Material, Fabrication, and Repair Considerations for Austenitic Alloys Subject to Embrittlement and Cracking in High Temperature 565 °C to 760 °C (1050 °F to 1400 °F) Refinery Services

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Introduction

The API Committee on Refinery Equipment, Subcommittee of Corrosion and Materials, identified a need to develop a technical report focusing on the materials, fabrication, and repair of austenitic stainless steels and nickel-iron-chromium alloys in high temperature 565 °C to 760 °C (1050 °F to 1400 °F) refinery services. Many of these alloys are subject to embrittlement and cracking after prolonged exposure to these temperatures. Susceptible equipment in the following processing units are addressed:

— fluid catalytic cracking units,

— hydrogen/syngas plants,

— catalytic reformers,

— cokers,

— hydroprocessing units.

This report summarizes industry experience and recommends methods to improve reliability and process safety, and increases industry awareness to high temperature embrittlement issues.

NOTE Embrittlement can be a serious personnel safety issue if plant personnel are not careful about hand-holds and foot-holds when inspecting embrittled piping and vessel components. There has been at least one case where an inspector was seriously injured when an embrittled support failed.

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1 Technical Approach/Report Organization and Scope

As a basis of this report, technical literature, industry experience, and published case studies were reviewed. The review included materials of construction, damage mechanisms, and component-specific fabrication and repair issues.

The scope of this report includes the following wrought austenitic alloys: Alloys 800, 800H, 800HT®, and 300 series austenitic stainless steels, and corresponding welding consumables. Limits in chemical composition, microstructural requirements, and heat treating practices that mitigate susceptibility to embrittlement and cracking are identified. Potentially viable upgrades to commonly used alloys are identified where applicable.

The remainder of this report is organized as follows.

Section 3, Process Units, gives a brief process overview followed by an explanation of the various damage mechanisms found in that unit. Component specific considerations and examples of in-service damage are also included. Inspection recommendations and general repair method considerations are also included.

Section 4, Damage Mechanisms, contains detailed discussions of high-temperature damage mechanisms; including fundamental details of the solid state reactions, their rate of reaction, and recommended mitigation measures. Section 4 also incorporates fabrication and repair practices that can be used for cracked or embrittled equipment.

NOTE Excluded from the scope of this document are Hydrogen Reformer catalyst tubes, outlet pigtails and outlet headers. With the exception of catalyst tubes, these are covered in TR 942-A, *Materials, Fabrication, and Repair Considerations for Hydrogen Reformer Furnace Outlet Pigtails and Manifolds*. Also excluded are expansion bellows in elevated temperature service.

2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

CCC	complete carbon monoxide combustion
CO	carbon monoxide
CRCR	continuously regenerated catalytic reformer
CVN	Charpy V-notch
FCCU	fluid catalytic cracking unit
FN	ferrite number
GTAW	gas tungsten arc welding
ID	inside diameter
MTR	material test report
NDE	non-destructive examination
NDT	non-destructive testing

PASCC polythionic acid stress corrosion cracking

PCC partial CO combustion

PFZ precipitation free zone

PT penetrant testing

PWHT post weld heat treatment

SAGBO stress assisted grain boundary oxidation

SRC stress relaxation cracking

SS stainless steel

T/C thermocouple

TTT time temperature transformation

UT ultrasonic testing

UTSW ultrasonic testing shear wave

WRC Welding Research Council

3 Process Units

3.1 General

Table 1 summarizes common embrittlement mechanisms in each of the listed refinery process units. Implications for specific equipment are discussed in more detail in the section for each respective process unit. Information on damage mechanisms can be found in API 571 and in Section 4 of this document.

3.2 Fluid Catalytic Cracking Units (FCCUs)

3.2.1 Process Description

FCCUs are used to process heavy feedstocks, converting them to gasoline, diesel, and furnace oils. A simplified process flow diagram for the FCCU is shown in Figure 1 [1]. The catalytic reaction occurs mostly inside the riser prior to reaching the reactor at temperatures ranging from approximately 480 °C to 565 °C (900 °F to 1050 °F). In modern FCCUs, the “reactor” functions as a hydrocarbon/catalyst separator. During the process, the catalyst becomes deactivated as it becomes coated with carbon (coke). The catalyst is sent to the regenerator where it is exposed to air, promoting the burn off of coke at approximately 650 °C to 780 °C (1200 °F to 1475 °F).

Inside FCCU reactors and regenerators are cyclones which are used to separate the catalyst from the overhead vapor streams. Most regenerators have multiple sets of primary and secondary cyclones. Primary cyclones direct the vapor flow from inside the reactor or regenerator in a centrifugal pattern, forcing the heavier catalyst particles outward against the inside wall, and allowing the catalyst particles to then fall down into the catalyst bed. The lighter vapor stream exits out the top of the primary and into the secondary cyclone to remove residual catalyst from the vapor stream. Primary and secondary cyclones can be seen in Figure 2 [2].

Units that process heavier feeds are called resid fluid catalytic cracking units (resid FCCUs) and these feeds typically have higher sulfur contents. In addition, resid FCCU feeds typically develop higher carbon residues on the catalyst particles. Carbon residues, as indicated by the Conradson Carbon Residue test of Resid FCCU feeds, are significantly higher with up to 5 to 10 wt.%, compared to <1 wt.% for a typical FCCU feed. These heavier feeds also