Analysis of Erosion/Corrosion Data for High-Level Waste Pipelines at Hanford– 15519

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ABSTRACT

Washington River Protection Solutions (WRPS) has implemented a fitness-for-service program which will evaluate the degraded condition of the tank farm waste transfer system. The Tank Farms Waste Transfer System Fitness-for-Service Requirements and Recommendations, includes a requirement to inspect primary piping, encasements, and jumpers for corrosion/erosion. The 242-A Evaporator pump room was upgraded by adding instrumentation to the feed and return jumpers, prior to running the next campaign. As part of this upgrade, several jumpers were removed for disposal and a total of five jumpers were selected for ultrasonic thickness (UT) inspection. The jumpers selected were the following: 18-4, C-4&5, J-13A, 13-K, and 19-5. All of these jumpers will be removed permanently except for jumper 19-5 which will be reinstalled for further service. As part of this study, several jumpers from the AW-02E Feed Pit were also removed for disposal and two were selected for UT inspection. The jumpers selected were the 1-4 and B-2 which were packaged and sent to the 222-S Laboratory for UT assessments. This paper includes details of each jumper as well as the estimated remaining useful life (ERUL), if applicable, for its components based on the wall thinning measured in elbows and straight sections. The jumper's ultrasonic thickness measurements are plotted and trends are assessed based on the volume of fluid transferred or time of service. Variability in thickness is generally evaluated in two approaches, radially around the circumference of the pipe or component and longitudinally along the length. The paper also explains the analysis procedure for evaluating the different components. In particular, issues related to thinning from manufacturing different types of elbows (long radius, five diameter bend radius) are presented. Analysis techniques are developed for elbows that differentiate thinning from erosion/corrosion and manufacturing which is critical for this analysis. Results demonstrate that in most components, the thickness measurements are still greater than the manufactured nominal thickness. For the cases in which the thickness is below the nominal thickness, the ERUL well exceeds the life needed for servicing the Waste Treatment Plant.

INTRODUCTION

Washington River Protection Solutions has implemented a fitness-for-service program which will evaluate the degraded condition of the tank farm waste transfer system. The Tank Farms Waste Transfer System Fitness-for-Service Requirements and Recommendations [1], includes a requirement to inspect primary piping, encasements, and jumpers for corrosion/erosion. This study includes evaluation of jumpers from the 242-A Evaporator pump room and the AW0-2E Feed Pit.

The 242-A Evaporator employs a forced-circulation, vacuum-evaporation system to concentrate dilute radioactive salt waste solutions and recover double-shell tank space. One-million gallon evaporator feed batches are accumulated in tank 241-AW-102, and pumped to the evaporator (via the AW-02E Evaporator Feed Pump Pit). Slurry product containing up to about 20% solids (volume) is pumped to a double-shell receiver tank. Waste volume reductions as high as 90 – 95% can be achieved using the process.

The 242-A Evaporator pump room was upgraded by adding instrumentation to the feed and return jumpers, prior to running the next campaign. As part of this upgrade, several jumpers were removed for disposal and a total of five jumpers were selected for UT inspection. The jumpers selected were the following: 18-4, C-4&5, J-13A, 13-K, and 19-5. All of these jumpers will be removed permanently except for jumper 19-5 which will be reinstalled for further service. The UT measurements collected from jumper 19-5 will assist in future 242-A integrity assessments.

Several jumpers from the AW-02E Feed Pit were removed for disposal and two were also selected for UT inspection. The jumpers selected were the 1 to 4 and B to 2 which were packaged and sent to the 222-S Laboratory for UT assessments [2].

This paper includes details of each jumper as well as the estimated remaining useful life for its components based on the wall thinning measured in elbows and straight sections. The jumper's ultrasonic thickness measurements are plotted and trends are assessed based on the volume of fluid transferred.

242-A EVAPORATOR PUMP ROOM

Jumper Descriptions

The 242-A Evaporator pump room was upgraded by adding instrumentation to the feed and return jumpers, prior to running the next campaign. As part of this upgrade, several jumpers were removed for disposal and a total of five jumpers were selected for UT inspection. These include jumpers 18-4, C-4&5, J-13A, 13-K, and 19-5. All jumpers were manufactured with Schedule 40 ASTM 312 TP 304 stainless steel pipe. Jumpers 19-5, C4&5, and 18-4 have 50.8 mm diameters and 13-K and J-13A have 76.2 mm diameters. Each jumper has different service lives, with different flow types and volumes. Below is a table listing the service information for each jumper.

Table 1. Jumper Service Information

Jumper	Flow Type	Volume (m^3)	Service Life
19 - 5	Slurry	158,987	1980 - 2010
C 4 & 5	Slurry	41,639	Since 1992
18 - 4	Slurry	0	N/A
13 - K	Supernatant	321,760	Since 1983
J - 13A	Supernatant	109,777	Since 1983

* Transfer velocities are < 1.83 m/s and solid concentrations range from <1 t0 ~20 vol.% solids.

Ultrasonic thickness measurements were taken with an Ultrasonic Transducer (Manufacturer: Olympus, Model: 45m6) and a grid pattern wrapped around the outside diameter (OD) of the jumper at various locations. For Jumpers 19-5, 18-4 and 13-K, measurements were taken at two straight section locations and two different elbows. For Jumper C4&5 measurements were taken at one straight section and two elbows and for Jumper J-13A, measurements were taken at two straight sections and one elbow.

Data and Analysis

Examples of the measurements taken and analysis conducted for each of the jumpers are provided in this section. Note that measurements and analysis for all the 242-A jumpers is provided in a report authored by FIU [3]. A 3D CAD drawing of the Jumper 19-5 with Elbow-3 (5D bend radius) highlighted in red is provided in Figure 1. The figure also provides the positions at which measurements were taken. The grid was labeled 1 through 7 around the extrados of the pipe and PS-1 to PS-3 running horizontally along the length of the jumper. The three locations running horizontally were separated by approximately 22.5°

along the radius of the elbow, and the seven measurements along the extrados were taken every 30° as shown in Section A-A of the figure. The results of the elbow thickness measurements are shown in Table 2.

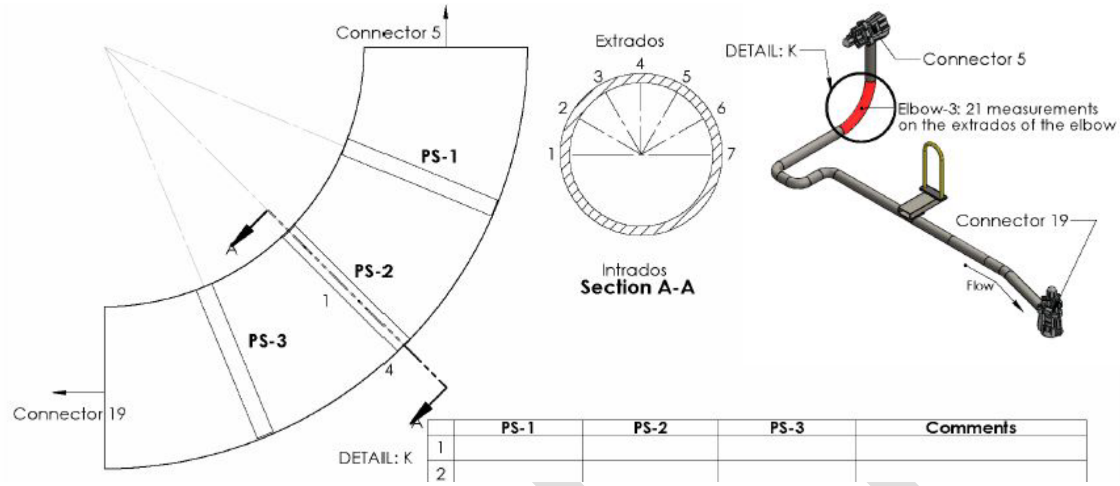

Figure. 1. Position of UT Measurements around Elbow-3 of Jumper 19-5.

Table 2. UT Measurements for Elbow-3 of Jumper 19-5

Location	PS-1 (mm)	PS-2 (mm)	PS-3 (mm)
1	3.99	3.63	4.06
2	3.81	3.84	3.91
3	3.73	3.84	3.71
4	3.66	3.68	3.66
5	3.66	3.66	3.76
6	3.76	3.76	3.76
7	3.96	3.81	3.94

A summary of the wall thickness measurements and calculations for Elbow-3 is shown in Table 3 which includes the average thickness and standard deviations. Nominal, maximum and minimum manufacturing thicknesses are not provided for elbows in current standards so the thicknesses for straight pipe sections are provided for comparison. These manufacturing thicknesses were obtained using information for 50.8 mm Schedule 40 pipes. Nominal thicknesses for straight pipe sections were obtained from ASTM A312-77, Table X1 [4]. The minimum and maximum manufacturing thicknesses are not provided in this standard but guidance is provided in ASTM A53-72a for carbon steel pipes [5]. The nominal thicknesses for the same size carbon and stainless steel pipes are 3.91 mm, so ASTM A53-72a is used as a reference for the minimum and maximum thicknesses in this analysis. The minimum thickness is found in Table A4 of ASTM A53-72a. The maximum manufacturing thickness for straight sections, however, was not provided in the tables and was determined following the guidelines from ASTM A53-72a Paragraph 14.2. This paragraph states that the outside diameter should not vary more than 1% from the standard specified. For the 50.8 mm schedule 40 pipe, a manufacturing maximum thickness of 4.22 mm is obtained.

Five diameter bend radius elbows are typically manufactured using a rotary draw bending technique in which a straight pipe section is bent over a rotating bending die. During this process, the thickness at the extrados of the pipe is reduced and the thickness at the intrados has a corresponding thickening. Various standards provide guidelines for the percentage of thinning at the extrados from the nominal thickness of the straight section. ASME B31.1 Section 102.4.5 states that a minimum thickness prior to bending is 1.08 times the nominal thickness of the straight section for a 5D bend radius elbow [6]. The Piping Handbook provides guidelines for determining the thickness reduction of the extrados [7]. For a 50.8 mm 5D bend, the reduction is 10.6% from the nominal thickness.

Table 3. Summary of Elbow-3 of Jumper 19-5 Thickness Measurements

Overall Average Wall Thickness Measurements	3.79 mm
Overall Standard Deviation	0.12 mm
Average -2 Standard Deviation	3.54 mm
Average +2 Standard Deviation	4.04 mm
Manufacturer Nominal Thickness (straight)	3.91 mm
Minimum Manufacturing Thickness (straight)	3.43mm
Maximum Manufacturing Thickness (straight)	4.22 mm
Amount of Slurry Transferred	158,230 m^3
Note: Nominal thickness based on Stainless Steel, 50.88 mm Diameter, Schedule 40	

To determine how the thickness varies along the circumference, the average longitudinal thickness measurements are plotted at each radial location (Figure 2). The average thickness, nominal thickness (straight section), and the manufacturing minimum and maximum thickness (straight section) are also plotted. Additionally, a compensated thickness is plotted to incorporate thinning at the extrados and provide a better understanding of the potential thinning due to erosion. This curve was created by adding 10% of the average thickness of Radial Positions 1 and 7 to the thickness at the extrados (Radial Position 4). Similarly, 6.7% of the average thickness of Positions 1 and 7 was added to Positions 3 and 5 and 3.3% was added at Positions 2 and 6. Radial Positions 1 and 7 are on the top and bottom of the pipe and should not have a change in thickness due to the bending process.

For this data set, the average thickness measurements vary symmetrically along the extrados between the top and bottom of the elbow with the minimum thickness occurring at the outer edge (radial position 4), and the maximum thickness occurring at the top and bottom (Radial Position 1 and 7). The difference between

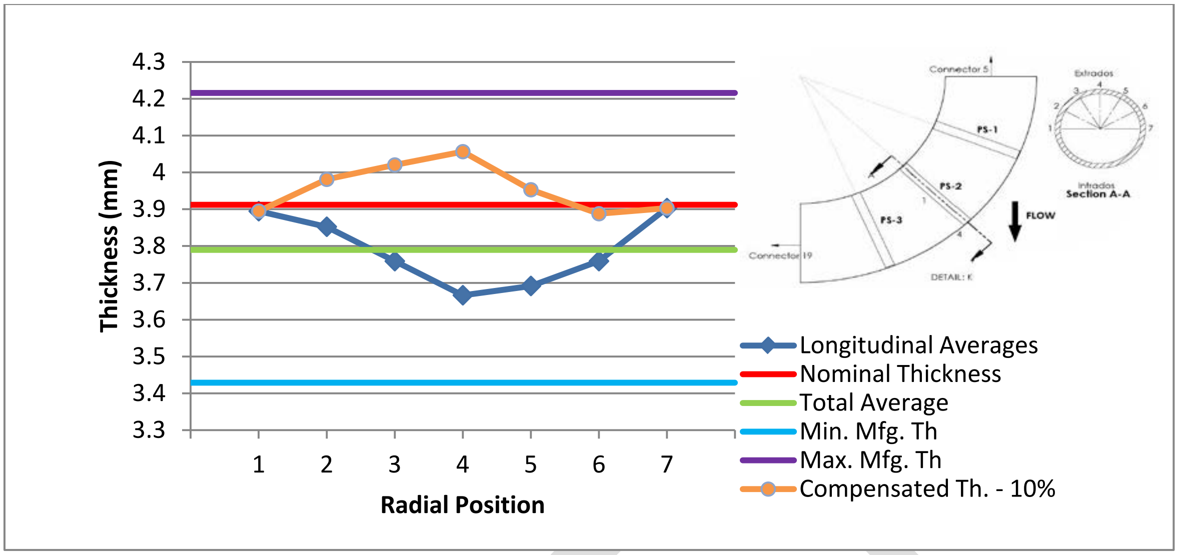

Figure. 2. Jumper pipe longitudinal average measurements grouped by radial position (19-5 Elbow-3).

the maximum and minimum longitudinal averages is approximately 0.254 mm. The data for the compensated thickness shows a slight increase at Radial Position 4, and does not reveal any wear typical of erosion.

The average radial measurements are plotted at each longitudinal position to determine how the thickness in the pipe varies along the longitudinal position (Figure 3). The average thickness, nominal thickness, and the manufacturing minimum and maximum thicknesses (for straight sections) are also plotted. The average radial measurements along the longitude of the pipe are very similar with a slight drop at PS-2. This difference in thickness is small and likely due to variances from manufacturing.

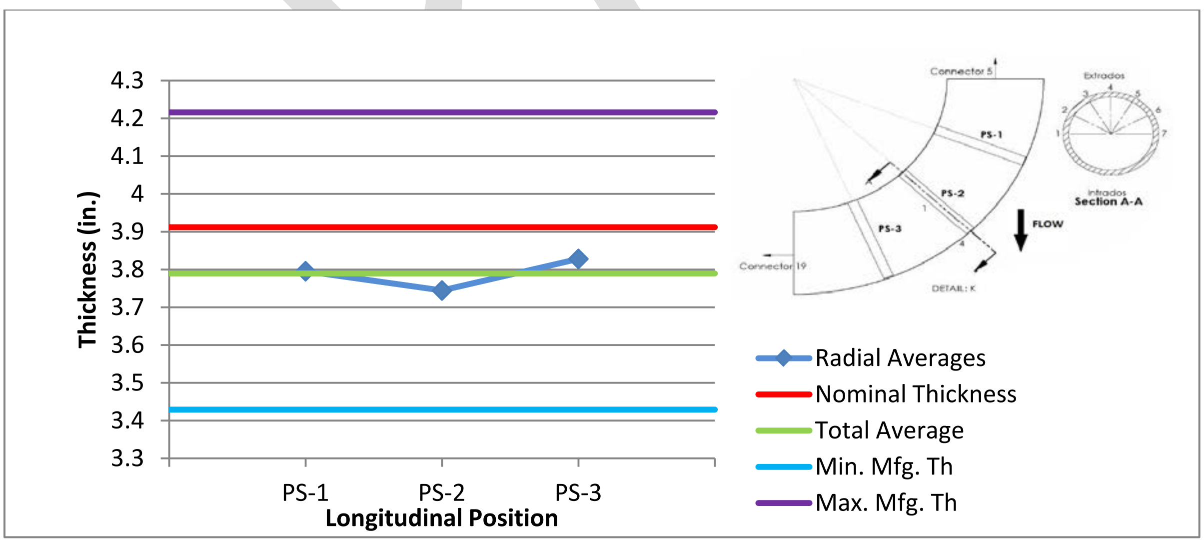

Figure. 3. Jumper pipe radial average measurements grouped by longitudinal position (19-5 Elbow-3).

To determine the allowable erosion rate, the minimum thickness required for the pipeline components to maintain its required design pressure of 2.76 MPa was calculated using ASME B31.3 Section 304.1.2 Eqn 3a. The minimum thickness for a 50.88 mm 5 diameter bend radius elbow was found to be 0.69 mm [5].

Table 4 provides the nominal thickness, the average wall thickness measured in 2013, and the minimum thickness required for the pipeline to continue operating. The corresponding volume of waste transferred for the measurements in 2013 is also provided. With this data, a simple linear relationship was determined for the life expectancy of the pipeline as a function of volume transferred. Based on these estimations, the ERUL for Elbow-3 would be significantly greater than the life required for the estimated volume to be transferred.

Table 4. Thicknesses with Corresponding Flow and Erosion Rate

	Thickness (mm)	Waste (m^3)
Nominal	3.91	0
Average Measured (2013)	3.79	158,230
Minimum for Operation	0.69	4,163,545
Erosion Rate (mm/m^3)	-8.0263E-07	

Thickness measurements and complete analysis of the four sections in Jumper 19-5 have been conducted and are provided in [3]. Table 5 provides a summary of the average thicknesses measured for each section and the nominal and minimum manufacturing thickness. In all cases, the average thickness was greater than the minimum thickness; however, for three of the four sections, the average thickness was less than the nominal thickness. Trends associated with the thickness measurements for the sections were significantly different and not consistent with erosion patterns. Additionally, the differences between the maximum and minimum thickness values were minimal, suggesting that any thicknesses below nominal values are due to variations from manufacturing. Even though the analysis does not indicate erosion occurred, ERULs for three sections (Elbow-3, Straight-3, Straight-4), were determined based on the volume of slurry transferred and a minimum allowable thickness. Table 6 provides the amount of volume required to reach the minimum allowable thickness as well as the erosion rate for each section. Based on these measurements and estimations, Jumper 19-5 ERUL will significantly extend beyond its expected life in terms of flow volume transferred.

Table 5. Thicknesses Summary for Each Section of Jumper 19-5

Section	Average Thickness (mm)	Manufacturer's Nominal Thickness (mm)	Minimum Manufacturing Thickness (mm)
Elbow-3 (5D Bend Radius)	3.79	3.91*	3.43*
Elbow-4 (Long Radius)	4.09	3.91*	3.43*
Straight-3	3.73	3.91	3.43
Straight-4	3.81	3.91	3.43

* Thicknesses based on straight pipe sections

Table 6. ERUL and Erosion Rate for Each Section of Jumper 19-5

Section	Volume Required for Minimum Thickness (m^3)	Erosion Rate (mm/m^3)
Elbow-3	4,178,337	-8.026E-07
Straight-3	2,848,143	-1.125E-06
Straight-4	4,958,511	-6.446E-07

Similar analysis has been conducted for data obtained for the four other jumpers from the evaporator pump room (18-4, C-4&5, J-13A and 13-K). Summaries for the jumpers are provided in the section below.

Summary for the 242-A Evaporator Pump Room Jumpers

Jumper 18-4 has not transferred any waste and can be used as a baseline for comparing C-4&5 and 19-5 which transferred approximately 41,639 and 158,987 m^3 of slurry, respectively. Average thickness measurements for the sections in Jumper 18-4 (one 5D elbow, one long radius elbow and two straight sections) were slightly above the manufacture's nominal thickness (see Table 7). Average thicknesses for the sections evaluated in Jumper C-4&5 (one long radius elbow and two straight sections) were very similar with only Straight-5 having an average thickness of 0.0254 mm below nominal (Table 8 and Table 9). This suggests that no erosion has occurred in Jumper C-4&5. Jumper 19-5 has transferred approximately 4 times the volume that Jumper C-4&5 transferred. Average thickness measurements for Jumper 19-5 were also similar to the nominal thickness; however, three sections (one 5D bend elbow and two straight sections) were slightly below nominal (see Table 5). For these three sections, the ERULs were determined and the required transfer volume well exceeds the volume transfer required for the life of the plant. The 5D bend elbows from 18-4 and 19-5 had similar longitudinal averages with expected thinning at the extrados of the elbow due to the manufacturing process. The long radius jumpers from each of the three jumpers also showed the thinning at the extrados, but slight variations in thicknesses at the top and bottom of the elbows suggest that the variances observed are random and due to manufacturing processes. The straight sections from 18-4 had different trends associated with the average longitudinal measures. Straight-1 thickness averages were consistent around the circumference while Straight-2 had an increase towards the bottom. This demonstrates the potential variance that should be expected in terms of the manufacturing process, since 18-4 has not transferred any waste. Straight-5 and Straight-6 from Jumper C4&5 also had consistent averages around the radius with averages very similar to nominal. The straight sections in Jumper 19-5 showed very different longitude average trends, with Straight-3 slightly increasing as the position rotates clockwise and Straight-4 having an oscillatory trend as the position rotates clockwise. These variances are small and the trends do not suggest that erosion has occurred.

Jumpers J-13A and 13-K transferred approximately 109,777 and 325,545 m^3 of supernatant, respectively. Average thicknesses for the sections evaluated in Jumper J-13A (one long radius elbow and two straight sections) were slightly different with Elbow-8 being below nominal, Straight-9 being just above nominal and Straight-10 being significantly above nominal (see Table 10 and Table 11). The different averages for each section do not demonstrate an erosion trend for this jumper. Average thickness measurements for the sections in Jumper 13-K (one 5D elbow, one long radius elbow and two straight sections) were all above the manufacture's nominal thickness (see Table 12) and in three of the sections, significantly above nominal. Jumper 13-K transferred approximately three times the supernatant that Jumper J-13A transferred, yet did not have any component below the manufacturer's nominal thickness. This suggests that the variations observed are not due to erosion. The long radius elbows in J-13A and 13-K did have similar longitudinal average trends with thinning at the outer extrados; however t J-13A transferred a lower volume of supernatant, yet had the lower thickness average when compared with 13-K. This is not consistent with any type of erosion. The straight sections in 13-A had fairly consistent longitudinal averages around the circumference; however, on section was slightly above nominal and the other was significantly above nominal. Jumper 13-K straight sections were both significantly above nominal, but each section had different longitudinal average trends.

Table 7. Thicknesses Summary for Each Section of Jumper 18-4

Section	Average Thickness (mm)	Manufacturer's Nominal Thickness (mm)	Minimum Manufacturing Thickness (mm)
Elbow-1 (5D Bend Radius)	3.91	3.91*	3.43*
Elbow-2 (Long Radius)	4.37	3.91*	3.43*
Straight-1	3.94	3.91	3.43
Straight-2	3.94	3.91	3.43

* Thicknesses based on straight pipe sections

Table 8. Thicknesses Summary for Each Section of Jumper C-4&5

Section	Average Thickness (mm)	Manufacturer's Nominal Thickness (mm)	Minimum Manufacturing Thickness (mm)
Elbow-5 (Long Radius)	4.09	3.91	3.43*
Straight-5	3.89	3.91	3.43
Straight-6	3.94	3.91	3.43

* Thicknesses based on straight pipe sections

Table 9. ERUL and Erosion Rate for Each Section of Jumper C-4&5

Section	Volume Required for Minimum Thickness (m^3)	Erosion Rate (mm/m^3)
Straight-5	5,294,277	-1.6086E-6

Table 10. Thicknesses Summary for Each Section of Jumper J-13A

Section	Average Thickness (mm)	Manufacturer's Nominal Thickness (mm)	Minimum Manufacturing Thickness (mm)
Elbow-8 (Long Radius)	5.31	5.49*	4.80*
Straight-9	5.54	5.49	4.80
Straight-10	5.79	5.49	4.80

* Thicknesses based on straight pipe sections

Table 11. ERUL and Erosion Rate for Each Section of Jumper J-13A

Section	Volume Required for Minimum Thickness (m^3)	Erosion Rate (mm/m^3)
Elbow-8	2,835,652	-1.6086E-06

Table 12. Thicknesses Summary for Each Section of Jumper 13-K

Section	Average Thickness (mm)	Manufacturer's Nominal Thickness (mm)	Minimum Manufacturing Thickness (mm)
Elbow-6 (5D Bend Radius)	5.51	5.49*	4.80*
Elbow-7 (Long Radius)	5.89	5.49*	4.80*
Straight-7	5.77	5.49	4.80
Straight-8	5.79	5.49	4.80

* Thicknesses based on straight pipe sections

AW-02E FEED PIT JUMPERS

Jumper Descriptions

As part of this study, several jumpers from the AW-02E Feed Pit were removed for disposal and two were selected for ultrasonic thickness (UT) inspection. The jumpers selected were the 1 to 4 and B to 2 which were packaged and sent to the 222-S Laboratory for UT assessments [8]. The jumpers were manufactured with 76.2 mm Schedule 40 ASTM A53 Type S Grade B or ASTM A106 Grade B carbon steel and was coated with Amercoat No. 187 primer followed by Amercoat No. 33 protective coating. Each jumper has a different service life, with different flow types and volumes. Below is a table listing the service information for each jumper.

Table 13. AW-02E Jumper Service Information

Jumper	Flow Type	Volume (m^3)	Service Life
1 - 4	Feed Waste	64,352*	Since 1997
B - 2	Feed Waste	158,987	Since 1983

* 1-4 transferred an unknown amount recirculation waste

Ultrasonic thickness measurements were again taken with an Ultrasonic Transducer (Manufacturer: Olympus, Model: 45m6) and a grid pattern wrapped around the outside diameter (OD) of the jumper at various locations. For Jumper 1-4, measurements were taken at the following locations: Elbow-1 (long radius), Straight-1, Straight-2, Straight-3, Straight-4, Connector-1 and Connector-4. For Jumper B-2, measurements were taken at the following locations Elbow-1 (long radius), Elbow-2 (long radius), Straight-1, Straight-2, Straight-3, Connector-B and Connector-2.

Data and Analysis

Examples of the measurements taken and analysis conducted for each of the jumpers from the AW-02E Feed Pit are provided in this section. Note that measurements and analysis for these jumpers are provided in a report authored by FIU [9]. A 3D CAD drawing of the jumper with Elbow-2 noted is provided in Figure 4. It should be noted that the selection of some components for analysis were a compromise due to limited accessibility and radiological conditions. High radiation dose rates made rapid, easily completed measurements mandatory. Figure 4 also provides the positions at which measurements were taken. The grid was labeled 1 through 9 around the extrados of the pipe and B-2-12, B-2-13 and B-2-14 running horizontally along the length of the elbow. The three locations running horizontally were separated by approximately 22.5° along the radius of the elbow, and the nine measurements along the outer diameter were taken every 30° as shown in Section B-B of the figure. The results of the elbow thickness measurements are shown in Table 14. The cell highlighted in green indicates that the measurements could not be taken due to epoxy paint on the surface.

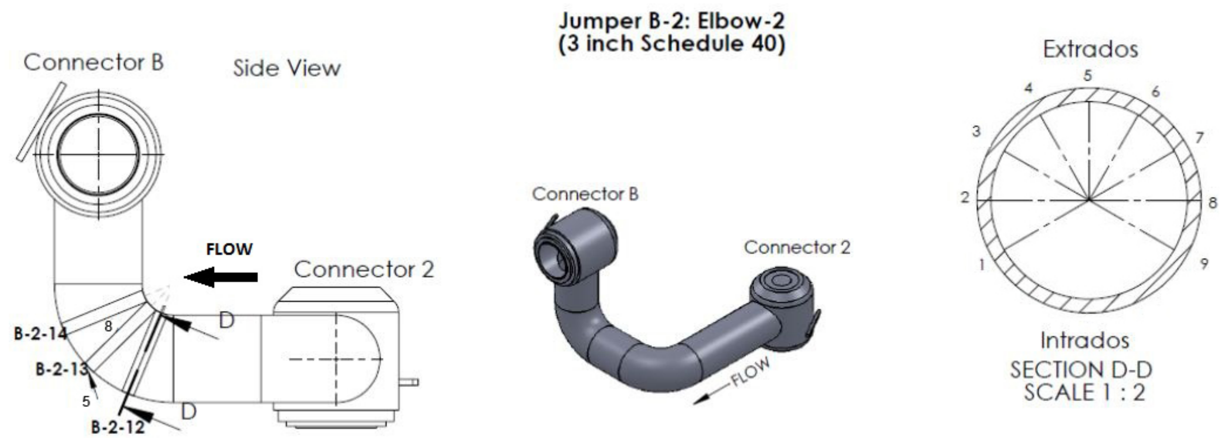

Figure 4. Position of UT Measurements around Elbow-2 of Jumper B-2.

Table 14. UT Measurements for Elbow-2 of Jumper B-2

Location	B-2-12 (mm)	B-2-13 (mm)	B-2-14 (mm)
1		6.81	6.73
2	6.53	6.53	6.55
3	6.65	6.65	6.50
4	6.43	6.12	5.97
5	5.61	5.54	5.74
6	5.87	5.94	5.94
7	5.97	6.02	6.25
8	6.35	6.05	6.25
9	6.40	6.22	6.50

A summary of the wall thickness measurements and calculations for Elbow-2 is shown in Table 15 which includes the average thickness and standard deviations. Nominal, maximum and minimum manufacturing thicknesses are not provided for elbows in current standards so the thicknesses for straight pipe sections are provided for comparison. These manufacturing thicknesses were obtained using information for 76.2 mm Carbon Steel Schedule 40 pipes. Nominal and minimum thicknesses for straight pipe sections were obtained from ASTM A53-1972a Table A3 and A4 [5]. The maximum manufacturing thickness for straight sections, however, was not provided in the tables and was determined following the guidelines from ASTM A53-1972a Paragraph 14.2. This paragraph states that the outside diameter should not vary more than 1% from the standard specified. For 76.2 mm schedule 40 pipe, a manufacturing maximum thickness of 4.80 mm is obtained.

Table 15. Summary of Elbow-2 of Jumper B-2 Thickness Measurements

Overall Average Wall Thickness Measurements	6.248
Overall Standard Deviation	0.356
Average -2 Standard Deviation	5.563
Average +2 Standard Deviation	6.960
Manufacturer Nominal Thickness (straight)	5.486
Minimum Manufacturing Thickness (straight)	4.801
Maximum Manufacturing Thickness (straight)	5.944
Amount of Feed Waste Transferred	158,970 m^3
Note: Nominal thickness based on Carbon Steel, 76.2 mm Diameter, Schedule 40	

Long radius elbows can be manufactured using a number of methods, each providing different changes to the thickness at the intrados and extrados. Recall that 5D bend elbows are typically manufactured using a rotary draw bending technique. With the long radius elbows, a methodology can be developed from information provided in ASME B16.9 and ASME 31.3 to understand the difference in thickness requirements between straight pipe and the extrados of an elbow. This information demonstrates that a 76.2 mm radius elbow can have up to a 14% reduction in thickness at the extrados of the elbow and still have the capacity of the straight pipe.

To determine how the thickness varies along the circumference, the average longitudinal thickness measurements are plotted at each radial location (Fig. 5). The average thickness, nominal thickness (straight section), and the manufacturing minimum and maximum thickness (straight section) are also plotted. Additionally, a compensated thickness is plotted to account for a smaller thickness at the extrados and provide a better understanding of the potential thinning due to erosion. This curve was created by adding 10% of the average thickness of Radial Positions 2 and 8 to the thickness at the extrados (Radial Position 5). Similarly, 6.7% of the average thickness of Positions 2 and 8 was added to Positions 4 and 6 and 3.3% was added at Positions 3 and 7. Radial Positions 2 and 8 are on the top and bottom of the pipe and should not have a change in thickness due to the bending process. Positions 1 and 9 are actually on the intrados of the pipe so values have been subtracted to account for the corresponding thickening.

For this data set, the average thickness measurements decrease from the top to the side of the elbow and then increase toward the bottom. The minimum thickness occurs on the side (Radial Position 5) and the maximum thickness occurs near the top at Radial Position 1. The difference between the maximum and minimum longitudinal averages is approximately 1.14 mm. The data for the compensated thickness has less variation but does show a decreasing trend around the extrados.

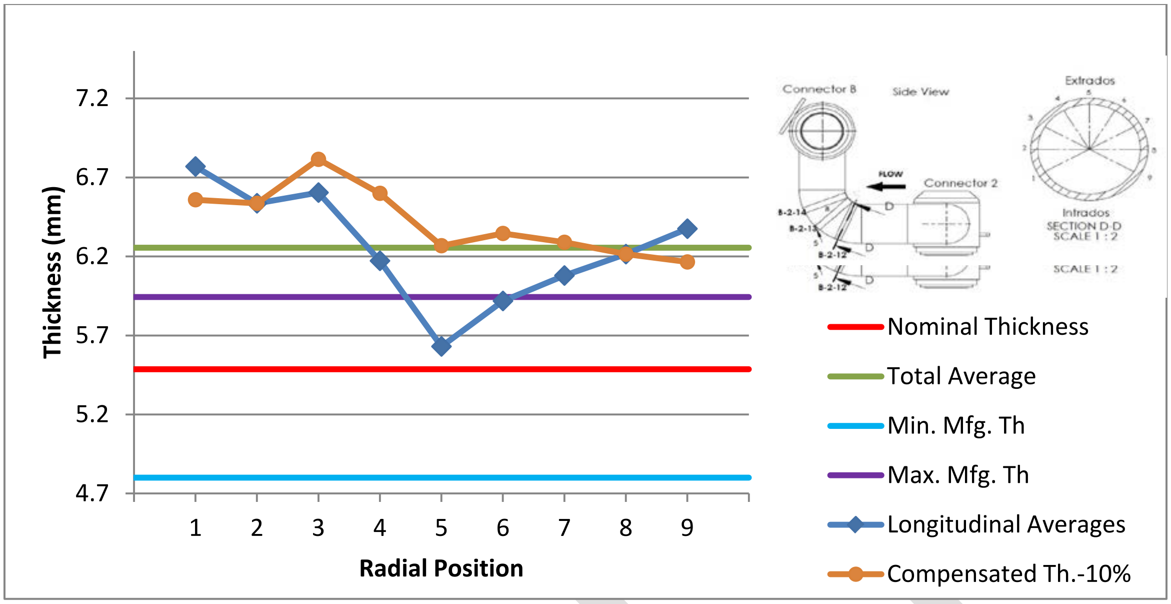

Figure 5. Jumper pipe longitudinal average measurements grouped by radial position (B-2 Elbow-2).

The average radial measurements are plotted at each longitudinal position to determine how the thickness in the pipe varies along the longitudinal position (Fig. 6). The average thickness, nominal thickness, and the manufacturing minimum and maximum thicknesses (for straight sections) are also plotted. The average radial measurements along the longitude of the pipe are very consistent with a slight increase at B-2-14.

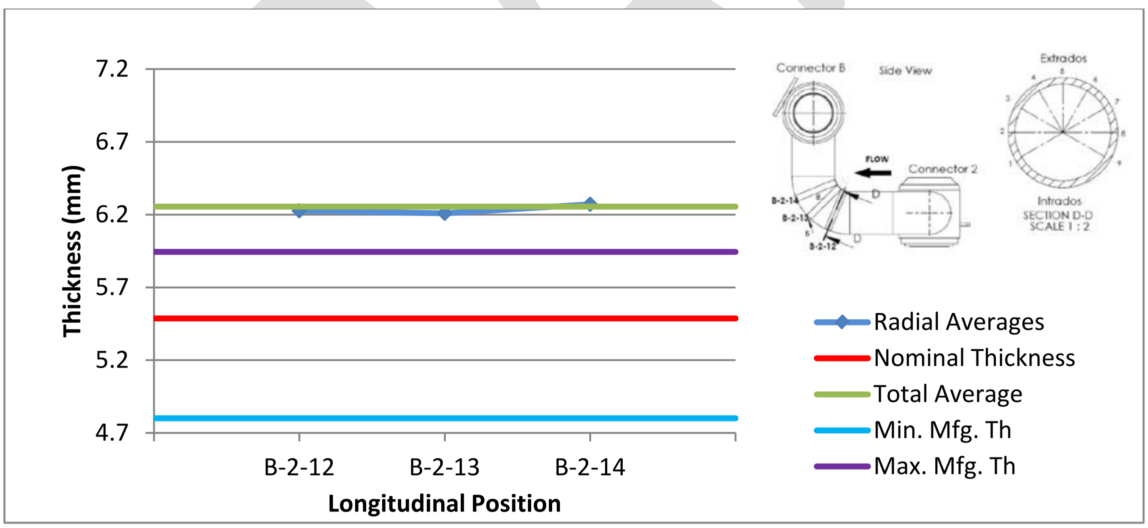

Figure 6. Jumper pipe radial average measurements grouped by longitudinal position (B-2 Elbow-2).

These graphs demonstrate that the average wall thickness is greater than the nominal wall thickness. This suggests that the initial thickness of Elbow-2 was greater than the nominal thickness. Unfortunately, there is no record of the original thickness prior to installation and the only baseline for comparison of these thickness measurements is the nominal thickness of a 76.2 mm Carbon Steel Schedule 40. Thus, there is no detectable wear in this component and a life expectancy analysis based on the manufacturing nominal wall thickness and present wall thickness is not practical.

Thickness measurements and complete analysis of the four sections in Jumper B-2 have been conducted and are provided in [9]. Table 16 provides a summary of the average thicknesses measured for each section and the nominal and minimum manufacturing thickness. In all cases, the average thickness was greater than the minimum thickness. Thickness trends for the straight sections are oscillatory in nature around the circumference and vary minimally along the axis of the pipe. Little variation in thickness is also observed with the connectors, indicating that erosion has not taken place. Thicknesses in the elbows were smallest at the center locations of the extrados which is consistent with thinning due to rotary die bending. Compensation for the thinning showed more consistent data. In general, the differences between the maximum and minimum thickness values were minimal, suggesting that any thicknesses measurements below nominal values are due to variations from manufacturing.

Table 16. Thicknesses Summary for Each Section of Jumper B-2

Section	Average Thickness (mm)	Manufacturer's Nominal Thickness (mm)	Minimum Manufacturing Thickness (mm)
Elbow-1	6.68	5.49*	4.80*
Elbow-2	6.25	5.49*	4.80*
Straight-1	5.92	5.49	4.80
Straight-2	5.99	5.49	4.80
Straight-3	5.87	5.49	4.80
Connector-B	25.10	24.64	23.88
Connector-2	25.25	24.64	23.88

* Thicknesses based on straight pipe sections

Summary for the AW-02E Feed Pit Jumpers

Jumper 1-4 was the other feed pit jumper that had measurements taken and analyzed which included seven sections of the jumper. The sections analyzed were Elbow-1, Straight-1, Straight-2, Straight-3, Straight-4, Connector-1 and Connector-4. Table 17 provides a summary of the average thicknesses measured for each section and the nominal and minimum manufacturing thickness. In all cases, the average thickness was greater than the minimum thickness. Thickness trends for the straight sections are oscillatory in nature around the circumference and do not vary significantly along the axis of the pipe. Little variation in thickness is also observed with the connectors, indicating that erosion has not taken place. In general, the differences between the maximum and minimum thickness values were minimal, suggesting that any thicknesses measurements below nominal values are due to variations from manufacturing.

Table 17. Thicknesses Summary for Each Section of Jumper 1-4

Section	Average Thickness (mm)	Manufacturer's Nominal Thickness (mm)	Minimum Manufacturing Thickness (mm)
Elbow-1	6.20	5.49	4.80
Straight-1	6.35	5.49	4.80
Straight-2	5.87	5.49	4.80
Straight-3	5.94	5.49	4.80
Straight-4	5.89	5.49	4.80
Connector-1	25.25	24.64	23.88
Connector-4	25.25	24.64	23.88

* Thicknesses based on straight pipe sections

Jumper 1-4 transferred at least 64,345 m^3 of feed waste in addition to an unknown amount of recirculation waste. This uncertainty makes it difficult to assess erosion trends between the two jumpers. Regardless, average thickness measurements for the sections analyzed for both the 1-4 and B-2 jumpers were above the manufacturer's nominal values. Similar trends were observed the straight sections in both jumpers. Longitudinal averages around the circumference of the pipe had thickness trends that were oscillatory but radial averages along the length of the pipe were fairly consistent. Of the three types of components analyzed, the connectors had the least amount of thickness variation. This was also true for both jumpers. The elbows did not show any consistent thickness trends for the two jumpers in terms of longitudinal averages. The radial averages for each of the elbows were all consistent along the length of the pipe.

CONCLUSIONS

As part of a fitness-for-service program implemented by WRPS, a number of sections of jumpers removed from the AW-02E Feed pump pit and the 242-A Evaporator pump room have been evaluated for potential erosion/corrosion. Thickness measurements were taken at various locations along elbows, straight sections, and connectors. The data was analyzed and plotted along the longitudinal and radial measurement locations. Analysis methods to evaluate elbows that may have thinned at the extrados during manufacturing are described to provide a means to differentiate thinning due to manufacturing and erosion.

Results from the analysis of the 242-A Evaporator pump room show that only a few sections of the five jumpers analyzed have average thicknesses below the nominal thickness. For those that were below, ERUL values were estimated. The ERUL values for all component sections indicate that the jumpers would far exceed the service life needed for the Tank Farm and WTP. Similar results were found for the jumpers in the AW-02E Feed pump pit except that all average thickness measurements were above the manufacturer's nominal thicknesses. Thus, it was not practical to estimate the ERUL.

The extrapolation of the wear does assume that the jumpers continue to use transfers of waste having the same waste properties. However, the tank farms contain $2.1x10^5$ of waste with a wide range of physical and chemical properties generated from numerous historical chemical processes. Jumpers, including those in the 242-A Evaporator, 241-AW-02E Evaporator Feed Pump Pit, and the 241-SY tank farm lines that have been non-destructively and destructively evaluated have waste volume throughputs ranging up to 6.1 $x10^5$ mgal. In the aggregate they have been exposed to all of the chemical components and rheology existing in the waste inventory. To date, none of the piping has experienced any serious erosion/corrosion; in most cases none has been detected.

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