

Premature Failure of Ni-coated Carbon Steel Fittings in Water Injection Service due to Microbiologically Induced Corrosion

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ABSTRACT

This paper presents the findings of an investigation that was carried out to determine the root cause of the premature failure of Ni-coated carbon steel fittings on the water injection composite piping system installed at an oil production facility in Western Canada. The facility had been in operation since 2011 without major corrosion issues. Many of the Ni-coated fittings, which are expected to have a service life of 20 years, started to fail (developed leaks) unexpectedly after about 4 years. The core structure of composite pipe is a high-density polyethylene (HDPE) inner pipe, a middle layer of high-strength dry fiberglass, and a protective thermoplastic outer jacket. The interconnecting fittings are made of carbon steel coated with a thin, ~40 micron (1.5 mil) layer of Nickel.

The failure investigation results (bacteria, water, and corrosion product analyses as well as photographic documentation of the corrosion damage morphology) provided quite convincing evidence that the premature failures observed in the fittings occurred as a result of MIC (Microbiologically Influenced Corrosion) due to the presence of high counts of SRB (sulfate reducing bacteria) and APB (acid producing bacteria) in the system. Of course, under-deposit corrosion, crevice type corrosion and galvanic corrosion may also have occurred in conjunction with MIC. It is also to be noted that if the integrity of the thin Ni coating is compromised in any way, such as pitting damage due to MIC, or manufacturing flaws, accelerated galvanic corrosion attack of the carbon steel substrate would be expected at that location, since Ni is cathodic to carbon steel.

Key Words: MIC, composite pipe, Ni-coated carbon steel fittings, galvanic attack

INTRODUCTION

An Oil and Gas Production company in Western Canada operates some 300 crude oil production wells using Flexpipe Linepipe (FPLP) water injection systems for Enhanced Oil Recovery which has been functioning from 2011 to September 2020 without major corrosion issues. FPLP has a three-layer construction consisting of an inner pipe of high-density polyethylene (HDPE), a middle layer of helically wound epoxy-free, high-strength dry fiberglass, and a protective thermoplastic outer jacket. The interconnecting fittings are made of 0.25 inch (63.5 mm) carbon steel internally coated with a thin, ~40 micron (1.5 mil) layer of Electroless Nickel. The fittings are installed in the system by crimping and were installed between 2011 and 2016. The oil production system was shut down for approximately 6 weeks from early May 2020 to mid-June 2020. The system was depressurized but was not drained. Approximately 3 months after start-up following the shutdown, numerous fitting failures were encountered. Failures were first noticed in the Produced Water (PW) fluid stream and subsequently in the Polymer Treated Water (PTW) and Oil Emulsion (OE) streams. Many of the Ni-coated fittings, which are expected to have a service life of 20 years, failed (developed leaks) prematurely after about 4 years.

A failure investigation was conducted to find the root cause of these failures. Nine (9) failed Flexpipe fittings from three different streams (PW, PTW and OE), approximately 16.0-inch (400 mm) long and 4-inch (50 mm) in diameter, were longitudinally sectioned in half (i.e. a total of 18 half sections) and 16 of these half sections were available for the failure investigation. However, only eight (8) fitting halves from the 16 were selected for the investigation. Some of the fittings had flanges and some were without flanges.

METHODOLOGY FOR FAILURE INVESTIGATION

The following methodology was adopted for the failure investigation:

1. (a) Collection of background information for the fluid streams and (b) Sample selection
 - (a) Collection of detailed operational data for the oil production process using different types of waters (PW, PTW and OE), including information regarding the process system and piping layout with location of fittings, operational parameters, shutdowns, and water analysis data.
 - (b) Preliminary evaluation of all the 16 half-sections of the failed fittings to select eight (8) of the samples for detailed evaluation.
2. Detailed Visual Examination of the eight (8) selected half sections

Careful visual examination of four (4) half sections from the PW system, two (2) half sections from the PTW system, and two (2) half sections from the OE stream, to determine the type and features of the corrosion damage including photographic documentation of the examined sites using a high-resolution digital camera.
3. Analysis of water samples as well as planktonic and sessile bacteria samples from PW, PTW and OE Streams. Sample collection and analysis were done by a third party laboratory using standard NACE procedures^{A B}. Details are not provided here due to lack of space in the paper.
4. Analysis of solid products from the PW, PTW and OE streams to determine the chemical composition of the compounds present in the solid products. Sample collection and analysis were done by a third party laboratory. X-Ray Diffraction (XRD) technique was used for sample analysis.
5. Data Analysis, Interpretation, and Integration.

^A NACE TM0212-2012, "Detection, Testing, and Evaluation of Microbiologically Influenced Corrosion on Internal Surfaces of Pipelines" NACE International, Houston, TX, 2012.

^B NACE TM0194-2014 "Standard Test Method – Field Monitoring of Bacterial Growth in Oil and Gas Systems," National Association of Corrosion Engineers International, Houston, Texas, 2014

RESULTS

1 (a) Background Information

Two different types of fluids are used for water injection, namely, Produced Water (PW) and Polymer Treated Water (PTW). Briefly, the production process entails the following: Oil Emulsion (OE) from the production wells enter 3 separate FWKO (Free Water Knock-Out) facilities where oil and water are partially separated. The separated water, known as Produced Water (PW), is drawn off the bottom of the FWKO's and is used as straight injection water (in about 35 injection wells) or to produce Polymer Treated Water (PTW). The operating pressures are as follows: (1) OE system – 2000 kPa (290 psi) at the wells down to 500 kPa (73 psi) at each facility (2) PW system – 8000 kPa (1160 psi) and (3) PTW system – 9150 kPa (1327 psi) at the pumps down to 8000 kPa (1160 psi) at the extremities of the field.

The PTW is produced at different Polymer Skids where water-soluble polymer pellets are mixed at a concentration of 1275 mg/L (1275 ppm) with fresh water from 6 source wells. PW is mixed with PTW downstream of the polymer skids, and the entire polymer system feeds about 200 polymer injection wells. The operating temperature is 25° C in all systems.

A schematic flow diagram for the oil production and processing system is depicted in Figure 1, which shows the layout of the various process streams with the key facilities and equipment. The specific locations of the failed fittings that were used for the failure investigation, including the locations of the collected samples of water, solids, and bacteria, are also indicated on the diagram.

1 (b) Sample Selection

The as received 16 failed fitting sample halves (representing 9 different fittings) that were available are listed in Table 1 along with Fluid Stream, Fitting ID, Fitting Location, Sample ID, Orientation, and Install Dates. The specific locations of these 9 fittings are indicated in Figure 1. Two representative photos of the fitting halves are shown in Figures 2 and 3 for an un-flanged and flanged fitting respectively. All 16 samples were visually examined to select the 8 most suitable ones for detailed examination and evaluation.

2. Detailed Visual Examination of the Eight (8) Selected Half Sections of Fittings

As mentioned earlier, 8 failed pipe-fitting half sections were selected for detailed visual examination and evaluation. These included 4 half sections from the PW system, 2 half sections from the PTW system, and 2 half sections from the OE stream, which are listed in Table 2.

Each of the 8 sections was carefully examined to observe the internal condition of the fittings in terms of the type and extent of the corrosion damage as well as the color and characteristics of the deposits on the surface. Photographic documentation was made with a digital camera. It may be noted that all samples listed in Table 2 were examined prior to cleaning any deposits from the inner surface as well as after cleaning with an acid solution as per standard ASTM procedure. Photographs taken are shown in Figures 4-11.

A summary of the visual observations before and after cleaning is presented in Table 3. The internal surfaces of the uncleaned samples were covered with deposits ranging in color from black to various shades of brown and grey. It was difficult to discern if any Ni coating was present on the internal surface. Based on the material of the fitting and a knowledge of the type of environmental exposure conditions, these deposits were most likely corrosion products and/or scale deposits consisting of oxides, sulfides, chlorides, sulfates, and carbonates. The exact composition of these deposits, collected from a few locations, are presented in a later section. The cleaned specimens gave a better idea of the status of the Ni coating and the corrosion morphology.

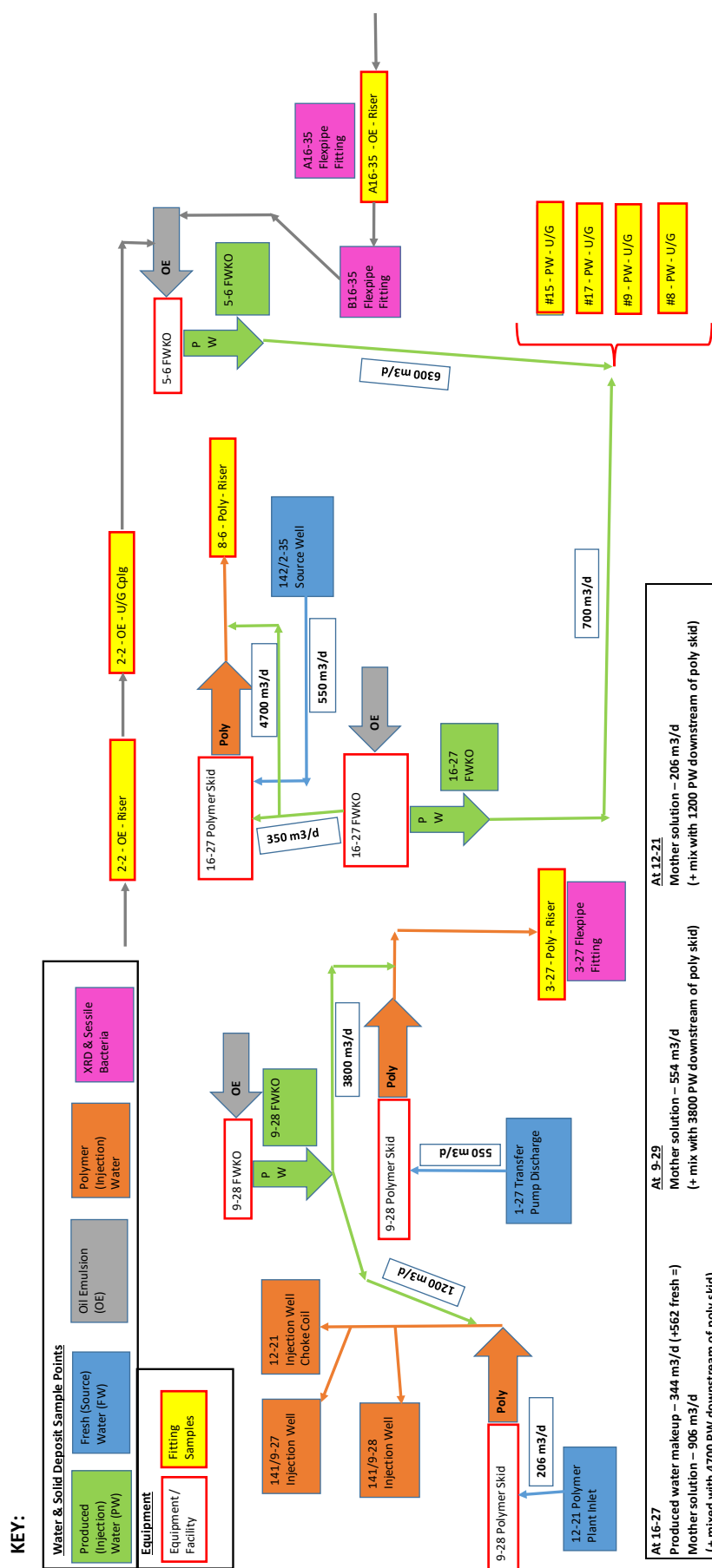


Figure 1. Process Flow Diagram of the Oil and Gas Production Facility Showing the Various Process Streams with Key Facilities, Equipment and Locations of the Collected Samples of Water, Solids, and Bacteria

Table 1
List of Flexpipe Fitting Halves Available for Investigation

Sample No	Fluid Stream	Fitting ID	Fitting Location	Sample ID	Orientation	Install Date
1	Produced Water (PW)	#8	A5-35-35-28W3 Underground	#8-a (x, y) Outer	Horizontal	2011
2				#8-b (x, y) Inner		
3	Produced Water (PW)	#9	A6-35-35-28W3 Underground	#9- a (x, y) Outer	Horizontal	2016
4				#9- b (x, y) Inner		
5	Produced Water (PW)	#15	2-2-36-28W3 Surface Riser	#15-a (x Outer, y Inner)	Horizontal	2016
6	Produced Water (PW)	#17	2-2-36-28W3 Underground	#17-b (x Outer, y Inner)	Horizontal	2016
7	Oil Emulsion (OE)	#2-2	2-2-36-28W3 Surface Riser	#2-2- a (x, y) Outer	45°	2013
8				#2-2- b (x, y) Inner		
9	Oil Emulsion (OE)	#2-2	2-2-36-28W3 Underground	#2-2- a (x, y) Outer	Horizontal	2013
10				#2-2- b (x, y) Inner		
11	Oil Emulsion (OE)	#A16-35	A16-35-35-28W3 Surface Riser	#A16-35- a (x, y) Outer	45°	2013
12				#A16-35- b (x, y) Inner		
13	Polymer Water (PTW)	#8-6	8-6-36-27W3 Surface Riser	#8-6- a (x, y) Outer	45°	Unknown
14				#8-6- b (x, y) Inner		
15	Polymer Water (PTW)	#3-27	3-27-35-28 Surface Riser	#3-27- a (x, y) Outer	45°	2012
16				#3-27- b (x, y) Inner		

***Refer to Figure 1 for Fitting ID.**

****Sample ID used to identify all 16 half-sections**