Predicting/Mitigating Impact of Boiler/HRSG Stress-Rupture Tube Failures

Motivation - *Major Impact on O&M Costs and Unit Availability*

- *Boiler-HRSG tube failures account for a loss of 4% in unit availability[*]*
- *Single tube failure in a 500 MW boiler requiring four days of repair work can result in a loss of more than $1,000,000 apart from the generation loss[**]*

** "Guideline for Control and Prevention of Fly Ash Erosion", EPRI Abstract, ID: 1023085, 4/11/15*

***Bright Hub Engineering, http://www.brighthubengineering.com/power-plants/34265-understanding-tube-failures-in-high-pressure-boilers*

*Objective: Identify & Develop Tube Failure Prediction Techniques**

If We Can Predict Time of Individual Tube Failure, We Can:

1. *Set Up a Tube Monitoring Program to Track Tube Degradation*
2. *Replace/Plug Tubes Using Just-In-Time Maintenance Strategies During a Scheduled Outage*
3. *Perform Cost-Benefit Analysis to Determine Advisability of Individual Tube Fix or Bundle Replacement*

*** i.e., That can be Optimally Embedded in Performance Monitors and Asset Managers***

Ignoring Manufacturing Issues, There are Generally Five Classes of Boiler Tube Failures*

1. ***Stress rupture***
   - ☑ *Short term overheating failure*
   - ☑ *Long term overheating failure (called also as creep failures)*
   - ☐ *Dissimilar metal weld failure*
2. ***Fatigue***
   - ☐ *Fatigue caused by vibration*
   - ☐ *Thermal fatigue due to temperature fluctuation*
   - ☐ *Corrosion fatigue failures*
3. ***Water side corrosion***
   - ☐ *Caustic corrosion inside the tube*
   - ☐ *Hydrogen damage in water wall internal surface*
   - ☐ *Tube internal pitting*
4. ***Erosion***
   - ☐ *Fly ash erosion*
   - ☐ *Falling slag erosion*
   - ☐ *Soot blower erosion*
   - ☐ *Coal particle erosion*
5. ***Fire side corrosion (Also Called "High temperature Corrosion")***
   - ☐ *Low temperature flue gas corrosion*
   - ☐ *Fire side water wall corrosion*
   - ☐ *Coal ash corrosion*
   - ☐ *Oil ash corrosion*

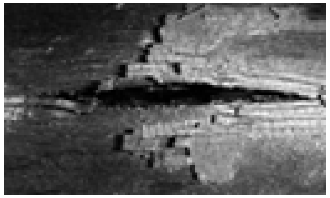
**For Additional Information See: http://www.steamforum.com/pictures/e1013153.pdf*

Stress-Rupture Tube Failures Initially Considered

***Stress Rupture Failures* ***

"Fish Mouth" Short Term Failures Typically at Startup
Cause: Tube Full of Water Blocking Steam Flow

Tube Failures w/Minimal Swelling, Narrow Longitudinal Splits Long Term Failures
Causes: Overheating Due to Internal Tube Scaling

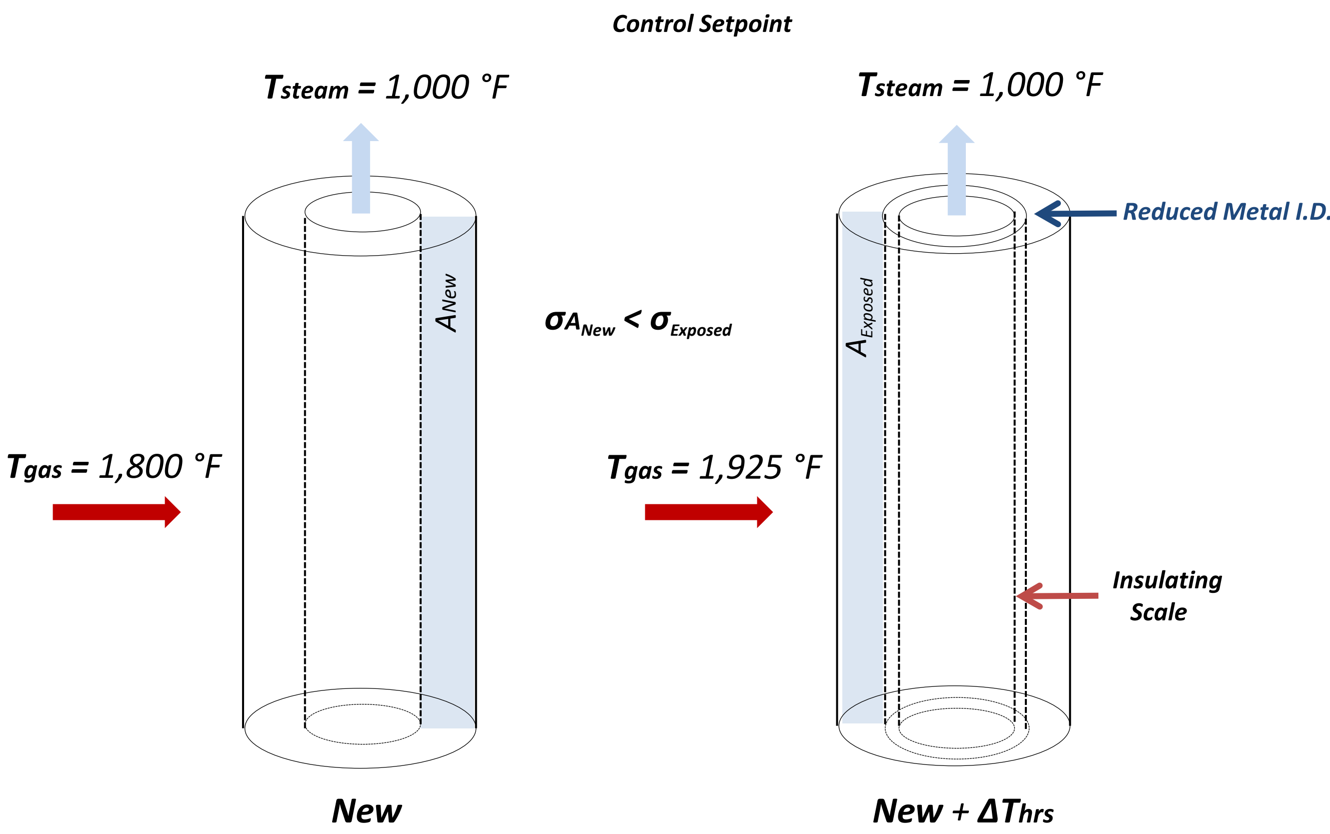


**Discussion on Boiler Tube Failures Types Causes & Remedies" Heavy Electricals Limited Tiruchirapalli See: http://www.authorstream.com/slideshows/Bharat*

***"Nova Scotia Power's Point Aconi plant overcomes CFB design problems to become rock of reliability" Dr. Robert Peltier, PE, Power Magazine, 09/15/2006*

Mechanisms of Long Term Stress Rupture Failure

(The oxide scale insulates the wall leading to chronic overheating, ultimately tube failure and forced outages.)



Typical Super Heater Tube

Keys to Predicting Long Term Stress-Rupture Failure:

1. *An Oxide (Fe_3O_4 - Magnetite) Scale Thickness Is Formed on Inner Ferritic and Carbon Steel* Tube Surfaces By Contact w/High Temperature Steam*

2. *The Oxide Thickness Is a Function of Temperature and Time-at-Temperature.*

3. *The Scale Thickness is Measurable w/Non-Intrusive Ultrasonic Measurement Techniques*

4. *Empirical Relationships Linking Tube Rupture Stress, Temperature, and Exposure Time to Scale Thickness*

* *e.g., SA-213 grades T11 and T22*

Models to Predict Tube Life – Creep Failure

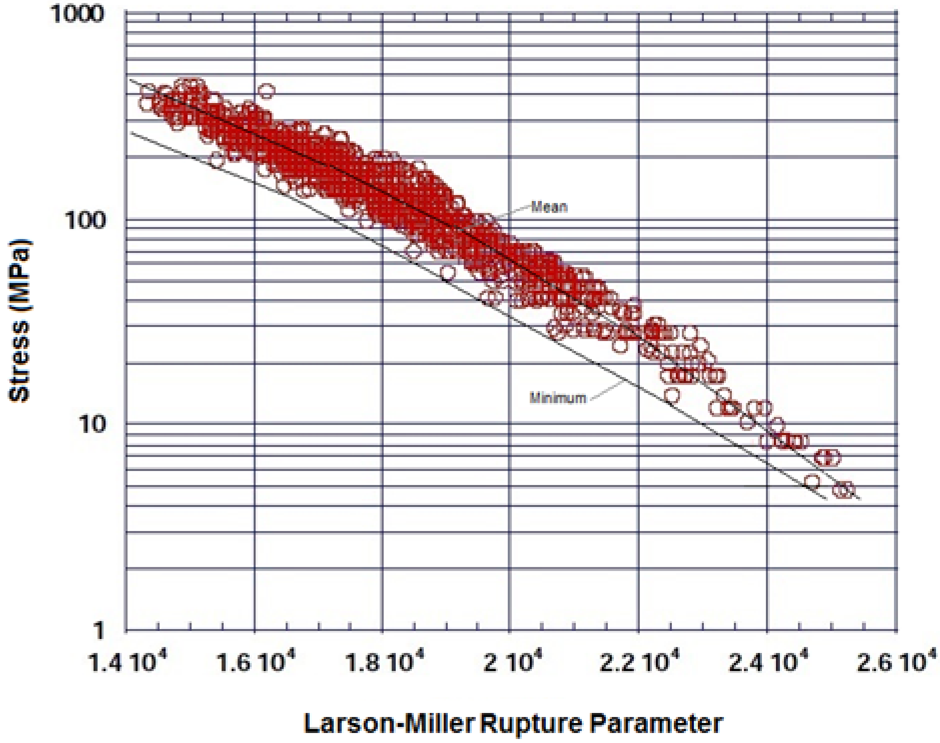
***Empirical Relationship of the Form**:*

Log X = 0.00021761 (P) - 7.25 (Eqn. 1)*

Where X is Oxide Thickness and P is the Larson-Miller Parameter

$$P = T * (20 + \log t)^{**} \quad \text{(Eqn. 2)}$$

Where T is Absolute Temperature and t is Time. T is "Apparent" Temperature for Time Tube is New to Time Scale Measured.



** D.N. French, Metallurgical Failures in Fossil Fired Boilers, John Wiley & Sons, New York, 1983, p249*

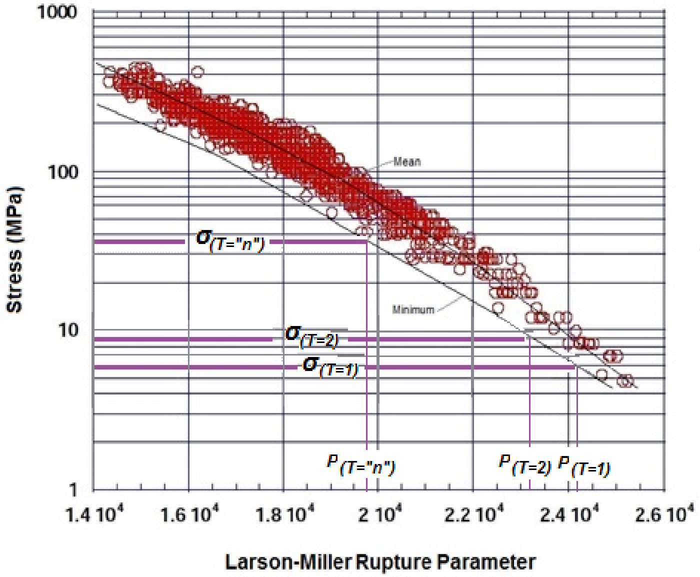
*** F.R. Larson and J. Miller, "A Time-Temperature Relationship for Rupture and Creep Stresses," Trans ASME, July 1952, p765-775.*

Procedure for Predicting Long Term Stress Rupture

- *Assume Scale Buildup is Linear with Time*
- *Break Time New to Measurement Time, ΔHrs, Into "n" Equal Time Intervals, Such That*

  $t(i) = i*(\Delta Hrs/n)$
- *Find Rupture Parameter* $P_{(i=1)}$ *at* $\sigma_{(i=1)}$ *(From Adjacent Figure)*
- *Solve Eqn. 1 to Find* $P_{(i=1…n)} = f(\text{Scale Thickness})$
- *Find Interval Tube Temperatures,*

  $T_{(i=1…n)} = P_{(i=1…n)}/(20 + \text{Log}(t_{(i=1…n)}))$ *(Eqn. 3)*
- *Solving Eqn. 2 for t, Find Tube Rupture Time(i)*
- *Find Fraction of Useful Life Expended in Each Time Interval, UL(i) Using Temperatures* $T_{(i=1…n)}$ *and the as-Measured* $P_{(i=1)}$
- *Summing UL's Find Fraction of Life Expended to Scale Measurement and Extrapolate to Remaining Life*



Verified by Comparing w/Sample Calculations Described in "Mechanisms and Life Assessment of High-Temperature Components" R. Viawanathan ASMI Third Printing September 1995 pg 230

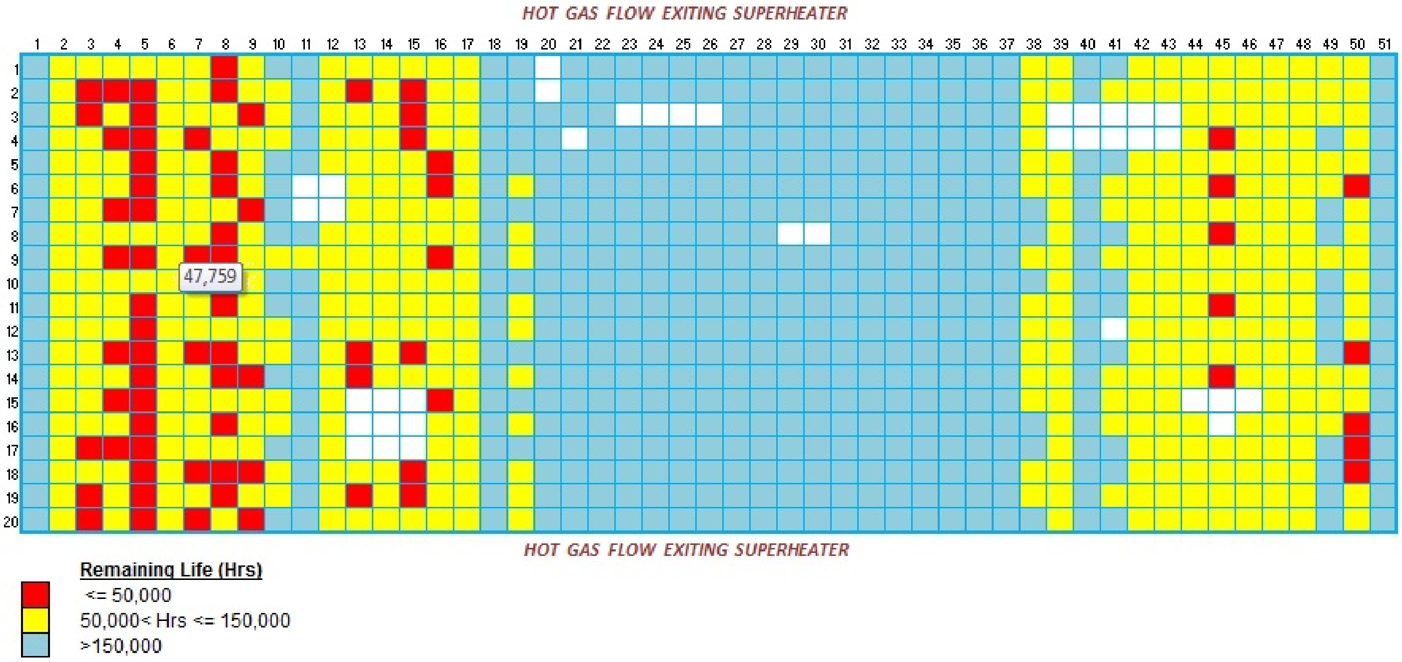
Long-Term Tube Creep Failure Results

Remaining High Temperature Tube Life (Hrs)

About

Execute About

Minimum	Average	Mazimum
39,763	228,484	776,367
37,035	222,906	772,733
34,177	228,581	720,105
42,527	235,686	977,473
29,425	224,488	719,320
40,128	235,040	992,316
31,019	230,540	888,556
43,161	207,872	706,448
41,370	239,043	876,461
58,143	292,186	1,015,408
23,957	228,195	951,126
26,333	232,249	890,479
36,870	236,891	950,953
30,134	227,438	676,496
35,862	249,966	756,216
34,633	246,838	773,227
31,031	239,768	809,278
44,253	227,973	715,415
30,400	227,225	674,810
38,970	235,319	770,515



Thank You for Your Time and Attention