Fatigue Life of Tube and Header of Evaporator

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Abstract - *The study is conducted to find the stresses and thermal expansion in the evaporator module, which is subjected to internal pressure cycles. The finite element technique is employed to determine the safety of component to given operating conditions. In a power plant, the tubes and pipes are critical areas, which affects the pressure cycles. Some cracks were noted in the tubes of evaporator module and hence there was need for the analysis to be carried out to determine if the component sustains for remaining life. Deformation and stresses are studied in details to evaluate finite element analysis result. The S-N curve and stress- strain properties are calculated from ASME Sec VIII, Div -2, 2015 The same code is referred for the analytical calculations. From the site data we can determine the pressure cycles, which includes the several variations in pressures with respect to working conditions and also shut down and start up cycles. The life is found from the numerical analysis and the results are validitated with analytical calculations performed as per the standard code.*

Key Words: Fatigue life, S-N curve, fluctuating loads

1. INTRODUCTION

It has been observed that material fail under fluctuating stresses, at a stress magnitude, which is lower than the ultimate tensile strength of the material. Sometimes, the magnitude is smaller than the yield strength. Further, it has been found that the magnitude of the stress, which is causing fatigue failure, decreases as the number of stress cycles increases. This phenomenon of decreased resistance of the material to fluctuating stresses is called fatigue.

There is a basic difference failure due to static load and that due to fatigue. The failure due to static load is illustrated by doing the experimentation of the simple tension test. In this case, the load is gradually applied and there is sufficient time for elongation of fibers. The fatigue failure begins with a crack at some point in a material.

The size in crack increases due to the fluctuating stresses, until the area of cross section of the component is decreased so that remaining portion is subjected to sudden fracture.

The S-N curve which is shown below is a graphical representation of the maximum applied stress S_f versus the number of stress cycles N before the fatigue failure on a log - log as shown in figure 1

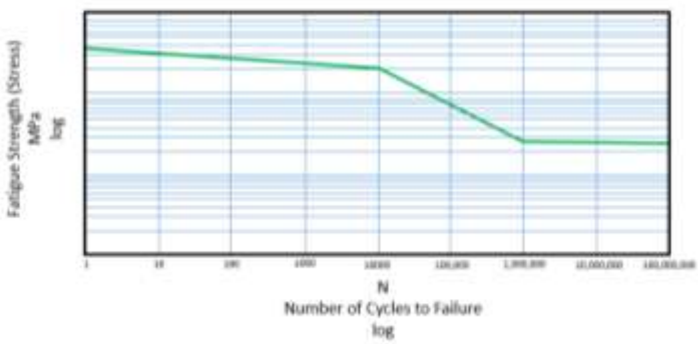

Figure 1 S - N curve

Fatigue life is a mechanical and scientific term that relates to how long an object or material will last before failing because of concentrated stresses. In most cases, life is determined with the help of number of stress cycles that an material can handle before the failure occurs. It is not immediately noticeable. Small cracks and holes are formed at the highest stress locations.

1.1 Problem Statement

At high operating pressure and temperature, power plant components undergo ageing effect. In most of the cases, there is failure of tubes and pipes, which affects the shutdown of plant. In many areas, the small cracks are developed due to continuous thermal conditions. The same condition is analyzed in this paper for tube and pipe of evaporator module, which are operated at high temperatures and pressures. There was a failure in tube and header pipe of power plant evaporator module. Refer image 2, which shows the failure of tube and pipe.

The tube carries pressurized steam, which has cyclic pressure for various intervals of time. Hence, there was a need to find if the evaporator module components were failing due to cyclic conditions. In addition, it is need to find further how much years it will work under safety before components tends to fail for the operating conditions.

Image 2 Failure of tube and pipe joint

2. MATERIAL PROPERTIES AND LOADING CONDITIONS

The material properties and the design conditions and sizes for which the header pipe and tubes are operated are given in below table.

Table 1

Sr .No.	Parameters	Values
1	Header Size (mm)	NPS 8"x SCH.160
2	Tube Size (mm)	OD 38.1 x 5.0 THK.
3	Design Temperature	280ºC(Headers)479ºC (Tubes)
4	Design Pressure	52.0 bar

Table 2

Material Properties	SA 213 T22 (Tubes) @ 479ºC	SA 335 P22 (Headers) @ 280ºC
Density (kg/ m³)	7750	7750
Young's Modulus (E) (MPa)	174200	193600
Poisson's Ratio	0.3	0.3
Allowable stress (S) (MPa)	96.9	114
Yield Strength (MPa)	205	205
Tensile Strength (MPa)	415	415

3. SIMULATION SCHEME

The Evaporator module consists of two headers i.e. inlet header and outlet header which are connected with downcomers and risers. The tubes are connected in between these two headers. There are four tubes in a column and 30 rows of tubes with 100mm pitch. The full model is shown in below fig. 3

Image 3 Evaporator module

As per the ASME code, the analytical calculations are performed and found out that fatigue damage is approximately 3.18 x 10^{-4} for a operating period of 15 years.

If $D_{f,k}$(fatigue damage for k^{th} cycle) ≤ 1,

(Eq.5.38, ASME Sec VIII Div - 2)

Then the design is safe against fatigue loading.

In addition, the allowable thermal expansion of material is calculated as per code, it is 49.73mm

3.1 Meshing

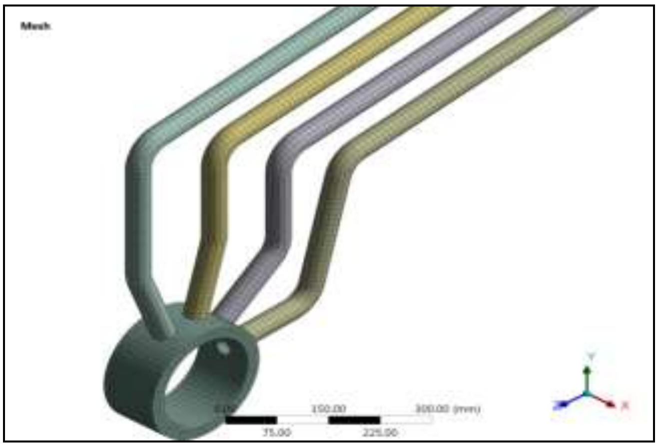

Image 4 Header and tube meshing

Mesh built up in several sections;

Higher order elements are used throughout the model to increase the accuracy of the solution.

Meshing is carried out with hexahedral elements, which contains more node counts and greater accurate solutions.

Image. 4 and image. 5 shows the meshing of the model.

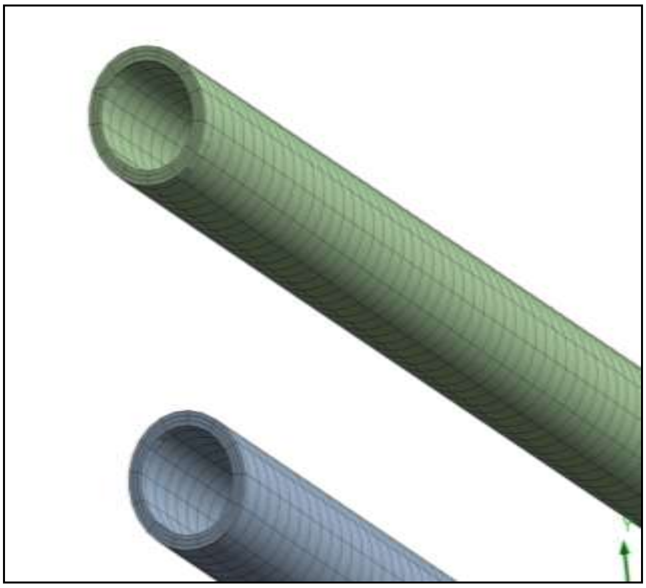

Image 5 Meshing of tubes along the thickness

3.2 Loading Conditions

The loading cases for the analysis is as follows:-

(i) Thermal analysis for temperature distribution.

(ii) Static thermal analysis for effect of temperature

(iii) Static analysis for effect of pressure cycles

(iv) Static analysis combining the above two analysis i.e. temperature and pressure effect and also fatigue life determination

The boundary conditions are applied as per the actual operating conditions and at the supports locations at inlet and outlet header respectively.

3.3 Result plots for case i

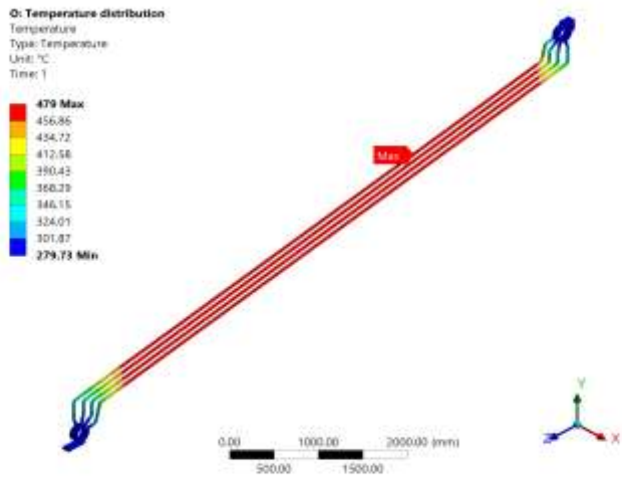

Image 6 Temperature distribution plot

The operating temperature of tube is 479°C and for header is 280°C. The temperature distribution is found from the thermal analysis and the distribution plot is shown in image 6.

3.4 Result plots for case ii

The analysis is carried out for the temperature distribution and the stress and thermal expansion is plotted as a results. Images 7 and 8 shows the plot of stress and expansion of module respectively.

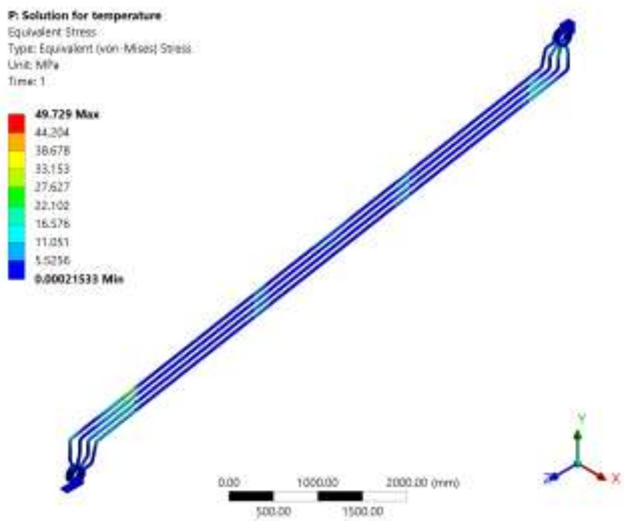

Image 7 Stress for temperature effect

The deformation is the thermal expansion of material, which is due to high temperature operations. The expansion is within limits hence it is safe from failure point of view.

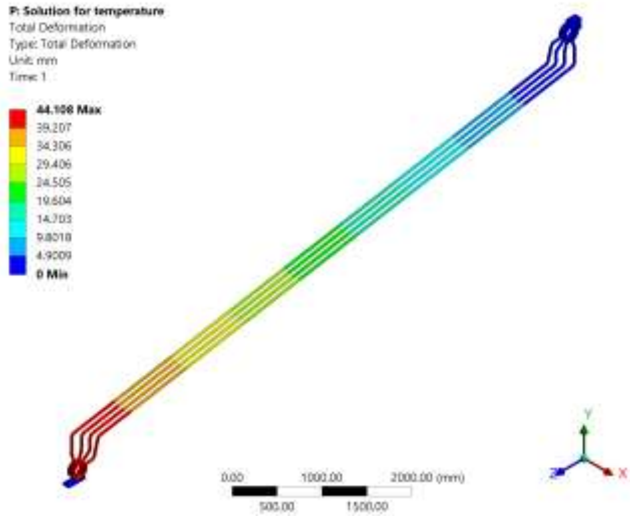

Image 8 Deformation for temperature effect

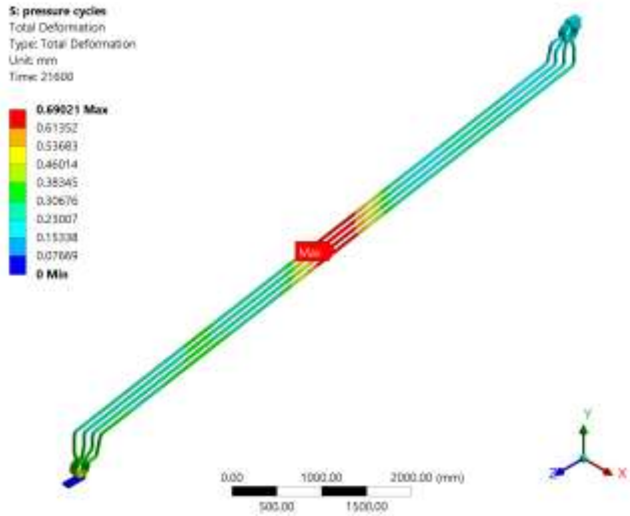

Image 10 Deformation for pressure effect

Table 3

Solution	Actual	Remark
Equivalent Stress (MPa)	49.72	SAFE
Deformation (Expansion) (mm)	44.108	SAFE

Table 4

Solution	Actual	Remark
Equivalent Stress (MPa)	75.977	SAFE
Deformation (mm)	0.69	SAFE

3.5 Result plots for case iii

The analysis is carried out for the pressure variation cycles and the stress and deformation is plotted as a results. Images 9 and 10 shows the plot of stress and deformation of module respectively.

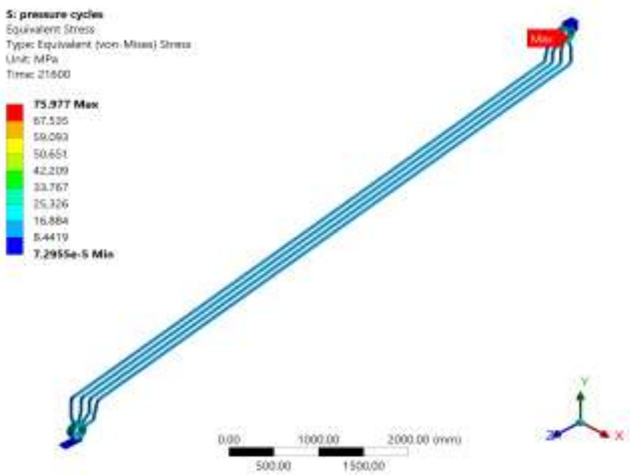

Image 9 Stress for pressure effect

3.6 Result plots for case iv

The analysis is carried out for the pressure variation cycles combine with temperature effect cycle and the stress and deformation is plotted as a results. Images 11 and 12 shows the plot of stress and deformation of module respectively.

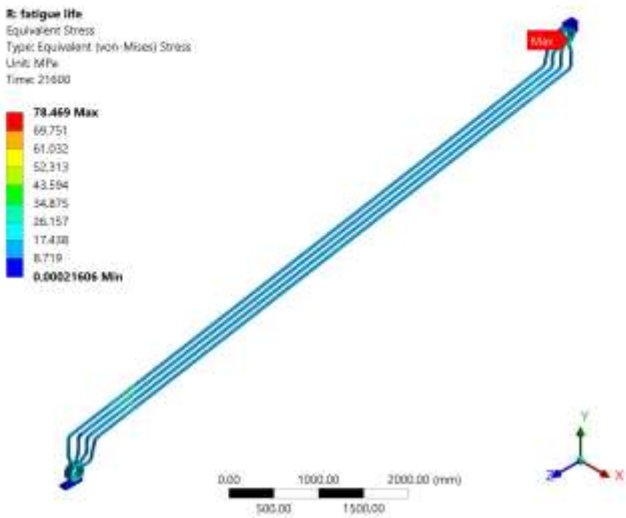

Image 11 Stress for pressure and temperature effect

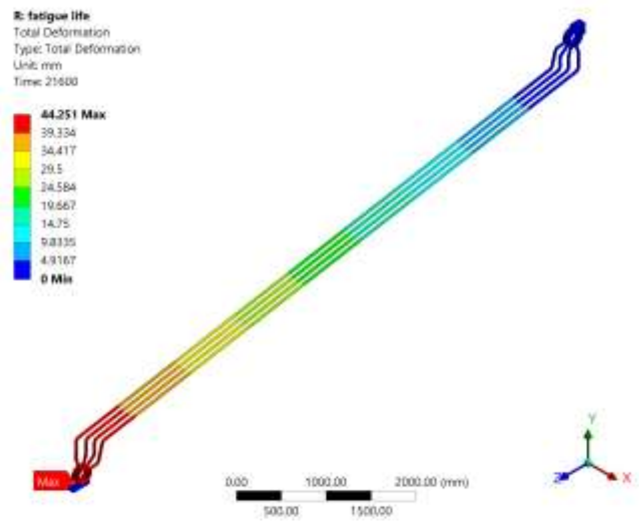

Image 12 Deformation for pressure and temperature effect

Table 5

Solution	Actual	Remark
Equivalent Stress (MPa)	78.469	SAFE
Deformation (mm)	44.251	SAFE

From the above case iv, it is clear that the evaporator module is safe for the operating conditions and the life is determine below from the fatigue analysis

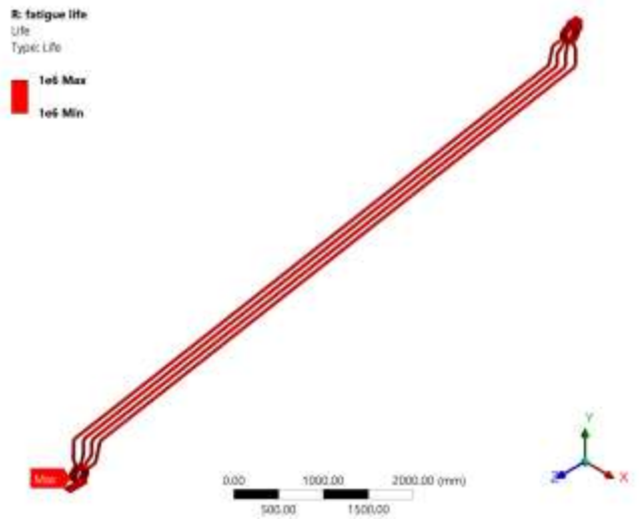

Image 13 Life of tube and header

From the above image 13, it is clear that the fatigue life is infinite for the tube and header at given operating conditions.

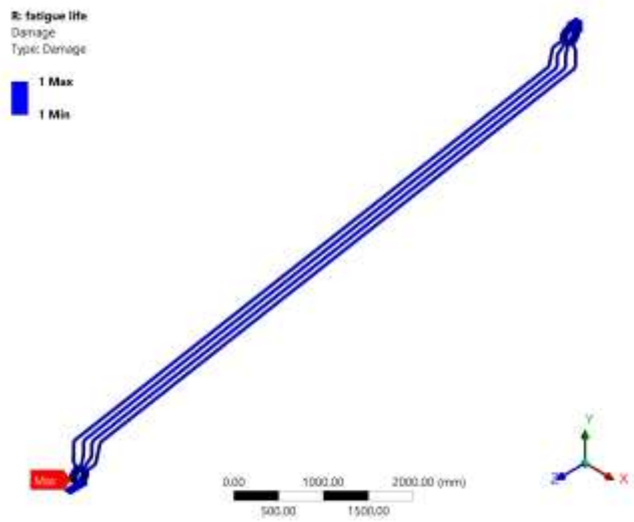

Image 14 Damage of tube and header

From the above image 14, the damage for the tube and header is maximum 1, and as per the code the design is safe against fatigue failure. Hence, the evaporator tube and header is safe against fatigue failure.

4. CONCLUSIONS

The main objective to perform the analysis is to find out whether there was failure in the evaporator tube and header due to fatigue loading.

We have analyzed the fatigue life for the evaporator module from the history data of operations and it was found that for the next 15 years it is safe against fatigue failure. The same results are validitated with the analytical calculations and it is coming out to be safe design against cyclic loadings.

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