# EDDY CURRENT INSPECTION IN PROCESSING FURNACE REMAINING LIFE PREDICTION

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## Abstract:

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. The cost optimization of industrial plants maintenance by preventing non-scheduled outages or extending service life-time is increasingly important. Life management is ordinarily dominated by the service capability of the radiant catalyst tubes. Their lives are limited by creep, driven by a combination of internal pressure stress and through-wall thermal stresses generated by operational transients. Although the service life may be estimated making use of theoretical models, due to the degradation process complexity, still it is necessary to characterize the materials of concern by non-destructive testing methods. Non-destructive testing (NDT) plays an essential role on maintenance program to assure operation of industrial plants.Proper determination of tube condition and its remaining life requires specific insitu examinations.

The current condition either can be measured by some destructive or nondestructive test method or calculated using an analytical model or statistical model, such as the TUBELIFE computer program. TUBELIFE is a probabilistic tube life assessment software package offered by Magnetische Pruefanlagen GmbH in Germany, US Thermal Technology Inc, and Hainsco in Saudi Arabia. The program analyses data gathered from nondestructive testing techniques to produce a probabilistic rather than deterministic analysis in predicting of reformers remaining life. Custom software program TUBELIFE and inspection technologies (eddy current, laser OD measurement) as well as metallographic examinations are outlined in the papers discussion.

## 1. Introduction

Steam reformer units are critical to many processes in refining and chemical plants, being used in the production of synthesis gas. Despite this wide variety of roles, there is great similarity in general design, material selection and operational conditions, allowing a common approach to integrity assessment and life prediction. Reformers are essentially large furnaces packed with banks of tubes packed with catalyst through which the reaction gases pass (figure1).

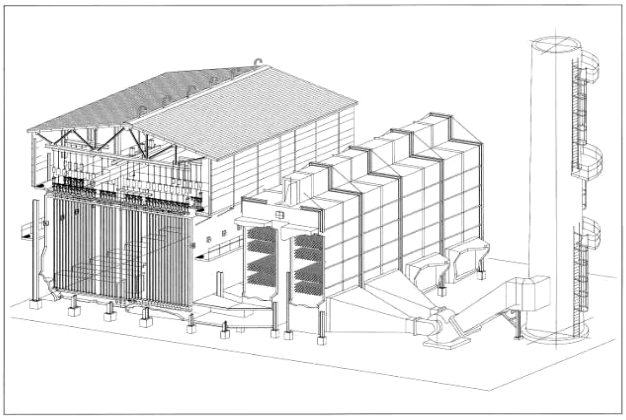

Figure1: Scheme of fertilizer factories primary reformer unit [7]

Heat realized by the burners is transferred to the reformer tubes. Considerable thermal stress is placed upon the reformer tubes themselves, making them prone to a variety of problems, and fractures and mechanical failures are common. Furthermore, as pressure to enhance plant efficiency increases, so the focus is on critical equipment items which can cause plant shutdowns. Their lives are limited by creep, driven by combination of internal pressure stress and through-wall thermal stresses generated by operational transients. Creep life exhaustion may be accompanied by progressive grain boundary cavitation-depending on the microstructure of the material- and may be exacerbated by micro-structural degradation processes, such as sigmatization. The primary reformer in any steam reforming synthesis gas complex is the most expensive and energy-intensive part of the plant equipment items which can cause plant shutdowns. Plant productivity can be directly controlled by the reliability of the steam reformer. A design life of 100,000 operating hours has been the normal time-based criteria for considering retirement of tubes. Non-destructive testing (NDT) plays an essential role on maintenance programs to assure operation of industrial plants. Many operators of furnaces using such tubesdesireto change their maintenance philosophy for tube retirement to condition-based assessment rather than time-based assessment.

## 2. Reformer tubes materials

Reformer catalyst tubes are commonly manufactured from high strength, creep and corrosion resistant alloys. They are of relatively thick wall and are usually produced by centrifugal casting.

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Tube design is traditionally based on pressure stresses, conservative outside wall temperatures and factored lower bound material rupture lives, according to API-calculation formula.

The characteristics of these alloys at temperatures up to 1000° C are mainly:

- creep resistance;
- oxidation resistance;
- ductility at high temperature;
- thermal fatigue resistance;
- weldability after aging.

The range of high temperature alloys needed by the petrochemical industry for fired heaters often cause confusion since the majority are not included in international specifications and design codes such as ASTM and ASME. Furthermore, the alloys are often known by their proprietary name. In fact there is a small family of alloys available for selections for fired heater tubes. Originally, in the 1960's two cast alloys became important, designated in ASTM and ASME as HK-25%Cr20%Ni0,4%C and HP-25%Cr35%Ni0,4%C. During the 1970's HK was improved with additional nickel and small additions of niobium. The obsolete HP grade was reintroduced with various additions of niobium and tungsten to give the now well known HP modified range. The latest development is the additional of small amounts of titanium and zirconium to the HP modified alloys. This micro alloys currently offer the highest creep strength giving thinner tube walls and greater furnace efficiency [1].

## 3. The NDT techniques combination analyses

The actual technique used is heavily dependent upon the following:

- Costs
- Individual plant preferences (limited knowledge of technologies)
- Historical experiences at the specific location
- Turnaround duration
- Availability of analyzed data from reformer tube testing
- Knowledge of the different NDT technologies (strengths and weaknesses)
- Availability of specialist services.

To reduce the occurrences of furnace tube removal for condition-based assessment and to improve overall reliability of tube life, the use of NDT techniques on a regular basis during reformer furnace turnarounds is beneficial. The condition of a reformer tube is inferred from the response of a NDT sensor to a change in material properties. As such, there are certain limits on detectability, sizing and characterization of flaws that are heavily dependent on the overall test system characteristics, comprised of the environment, instrumentation, sensor, material under test and, of course, the operator.

The combination of techniques provides valuable date for the prediction of the remaining life of tubes

Separately, in paper will be emphasized using CT (combination technique)of diametrical growth-laser profilometry and eddy current techniques due to their advantages of integrated works with automatic climbing device.

**3.1. Profilometry-diametrical growth**

As creep damage occurs, an apparent decrease in wall thickness is evident. Due to the difference in O.D. measurements of the tube segments caused by manufacturing variations, it is preferable if baseline data can be obtained on the tubes when initially installed so accurate trends may be developed.

The principal rationale behind this technique is that, as creep damage occurs, the tube bulge (normally at burner locations).

Each material type has its own nominal value of diameter change where creep is considered to have occurred. The following rules of thumb have been reported by various operators over the years.

Only through the application of other techniques is possible. Yet, recent findings show that in some cases, significant growth may be apparent, but the tube may show the absence of internal damage. Using diametrical 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 lead to a significant false call on the actual condition of the tube. The issue is further complicated by the fact that no tolerance is given by the manufacturer for tube O.D. measurement; and the tube I.D., while machined, can vary greatly over the length of the tube segment. In fact, the machining process may produce a given I.D. dimension, but because of the variation in the machining process, the tube may see a significant reduction in wall thickness on one side of the tube while having an abundance of material on the other side. After testing each tube profilometry result will be evaluate and assigne a damage grade per tube determined on the worst section of tube. These grades are assigned based on comparison of each tube to the NDT responses obtained from samples subjected to metallography confirmation. Final evaluation tube grading and dimensions are then transferred automatically to a life assessment software (figure2).

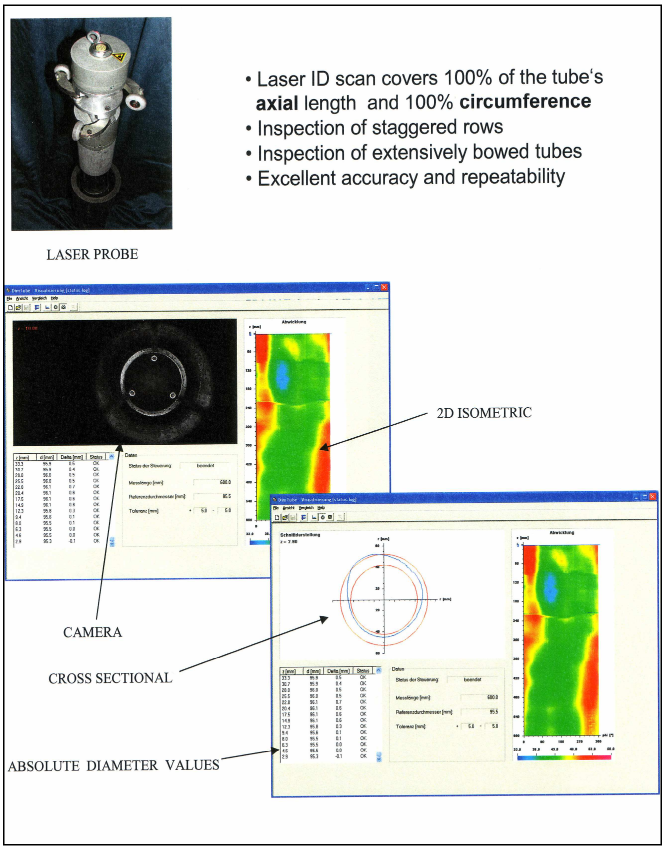


Figure2: Review of laser scanning measurement performances[8]

### 3.2. Eddy- current method

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 these 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 basic principles of the technique can be found in Reference [1].The depth of penetration of eddy currents is primarily influenced by frequency, conductivity, and relative permeability.

Eddy Current coil design is important to obtain adequate sensitivity and signal to noise ratio. Some tubes, such as HP-40 and similar materials that have a high percentage of nickel, require the use of magnetically shielded or biased coils to reduce the effects of material permeability variations. This improves the signal to noise ratio so a reliable test result is obtained, allowing adequate discrimination of creep damage from general material property characteristics.Referring to varying degrees of damage within a reformer tube, the eddy current operator evaluates these changes in signal response.

Other factors that the operator considers are:

- Varying lift-off, influencing the signal response, scale and welds being typical examples
- Overheating that causes chromium migration, scale formation, and a significant eddy current response in terms of phase and amplitude changes
- Variations in material permeability

Noticable change in the OD orID dimension (for instanceHK-40…2-3% andHP-45…5-7 %).

The advantages of eddy current inspection technique are the followings:

- no requirement for cleaning the tubes;
- no need to remove catalyst;
- no variation due to coarse grains;
- no coupling medium (water) is required;
- no limitation due to defect orientation;
- 120° on each fire side are tested;
- eddy current penetration into tube wall up to 25mm,
- 200-250 inspected tubes per normal work shift (0,3 m/sec);
- high repeatibility of the results.

The inspection is performed with a pneumatic tube crawler with speed of 0,3m/sec. This translates into an estimated 250 tubes inspected per normal work shift (figure3). Increment of tube diameter is an indicator of creep relaxation presence. Then, as the laser scanner is inspecting and moving vertically,

two perpendicular tube diameters are measured along the tube.

Creep crack depth measured by eddy current technique is rated in percentage of sound wall lost to the crack (i.e. 30%, 40 %, 50% etc.). The crack normally begin approximately one third from the wall-thickness inside diameter, growing first toward the ID and then the OD.Combination both results provide optimum information on the tube condition and remaining life expectancy.

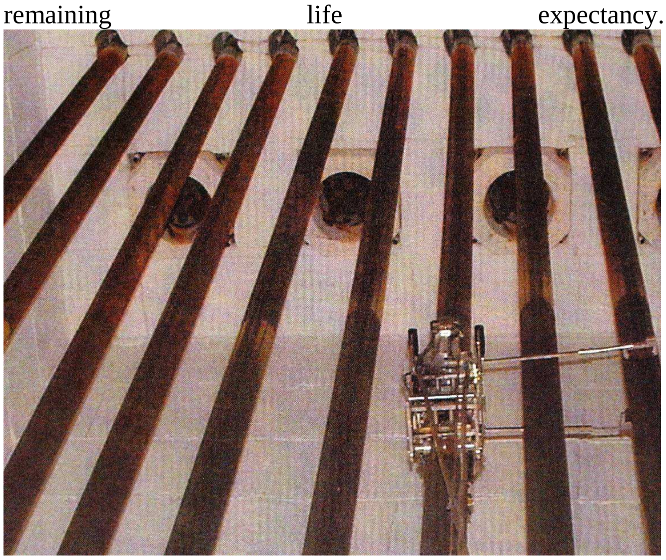

Figure 3 : MP- climbing device for eddy current crack depth and laser outside diameter (OD)measuring during in-sevice inspection of in reformer tubes[8]

## 4. Metallographic analysis of damaged tube

However, the condition of the sample tube may or may not be a representative of the total number of tubes in the furnace. For an operating facility to change from a time-based to condition-based philosophy requires confidence in the methods and techniques used to determine tube condition. Extracting tubes at a turnaround close to the end of their design life and subjecting them to metallurgical investigation would appear to be fairly well accepted practice. Some facilities have also embraced the use of certain NDT techniques to trend changes in tubes. Exactly, this tubes structures anisotropy acts a lot of difficulties at NDT. For reformer tubes ratio between columnar and equiaxed grains in structure of min. 50% / 50% is recommended. From the metallographic point of view, the state of the material is classified in several stages. Table1 reproduces a possible classification method based on the presence of carbides, voids and cracks, from level 1 (undamaged material) to level 6 (highly damaged material).

Table 1: Creep damage level classification [8]

| Level | Micrographic observation |
|---|---|
| 1 | Only coalesced carbides |
| 2 | Creep voids |
| 3 | Aligned creep voids |
| 4 | Few cracks |
| 5 | Cracks <50% thickness |
| 6 | Cracks >50% thickness |

On Figure 4; progress of failure of furnace tubes regarding on thermal creep degradation and oxidation on high temperatures is presented. Depending on work hours, the presences of different degradations stages (i.e. third stage creep damages or fissured material) are noticed.

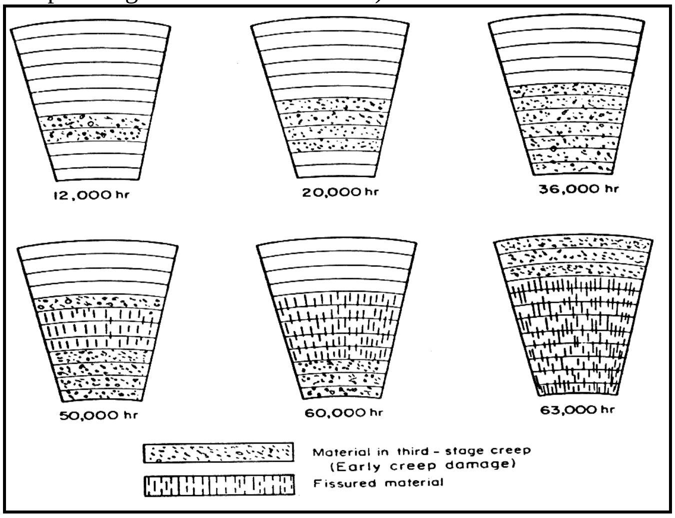


Figure 4: Presentation of progressive failures flow of furnace tubes [8]

Metallographic analysis of damages tubes was performed on one example with eddy current registered cracks.The evaluated damages are metallographic confirmed (figures 6, 7). The microstructure of reformer tubes (ASTM A297 HK40) is developed by “Glyceregia “etching (HNO3 + HCl + glycerol).

Macrostructure is developed by etching in Adler's reagent. Structure is characteristic for centrifugally cast process, i.e. The2/3 of outer side of tube thickness consists of columnar grains. The following 1/3 of thickness has equiaxed grains (Figure5).

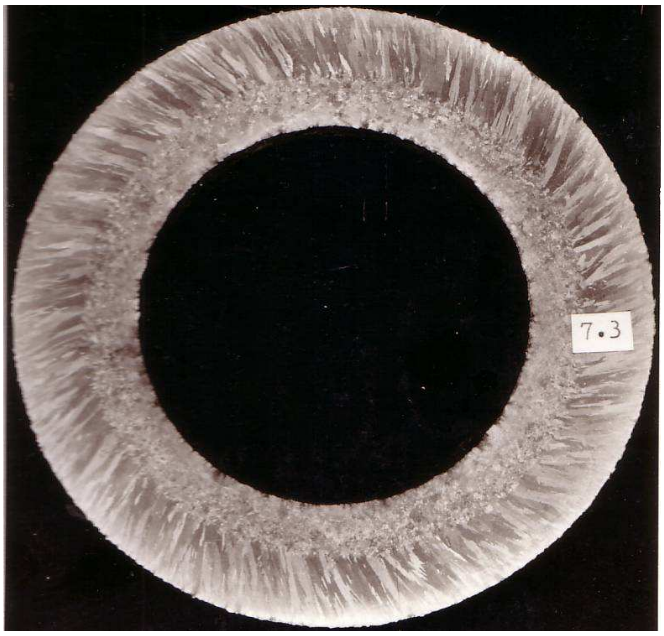


Figure 5: Macrostructure of centrifugally cast tube,1:1

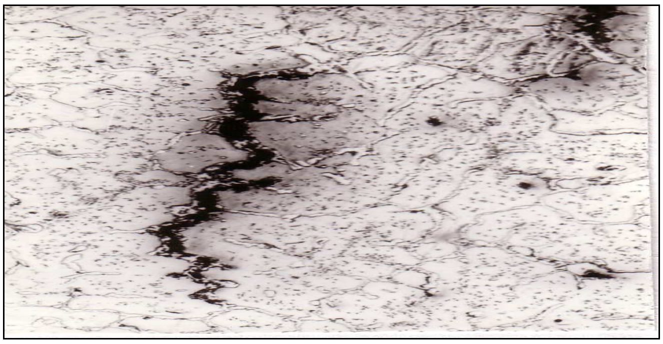

Figure 6; Microstructure of cracked tube-macrofissure, 100:1;

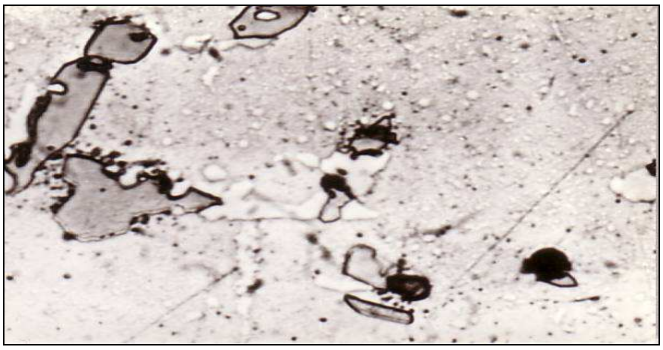

Figure7; σ –phase with disperged Cr-carbides, 1000:1

## 5. Tube remaining life prediction

Life assessment based upon the TUBELIFE second generation probabilistic methodology combined with the leading inspection capabilities of Magnetische Prüfanlagen provides state-of-the-art tube life assessment and operational planning. MP offers the industry an integrated inspection-service package, including tube life assessment based on the TUBELIFE software, enabling the industry to achieve:

• lower risk of unplanned failures and plant outages;
• optimised spares strategy;
• through yield optimisation features improve resource management.

Software for the probabilistic life assessment of radiant catalyst tubes incorporates:

–TubeEntry - data input interface

–TubeLife- probabilistic life assessment software

–TubePost - post processing

Life prediction probabilistic analysis accounts (spatial and temporal variations) for:

- Unit configuration (flux & temperature profiles)
- Process variability
- Material property variation
- Skin temperature variability
- Axial and circumferential heat flux variation
- 

In this chapter the approach to predicting of remaining life with example of results is shown.
In analysing of life prediction always is the question: **what is the driving force for failure?**

Under normal operations conditions:

- creep
- thermal stress redistribution
- local heat flux
- operational transients.

New features of MP software package are:

- revised stress analysis
- revised creep models
- account of transient operation ( loss of steam)
- Flux and skin temperature profiles for top-fired, side-fired and Foster Wheeler design configurations (example see figures 8,9)
- Due account taken of inspection findings
- Guidance and software for data collation.

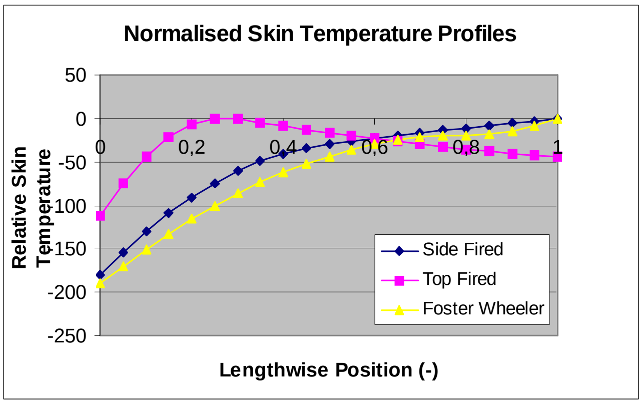


Figure 8; Processing data related on skin tubes temperature [10].

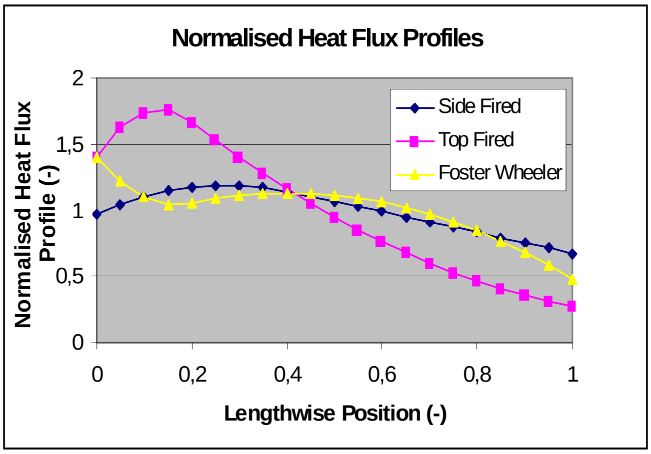


Figure 9; Processing data related on tubes heat flux [10].

Where, on which tube, is failure going to occur first?, including all processing data ,using TUBELFE, predicting tubes failure is possible with low level of risk (Figure 1o,11).

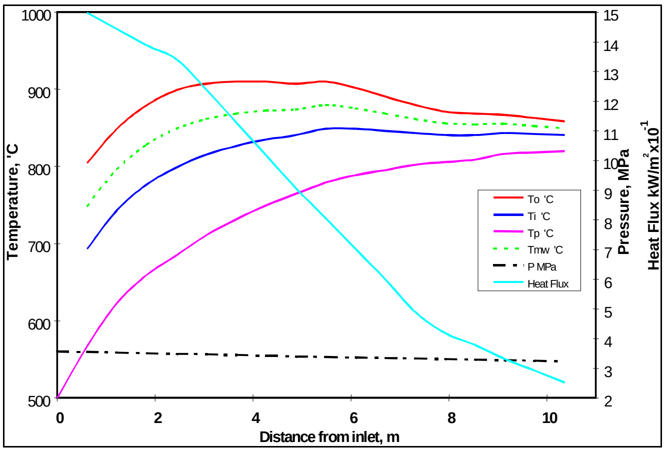


Figure10; Unit configuration profiles data
( flux & temperatures&pressure ) [10].

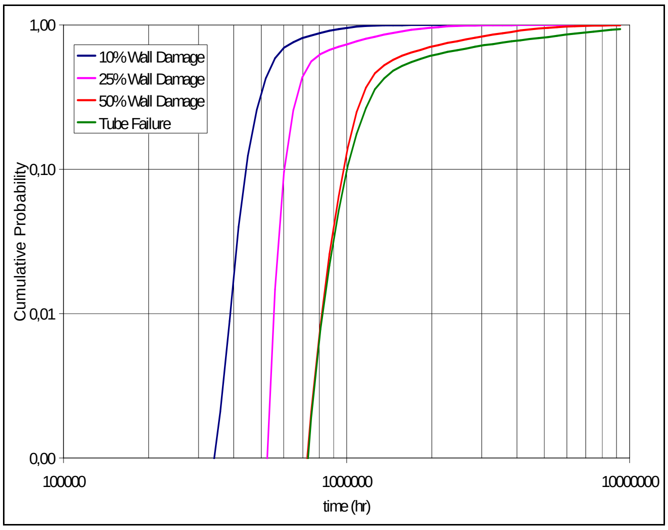


Figure 11: Final report on TUBELIFE assessment by probabilistic methodology [11].

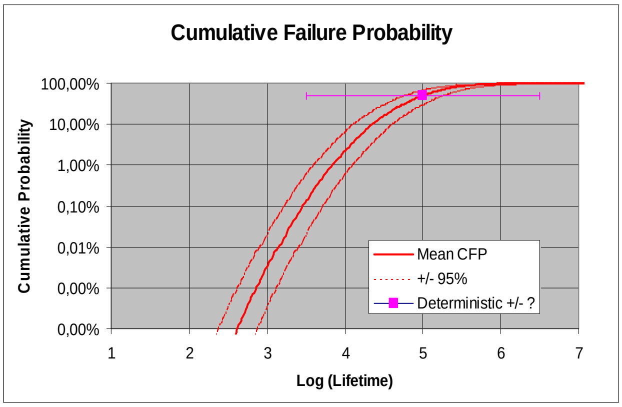


Figure 12; Final report on TUBELIFE cumulative failure probability predicting by probabilistic methodology comparing with deterministic approach [11].

Finally, comparing two present approaches of predicting reformer life, it is necessary show the characteristics of both, with cumulative failure probability final sample report (figure12).

Probabilistic approach:

- o Considers all failure scenarious
- o Considers all tubes in the cell/row
- o Considers variability of :
- o Material
- o Operational parameters (flux and temperatures)
- o Considers evolution of damage and tube failure.

Deterministic approach:

- Considers one failure scenario
- Single life estimate for all tubes in cell
- Assumea a niminal confidence level
- “simplified” approach
- “less” input data
- “simple” to implement
- Which tube?

## 6. Conclusions

Accurate prediction of remaining reformer tube life has become crucial to scheduling maintenance turnarounds and tube replacement. The all results of NDT measuring regarding on eddy current crack depth and laser diameter growth are implemented into remaining life software TUBELIFE. Combining both test results (eddy current creep crack depth and laser diameter growth) provides the optimum information on the tube condition and for remining life predicting.

## 7. References

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