# "Individual Tube Hydrotesting Verifies Heat Exchanger Tube Integrity"


Mike Catapano
President
Powerfect, Inc.

Eric Svensson
Vice President – Engineering
Powerfect, Inc.


## Introduction

In some of our past articles we have stressed the need for a comprehensive programmatic approach to optimize heat exchanger life-cycle management. We have previously identified the integral elements of these programs relative to various inspection and testing methods that should be employed periodically in order to obtain a true picture of the overall health of utility plant feedwater heaters, condensers, and balance of plant (BOP) shell and tube heat exchange equipment. Over time, all types of heat exchangers will degrade, none are immune to failure. Therefore, a proactive maintenance approach of periodic condition assessment techniques and the trending of results over time is the most important thing that can be done to optimize their remaining useful life and overall reliability. The results of all evaluation methods will aid in understanding the root cause(s) of why damage is occurring and can provide a basis for establishing remedial actions when possible.

The best life cycle management programs are ones that use a variety of complimentary techniques since in most cases, none are adequate by themselves to properly quantify and validate failure mechanisms. They include but are not limited to:

- Visual Inspections
- Leak Testing
- Individual Tube Hydrotesting (ITHT)
- Non Destructive Examination / Eddy Current Testing (NDE/ECT)
- Tube Leak Location Detection
- Failed Tube Sampling

The main intent of this article is to stress that the most successful maintenance programs do not rely on only one method for assessment. All too often, responsible heat exchanger component engineers put too much emphasis on subjective NDE/ECT results when formulating decisions regarding details of how and when to repair, refurbish, and/or replace the equipment. Our experience has shown that the often omitted method of ITHT affords the only practical method of establishing remaining tube integrity. Backing up the NDE results with follow-up ITHT can help make the important decisions of what to plug more practical and less subjective.

## Background History

ITHT was developed back in the mid 1970's in order to try to eliminate insurance plugging and to offer a more practical approach to establishing feedwater heater (FWH) plugging criteria in the days when ECT technology was not very reliable and its user's capabilities were still developing.

**Alternative to Insurance Plugging**

For many years, insurance plugging was common practice in the utility industry. The purpose of plugging unfailed tubes was to prevent subsequent forced outages from secondary failures of the tubes adjacent to the original tube failure. Such failures were expected because the high velocity streams from the original leaking tube often degraded the surrounding tubes. Lacking further information regarding the condition of the surrounding tubes, the station guessed which tubes were suspect and plugged them for "insurance". This approach seemed expedient at the time, but it led to other problems and under normal circumstances is no longer considered good maintenance practice. In addition to the wasted time and cost of plugging good tubes, insurance plugging accelerated the demise of the heaters for two reasons. First, it greatly increased the plugging rate. This not only affected heaters because of thermal penalties and higher tube velocities/pressure drops, but also led to premature decisions to replace affected heaters because these decisions were based upon the large number of tubes plugged (although many were still good tubes). Second, the weld repairs (the prevalent plugging method of that day) used to plug the tubes surrounding a leak often produced clusters of weld areas at the face of the tube sheet. Large differential temperatures were created in these areas; particularly in fossil plant 3-zone high-pressure (HP) FWHs, because the plugged tubes no longer removed the heat imparted by the superheated steam. The end result in many cases was severe cracking of both the brittle weld repair material and the adjoining tube sheet ligaments, and was the direct cause of many heater replacement decisions.

Figure 1 – Powerfect Individual Tube Hydrostatic Test Plug

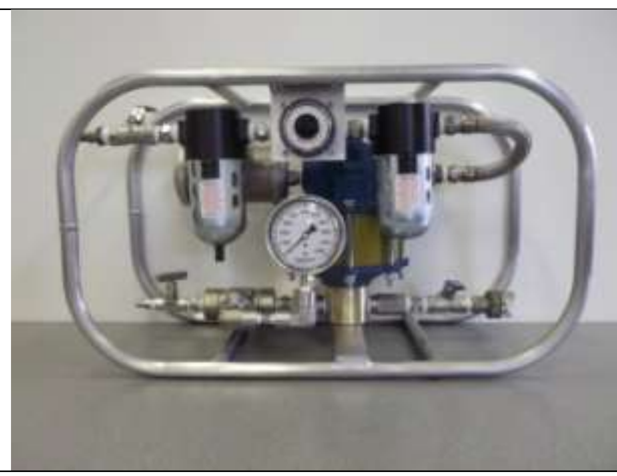

Figure 2 – Powerfect Portable Individual Tube Hydrostatic Tester

The development of an individual tube hydrotesting system used with test plugs that gripped and sealed the tubes from the internal diameter became a preferred alternative to insurance plugging. ITHT of the surrounding tubes can prevent the need for insurance plugging by testing each tube to a much higher pressure than the feedwater tube side operating pressure. Any weakened tubes on the verge of failure will not pass this go/no-go integrity test and will be plugged. Tubes that pass the test can be returned to operation with a high level of confidence.

## Integrity Test of Suspect Tubes Compliments ECT/NDE

Users found ITHT to be equally applicable to testing tubes found suspect via ECT and other non-destructive examinations. ECT of heat exchanger tubing is a very useful tool in establishing an overall picture of areas within the exchanger that are degrading and /or experiencing damage, but it does have its limitations. ECT data can be questionable if there is not a good correlation between the tubes being tested and the standard used for calibration. Additionally, the accuracy of the results is often dependent on the skill of the interpreter. Standard ECT methods cannot be used on ferro-magnetic tubing such as carbon steel, Monel, or Type 439 tubing. Specialized ECT methods such as Remote Field, Magnetic Saturation and Flux Leakage, as well as UT testing using IRIS have been developed as the state of the art has improved dramatically over the past 40 years; however limitations with ECT still remain.

Despite its limitations, ECT is still recognized as a useful source of information with regard to heat exchanger tube condition assessment; however other test methods are needed to help thoroughly evaluate remaining tube integrity. ITHT can provide a complimentary test in support of any suspicious damage called by the ECT surveillance, the results of which offers a more practical criteria in determining the suitability of the individual tube for continued operating service.

## Principals of Individual Tube Hydrostatic Testing

Tubes may be individually tested in order to provide a go-no/go test to determine whether the tube is failed or weakened and on the verge of failure. By treating each tube as an individual pressure vessel, the tube can be tested to pressure higher than the tubeside operating and design pressures as per UG-27 of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, which gives equations for calculating the maximum allowable working pressure (MAWP). UG - 99 of the current Code prescribes the 1.3 multiplier times the MAWP for the allowable hydrotest pressure.

The MAWP is defined by the Code as the lesser of two equations:

$$P = \frac{SEt}{R + 0.6t} \quad or \quad P = \frac{2SEt}{R - 0.4t}$$

Where:
P = Internal design pressure
S = Maximum allowable stress values (per ASME Code, Section II, Part D)
E = Joint efficiency (1 for seamless tubes, 0.8 for welded tubes)
R = Inside radius of tube in inches
t = minimum thickness of tube

In addition to the details of the tubing and the material characteristics, the selection of the optimum test pressure is application specific and should also take into account the objective of the testing, the age of the exchanger, any known failure mechanisms, as well as the specifics of the operating parameters. Test pressure judgments for HP FWHs are different than those for Condensers or BOP exchangers.

Figure 3 – Testing a FWH with ITHT.

**Advantages of ITHT**

Individual tube hydrostatic testing has the following advantages:

- Go-No/Go test for remaining tube integrity - Offers practical plugging criteria
- More stringent test than overall system tube side hydro - individual tube test pressure is often higher than operating pressure or even vessel design test pressure
- Precludes insurance plugging - only tubes that are failed or weakened are plugged. The tubes surrounding a known leak that were traditionally insurance-plugged are tested to ensure that they can handle the higher hydrostatic test pressure.
- Prevents future forced outages - any tubes that are weakened from leak impingement and on the verge of failure will be failed during the hydrostatic test and plugged.
- Portable systems available - testing can be performed anywhere.
- Compliments other NDE inspections – provides indication of stress concentration factors.

**Understanding Stress Concentration Factors**

Test trials conducted on tubes with known machined defects of various configurations confirmed that the nature and characteristics of the defect had a significant effect on remaining integrity, and the yield point and burst pressure at which the tube failed. Tubes with longitudinal defects tended to fail at lower than predicted pressures as the tube was axially pulled apart by amplification of the internal pressure. Tubes with circumferential defects of about the same percentage wall loss tended to fail at higher pressures than empirically calculated. Tubes with simulated pits of the same wall loss held even higher pressures. Since the characteristic of a pit is a localized point of severe wall loss with significant reinforcement surrounding it, often times these tubes would not fail when subjected to full hydrostatic test pressure. This indicates that the equations in UG-27 are not suitable alone as the basis for plugging criteria. This is mainly due to the fact that the minimum wall thicknesses required as calculated by UG-27 assumes a uniform thickness for the entire tube wall. That is not usually the case.

Prior experience has shown that the sizing of defects as reported in ECT results sometimes do not directly correlate with hydrotest results. Some tubes that failed the test were reported in the 50% wall loss range or even less, while others that were reported as 91-100% wall loss withstood a 7,000 psig ITHT without failure. These test results support the need for multiple test and inspection condition assessment methods. If the ECT results are valid and true, then they confirm that there are stress concentration factors related to certain types and configurations of defects and that their effects play a significant part in remaining tube integrity. Therefore, simply using a criterion of 50, 60, or even 70% wall loss based on an ECT report may remove a significant number of good tubes from service. A better approach would be to individually hydrotest tubes when they exhibit wall loss above 50% or other specified value, and let the results of the ITHT dictate which tubes should be plugged. If percent wall loss has been trended for some time and the rate of wall loss increases significantly, then the station should investigate the root cause; try to eliminate the factors that have caused the increase in rate and individually hydrotest questionable tubes.

## Case Histories

The usefulness of ITHT as a method to confirm remaining tube integrity can be illustrated in two case histories.

### Case History #1 – High Pressure Feedwater Heater

During a recent outage, a station was conducting ECT of their HP FWHs, which had been in service for over 30 years. This FWH has a drains inlet nozzle near the back of the heater with an associated integral flash chamber and a weir plate in order to protect the U-bends. In the past, only the straight lengths of the tubes had been tested, however, in this outage, it was decided that the U-bends would also be tested. It was discovered in the U-bends, there was approximately 340 restricted tubes, located primarily in the outer 13 rows on the east side of the heater. A tube-side videoprobe inspection revealed that the tubes had been dented at a location near the centerline of the U-bend. It was suspected that the U-bend supports may have moved and crimped the tubes. A shell side videoprobe inspection was conducted via the relief valve flange and pressure taps in the drains inlet nozzle in order to inspect the U-bend supports and the weir plate. This inspection revealed that the weir plate attachment welds had failed and that the plate had become dislodged on the east side and was pushed against the bundle.

It was unknown how long this condition had existed within the FWH.  In order to confirm that the tubes had not become weakened and would fail while subjected to operating pressure, each dented tube was individually hydro tested to the heater design pressure of 1800 psig, well above the operating pressure of 1200 psig. Of the 340 tubes tested, only one tube failed the test.

Although a dent is a deformity due to a force strong enough to plastically deform the tube, it may not have appreciable effect on the tube burst pressure in the absence of other damage mechanisms.  Therefore, the dent itself should not always be considered a damage mechanism that significantly affects the integrity of the tube, though there have been instances where the dent is large enough to prohibit passage of an eddy-current probe.  Since it was unknown how long the weir plate had been dislodged, if the plate was wedged into place or could still vibrate in operation, and whether or not there was potential for further damage, the station plugged some of the tubes closest to the weir plate in order to minimize the chances of an in-service tube leak. However, this was a fraction of the tubes that would have been plugged solely on the ECT indications.

Figure 4 – Dented Tube in U-bend identified via video-probe

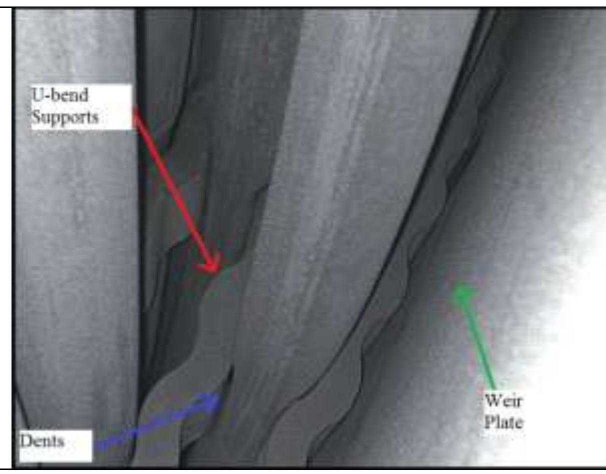


Figure 5 – Tubes dented due to Weir Plate being pushed against U-bend supports.

<u>Case History #2 – Main Surface Condenser</u>

Over the course of many years, a station plugged a significant number of condenser tubes during short duration outages.  Typically, when a forced outage was taken to resolve an apparent condenser leak, the shell side was flooded overnight and the waterboxes were opened.  The following morning station mechanics were sent in to find and plug the leak(s).  In most cases, water leakage was found cascading down the face of the tube sheet and the actual leak locations were difficult to identify.  Many times the tubes that they thought were leaking were plugged along with several other tubes in the surrounding area just to ensure that the leak was stopped. They simply plugged everything they thought may be leaking. Although this allowed the unit to be returned to service as quickly as possible, this practice resulted in many unfailed tubes being plugged. Additionally, the plugs they were using were unreliable and tended to loosen over time.

A refurbishment program was developed which included removal of older, unreliable tube plugs and individually hydrotesting the plugged tubes to 500 psig. Tubes that failed the ITHT were re-plugged with more reliable mechanical seal plugs, whereas tubes that passed the ITHT were able to be returned to service based on the high amount of confidence that the tube would not fail in operation.

Overall, the program was deemed to be successful. The improved tube plugs prevented any re-initiation of tube leaks due to loose or dislodged plugs over the course of operations between outages, thereby increasing condenser reliability. In total, 812 tubes out of 1,571 previously plugged (just over 50%) were able to be returned to service, thereby restoring additional surface area in the condenser that was unnecessarily plugged and improving condenser efficiency.

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| Figure 6 – Condenser Tube plugs prior to testing | Figure 7 – Condenser tubes following refurbishment. Tubes that passed hydrotest remained unplugged and were returned to service |

**Conclusion**

There are many instances where Individual Tube Hydrotesting can help to ascertain the actual condition of heat exchanger tubes. As a part of a comprehensive life cycle management program, complimentary techniques of testing tubes can be used in order to help determine root causes for failure mechanisms, while also maintaining heat exchanger performance by only plugging the number of tubes that is necessary for continued reliable operation. ITHT should be considered in cases where ECT results are suspected of having too high a margin of error, or are ambiguous or unclear, or if a large number of tubes exceed the station's "plugging criteria" based on called wall loss. In these cases, ITHT can help determine which tubes should actually be plugged and which are suitable to remain in service. Some of the best maintenance programs screen the tubes with ECT, then employ follow-up ITHT as the criteria for plugging repairs on all tubes found to be damaged and/or suspect via the ECT results. Utilizing these two complementary inspection and test techniques make heat exchanger repair/replace decisions much more practical than the results of either of them used alone. Together they add much needed credence to determining actual remaining tube integrity.