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Submarine Biofouling Control-Chlorination DATS Study at Pearl Harbor

JOHN WEGAND
KEITH LUCAS
TIM JACKOVIC
PAUL SLEBODNICK
JAN BERGH
E. DAIL THOMAS

Center for Corrosion Sciences and Engineering
Chemistry Division

D. KENNETH CHRISTIAN

CHEMCorr
Fredericksburg, VA

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J. Wegand, K. Lucas, T. Jackovic, P. Slebodnick, J. Bergh, E.D. Thomas, and D.K. Christian*

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Naval Research Laboratory
4555 Overlook Avenue, SW
Washington, DC 20375-5320

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*CHEMcorr, Fredericksburg, VA

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13. ABSTRACT (*Maximum 200 words*)

The intent of this document is to sumarize the chlorination studies performed at Naval Station, Pearl Harbor in support of biofouling control initiatives for the submarine community, as requested by NAVSEA 92T. The document is a compilation of the status reports, as well as a comprehensive summary of the data collected/analyzed reviewing the concerns and recommended approaches for the submarine community on the implementation of chlorine to control biofouling at Pearl Harbor.

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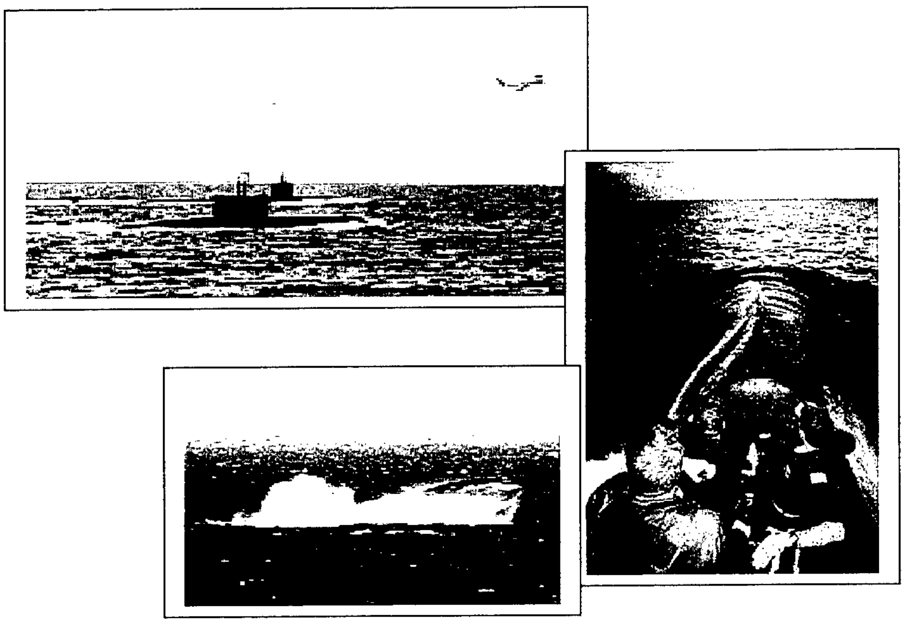

John Wegand
Keith Lucas
Tim Jackovic
Paul Slebodnick
Jan Bergh
E. Dail Thomas

Naval Research Laboratory
Washington, DC

D. Kenneth Christian

CHEMCorr
Fredericksburg, VA

Naval Research Laboratory

Washington, DC ✻ Stennis Space Center, MS ✻ Monterey, CA

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SUBMARINE BIOFOULING CONTROL- CHLORINATION DATS STUDY AT PEARL HARBOR

BACKGROUND

The Naval Research Laboratory (NRL) has been investigating and developing chlorination methods to control biological fouling (biofouling) in ship seawater systems. As part of these efforts, a Deposit Accumulation Testing System (DATS) was installed at the Sierra 15 mooring site in SUBASE Pearl Harbor. The DATS test was designed to evaluate the accumulation of biofouling on heat exchanger materials in environments representative of shipboard conditions. This was accomplished by measuring the change in heat transfer resistance on a model heat exchanger tube due to the buildup of biofouling over time. The DATS test in Pearl Harbor was used to evaluate the effect of biofouling on titanium heat exchanger materials being implemented on the MOD-25 SSN 688 class submarines homeported at Pearl Harbor as well as to establish chlorination levels, for control of biofouling. This test will also assist in the determination of dechlorination requirements chemical injection rates to ensure an environmentally acceptable chlorine discharge into Pearl Harbor.

TEST DESIGN

A modular DATS test assembly (Figure 1) was constructed, which could provide and regulate a test environment typical of SSN 688 Class seawater system conditions. Three DATS model heat exchangers equipped with CP-2 titanium tubes were employed at Auxiliary Sea Water (AWS) operating conditions typical of SSN 688 Class while import. An additional DATS heat exchanger with 70/30 copper-nickel (CuNi) tubing was also installed to gather information on ASW fouling for this material. The 70/30 CuNi DATS unit was installed with a zinc anode to provide cathodic protection to simulate current service conditions. In order to determine chlorine treatment parameters necessary to control biofouling on SNN 688 MOD-25 Class Ships while in port, liquid chlorine (sodium hypochlorite) was selectively injected into some of the seawater feeds for the titanium heat exchanger tubes. Chlorine was designed for daily operation, 2 hours per day as is required by SUBASE Pearl Harbor regulations. Heat exchanger tube heat input was set at 1,200 BTU. A submersible pump was used to provide continuous, raw seawater. The DATS Test Platform Piping Schematic has been provided in Figure 2.

Installation of the DATS test assembly was accomplished during the period 09-14 February 1997. An initial DATS "break-in" test run was conducted to determine the baseline biological fouling responses for CP-2 titanium and 70/30 CuNi under typical, in port SSN 688 Class ASW operations. Further, the effect of chlorination on titanium was

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also examined in two units at two injection levels, 0.1 mg/L and 0.2 mg/L total residual oxidant (TRO). The seawater flow was set to 4.0 ft/sec. The initial break-in test phase allowed any bugs to be worked out of the DATS platform prior to testing. The standard "biofouling" heat transfer resistance (R_f) threshold of 0.0003 Hr ft^2 ^oF/BTU was utilized to mimic R-114 condenser heat transfer design criteria.

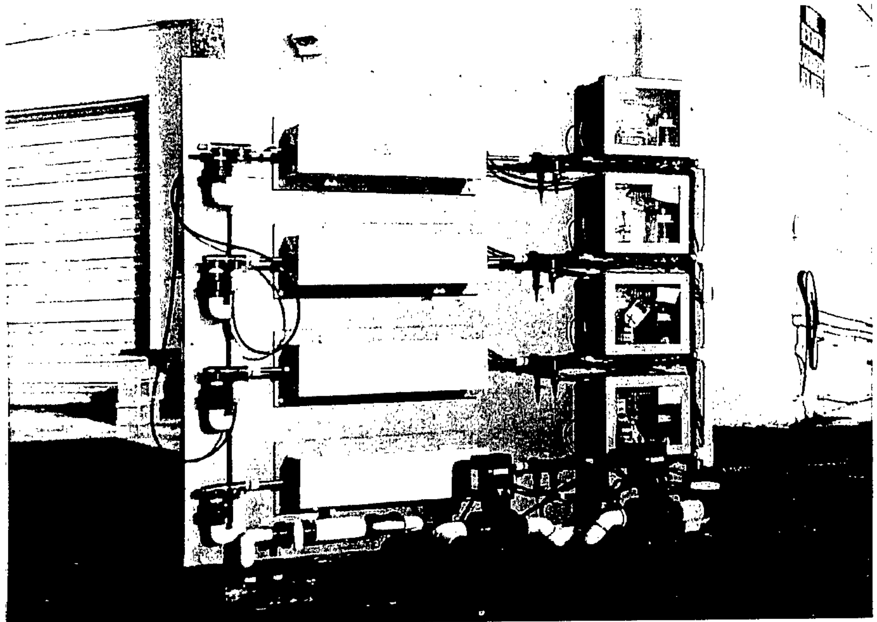

Figure 1 The DATS configuration utilized in the Pearl Harbor Fouling Study consisted of 4 DATS units on a palletized back-plane allowing for quick setup to operation.

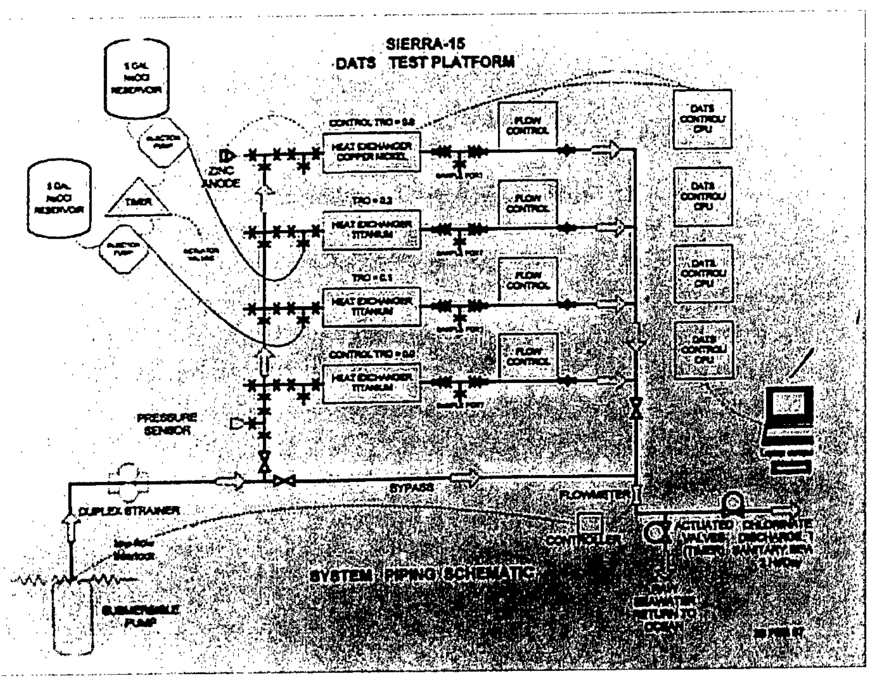

Figure 2 This piping schematic was used for the SIERRA-15 DATS Test Platform.

RESULTS

Summary results for each DATS testing phase conducted at the Sierra –15 test site SUBASE Pearl Harbor are presented below. Table 1 documents total testing time achieved during DATS testing; a total of 248 days of testing was accomplished at the Sierra –15 test site location. Some test runs were of an abbreviated nature due to intake pump failure, data acquisition failure, and/or electrical power malfunctions. Data reported in Tables 4, 6 & 8 represent those test runs that were of sufficient data quality and duration to wholly document the effects of biofouling on the DATS.

DATS Testing Phases I - III

DATS Run #	Phase No.	Flow Velocity (ft/sec)	Testing Days per Phase
1, 2 & 3	I	4.0, 2.0	98
4	II	3.4	42
5, 6 & 7	III	1.8	108

Table 1

PHASE I TESTING

As previously noted, an initial break-in test phase was conducted to work out startup bugs from the DATS system. The standard "biofouling" heat transfer resistance (R_f) threshold of 0.0003 $hr \cdot ft^2 \cdot {}^\circ F/BTU$ was utilized to mimic R-114 condenser heat transfer design criteria.

Phase I testing was conducted for a period of approximately 2,000 hours (83 days). Start up problems encountered included several seawater intake pump malfunctions, DATS system flow interruptions due to entrained debris in paddle wheel flow sensors, and at least one computer data storage lapse. Each of these problems were troubleshot and solved as they arose. During this initial test phase, baseline biofouling data on the 70/30 copper-nickel and titanium heat exchanger materials was obtained. In addition, the effectiveness of both 0.1 mg/L and 0.2 mg/L chlorine treatment at 4.0 ft/sec flow was established for a 1000 hour, 42 day, time period (Table 2). After this initial 42-day test period, chlorination was stopped and the flows were adjusted on some of the DATS units as shown in Table 3. These changes were made to evaluate the influence of flow velocity on baseline biofouling accretion (Unit #2) for titanium and confirm the effectiveness of 0.1 mg/L chlorination for 2 hours/day on titanium (Unit #3) by observing biofouling accretion once chlorine treatment was discontinued. The second set of test conditions was conducted for an additional 1000 hours (Days 42-83).

A summary of the results of the DATS break-in test phase is provided in Table 4. The data indicates that both 0.1 mg/L and 0.2 mg/L chlorine injection for 2 hours/day were fully effective in preventing biofouling accretion on CP-2 titanium heat exchanger surfaces at a flow velocity of 4.0 ft/sec. Also, a biofouling gradient seems to exist based on flow velocity as evident by the shorter time to reach the heat transfer resistance threshold, R_f, for titanium at 2.0 ft/sec (Unit #2) vice both the anode protected 70/30 CuNi and titanium units at 4.0 ft/sec (Units #1 and #3).

Initial DATS Test Parameters for Break-In Test Phase I (Days 1-42)

DATS Unit Number	Tube Material	Flow Velocity (ft/sec)	Chlorine Conc. (mg/l)
Unit #1	70/30 with Zn Anode	4.0	0.0
Unit #2	CP-2 Titanium	4.0	0.2
Unit #3	CP-2 Titanium	4.0	0.1
Unit #4	CP-2 Titanium	4.0	0.0

Table 2

Adjusted Phase I DATS Test Parameters (Days 42-81)

DATS Unit Number	Tube Material	Flow Velocity (ft/sec)	Chlorine Conc. (mg/l)
Unit #1	70/30 with Zn Anode	4.0	0.0
Unit #2	CP-2 Titanium	2.0	0.0
Unit #3	CP-2 Titanium	4.0	0.0
Unit #4	CP-2 Titanium	4.0	0.0

Table 3

Results of DATS Test Phase I

DATS Unit Number	Flow Velocity (ft/sec)	Chlorine Conc. (mg/L)	Days To Reach Threshold R_f>0.0003 Hr ft^2 ^oF/BTU
Unit #3 (Ti)	4.0	0.0	30 days
Unit #2 (Ti)	2.0	0.0	17 days
Unit #1 (CuNi)	4.0	0.0	20 days
			Days Below Threshold R_f<0.0003 Hr ft^2 ^oF/BTU
Unit #3	4.0	0.1	42 days
Unit #2	4.0	0.2	42 days

Note: Unit #4 (Ti) experienced several significant flow interruptions during the initial phase of testing that made data unreliable for reporting purposes.

Table 4

It is noted that all DATS results for CP-2 titanium obtained during Naval Surface Warfare Center (NSWC) testing at SUBASE Kings Bay were obtained at the lower flow velocities of 2.0 and 1.8 fps. Results obtained at these velocities led to the final chlorine treatment recommendation of 0.4 mg/L for 2 hours/day.

After Phase I testing, future testing will further evaluate the influence of flow velocity on biofouling accretion for both CP-2 titanium and 70/30 CuNi. In order to more closely simulate shipboard conditions, appropriate tube velocities were determined for R-114 condenser operation at one ASW pump in Fast Speed. This resulted in a calculated heat exchanger flow velocity of 3.4 ft/sec. Testing will therefore proceed with the same chlorine treatment parameters utilized in the break-in phase but with DATS heat exchanger tube velocities set at 3.4 ft/sec vice 4.0 ft/sec.

PHASE II TESTING

Phase II testing further evaluated the influence of flow velocity on biofouling accretion for both CP-2 titanium and 70/30 CuNi. In order to more closely simulate shipboard conditions, appropriate tube velocities were determined for R-114 condenser operation at one ASW pump in Fast Speed. This resulted in a calculated heat exchanger flow velocity of 3.4 ft/sec. Testing thus proceeded with the same chlorine treatment parameters utilized in Phase I but with DATS heat exchanger tube velocities set at 3.4 ft/sec vice 4.0 ft/sec. Table 5 notes the testing parameters for Phase II.

Table 6 presents the results obtained during Phase II testing. DATS testing was conducted for a period of 40 days. Results indicate that the change in flow velocity from 4.0 fps to 3.4 fps had little effect on the DATS control unit fouling accretion. The two control DATS (units #1 and #4) reached the critical heat transfer threshold at 21 days and 20 days respectively. During Phase I testing, unit #1 reached the heat transfer threshold at 20 days. The reduction of flow to 3.4 fps on the chlorinated DATS (units #2 and #3) did have some effect on biofouling accretion. Both units 2 & 3 in Phase II reached the heat transfer threshold after a period of 35 days. During Phase I, these units did not reach the critical threshold until 42 days. These results seem to indicate that flow reduction may play a role in biofouling accretion per unit time, despite the 2-hours/day chlorine treatment.

DATS Test Parameters for Test Phase II (Days 1-40)

DATS Unit Number	Tube Material	Flow Velocity (ft/sec)	Chlorine Conc. (mg/l)
Unit #1	70/30 with Zn Anode	3.4	0.0
Unit #2	CP-2 Titanium	3.4	0.2
Unit #3	CP-2 Titanium	3.4	0.1
Unit #4	CP-2 Titanium	3.4	0.0

Table 5

Results of DATS Test Phase II

DATS Unit Number	Flow Velocity (ft/sec)	Chlorine Conc. (mg/L)	Days To Reach Threshold R_f>0.0003 Hr ft^2 ^{o}F/BTU
Unit #1 (CuNi)	3.4	0.0	20 days
Unit #4 (Ti)	3.4	0.0	21 days
			Days Below Threshold R_f<0.0003 Hr ft^2 ^{o}F/BTU
Unit #3 (Ti)	3.4	0.1	35 days
Unit #2 (Ti)	3.4	0.2	35 days

Table 6

PHASE III TESTING

Phase III testing attempted to further quantify the effect of flow velocity on biofouling accretion. As previously noted, test results obtained by the Naval Surface Warfare Center (NSWC) at SUBASE Kings Bay were obtained at flow velocities of 2.0 and 1.8 fps. Test results led to a treatment recommendation of 0.4 mg/L TRO for 2 hours/day for biofouling control on CP-2 titanium. DATS Phase III testing utilized a flow velocity of 1.8 fps to directly compare biofouling accretion patterns at SUBASE Pearl Harbor to those observed at King Bay. Table 7 notes the testing parameters for Phase III.

Table 8 presents results obtained during Phase III testing. In comparison to earlier test phases, control DATS (units #1 and #4) fouled at a slower rate. Control DATS reached the critical heat transfer threshold at 29 days and 32 days respectively (Figure 3). The reduction of DATS flow velocity from 3.4 to 1.8 fps seemed to have little impact on biofouling accretion. Subsequent discussions with Pearl Harbor PMT personnel indicated that ship inspections reveal a difference in fouling accretion in SSN 688 seawater system components depending on time of year. Fouling is documented as being "heavier" during the period of April through October. A review of temperature data for the Pearl Harbor area does show a temperature gradient with an increase in water temperature (> 80 °F) from the end of March to the beginning of April through the end of October on a yearly basis. This could account for a "quicker time to foul" for DATS testing conducted in the summer months vice late fall or winter. Phase III DATS testing was terminated on 03 April 98 due to hard disk failure on the computer.

DATS Test Parameters for Test Phase III (Days 1-38)

DATS Unit Number	Tube Material	Flow Velocity (ft/sec)	Chlorine Conc. (mg/l)
Unit #1	70/30 with Zn Anode	1.8	0.0
Unit #2	CP-2 Titanium	1.8	0.2
Unit #3	CP-2 Titanium	1.8	0.1
Unit #4	CP-2 Titanium	1.8	0.0

Table 7

Results of DATS Test Phase III

DATS Unit Number	Flow Velocity (ft/sec)	Chlorine Conc. (mg/L)	Days To Reach Threshold R_f>0.0003 Hr ft^2 ^oF/BTU
Unit #1 (CuNi)	1.8	0.0	29 days
Unit #4 (Ti)	1.8	0.0	32 days
Unit #3 (Ti)	1.8	0.1	Not reached
Unit #2 (Ti)	1.8	0.2	Not reached

Table 8

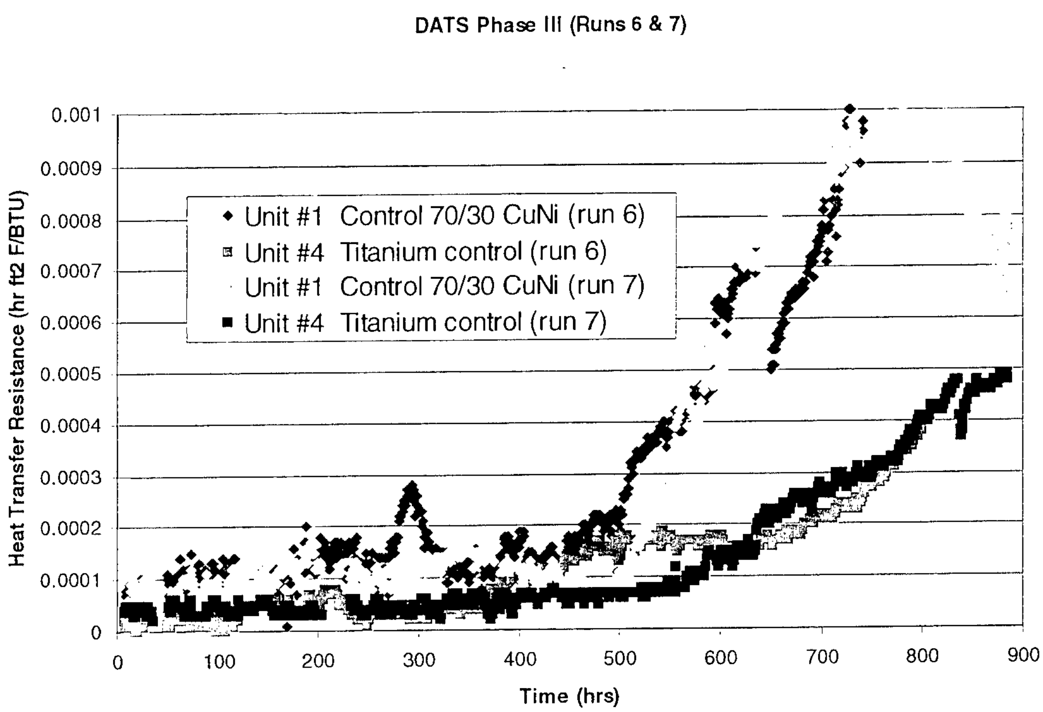

Figure 3 Units 1 & 4 reached the threshold within 500 to 700 hrs.

Phase III results also indicate that both 0.2 mg/L TRO (unit #2) and 0.1 mg/L TRO (unit #3) were effective in limiting biofouling below the critical threshold for the duration of the 38-day test (Figure 4). However, the data started to slope towards the critical heat transfer threshold around day 33 of Phase III.

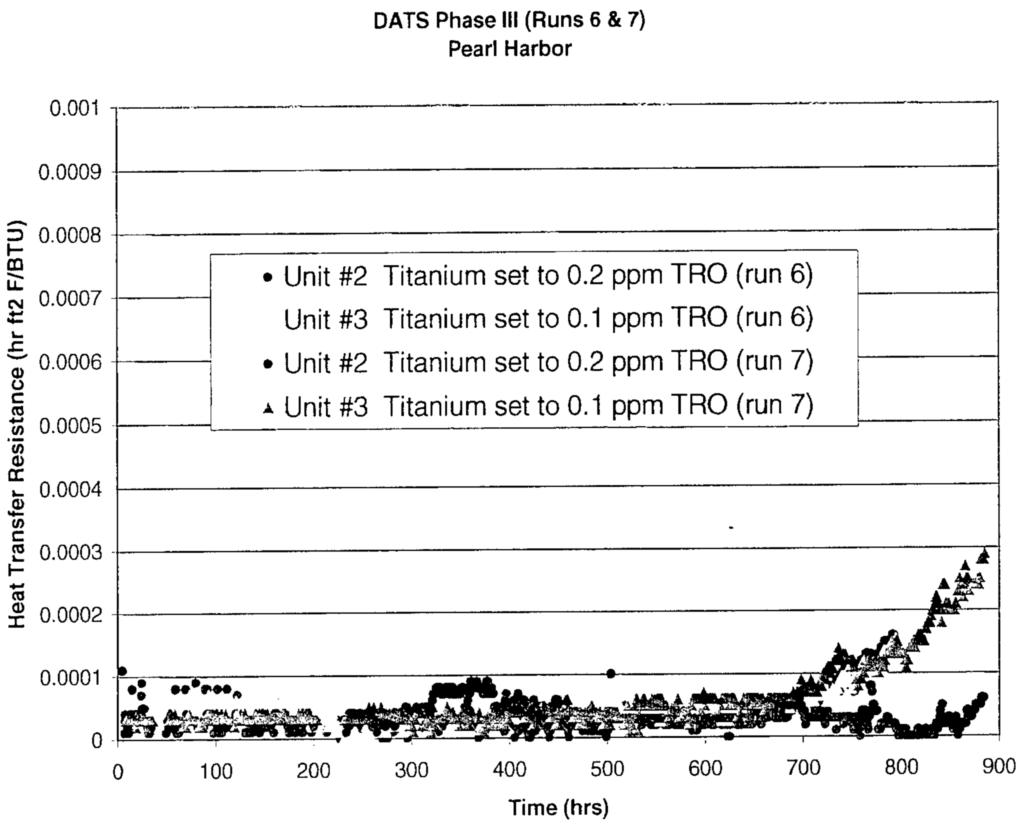

Figure 4 Units 2 & 3 started to demonstrate the effects of fouling after 700 hrs.

CONCLUSIONS

The most significant conclusion that may be drawn from the results of the DATS testing at SUBASE Pearl is that 0.2 mg/L TRO for 2 hours/day is NOT fully effective in limiting biofouling in titanium (Phase II results at 3.4 fps). As depicted in Table 6, both chlorinated DATS units crossed the critical heat transfer threshold at day 35 of the 40-day test. Due to premature termination of DATS testing, concentrations greater than 0.2 mg/L TRO were not evaluated.

Also noted is the "seasonal" biofouling component that seems to exist at the Pearl Harbor basin. Phase II testing (run #4) was conducted during the period of July through September 97 when water temperature consistently averaged above 83 °F. Phase III testing, however, was conducted during the months of late October 97 through early April 98. During this period seawater temperatures averaged 76-79 °F. This serves to support PMT assertion that "SSN 688 seawater system fouling is heavier from April to October"!

Based on the above, it is difficult to sort out the impact of flow velocity on biofouling accretion. In view of Phase I and II test results, both 4.0 and 3.4 fps allowed control DATS units to reach the critical heat transfer threshold at around day 20/21. However, during Phase III testing conducted at 1.8 fps, DATS control units did not reach the heat transfer threshold until day 29/32. This serves to further support the assertion that temperature maybe a controlling factor for biofouling accretion at Pearl Harbor.

The TRO measurements were obtained routinely (day-to-day basis) using a colorimetric procedure. Due to the colorimetric procedure employed, variations in TRO readings existed in that 0.1 mg/L reading consists of the range 0.10 to 0.15 mg/L and 0.2 mg/L reading the range 0.20 to 0.25 mg/L. Therefore, the recorded TRO values are conservative in that actual concentrations may be slightly higher than those reported.

Based on the DATS testing results, the data indicate that the cathodically-protected 70/30 copper nickel exhibited biofouling accretion rates similar to that of CP-2 titanium. In fact, in all testing phases, the control copper nickel reached the critical heat transfer threshold slightly ahead of the control titanium (although not in any statistically significant manner). Termination of Pearl Harbor testing, due to computer hard disk failure did not permit further evaluation of the impact of non-cathodically-protected copper nickel on biofouling accretion rates.

RECOMMENDATIONS

Specific recommendations based on Pearl Harbor DATS testing are as follows:

1. Utilize a minimum of 0.2 mg/L TRO for 2-hours/day in-system concentration for MOD-25 SSN 688 seawater system biofouling control at SUBASE Pearl Harbor. This recommendation also applies to SSN 688 Class with 70/30 copper nickel systems. In-system concentration is defined as TRO measurement taken at the sampling location indicating MSW in-system concentration on MOD-25 ships. For SSN 688 Class ships using topside or dockside chlorine injection, TRO measurements are either taken at the ASW-80 sampling port on the Ship Topside Chlorination Unit or at R-114 HX drain valve if utilizing dockside chlorine injection.
2. If 0.2 mg/L TRO is insufficient for in-system biofouling control during April – October time period, consider elevating TRO to 0.3 -0.4 mg/L (based on NSWC Report, CARIVNSWC-TR-82-95/17).
3. Utilize dechlorination injection to neutralize TRO prior to SSN 688 Class seawater system discharge when utilizing topside or dockside chlorine injection. The above treatment recommendations could cause TRO discharge above the current 0.1 mg/L limit imposed by the NPDES (National Pollutant Discharge Elimination System) permit at SUBASE Pearl Harbor.