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Magnetec Inspection, Inc.

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" FROM THE FIELD "

Excellence in Eddy Current Inspection Technology & Failure Analysis

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Subject: Creep

Creep is the term used to describe the tendency of a material to move or to deform permanently, to relieve stresses. Material deformation occurs as a result of long term exposure to levels of stress (mitigated with elevated temperatures) that are below the yield or ultimate strength of the material.

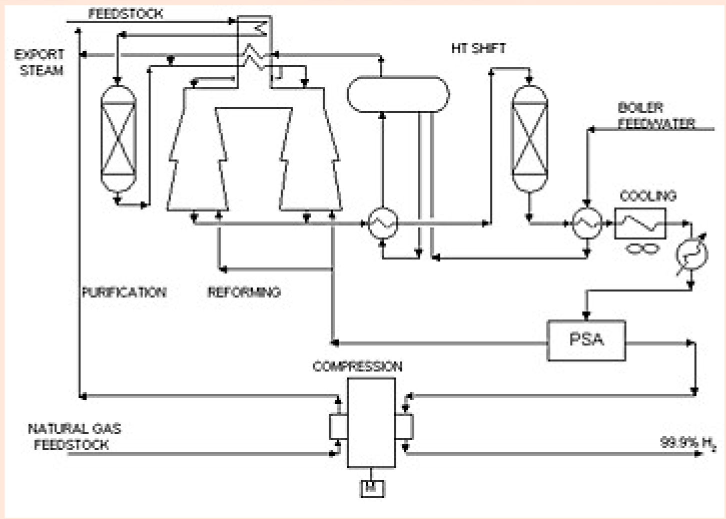
Creep is more severe in materials that are subjected to short periods of high heat and/or lower for long periods. The rate of this damage is a function of the material properties and the exposure time, exposure temperature & the applied load (stress). Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function. Creep is usually a concern in high heat, high temperature reformer furnaces in the chemical & petro-chemical industries.

Creep is not necessarily a failure mode, but is instead a damage mechanism that over extended service cycles yields failures. The dominant loading on these tubes is the through-wall thermal stress and life consumption is by cyclic creep relaxation, on a time-scale controlled by the operational pattern of the unit. Strain and damage accumulate through life and may, respectively, be monitored by diametral measurements and non-destructive techniques based on eddy current or ultrasonic methods. Experience shows that in many cases, a significant portion of service life is available after crack initiation.

The combination of stress and thermal gradients, coupled with microstructural variation through-wall, leads to damage initiation within the inner third of the tube wall. Creep cavities nucleate and grow linking to form cracks, which propagate to the inner and outer surfaces. It is usual to find a dense network of parallel cracks, of similar length, spaced radially by the width of the columnar grains. For much of the growth period, the stress field ahead of the cracks is compressive towards the outer surface.

Steam reformers are an integral part of ammonia, methanol, hydrogen, and gas process plants around the world. They are one of the highest cost, both in capital and maintenance, pieces of equipment in the plant. Typically, reformers contain several hundred vertically orientated straight tubes, referred to as catalyst tubes. Due to specific material grades, fabrication requirements, & in-situ support structures these tubes represent a significant cost for replacement and can be a major source of plant unavailability if unplanned failures occur. The Inner Diameter (ID) of these reformer tubes is generally between 3.0 inches and 5.0 inches. During plant operation the catalyst filled tubes are externally heated to allow the reforming reaction to occur.

Figure #1



One of the major concerns in plant operation is that the reformer tubes operate at an elevated temperature such that they are susceptible to a failure mechanism referred to as "creep". This condition exists due to the elevated temperatures and stresses imposed by internal pressure, thermal gradients, and mechanical loading cycles. Being able to identify and locate such damage in its early stages is essential for optimizing plant operation.

Conventional Non-destructive examination (NDE) inspection techniques currently applied to reformer tubes are geared to finding creep damage in the form of internal cracking. However, with the trend towards larger tube diameters and longer intervals between turnarounds, the detection of such defects may not allow for sufficient time for forward planning of tube replacements. Also, such techniques do not allow any differentiation between stages of creep that can separate tubes with remaining life and tubes which should be replaced. Early detection of underutilized tube life can prevent the lost opportunity on both unrealized production through running them too cool and tube life 'giveaway' if good tubes are discarded prematurely.

Reformer tube condition can currently be inferred in-situ by qualitative NDE assessment using the following techniques:

- **Diametrical Growth (diameter change with creep in some cases)**
- **Wall Thickness Measurement (apparent decrease in wall thickness with creep)**
- **Replication (final stages of creep damage; i.e., macrocracking)**
- **Radiography (final stages of creep damage; i.e., macrocracking)**
- **Eddy Current (responds to chromium migration due to overheating and conductivity changes)**
- **Ultrasonic (responds to attenuation and scattering)**

Typically, destructive testing is used on a small number of tubes removed from the reformer to try and determine the absolute life remaining. Whatever the method that is used to do this, the results are from a sample size that is statistically not valid. It is imperative therefore that all the tubes are surveyed with a NDE technique to characterize their relative condition in order to make sense of the absolute condition assessment provided by the destructive testing.

Inspection techniques

The principle of the eddy current method is that a determined energy flux is induced into the material to be tested with an EC-probe by generating a magnetic field which penetrates the material causing eddy currents. Any defects or irregularities in the grain structure disturb the energy flow leading to indications which correlate to the specific changes in material.

Reformer tubes undergo creep strain, in the form of diametrical growth, from the first day that they are fired.

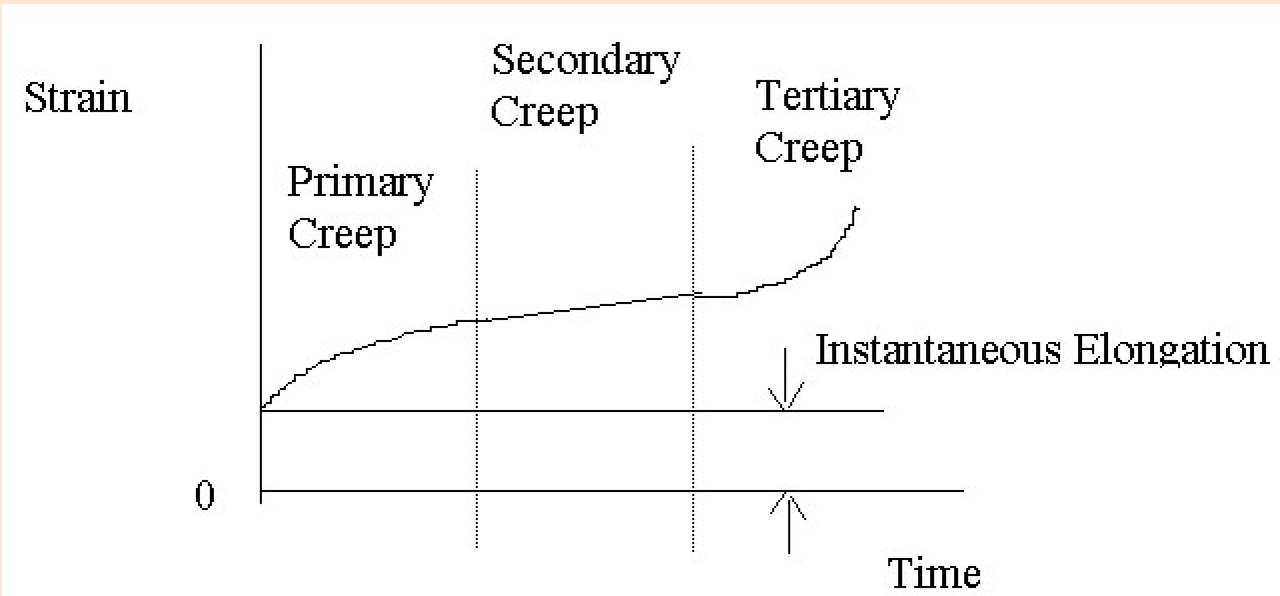


Figure #2

The ability to accurately measure and record this growth means that the tubes' condition can be monitored from day one. Therefore, not only can individual tubes be retired from service at an appropriate time, but also the reformer as a whole can be assessed for performance. The use of Eddy Current inspection techniques is not only useful in preventing tube failures but has huge potential in optimizing production from the whole tube set without sacrificing reliability. Of course, external diameter measurements can be used but they are limited as the automated devices only measure across one diameter and are often access restricted by tube bowing.

Manual measurements are too time consuming to provide more than a few readings per tube. External measurements are inherently less precise as they are based on a cast surface rather than the internal machined surface and do not take into account the effects of oxide shedding. The most accurate growth measurements are obtained when 'as new' baseline data has been taken prior to the tube being fired for the first time. However, if this is not available by using the top portion of the tube that is operating outside the creep temperature as a reference diameter, the growth profile of the tube can be determined at any stage in its life. The use of new laser techniques coupled with Eddy Current and UT techniques provides much more tube material information than older/single inspection techniques.

Creep cracks originating from I.D. surface.