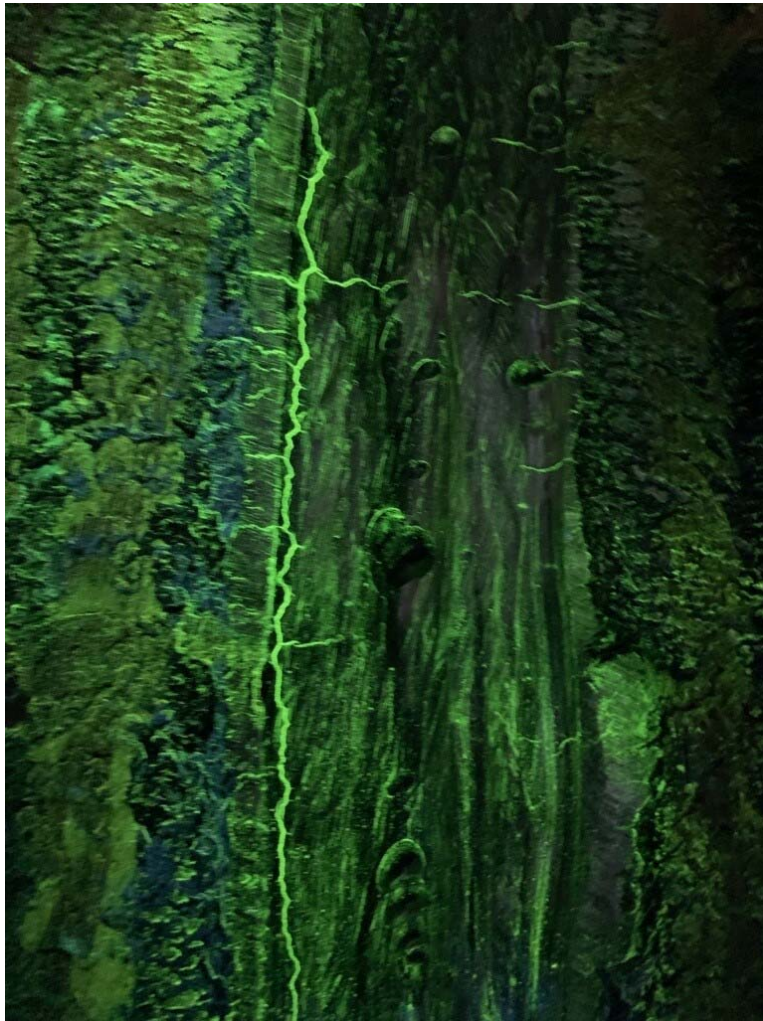


Continuous Digester Process Safety Improvements

Chad Harrod – Georgia-Pacific, Process
Engineering Leader

Jon Freeman – Millennium Metallurgy Ltd.,
Vice President

Mick Brayman – Miller Mechanical
Services Inc., Field Operations Manager



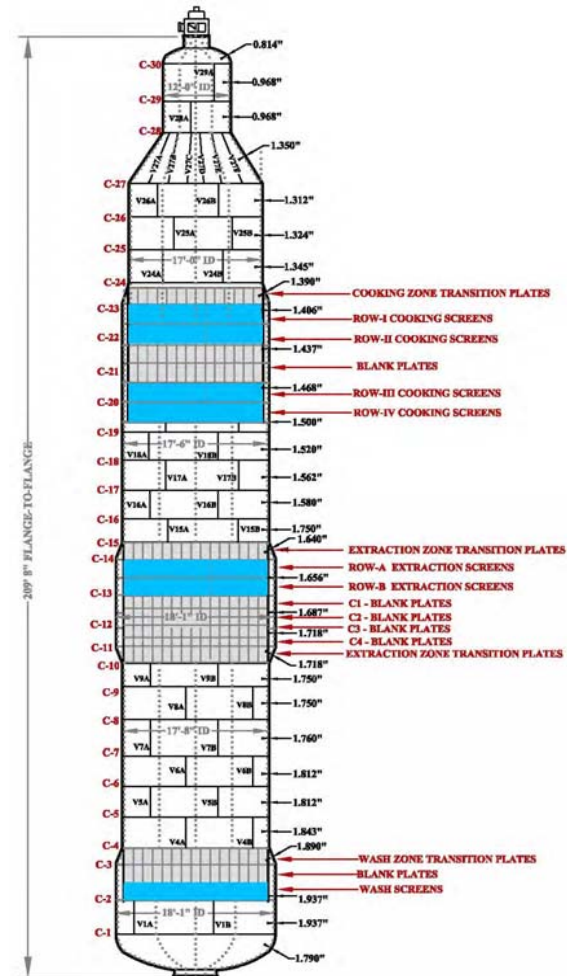
Continuous Digester Stress Corrosion Cracking (SCC) Case Studies

- Two Continuous Digester case studies with SCC
 - Both single vessel hydraulic vessels
 - Digester “A” built in 1966
 - Digester “B” built in 1964
 - Both located in SE USA
 - Fiber and cooking method
 - Digester “A”: 100% Softwood, Downflow cooking
 - Digester “B”: 100% Softwood, Downflow cooking



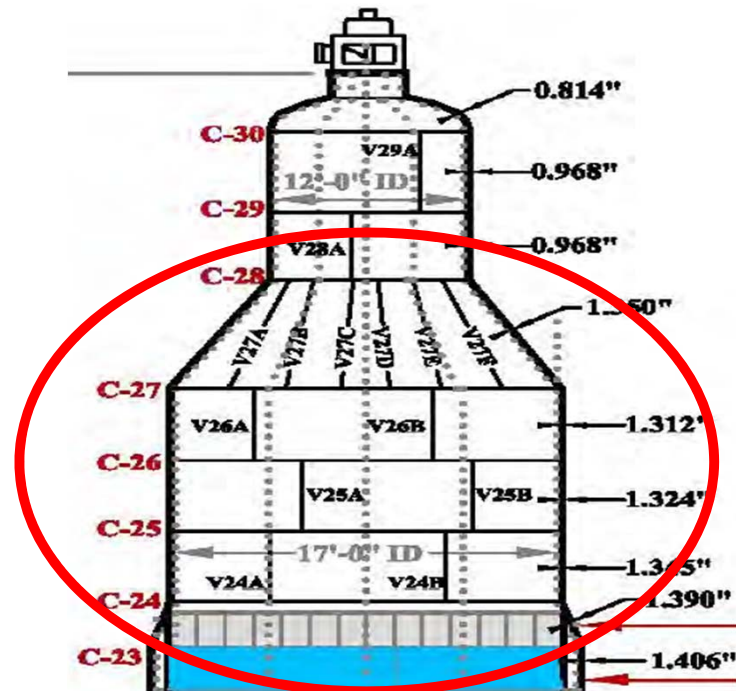
Digester “A” SCC case study information

- 1966 Kamyr single vessel hydraulic continuous digester
- MAWP: 165 psi @ 350F, original corrosion allowance 0.250"
- Overall dimensions: roughly 17' diameter X 209'-8" high (with top neck down to 12' dia., step outs at screens)
- 30 circumferential weld seams – noted as “C1-C30” with higher elevation
- 2 to 6 vertical seams per course, labeled with prefix “V” and suffix “A-F” based on position clockwise from lower manway.



Digester “A” SCC case study information

- Materials of construction
 - SA212 Gr B FBX with PWHT to C19
 - SA516 Gr 70 FBX above C19, no PWHT
 - SA264 304L cladding on top and bottom heads
- No other shell weld overlay or corrosion protection (no anodic protection)
- Previous inspections found SCC cracking in the impregnation zone circumferential welds (C24 thru C28)
- Major weld restoration executed in 2021 with transverse weld boat samples sent for analysis
- Leak detected during 2021 post outage hydro on top dome – undetected atmospheric corrosion forced unplanned flush plate repair (separate presentation)



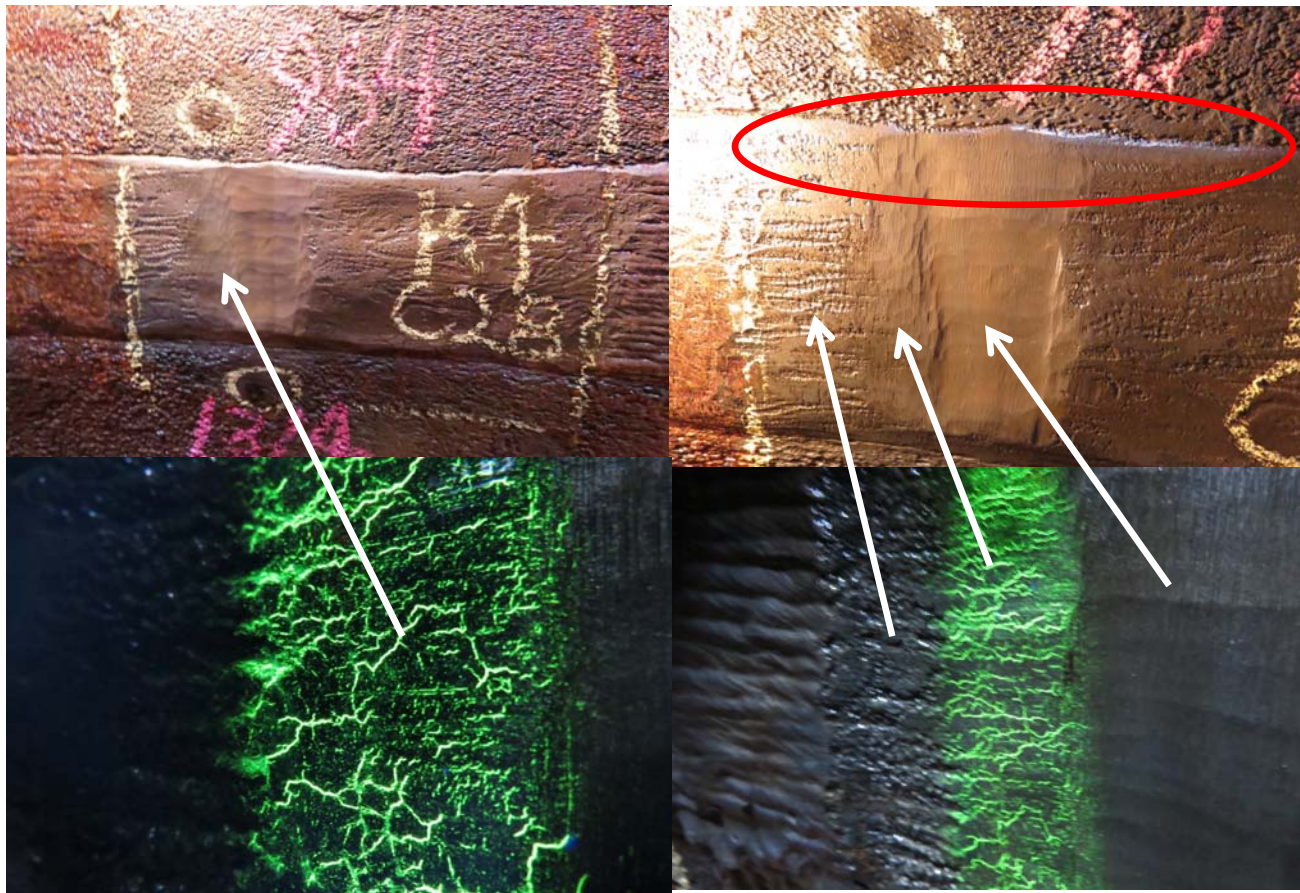
Digester “A” SCC Case Study Repair history

Weld seam	Previous restoration year	Preheat
C28	1989	550F
V28	1999	550F
C27	1997	550F
V27A-F	1992-2000	550F
C26	1994	550F
V26A-B	1992	550F
C25	1991	550F
V25A-B	1992	550F
C24	Not noted	N/A
V24A-B	1993	550F

Note: New Cooking and Extraction screens installed in 2011.



Digester “A” case study – C28 previous inspection technique



2019 – “C28 Showing #4 monitor point with shallow new emerging issues in 24 months. Not removed.”

Four (4) spot inspection points
~ 5% of weld circumference.
Vertical welds were not inspected.

Note – weld toe not ground to base metal for inspection.



Digester “A” case study – C27 previous inspection technique

2019 C27/V27 inspection – typical wire brush weld NDE inspection preparation

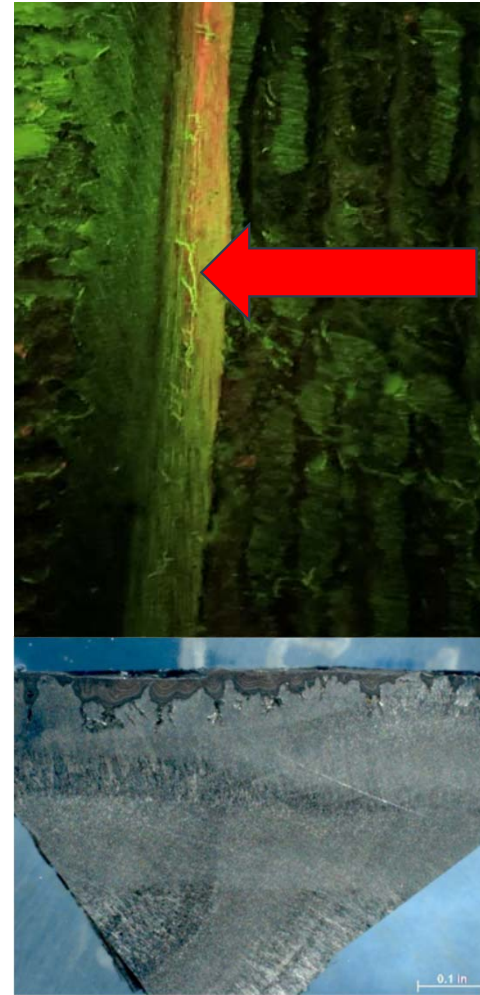


2021 weld boat sample analysis showing weld and base metal not completely cleaned



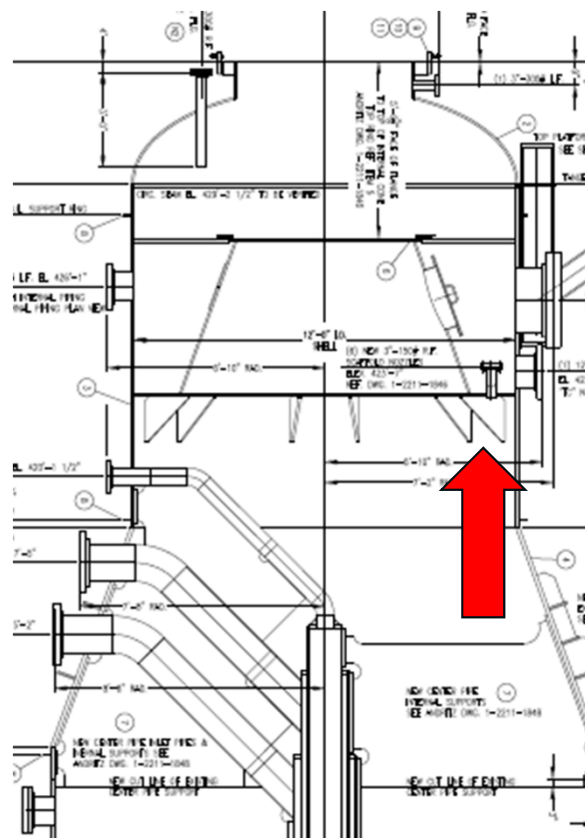
Digester “A” SCC Case Study – new inspection technique

- Previous inspection method is flawed since weld toe was not completely cleaned prior to testing
 - Failure of Wet Fluorescent Magnetic Particles (WFMT) to reveal cracks on the test surface
 - Likely not detectable by WFMT with crack initiation behind “finger-nailing” of weld toe
- Inspection technique change – grind weld toes to shiny base metal
 - Welds now show SCC
 - Wire-brush cleaning was inadequate surface preparation

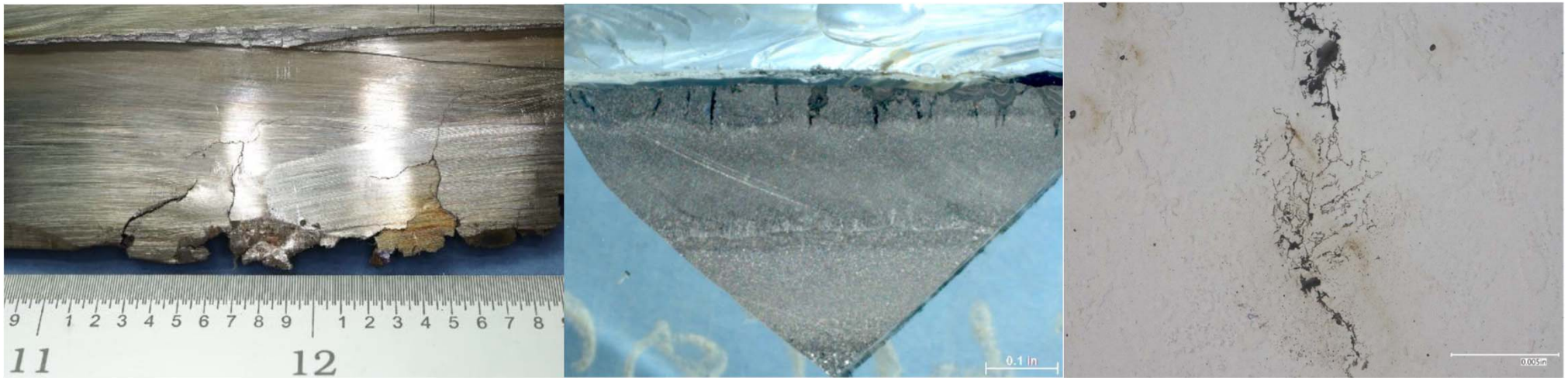


Digester “A” SCC Case Study – new inspection technique

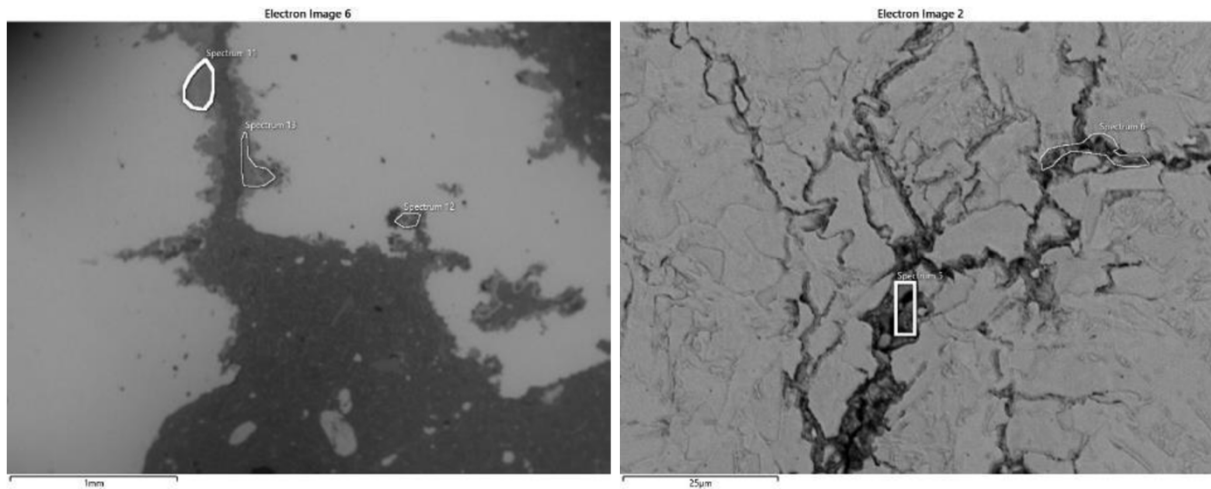
- SCC was not just found on vertical and circumferential seam welds
- Inner cone bottom ring stitch and gusset welds (13 total gussets, located above C28) had SCC detected - removal and repairs took longer than planned
 - Stitch weld SCC propagated behind the ring into the shell
 - Plan 309L weld overlay in these areas
 - **Difficult area to access** for inspection (not accessible from sky-climber scaffolding)



Digester “A” Case Study – Weld Boat Sample Analysis photos



Digester “A” SCC Case Study – Boat Sample Semi Quantitative Analysis (weight %) – four (4) SEM samples



- “Cracking propagated out of the bottom of the pits and was consistent with caustic stress corrosion cracking (SCC).”
 - “Deposits within cracks had sodium and sulfur ...Significant amounts of sulfur were noted.”
- “...it is also notable that no chloride were noted.”

Element	C	O	Na	Al	Si	S	Ca	Mn	Fe	Zn	P
Avg	11.4	13.9	0.7	0.6	1.8	7.3	1.5	1.0	61.6	0.3	0.0
Min	4.4	8.3	0.0	0.0	0.4	0.4	0.0	0.8	45.7	0.0	0.0
Max	21.0	20.7	1.4	1.8	4.7	16.7	4.6	1.3	82.3	1.0	0.1
Std Dev	6.8	5.6	0.5	0.7	1.7	6.4	1.9	0.2	14.2	0.4	0.0



Digester “A” SCC case study – weld boat sample analysis

- **Hardness values** in many of the welds **were elevated** above the base metal hardness...
 - “Elevated hardness values are indicative of stress risers, which are areas prone to crack initiation.”
- Long term effectiveness of NBIC Alternate Welding Method 1 without Post Weld Heat Treatment repair?
- Quality control concerns:
 - Likely inadequate QAQC plan to confirm preheat
 - Preheat applied from the inside in 1990’s.
 - Put yourself in the welder’s shoes: what would be the quality of your work be in an oven (inside 300-550F vessel) for 12 consecutive 12-hour shifts?

Indent #	C27 Lower	C27 Upper	C27 Reject	C28 Lower	C28 Upper	V28A	V28B	V28C
1	214.27	190.44	205.36	182.38	218.56	224.68	218.89	175.13
2	189.47	182.80	217.37	195.87	209.49	208.57	206.95	175.52
3	215.23	184.90	214.27	203.00	221.54	202.51	206.65	183.04
4	209.28	192.32	167.78	180.89	233.57	204.86	176.15	193.77
5	201.73	170.83	210.41	200.67	233.21	215.55	179.99	178.86
6	192.86	198.58	212.07	193.04	227.20	173.73	201.73	172.27
7	196.06	197.08	201.73	200.96	201.35	215.22	215.33	202.31
8	182.38	175.21	203.29	187.55	222.88	220.43	182.38	201.45
9	191.33	179.02	202.22	201.64	231.54	220.10	190.00	186.01
10	189.03	183.88	222.43	184.31	229.64	213.01	197.36	175.13
11	199.34	205.66	214.06	196.43	192.86	234.17	178.86	165.11
12	177.89	181.72	190.98	178.54	200.10	222.99	193.68	188.77
13	203.87	189.74	211.13	206.55	249.90	213.53	197.64	192.32
14	195.51	200.01	220.64	187.64	232.97	222.76	230.47	170.46
15	200.77	185.49	213.74	218.02	230.59	231.30	211.34	172.20
B1	190.8	188.51	213.21	190.71	185.41	190.71	179.34	197.83
B2	173.58	186.78	218.79	184.05	175.99	187.99	179.67	173.88
B3	176.07	177.90	242.86	193.04	165.39	201.25	172.58	170.98
B4	192.68	171.36	236.49	196.06	186.43	200.20	171.66	168.82
B5	182.80	188.16	234.05	185.92	166.69	209.39	176.55	174.04
Max	96	95	20 HRC	97	21 HRC	99	98	94
Min	86	85	85	87	84	86	86	84
Range	10	10	~15	10	~17	13	12	10

Figure 42. Microhardness measurements were taken in the Vickers (HV) scale in the weld around the cracking (indents 1-15) and in the base metal (B1-B5). Values above 206 HV are highlighted in red. Maximum, minimum, and hardness range are shown in the Rockwell B (HRB) scale unless noted as HRC. Orange values indicate a range above 10 points HRB.



Digester “A” SCC case study – projected vs actual SCC depth

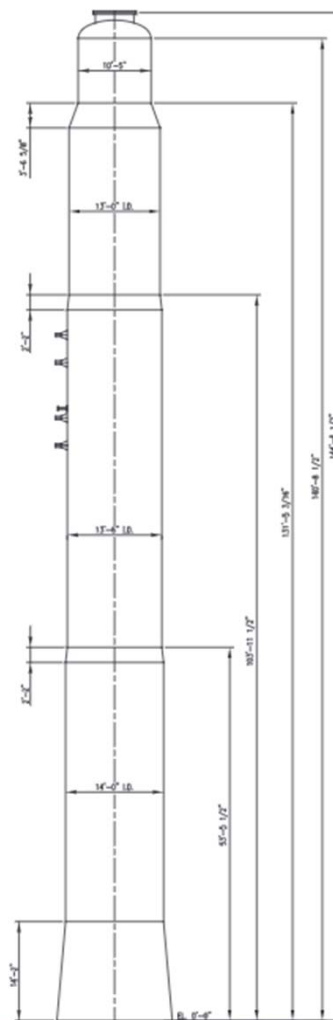
Weld seam	ASME tmin	Projected remaining thickness	Actual remaining thickness (avg)	Actual remaining thickness (min)	Actual remaining thickness Std Dev	Number of readings
V28	0.718	0.804	0.595	0.143	0.133	12
C28	0.718	0.804	0.660	0.434	0.124	38
V27	1.100	1.059	0.966	0.799	0.117	64
C27	1.100	1.059	0.948	0.681	0.124	54
V26	1.062	1.056	0.832	0.667	0.119	12
C26	1.062	1.056	0.887	0.229	0.231	19

Note: All welds shown above had 100% SCC removed and full weld restoration. Remaining thickness variation was up to **6X** the predicted propagation rate.



Digester “B” CSCC case study information

- 1964 Kamyr single vessel hydraulic continuous digester
- MAWP: 165 psi @ 350F, original corrosion allowance 0.250”
- Overall dimensions: roughly 14’ diameter X 144’-5” high (with top neck down to 13’ dia., step outs at screens)
- 17 circumferential weld seams – noted as “C1-C17” with higher elevation
- Materials of construction
 - SA285 Gr C FBX with PWHT to C7
 - SA264 304L cladding on top and bottom heads
- 2 to 4 vertical seams per course, labeled with prefix “V” and suffix “A-D” based on position clockwise from lower manway.
- An anodic protection system installed in the 1980’s (no record of exact year when it was installed), and it was rebuilt in 1996. After several years of issues, it was removed and replaced in 2021.
- C14 had thermal spray coating added in 2004 and C17 (penthouse) has Inconel weld overlay.
- Previous inspections found SCC cracking in the impregnation zone circumferential and vertical welds
- Major weld restoration and corrosion resistant weld overlay completed in 2023



Digester “B” SCC Case Study Repair history

Weld seam	Previous restoration year	Preheat
C17	2010 (insert plate) 2004 metal spray	No data
C16 V16 A	2002 (spot ground) ? – contour ground	No data
C15 V15 A-D	2002 2002 – 2 of 4 contour ground	No data
C14 V14 A	2004 (and thermal spray) 2002 contour ground	No data
C13 V13 A	1998 (spot ground 2002) 2002 contour ground	No data
C12 V12A	1998 (spot ground 2002) 1993 (contour ground 2002)	No data

Note: Center-pipe and Anodic Protection replaced in 2021 (originally installed in 1980's)



Digester “B” SCC case study – inspection and SCC removal

- 100% Inspection found SCC on C12, V12, and C13
 - TAPPI recommendation is spot inspection
- SCC was completely removed from these welds
- Anodic protection system is working well and mitigates SCC and generalized thinning
- Do not have history of generalized thinning, expected corrosion rate is $<0.005''$ per year



Digester “B” SCC case study – projected vs actual SCC depth

Weld seam	ASME tmin	Projected remaining thickness	Actual remaining thickness (avg)	Actual remaining thickness (min)	Actual remaining thickness Std Dev
V13	1.037	N/I	N/R	1.037	N/A
C13	1.021	1.115	0.975	0.850	0.082
V12	1.041	N/I	1.171	1.017	0.050
C12	1.041	1.144	0.942	0.846	0.085

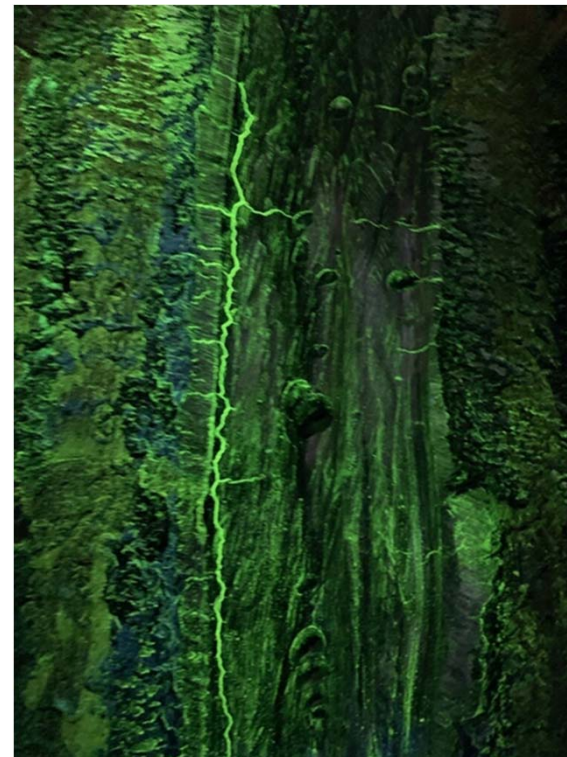


Fitness for Service evaluation was conducted, and NBIC code repairs were completed during June 2023 outage



GP Continuous Digester changes since 2020

- New Continuous Digester Inspection Protocol requiring qualified 3rd party Corrosion SME for inspection.
- Inspection technique change from wire brushing and cross notch to grinding to shiny metal, especially at weld toes.
- 100% Phased-Array Ultrasonic Testing (PAUT) required on all circumferential and vertical weld seams prior to application of corrosion resistant overlay (AWS D1.1 acceptance criteria)
- Strategy change to align with industry SME's:
Eliminate SCC vs monitor and repair
 - SCC depth is not predictable – spot testing results and methods inadequate
 - Elimination methods:
 - Full corrosion resistant weld overlay
 - Replace shell with Duplex SS or SS clad carbon steel



Overpressure protection case studies

- Second focus area of GP cross functional team review
- Several digesters updated to the latest OEM overpressure protection design guidance (2012 safety alert)
- Inconsistent instrument purge water and freeze protection – experience with plugged nozzles
- Experienced overpressure scenario that exceeded ASME limits during functional test



GP Overpressure protection changes

- Functional test procedures completed for each digester (meeting internal GP standards)
- Functional testing required every major scheduled maintenance outage
- Pressure transmitters are deemed “Critical Instruments” and subject to maintenance per internal standards
- Active participation in TAPPI Digester Safety work group to improve overpressure protection guidance



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Recommendations

- TAPPI needs to review TIP 0402-27 and update the inspection technique with more specific surface preparation guidance.
- TAPPI should develop a weld quality control TIP that owners could utilize when performing continuous digester weld restoration. TAPPI should publish considerations of the effectiveness of repeat repairs compared to replacement (i.e., end of life).
- TAPPI should sponsor additional research on key process drivers that determine Continuous Digester SCC propagation rates and mitigation strategies to prevent accelerated SCC.



Recommendations (continued)

- TAPPI should develop a TIP on continuous digester overpressure protection design, operation, and maintenance.
- TAPPI should develop a TIP with chemical cleaning guidance for continuous digesters.
- TAPPI should define and categorize continuous digester safety incidents and develop a safety incident self-reporting and knowledge sharing forum.

