# Inspection and assessment

# Tim Hill and Katherine Petersen, Quest Reliability, USA, look at proven fired heater tube inspection and assessment technology.

Fired heater reliability is a crucial economic determinant in today's petroleum refinery asset management programs. Unreliable operation due to radiant or convection tube failures of these assets can quickly lead to multimillion dollar losses. Refineries are seeking services and tools which detect flaws in process coils whether due to changes in crude slates, off design operation, or production goals that push existing fired heater tube temperatures beyond their intended threshold.

Advancements in tube inspection technology have been made that allow real time, nearly 100% coverage of process coils for corrosion and creep damage. Intelligent pigging technology (Smart Pig) has been developed which can be applied internally, passing from the inlet to outlet of the process coil, even through short radius return bends. This technology applies sophisticated ultrasonic sensor technology to automatically acquire pipe wall thickness and dimensional data as it passes through the furnace coil at nearly 2 ft/s.

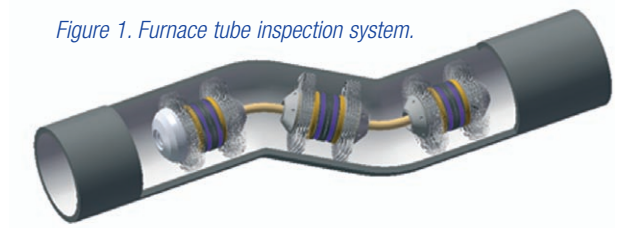
Quest TruTec, a subsidiary of Quest Integrity Group, has created an accurate, cost efficient product that effectively gathers and processes massive amounts of raw data by converting it into actionable results.

Since 1995, Quest TruTec's Furnace Tube Inspection System (FTIS™) technology has seen many revisions and improvements to further facilitate the quantity of data collected. Now on its sixth generation and with multi millions invested into the design, the FTIS Smart Pig has increased data sampling nearly tenfold since its original design.

Acceptance of this revolutionary inspection process created the need for improved assessment techniques. Clients have asked for a method to assess remaining life of process coils within a 24 hour period, as well as the ability to utilise historical data and compare prior data sets.

In 2004, Quest TruTec came to fracture mechanics and fitness for service expert Dr. Ted Anderson at Quest

Figure 1. Furnace tube inspection system.



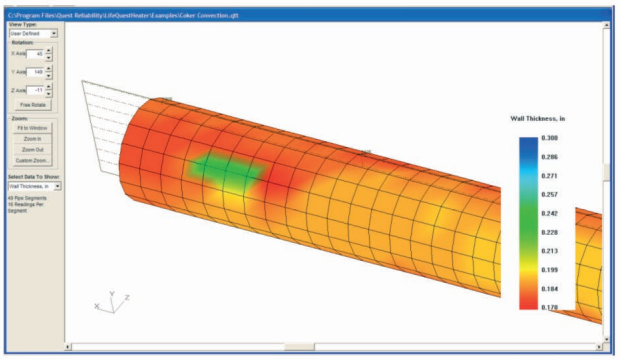



Figure 2. 3D corrosion results.

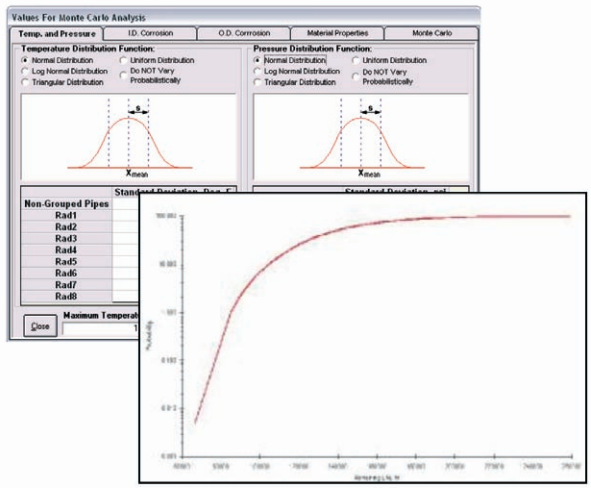



Figure 3. Monte Carlo failure probability curve.

Reliability (then SRT), with the initiative of creating a unique product capable of assessing process coil reliability data and calculating remaining life assessments, both deterministic and probabilistic. Clients needed a program capable of interpreting FTIS data to make key decisions concerning the safety and reliability of heater operations by better quantifying the damage mechanisms, such as corrosion and creep flaws. Capable of analysing 100% of the FTIS inspection data, as well as incorporating clients' desires and industry standards, LifeQuest™ Heater 1.0 was released.

LifeQuest Heater is an engineering program that automates the fired heater coil flaw assessment to deliver an API 579 Level II fitness for service and remaining life assessment within hours of completing the inspection process. Whereas historically an engineering assessment of inspection data could have taken months to complete, the unique combination of FTIS inspection data and LifeQuest Heater has allowed the asset manager to immediately define a risk of operation that is largely unburdened with the uncertainty of old assessment methodologies. Within time, the employment of these expert systems will lead to a new understanding of fired heater reliability and performance in today's refineries and will drive strategic improvements for better operation and maintenance of furnace coils.

## The inspection process

Quest TruTec dispatches ASNT certified technicians into the field to inspect coils for the presence of flaws. The objective of this inspection is to determine the location of degradation, size and rate of damage. The gathered FTIS data is later combined with recording and visualisation software to produce detailed proprietary contour maps showing the location, as well as the nature and severity of damage or degradation. By providing clients with several sizes of intelligent pigs (4 - 8 in. nominal diameters), nearly 65% of heater coil sizes in the market are currently able to be inspected. Tool development for a 3.5 in. nominal diameter tube is currently underway, which will allow Quest TruTec to obtain data from nearly 90% of all process coil sizes.

Before beginning the inspection, the heater process coils must be thoroughly cleaned and flushed in order to collect the most accurate inspection data possible. Quest TruTec contracts the cleaning process with numerous mechanical decoking companies worldwide. By partnering with major mechanical decoking companies, Quest TruTec is able to train these companies to properly propel the specialised intelligent pigs through the furnace heater coils, thereby allowing field experts to focus solely on the inspection process, the clients' needs, and the collection of accurate data.

The intelligent pig is comprised of multiple modules and is propelled with water throughout the length of a heater coil. As the Smart Pig travels through the coil, the proprietary ultrasonic transducers are continuously transmitting, receiving and storing sound waves that when processed provide high resolution, digital measurements of the tubes' inner radius and wall thickness. Traveling at nearly 2 ft/s, the data is obtained within a matter of minutes, and does not require entering the furnace firebox.

For heater coils which contain 'plugged headers' (aka mule ears) Laser Optic Tube Inspection System (LOTIS®) is applied to collect the inspection data. To utilise LOTIS, the header plug on each individual tube requiring inspection is removed to allow insertion of the 'internal' laser based tube testing technique to obtain information relating to inside tube damage. Development is underway to allow the FTIS to pass through these 'plugged' headers.

After the FTIS Smart Pig passes through the entire section of process coils being inspected; the data is immediately ready to be transferred to a computer for processing. This is easily achieved by connecting the pig to an ordinary laptop or desktop PC via a USB cable. Once the transferring process is complete, clients can immediately view the raw data through Quest TruTec's data analysis package or Quest Reliability's LifeQuest Heater software.

## The assessment process

LifeQuest Heater immediately generates a simple pass or fail status for each tube section in the coil by calculating the deterministic remaining life of the sections based on normal operating conditions. The life analysis processes 100% of the FTIS inspection data, collected all while adhering to Part 5 and Part 10 of API 579. The inspection data is downloaded directly into the software allowing evaluation of the impact of locally thin areas or creep damage on each 1 ft section throughout the heater coil.

Two common service flaws for process coils define the fitness for service of the coil: corrosion and creep damage.

The corrosion damage of the coil is evaluated using Part 5 (local metal loss) of API 579, and is described by the remaining strength factor (RSF). The RSF is the ratio of the coil's current strength to new undamaged strength and quantified by a number between 0 and 1, with 1 representing no damage. The damage from local metal loss is characterised by comparing the FTIS measured wall thickness data with the manufacturer's nominal wall thickness within automatically generated inspection area planes.

## RSF calculation

$$RSF = \frac{L_{DC}}{L_{UC}}$$

Where

- $L_{DC}$ = Limit or plastic collapse load of the damaged componene (component with flaws), and
- $L_{UC}$ = Limit or plastic collapse load of the undamaged component.

The creep damage impact on the coil is evaluated using Part 10 of API 579, creep operating range and Annex F. The magnitude of creep damage is illustrated by the prior damage factor (PDF). The PDF represents the fractional amount of creep life consumed, displayed by number between 0 and 1, where 0 represents no creep life expended. The PDF can be determined from the historical tube metal temperature conditions that the tube has been exposed to using the Omega parameter method provided in API 579, Annex F. The equivalent tube metal temperature, as defined by API 530 (and based upon the typical beginning and end of run temperature for the heater coil), is used in determining the coil's PDF.

## PDF calculation

$$D_c = \sum \frac{t^i}{L^i} \leq D_{ca}$$

- $D_C$ = Creep damage computed based on the loading history
- $D_{Ca}$ = Allowable creep damage usually taken as 1.0
- $L^t$ = Rupture time for the loading history in time increment $t^i$ (hours), and
- $t^i$ = Time increment or load duration for use in the damage calculation (hours).

Creep damage is measured directly by the FTIS inspection tool. Tube diametrical strain growth provides an indication of the extent of material creep damage. The diametrical strain growth (DSG) is the ratio of the existing tube outside diameter to the nominal outside diameter for the tube size. The existing outside diameter is directly determined from the FTIS inspection data set. The result is displayed in a color chart along the entire length of the tube.

A comparison between the historical tube metal temperature measurements provided by the end user and the measured DSG is done to adjust the creep PDF value. Tube areas with significant DSG would be expected to have higher lifetime metal temperatures, as well as a higher PDF value. The equivalent metal temperature in these areas is increased within industry and end user expectations to reflect a higher creep life consumption rate, resulting in a higher creep PDF value.

The coil's current fitness for continued service (as defined by RSF and PDF values) is factored into a life calculation when calculating time until failure based upon user defined future operating conditions. The future corrosion rate used in calculating the remaining life is determined from the wall thickness loss rate based on the plant's historical inspection data and other available FTIS inspection data sets.

The resulting remaining life calculations can be used to evaluate life consumption rate versus operating practices, plan tube replacement strategy, establish inspection interval and assess the overall operating risk of the fired heater. Quest Reliability recommends that the deterministic remaining life be used in evaluating current and future plant operating practices, as well as tube replacement strategy. The probabilistic remaining life is best utilised in establishing the next inspection interval and managing the fired heater risk of operation.

The probabilistic remaining life of the coil is calculated using the Monte Carlo method. The Monte Carlo calculations take into account a range of operating, material and mechanical conditions experienced. The tube metal temperature, operating pressure, coil corrosion rate, and tube material property values can be varied in order to define the probability of a failure (measured in hours). The range of operating conditions is determined from the plant's operating history. The material properties are varied in accordance with ASTM manufacturing tolerances.

Tube replacement decisions are based on understanding the fitness of the coil, projected remaining life, and user defined risk threshold. Tube evaluations are performed on one foot sections including return bends. This detailed evaluation allows for minimal replacement versus replacing an entire coil, as would be the case previously with data uncertainties. Additionally, a probabilistic analysis allows evaluation of all operating conditions when calculating remaining life of each one foot portion.

In some cases, a Level III fitness for service assessment is required to further analyse damage and project remaining life. This assessment is considered when unique operating conditions of the furnace affect a tube's material condition that cannot be detected through a standard FTIS inspection. Material testing, such as stress rupture, may be performed with a tube sample from the process heater coil.

In addition to Quest Integrity Group's FTIS inspections and LifeQuest Heater software, Quest Reliability offers three other commercial software products that perform fitness for service, fracture mechanics analysis, and inspection database management. The fitness for service and fracture mechanics products have capabilities spanning a full range of applications including simple API 579-1 Level 1 assessments to highly advanced Level III finite element analyses.

Whether the primary concern has been bulging, creep strain, isolated corrosion, or other material defects in tube wall thickness, an optimum risk management program must start with inspection and assessment of these flaws. The combination of Quest Integrity Group's FTIS data and LifeQuest Heater software provides clients with the tools they need to keep refineries safe and achieve long term goals.