

Damage Mechanisms Affecting Fixed Equipment in the Refining Industry

RECOMMENDED PRACTICE 571
FIRST EDITION, DECEMBER 2003



American
Petroleum
Institute

**Helping You
Get The Job
Done Right.SM**

Currently in preview, click buy full version

Damage Mechanisms Affecting Fixed Equipment in the Refining Industry

Downstream Segment

RECOMMENDED PRACTICE 571
FIRST EDITION, DECEMBER 2003



**American
Petroleum
Institute**

**Helping You
Get The Job
Done Right.SM**

Currently in preview, click buy full version

This page intentionally left blank.

SPECIAL NOTES

(December, 2003)

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect five years after its publication date as an operative API standard or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Standards department telephone (202) 682-8000. A catalog of API publications, programs and services is published annually and updated biannually by API, and available through Global Engineering Documents, 15 Inverness Way East, M/S C303B, Englewood, CO 80112-5776.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this standard or comments and questions concerning the procedures under which this standard was developed should be directed in writing to the Director of the Standards department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should be addressed to the Director, Business Services.

API standards are published to facilitate the broad availability of proven, sound engineering and operating practices. These standards are not intended to obviate the need for applying sound engineering judgment regarding when and where these standards should be utilized. The formulation and publication of API standards is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, N.W., Washington, D.C. 20005.

Copyright © 2003 American Petroleum Institute

Currently in preview, click buy full version

This page intentionally left blank.

FOREWORD

(December, 2003)

This publication is a result of a need for a document that describes damage mechanisms affecting equipment in the refining and petrochemical industries. A key first step in safely and reliably managing equipment is identifying and understanding the relevant damage mechanisms. Proper identification of damage mechanisms is important when implementing the API Inspection Codes (API 510, API 570, API 653) and in conducting risk based inspection per API 580 and API 581. When performing a fitness-for-service assessment using API 579, the damage mechanisms need to be understood and need to be considered when evaluating the remaining life.

This publication contains guidance for the combined considerations of:

- Practical information on damage mechanisms that can affect process equipment,
- Assistance regarding the type and extent of damage that can be expected, and
- How this knowledge can be applied to the selection of effective inspection methods to detect size and characterize damage.

The overall purpose of this document is to present information on equipment damage mechanisms in a set format to assist the reader in applying the information in the inspection and assessment of equipment from a safety and reliability standpoint.

This document reflects industry information, but it is not a mandatory standard or code. In this regard, the terms *shall* and *must* are only used to state mandatory requirements with respect to the assessment procedures which may not otherwise be correct unless followed explicitly. The term *should* is used to state that which is considered good practice and is recommended but is not absolutely mandatory. The term *may* is used to state that which is considered optional.

This publication was prepared by an API Task Group that included representatives of the American Petroleum Institute and the Pressure Vessel Research Council, as well as individuals associated with related industries.

It is the intent of the American Petroleum Institute to periodically revise this publication. All owners and operators of pressure vessels, piping, and tanks are invited to report their experiences in utilizing this document.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to API, Standards department, 1220 L Street, NW, Washington, DC 20005.

Currently in preview, click buy full version

This page intentionally left blank.

TABLE OF CONTENTS

1.0 INTRODUCTION AND SCOPE	
1.1 Introduction.....	1-1
1.2 Scope	1-1
1.3 Organization and Use	1-2
1.4 References	1-2
1.5 Definition of Terms.....	1-2
1.6 Technical Inquiries.....	1-2
2.0 REFERENCES	
2.1 Standards	2-1
2.2 Other References	2-
3.0 DEFINITION OF TERMS AND ABBREVIATIONS	
3.1 Terms.....	3-1
3.2 Symbols and Abbreviations.....	3-2
4.0 GENERAL DAMAGE MECHANISMS – ALL INDUSTRIES	
4.1 General.....	4-1
4.2 Mechanical and Metallurgical Failure Mechanisms	4-1
4.2.1 Graphitization	4-1
4.2.2 Softening (Spheroidization)	4-5
4.2.3 Temper Embrittlement	4-8
4.2.4 Strain Aging.....	4-12
4.2.5 885°F Embrittlement	4-14
4.2.6 Sigma Phase Embrittlement.....	4-16
4.2.7 Brittle Fracture	4-19
4.2.8 Creep / Stress Rupture	4-23
4.2.9 Thermal Fatigue.....	4-27
4.2.10 Short Term Overheating – Stress Rupture	4-32
4.2.11 Steam Blanketing	4-35
4.2.12 Dissimilar Metal Weld (DMW) Cracking	4-38
4.2.13 Thermal Shock.....	4-42
4.2.14 Erosion / Erosion-Corrosion	4-44
4.2.15 Cavitation.....	4-49
4.2.16 Mechanical Fatigue	4-53
4.2.17 Vibration-Induced Fatigue	4-59
4.2.18 Refractory Degradation	4-62
4.2.19 Reheat Cracking.....	4-63
4.3 Uniform or Localized Loss of Thickness	4-65
4.3.1 Galvanic Corrosion	4-65
4.3.2 Atmospheric Corrosion	4-69
4.3.3 Corrosion Under Insulation (CUI)	4-71
4.3.4 Cooling Water Corrosion	4-75
4.3.5 Boiler Water Condensate Corrosion	4-78
4.3.6 CO ₂ Corrosion	4-80
4.3.7 Flue Gas Dew Point Corrosion	4-84
4.3.8 Microbiologically Induced Corrosion (MIC).....	4-86
4.3.9 Soil Corrosion	4-91
4.3.10 Caustic Corrosion	4-95
4.3.11 Dealloying	4-98
4.3.12 Graphitic Corrosion.....	4-101
4.4 High Temperature Corrosion [400°F (204°C)]	4-105
4.4.1 Oxidation.....	4-105

4.4.2	Sulfidation	4-109
4.4.3	Carburization	4-113
4.4.4	Decarburization.....	4-116
4.4.5	Metal Dusting.....	4-118
4.4.6	Fuel Ash Corrosion	4-121
4.4.7	Nitriding.....	4-126
4.5	Environment – Assisted Cracking	4-130
4.5.1	Chloride Stress Corrosion Cracking (Cl ⁻ SCC)	4-130
4.5.2	Corrosion Fatigue	4-135
4.5.3	Caustic Stress Corrosion Cracking (Caustic Embrittlement)	4-138
4.5.4	Ammonia Stress Corrosion Cracking.....	4-144
4.5.5	Liquid Metal Embrittlement (LME)	4-148
4.5.6	Hydrogen Embrittlement (HE)	4-152
5.0 REFINING INDUSTRY DAMAGE MECHANISMS		
5.1	General.....	5-1
5.1.1	Uniform or Localized Loss in Thickness Phenomena	5-1
5.1.1.1	Amine Corrosion.....	5-1
5.1.1.2	Ammonium Bisulfide Corrosion (Alkaline Sour Water).....	5-4
5.1.1.3	Ammonium Chloride Corrosion	5-8
5.1.1.4	Hydrochloric Acid (HCl) Corrosion	5-10
5.1.1.5	High Temp H ₂ /H ₂ S Corrosion	5-13
5.1.1.6	Hydrofluoric (HF) Acid Corrosion	5-16
5.1.1.7	Naphthenic Acid Corrosion (NAC)	5-19
5.1.1.8	Phenol (Carbonic Acid) Corrosion.....	5-23
5.1.1.9	Phosphoric Acid Corrosion.....	5-24
5.1.1.10	Sour Water Corrosion (Acidic)	5-25
5.1.1.11	Sulfuric Acid Corrosion	5-27
5.1.2	Environment–Assisted Cracking.....	5-31
5.1.2.1	Polythionic Acid Stress Corrosion Cracking (PASCC)	5-31
5.1.2.2	Amine Stress Corrosion Cracking	5-37
5.1.2.3	Wet H ₂ S Damage (Blistering / HIC / SOHIC / SCC)	5-41
5.1.2.4	Hydrogen Stress Cracking – H ₂	5-50
5.1.2.5	Carbonate Stress Corrosion Cracking	5-52
5.1.3	Other Mechanisms.....	5-56
5.1.3.1	High Temperature Hydrogen Attack (HTHA).....	5-56
5.1.3.2	Titanium Hydriding.....	5-61
5.2	Process Unit PFD's	5-65
5.2.1	Crude Unit / Vacuum	5-65
5.2.2	Delayed Coker	5-65
5.2.3	Fluid Catalytic Cracking.....	5-65
5.2.4	FCC Light Ends Recovery	5-65
5.2.5	Catalytic Reforming – CCR	5-65
5.2.6	Catalytic Reforming – Fixed Bed	5-65
5.2.7	Hydroprocessing Units – Hydrotreating, Hydrocracking.....	5-65
5.2.8	Sulfuric Acid Alkylation.....	5-65
5.2.9	Hydro Alkylation.....	5-65
5.2.10	Amine Treating.....	5-65
5.2.11	Sulfur Recovery	5-65
5.2.12	Sour Water Stripper	5-65
5.2.13	Isomerization	5-65
5.2.14	Hydrogen Reforming	5-65
APPENDIX A – TECHNICAL INQUIRIES		
A.1	Introduction	A-1
A.2	Inquiry Format.....	A-1

SECTION 1.0

INTRODUCTION AND SCOPE

1.1	Introduction.....	1
1.2	Scope	1
1.3	Organization and Use.....	2
1.4	References	2
1.5	Definitions of Terms	2
1.6	Technical Inquires	2

This page intentionally left blank.

1.1 Introduction

The ASME and API design codes and standards for pressurized equipment provide rules for the design, fabrication, inspection, and testing of new pressure vessels, piping systems, and storage tanks. These codes do not address equipment deterioration while in service and that deficiencies due to degradation or from original fabrication may be found during subsequent inspections. Fitness-For-Service (FFS) assessments are quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage. The first step in a fitness-for-service assessment performed in accordance with API RP 579 is to identify the flaw type and the cause of damage. Proper identification of damage mechanisms for components containing flaws or other forms of deterioration is also the first step in performing a Risk-Based Inspection (RBI) in accordance with API RP 580.

When conducting a FFS assessment or RBI study, it is important to determine the cause(s) of the damage or deterioration observed, or anticipated, and the likelihood and degree of further damage that might occur in the future. Flaws and damage that are discovered during an in-service inspection can be the result of a pre-existing condition before the component entered service and/or could be service-induced. The root causes of deterioration could be due to inadequate design considerations including materials selection and design details, or the interaction with aggressive environments/conditions that the equipment is subjected to during normal service or during transient periods.

One factor that complicates a FFS assessment or RBI study for refining and petrochemical equipment is that material/environmental condition interactions are extremely varied. Refineries and chemical plants contain many different processing units, each having its own combination of aggressive process streams and temperature/pressure conditions. In general, the following types of damage are encountered in petrochemical equipment:

- a) General and local metal loss due to corrosion and/or erosion
- b) Surface connected cracking
- c) Subsurface cracking
- d) Microfissuring/microvoid formation
- e) Metallurgical changes

Each of these general types of damage may be caused by a single or multiple damage mechanisms. In addition, each of the damage mechanisms occurs under very specific combinations of materials, process environments, and operating conditions.

1.2 Scope

General guidance as to the most likely damage mechanisms for common alloys used in the refining and petrochemical industry is provided in this recommended practice. These guidelines provide information that can be utilized by plant inspection personnel to assist in identifying likely causes of damage, and are intended to introduce the concepts of service-induced deterioration and failure modes.

The summary provided for each damage mechanism provides the fundamental information required for a FFS assessment performed in accordance with API RP 579 or an RBI study performed in accordance with API RP 580.

The damage mechanisms in this recommended practice cover situations encountered in the refining and petrochemical industry in pressure vessels, piping, and tankage. The damage mechanism descriptions are not intended to provide a definitive guideline for every possible situation that may be encountered, and the reader may need to consult with an engineer familiar with applicable degradation modes and failure mechanisms, particularly those that apply in special cases.