

HRSG TUBE FAILURE DIAGNOSTIC GUIDE

TABLE OF CONTENTS

1	INTRODUCTION.....	1-1
2	HRSG TUBE DESIGN.....	2-1
2.1	OVERVIEW	2-1
2.2	TYPICAL HRSG LAYOUT	2-2
2.3	GENERAL TUBE DESIGN CONSIDERATIONS	2-4
2.3.1	<i>Tube Materials</i>	2-4
2.4	WATER CHEMISTRY IN HRSGS.....	2-9
2.4.1	<i>Tube Failures Related to Water Chemistry</i>	2-11
2.4.2	<i>Tube Failures Related to Layup</i>	2-11
2.5	TUBE FABRICATION	2-13
2.5.1	<i>Tube Bends</i>	2-13
2.5.2	<i>Tube-to-Header Welds</i>	2-14
2.5.3	<i>Seam Welds</i>	2-15
2.5.4	<i>Butt Welds</i>	2-16
2.5.5	<i>Groove Welds</i>	2-16
2.5.6	<i>Tube Fins</i>	2-18
3	HRSG TUBE FAILURE DIAGNOSTICS.....	3-1
3.1	DIAGNOSING THE PROBLEM	3-1
3.2	TUBE FAILURE DIAGNOSTIC ELEMENTS.....	3-2
3.3	TUBE FAILURE DIAGNOSTIC CHARTS.....	3-3
3.3.1	<i>Failure Diagnosis Charts</i>	3-3
3.3.2	<i>Failure Cause Specification Sheets</i>	3-3
3.4	FAILURE CAUSE SPECIFICATION SHEETS.....	3-25
3.4.1	<i>Corrosion Fatigue</i>	3-26
3.4.2	<i>Creep/Creep Fatigue</i>	3-31
3.4.3	<i>Deposition and Under-Deposit Corrosion</i>	3-35
3.4.4	<i>Erosive Wear and Flow Accelerated Corrosion</i>	3-39
3.4.5	<i>External Corrosion</i>	3-44
3.4.6	<i>Fatigue</i>	3-47
3.4.7	<i>Pitting</i>	3-50
3.4.8	<i>Stress Corrosion Cracking</i>	3-54
3.4.9	<i>Sulfuric Acid Dew Point Corrosion</i>	3-59
3.4.10	<i>Wear</i>	3-62
3.4.11	<i>Weld Defects</i>	3-65
3.5	FAILURE CAUSES BY HRSG MODULE.....	3-70
3.5.1	<i>Superheater Tube Failures</i>	3-71
3.5.2	<i>Reheater Tube Failures</i>	3-75
3.5.3	<i>Evaporator Tube Failures</i>	3-77
3.5.4	<i>Economizer Tube Failures</i>	3-79
3.5.5	<i>Feedwater Pre-Heater Tube Failures</i>	3-81
4	ROOT CAUSE EVALUATIONS.....	4-1
4.1	OVERVIEW	4-1
4.2	ROOT CAUSE ANALYSIS PROCESS.....	4-1
4.2.1	<i>Make Area Safe and Avoid Contamination</i>	4-1
4.2.2	<i>Visual Examination</i>	4-2
4.2.3	<i>Photography</i>	4-2
4.2.4	<i>Document Conditions</i>	4-2
4.2.5	<i>Identify Origin of Failure</i>	4-2
4.2.6	<i>Identify Mode of Failure</i>	4-2
4.2.7	<i>Identify Similar Locations</i>	4-3
4.2.8	<i>Select and Remove Tube Section</i>	4-3

HRSG TUBE FAILURE DIAGNOSTIC GUIDE

4.2.9	<i>Perform Laboratory Tests and Examinations</i>	4-4
4.3	ROOT CAUSE ANALYSIS CONCLUSIONS	4-5
5	TECHNICAL DESCRIPTIONS	5-1
5.1	SUMMARY	5-1
5.2	CORROSION FATIGUE	5-2
5.3	CREEP	5-3
5.3.1	<i>Overview</i>	5-3
5.3.2	<i>Description of Damage Mechanism</i>	5-3
5.3.3	<i>Characteristics of Damage for HRSG Service</i>	5-4
5.3.4	<i>Component Life Prediction</i>	5-5
5.3.5	<i>Environmental Factors</i>	5-5
5.3.6	<i>Material Factors & Ranking</i>	5-6
5.4	DEPOSITION AND UNDER-DEPOSIT CORROSION	5-8
5.4.1	<i>Overview</i>	5-8
5.4.2	<i>Description of Damage Mechanism</i>	5-8
5.4.3	<i>Characteristics of Damage for HRSG Service</i>	5-10
5.5	EROSION AND FLOW ACCELERATED CORROSION.....	5-11
5.5.1	<i>Overview</i>	5-11
5.5.2	<i>Description of Damage Mechanism</i>	5-11
5.5.3	<i>Characteristics of Damage for HRSG Service</i>	5-15
5.5.4	<i>Component Life Prediction</i>	5-19
5.5.5	<i>Environmental Factors</i>	5-22
5.5.6	<i>Material Factors & Ranking</i>	5-22
5.6	EXTERNAL CORROSION	5-24
5.6.1	<i>Overview</i>	5-24
5.6.2	<i>Description of External Corrosion Mechanisms</i>	5-24
5.6.3	<i>Characteristics of External Corrosion Damage for HRSG Service</i>	5-24
5.6.4	<i>Characteristics of Damage for HRSG Service</i>	5-25
5.6.5	<i>Component Life Prediction</i>	5-25
5.7	FATIGUE.....	5-26
5.7.1	<i>Overview</i>	5-26
5.7.2	<i>Description of Damage Mechanism</i>	5-26
5.7.3	<i>Characteristics of Damage for HRSG Service</i>	5-29
5.7.4	<i>Stresses in Tubes</i>	5-30
5.7.5	<i>Fretting Fatigue</i>	5-32
5.7.6	<i>Creep Fatigue</i>	5-33
5.7.7	<i>Corrosion Fatigue</i>	5-33
5.7.8	<i>Low Cycle Fatigue / Thermal Shock</i>	5-34
5.7.9	<i>High Cycle Fatigue</i>	5-36
5.7.10	<i>Component Life Prediction</i>	5-37
5.8	PITTING CORROSION	5-39
5.8.1	<i>Overview</i>	5-39
5.8.2	<i>Description of Damage Mechanism</i>	5-39
5.8.3	<i>Characteristics of Damage for HRSG Service</i>	5-39
5.8.4	<i>Component Life Prediction</i>	5-41
5.8.5	<i>Environmental Factors</i>	5-41
5.8.6	<i>Material Factors & Ranking</i>	5-41
5.9	STRESS CORROSION	5-42
5.9.1	<i>Overview</i>	5-42
5.9.2	<i>Description of Damage Mechanism</i>	5-42
5.9.3	<i>Characteristics of Damage for HRSG Service</i>	5-43
5.10	SULFURIC ACID CORROSION	5-46
5.10.1	<i>Overview</i>	5-46
5.10.2	<i>Description of Sulfuric Acid Dew Point Corrosion Mechanism</i>	5-46
5.10.3	<i>Characteristics of Sulfuric Acid Damage for HRSG Service</i>	5-47

HRSG TUBE FAILURE DIAGNOSTIC GUIDE

5.10.4	Component Life Prediction	5-47
5.10.5	Environmental Factors	5-48
5.10.6	Material Factors & Ranking.....	5-50
5.11	WEAR.....	5-52
5.11.1	Overview.....	5-52
5.11.2	Description of Wear Damage Mechanisms.....	5-52
5.11.3	Characteristics of Wear Damage for HRSG Service	5-53
5.11.4	Component Life Prediction	5-55
5.11.5	Environmental Factors	5-55
5.12	WELD DEFECTS.....	5-56
5.12.1	Overview.....	5-56
5.12.2	Description of Damage Mechanism.....	5-56
5.12.3	Characteristics of Damage for HRSG Service.....	5-58
5.12.4	Component Life Prediction	5-59
5.12.5	Environmental Factors	5-59
5.12.6	Material Factors & Ranking.....	5-59
6	CASE STUDIES OF HRSG TUBE FAILURES	6-1
6.1	LP FEEDWATER TUBE #1 CASE STUDY	6-4
6.1.1	Background.....	6-4
6.1.2	As Received Specimen.....	6-4
6.1.3	Laboratory Test Plan.....	6-6
6.1.4	Optical Metallography.....	6-7
6.1.5	Optical Fractography	6-9
6.1.6	Base Material Test.....	6-11
6.1.7	Energy Dispersive Spectroscopy.....	6-11
6.1.8	Conclusion	6-11
6.1.9	Recommendations	6-12
6.2	REHEATER TUBE CASE STUDY	6-13
6.2.1	Background.....	6-13
6.2.2	As Received Condition	6-13
6.2.3	Laboratory Test Plan.....	6-14
6.2.4	Optical Metallography.....	6-15
6.2.5	Optical Fractography	6-16
6.2.6	Chemical Analysis.....	6-17
6.2.7	Tensile Test	6-17
6.2.8	Hardness Tests.....	6-18
6.2.9	Conclusion	6-18
6.2.10	Recommendations	6-18
6.3	LP FEEDWATER TUBE #2 CASE STUDY	6-19
6.3.1	Background.....	6-19
6.3.2	As-Received Condition.....	6-19
6.3.3	Section Plan.....	6-21
6.3.4	Optical Fractography	6-23
6.3.5	Optical Metallography.....	6-24
6.3.6	Scanning Electron Microscopy / Energy Dispersive Spectroscopy	6-26
6.3.7	Chemical Analysis.....	6-27
6.3.8	Conclusion	6-28
6.3.9	Recommendations	6-29
7	REFERENCES.....	7-1
8	APPENDIX.....	8-1
9	INDEX	9-1