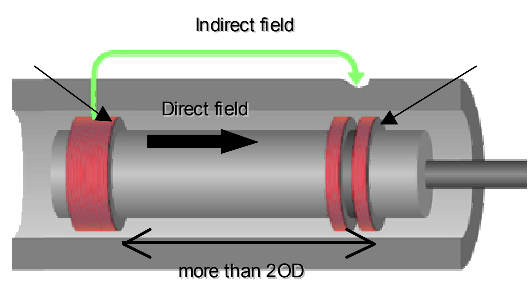

Fig. 2: RFEC Inspection Principle

Advantages:

RFEC can be used to inspect Ferro-magnetic tubes in Shell and Tube Heat Exchanger& Boilers. It is well suited for the detection of the following types of corrosion

- General Corrosion / Erosion
- Localized Corrosion and Pitting
- Support Plate Fret wear extending beyond the baffle

Limitations:

It has limitations in the detection and sizing of under baffle corrosion and isolated pitting / pin holes. Two primary paths exist for coupling the energy between the exciter and the receivers. The direct field (Fig. 2) which carries no useful information of the tube wall condition is rapidly attenuated with distance down the pipe and undetectable beyond about two pipe diameters. The indirect field diffuses radially outward through the pipe wall, moves along the pipe, and re-diffuses radially back through the pipe wall. The zone in which this indirect field is dominant is named the "remote field zone". Any discontinuity present in the material will affect the Remote Field signal. These changes in the Remote Field can be compared to those measured on known machined flaws in a calibration tube with properties similar to the one being tested. A comparative analysis provides the value of tube wall loss on the tube being tested.

2.3 Magnetic Flux Leakage (MFL)

MFL is a tube testing technique primarily designed for rapid testing of ferromagnetic tubes with non-ferromagnetic fins wrapped around them, as in Air Fin Coolers. Two strong magnets generate a static magnetic field that saturate the tube wall (Fig. 3). When a flaw (Pitting, Wall Loss, etc.,) is located between the two magnets, the magnetic flux in the tube wall is disturbed and a small amount of flux will leak in the inner tube. This leak of flux is detected by the coils placed between the magnets. The variation of the flux leakage induces the current in the coils, thereby causing a signal output. This signal output can be used to provide information on wall thickness reduction, if any, in the tube. Magnetic Flux Leakage (MFL) is mainly applied for the inspection Air Fin Coolers, however it can be used for inspecting bare tubes with diameters one inch and above.

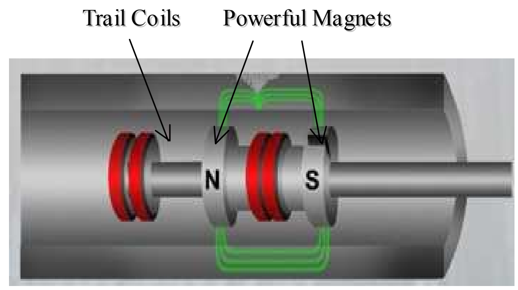

Fig. 3: MFL Inspection Principle

Advantages:

- It is not affected by the presence of Aluminum Fins.
- Relatively High Speed Inspection (up to 1 meter/sec).
- It has very good sensitivity for both Pitting and Circumferential Grooves.

Limitations:

- It is more a detection tool & is not very useful for flaw sizing since the signal represents volumetric change and not the change in depth of the flaw.
- Signal sensitivity depends on pull speeds & isolated Pin Hole type of flaws cannot be detected.

2.4 Ultrasonic Internal Rotating Inspection System (IRIS)

IRIS is a pulse-echo based tube inspection technique. A transducer excited by a high frequency pulse producers an ultrasonic wave that propagates into water. A mirror deflects the wave to produce a normal incidence beam on the inner diameter (ID) of the tube. Echoes reflected from each metal water interface are digitized and processed to extract the time of flight and amplitude of the front wall and back wall echoes. Further processing is applied to calculate the tube inner diameter (ID), outer diameter (OD) and wall thickness (WT). Complete tube inspection is obtained by rotating the mirror. A hydraulic turbine (IRIS) or an electric motor produces the driving force. Synchronization of the rotation can be obtained by various methods like ultrasonic targets or encoders (Fig. 4). State-of- Art IRIS systems can accommodate these synchronization modes in order to display in real time, the data either on a cross-section thickness display (B-scan), or as a surface area thickness map (C-scan). IRIS can be applied on all types of heat exchanger and boiler tube materials. It can be applied on tubes with diameter of 0.75 inch and thickness greater than 1 mm for best results.

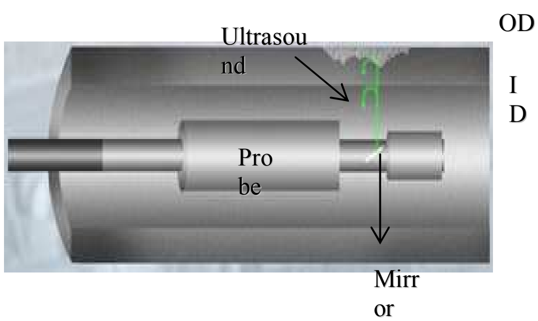

Fig. 4: IRIS Inspection Principle

Advantages:

- Only technique that gives exact tube wall thickness.
- Will provide information on flaw profile and location i.e. on the ID or OD of the tube.
- With real time C-scan capabilities during data collection, pits as small as 1 mm diameter can be easily detected.

Limitations:

- Relatively slower speed of operation.
- Requires extensive tube cleaning.
- Limited to minimum wall thickness measurement of 0.8mm for Carbon steel tubes.

2.5 Partial Saturation Eddy Current

This technique is applied on ferromagnetic tubes that are too thick to be fully saturated. The technique uses a conventional eddy current instrument and monitors changes in impedance caused by changes in permeability. The permeability changes with thickness. A loss of thickness increases the intensity of the magnetic field and hence reduces the permeability. The reduction in permeability changes the impedance of the coil that is measured by the eddy current instrument.

Since this technique depends on gross changes in permeability, it is limited to variations in tube wall loss. Small defects such as pits will not influence the total magnetic field and are therefore insensitive to this technique.

2.6 Laser Optics

The laser optical technique uses a rotating laser beam that scans the ID surface as the probe is pulled out of the tube. The reflected laser beam is picked up by a lateral detector that measures changes in proximity caused by variations on the ID surface. The technique is limited to ID surface inspection with a speed of up to 3 in./s. The technique also requires the tube to be cleaned to avoid any unnecessary optical scattering. It has proven applications for large diameter tubes such as those in reformers and furnaces. Because of its limitations it is mainly used as a complimentary inspection tool.

3. Parameters Influencing Inspection Technique Selection

The choice of employing a specific technique / combination of more than one technique depends on various parameters for Carbon Steel Tubes. The parameters include;

1. Nature of tube degradation.
2. Type of unit to be inspected.
3. Nature of result required.
4. Degree of tube cleanliness achievable.
5. Reliability of the Inspection Techniques and Human factors.

3.1 Nature of Tube Degradation

It is important to assess the nature of tube degradation expected in the unit. A simple study of the unit's service parameters will provide the necessary information for the same.

For example, the outside surface of tubes opposite to the shell inlet nozzle, may be subject to erosion or impingement corrosion. When the shell side fluid is mildly corrosive, the maximum corrosion often occurs at the inlet areas due to erosion – corrosion effect.

Fig. 5: Common tube damage mecha-nisms

Common tube damage mechanisms seen in carbon steel tubes (Fig. 5) are due to:

- Corrosion
- Erosion
- Vibration fret wear
- Temperature related wall thinning

Based on the nature and size of defects expected, the choice of techniques to be employed may be decided.

Example 1: In an open cycle cooling water system, the chance of pitting corrosion in the tubes is very high. Detection of pitting corrosion by techniques like RFET and MFL is quite difficult under normal field conditions. In some instances the same occurs close to the baffles. Furthermore, the presence of scale impairs the application of both IRIS and LOTIS. In such a scenario, selective cleaning of tubes with sophisticated tools need to be employed. This followed with IRIS inspection using equipment that have C-Scan features during data collection ensures the detection and sizing of defects as small as 1mm in diameter (Fig. 6).

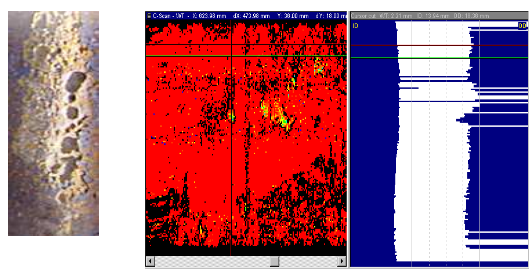

Fig. 6: A One millimeter diameter Pitting Corrosion detected and sized by an RD-Tech IRIS system

Example 2: If the unit has susceptibility to under baffle corrosion it will be preferable to employ IRIS as the initial screening tool itself (Fig. 7). This is because all other techniques will not be reliable in the detection and sizing of such tube degradation in the vicinity of the baffle and under the baffle.

Example 3: In a petrochemical plant a surface condenser with about 4900 tubes was inspected in the past turnarounds using the RFEC technique. The inspection focused on all the tubes in the bottom pass. However, the susceptible area in the unit are the upper rows of tubes due to the possibility of steam condensation. During a recent turnaround of the plant, inspection was reduced to 40% of the total tubes. Hundred percent coverage of the tubes on the outer periphery was ensured. All the corrosion in the tubes were detected, sized and confirmed by employing the RFEC technique (Fig. 8).

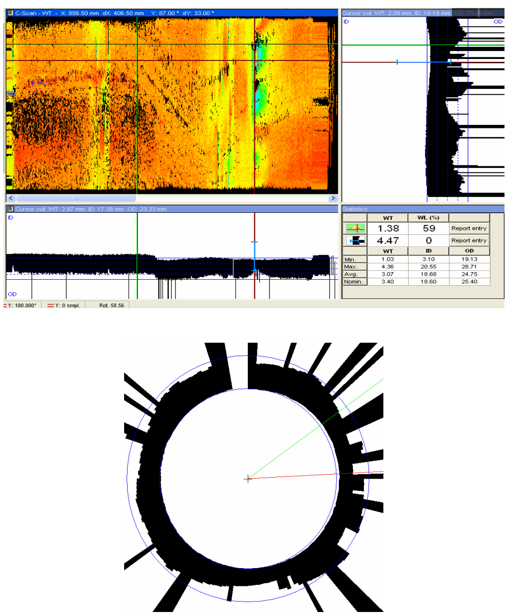

Fig. 7: Under baffle corrosion and external thinning detected by an RD-Tech IRIS system

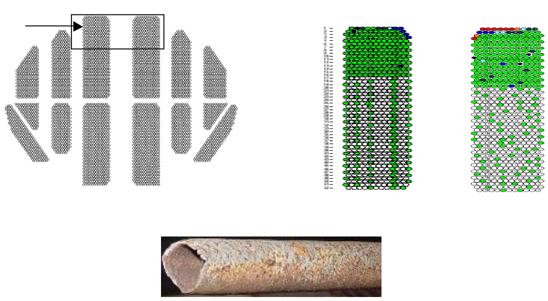

Fig. 8: Corrosion detected and sized by RFEC in a surface condenser

3.2 Type of Unit

The type of unit also plays an important role in determining the inspection methodology. For example an air fin cooler has carbon steel tubes with fins on them. The RFEC technique will work on such tubes but may produce dubious results due to the fins affecting the RFEC signal. Hence, despite the fact that the MFL technique needs additional cross-verification of its findings with IRIS, it is a more suited technique for the preliminary screening of Air-Fin Cooler tubes.

3.3 Nature of Result Required

Should the information of the location of the flaw in terms of its presence on the tube ID or OD be required, along with the minimum wall thickness remaining at the location of the tube de-gradation, the only technique that can deliver the same is Ultrasonic IRIS. All the others are comparator techniques that only reveal the percentage wall loss information and do not reveal the exact value of tube wall thickness at any location of the tube.

3.4 Degree of Tube Cleanliness Achievable

The biggest challenge to inspection quality in carbon steel exchangers is tube cleanliness. Though equipment catalogues may reveal that scale has minimum effect on their signals, the truth is scale in the tube wall always affects the quality of data and results. When tubes cannot be cleaned to remove the hard scale on the tube internal especially, the deployment of techniques like IRIS and LOTIS is impossible. This may therefore lead to the usage of techniques like RFEC and MFL only. In this process the sensitivity to smaller flaws is greatly reduced thus affecting the nature of results obtained in such cases.

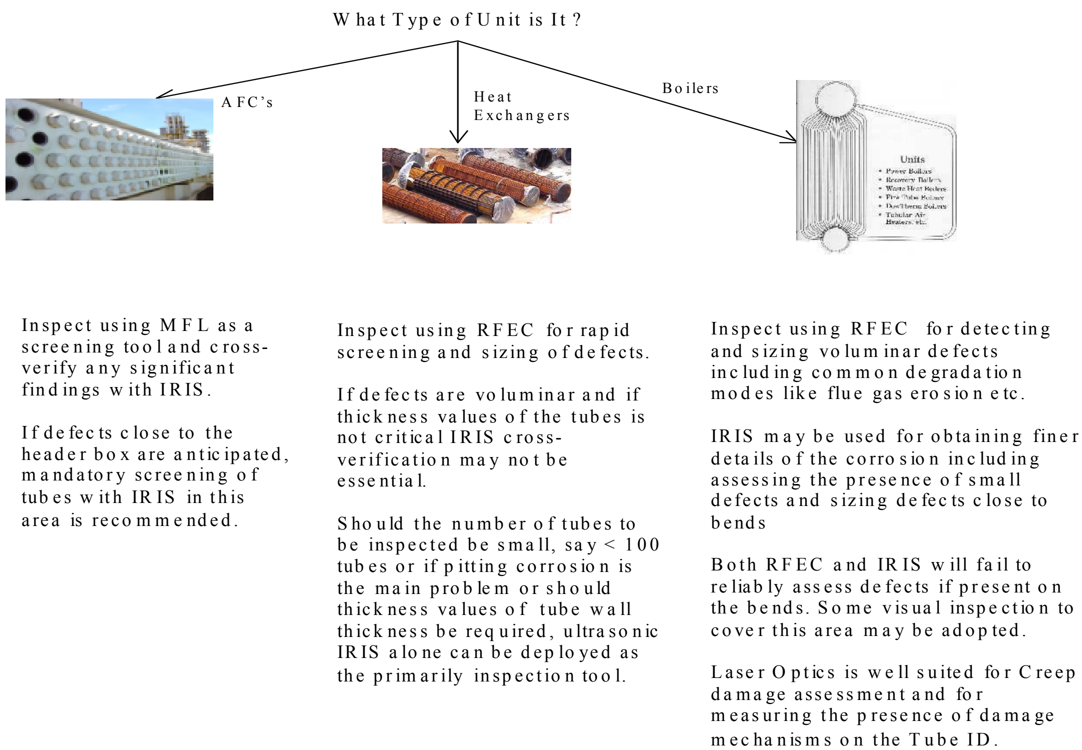

Fig. 9: Technique deployment strategy

3.5 Reliability of Inspection Techniques & Human Factors:

The reliability of an inspection technique for a particular tube degradation form needs to be assessed prior to its deployment as an inspection tool. Electric Power Research Institute (EPRI) in the USA, carried out an exhaustive assessment of various techniques & equipment to study the reliability of tube inspection in general. For carbon steel tube inspection, IRIS had the highest reliability of 83% followed by RFEC with 77%.

The most interesting part of the study was on operator performance. Different operators with similar qualifications were tested on mock-up samples. It was found that some performed better on different materials compared to others. This was due to the difference in their tube inspection work background.

Another incident was reported in an article in the Materials evaluation. An operator performing RFEC on a Boiler reported enormous wall loss in the tubes. When the owner opened up the insulation around the Boiler tube all they found were some welded supports on the tube and some bends on the same to allow for piping to pass through.. The signals actually seen by the operator that resembled wall loss signals were spurious ones and were from the bends on the tubes. This misinterpretation could have been avoided had the operator looked into the Boiler tube drawings thoroughly. The net result of this act of an inexperienced operator was that the plant lost its belief in RFEC. This can perhaps explain why several plants prefer the IRIS technique over RFEC and MFL.

Hence it is important to choose an inspection methodology based on the quality of resources available to make the inspection meaningful.

5. Recommended Inspection Strategy

The following can be used as a guideline / strategy for the selection of techniques (Fig. 9) for carbon steel tube inspection based on various parameters mentioned earlier.

6. Conclusions

No single technique can be used as a one stop solution for all Carbon Steel tubes. Proper understanding of the inspection techniques and knowing their advantages and limitations is very important. In addition, sufficient knowledge of corrosion mechanisms in Heat Exchangers, Boilers and Air Fin coolers, plays a crucial role in applying the correct inspection methodology.

7. References

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