Fitness-for-Service Assessment as Part of the Life-Cycle Management of Fixed Equipment and Piping

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• OUTLINE OF TODAY’s PRESENTATION:
  – What is **LIFE CYCLE MANAGEMENT** and how does FFS (the API 579 Standard) fit in to LCM?
  – What type of **FFS Assessments** are available in the current API 579 (what are the **Basics** of FFS using API 579 – not the details)?
  – **Case Studies** – how has API 579 FFS been used to SOLVE specific example PROBLEMS?
  – **What changes** are coming in 2016 Edition?
LIFE CYCLE MANAGEMENT

• **Owner-users** of pressurized fixed equipment, including pressure vessels, piping, and tankage are becoming increasingly interested in Life-Cycle Management (LCM) to **maximize reliability and availability**

• **Regulators** responsible for public safety and the environment also have a stake in assuring reliability

• LCM is defined as the process of managing the **entire life-cycle** of fixed pressurized equipment; including **design, construction, in-service use, repair** if required, and **retirement**
HOW STANDARDS FIT INTO LCM

FFS AND LCM:

• **GOAL of LCM**: maximize reliability, availability of equipment

• **Key**: Technology integration between construction codes, inspection codes and FFS

• **BEST PRACTICES** are a key aspect of LCM; **RAGAGEP** term used in US (Mechanical Integrity Programs)
API 579 OVERVIEW

ORGANIZATION

GENERAL REQUIREMENTS
API 579-1/ASME FFS-1

**HISTORY OF THE FFS STANDARD:**

- First edition of **API 579** published in 2000
- 3rd Edition coming out in 2016
- **API 579-2/ASME FFS-2** Example Problems Manual came out in 2009: 62 examples (great teaching tool; tool to validate software)
API 579-1/ASME FFS-1

• **BASICS** of API 579 FFS Document:
  – Procedures are provided for Fixed Equipment
    • Vessels, Piping, Tanks (+ Pipelines in 2016)
  – Generally based on **Petrochemical Industry**, but gaining more and more use outside PI
  – In US there is Jurisdictional acceptance (through API 510, etc.); we have been promoting API 579 (and other LCM Standards) to other jurisdictions
API 579-1/ASME FFS-1

• **BASICS** of API 579 FFS Document:
  – Assessment procedures for **12 types** of damage (currently) – NEXT SLIDE
  – For each type of assessment, **3 LEVELS** of FFS Assessment:
    • **LEVEL 1 → LEVEL 3**: Increasing Data Requirements, Analyst Qualifications and Calculation Complexity
    • **LEVEL 1 → LEVEL 3**: Decreasing Conservatism
    • **LEVEL 1** (Inspector, Engineer); **LEVEL 2** (Engineer); **LEVEL 3** (Specialist/Expert)
API 579-1/ASME FFS-1

ORGANIZATION

• 14 PARTS (Sections) overall
• FFS Methodology Organized by DAMAGE MECHANISM (12 ASSESSMENT PARTS)
• Annexes with Construction Code equations, DBA procedures, general material data – VERY USEFUL data in Annexes even if not doing FFS
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FFS METHODOLOGY

- Basic API 579 Methodology (8 STEPS) for all types of Damage:
  - STEP 1 - Flaw & damage identification (API 571)
  - STEP 2 - Applicability & limitations of FFS procedures
  - STEP 3 - Data requirements
  - STEP 4 - Assessment techniques & acceptance criteria
  - STEP 5 - Remaining life evaluation
  - STEP 6 - Remediation
  - STEP 7 - In-service monitoring
  - STEP 8 - Documentation
ACCEPTANCE CRITERIA

3 METHODS FOR JUDGING FFS

• Stresses / Strains (similar to design Codes)
• Remaining Strength Factor (RSF). RSF Allowable = 0.90

\[
\text{RSF} = \frac{\text{Collapse Load Of Damaged Component}}{\text{Collapse Load Of Undamaged Component}}
\]

• Failure Assessment Diagram (FAD): Cracking Evaluation
PROACTIVE vs. REACTIVE FFS

REACTIVE
• Flaws or damage are found during inspection
• A leak occurs and other components needs to be operated until repair/replacement
• A fire has occurred
• Equipment is out of design-code tolerances during initial fabrication or installation

PROACTIVE
• Undocumented equipment is found (Mechanical Integrity Gap audit) – reverse engineer
• Change occur in design codes (Rerate?)
• Brittle fracture screening (study a pressure-temperature trade-off)
• Creep life assessment (study a temperature-life trade-off)
• NDE and Flaw sizing guidelines for future inspection
FFS TECHNIQUE OVERVIEW

**BASICS** OF 12 TYPES OF DAMAGE ASSESSMENTS
CASE STUDIES – EXAMPLES OF FFS **SOLUTIONS**
TO ACTUAL FFS **PROBLEMS**
BRITTLE FRACTURE

PART 3

- Not a **REACTIVE** assessment to particular damage
- **Usually a PROACTIVE** assessment when MORE SEVERE operations considered,
- Material toughness degrades or equipment is **REPAIRED** or **UNDOCUMENTED** equipment
- **LEVEL 1** Screening, **LEVEL 3** uses **PART 9** (Crack-like Flaw) Methods
BRITTLE FRACTURE

PROBLEM – MPT NEEDED

• MINIMUM PRESSURIZATION TEMPERATURE (MPT)
• LEVEL 3 Used
• FEA Stress Analysis
• Crack-like Flaws assumed in all critical regions
• PART 9 Calculations performed

HEAT EXCHANGER EVALUATED
BRITTLE FRACTURE

CASE STUDY RESULTS

• Results – MPT Curve for all critical areas
• Guide Operations
• Assess needs for design changes
METAL LOSS

PARTS 4, 5, 6 PROCEDURES

• **PART 4**: General Metal Loss
• **PART 5**: Local Metal Loss
• **PART 6**: Pitting
• **Key**: Thickness Averaging
• Typically a **RSF** approach
• LEVEL 3 uses DBA concepts
METAL LOSS

PARTS 4, 5, 6 PROCEDURES

- **PART 4**: General Metal Loss (GML)
- **PART 5**: Local Metal Loss (LTA)
- **PART 6**: Pitting
- Thickness Averaging Methods differ from API 510, 570, 653
- RSF Approach to FFS
- LEVEL 3 uses DBA Concepts (often limit load analysis)

THICKNESS AVERAGING

\[ L = Q \sqrt{D t_c} \quad \text{where} \quad Q = f(R_t, RSF_a) \]

**API 579**

\[ L = \min[D/2, 20 \text{ inches}] \quad \text{when} \quad D \leq 60 \text{ inches} \]

\[ L = \min[D/3, 40 \text{ inches}] \quad \text{when} \quad D > 60 \text{ inches} \]
METAL LOSS

EX. PROBLEM – LOCAL THINNING

• Channel of Heat Exchanger – found routine on-line UT – near nozzle
• Aggressive corrosion, greater than 500 mpy (12.7 mm/year), was observed (internal coating failed)
• Mapped thickness data was provided by UT
• Level 3 analysis was required to show FFS; Level 1 and 2 not adequate
METAL LOSS

RESULTS

- **Part 5 Level 3** showed the HEX fit for the desired time frame.
- **FCA** was based on the observed corrosion and the time needed to **PLAN** for repairs.
- Repairs could be delayed about a year.
HYDROGEN DAMAGE

PART 7 PROCEDURE

• For **BLISTERS**, Hydrogen Induced Cracking (**HIC**), Stress-oriented HIC (**SOHIC**)
• Low-Temperature (Below 400°F)
• **HTHA** coming later to API 579
• Screening methods in **LEVEL 1**
• **LEVEL 2**: RSF (Strength) and crack assessment (**PART 5, 9**)
• Data intensive

DAMAGE APPEARANCE
HYDROGEN DAMAGE

PROBLEM SOLVED – HIC

- HIC found in a high pressure (2640 psig) vessel in hydrogen charging service; appear to be growing in size and number
- Strength evaluated in accordance with PART 7 (and by reference, PART 5) and fracture toughness evaluated in accordance with PART 9

DAMAGE APPEARANCE, DATA
HYDROGEN DAMAGE

CASE STUDY RESULTS

- Strength results indicated that the damaged region strength sufficient to permit continued operation.
- Fracture evaluation of damage indicates that operation below 150°F (65°C) could lead to brittle fracture.
- Recommendation was to monitor damaged regions and maintain metal temperature as high as possible (within design maximum).

MAT CURVES

![Part 9 MAT Curves graph showing maximum allowable pressure (psig) vs. metal temperature (°F)]
DISTORTION, MISALIGMENT

PART 8 PROCEDURES

• Shell distortions – global out-of-roundness, bulging
• Construction code tolerances form LEVEL 1
• LEVEL 2: RSF methods
• Most of PART 8 requires LEVEL 3 due to complexity of damage

DISTORTION DAMAGE
DISTORTION, MISALIGNMENT

PART 8 PROCEDURES

• Weld misalignment: offset, peaking, combinations
• Construction code tolerances form LEVEL 1
• LEVEL 2: also RSF methods
• Fatigue and reduction in buckling capacity is a real concern with all distortions

MISALIGNMENT APPEARANCE

(a) Angular Weld Misalignment

(b) Angular and Centerline Offset Weld Misalignment
DISTORTION, MISALIGNMENT

PROBLEM SOLVED - OOR

- Tanks – numerous settlement examples of Out-of-Round (OOR) Tanks
- Beyond allowables in API 653 Annex B
- Open (Floating Roofs) and Fixed Roofs – OOR affects stability and operation

DAMAGE EXAMPLE
DISTORTION, MISALIGNMENT

CASE STUDY RESULTS

• Results generally find tanks to be fit for service for product loads (true of many PART 8 studies)
• May have compromised wind or seismic buckling capacities and need local stiffening (stability issues)
• Frequently no other need than to monitor future settlement, and/or deformation

WIND BUCKLING ANALYSES

(A) Radial Displacement (in)
(B) Radial Displacement (in)
(C) Radial Displacement (in)
(D) Radial Displacement (in)
CRACK-LIKE FLAWS

PART 9 PROCEDURES

• Surface, embedded or through-wall cracking – look to evaluate a certain flaw (or flaws) with specific depth, length and orientations

• Screening curves for LEVEL 1
• LEVEL 2: FAD method
• Interaction of plastic collapse (FAD Load Axis) and brittle fracture (FAD Toughness axis)
• Also fairly data (inspection and material property) intensive

CRACKING APPEARANCE

![Crack-like flaws example image]

Figure 5-29 – A photomicrograph of a cross-section of a weld in non-PWHT piping showing a SCC in the vicinity of a piping weld. Mag. 6X (From API 545)
CRACK-LIKE FLAWS

PART 9 PROCEDURES

- Computationally pretty complex: software usually involved
- Use **Stress Intensity Factor Solutions** (current Annex C)
- Use **Reference Stress Solutions** (current Annex D)
- Need **Weld Residual Stress** (current Annex E)
CRACK-LIKE FLAWS

PROBLEMS SOLVED – MOV, RTJ

• Cracking in cyclic MOVs in Reformer Unit
• Cracking in RTJ Flanges
• MOV historically shown to have surface cracking every 2 to 4 years
• RTJ cracks at root of gasket area, H2 Charged environments

MOV, RTJ CRACKING
CRACK-LIKE FLAWS

CASE STUDY RESULTS

• **CFD** performed in some cases to get accurate temperature (use FEA for stresses)

• Limited costly **MOV** repairs; focused inspections; extended run time and valve life

• Find that **RTJs** don’t always require repair; conversion gaskets solve issue many times

CFD, FEA RESULTS
CREEP DAMAGE

PART 10 PROCEDURES

• **Stress-Temperature-Time**
• PART 10 has 2 methods: Larson-Miller and Omega Method for evaluating Creep Damage
• **Need good operating history**
• With testing, Omega Method lets you evaluate past damage without good history (need material sample)
• API 579 has a very good material creep property resource (Annex F)

DAMAGE APPEARANCE

Failed Waterwall Tube From A Gas Fired Water-Tube Boiler
CREEP DAMAGE

CREEP CONCERN:

- Carbon Steel: 750°F (399°C)
- Graphitized CS: 700°F (371°C)
- C-0.5Mo: 800°F (426°C)
- 1.25Cr-0.5Mo: 800°F (426°C)
- 2.25Cr-1Mo: 800°F (426°C)
- 5Cr-0.5Mo: 800°F (426°C)
- 9Cr-1Mo: 900°F (482°C)
- 9Cr -1Mo-V: 1000°F (538°C)
- 12 Cr: 950°F (510°C)
- 300 Series SS: 1050°F (566°C)
- Alloy 800, 800 H: 1100°F (593°C)
- HK, HP modified: 1400°F (760°C)
CREEP DAMAGE

PROBLEM SOLVED – TUBES

• 2.25Cr Heater Tubes in Reformer Unit
• History: Multiple operational conditions
• Tubes were also thinning (oxidation)
• Frequently Creep plus Thinning (Stress Changing)

TEMPERATURE HISTORY
CREEP DAMAGE

COMPLEX PROBLEM

• Creep plus Thinning

• LEVEL 3: One way of dealing with uncertainty is to use Probabilistic analyses

• Statistical distribution used on stress, temperature, etc.

• Developed probability of failure (POF) for various Operating Temperatures – can be used to weight risk versus benefits of higher operating temperatures

RESULTS – POF CURVES
FIRE DAMAGE

PART 11 PROCEDURES

• How to assess the temperatures seen by equipment during fires

• How to assess the impact of these temperatures – Heat Exposure Zones (I thru VI)

• Mainly a screening process; leading to FFS by other PARTS of the Standard

DAMAGE, CRITICAL ZONES

Heat Exposure Zones

III Light
IV Moderate
V Heavy
VI Severe

“Rupture”
DENTS & GOUGES

PART 12 PROCEDURES

• Inward distortion with small radius = Dent

• Elongated removal of material with cold worked layer (type of metal loss where the material may have lost toughness) = Gouge

• Combined Dent & Gouge

• Mainly a damage that is seen in piping and pipelines – mechanically produced
DENTS & GOUGES

PART 12 PROCEDURES

- Dents & Gouges can be in combination
- **LEVEL 1**: Screening with various dimensions needed
- **LEVEL 2**: RSF calculations; also a fatigue cycle check
- For **Gouges**: need to check toughness of cold-worked layer (concern if < 30 ft-lbs, 40 Joules)
LAMINATIONS

PART 13 PROCEDURES

• Was originally part of PART 7

• Mostly **Screening** with various dimensions needed

• Laminations are not a major concern except with compressive stress (buckling) situations; at a weld or discontinuity; not parallel to the thickness direction of the plate
CONCLUSION – NEXT EDITION

WHAT CHANGES ARE COMING IN 2016 EDITION OF API 579-1/ASME FFS-1
## RE-ORGANIZATION

**BLUE = NEW, RED = RELOCATED**

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NEW TO API 579-1/ASME FFS-1

• **Added Pipelines**
  – ASME B31.4 (Pipeline Transportation Systems for Liquids and Slurries)
  – ASME B31.8 (Gas Transmission & Distribution Piping Systems)
  – ASME B31.12 (Hydrogen Piping and Pipelines)

• **Added PART 14 – FATIGUE**

• LEVEL 3: Allow use of **RSF allowable** other than 0.90

• Changes to **Thickness Averaging**

• Other updates to **Creep, Cracking** and **Residual Stress** Procedures
  (new Annex material)
QUESTIONS?

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