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Fitness for service assessment of a pressure vessel subjected to fire damage in a refinery unit

R. Bakhtiari[a,*], S. Zangeneh[a], M. Bakhtiari Fotouh[b], S.M. Jamshidi[b], A. Shafeie[b]

[a] *Department of Materials and Textile Engineering, Faculty of Engineering, Razi University, Kermanshah, Iran*
[b] *Kermanshah Oil Refinery Company (KORC), Kermanshah, Iran*

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ABSTRACT

The fire-damaged pressure vessel reactor, evaluated in this study, was a cylindrical vessel with design conditions of 460 psig (3.17 MPa) at 413 °C. The fitness for service (FFS) of the fire-damaged pressure vessel was assessed according to API 579-1/ASME FFS-1. First, the maximum temperature during the fire accident was determined based on deterioration of outer protective layer. Then, the possible damage was examined by hardness test, in-situ field metallography and metallographic replicas. Grain growth and spheroidized pearlite were observed in the base metal at the inner surface of the vessel. Outer surface of the vessel showed ferritic microstructure with smaller grain size as compared to the inner surface. Decarburizing and carbide formation were also visible at the outer surface. The lower hardness of the base metal at both sides of the vessel was compared to the standard value and related to the microstructure evolution during high temperature/fire exposure condition. The results of the FFS evaluation indicated that the vessel is not suitable for the current design conditions, and therefore a new maximum allowable working pressure was determined.

1. Introduction

Some parts of refineries and petrochemical industries may be damaged and need to be assessed to ensure continued safe operation. Replacement is frequently not a good option because of high capital costs, and the much lower cost of continuing the operation of the older plant. However, reliability and safety are issues that have become much more important in recent years, so the assessment of damage and the failure risk have become increasingly important [1], especially for pressure vessels used in petroleum industries [2].

Design methods and code structure generally have specific damage tolerances and their application for damage assessment during the operation life is likely to produce improperly conservative assessments. Therefore, design codes do not provide rules to evaluate equipment that degrades during service, and deficiencies due to degradation or original fabrication that may be found during subsequent inspections [3]. Fitness-for-service (FFS) assessment method has been developed in recent years to deal with this challenge by (I) assessment of the current state of the (damaged) structure, (II) extrapolation from the current state to estimate the remaining safe and serviceable life, and (III) providing guidelines to make run, rerate, repair, or replace decisions about aging pressure components and defect-containing structures. API 579-1/ASME FFS-1 defines FFS as quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component that may contain a flaw or damage.

* Corresponding author.
undefinedr.bakhtiari@razi.ac.ir",0,0,2
>r.bakhtiari@razi.ac.ir (R. Bakhtiari).

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In general, FFS assessments are quantitative engineering evaluations, which are especially used in oil and gas industry. Crack-like flaws is one of the major failure modes of pressure vessels. Furthermore, pressure vessels have been assessed using FFS according to pitting corrosion and thermal hot spots [4–6].

If the results of a FFS assessment indicate that the equipment is suitable for the current operating conditions, then the equipment can continue to be operated at designed condition provided that suitable monitoring/inspection programs are established. If the results of the FFS assessment indicate that the equipment is not suitable for the current operating conditions, then the equipment can be rerated using the calculation methods based on API 579-1/ASME FFS-1. These calculation methods can be used to find a reduced maximum allowable working pressure (MAWP) [7].

Low alloy steels, used in pressure vessels and piping at high temperatures, typically have a microstructure of pearlite colonies in a matrix of ferrite grains of a given average size. With extended exposure to high temperatures, the pearlite decomposes to form a dispersion of carbides in a ferrite matrix. Similar effects occur in carbon–molybdenum and carbon–chromium–molybdenum steels. Over-aging promotes the coalescence of the small carbides, formed during the pearlite decomposition, and prolonged aging leads to a ferritic structure including spheroidized carbides with an almost uniform distribution. This occurs after prolonged exposure to temperatures higher than 400 °C for carbon steels, and of around 420 °C for low alloy steels. For low-carbon steel pressure vessels, the short-time heat exposure higher than 850 °C, the temperature level for the complete transformation to austenite, could produce grain refinement rather than grain growth. Therefore, estimating the temperatures of heat exposure based on grain size is difficult [8]. Furthermore, decarburizing could occur for these steels during exposure to high temperatures which is important for quality control of the related parts as can affect the mechanical properties such as hardness, wear and fatigue resistance. Destructive methods of determining the depth of decarburized layer include metallographic and hardness tests [9].

2. Background of the damaged pressure vessel reactor

The fire-damaged pressure vessel reactor (named V-201), evaluated in this study, was a cylindrical vessel which was used in Kermanshah Oil Refinery Company (Fig. 1). The reactor had a 5969 mm height, 1067 mm inside diameter and 20.2 mm (including 3.2 mm thick cladding material) thick wall. The reactor was fabricated from SA-204 Grade 70 steel with an A-240 corrosion-resistance cladding. The vessel design conditions are 460 psig (3.17 MPa) at 413 °C, and the weld joint efficiency (E) is 1. A future corrosion allowance of 1/16 in. (1.59 mm) is required for operation.

The pressure vessel reactor was subjected to a fire damage due to spontaneous combustion. According to observations of the fire marshal, the flames expanded upward and covered half of the reactor. Since an accidental fire is a random event, extensive data collection during an accidental fire is seldom possible. Unfortunately, in this case, there was no evidence such as videotape to determine the nature and extent of the fire. Whereas videotape evidence is available, it could be possible to deduce the nature of the fuel, the fire's progression from its ignition source, and temperature extremes from visual evidence on the tape. Therefore, the data of the fire damage was collected after the fire was extinguished.

3. Experimental/FFS procedure

To investigate the damage of V-201 vessel reactor, three different zones on the inner surface and two ones on the outer surface were studied to determine the extent of damage. The base metal of the reactor is a low alloy steel (ASTM A204) with chemical composition given in Table 1. For the selected zones, surface preparation and replicating were conducted according to ASTM E 1351 standard. On the inner surface, the cladding was removed and preparation was carried out on the base metal surface. Then, metallographic preparation of the replicas was conducted using ASTM E 3-01(2007):2010 standard. Micro-etching of the Au-coated replicas was performed through ASTM E 407-07:2010 standard using Nital-2% etchant. Olympus-DP12 optical microscope was used to study the microstructures, using ASTM E 883-02(2007): 2010 standard. An image analyzer software was used to measure phase

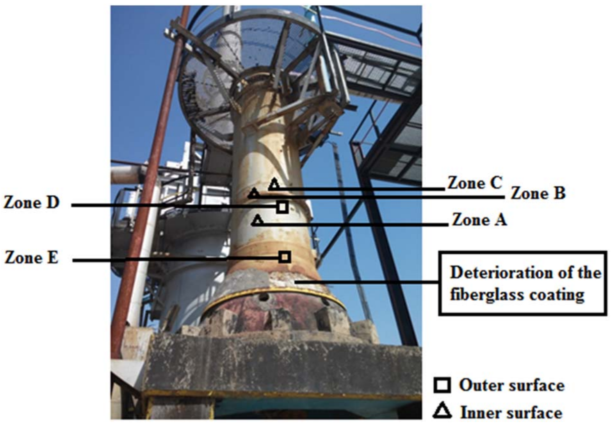

Fig. 1. Image of V-201 vessel reactor in Kermanshah Oil Refinery Company (KORC), showing different studied zones.