MEASUREMENT OF CORROSION UNDER INSULATION AND EFFECTIVENESS OF PROTECTIVE COATINGS

Dharma Abavarathna
William G. Ashbaugh
Russell D. Kanev

CLIInternational, Inc.
14503 Bammel-North Houston
Suite 300
Houston, Texas 77014-1149

Nancy McGowan
Bob Heimann

ABSTRACT

A laboratory cell set-up was designed and constructed for the simulation of corrosion under insulation (CUI) on a pipe section at elevated temperature. The CUI cell consisted of six carbon steel ring specimens separated by insulation spacers and held together by blind flanged pipe sections on both ends. Thermal insulation which was placed around the testing section provided the annular space to retain the test environment. The ring specimens were used as test electrodes in two separate electrochemical cells. One cell was used as the control while the other was used to test applied protective coatings. Corrosion measurements were made using both electrochemical polarization resistance and mass loss data under isothermal and cyclic wet/dry test conditions. The test cell was used to:

- successfully simulate CUI in the laboratory
- evaluate the corrosivity and different modes of corrosion observed with CUI
- evaluate proprietary coatings for minimizing CUI under simulated CUI conditions.

Keywords:

INTRODUCTION

The corrosion failures observed on steel and other materials under insulation, which is referred to as corrosion under insulation (CUI) is a great concern for the petroleum and chemical processing industries. The insulation are utilized on piping and vessels to maintain the temperatures of i.e. operating systems for process stabilization and conservation energy. However, the insulation can also provide necessary essentials together with other (mostly environmental) factors CRC the occurrence of general and localized corrosion, and stress corrosion cracking.

Failures due to external stress corrosion cracking (ESCC) of stainless steel under thermal insulation are reported in the literature as early as in 1956.[1] The reported failures of ESCC extended to many areas of the 'United States, as well as in Europe. [2-4] A major study on CUI ,vas initiated by the Materials Technology Institute (MTI) of the Chemical Process Industry in 1 which continued through several phases. One focus of this study was to identify non-destructive . e techniques which were capable of detecting CUI. A novel electromagnetic technique of detecting CUT was the out come of this study which was further developed by B and `YV Research Laboratories. In 1983, a joint conference was held on this subject by National Association of Corrosion Engineers (NACE), American Society for Testing and Materials (AST'NI) and MTI The interest and activity on CUI has been increased since then. At present, NACE Work Group T-5A-30a is preparing a standard on control of CUT with assistance of MACE Task Group T-,;H30 and ASTM Committee C-16.40.3 on CUT. Additionally, ASTM Committee G' 1 preparing a standard test method for evaluation of CUT.

Major focus of this study was the simulation of CUI in a laboratory set-up (CUT cell) which is capable of providing various CLZ conditions. Once the laboratory set-up was designed and tested, the performance of a proprietary coating was evaluated under isothermal and wet/ dry conditions.

BACKGROUND

Mechanism of CUI

The corrosion of steel or other materials under insulation initiates due to the presence of water. oxygen and other corrodants. Once water and oxygen are present on a metal surface. corrosion takes place via metal dissolution (anodic reaction) which is balanced by the reduction of oxygen. The rate of CUI is determined by the availability of oxygen, contaminants in water, temperature and heat transfer properties of the metal surface and wet/dry conditions of the surface.

Role of Insulation

The main contribution of insulation to CUI is to provide an annular space for the retention or accumulation of water, with access to air (oxygen). Water may be introduced from external sources such as rainfall and wash downs or from condensation. The chemistry and properties

of the insulation also play a role in CUI. The insulation material may wick or absorb water thus providing the required aqueous environment for electrochemical reactions to take place. Furthermore, the chemicals within the insulation such as chlorides and sulfates, may leach into the electrolyte causing an acceleration in the corrosion.

Role of Temperature

The temperature of the metal surface plays an important role with regard to CUI In general. <u>Increasing </u>temperature increases the rate at which electrochemical reactions take place thus increasing the corrosion rate. Further increase in temperature will reduce the corrosion rate due to the lack of a corrosive environment as water evaporates. However, as water evaporates, the concentration of corrosive species on the metal surface increases Furthermore, high temperatures reduces the service life of protective coatings and sealants.

The effect of temperature on corrosion of steel in water is shown in Figure 1.[3] In an open system, the oxygen concentration in water decreases with increasing temperature, thus decreasing the corrosion rate. In contrast, the corrosion rate in a closed system increases with increasing temperature. The field measurements on CUI (see Figure 1) represents somewhat similar corrosion behavior as in a closed system.

EXPERIMENTAL PROCEDURES

Test Apparatus - CUI cell

The CUI cell was designed to simulate the corrosion under insulation on the outer surface of ring specimens which were machined from a pipe section. The schematic diagram of the designed CUI test cell for laboratory simulation of CUI in a pipe section is detailed in Figure 1.

This cell consisted of six ring specimens which were separated by insulation spacers. The insulation material used for the spacers was a polytetrafluoroethylene resin. The testing section which included alternate rings of insulation and pipe material was held together by two blind flanged pipe sections on both ends. Three pipe clamps were used to hold the cell set-up together. The test temperature at the ring surfaces were achieved via an immersion heater incorporated to the inside of the pipe section which was filled with a thermal conductive silicone oil. A block of thermal insulation placed above the testing section provided the annular space to retain test environment (see Figure 2). The insulation used was a water resistant molded perlite type with a low concentration of chloride (35-40 ppm).

Commercially available two inch carbon steel pipe, grade A106B, was used for the construction of the CUI cell. The test specimens, rings of thickness 0.187 inches were machined from the same A106B pipe. The test environment selected was an aqueous solution containing

100 ppm chloride with pH adjusted to 6 (with H_2SO_4) in order to simulate atmospheric condensate.'

One half of the outer surfaces of the ring specimens were exposed to the test environment during the testing (see Figure 1). The test solution was pumped into the annular space between the thermal insulation and the outer surfaces of the ring specimens through two ports. The ring specimens were used as test electrodes in two separate electrochemical cells. The two electrochemical cells were separated by placing a dam (ring of 3.0 inch 0. D.), machined from the same insulation material (polytetrafluoroethylene resin), at the center. In both electrochemical cells, the center ring was used for the working electrode (WE) while the other two rings were used as the counter electrode (CE) and the reference electrode (RE). Two electrochemical cells were incorporated into the CIA cell design in order to test the protectiveness provided by protective coatings compared to an unprotected surface (control) ; simultaneously.

Test Procedures

The test matrix selected for CUI cell tests is detailed in Table 1. Each test consisted of conducting measurements on the two electrochemical cells. The tests were designed to stud: the performance of the CLI cell, how well CUI can be simulated, and also to study the performance of protective coatings applied. A protective coating "A" (**RG-2400®**) which was used in this study.

On one cell (control cell), the working electrode (WE 1) was always used as the control with no protective coating treatments applied. The surface condition of the control was either as machined or pre-corroded by exposure to the test solution in a kettle for three days prior to placing in the CUI cell. The starting surface condition of the working electrode (WE^2) of the second cell was identical to that of WE 1 except that it was treated with the protective coating A. Four wicks were also placed on the surface of WE2 during the tests. The coating A was applied to the exposed surface of WE2 everywhere except where the wicks were placed. During test #3, measurements were attempted initially, without wicks in place, but were re-placed later as measurements were unable due to the lack of a conductive medium.

The test conditions selected for the tests were (1) isothermal and (2) wet/dry cycling The isothermal tests included maintaining the temperature at the ring surfaces at 150 F continuously The wet/dry tests included three cycles of maintaining temperature at 150 F (wet) for twenty_ hours followed by at 250 F (dry) for four hours.

All the ring specimens were de-Greased with acetone, dimensions were recorded and weighed prior to assembling in the CIA cell. For the test with pre-corroded surface condition, the cleaned and weighed rings (WE1, WE2 and an extra ring) were placed in a kettle containing test solution for three days. The extra ring was used to obtain the correction factor for the pre-exposure mass loss. The M cell was assembled with non-treated WE I and treated WE2 as explained above. Once the cell was assembled, the annular space between the test specimens and the insulator was

filled by the pumping the test solution using a micro-metering pump. The CUI cell was then brought to test temperature with the aid of the immersion heater.

Once test conditions were reached, electrochemical polarization resistance (PR) measurements were made on both electrochemical cells (on WE1 and WE2) using a potentiostat. The PR measurements were made every 20 minutes for three days. During the tests involving wet; dry; cycles, PR measurements were made only during the wet cycle (150 F) due to the lack of an electrolyte at 250 F. The tests were terminated after three days and the cell was disassemble:'.. The test specimens (WE I and WE2) were cleaned and after exposure weights were recorder:. The corrosion rates of the treated and non-treated rings were calculated using both electrochemical polarization resistance data and mass loss (NIL) data.

RESULTS AND DISCUSSION

Electrochemical Measurements in CUI Cell

The corrosion rates calculated based on electrochemical polarization resistance data over the entire three day exposure period are graphically represented in Figures 4-6 for tests 1-3. respectively. The corrosion rates measured towards the end of the exposure period for each test are provided in Table 2. The percent efficiency of the coating A applied based on electrochemical data are given in the last column of Table 2.

The efficiencies calculated for coating A applied to as machined ring specimens was 83 and 90 percent in isothermal (150 F) and wet/dry (150F/250F) tests, respectively. When coating A was applied to a pre-corroded specimen without any wicks, electrochemical measurements were unable to conduct due to the lack of a conductive medium (test #3). When this test was continued with wicks in place, an efficiency of 86 percent was obtained under wet/dry test conditions.

Mass Loss Data in CUI Cell

The corrosion rates calculated based on mass loss data over the three day exposure period are provided in Table 3. Here again, the percent efficiency for the coating A applied, based on mass loss data are given in the last column.

The corrosion rates calculated based on NIL data were much higher than those obtained from PR data. The mass loss corrosion rates obtained for the control (non-treated) specimen, ranged from 79 to 137 mpy in the CUI cell design, These values were somewhat similar to those of actual plant data (see Figure 1).

The efficiencies calculated for coating A based on ML data were lower than those based on PR data in most cases. The efficiencies of the protection both ML and PR data are shown in Figure 7. The efficiencies calculated based on ML data for coating A was 65 percent, when tested on an

as-machine specimen under isothermal conditions. During the wet/dry cycling tests, the coating A gave an efficiency of 79 percent when applied to an as machined specimen. The coating A applied to a pre-corroded ring and tested under wet/dry cycling conditions gave an of 70 percent.

CONCLUSIONS

1.   1.Corrosion under insulation can be simulated and the efficiency of the treatments applied can be investigated successfully in a laboratory cell.
2.   2.The electrochemical polarization resistance data provided somewhat conservative corrosion rates which were lower than actual plant data available. However, this technique provided a means to monitor variation of corrosion rate with time.
3.   3.The corrosion rates calculated from mass loss data resembled the actual plant data.
4.   Based on corrosion rates calculated from ML data, efficiencies calculated for coating, A ranged from 65 to 79 percent. Under wet/dry (15OF/250F) cycling conditions, a 10 percent decrease in the efficiency was observed for coating A when applied to a pre-corroded specimen instead of to a as-machined specimens under the same test conditions.

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6.   MTI Technical Report No- 7, "Investigation of an Approach for Detection of Corrosion Under Insulation", MTI Project #12, Phase II by 0. A. Ullrich, March 1982,

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TABLE I CUI Test Matrix

Environment:	100 ppm Cl⁻ Initial	pH adjusted to 6.0	(with H2,SO4)

| Test # | Test Conditions | Steel Surface Conditions | |
		WE1 †	WE2 ††
1	isothermal (150 F)	as machined	as machined/coating A
2	three wet/dry (1 ;0 F/250 F) cycles	as machined	as machined/coating A
3	three wet' 'dry (150 F/25OF) cycles	pre-corroded	pre-corroded/coating A

†   WE1 = Working electrode of cell 1 (control)
††   WE2 = Working electrode of cell 2 (coating -1 treated)

TABLE 2

Corrosion Rates from Electrochemical Data for CUI Tests

Environment: 100 ppm C1$^-$ Initial pH adjusted to 6.0 (with H2-S04)

Test Number	Test Conditions	Steel Surface Conditions	Duration	Corrosion	% Efficiency
1	Isothermal (150°F)	as machined	74.0	10.5	
		w/ coating A	74.0	1.8	83
2	3 Wet/Dry Cycles (150°F/250°F)	as machined	72.0	10.0	
		w/ coating A	72.0	1.0	90
3	3 Wet/Dry Cycles (150°F/250°F)	pre-corroded †	70.5	14.0	
		w/ coating A	70.5	2.0	86

† Corrected for pre-exposure weight loss.

Table 3

Corrosion Rates from Weight Loss Data for CUI Test Environment:
100 ppm Cl$^-$; Initial pH adjusted to 6.0 (with H$_2$SO$_4$)

Test Number	Test Conditions	Steel Surface Conditions	Duration	Corrosion	% Efficiency
1	Isothermal (150°F)	as machined	74.0	79.0	
		w/ coating A	74.0	27.5	65
2	3 Wet/Dry Cycles (150°F/250°F)	as machined	72.0	137.0	
		w/ coating A	72.0	29.3	79
3	3 Wet/Dry Cycles (150°F/250°F)	pre-corroded †	142.5	77.2	
		w/ coating A	142.5	23.5	70

† Corrected for pre-exposure weight loss.

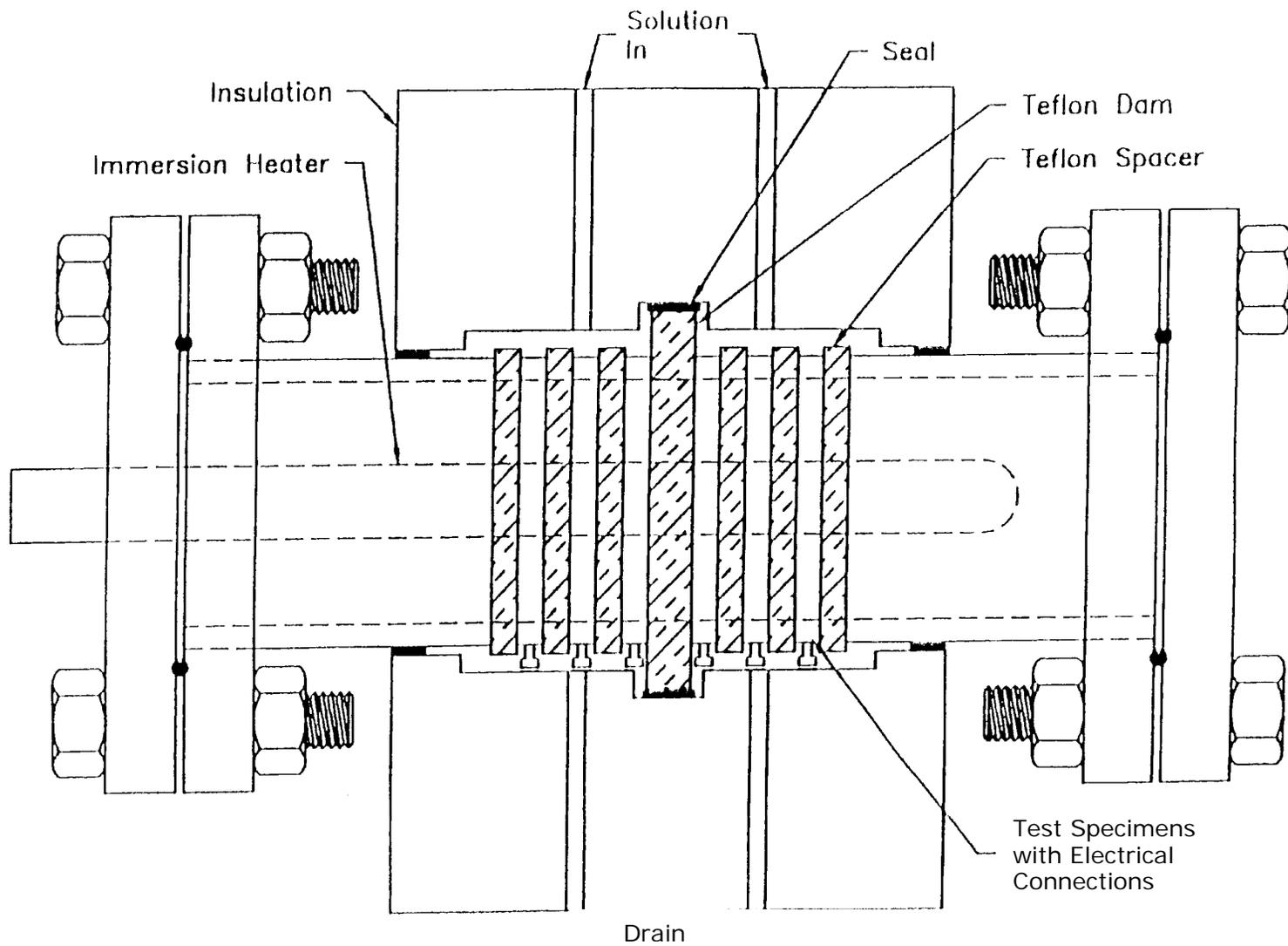**Figure 1 – Effect of temperature on corrosion of steel in water**
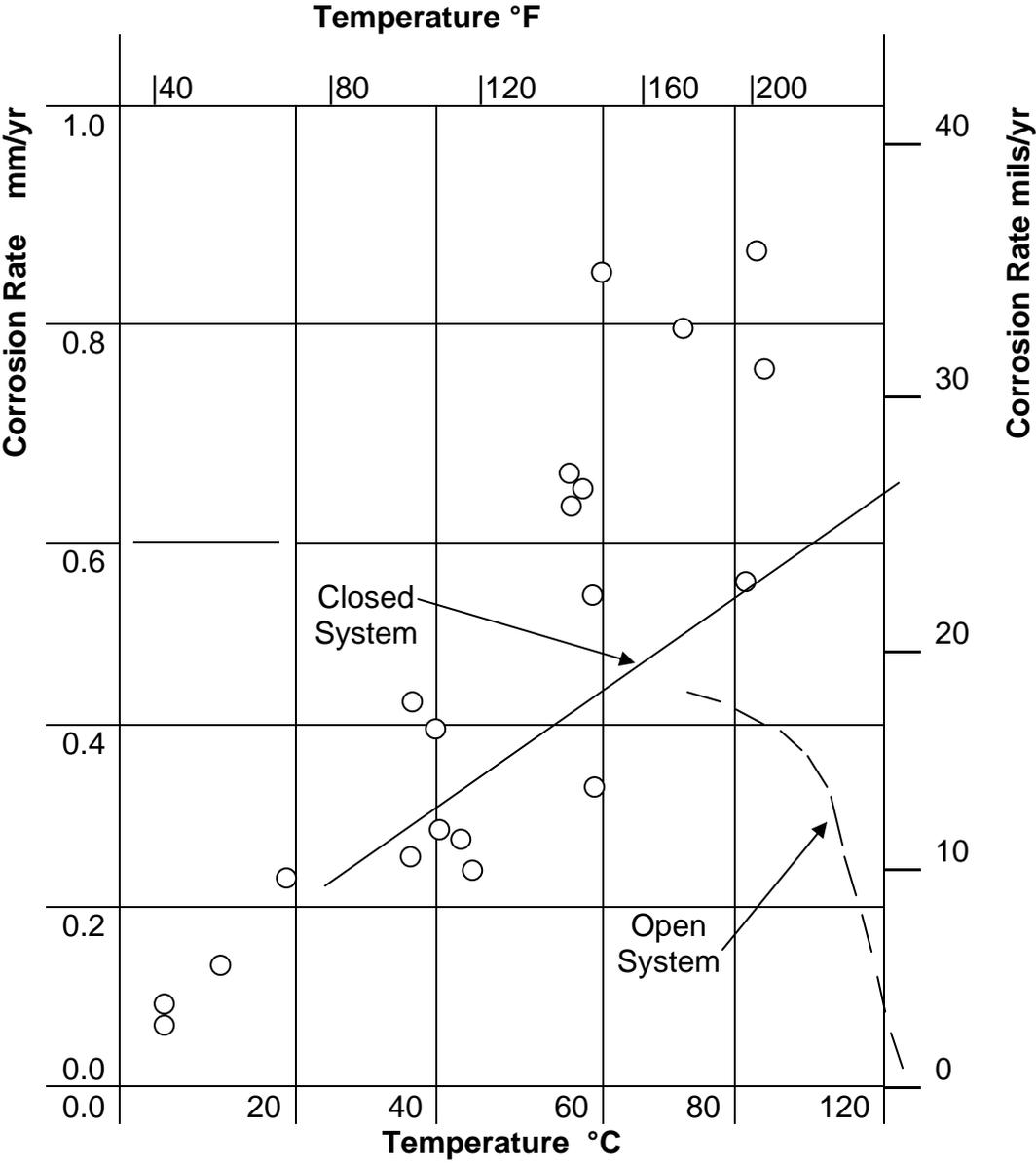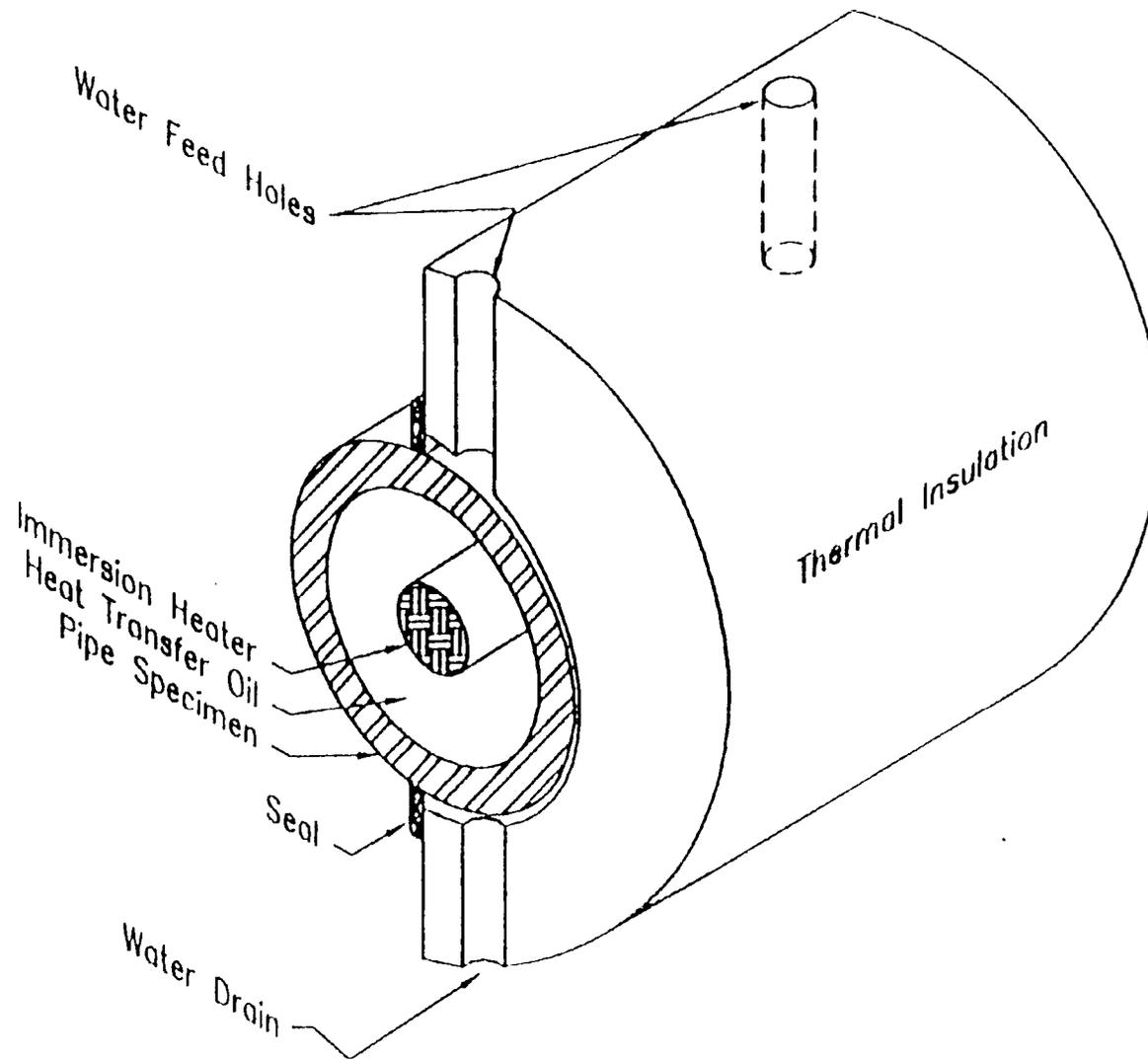
Figure 2 - Schematic diagram of CUI cell

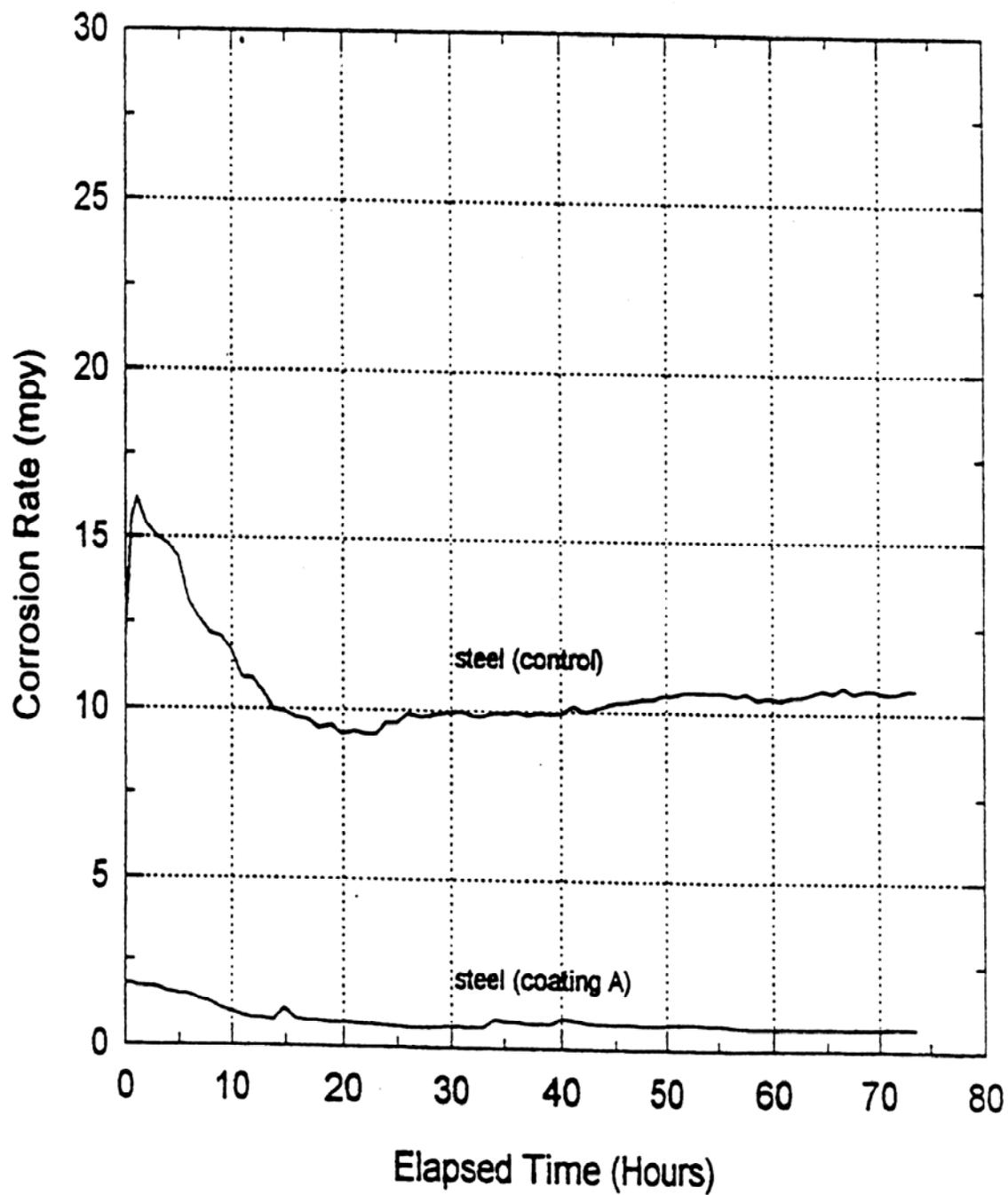*Figure 11 - A cross-sectional view of the CI Ul cell*

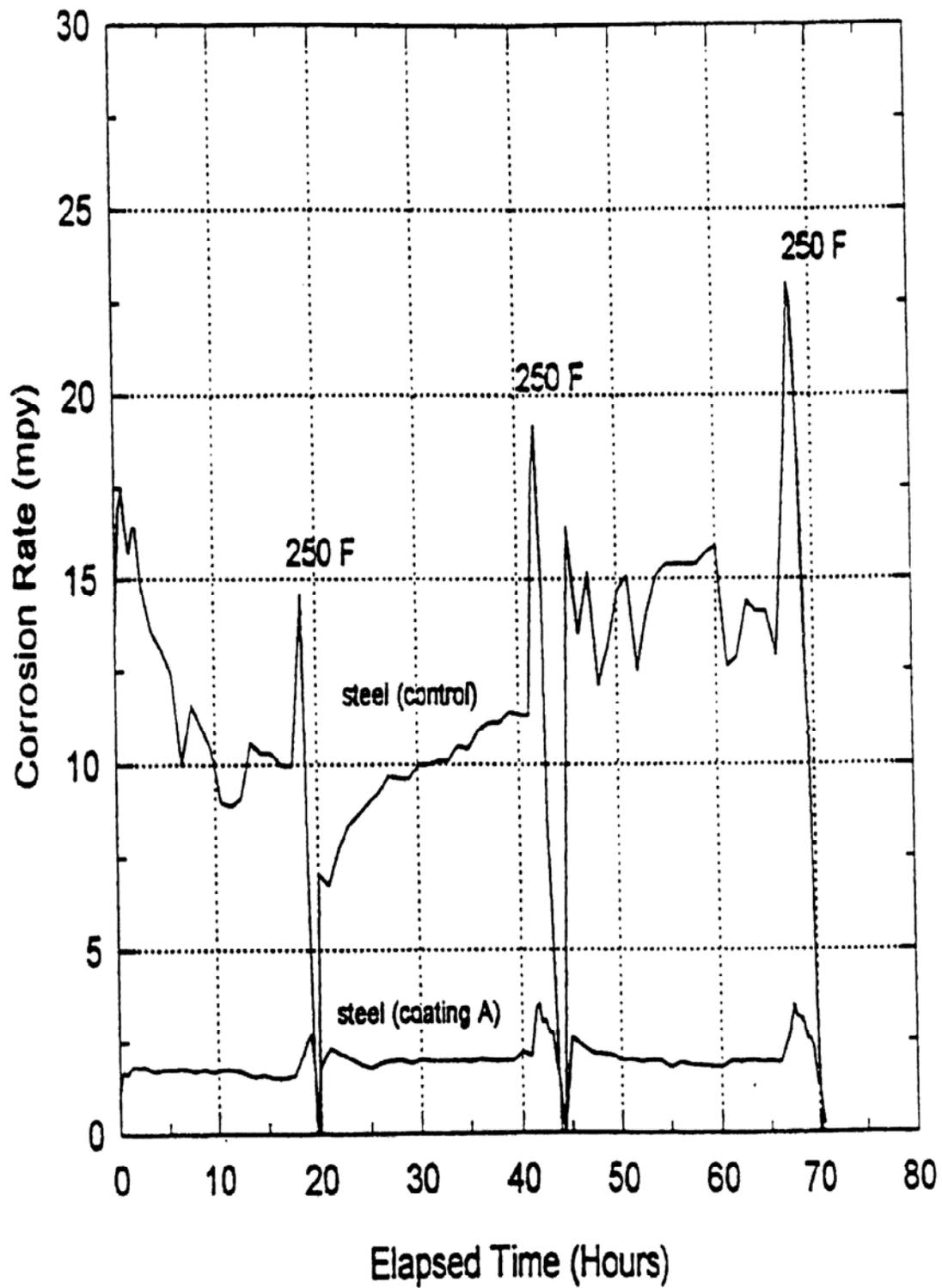Figure 4 - Corrosion rates obtained for the control and treated specimens during isothermal test (150 F)

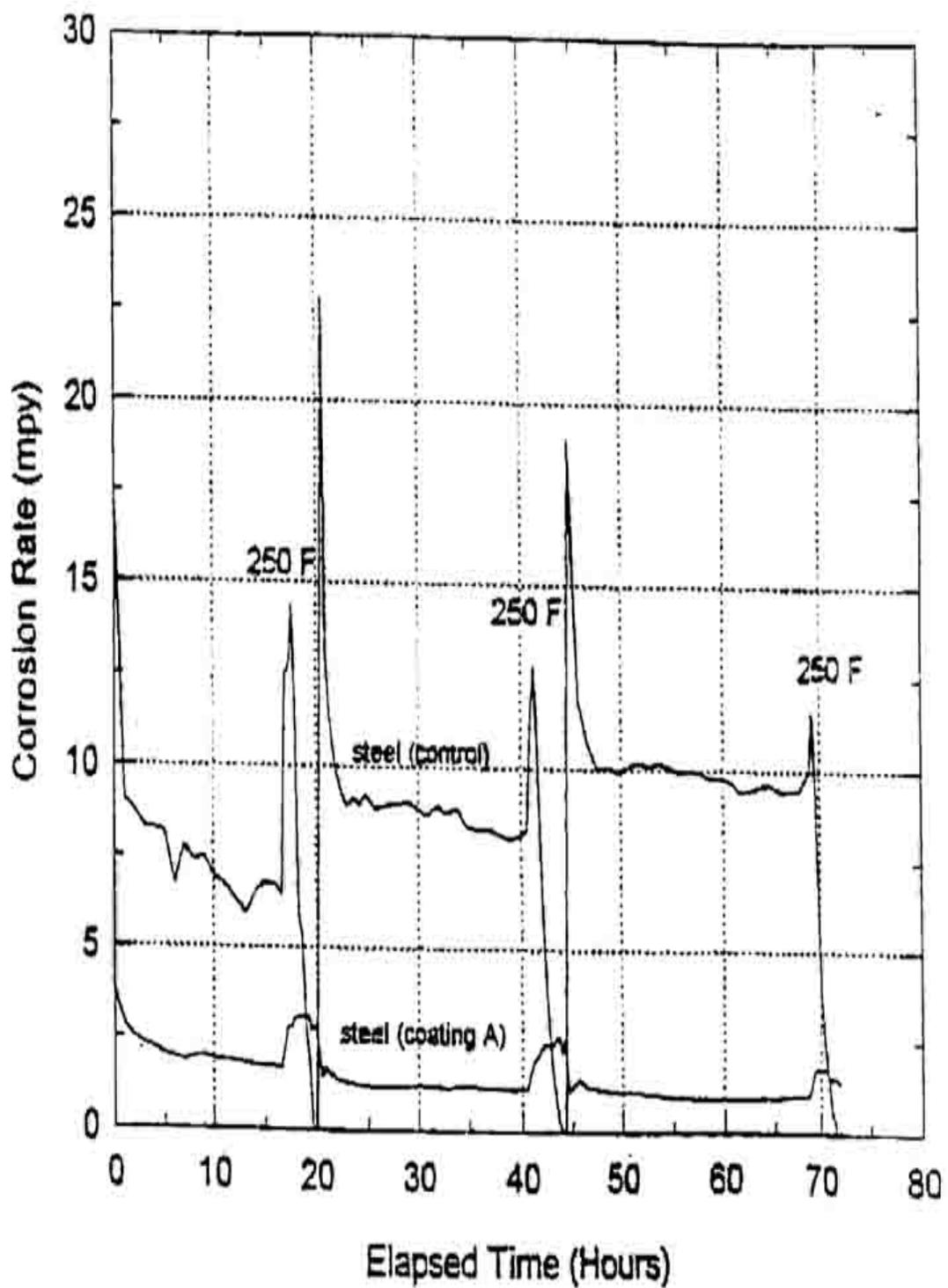Figure 5 - Corrosion rates obtained during cylic test (150F/250F; machined surfaces)

Figure 6 - Corrosion rates obtained during cylic test (150F/250F; pre-corroded surfaces)
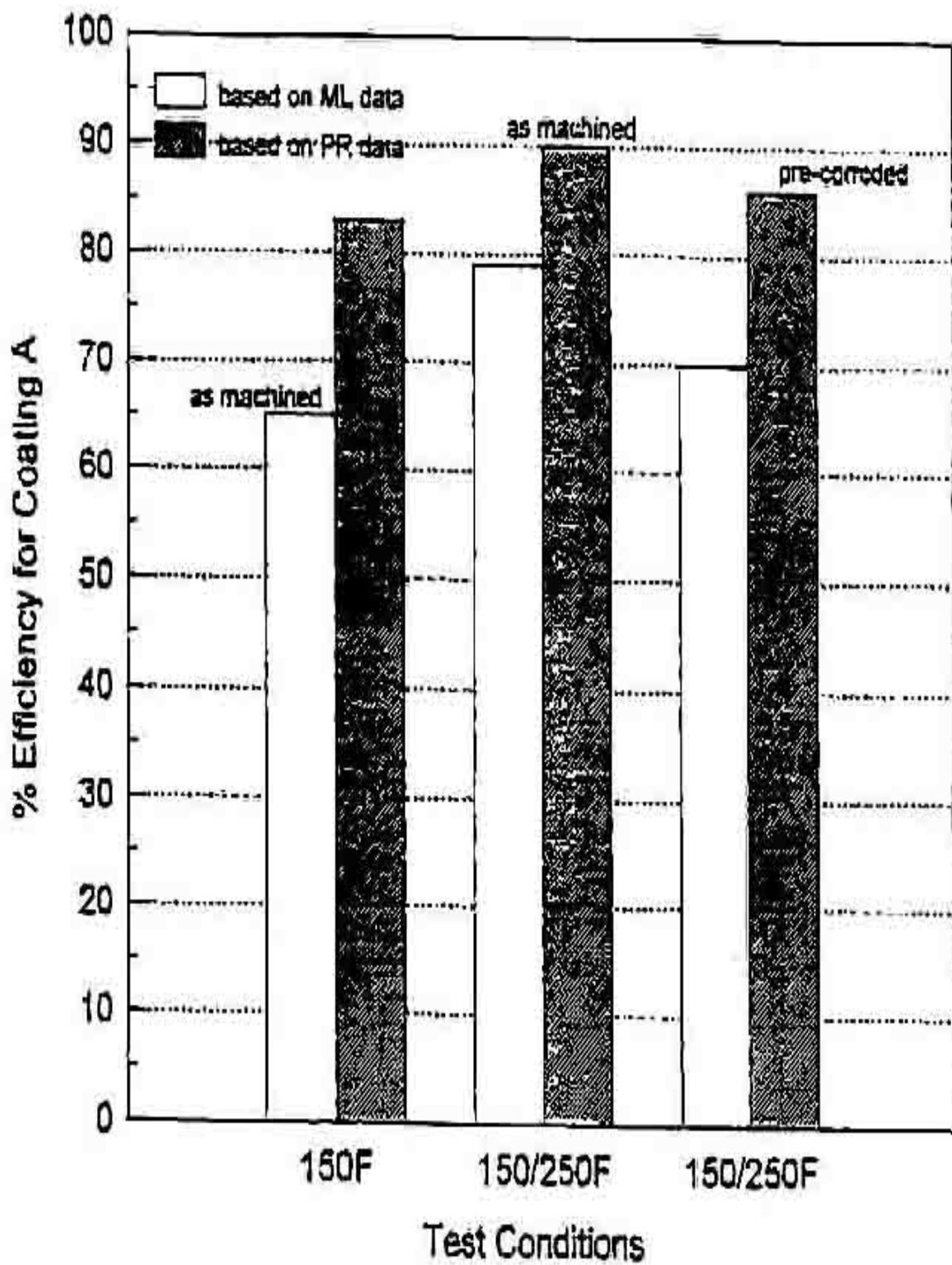
Figure 7 - Percent efficiency calculated for coating A under isothermal and wet/dry conditions