1. INTRODUCTION

Pennsylvania Power and Light (PP&L) and Jacksonville Electric (JE) are presently using Arcor S-16 lining for corrosion protection in a variety of locations such as cooling towers, water boxes, and tubesheets. The coating has shown repeated failures in areas where a temperature gradient exists between a cold substrate and relatively warm fluid ("cold wall" blistering). The temperature gradient accelerates the rate of water permeation through the coating (toward the cooler substrate) which promotes substrate corrosion and subsequent delamination.

Results from a recent inspection of blistered coating sections on the reactor building closed cooling water heat exchanger at PP&L's Susquehanna Steam Electric Station are presented in the Appendix. Coating delamination as described by those results has consistently occurred with the Arcor lining at PP&L on the warm side of substrate surfaces which separate relatively warm and cold fluids, and also on warm substrate surfaces which separate warm fluid and cooler air. JE has reported similar circumstances, and an atlas cell test[1] conducted on the coating at a water temperature of 130-135°F (outside ambient air temperature) resulted in blistering in 90 days of exposure. These observations indicate that Arcor lining is susceptible to cold wall blistering. Further testing of the Arcor lining is required to provide a better understanding of temperature gradients which can be tolerated by the coating while still providing useful service life. In addition, other comparable coatings need to be evaluated under similar temperature gradients in order to identify materials which may be more resistant to this form of degradation. This proposal outlines a test program for testing the susceptibility of Arcor and other candidate linings to cold wall blistering. Results of the test program should provide information which can be applied to 1) determine service environments where the Arcor lining will provide adequate as well as inadequate service life and 2) provide a ranking of candidate materials' resistance to cold wall blistering for selection of coating materials.

1. Atlas Testing and Cathodic Disbondment (of Arcor Lining), Laboratory Investigation, KTA-TATOR, Inc., Pittsburgh, PA, December 7, 1990.

2. PROPOSED TEST PROGRAM

2.1 *Objective*

Conduct modified atlas cell testing of Arcor and other candidate coatings to 1) determine service environments where the Arcor lining will provide adequate service life and 2) develop a ranking of candidate materials' resistance to cold wall blistering for use in selecting coating materials.

2.2 *Workscope*

There are two general operating conditions which may induce a temperature gradient across a coated substrate. In the first case, a temperature gradient is achieved across water-to-water conditions, i.e., the coated substrate is in contact with water of different temperatures on each side. In the second case, a thermal gradient is achieved with warm water on one side of the coated substrate and cooler air on the other side. The rate of water permeation generally increases with increased thermal flux through the substrate. Since water has a higher specific heat than air, the former case generally promotes higher permeation rates and corresponding decreased coating life. The test program must evaluate each of these conditions.

The test will consist of a modified version of NACE Standard TM0174-74. An apparatus capable of satisfying water-to-water and water-to-air conditions is shown schematically in Figure 1. An atlas cell (constructed of glass) is fitted with coated panels at each end. Each panel is 8" x 8" square x ≈0.25" thick (carbon steel), and the atlas cell is 6" in diameter. To the left side, a panel is coated on one side to achieve water-to-air conditions. To the right, a panel coated on both sides is positioned between the atlas cell and a water jacket to achieve water-to-water conditions. Tap water is continuously circulated through the jacket to maintain the desired temperature gradient. The outside water and air temperatures are held at approximately 75°F. The atlas cell is fitted with two ports to accommodate a condenser and thermometer.

Four solution temperatures will be employed: 85, 100, 115, 130°F. This will induce respective temperature gradients of 10, 25, 40, and 55°F. The test solution will be heated via an electrical heating mantle or tape wrapped around the cell exterior. The cell will be filled to approximately 3/4 capacity with test solution so that both water and vapor conditions are achieved. A standard test solution must be used for each test. Obviously, water chemistry can vary significantly from utility to utility. A standard solution will need to be decided upon based on the water chemistry of utilities which are involved in the test program. The test solution will be changed approximately once a month.

Four brand name coatings will be exposed to the conditions stated above: The Arcor S-16 coating presently being used by PP&L and JE, a new coating being developed by Arcor, a Plastocor coating, and a Palmer coating. Thus, a total of 16 individual test cells are required for the program (4 coatings x 4 test temperatures). All coated samples should be prepared under field conditions as per manufacturers recommendations.

Pre-test evaluations will include coating thickness measurements per ASTM G12, photographic documentation of as-applied coatings to be used for comparison after coatings are exposed, and total organic content (TOC) of the test solution. Potential measurements (shown schematically in Figure 4) will be acquired on a weekly basis to detect the occurrence of substrate corrosion. A saturated calomel electrode (SCE) will be used as the reference electrode. Scheduled detailed evaluations will be conducted approximately once a month, depending on the rate of blistering as determined by daily visual observations. At these detailed evaluations, the panels will be removed for visual inspection (documented by photography), and the degree of blistering will be determined at each evaluation by quantitative image analysis. Blistering will be measured as total blistered area and blistering frequency (number/unit area). The test solution will be changed at each evaluation. Test solutions removed from the cell will be analyzed for TOC to determine if any constituents have leached out of the coating. The test panels will be exposed for up to one year. At the conclusion of the test, the panels will be evaluated as described above. In addition, the coating will be removed to evaluate the degree of coating degradation and substrate corrosion. Results will be documented as previously mentioned.

2.3 Deliverables

Results of the test program will be summarized in a final report to be submitted to involved utilities. Intermediate reports of preliminary results will also be prepared. The final report will contain detailed descriptions of testing procedures; pre-test results such as coating thickness and pre-test coating conditions; and results from scheduled evaluations. Quantitative data from scheduled inspections will be presented in graphical form where appropriate, e.g., blistering frequency with time. A discussion of results for applying test data to the selection of coating materials will be included.

2.4 Schedule

The test program can be divided into three sequential steps. The approximate time required for completion of each task is presented below in Table 1. The program will require approximately 16 months to complete.

Table 1. Approximate schedule for coatings evaluation program.

TASK:	MONTH: Start	2	4	6	8	10	14	16
Experimental Set-Up/ Sample Preparation	██	██						
Sample Exposure/ Data Collection		██	██	██	██	██	██	
Data Analysis/ Report							██	██

3. BUDGET

The budget required to evaluate four coatings is listed below in Table 2. The budget required to evaluate one coating is also presented in Table 3 for PP&L's information.

Table 2. Budget requirement for evaluation of four coatings.

Equipment	$25,000
Equipment Usage	
Photography	
Quantitative Image Analysis	$5,000
Salaries	
Research Engineer (3 months)	
Technician (4 months)	
Employee Benefits (30%)	$27,950
TOTAL	$57,950
Indirect Costs	
(61% of Equipment Usage and Salaries)	$20,100
GRAND TOTAL	$78,050

Table 3. Budget requirements for evaluation of one coating.

Equipment	$6,250
Equipment Usage	
Photography	
Quantitative Image Analysis	$1,250
Salaries	
Research Engineer (1 month)	
Technician (2 months)	
Employee Benefits (30%)	$10,400
TOTAL	$17,900
Indirect Costs	
(61% of Equipment Usage and Salaries)	$7,100
GRAND TOTAL	$25,000

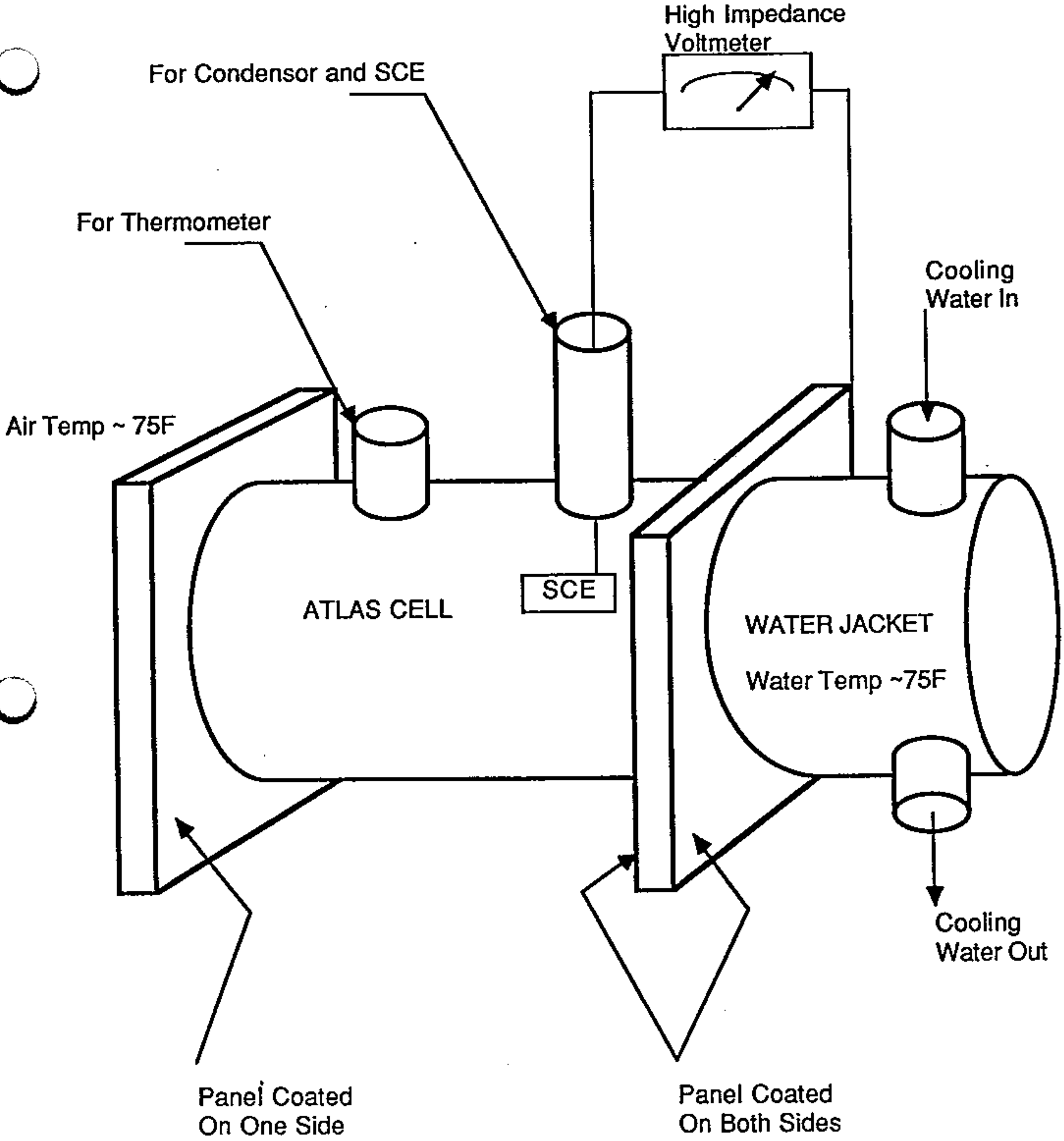

FIGURE 1. Test cell to achieve water-to-water and water-to-air conditions for testing of protective coatings.

APPENDIX

INSPECTION OF A BLISTERED COATING AT SUSQUEHANNA STEAM ELECTRIC STATION

Prepared for Pennsylvania Power and Light

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November 15, 1991

1. EXECUTIVE SUMMARY

An inspection of a delaminated heat exchanger coating was conducted at Pennsylvania Power and Light (PP&L) Susquehanna Steam Electric Station. Results of the inspection indicated the coating failure was caused by permeation of water through the lining. The water permeation rate through the coating was accelerated by a temperature gradient which existed across the coated substrate. A test program is presently being formulated to evaluate candidate coatings which may be more resistant to this form of degradation.

2. INTRODUCTION

PP&L is presently using Arcor S-16 lining in the circulating water system, water boxes, and tubesheets at the Susquehanna Steam Electric Station. The coating has exhibited repeated failures on the warm side of the tube sheet pass partition plates. Failure has occurred in the form of blistering and associated delamination between the coating and substrate. During a recent scheduled outage, coated sections of the reactor building closed cooling water (RBCCW) heat exchanger were inspected to assess the possible cause of coating failure. The RBCCW heat exchanger is coated with Arcor lining at the inlet/outlet end and on the end bell. This report summarizes the results of the inspection conducted on the RBCCW heat exchanger at PP&L.

3. INSPECTION PROCEDURE

The RBCCW heat exchanger inlet/outlet and end bell was visually inspected while the coating was being removed for replacement. Photographs were taken before and after removal of the coating in areas which contained well-bonded and blistered coating. Bonded and blistered coating samples were removed from the inlet/outlet end cover for further inspection. The interface surfaces of these samples were examined by stereomicroscopy and scanning electron microscopy.

4. RESULTS AND DISCUSSION

Figure 1 shows the heat exchanger end bell after the Arcor lining was removed. The top half of the end bell is shown in Figure 1a, and the bottom half is shown in Figure 1b. The white marks represent locations where the lining was well bonded to the end bell and had to be removed with a chisel. The area free of these marks contained coating which was completely separated from the end bell and could be removed from the substrate by hand with minimal force. Inspection of Figure 1b indicates that the coating was well bonded to the bottom of the end bell and the bottom of the pass partition plate where cold inlet water circulates. In contrast, Figure 1a shows that the coating was completely disbonded on most of the top half of the end bell and all of the partition plate top surface where the warmer water is circulated (area outlined by arrowheads in Figure 1a). Figure 2 shows the same characteristics at the heat exchanger inlet/outlet end: the coating on the surfaces of the outlet partition (warm water circulation) has completely disbonded while the remaining surfaces contained bonded coating. Figure 3a shows the inlet/outlet cover before the coating was removed from the outlet section. The coating is obviously severely blistered. Figure 3b shows the coating immediately after removal. The coating was easily stripped from the cover by hand. The dark appearance on the freshly removed coating and substrate surface is due to the presence of water between the coating and substrate, clearly indicating that water has permeated the lining. Evidence of blisters are apparent on both sides of the coating and the cover surface.

Figure 4 shows stereomicroscope photographs of blistered and bonded coating samples which were removed from the inlet/outlet cover. The blistered sample is shown in Figure 4a, and the bonded coating is shown in Figures 4b and 4c. Figures 4a and 4b were taken at identical magnifications. Figure 4c is a higher magnification photograph of the bonded coating surface. The outline of blisters (arrowheads) and presence of corrosion products are visible on the blistered coating (Figure 4a). The bonded coating contains only clean metal which was stripped from the cover surface during removal of the sample. Figure 5 shows scanning electron micrographs of these samples. The blistered coating sample is shown in Figure 5a, and the bonded sample is shown in Figure 5b. Again, the bonded coating shows a clean surface appearance with no indications of degradation while the blistered coating contains corrosion products covering the surface.

These observations confirm previous indications[1] that Arcor lining is susceptible to water permeation when temperature differentials exist between a cold substrate and warm fluid (commonly referred to as "cold-wall" blistering). The disbonded areas of the heat exchanger conform to this condition. For example, the outlet partition contains the warmest water while the surrounding partitions contain cooler water. The temperature gradient across the partition plate promotes accelerated water permeation through the coating towards the cooler substrate which leads to substrate corrosion and destruction of the bond between the coating and substrate.

5. CONCLUSIONS/FUTURE WORK

The Arcor lining exhibited typical characteristics of cold wall blistering. Further testing of the Arcor lining should be conducted in order to provide a better understanding of the temperature gradients which are required to promote accelerated permeation and associated coating failure. In addition, other comparable coatings should be tested under similar temperature gradients in order to identify materials which may be more resistant to this form of degradation. The Energy Research Center is presently developing a test program for PP&L to address these issues.

1. Atlas Testing and Cathodic Disbondment (of Arcor Lining), Laboratory Investigation, KTA-TATOR, Inc., Pittsburgh, PA, December 7, 1990.

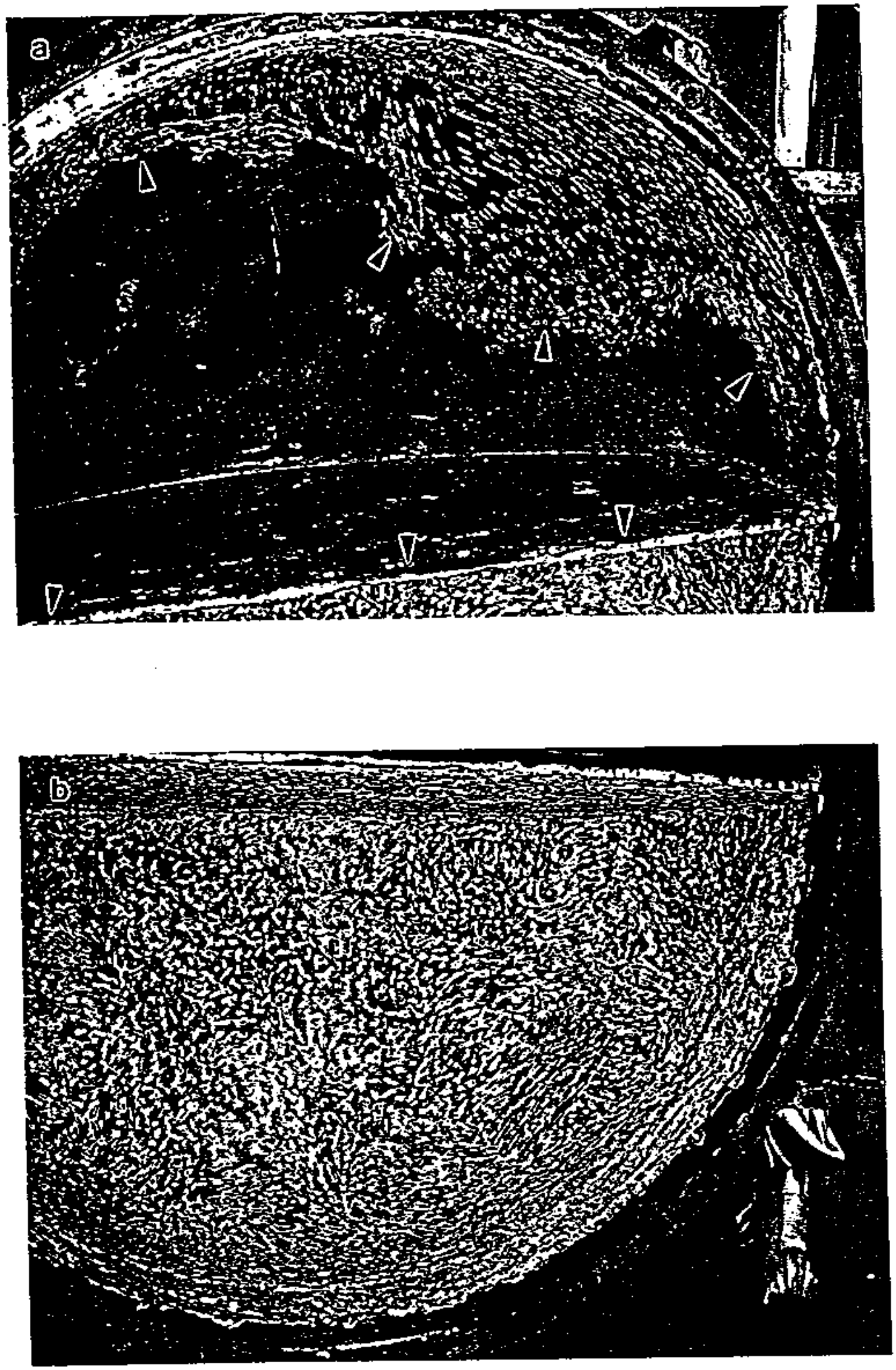

Figure 1. Heat exchanger end bell after the Arcor lining was removed. The top half of the end bell is shown in Figure 1a, and the bottom half is shown in Figure 1b.

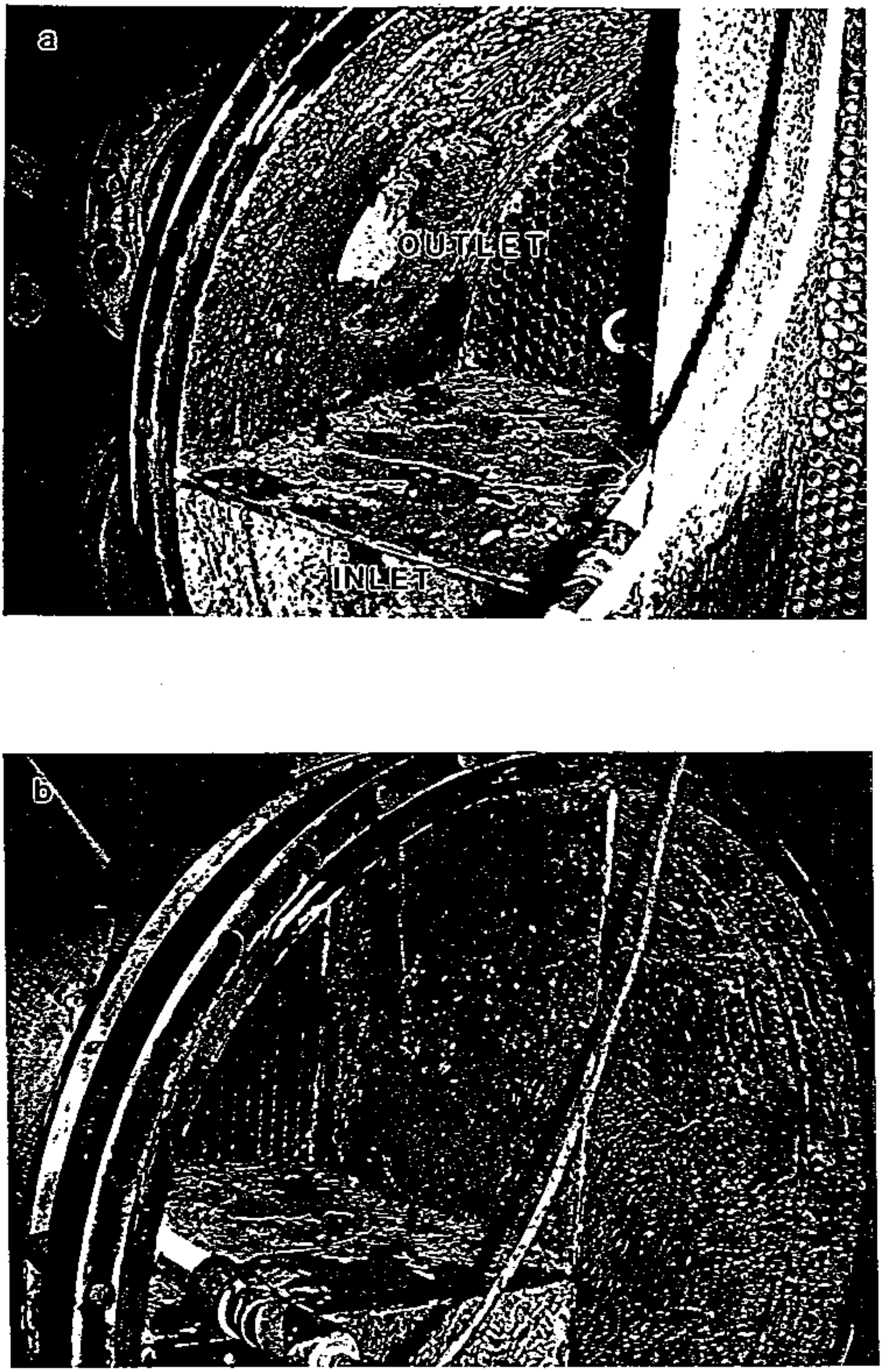

Figure 2. Heat exchanger inlet/outlet end. The coating on the surfaces of the outlet partition (warm water circulation) have completely disbonded while the remaining surfaces contained bonded coating.

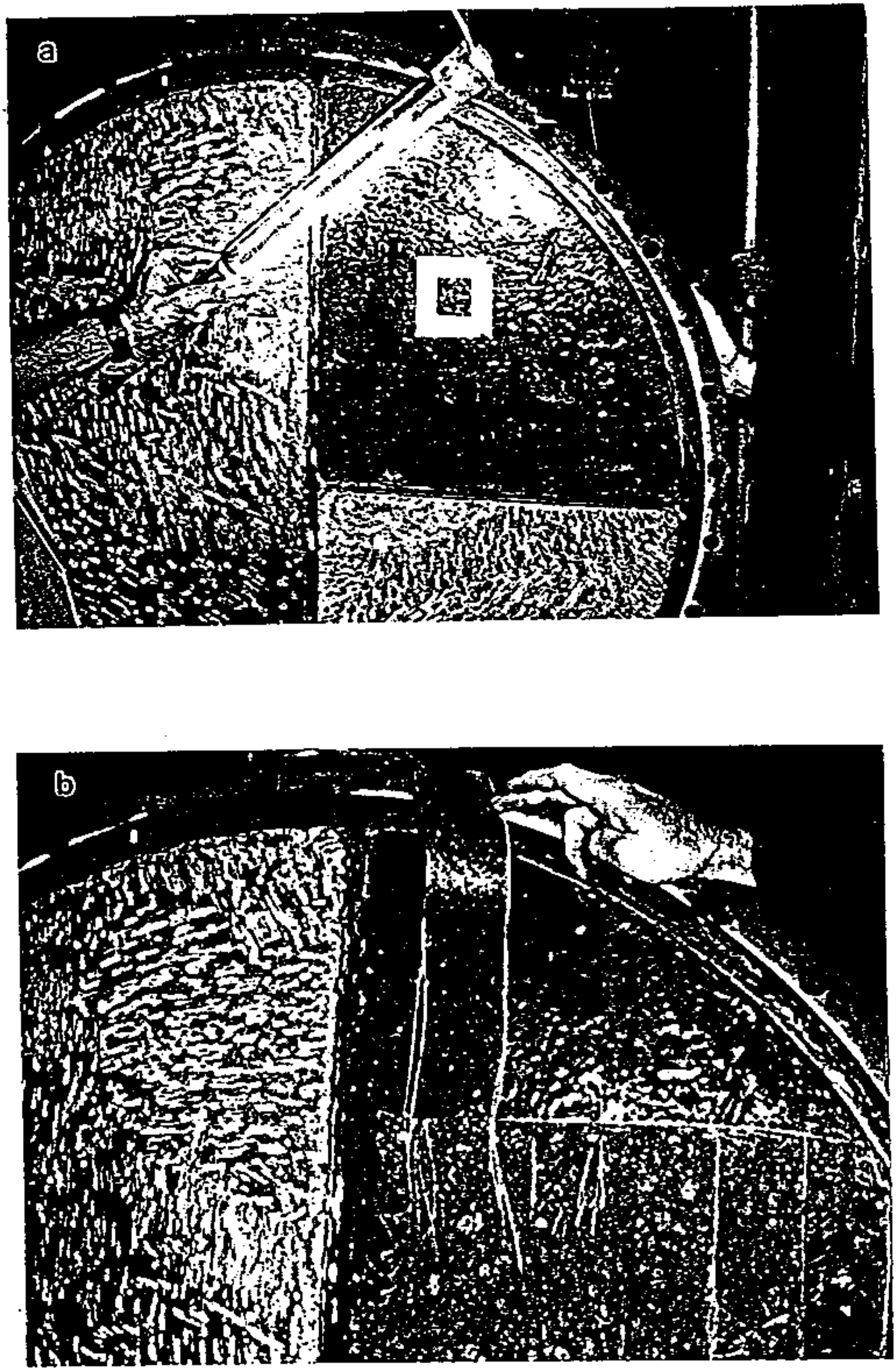

Figure 3. Inlet/outlet end cover. Figure 3a shows the cover before the coating was removed from the outlet section. Figure 3b shows the coating immediately after removal.

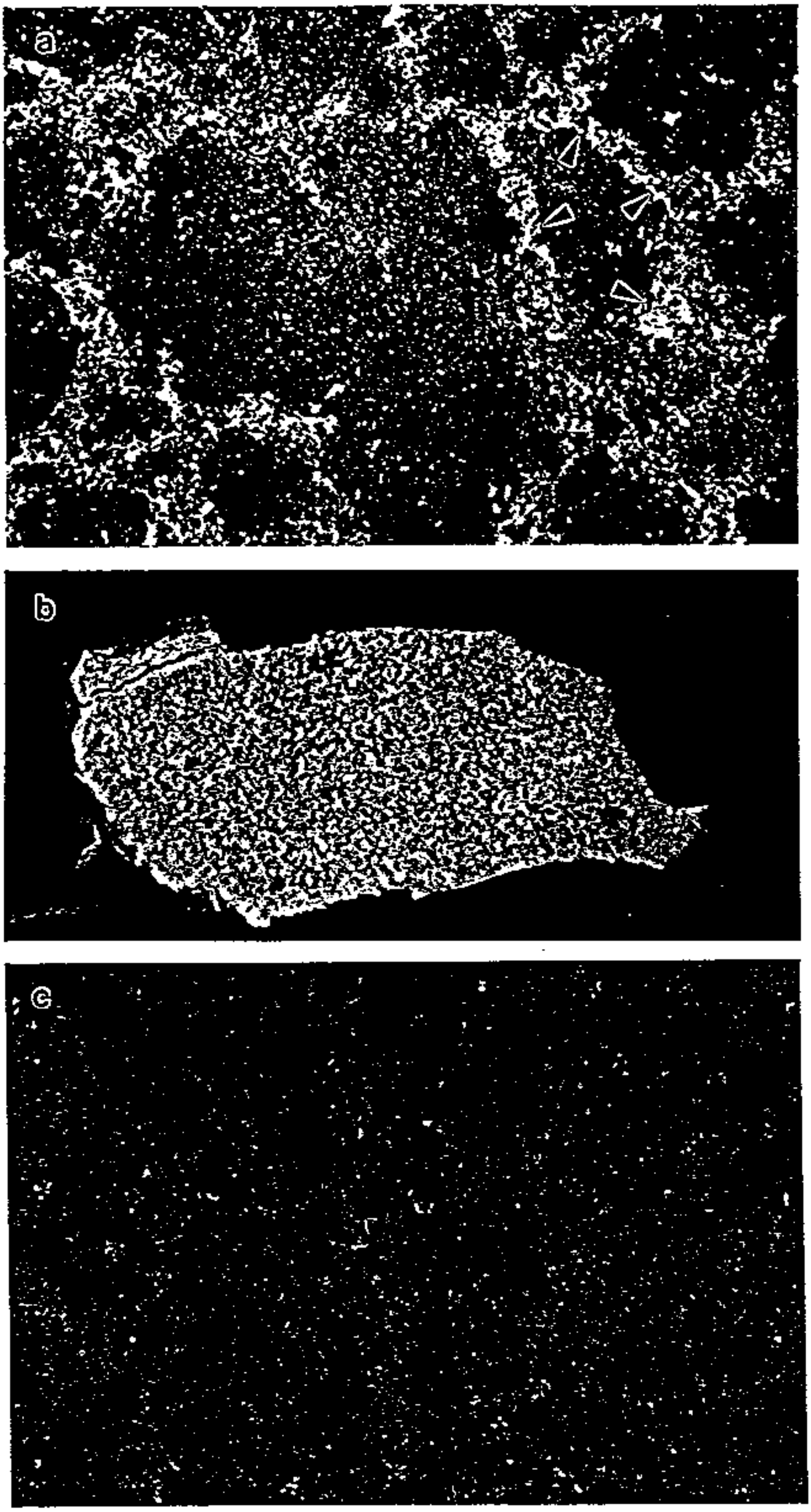

Figure 4. Stereomicroscope photographs of blistered and bonded coating samples which were removed from the inlet/outlet end cover. The blistered sample is shown in Figure 4a, and the bonded coating is shown in Figures 4b and 4c. Figures 4a and 4b were taken at identical magnifications. Figure 4c is a higher magnification photograph of the bonded coating surface.

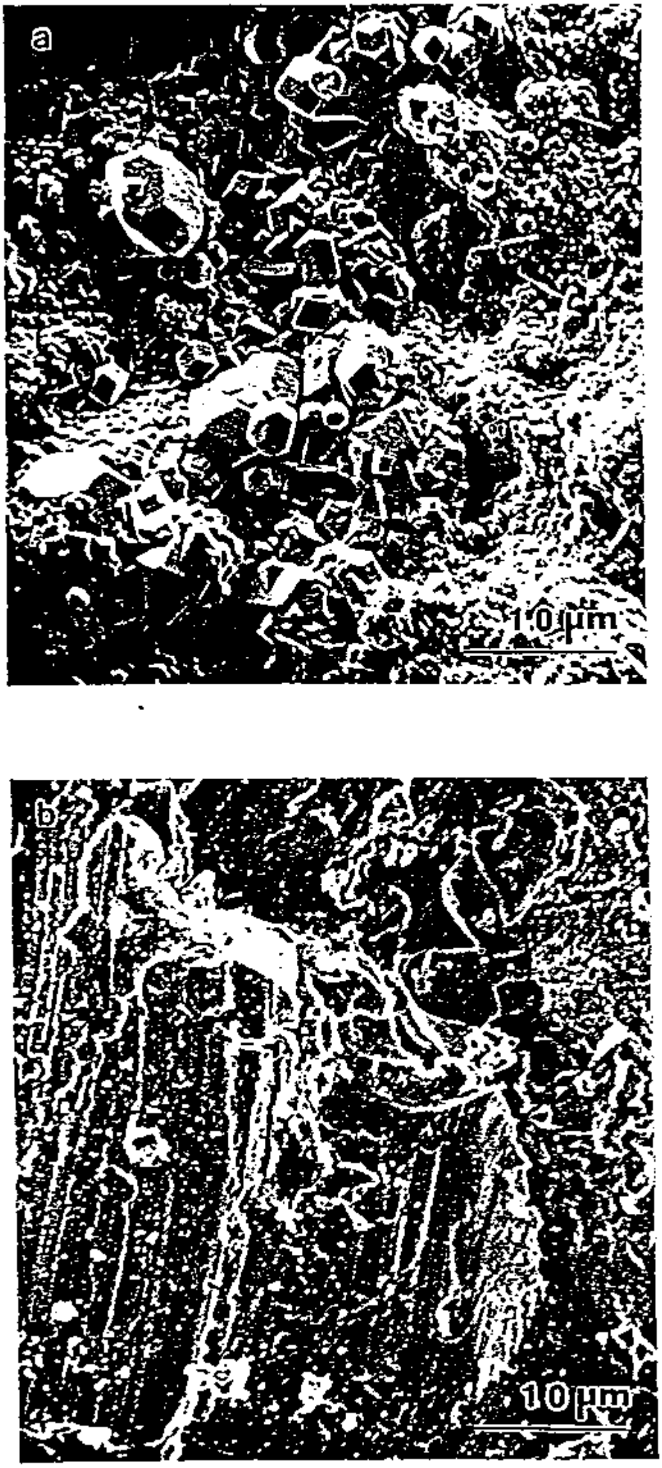

Figure 5. Scanning electron micrographs of coating samples. The blistered coating sample is shown in Figure 5a, and the bonded sample is shown in Figure 5b.