CORROSION UNDER INSULATION (CUI)
A Nanotechnology Solution

Explanation:

Corrosion is the deterioration of essential properties in a metal, due to reactions with its surroundings. In the most common usage of the word, this means a loss of an electron of metal reacting with either water or oxygen.

Corrosion Under Insulation (CUI) is a localized corrosion occurring at the interface of a metal surface and the insulation on that surface. This can be a particularly severe form of corrosion because of the difficulty in detection due to the corrosion occurring beneath insulation. Inspections for corrosion under insulation are generally not completed regularly enough to eliminate this problem due to the cost of insulation removal and replacement and cost of labor.

Causes:

Causes of CUI are similar in most ways to other types of corrosion, with the largest difference being the environment.

Moisture combined with Oxygen of course is the largest contributing factor to corrosion. The closed environment of the insulation material over the pipe, tank or equipment creates conditions that encourage build up of moisture and resulting corrosion. The corrosion is often times more severe due to the insulation not allowing evaporation and the insulation acting as a carrier whereas moisture occurring in one area moves through the insulation to another area causing the corrosion to spread more rapidly. (See fig A)

Figure A:

Rockwool, fiberglass, or other traditional types of insulation promote corrosion, and also act as a carrier and spread the corrosion to other areas of the pipeline

Warm temperatures normally result in more rapid evaporation of moisture and reduced corrosion rates, however a surface covered with insulation creates an environment that holds in the moisture instead of allowing evaporation.

Traditional thermal insulation materials contain chlorides. If they are exposed to moisture, chlorides may be released into a moisture layer on the pipeline surface and pitting/stress corrosion cracking may result.

Acids, acid gases and strong bases like caustics and salts are aggressive corrosive agents and will not only cause but also accelerate existing CUI.

Costs:

A study done by Exxon Mobil Chemical that was presented to the European Federation of Corrosion in September of 2003 indicated that:

> -The highest incidence of leaks in the refining and chemical industries is due to CUI and not to process corrosion;
>
> -Between 40 and 60 percent of piping maintenance costs are related to CUI. (1)

Nanotechnology solution to CUI:

The nanotechnology material in Nansulate® coatings offers a new solution to the issue of CUI by introducing a coating that provides corrosion resistance and in addition, has a low thermal conductivity, which allows it to act as an insulator.

One of the ways that CUI is dealt with when using traditional insulation is to use an anti-corrosive coating underneath the insulation. This however does not alleviate the cost of removing and replacing the insulation for required corrosion inspections, and is also does not cure the environmental conditions that feed moisture build up beneath the insulation, which breeds corrosion and decreases the effectiveness of the insulation.

Nansulate® has four main characteristics that combat problems with CUI:

1. Low thermal conductivity (making it an insulator)
2. Corrosion Resistance
3. Resistance to moisture
4. Clear finish that allows visual inspection without insulation removal

The nanotechnology material in Nansulate®, Hydro-NM-Oxide, had a thermal conductivity of 0.017 W/mK. When fully cured, the coating contains approximately 70% Hydro-NM-Oxide and 30% acrylic resin and performance additive. Nansulate acts as an insulator by decreasing the amount of heat energy transferred. (See Appendix A, Temperature Gradient Chart, and Appendix B High Heat Empirical Calculation). The main benefit of using a thin film insulator as opposed to a traditional insulation, such as rock wool, is the increased longevity of the product and consistent insulating performance. A thin film nanotechnology coating is not subject to the same infiltration by dust, moisture, and microorganisms that reduce the effectiveness of traditional insulations.

Due to the extreme hydrophobic nature of the nanotechnology material in Nansulate® and the excellent adhesion to the surface, the coating retains corrosion resistance capabilities. For the ASTM B-117 it has passed 2000 hours, and in the more rigorous GM9540P Accelerated Corrosion Test it passed 24 cycles with no red rust present.

The coating bond with the surface is one that repels excess moisture, instead of creating a desirable environment for the collection of moisture and resulting corrosion.

The clear appearance of the coating makes visual inspection of the surface possible without damage to or removal of the coating. This combination of corrosion resistance and thermal insulation in a clear coating is an innovation of nanotechnology that has not been available in the past.

Conclusion:

CUI has remained a prevalent problem in many industries. The cost of regular removal and replacement of insulation systems for corrosion inspections is one that is high, and has become problematic. Furthermore the traditional types of insulation create the perfect environment for moisture and resulting corrosion and create a conduit for that corrosion to spread more rapidly.

Nanotechnology offers a way to for inspection personnel to inspect for corrosion more regularly and without removal of the insulation. This lowers both labor costs and costs of pipeline and equipment replacement due to CUI. Nansulate® nanotechnology coatings offer a single product solution for corrosion resistance and insulation for pipelines, tanks and other plant equipment, which is easily applied, and maintains its effectiveness over time.

(1) Reference: Insulation.org; “is there a cure for corrosion under insulation? By Michael Lettich

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Temperature Gradient Chart

Demonstrates surface temperature differences achieved at various high temperatures
Metal substrate

Temp F of hot surface	100-120	170-190	191-210	211-230	231-250
Temp C of hot surface	38-49	77-88	89-99	100-110	111-121
3 coats (7 mils) Surface temperature difference shown	10-18F (5-10C)	20-35F (12-19C)	40-55F (20-27C)	60-75F (30-36C)	78-93 (37-44C)

NOTE: Testing is currently being conducted on samples of higher dry mil thicknesses and at higher temperature ranges (250-400F) in order to show the extra benefit achieved with subsequent coats of Nansulate®.

Oil/Cylinder Gradient

Demonstrates temperature differences achieved between heated oil and outer wall surface.

1) Substrate is 2" dia. stainless cylinder with wall thickness of .065 in. and 14 mils DFT (approx. 6 coats) of Nansulate® Translucent High Heat.

2) Heated cooking oil to 325 deg F and poured into cylinder, taking temperature readings of oil and outer wall at the same time.

3) Following are temperatures at various points of cooling ; first figure is oil temperature, second is outer wall temperature. (all temperatures are in F)

Oil Temp	Outer Wall Temp
250	135
212	120
204	119
190	115
180	109
169	109
165	104
141	97

Sources for information:
Temperature Gradient Chart: Figures were averaged from five testing applications. Applications include: Testing beginning May 4, 2005 by Protan S.A. on coated steel panels. Testing beginning May 31, 2005 by Protan S.A. on oil pipeline used on AM3 platform where petroleum is transferred to the continent. Testing done beginning July 4, 2005 by Nansulate Asia on coated metal panel. Testing beginning March 15, 2005 in house by Industrial Nanotech, Inc. on coated metal panels, Testing beginning June 2004 in house by Princeton Polymer Laboratory on coated metal panels.

Oil/Cylinder Gradient: Testing information from Mobeq Industrial Products, Ltd from in house testing.

Nansulate High Heat Empirical Calculation

No.of Coats	Initial Surface Temp. / C	200	190	180	170	160	150	140	130	120	110	100	95	90	85	80	75	70	65	60	55	50	45
1		182	173	164	155	146	137	128	119	110	101	92	88	83	79	74	70	65	61	56	52	47	43
2		166	158	150	142	133	125	117	109	101	93	85	81	77	73	69	65	61	56	52	48	44	40
3		151	144	137	129	122	115	107	100	93	86	78	75	71	67	64	60	56	53	49	46	42	38
4		138	132	125	118	112	105	99	92	86	79	72	69	66	63	59	56	53	50	46	43	40	36
5		126	120	114	109	103	97	91	85	79	73	67	64	61	58	55	52	50	47	44	41	38	35
6		116	110	105	100	94	89	84	78	73	68	63	60	57	55	52	49	47	44	41	39	36	33
7		106	101	97	92	87	82	77	73	68	63	58	56	53	51	49	46	44	42	39	37	34	32
8		97	93	89	85	80	76	72	67	63	59	54	52	50	48	46	44	42	39	37	35	33	31
9		90	86	82	78	74	70	66	63	59	55	51	49	47	45	43	41	39	37	35	34	32	30
10		83	79	76	72	69	65	62	58	55	51	48	46	44	43	41	39	37	36	34	32	30	
11		76	73	70	67	64	61	58	55	51	48	45	44	42	40	39	37	36	34	33	31		
12		71	68	65	62	60	57	54	51	48	45	43	41	40	38	37	36	34	33	31	30		
13		66	63	61	58	56	53	51	48	45	43	40	39	38	37	35	34	33	31	30			
14		61	59	57	54	52	50	47	45	43	41	38	37	36	35	34	33	31	30				
15		57	55	53	51	49	47	45	43	41	39	36	35	34	33	32	31	30					
16		53	52	50	48	46	44	42	40	39	37	35	34	33	32	31	30						
17		50	48	47	45	43	42	40	38	37	35	33	33	32	31	30							
18		47	46	44	43	41	40	38	37	35	34	32	31	31	30								
19		44	43	42	40	39	38	36	35	34	32	31	30										
20		42	41	39	38	37	36	35	33	32	31	30											
21		40	39	38	36	35	34	33	32	31	30												
22		38	37	36	35	34	33	32	31	30													
23		36	35	34	33	32	32	31	30														
24		34	34	33	32	31	30	30															
25		33	32	31	31	30																	
26		32	31	30	30																		
27		30	30																				

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3rd Party Corrosion Testing

RESISTANCE TO CUI

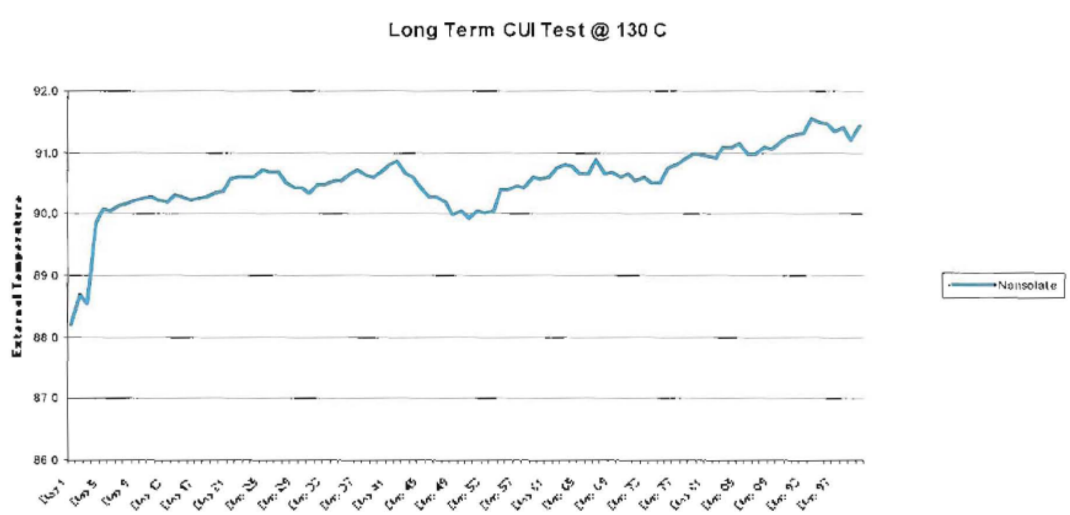
Resistance to CUI exposure at 130°C internal temperature

The externally coated pipe was filled with Shell Thermal B oil with four internal and four external thermocouples. One internal and one external thermocouple were positioned so they were at the same position to enable the measurement of the temperature difference. The sets of thermocouples were at different depth and equally spaced around the pipe. The oil was heated to 130°C and held for 100 days. During the 100 days the coating was sprayed with artificial seawater periodically over every 24 hours. Before the exposure test the coating has 020mm holidays milled through the coating to the substrate at three locations and saw cuts were made through the coating at the top and bottom of the cornered joint.

CUI Exposure Test
Test Specification BC/BP/JC issue 1 revision C
Result
After completing the exposure the coating exhibited no visible signs of cracking, flaked or disbondment.

CUI Exposure Test		
Rating Assessment After Exposure		
Test Specification	Assessment	Rating
BS 3900 Part H2	Degree of Blistering	2(S4)
BS 3900 Part H3	Degree of Rusting	Ri3 (less than 1%)
BS 3900 Part H4	Degree of Cracking	0(0)
BS 3900 Part H5	Degree of Flaking	0(0)

Graph: CUI exposure test



Nansulate showed consistent performance over the 97 day test timeline.

3rd Party Thermal Conductivity Testing

THERMAL CONDUCTIVITY

Thermal conductivity exposure 60°C to 130°C

The externally coated pipe was filled with Shell Thermal B oil with four internal and four external thermocouples. One internal and one external thermocouple were positioned so they were at the same position to enable the measurement of the temperature difference. The sets of thermocouples were at different depth and equally spaced around the pipe. The oil was heated to 60°C and held for 24 hours then increased to 90°C and held for 24 hours then increased to 110°C and held for 24 hours then increased to 130°C.

Thermal Conductivity Test
Test Specification BC/BP/JC issue 1 revision C
Result
After completing the exposure the coating exhibited no visible signs of cracking, flaked or disbondment.

CUI Exposure Test		
Rating Assessment After Exposure		
Test Specification	Assessment	Rating
BS 3900 Part H2	Degree of Blistering	2(S4)
BS 3900 Part H3	Degree of Rusting	Ri3 (less than 1%)
BS 3900 Part H4	Degree of Cracking	0(0)
BS 3900 Part H5	Degree of Flaking	0(0)

Graph: Thermal conductivity test