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ASSESSING CREEP DAMAGE IN CAST MATERIAL FOR REFORMER TUBES UTILIZING MULTI-PARAMETER APPROACH

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ABSTRACT

Centrifugally cast materials, namely HK-40, HP Modified and Micro-Alloy materials are used in Steam Reformer tube applications. These materials, operating in the creep range, are subject to time/temperature related degradation which can manifest in several ways. The quantification of damage is of vital importance if tube life is to be predicted accurately. A comprehensive nondestructive inspection approach has been developed to assess the exact degree of damage. The approach utilizes several NDE techniques including ultrasonic, eddy current and dimensional measurements. The combination of the techniques provides valuable data for establishing condition assessment and remaining tube life prediction. Experiences and findings are discussed in the paper. Discussion of destructive methodologies for tube life assessment are beyond the scope of this paper.

Keywords: reformer tubes, reformer furnaces, diametrical growth, creep damage, high temperature, heat resistant alloys, life assessment

INTRODUCTION

Reformer tubes normally used in the refining, petrochemical and fertilizer industries are manufactured by the centrifugal casting process and heat-resistant austenitic alloys such as HK−40, HP−40, and HP−Niobium modified materials. A design life of 100,000 operating hours has been the normal time-based criteria for considering retirement of tubes. Many operators of furnaces using such tubes desire to change their maintenance philosophy for tube retirement to condition-based assessment rather than time-based assessment. At a cost of several thousands of dollars per tube and a furnace retubing cost of $1MM-$8MM U.S. Dollars, a significant amount of capital can be inadvertently applied if tubes are retired either too early or too late.

There are many reformer furnaces remaining in service beyond the 100,000 operating hours criteria. Metallurgical examination of tubes removed from such service has typically indicated carbide agglomeration, but no discernable creep voids or fissures. This provides the opportunity to improve reformer furnace life-cycle value by life-extension of the tubes, using condition-based criteria. Rather than removing tubes from service, it is advantageous to use inspection/NDE data to screen and determine their condition with regarding to assessing tube remaining life.

Using Inspection Data for Remaining Tube Life Prediction

Before the remaining lives of in-service tubes can be calculated, their current condition must be determined. One can either measure the current condition by some destructive or nondestructive test method or calculate it using an analytical model. The major drawback of the latter approach is that the uncertainty of knowing the past operating conditions leads to a large uncertainty in analytically predicting the current condition of the tube material. Therefore, it is preferable to measure the current tube material condition and just use the analytical model to predict the remaining tube life based on expected operating conditions. The anticipated operating conditions may be similar to or significantly different than the past ones.

Tube Inspection and Condition Assessment

To fully evaluate reformer tubes for damage and to establish an accurate measure of their true condition, a series of inspections are performed. While several alternative inspection techniques are available, careful consideration must be given to the inspection effectiveness or performance of the approach. When developing an inspection plan, the following four key issues need to be evaluated.

Sensitivity: The ability of the technique to detect and quantify damage greater than a required minimum value with required sizing accuracy.

Coverage: The ability of a technique to adequately scan the areas of the tubes where damage will manifest itself with consideration to defect morphology and location.

Reliability: Requires the measurement of both the probability of detection (POD) and the number of false indications (NFI).

Speed: The ability to efficiently scan the tubes within the shutdown window. Extensive lab and field validations have been performed to assess inspection approaches. Both multiple inspections carried out by IESCO and field experiences for operating companies have also pointed out the need for multiple techniques to correctly identify tube condition. Table 2 provides an objective overview of the effectiveness of nondestructive examinations at quantifying damage in reformer tubes. Each of the techniques listed in Table 2 are discussed separately in the following subsections.

DISCUSSION

Eddy Current

Eddy current techniques have been used for a number of years on HK−40 and HP−45 tubes. The technique relies on changes in electric circuit conditions; the circuit being the instrumentation, cables, sensing coil, and the item under test. As
the mechanical properties of the test materials change, a change in overall circuit impedance occurs, which is displayed on an oscilloscope. By monitoring the impedance changes, it can be inferred that creep damage is present, based on observation of the signal parameters in comparison to similar changes that occurred on known creep-damaged materials. The depth of penetration of eddy currents is primarily influenced by frequency, conductivity, and relative permeability. Also, proper eddy current coil design is important to obtain adequate sensitivity and signal to noise ratio. During tube inspection, the eddy current operator evaluates the changes in signal response. Other factors that the operator considers are listed below:

The influence of varying lift-off on signal response, scale and welds being typical examples of locations that result in lift-off

Overheating of the tubes in service that causes chromium migration, scale formation, and a significant eddy current response in terms of phase and amplitude changes

• Variations in material permeability Eddy current examination is not reliable in the detection of early damage (i.e. less than 30% through-wall). See Figure #2.

Diametrical Growth (Creep Strain)

The principal rationale behind using diametral growth is that, as creep damage occurs, the tube bulges. Each material type has its own nominal value of diameter change where creep is considered to have occurred. The following rules of thumb for allowable diametral growth have been reported by various operators over the years. As an example:

HK−40 = 2−3%

HP−45 = 5−7% Yet, recent findings show that, in some cases, significant growth may be apparent, but the tube shows the absence of internal damage.[(1)] Conversely, it has also been established that tubes with little diametrical growth (<1%) can see significant damage. Using diametral growth (O.D. and I.D.) may provide a very general indication of tube condition; however, using diametrical growth as a stand-alone method for measuring creep damage, or lack of damage as the case may be, may lead to a significant false call on the actual condition of the tube.[(2)] See Figure 1 which illustrates the variability of damage versus strain measurements. Several methods for measuring strain can be employed; strapping, eddy current proximity sensors, lasers and displacement sensors.

Ultrasonic Examination

The primary ultrasonic technique utilized for the detection and estimation of creep damage is through transmission ultrasonic attenuation. This technique observes the absorption of UT energy as a function of damage accumulation in the form of microvoids and cracking, both microfissures and macrocracking. Recent validations have again found that ultrasonic is more reliable at the detection and quantification of creep damage, particularly in its early stages.[(1)]

Radiography

Random radiographic examination or x-rays are normally used as a supplementary technique to confirm the presence of severe cases of creep damage. It is reasonable to expect to locate such damage when it has extended 50% in the thru-wall direction, if the tubes are filled with catalyst and isotopes are used instead of an x-ray tube. Although using an x-ray tube provides an improved quality image, it is not normally employed because of practical conditions on site.

Replication

Replication is useful for in-situ assessment of reformer tube outside surfaces, to detect overheating that causes micro-structural changes. Replication is a "spot" type assessment and is normally used as a supplemental technique. Only the advanced stages of creep damage can be assessed utilizing in-situ replication, since damage occurs internally within the tube wall.

Wall Thickness Measurement

As creep strain occurs, an apparent decrease in wall thickness is evident. Thus, the measured value of wall thickness compared with the original value of wall thickness may indicate the amount of creep strain that has occurred. Wall thickness is measured using customized transducers. Original wall thickness is obtained from an unfired portion of tube.

COMBINING NDE TECHNIQUES

Review of the NDE techniques outlined above illustrates some of the advantages and disadvantages associated with each individual technique. Extensive trials have been conducted to determine the viability and optimization of the various techniques. No one technique was found in all cases to provide stand-alone information that will allow complete quantitative assessment of tube condition. It is therefore prudent to combine NDE techniques to improve the overall reliability of reformer tube condition evaluation. The NDE specialists evaluate each tube and assign a damage grade per tube determined on the worst section of tube. These grades are assigned based on comparison of each tube to the NDE responses obtained from samples subjected to metallographic confirmation. One of the five following damage grades is assigned to each tube:

Grade 1: no detectable creep voids between the inner surface and mid-wall or equivalent to new material.

Grade 2: several small voids aligned between the inner surface and mid-wall

Grade 3: many voids and small fissures between the inner surface and mid-wall

Grade 4: fissures extending to the mid-wall with many voids near the inner surface and a few voids between the mid-wall and outer surface

Grade 5: fissures extending about two-thirds of the way through the wall from the inner surface or approaching final tube failure

The final tube grading and dimensions are then transferred automatically to life assessment software to provide reliable predictions of remaining tube life.

CONCLUSIONS

Tube lives predicted using simple design methods do not reflect actual operating lives. Specialized stress analysis and prediction models, are suitable for assessing tube life. The reliability of assessment is greatly enhanced by establishing the correct condition in terms of creep damage and dimensions. To correctly establish condition, a series of nondestructive techniques have been shown to optimize the inspection effectiveness on cast tubes. No one technique will define all of the damage, all of the time.

REFERENCES

1 C.E. Jaske and B.E. Shannon, “Optimizing Reformer Tube Life by Employing a Realistic Condition Based Methodology,” Nitrogen, Vienna, 2006.

2 G.R. Lobley, A. Kermad, et.al., “Assessment of Aged Steam Reformer Furnaces,” CAPE, 2003.

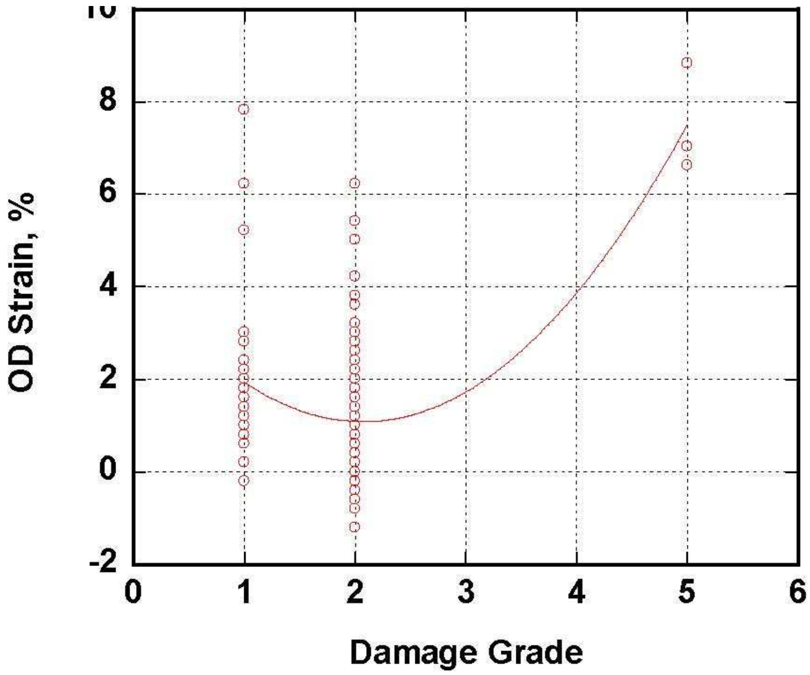

Table 1

Damage Attribute	*WT Factor	Eddy Current OD	Laser (Strain)	UT Attenuation	RT	Field Metallography/ Replication	H-Scan	Eddy Current ID
Creep Strain (OD)	1	Yes	No	No	No	No	Yes	No
Creep Strain (ID)	1	No	Yes	No	No	No	Yes	Yes
Initial Damage (<30% Wall Volume)	2	No	No	Yes	No	No	Yes	Yes
Moderate – Severe Damage (>30% Wall Volume)	2	Yes	No	Yes	Yes	No	Yes	Yes
ID Cracking	1	No	No	No	No	No	No	Yes
OD Cracking	1	Yes	No	No	Yes	Yes	Yes	No
Wall Thickness	2	No	No	No	No	No	Yes	No
TOTAL	**10**	**4**	**1**	**4**	**3**	**1**	**9**	**6**

OD Strain, %

Figure 1
OD Strain vs. Damage Grade-
H2 Plant 54 HPM Tubes

10 8 6 4 2 0 -2

0123456 Damage Grade Table 1

*WT Factor total represents 100% inspection effectiveness. Individual WT Factor values represent the effectiveness of the various techniques.

Figure 2