Reformer Tube Life Assessment

Prepared by: Eitzaz Hussain

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Primary Reformer

Primary reformers are used to convert a “process gas” mixture of hydro carbons & steam into hydrogen-rich gases which can be used in the manufacture of ammonia. The process gas is passed under pressure through vertical tubes filled with catalyst and, since high temperature(900-950 ^{O}C) is required to maintain the required chemical reaction, the outside of the tubes are heated by burners in a large furnace.

$$H_2O + CH_4 \xrightarrow{\text{catalyst}} CO_2 + 4H_2$$

F-2501(History)

- Foster Wheeler designed Terrace type
- Operated 19 years(1967-1986) in Pascagoula (USA)
- Mothballed for 5 years(1986-1991)
- Reconstructed with new radiant tubes, arch roof sealing, roof & wall refractory, outlet pigtails and header (incoloy 800H)

Tube Design Parameters

- Design pressure

  500 psig
- Design temperature

  1780 ^{0}F
- Theoretical design life

  100,000 hours

- Quantity 392
- Material Abex TX-63
- O.D 4.7 inch
- I.D 3.7 inch
- Length 42 ft
- MSW 0.465 inch

Tube Damages & Assessment

Damages

- Creep damage
- Thermal cycling /shock
- External oxidation
- Internal carburization

Damage assessment

- Ultra sonic technique
- Eddy current testing
- Radiography
- Dye penetrant test
- Leak test (soap solution)
- Thermography
- Refractory inspection

Methods of Life Assessment

1. Destructive stress rupture testing
2. Larson-Miller Equation (Paper study)

Scope of LM Method

1. Estimation of tube life at given temperature, pressure, corrosion rate ??
2. Estimation of temperature for specified life at given pressure & corrosion rate??
3. Operating pressure & TMT reduction for the extended tube life??

Larson-Miller Method

- Tabulation of required data
- Calculation of average stress
- Evaluation of Larson-Miller parameter & constant
- Rupture time calculation
- Remaining tube life

Required Data

- Tube material
- Tube metal temperature (TMT)
- Operating gauge pressure (P)
- Tube O.D (D_0)
- Initial minimum tube thickness(δ)

Average Stress Calculation

Mean diameter equation

$$\sigma_{beginning}=P/2\{(D_0/\delta_{beginning})-1\}$$

$$\sigma_{end}=P/2\{(D_0/\delta_{end})-1\}$$

$$\sigma_{AVG}=(\sigma_{beginning}+\sigma_{end})/2$$

σ=Stress

P=Pressure

δ=Thickness

Larson-Miller Parameter

Larson Miller Parameter Curves

(LM values are taken against average stress from curves)

(S.I units)

$$LMP= (T+273)(C_{LM} + \log t_r)x10^{-3}$$

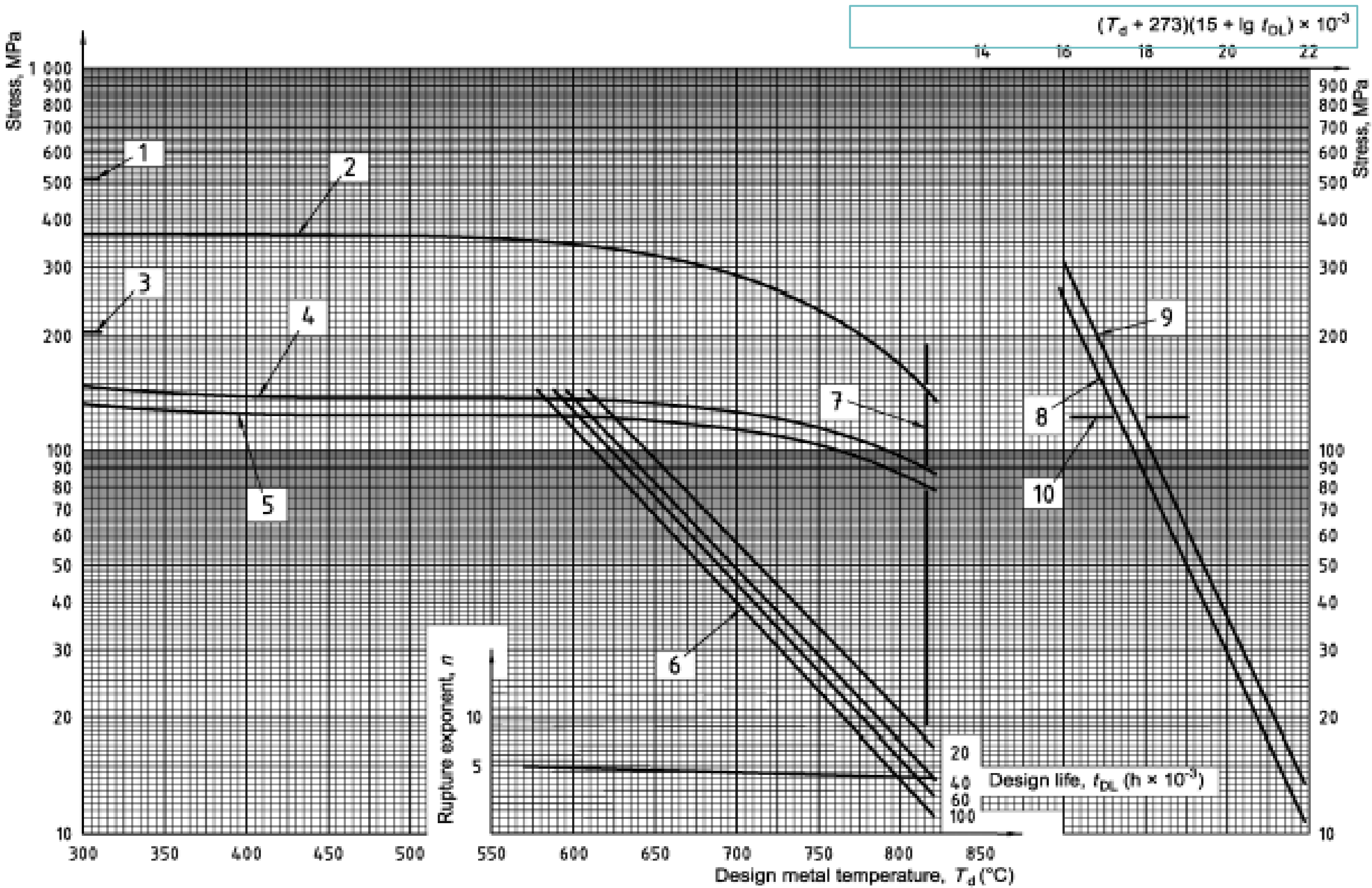
(US customary units)

$$LMP= (T+460)(C_{LM} + \log t_r)x10^{-3}$$

LMP=Larson Miller Parameter

C_{LM} = Larson Miller Constant

t_r = Rupture Time



$(T_d + 273)(15 + \lg t_{DL}) \times 10^{-3}$
14
16
18
20
22
Stress, MPa
1 000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
Rupture exponent, n
10
5
20
40
60
100
Design life, t_{DL} ($h \times 10^{-3}$)
300
350
400
450
500
550
600
650
700
750
800
850
Design metal temperature, T_d (°C)

Graph Guide

1. Specified minimum tensile strength
2. Tensile strength
3. Specified minimum yield strength
4. Yield strength
5. Elastic allowable stress
6. Rupture allowable stress
7. Limiting design metal temperature
8. Minimum rupture strength
9. Average rupture strength
10. Elastic design governs above this stress

Graph----Stress curves (SI units) for ASTM A 213, ASTM A 271, ASTM A 312 and ASTM A 376 types 347 and 347 H(18 Cr-10 Ni-Nb)stainless steel

Rupture Time

- Calculated from LM parameters
- Minimum strength rupture time
- Average strength rupture time

$$t_{r(avg)} > t_{r(min)}$$

Remaining Tube Life

- Life fraction = operating period ÷ rupture time
- Life accumulated = Σ life fractions
- Remaining fraction = 1 - (Σ life fractions)
- Remaining tube life = Remaining fraction x rupture life

Material = 18Cr-10Ni-Nb (type 347) stainless steel

Outside diameter = 168,3 mm (6,625 in)

Initial minimum thickness = 6,8 mm (0,268 in)

Operation period	Duration [a]	Operating gauge pressure		Tube metal temperature		Minimum thickness			
						Beginning		End	
	a	MPa	(psi)	°C	(°F)	mm	(in)	mm	(in)
1	1,3	3,96	(575)	649	(1 200)	6,81	(0,268)	6,40	(0,252)
2	0,6	4,27	(620)	665	(1 230)	6,40	(0,252)	6,20	(0,244)
3	2,1	4,07	(590)	660	(1 220)	6,20	(0,244)	5,51	(0,217)
4	2,0	4,34	(630)	665	(1 230)	5,51	(0,217)	4,83	(0,190)

[a] "a" is the international unit symbol for "year".

Operating period	Average stress		Larson-Miller values				Rupture time based on minimum strength		Rupture time based on average strength	
			minimum		average					
	MPa	psi	°C	(°F)	°C	(°F)	a	Life fraction	a	Life fraction
1	48,52	(7 045)	19,06	(34,32)	19,48	(35,09)	54,0	0,02	154,8	0,01
2	54,91	(7 973)	18,83	(33,90)	19,25	(34,66)	13,1	0,05	35,8	0,02
3	56,66	(8 213)	18,77	(33,80)	19,19	(34,55)	15,0	0,14	42,1	0,05
4	68,78	(9 985)	18,41	(33,15)	18,83	(33,90)	4,7	0,43	13,1	0,15
					Accumulated damage =			0,64		0,23

Uncertainties in LM Method

- Tube damage

  (uncertain TMT, Operating pressure, Corrosion rate etc.)
- Actual rupture strength is no precise
- Tube damage rule $\{t_r = t_r(\sigma, T)\}$

  (it asserts that creep rupture will occur when the life fraction totals unity)

Limitations of LM Method

- Apply to thin tubes
- No consideration for graphitization, carburization, oxidation & hydrogen attack
- Apply to seamless tubes

For more details & information, please contact us.

thePetroStreet Team
www.thepetrostreet.com
support@thepetrostreet.com