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Remaining life assessment of outlet radiant heater tube of naphtha cracking unit-a case study

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ABSTRACT

Traditionally, the equipments were replaced after their design life or if found damaged mechanically or metallurgically degraded during routine shutdown and maintenance. However in the present world economic scenario wherein industries are forced not only to take all possible measures e.g. minimum replacement cost and reduced down time to cut cost but also comply with the ever growing stringent safety norms. This gives an immense drive for continuous assessment of equipment's health and leftover useful life. Such assessments are now becoming a common phenomenon in chemical process and power generation industries.

The present case study pertains to an outlet radiant tube of heater of a Naphtha Cracking Unit. The tube has been in service of around 5.5 years ever since it's commissioning and subjected to 41 decoking cycles. As per licensor the tube replacement criteria is based on average service life of 6-6.5 years or 50 decoking cycles whichever is earlier. A cut tube sample was subjected to multiple laboratory tests including creep tests and was assessed for its suitability to further operation. The result of our study was in line to the general recommendations of the licensor.

Keywords: remaining life assessment, naptha cracking unit heater

INTRODUCTION

Cracking is a process wherein a heavy hydrocarbon molecule is broken into small molecule and in process more value added products are obtained. In petroleum refining industry, naphtha is one such feed stock which is converted into more useful products such as ethylene by cracking through various ways. Ethylene is further consumed in the production of high density / low density polyethylene and linear low density polyethylene.

The process of cracking normally requires the feed stock to heat to a specific temperature in a heater. While, the process fluid passes through the tubes of the heater, tubes are subjected to external firing. Though, the selection of materials for heater tubes is done on the basis of the design temperature and pressure of the tubes and the corrosivity of the process [1], the tube material is subjected to Creep damage as the tube skin temperature is normally quite high. The materials undergoing creep damage have a specific design life. However the actual life can be more / less than the design life depending upon the actual process conditions. It was reported by Hill T. in year 2000 that replacing heater tubes consistently on a premature basis can cost a medium-size refinery up to one million dollars per year or more in unnecessary capital costs [2]. Therefore, to achieve full potential of the furnace tubes safely, it is essential to take out a representative tube sample from the furnace and carry out an elaborate destructive study of the material. Precise Life assessment of components operating under high temperature requires determination of actual material properties such as tensile, impact or toughness from CVN or fracture mechanics test, creep rupture properties etc. [3].

To assess the remaining life of tubes of a heater of Naphtha Cracker Unit (NCU) of a refinery, a cut tube sample was taken up from outlet radiant section of the heater after a service life of around 5.5 years. The tubes have been subjected to 1800 days in cracking (run length) and 41 decoking cycles. As per licensor the tube replacement criteria is based on average service life of 6-6.5 years or 50 decoking cycles whichever is earlier. As the tubes were approaching design life, RLA study of the heater was desired by the operator.

Detailed laboratory investigations consisting of visual inspection, macro etching, microstructural study, hardness measurements, determination of room and high temperature mechanical properties and creep study. The following enumerates the findings of the study:

DESIGN DATA OF FURNACE TUBES

Background data on the heater tube sample along with the design conditions of the heater and the sample details are given at Table 1.

Table 1: Background data of heater tubes

Service	Naphtha / hydrogenated C4/C5/C6 recycle dilution steam
Inlet temperature	626 °C
Inlet pressure	2.5 kg/cm^2

Outlet temperature	836 °C
Outlet pressure	2.1 kg/cm^2
Tube material	O/L:0.4C-35Cr-45Ni-Nb MA
Tube size	O/L: 143 x 8 x 15753
Tube metal design temperature	1125 °C

LABORATORY INVESTIGATION

In order to assess the damages to the tube, different destructive & non-destructive tests were carried out. The details of the tests carried out and the observations made are tabulated at Table 2.

Table 2: Test details and observations

S. No.	Test details	Findings
1.	Visual observations	No significant oxidation on tube Sample OD surface. No appreciable corrosion marks on Tube ID surface.
2.	Tube Diameter & Thickness	3.5% increase in tube diameter which is within acceptable limits. Mild thickness loss (<0.8 mm) as compared to design thickness.
3.	Chemical analysis	Chemical analysis through wet analysis shows 0.52% and 0.23% Carbon on inner and outer surface respectively as against 0.5-0.6 % nominal indicating decarburization on outer surface inferred.
4.	Carburization on tube ID surface.	Macroetch test of tube ring section conducted using boiling 50% HCl revealed absence of carburization.
5.	Tensile tests using Universal Testing Machine on 6mm x6mmx50mm gauge length samples	YS, UTS & % elongation assessed at various temperatures compared with the supplier's data (Figure 1). Room temperature UTS indicates lowering of the property by 16% of the supplier specified data. YS at room temperature and YS & UTS at all other temperature found above the specified values. Percentage elongation at room temperature significantly lower than specified value indicating poor ductility on service exposure.
6.	Metallography on circumference – thickness section	Observations made at inner edge, middle & outer edge of tube cross section and given at Figure 2(a-d). The material shows decarburization on outer surface to an extent of 0.2mm. Presence of primary carbide of 'Cr' and 'Nb' in austenitic matrix seen throughout the section. Network of primary carbides completely broken with dissolution of inter dendritic secondary carbides. Few Micro-voids are also observed on primary carbide boundary.

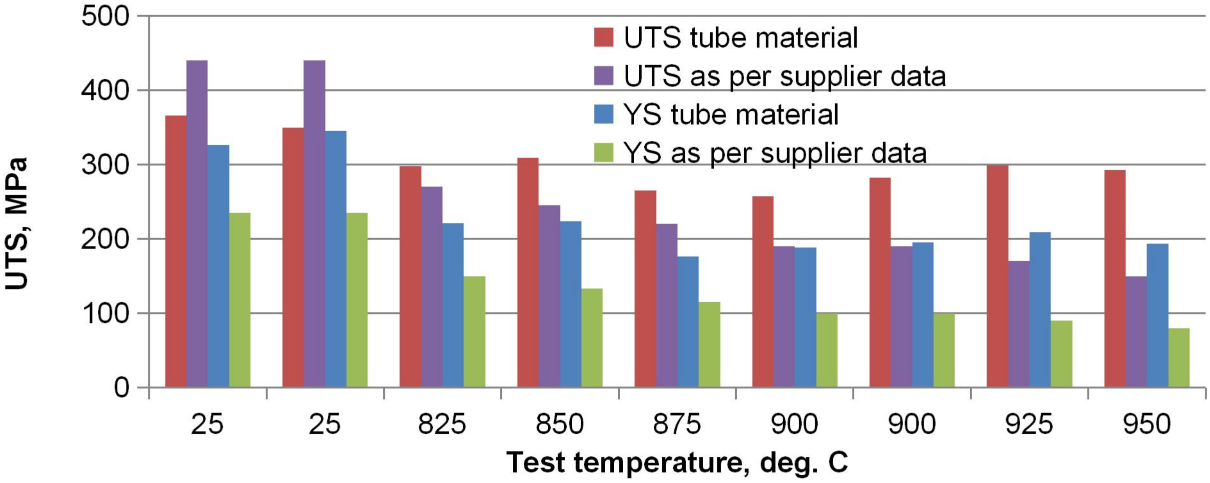

Figure 1: Variation of YS and UTS of tube material with test temperature along with virgin properties as provided by the supplier

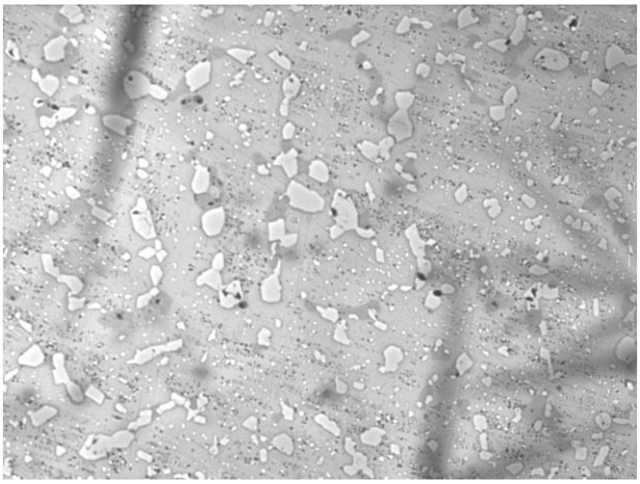

Figure 2(a): Inner edge of the CT section showing agglomerated primary carbide and extensive precipitation of secondary carbides (200X)

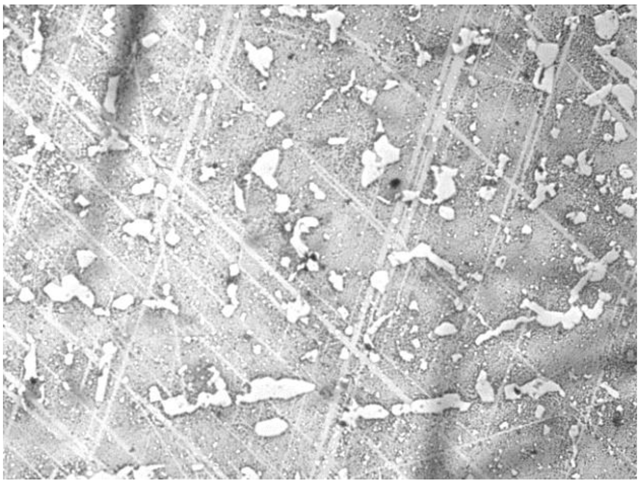

Figure 2(b): Mid section of the CT section showing agglomerated primary carbide and extensive precipitation of secondary carbides (200X)

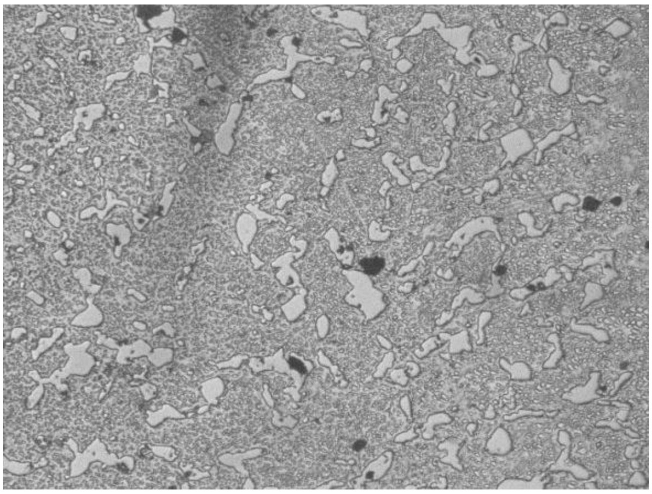

Figure 2(c): **Outer edge of the CT section showing agglomerated primary carbide and extensive precipitation of secondary carbides. Presence of a few voids is also seen. (100X)**

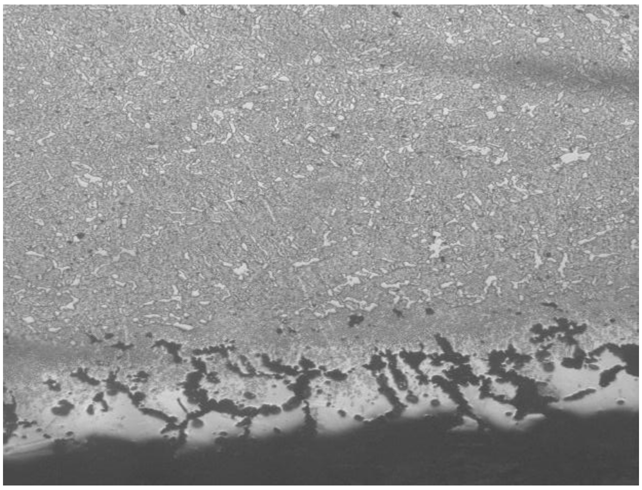

Figure 2(d): Outer edge of the CT section at lower magnification showing decarburized layer. (50X)

OBSERVATIONS AND DISCUSSION

From the laboratory studies carried out on the presumably representative tube of the heater, the following observations are made:

- No significant oxidation or evidence of corrosion noted on the tube surfaces
- Tube is free from any internal surface carburization.
- Tube is free from any significant thickness losses.
- Diametric expansion of the tube is seen to be within limits.
- Tubes are seen to have undergone surface decarburization on the external surface as inferred from microstructure and chemical analysis
- Microstructural degradation in the tube is seen to be commensurate with the service life.
- UTS at room temperature is seen to be 16% lower than the supplier specified value.
- YS at room temperature and both YS & UTS at all other temperatures are seen to be above the material supplier data
- Percentage elongation is found to be significantly less than the material supplier data indicating the poor ductility on account of service exposure.

RLA FOR CREEP DAMAGE AS PER VIRGIN PROPERTIES

Remaining life of the tube creep damage has been estimated based on supplier’s data using Larsen Miller Parameter (LMP) approach. Evaluation has been made considering the minimum rupture strength as provided in the material supplier’s data. It is necessary to estimate the accumulated tube damage (life fraction consumed) based on the operating history of tubes. As a conservative estimate, the following parameters are considered for life estimation:

1) Maximum operating tube skin temperature of 1125°C (TMT) is assumed to be uniform in the whole operating period of 5.5 yrs
2) Design operating pressure
3) Present diameter (148mm) and thickness value (7.2mm) of the tube
4) No consideration for corrosion allowance.

The residual life has been estimated presented at Table 3.

Table 3: Estimated residual life as per supplier's data

Design pressure (kg/cm^2)	Hoop Stress (MPa)	LMP	TMT in °C	t_r in hours	Service life in hours	Remaining Life in hours
2.5	2.62	34.9	1125	92094	50000	42094 (~5years)

RLA FOR CREEP DAMAGE AS PER PROPERTIES DETERMINED FROM ACCELERATED STRESS RUPTURE TESTS (ASRT)

The tube material has been tested for its actual its creep properties using ASRT machines. A limited number of Iso-stress tests have been conducted at accelerated stress (12MPa) and at temperature close to the maximum operating temperature in order to have creep rupture within a practical time. The test matrix along with the test results are given at Table 4.

Table 4: Test details and observations

S. No.	Test temperature, (K)	Rupture time (hour)	LMP
1	1373	244	30.74
2	1348	854	30.91
3	1398	198	30.17

The Stress-LMP laboratory data has been plotted on the Stress-LMP plot provided by the material supplier (Figure 3).

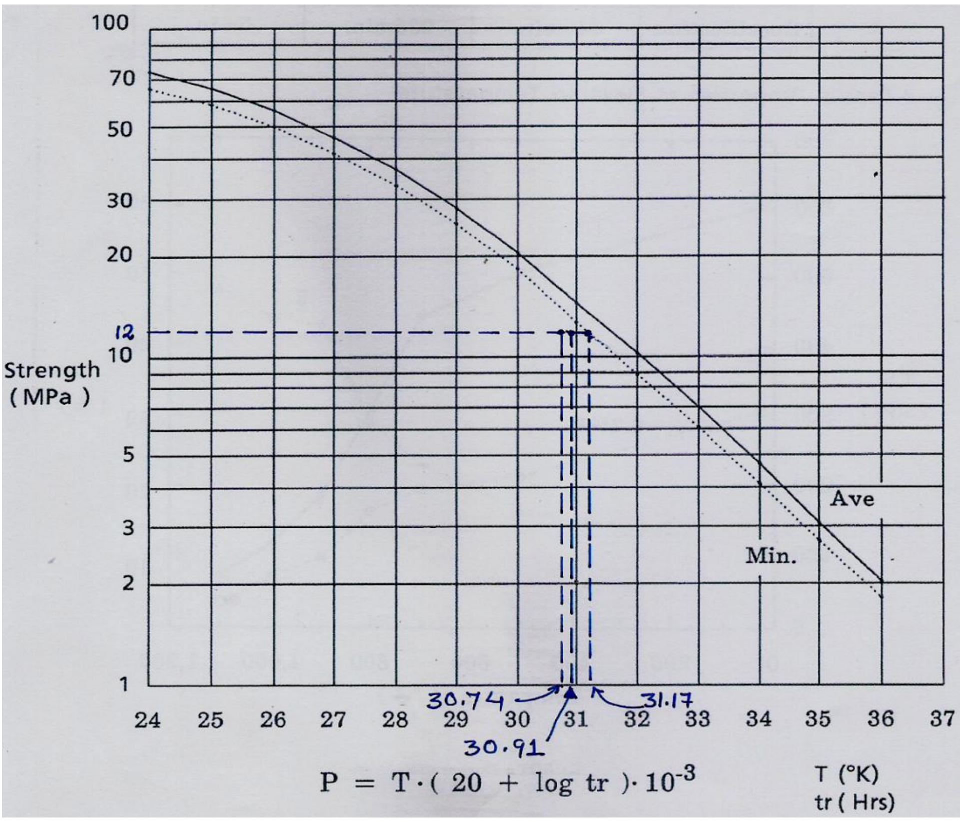

Figure 3: Stress - LMP laboratory data plotted on characteristic creep curve for the material provided by supplier

It is evident that all the three test points fall below the minimum creep rupture curve. A stress –LMP line parallel to the linear minimum rupture line passing through the experimental points has been drawn and LMP corresponding to hoop stress has been used for the estimation of remaining life and presented at Table 5.

Table 5: Estimated residual life as per creep test results

Design pressure (kg/cm^2)	Hoop Stress (MPa)	LMP	TMT in °C	t_r in hours	Service life in hours	Remaining Life in hours
2.5	2.62	34.5	1125	47655	50000	-2344
2.5	2.62	34.5	1120	58437	50000	8437
2.5	2.62	34.5	1115	71764	50000	21764
2.5	2.62	34.5	1110	88261	50000	38261

2.5	2.62	34.5	1105	108713	50000	58713
2.5	2.62	34.5	1100	134109	50000	84109

The above analysis indicates that the tube material does not have any more creep life at design tube metal temperature and design pressure.

CONCLUSION

Based on the laboratory test data conducted on a presumably representative tube sample of the heater, it inferred that the tubes have no remnant life left in them as evaluated at design conditions. The actual operating temperature and pressure are expected to be lower than the design values and hence a theoretically positive life may result. However, since no corrosion allowance, oxidation effect and effect of thermal stresses have been considered in the analysis, it concluded to plan for the replacement of the tubes.

REFERANCES

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