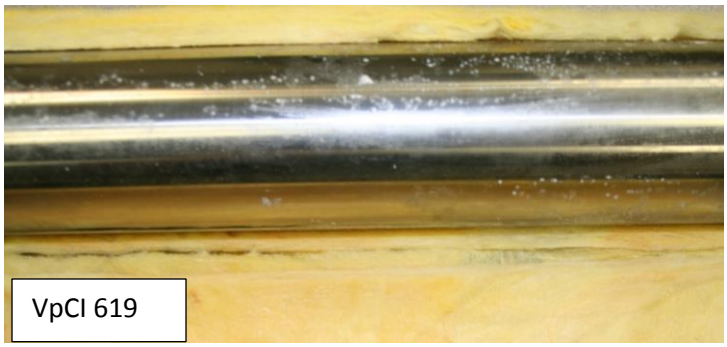


Protection Effectiveness of Vapor Corrosion Inhibitor VpCI 619 for Corrosion Under Insulation at Elevated Temperatures

For:

CORTEC Corporation

by

Behzad Bavarian,
California State University, Northridge, USA 91330

February 2018

California State University Northridge

CORTEC CORPORATION
Enviromentally Safe VpCI®/MCI® Technologies

Explosions, fires, plant shutdowns, injuries and destruction, the majority of these failures are corrosion related. More specifically, for refining, petrochemical, marine environments and power plants, industries with vast amounts of piping, the cause of production delay is due to corrosion damage under insulation that make it very hard to inspect and detect damages prior to failures. For corrosion under insulation, there are further complications from having to inspect the structures to ascertain the existence and extent of corrosion. Maintenance and plant inspection become labor and time intensive when large quantities of insulation have to be removed. Despite advances in materials and inspection technologies, CUI remains a serious and costly industry problem. In this investigation four API 5L X65 steel pipes were insulated with thermal insulator (fiberglass system) to determine the effective protection of a new vapor phase corrosion inhibitor (VpCI 619) against CUI. Corrosion behaviors were monitored under isothermal and cyclic wet/dry test conditions at 77 ^{o}C and 170 ^{o}C. Test results have demonstrated that VpCI 619 can successfully reduce corrosion attack under insulation even in a chronic wet environment. When VpCI 619 was added into 200 ppm salt solution and tested at boiling temperature, the corrosion rate was reduced by a factor of 15. The chemical analysis on the samples post corrosion tests revealed formation of a protective Mo-rich inhibition compound on these pipe surfaces. These results showed that an effective protective coating system under the insulation is critical and requires the inclusion of VpCI 619 to prolong the pipe integrity and lower inspection and maintenance cost.

Procedure

In this investigation, the effectiveness of recently developed VpCI 619 vapor phase corrosion inhibitors against CUI was determined. API 5L X65 mild steel piping (40 cm length x 5 cm diameter) was insulated with (1.0 cm) thermal insulation and sealed with aluminum sheet. All pipes were sand blasted, machined and polished to 600 grit using silica carbide (SiC) abrasive papers and rinsed with alcohol prior to use.

Three samples were assembled, one samples were used as controls (no inhibitor applied), and two samples were wrapped with thermal insulation that was impregnated with VpCI-619 inhibitor. The effectiveness of this inhibitor at minimizing CUI damages was evaluated by different temperature (77 ^{o}C and 170 ^{o}C) and corrosion conditions. Two samples (one with inhibitor, 1 without) were placed in in a cyclic corrosion test chamber for 240 hours. A 200 ppm sodium chloride solution (20 mL) was injected by tube into the pipe/insulation interfaces every 48 hours. The samples were also disassembled every 120 hours (5 days) for visual inspection and evaluation. Fig. 2-4 show corrosion initiation on non-protected pipes. Fig. 5 shows well developed localized corrosion attacks on non-protected pipe after 240 hours, while the VpCI619 coated pipe demonstrated well protected surfaces and no sign of any corrosion. Fig. 16 shows the performance of the coated pipe with VpCI 619 at 170 ^{o}C, some discoloration was observed but chemical analysis on surface deposits showed no sign of any corrosion but formation of the protective Mo-compound(source is the chemistry of the inhibitor). The inhibitor treated pipes were relatively clean and corrosion free. SEM/EDS analysis showed formation of a Molybdenum rich protective film on the tested pipe

surfaces and no sign of any iron oxide formation was detected The results verified that VCI managed to form a clear, dry, hydrophobic film on the pipe and protected the pipe surface. Fig. 17-20 verified these observation, no sign of any corrosion was detected.

Corrosion behavior of API 5L X65 mild steel pipe material samples in total immersion in boiling water when exposed to the VpCI619 and without inhibitor (control sample) using similar apparatus recommended in ASTM G123 (Erlenmeyer flask and condenser, hot plate to maintain solution at its boiling point, Fig. 6). These tests were conducted in control solution (200 ppm Cl- solution, no inhibitor), 1.0% and 5.0% VCI addition. Test duration was 240 hours. Fig. 6-8 show that VpCI 619 is very effective and protected these pipe samples against any corrosion attacks.

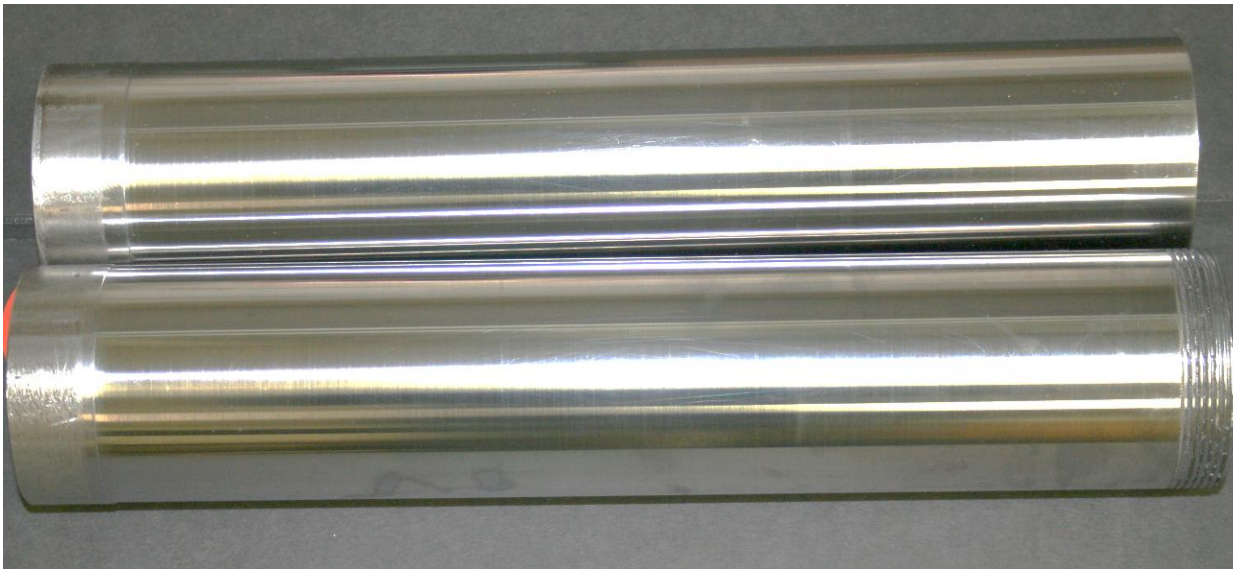
Summary

The effectiveness of vapor phase corrosion inhibitor VpCI619 against CUI was investigated using corrosion testing and corrosion rate measurements in isothermal condition at 77 and 170 ^{o}C. API 5L X65 steel pipes were insulated with thermal insulation and placed in laboratory simulated CUI environment to monitor the corrosion behaviors. Results have demonstrated that VpCI 619 can successfully reduce corrosion attack under insulation despite the pipe surfaces being maintained in continuously wet/dry cyclic conditions.

The corrosion rate measurement in boiling temperature showed corrosion rate reduced from ~5.3 mpy for the control samples to less than 0.36 mpy for the VCI treated pipes, a change of corrosion rate by a factor of 15 for the pipes protected with corrosion inhibitor.

SEM/EDS analysis showed formation of a Molybdenum rich protective film on the tested pipe surfaces and no sign of any iron oxide formation was detected.

These results showed that an effective protective coating system under the insulation is critical and application of VpCI 619 demonstrated to prolong the pipe integrity and lower inspection and maintenance cost at elevated temperature.



2” pipe samples surface condition prior to CUI tests

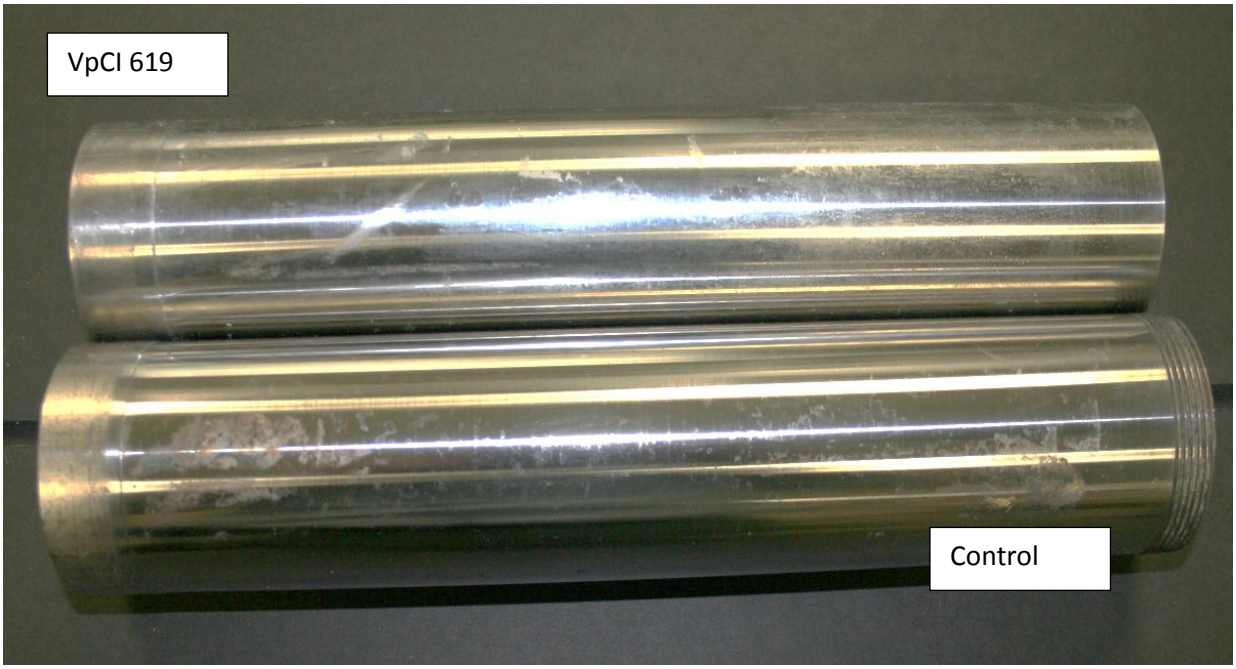


Fig. 1: Surface condition of the 2” pipe subjected to CUI tests after 120 hrs at 80 C and 50 ml 200 ppm Cl- containing solution injected into pipe/insulation. Control sample showed localized corrosion and red rust formation.

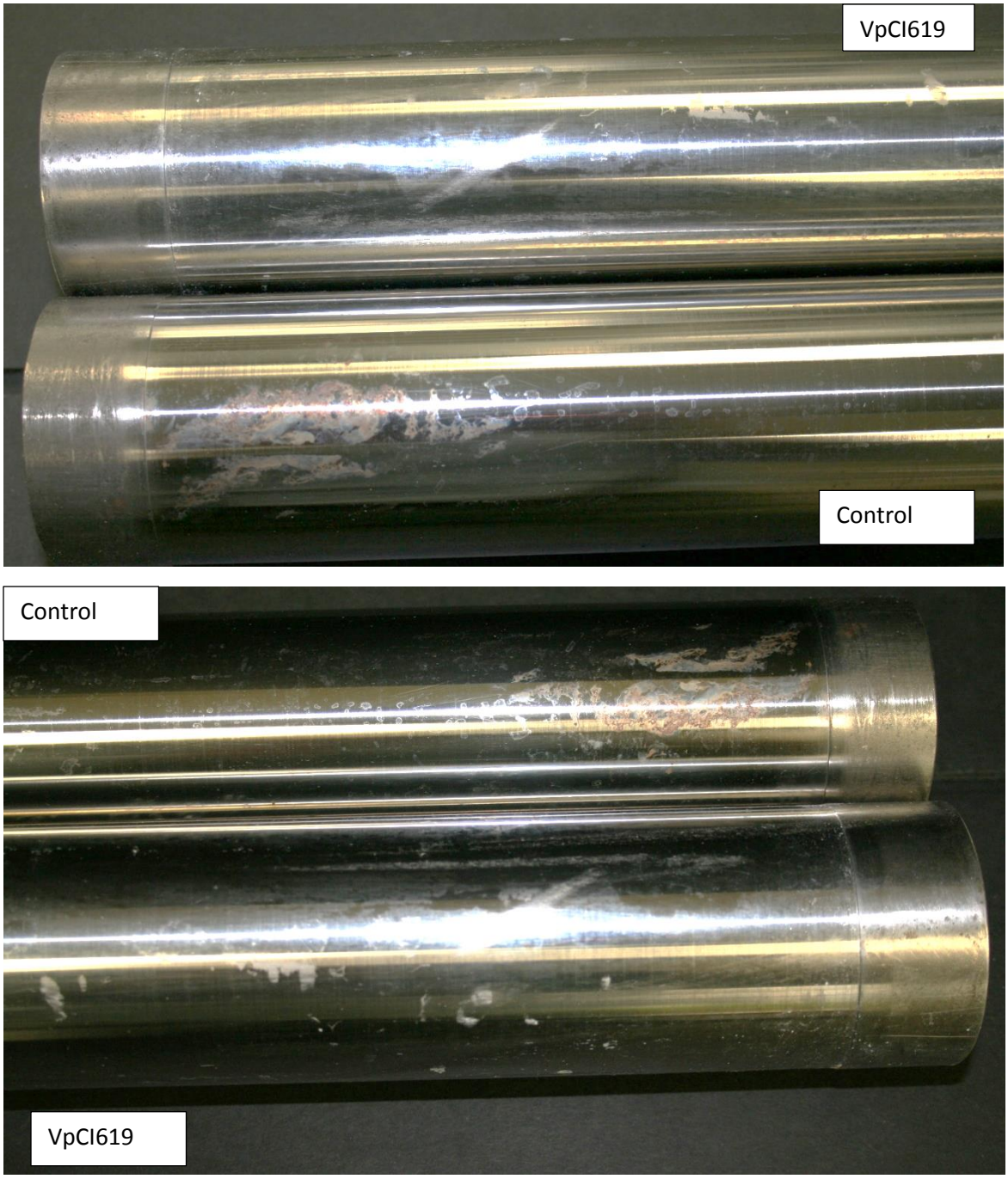


Fig. 2: Surface condition of the 2” pipe subjected to CUI tests after 120 hrs at 80 C and 50 ml 200 ppm Cl- containing solution injected into pipe/insulation. Control sample showed localized corrosion and red rust formation.

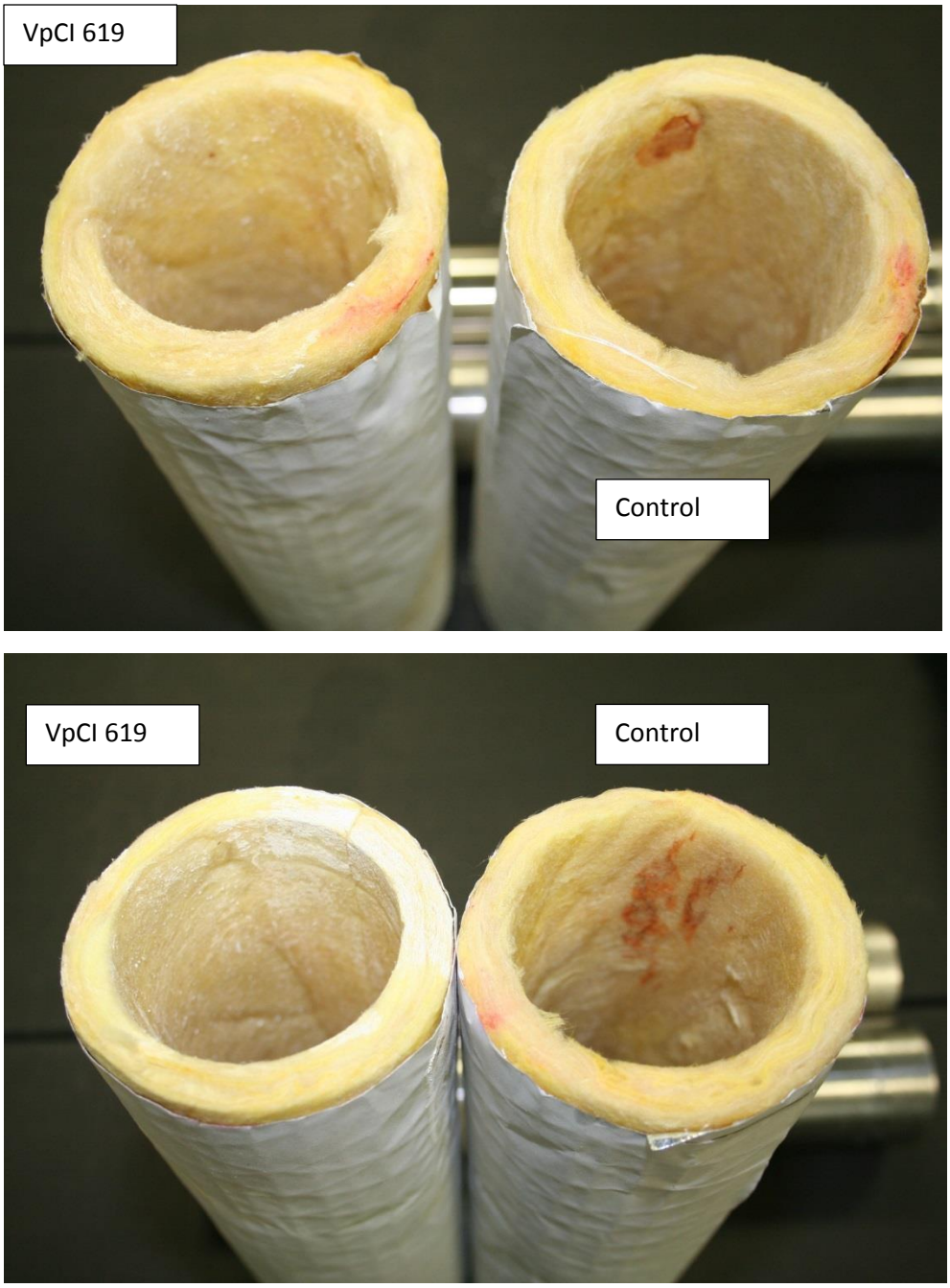


Fig. 3: Surface condition of the pipe insulation subjected to CUI tests after 120 hrs at 80 C, Control sample showed localized corrosion and red rust formation. No sign of any corrosion attack was observed on VpCI 619 treated sample.

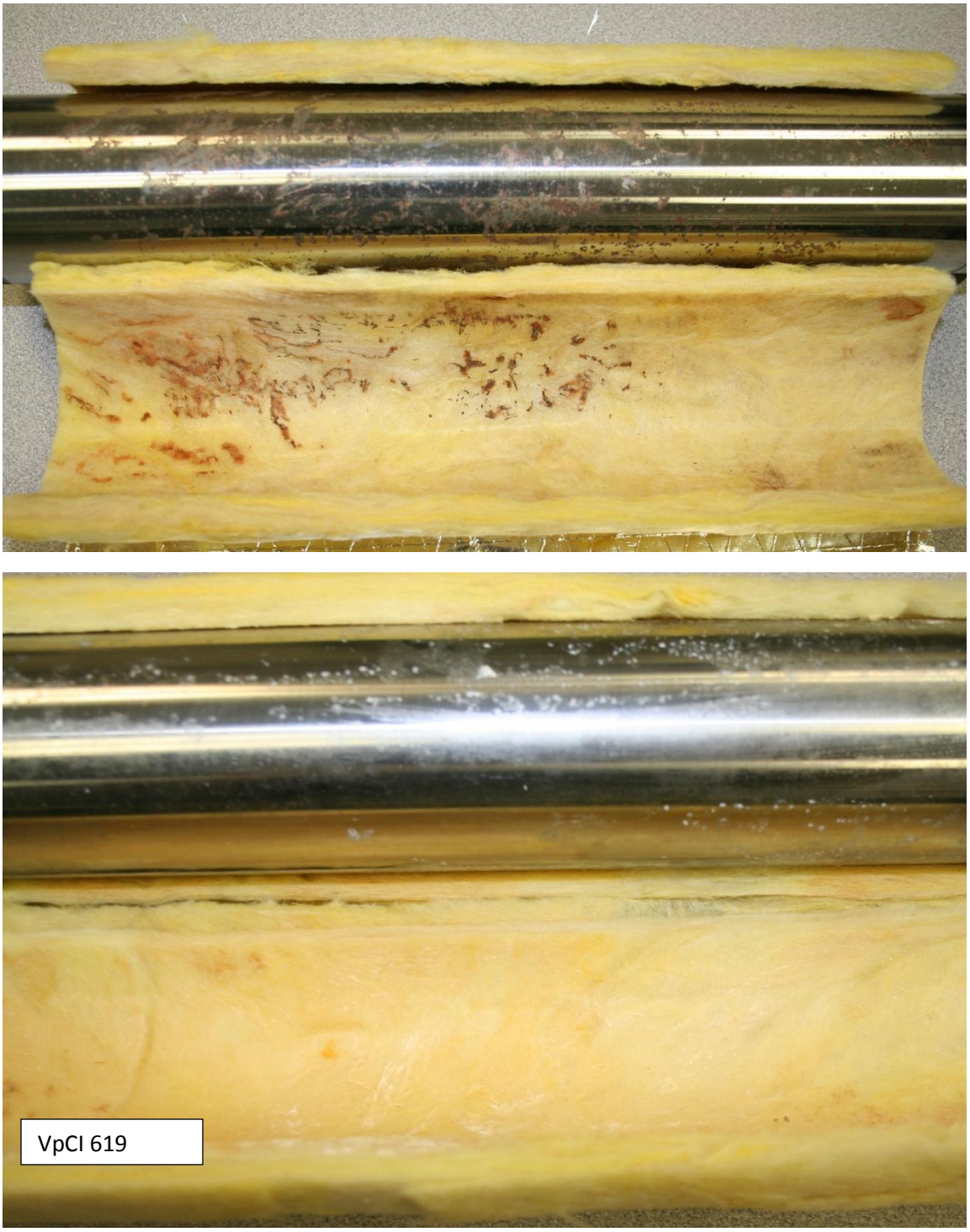


Fig. 4: Surface condition of the pipe insulation subjected to CUI tests after 240 hrs at 80 C, Control sample showed localized corrosion and red rust formation. No sign of any corrosion attack was observed on VpCI 619 treated sample.

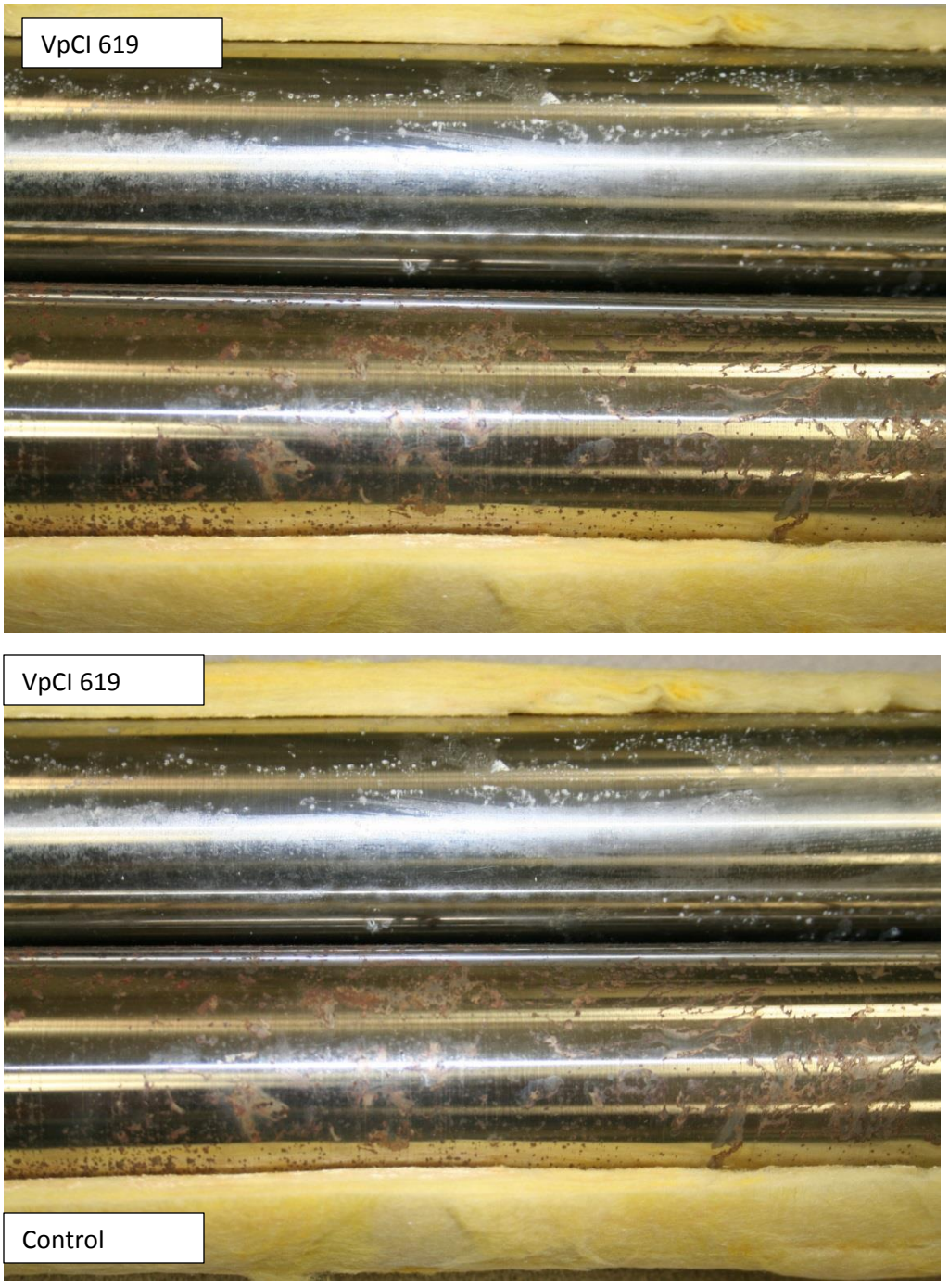


Fig. 5: Surface condition of the pipe insulation subjected to CUI tests after 240 hrs at 80 C, Control sample showed localized corrosion and red rust formation. No sign of any corrosion attack was observed on VpCI 619 treated sample.

1.0% VpCI 619 Control (200 ppm Cl-)

Corrosion test in boiling solution 200 ppm Cl-

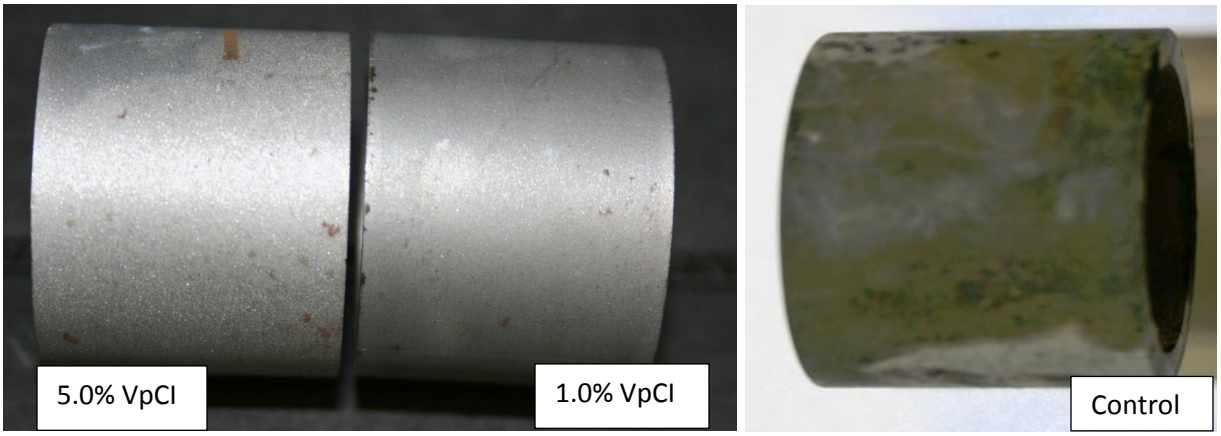


Fig. 6: Corrosion behavior of 1" steel pipe in 1.0% , 5.0% VpCI 619 and control in 200 ppm Cl- solution in boiling temperature (100 C) for 144 hours.

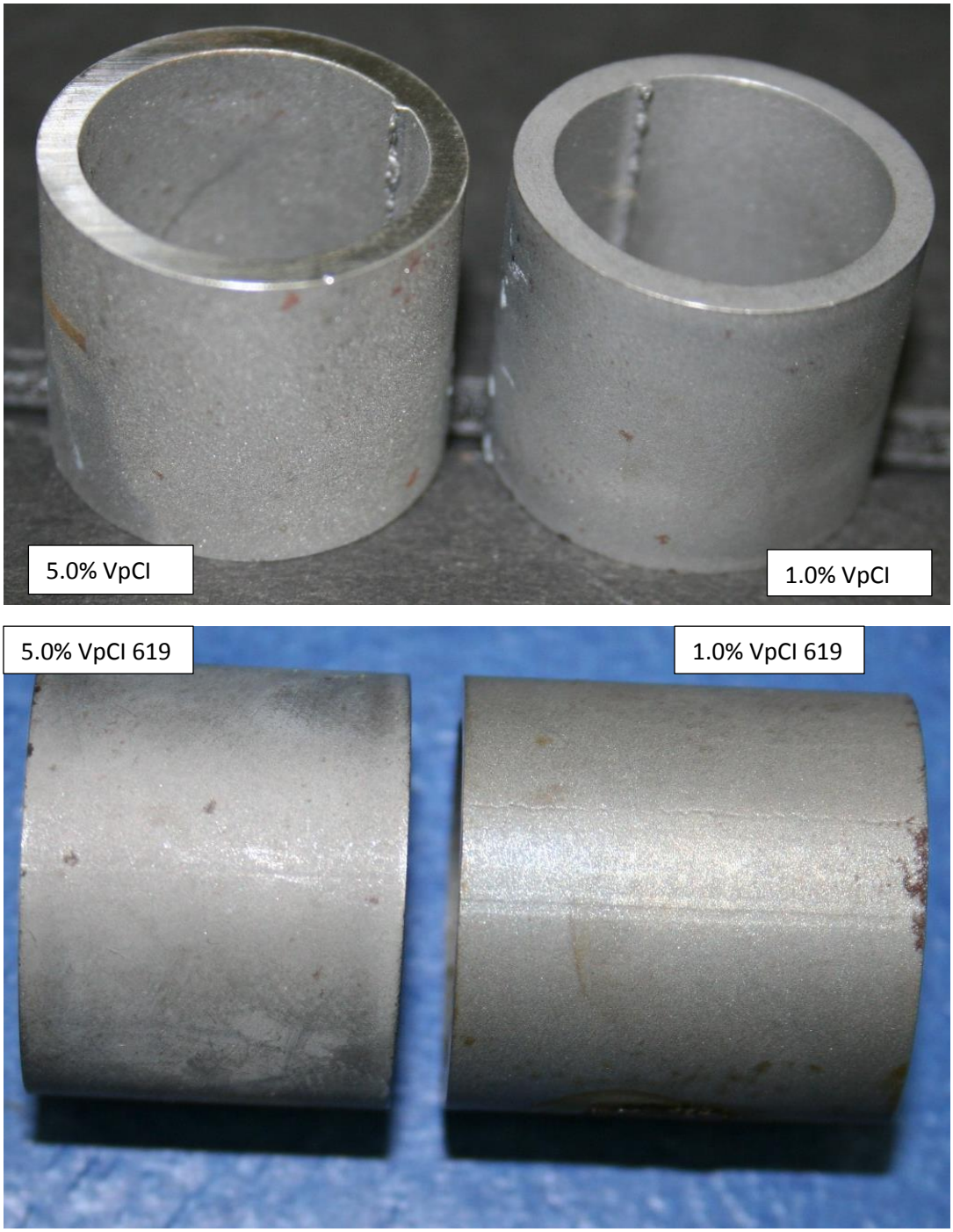


Fig. 7: Corrosion behavior of 1” steel pipe in 1.0% and 5.0% VpCI 619 in 200 ppm Cl- solution in boiling temperature (100 C) for 240 hours.

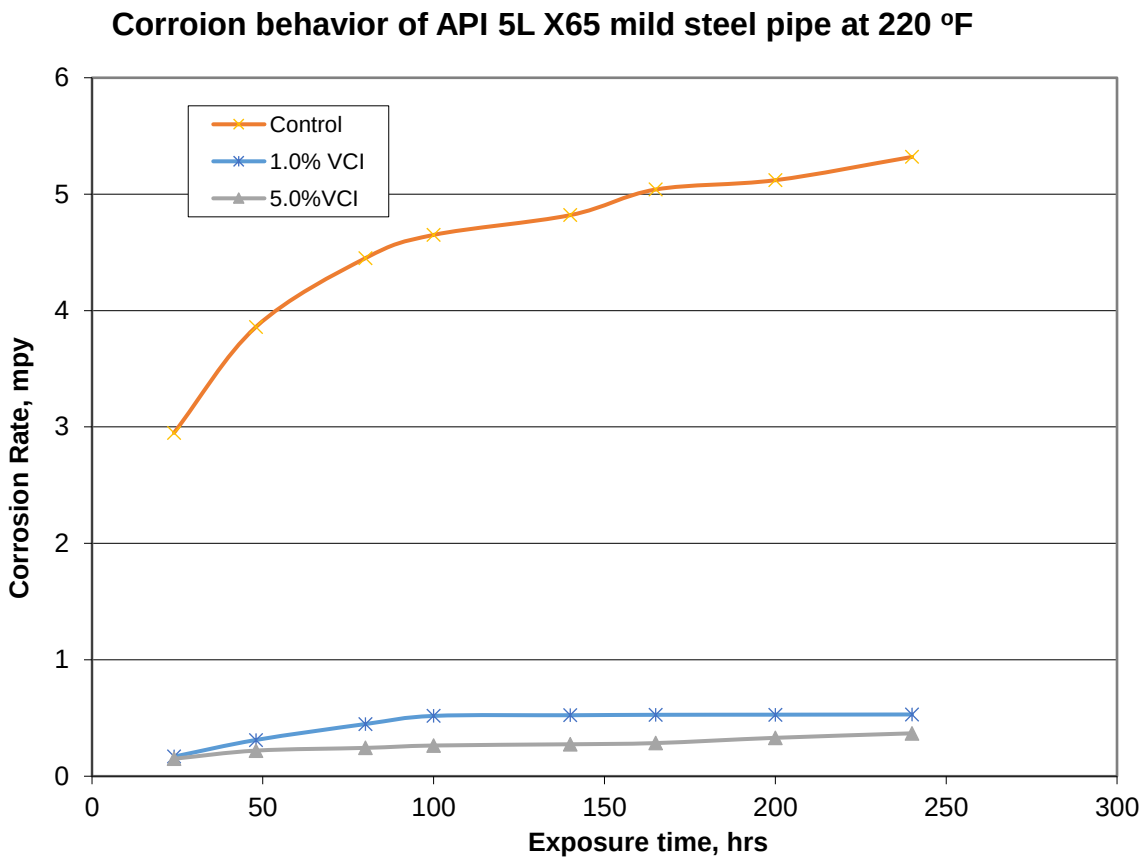


Figure 8: Corrosion behavior of steel pipes in boiling water solution in 100 ºC when exposed to control solution, 1.0% and 5.0% ppm VpCI 619.

Fig. 9: Corrosion behavior of 1” steel pipe in 1.0% and 5.0% VpCI 619 in 200 ppm Cl- solution in boiling temperature (100 C) for 240 hours.

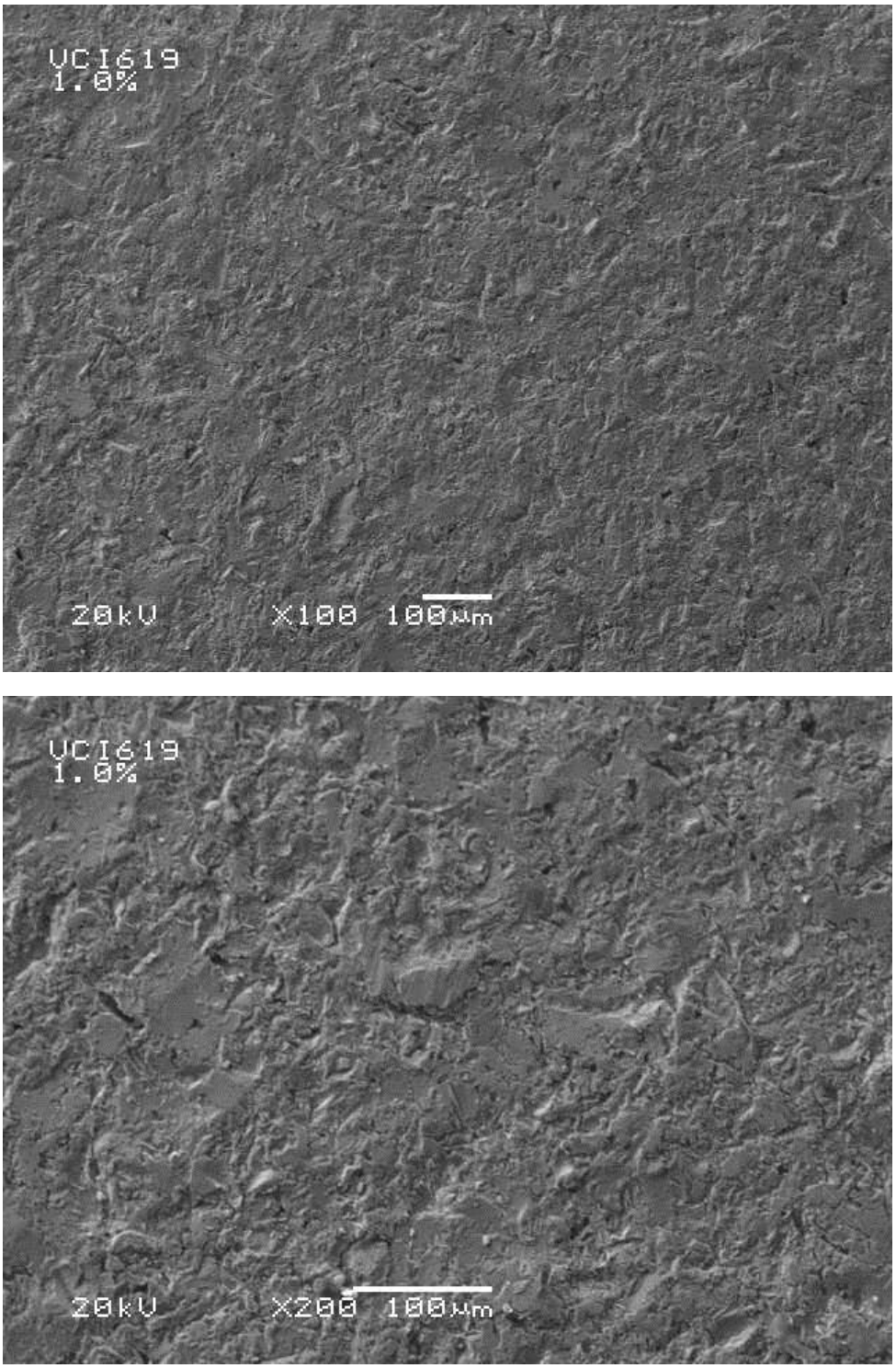
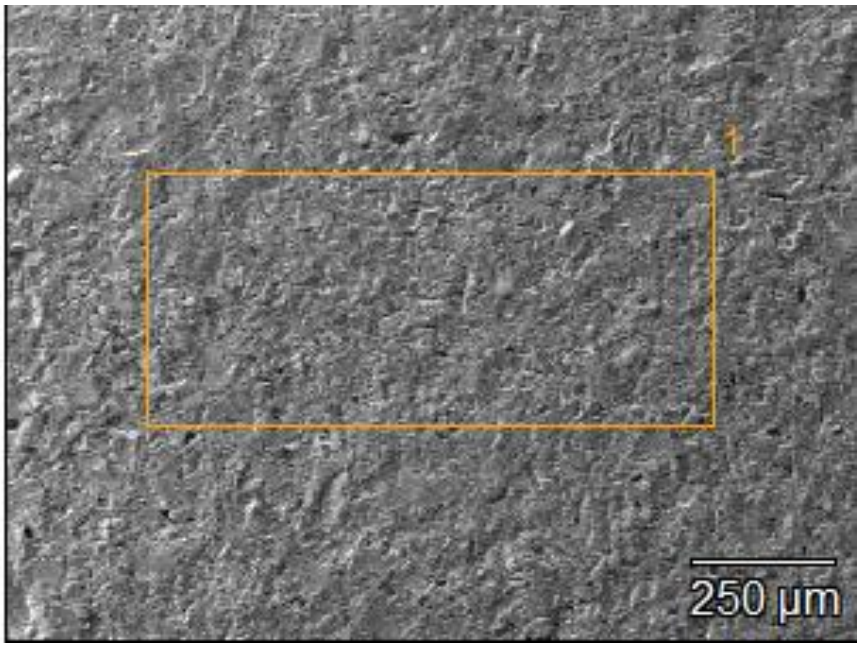
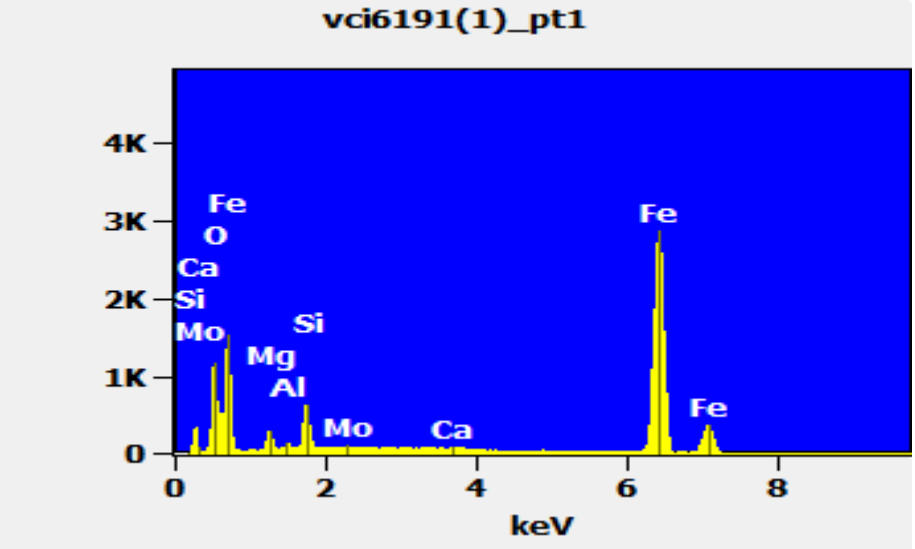


Fig. 10: SEM micrographs of Corrosion behavior of 1” steel pipe in 1.0% VpCI 619 in 200 ppm Cl- solution in boiling temperature (100 C) for 240 hours.





Weight %

	O	Mg	Al	Si	Ca	Fe	Mo
vci6191(1)_pt1	10.09	2.76	0.68	4.38	0.10	81.74	0.25

Fig. 11: SEM/EDS analysis on the 1" steel pipe in 1.0% VpCI 619 in 200 ppm Cl- solution in boiling temperature (100 C) for 240 hours, shows formation of protective film on the surface/

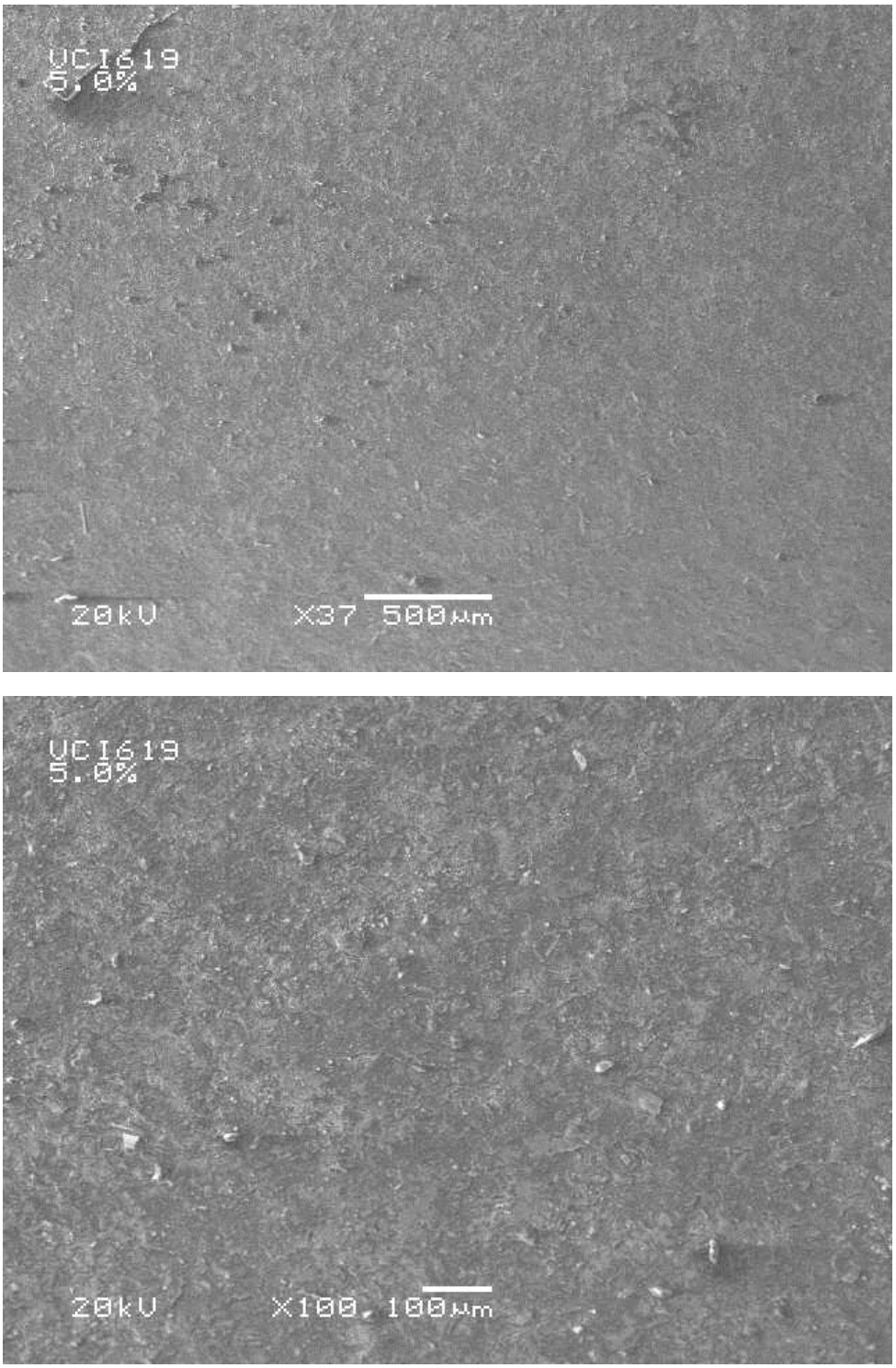
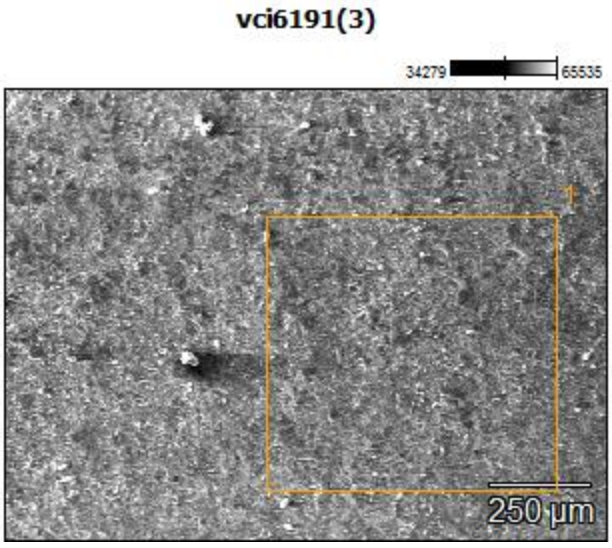
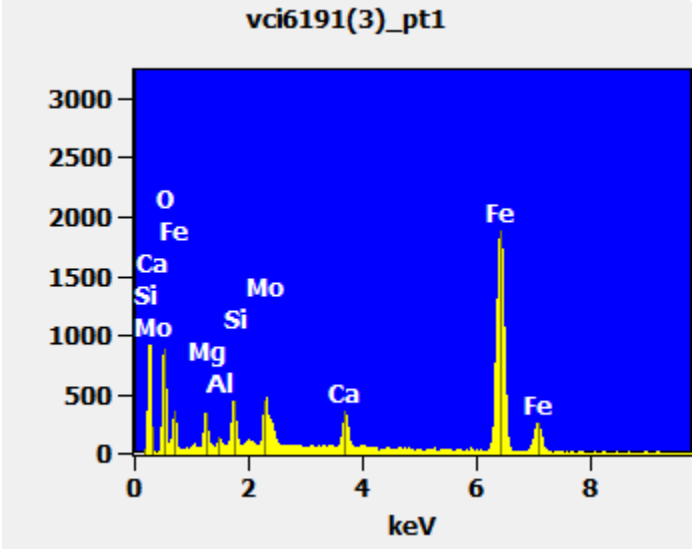


Fig. 12: SEM micrographs of Corrosion behavior of 1” steel pipe in 5.0% VpCI 619 in 200 ppm Cl- solution in boiling temperature (100 C) for 240 hours.





Weight %

	O	Mg	Al	Si	Ca	Fe	Mo
vci6191(3)_pt1	13.13	3.07	0.83	3.59	3.54	67.73	8.11

Fig. 13: SEM/EDS analysis on the 1” steel pipe in 5.0% VpCI 619 in 200 ppm Cl- solution in boiling temperature (100 C) for 240 hours, shows formation of protective film of Mo-rich on the surface.

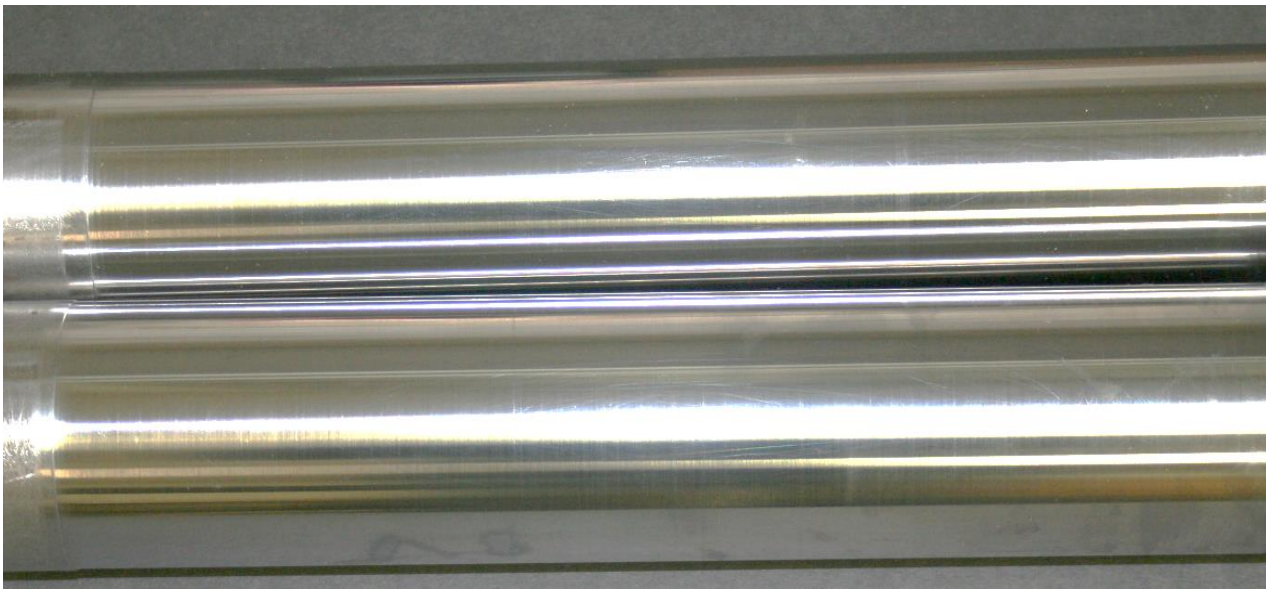


Fig. 1: 2” pipe samples surface condition prior to CUI tests

Fig. 14: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows some outer surface discoloration, but no corrosion was detected on pipe surface.

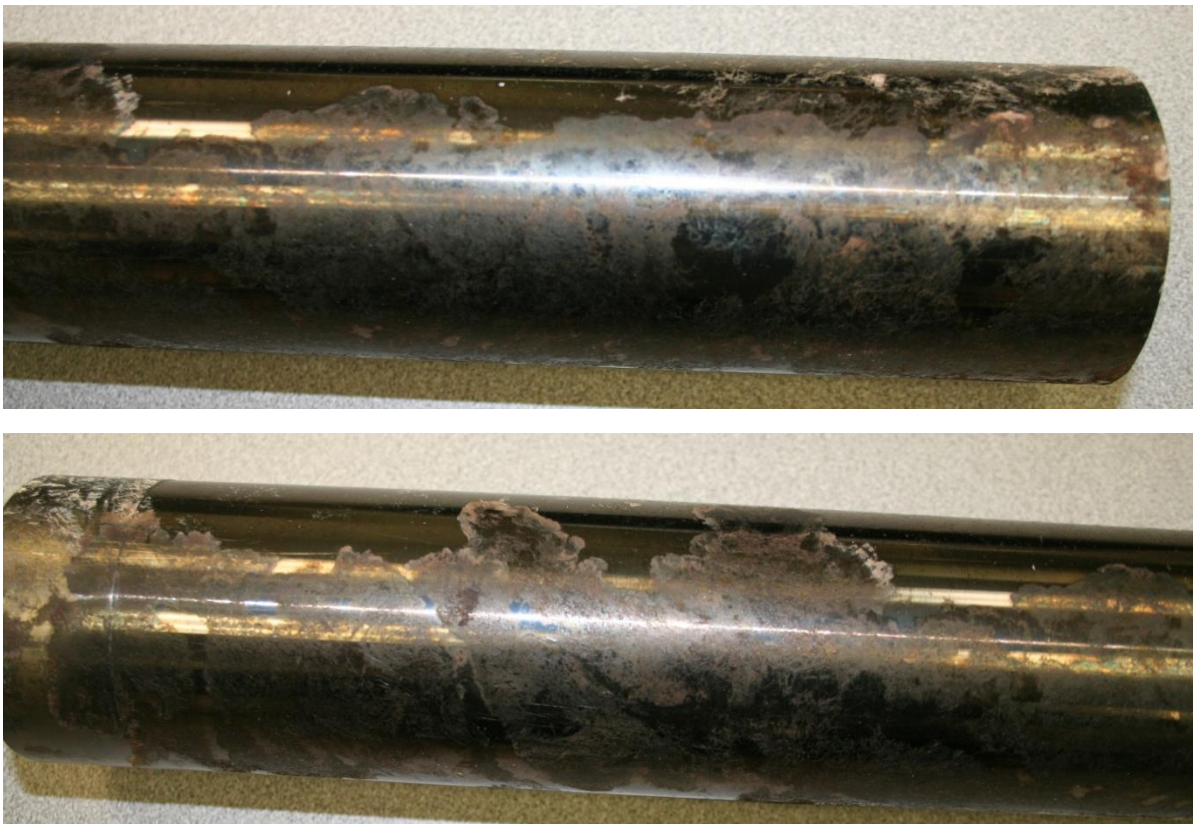


Fig. 15: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows some outer surface discoloration, but no corrosion was detected on pipe surface.

The discolored island on the surface are Mo-rich deposit (inhibitor compound)

Fig. 16: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows some outer surface discoloration, but no corrosion was detected on pipe surface. The discolored island on the surface are Mo-rich deposit (inhibitor compound)

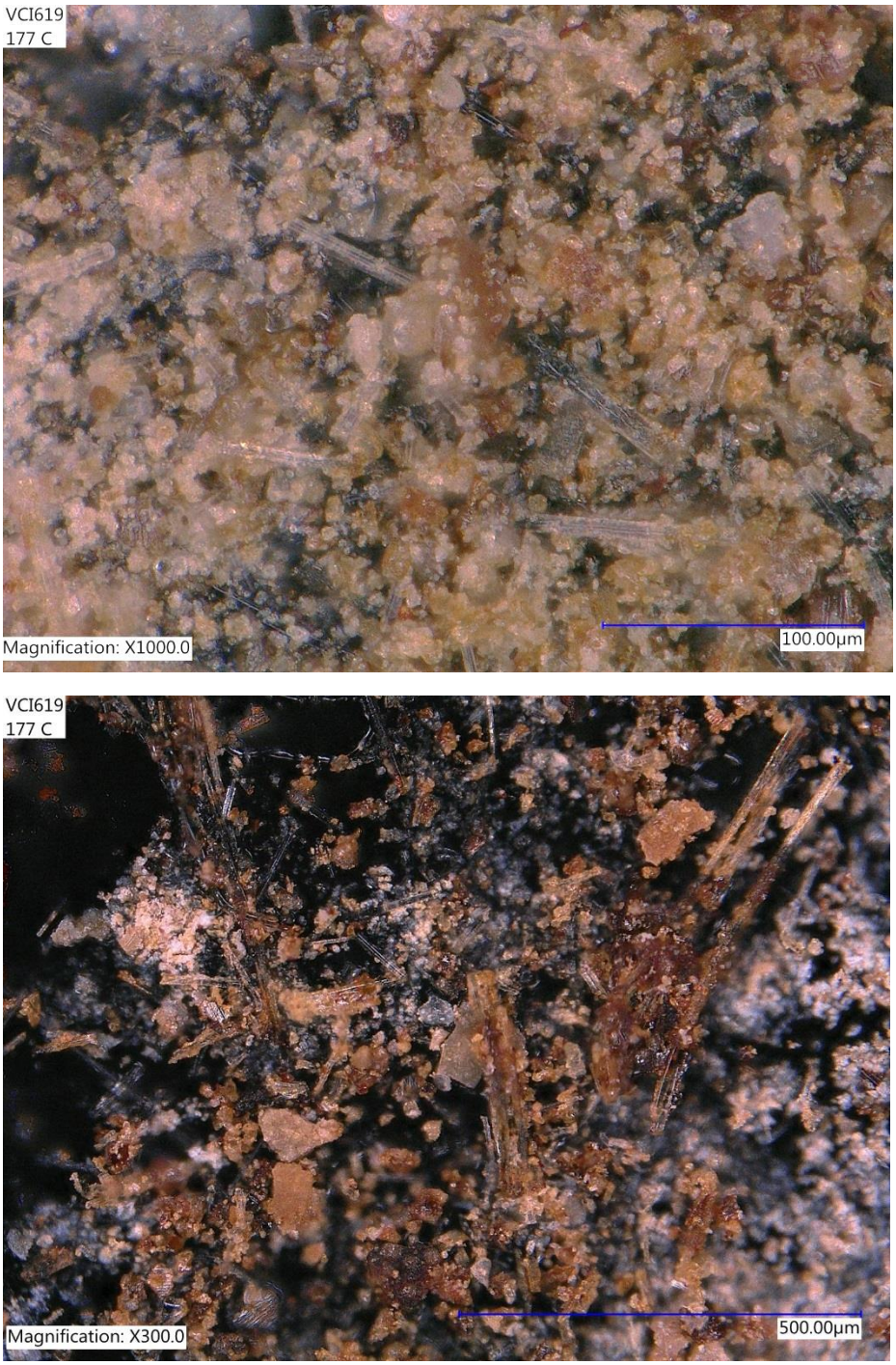


Fig. 17: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound), no Fe was detected in these deposits indicating no pipe corrosion.

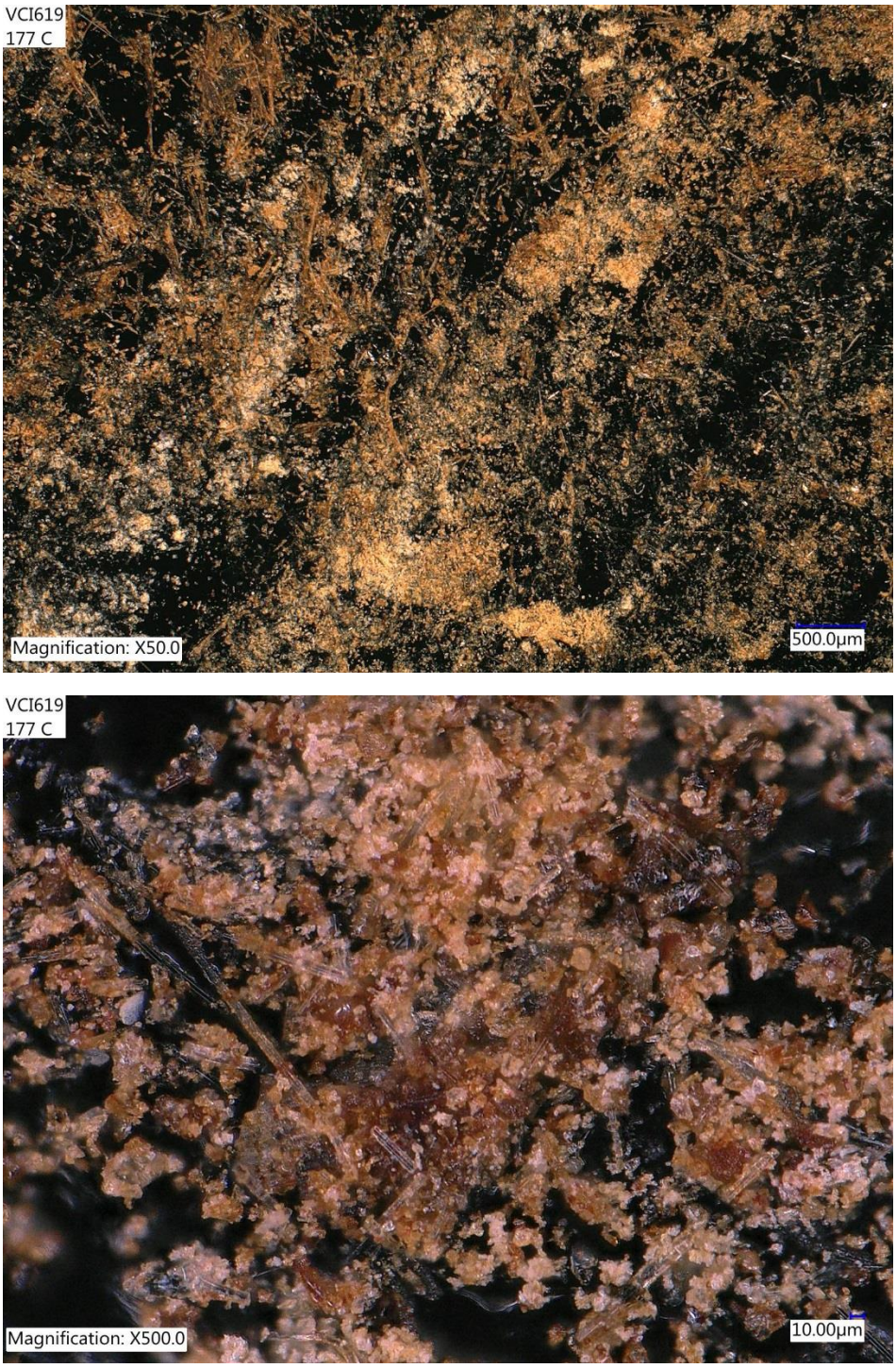


Fig. 18: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound), no Fe was detected in these deposits indicating no pipe corrosion.

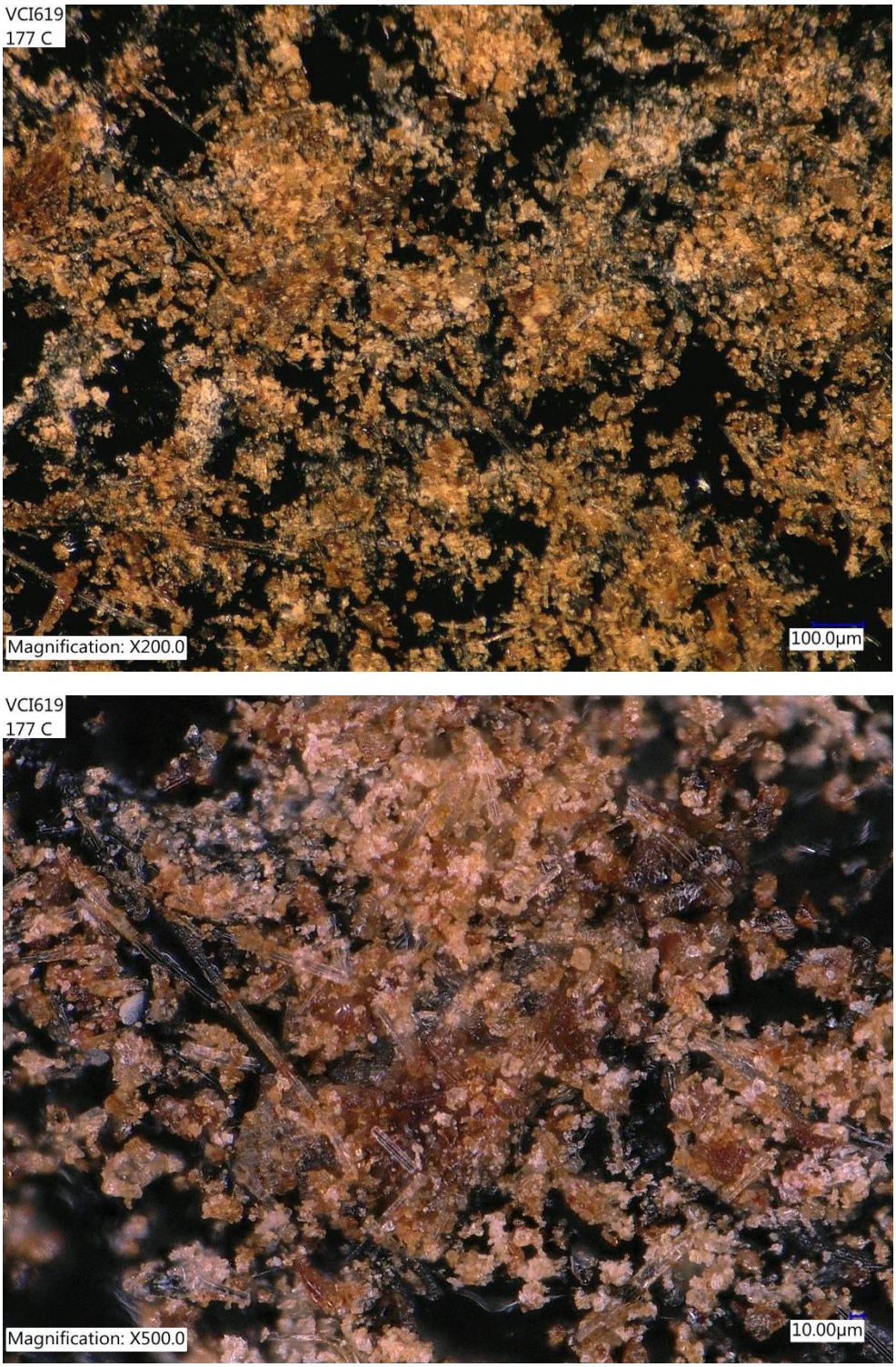
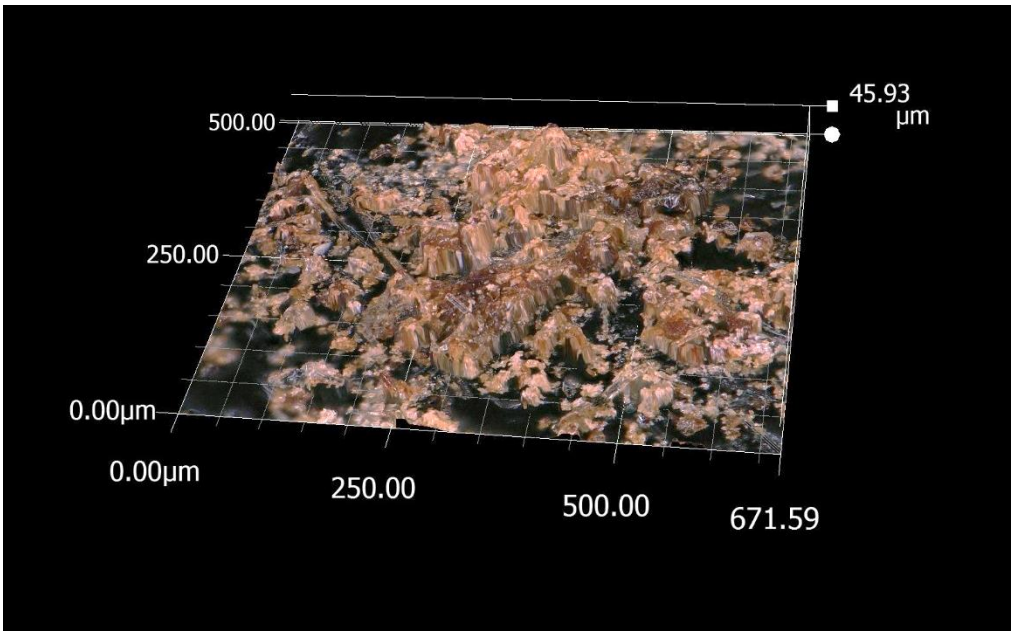


Fig. 19: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound), no Fe was detected in these deposits indicating no pipe corrosion.



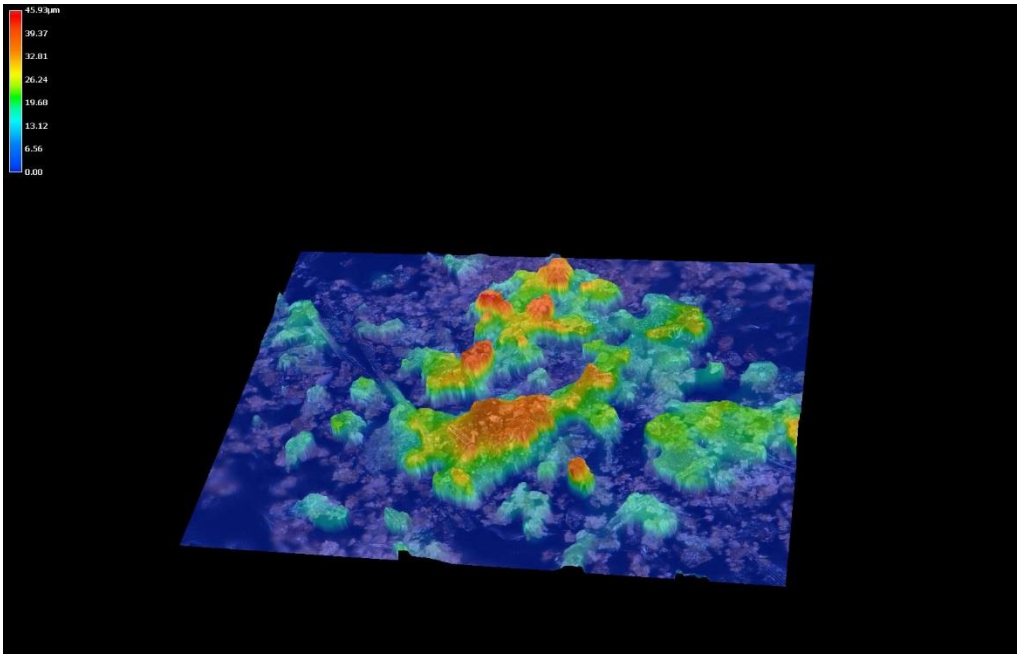


Fig. 20: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound), no Fe was detected in these deposits indicating no pipe corrosion.

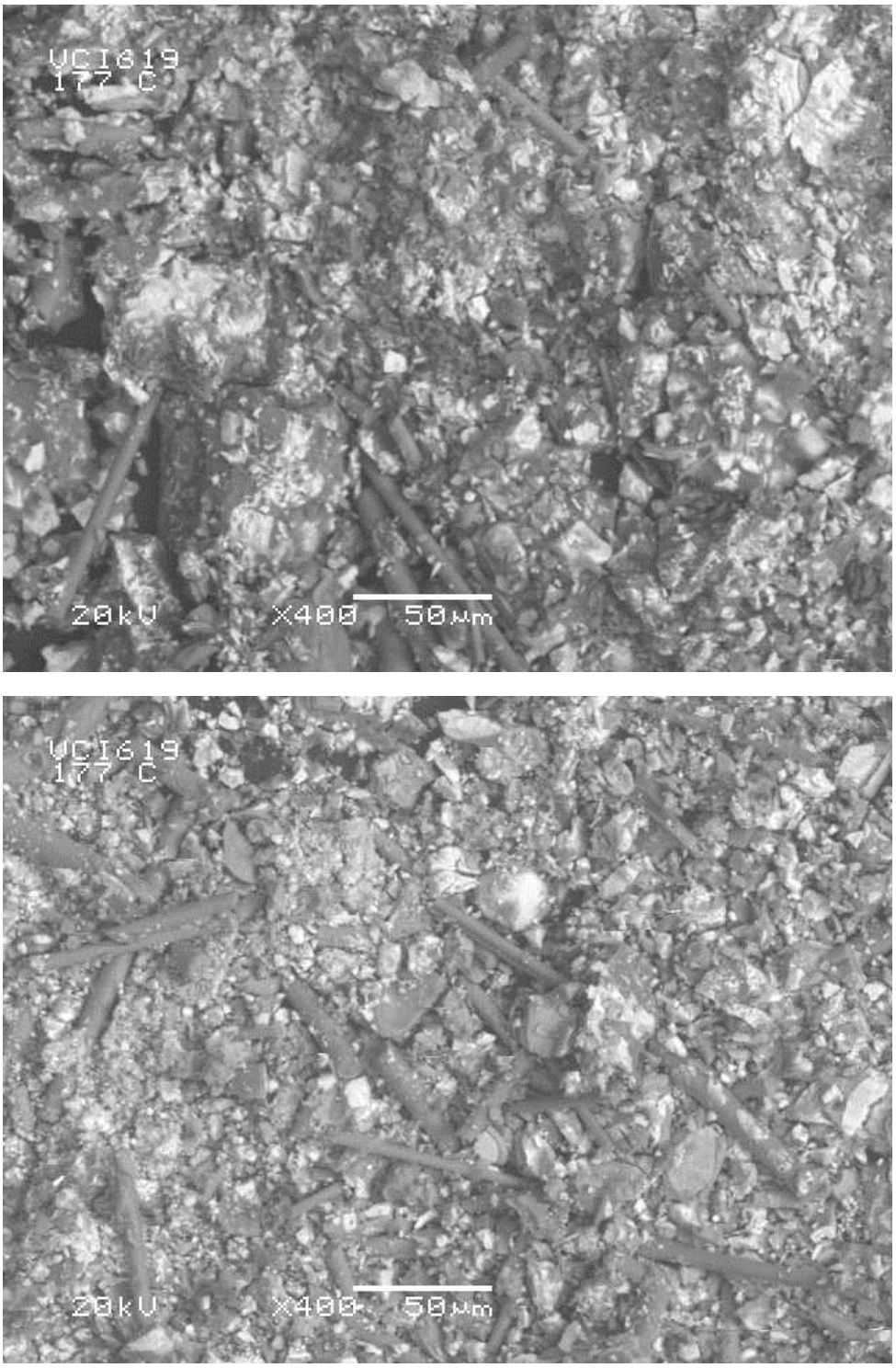


Fig. 21: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound), no Fe was detected in these deposits indicating no pipe corrosion.

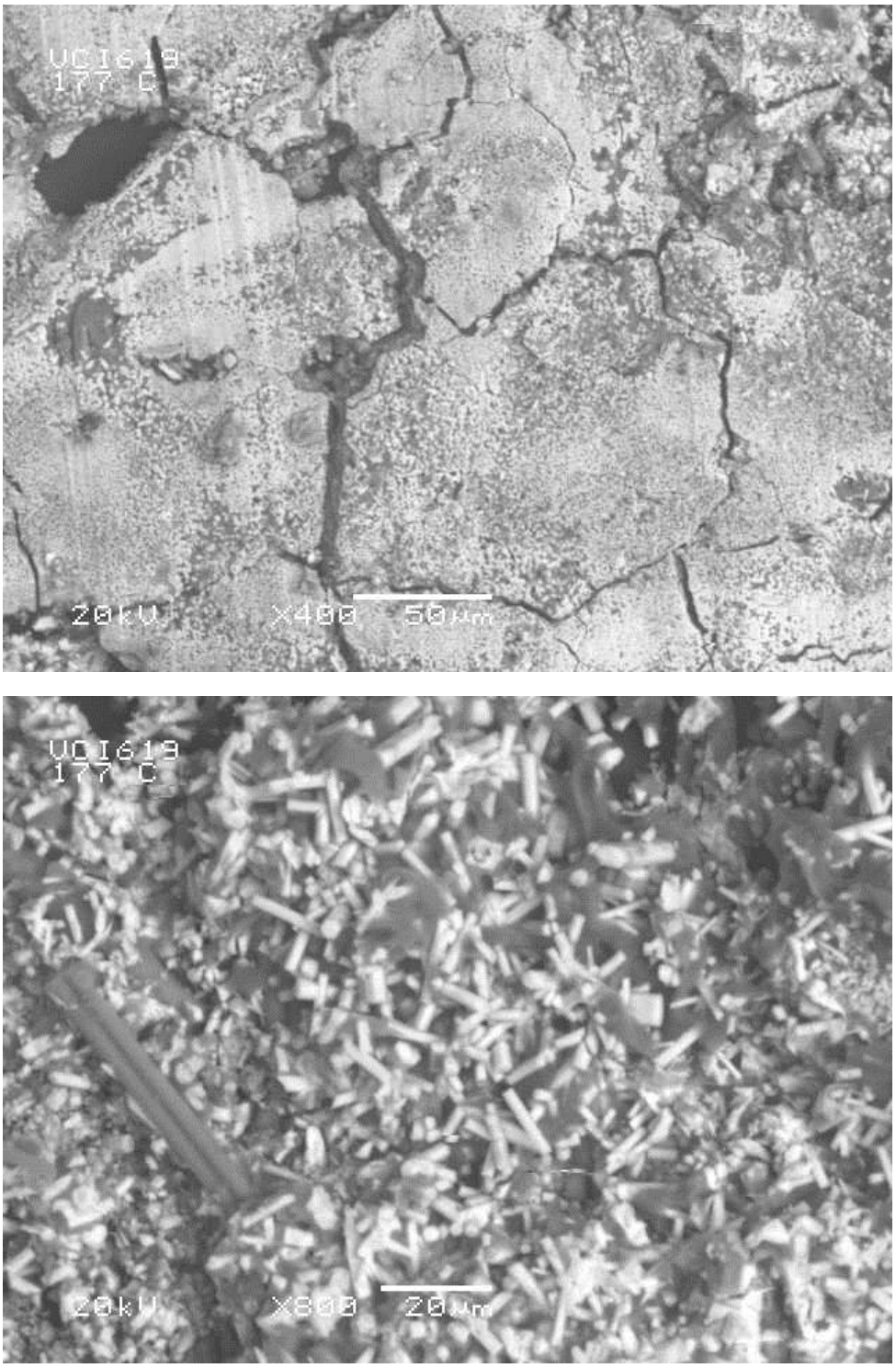


Fig. 22: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound).

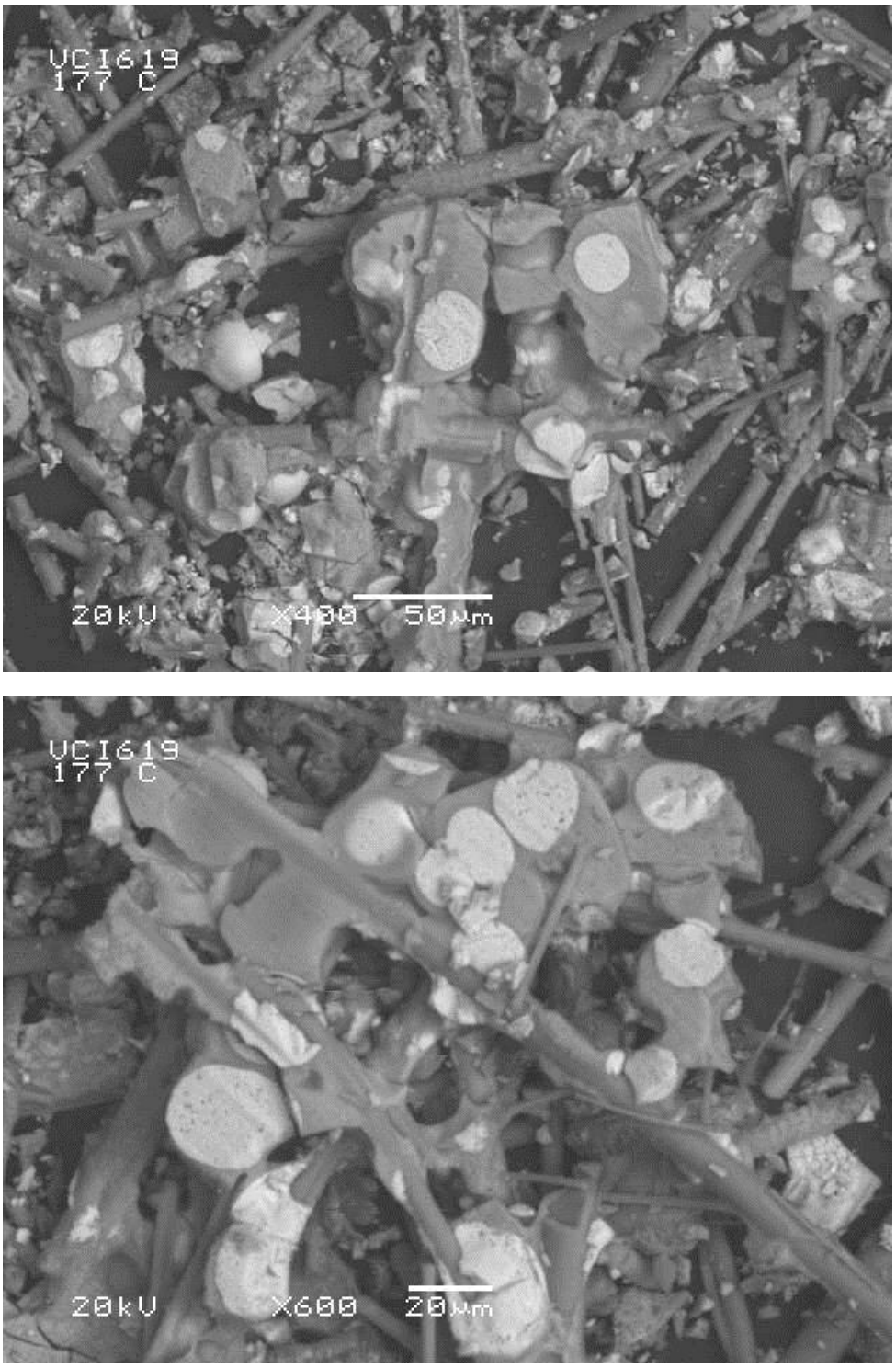
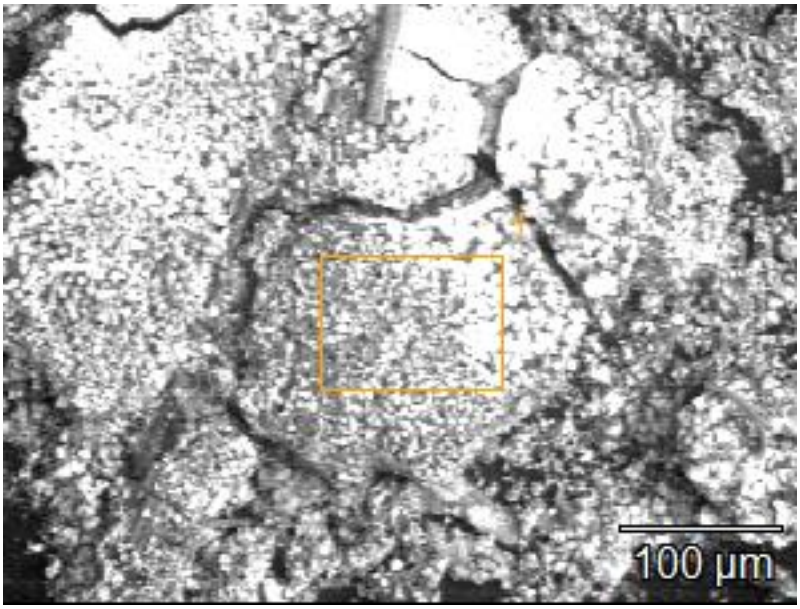
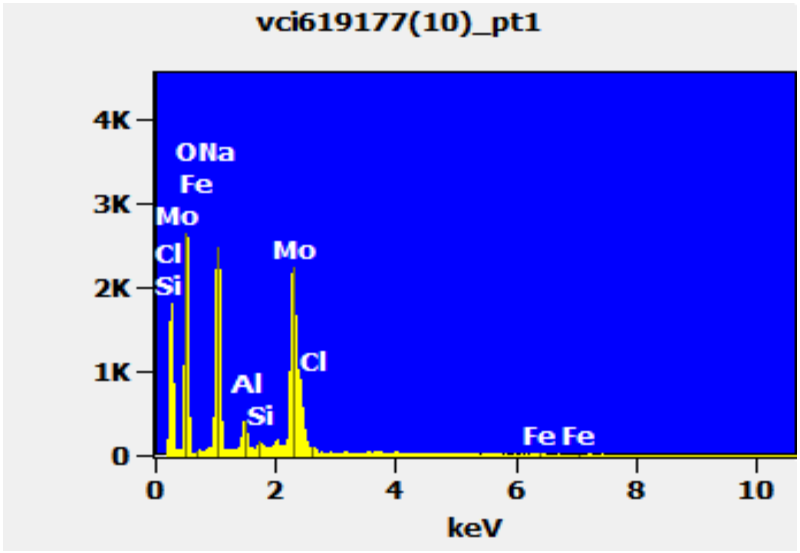


Fig.23: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that the circular spots are Mo-rich deposit (inhibitor compound).

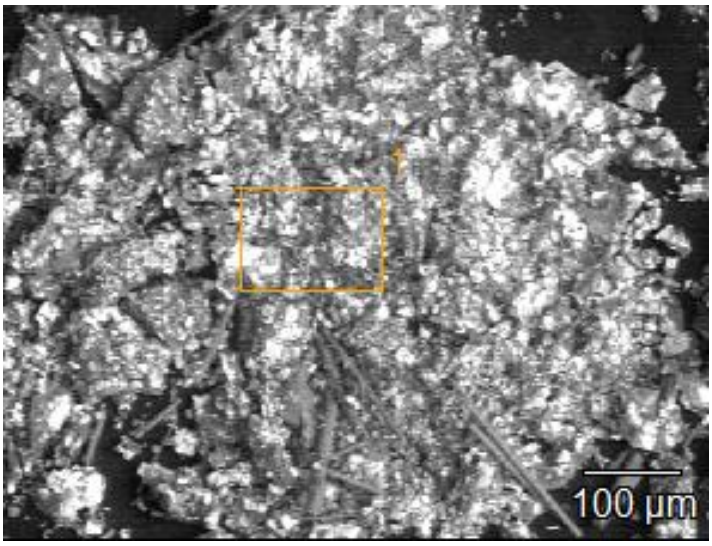


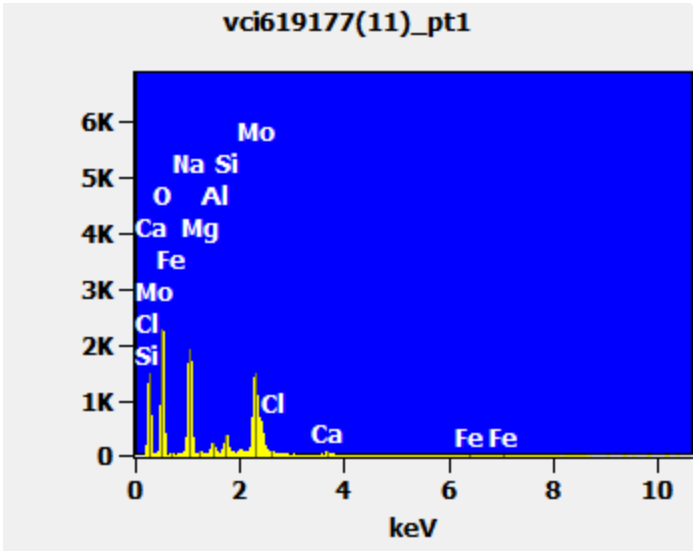


Weight %

	O	Na	Al	Si	Cl	Fe	Mo
vci619177(10)_pt1	45.47	19.41	2.13	0.49	0.30	0.20	31.99

Fig. 24: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound). The detected iron level is very low indicating no corrosion of the pipe.

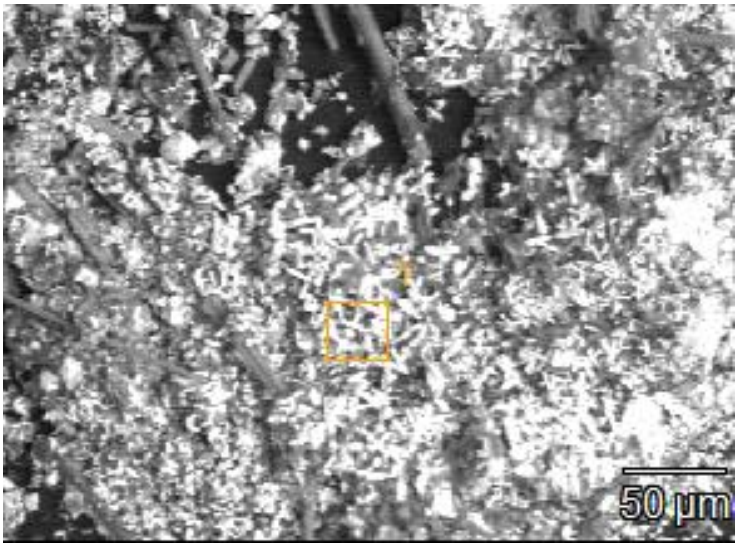


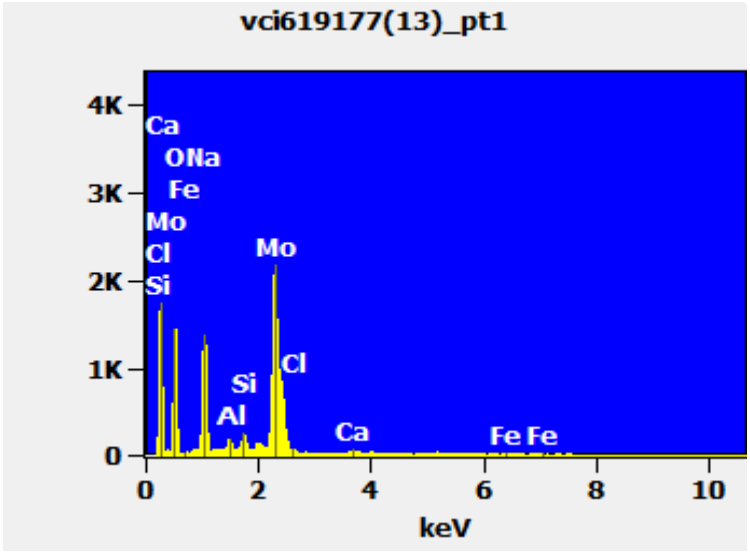


Weight %

	O	Na	Mg	Al	Si	Cl	Ca	Fe	Mo
vci619177(11)_pt1	47.95	19.03	0.29	1.33	2.39	0.24	0.67	0.14	27.94

Fig. 25: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound).

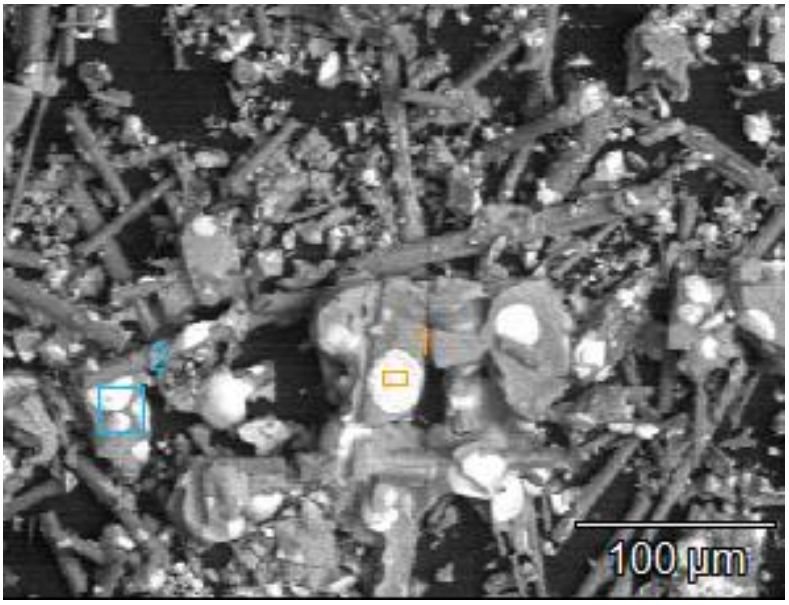


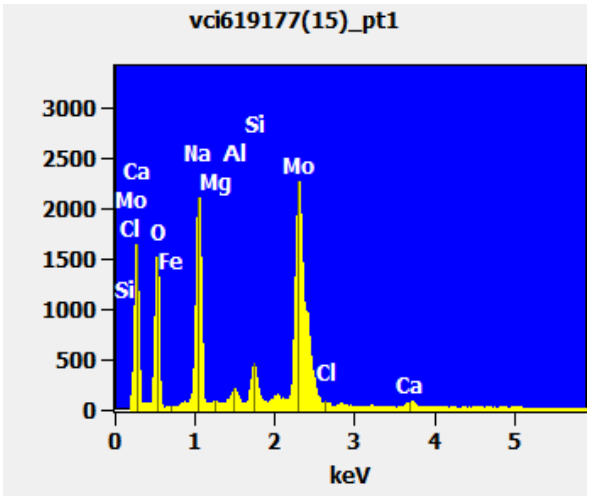


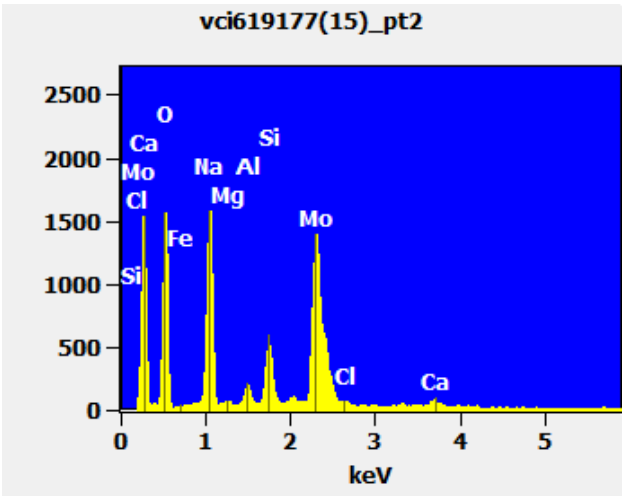
Weight %

	O	Na	Al	Si	Cl	Ca	Fe	Mo
vci619177(13)_pt1	41.84	14.94	0.87	1.16	0.18	0.56	0.13	40.33

Fig. 26: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits. SEM/EDS analysis showed that they are Mo-rich deposit (inhibitor compound). The detected iron level is very low indicating no corrosion of the pipe.



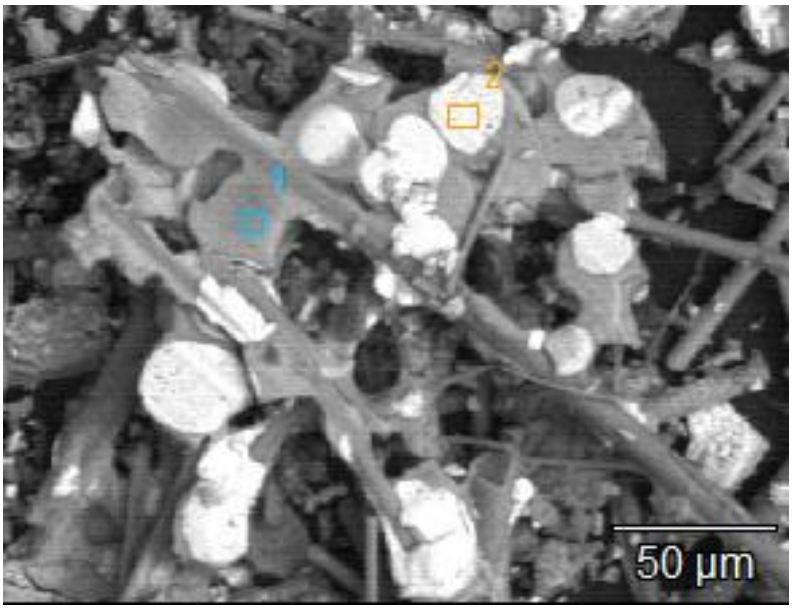


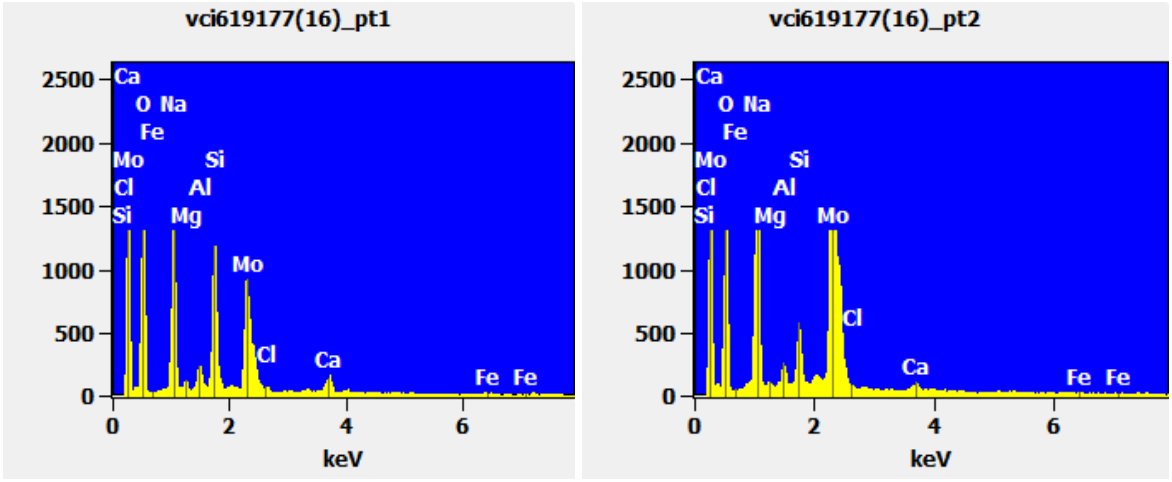


Weight %

	O	Na	Mg	Al	Si	Cl	Ca	Fe	Mo
vci619177(15)_pt1	37.10	19.42	0.23	1.05	2.55	0.03	0.79	0.35	38.47
vci619177(15)_pt2	43.06	18.06	0.46	1.47	4.31	0.23	0.97	0.38	31.06

Fig. 27: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that the circular spots are Mo-rich deposit (inhibitor compound). The detected iron level is very low indicating no corrosion of the pipe.





Weight %

	O	*Na*	*Mg*	*Al*	*Si*	*Cl*	*Ca*	*Fe*	*Mo*
vci619177(16)_pt1	45.47	16.10	0.69	1.74	10.49	0.32	2.35	0.45	22.39
vci619177(16)_pt2	36.65	19.82	0.32	1.12	2.84	0.00	0.65	0.25	38.36

Fig. 28: CUI tests of VpCI 619 coated pipe at 177ºC (350 ºF) after 4 cycles salt injection (192 hrs), shows morphology of surface deposits, some of insulation fibers can be seen. SEM/EDS analysis showed that the circular spots are Mo-rich deposit (inhibitor compound). The detected iron level is very low indicating no corrosion of the pipe.