

(REVIEW ARTICLE)



A novel restoration procedure for heat exchangers recovering from severe damage

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Abstract

Heat exchangers are critical stationary equipment in oil and gas processing plants. Following abnormal events such as fire, explosion, mechanical impact, or severe degradation, restoration requires a systematic engineering assessment to determine integrity and safe return to service. This paper presents a restoration methodology based on industry practices including API 579-1/ASME FFS-1, API 510, ASME Section VIII, and TEMA practices. The approach integrates inspection, material evaluation, fitness-for-service assessment, repair strategy, and controlled reinstatement.

Keywords: Restoration; Heat Exchangers; Fitness for Service; Air Coolers; Repair

1. Introduction

Heat exchangers provide essential heat transfer services in oil, gas, petrochemical, and process facilities. After major incidents, equipment integrity cannot be confirmed by visual inspection alone. A structured assessment is required to identify damage mechanisms, quantify degradation, and determine whether repair, replacement, or continued operation is acceptable.

The restoration sequence includes:

- Site assessment and damage identification
- Multidiscipline inspection
- Material integrity evaluation
- Fitness-for-Service assessment
- Repair strategy development
- Verification and return to service

2. Heat Exchanger Restoration Philosophy and Engineering Approach

The restoration philosophy is based on preserving pressure containment, restoring mechanical integrity, and ensuring reliable future operation. The process begins with immediate site assessment followed by detailed inspection, engineering evaluation, and risk-based decision making. Restoration decisions should consider safety, reliability, economic impact, future operating requirements, and compliance with applicable codes and standards.

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3. Damage Mechanisms

Damage following incidents can include one or combined mechanisms as:

3.1. Thermal and fire damage

- Loss of mechanical properties
- Metallurgical changes
- Permanent distortion
- Weld and material degradation

3.2. Mechanical damage

- Dents: local surface deformation by external force
- Bulges: local outward deformation
- Impact damage
- Cracking: material separation
- Misalignment: loss of correct position

3.3. Tube bundle damage

- Tube cracking: crack formation in tubes
- Wall loss: reduction in thickness due to corrosion
- Tube-to-tubesheet leakage: loss of sealing
- Reduced heat transfer performance
- Fins damage: deformation or deterioration
- Tubes keeper distortion
- Side frame distortion
- Gasket condition: loss of sealing

3.4. Associated system damage

- Piping
- Supports
- Valves
- Instrumentation and electrical systems
- Fans and plenum
- Transmission system (shafts, belts, pulleys)
- Motors
- Nozzles gasket seating

4. Restoration Assessment Methodology

The restoration assessment requires a multidisciplinary team including mechanical, materials, inspection, operations, and engineering specialists.

4.1. Typical activities

- Visual examination and damage mapping
- UT thickness measurements
- PT/MT examination
- Hardness testing
- Metallography and replica examination
- Dimensional inspection
- Pressure boundary evaluation
- Helium and Hydrostatic testing
- Fans and structure vibration validation

5. Fitness-for-Service Evaluation

API 579-1/ASME FFS-1 provides a structured approach to evaluate damaged equipment.

5.1. Assessment levels

- Level 1: Screening assessment using simplified criteria.
- Level 2: Detailed engineering assessment.
- Level 3: Advanced analysis requiring specialist evaluation.

Applications include

- Local thin areas
- Dents and distortions
- Fire damage assessment
- Blast impact
- Remaining strength evaluation

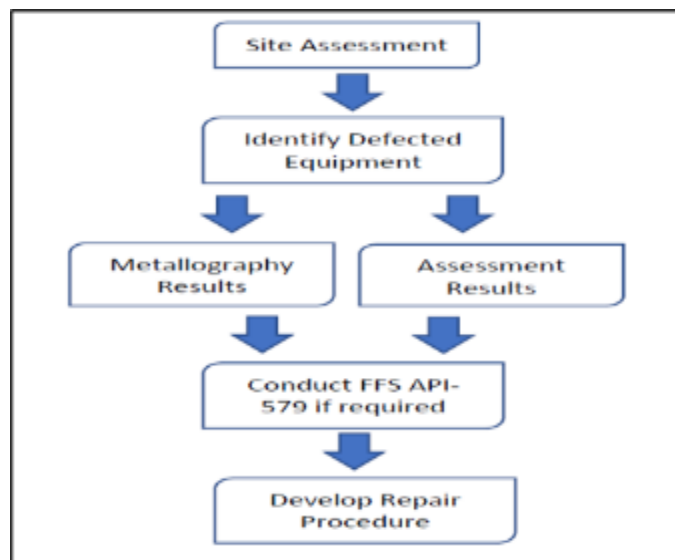


Figure 1 Engineering Verification

6. Repair and Reinstatement Strategy

Repair decisions should consider safety, reliability, economics, and future operating requirements.

6.1. Possible actions

- Component (shell/ channel) repair
- Tube plugging
- Tube replacement
- Tubes finning
- Fans replacement
- Transmission system replacement
- Headers reuse/ replacement
- Weld repair
- Nozzle restoration
- Complete equipment replacement
- Plugs and bolts replacement
- Plenum restoration
- Side frame repair

Final reinstatement requires completion of inspections, testing, documentation, and approval before operation.

7. Roles and Responsibilities (RACI Matrix)

Successful heat exchanger restoration requires clear definition of responsibilities among all involved entities. The RACI matrix below defines responsibility, accountability, consultation, and communication requirements during assessment, engineering evaluation, repair execution, and return-to-service activities.

Table 1 Restoration RACI

Activity	Engineering	Inspection	Operations	Maintenance
Initial site assessment and damage identification	C	R	R	C
Damage mapping and inspection planning	R	R	C	C
NDT activities (UT, PT/MT, hardness testing)	C	R	C	R
Material integrity and metallurgical evaluation	R	R	C	C
Fitness-for-Service assessment	R	C	C	I
Repair strategy development and approval	R	C	C	R
Repair execution and quality control	C	C	A	R
Pressure testing and final inspection	C	R	R	C
Return-to-service authorization	C	C	R	C
Lessons learned and integrity program update	C	C	R	C

RACI definition: Responsible (R) performs the task; Accountable (A) owns the decision and approval; Consulted (C) provides technical input; Informed (I) receives progress and final status information.

8. Restoration Assessment Framework

Table 2 Assessment Framework

Assessment Stage	Main Activities	Inspection / Engineering Tools	Outcome
Initial Damage Assessment	Site survey and damage mapping	Visual inspection, photographs, dimensional survey	Define damage extent
Mechanical Integrity Evaluation	Headers, shell, channel, tube and nozzle assessment	UT, PT/MT, NDT, hardness testing	Confirm integrity condition
Material Assessment	Evaluate thermal and mechanical degradation	Metallography, replica, PMI	Verify material suitability
Fitness-for-Service Evaluation	Remaining strength and acceptability assessment	API 579-1/ASME FFS-1	Repair or operate decision
Restoration and Reinstatement	Repair execution and verification	Testing and final inspection	Safe return to service

9. Restoration Decision Matrix

Table 3 Decision Matrix

Component	Potential Damage	Inspection Method	Engineering Assessment	Restoration Action
Shell / Channel/ Headers	Fire damage, distortion, thinning	VT, UT, hardness, NDT	FFS evaluation	Repair or replacement
Tube Bundle	Leakage, cracking, wall loss, fins damage	Eddy current, MFL, pressure test	Tube integrity review	Plug, repair, replace
Nozzles / Flanges	Deformation, cracking	Dimensional inspection, PT/MT	Pressure boundary evaluation	Repair connection
Supports	Buckling and distortion	Visual and dimensional inspection	Structural assessment	Restore alignment
Associated Piping	Thermal or mechanical damage	UT and NDT	Remaining life assessment	Repair or replace
Fans/ Plenum	Thermal or mechanical damage	VT	Remaining life assessment	Repair or replace

10. Reliability Improvement After Restoration

A restoration project provides an opportunity to improve long-term reliability. Inspection programs, RBI strategies, damage mechanism reviews, and operating controls should be updated based on findings. Lessons learned from incidents should be incorporated into future maintenance and integrity management programs.

11. Case Study: Incident Damage and Restoration Assessment

The following field photograph is incorporated as a case study example representing severe incident damage. The restoration evaluation includes damage mapping, structural assessment, material verification, fitness-for-service review, and repair strategy development.



Figure 2 Field damage condition requiring stationary equipment restoration assessment. (Ref. LinkedIn)

12. Conclusion

Heat exchanger restoration after major damage events requires a disciplined engineering process. Combining inspection data, material evaluation, and fitness-for-service principles enables safe decision-making and reliable plant recovery.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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