



## Calculation Example - Creep Assessment

For tubes or pipes operating in the creep regime, the following questions are asked:

1. What is the estimated time to failure at a given operating pressure, metal temperature and corrosion rate (metal thinning rate)?
2. For a specified operating pressure and corrosion rate, what temperature limit must be imposed for the tube to last a minimum period of time?
3. How much must the operating temperature be reduced to extend the life of the tubes or pipes by a given period of time?

The calculation of an answer for Question 1 is illustrated below. Consider an example of fired heater radiant tubes, under the following conditions:

Material = 18Cr-10Ni-Cb (Type 347 stainless steel)  
Outside diameter ( $D_o$ ) = 168.3mm  
Initial thickness ( $t_i$ ) = 6.8mm

The furnace tubes are known to have been in service for approximately 8 years:

$$8 \text{ years} \times 365.25 \text{ days} \times 24 \text{ hours} = 70,128 \text{ hours operating life}$$

For a creep design life of 100,000 hours, this furnace has used ~70% of its life. However, the tubes are subject to a metal thinning rate (MTR) of 0.15mm/yr from, for example, combined internal corrosion and external oxidation.

This assessment module makes use of the Life Fraction Rules (LFR). The operation of the furnace is divided into periods of time in which the pressure, metal temperature, and corrosion rate are assumed constant.

For each of these periods, the creep life fraction consumed is calculated. The sum of these fractions for each period, is the total accumulated creep damage.

The tube internal pressure hoop stress ( $S$ ) for each period, calculated from accumulated metal loss due to thinning at the end of the period is used, which is considered to provide sufficient conservatism, as follows:

$$S = (P_o / 2)((D_o / t_e) - 1)$$

The minimum Larson-Miller Parameters ( $LMP_{min}$ ) are determined from the pressure hoop stress ( $S$ ) using the curves in API RP 530, as follows:

$$LMP_{min} = A_0 + A_1S + A_2S^2 + A_3\ln S + A_4e^{-S}$$

In this example, refer to Figure 3O (SI) – Types 347. In an actual heater, neither the operating pressure nor the metal temperature is uniform.

However, for this calculation these parameters are treated as uniform:



Period #	= 1
Duration (increment)	= 1.3years x 365.25days x 24hours = 11,396 hours
Operating pressure ( $P_o$ )	= 3.96MPa
Metal temperature ( $T_o$ )	= 649°C
Initial thickness ( $t_i$ )	= 6.8mm
Thickness, end of period ( $t_e$ )	= 6.8 – (1.3 x 0.15) = 6.61mm
Stress (S)	= (3.96/2)((168.3/6.61)–1) = 48.5MPa (7.03ksi)
$LMP_{min}$	= 34.36 (US units)
$\log L_r$	= $10^{[(LMP \times 1000)/(T_o + 460)] - 15}$ (US units)
$L_r$	= 494,957 hours
Life fraction (minimum)	= 11,396 / 494,957 = 0.023

The life fractions are the increment period (11,396 hours) divided by the rupture time that corresponds to that period.

To calculate cumulative life fraction, the above calculation is simply repeated in increments (periods) of 1.3 years, and the accumulated creep damage is the sum of the fractions for each period.

At each calculation increment, the strength of tube should also be checked for failure by plastic collapse. This will occur if the tube stress (which is continually increasing due to corrosion) is equal to the allowable elastic strength ( $S_e$ ) at the specified operating temperature.

$S_e$  is equal to two-thirds of the specified minimum yield strength (SMYS,  $\sigma_y$ ) of the tube material at design temperature ( $T$ ).

The calculation of SMYS for 18Cr-10Ni-Cb (Type 347 stainless steel) is based on Table F.3 in API RP579, as follows:

$$\sigma_y = \sigma_y^r (A_0 + A_1 T + A_2 T^2 + A_3 T^3 + A_4 T^4 + A_5 T^5)$$

$\sigma_y^r$  is the yield strength (ie. 24.1ksi) at the temperature of 400°F (for TP347SS). In this particular example (after substituting values for  $A_i$  and  $T$  in the above formula), if  $T = 700^\circ\text{C}$  then  $\sigma_y = 18.49\text{ksi}$  (127.45MPa).  $S_e$  is therefore equal to 85.0MPa. The minimum allowable thickness ( $t_{min}^e$ ) at a design temperature of 700°C and at a design pressure of 4MPa is calculated as in API RP530.  $t_{min}^e$  is equal to 3.87mm.

Failure will occur when either of the following conditions is reached:

- i. By plastic collapse, when  $t_{actual} < t_{min}^e$ ; or
- ii. By creep rupture occurs when cumulative life fraction is greater than one.

These failure criteria are highlighted in red in the following table. The remaining life is then simply calculated as the cumulative period (148,148 hours) at which any of these two criteria are first reached, minus the operating life (70,128 hours). This is equal to 78,020 hours.



No. #	Cumulative Period (hrs)	P <sub>o</sub> (MPa)	T <sub>o</sub> (°C)	MTR (mm/yr)	t <sub>e</sub> (mm)	S (MPa)	t <sub>min</sub> <sup>e</sup> (mm)	LMP (US units)	Time to Rupture (hrs)	Cumulative Life Fraction
1	11,396	3.96	649	0.15	6.60	48.47	3.87	34.36	494,957	0.023
2	22,792	3.96	649	0.15	6.41	50.01	3.87	34.25	427,318	0.050
3	34,188	3.96	649	0.15	6.21	51.64	3.87	34.14	367,318	0.081
4	45,584	3.96	649	0.15	6.02	53.37	3.87	34.03	314,283	0.117
5	56,980	3.96	649	0.15	5.82	55.23	3.87	33.91	267,579	0.160
6	68,376	3.96	649	0.15	5.63	57.21	3.87	33.79	226,617	0.210
7	79,772	3.96	649	0.15	5.43	59.33	3.87	33.67	190,843	0.270
8	91,168	3.96	649	0.15	5.24	61.61	3.87	33.54	159,745	0.341
9	102,564	3.96	649	0.15	5.04	64.07	3.87	33.41	132,845	0.427
10	113,960	3.96	649	0.15	4.85	66.73	3.87	33.27	109,699	0.531
11	125,356	3.96	649	0.15	4.65	69.61	3.87	33.13	89,898	0.657
12	136,752	3.96	649	0.15	4.46	72.74	3.87	32.98	73,065	0.813
13	148,148	3.96	649	0.15	4.26	76.15	3.87	32.82	58,851	1.007
14	159,544	3.96	649	0.15	4.07	79.90	3.87	32.66	46,937	1.250
15	170,940	3.96	649	0.15	3.87	84.02	3.87	32.49	37,032	1.557
16	182,336	3.96	649	0.15	3.68	88.57	3.87	32.31	28,870	1.952
17	193,732	3.96	649	0.15	3.48	93.64	3.87	32.12	22,211	2.465
18	205,128	3.96	649	0.15	3.29	99.31	3.87	31.92	16,837	3.142
19	216,524	3.96	649	0.15	3.09	105.69	3.87	31.71	12,553	4.050
20	227,920	3.96	649	0.15	2.90	112.93	3.87	31.48	9,186	5.291

The effect of uncertainty about the operating temperature should be investigated by sensitivity analysis, ie. an analysis of how sensitive the outcomes (calculated lives) are to changes in the assumptions (metal temperatures).

**Note: Question 2 and Question 3 in this example is best answered using the sensitivity calculator in Creep Module in ENGFit Toolbox.**