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PILOT COOLING SYSTEM EVALUATION OF TREATMENT PROGRAM EFFECTIVENESS IN A REFINERY ENVIRONMENT

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ABSTRACT

A Pilot Cooling System was developed to simulate the operation of an open recirculating cooling system for the purpose of evaluating potential cooling water treatment programs on a pilot scale prior to their implementation in the refinery cooling system. Pilot scale evaluation of newer, more environmentally acceptable, treatment programs was desired to determine their effectiveness in a refinery environment, without the need to treat the entire refinery cooling system. This report outlines a side-by-side comparison of treatment program effectiveness observed for an alkaline chromate treatment program run on the main refinery cooling system and on the Pilot Cooling System. This test sequence was run with the objective of correlating results obtained in the Pilot System to those achieved on the main refinery cooling system. Results of laboratory screening tests are also compared to those achieved in the Pilot System and on the main refinery cooling system. A detailed description of equipment and methods is included.

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INTRODUCTION

Changing cooling water treatment programs can be a time consuming project for both the user and the water treatment service company involved. Users of water treatment programs are concerned about the impact of a new treatment approach upon:

* Corrosion control
* Deposition control and system cleanliness
* Microbiological control
* Ease of treatment application and control
* Actual versus theoretical costs.

A preknowledge of the impact of proposed treatments upon these aspects of program application and results is particularly desireable when converting from a long established, successful chromate based treatment to a more environmentally acceptable approach. A knowledge of the tradeoffs involved in converting to a new treatment can be a valuable decision-making tool for a manager charged with the decision on the alternative of choice.

There is no evaluation method that will predict the performance of a treatment program with 100% accuracy. There is no substitute for direct operating experience in a system. Laboratory studies have been used as screening tools to predict the performance of treatments in a cooling system. Laboratory studies can provide sufficient information to make a decision comfortably in many cases. A major criticism of laboratory procedures is that they typically use synthesized water, and do not concentrate the water naturally. Pilot cooling tower studies in a laboratory can extend confidence in a treatment approach even further. But there are cases where a laboratory environment will not allow the major factors affecting treatment performance to be incorporated into an experimental design, even when tested in a laboratory based Pilot Cooling System.

Examples of parameters which are difficult to simulate realistically in a laboratory environment include:

* Iron and manganese in the makeup water;
* Airborne contamination from a process (eg. ammonia in an ammonia plant, phosphates in a phosphate plant, coke in a steel mill or other coking facility, BOF dust in a steel mill, and other process contaminants that can enter a cooling system via the air);
* Microorganisms in the makeup water;
* Airborne suspended solids.

A transportable Pilot Cooling System was developed to minimize the impact of onsite variables by allowing an onsite pilot scale evaluation as a final step in collecting data for deciding on a new treatment program, and for a prediction of results prior to full scale implementation of a new treatment program. The onsite system also allows confirmation of laboratory derived data prior to initial field testing of new treatment approaches.

This paper describes the Pilot Cooling System developed for use in either a plant or laboratory environment, and its maiden run in a refinery environment. Objectives for the eighty (80) day test program at the refinery were to:

1) Determine how well the Pilot Cooling System corrosion and deposition control results correlated to those obtained in the refinery cooling system.

2) Evaluate the applicability of using the Pilot system in a plant environment with respect to its ability to operate continuously.

Several alternate treatment programs were also evaluated during the eighty (80) days of operation. Results of these tests are beyond the scope of this paper and will not be reported at this time.

The next section describes the Pilot Cooling System and outlines the rationale for its design. Results of the side by side evaluations of a treatment program in the Pilot and refinery cooling systems are summarized in a later section.

THE PILOT COOLING SYSTEM

The Pilot Cooling System includes six (6) major categories of equipment:

1) The Cooling Tower and recirculation pump.
2) The Heat Load exchanger
3) the Electrical Master Control Panel for the heat load exchanger, feed pumps, the recirculating pump, and other equipment.
4) Control Instrumentation including blowdown control by conductivity, and pH control by acid feed, alkali feed, or blowdown;
5) Monitoring equipment including a deposition monitor for fouling factor measurement, a coupon rack for corrosion coupons and instantaneous corrosion rate measurement probes, and a data logger for recording critical measurements.
6) A Chemical Feed System including mini chemical storage tanks, feed pumps, timer control, and interfacing with the pH controller.

Figure 1 depicts the system schematically. Two views are presented in Figures 2 and 3. Operating specifications are summarized in Table 1.

Central to the system is an off the shelf cooling tower which is a circular, single cell, induced draft unit of fiberglass construction with spiraled, corrugated fill. Four distribution lines and eight nozzles introduce the heated return water into the tower. A separate holding basin was added to the system to allow more flexibility in controlling holding time index by adjustment of holding capacity. A level control is used to add makeup water to the system and to adjust the system capacity.

The cooling tower fan is temperature controlled. A centrifugal pump provides cooling water recirculation in the range of 0 to 20 gpm. This allows regulation of the flow regime through the monitoring equipment (coupon racks, deposition monitor) from laminar through totally turbulent flow.

The heat load for the system is applied through two (2) 7.5 kilowatt immersion heaters enclosed in a stainless steel shell. This heat load exchanger can input up to 51,000 BTU/Hour of heat into the cooling water and allows for a 0 to 30 degree Fahrenheit temperature rise across the system at all flows.

Automatic safety shutoffs are included in the master control panel to shut the system down in the event of loss of cooling water flow or a high temperature alarm.

Standard pH and conductivity controllers are used to control pH via acid feed, alkali feed, or blowdown; and concentration ratio by conductivity controlled blowdown.

The chemical feed system incorporates four mini storage tanks and four feed pumps. One of the pumps can be activated by the pH controller or run independently. One of the pumps can be timer controlled for biocide or other slug chemical addition.

The monitoring equipment on the unit includes a corrosion coupon rack with both coupons and corrosion rate probes, and a deposition monitor. The deposition monitor is an electrically heated, annular space cooling water flow exchanger equipped with thermocouples and flow measurement to allow for fouling factor calculations. All desired parameters can be logged on a datalogger which includes a floppy disk drive as well as a hard copy output.

The cooling system includes ample quick disconnects and unions to allow for the easy installation of additional monitoring devices such as biofilm monitors, ion analyzers, or other equipment required to fulfill the experimental design for a study.

PILOT SYSTEM CORRELATION TO THE OPERATING COOLING SYSTEM

The Pilot Cooling System provided the refinery with a means to evaluate proposed chromate alternatives in an intermediate step between laboratory screening tests and full scale implementation in the refinery cooling system. The overall project was divided into two main steps:

1) The validation of the Pilot Cooling System as a means to simulate the refinery cooling system.

2) The evaluation of alternative treatment programs suggested by laboratory testing which are more environmentally acceptable than the chromate based treatment being used .

This paper reports on the correlation of corrosion and deposition control results achieved between the Pilot Cooling System and the refinery cooling system as a validation of the test method. The study was run to determine if similar results would be obtained with the same treatment program in place in the refinery cooling system, and in the Pilot Unit. A secondary objective was to determine if the Pilot Cooling System could operate in a plant environment with a minimum of down time and manpower.

The Pilot Cooling System was started up in the refinery environment at a time when the cooling water chemistry control limits were undergoing two (2) major changes:

1) The cooling water chemistry control was being changed from a neutral pH operation to an alkaline control range. The pH control range was being increased from a neutral 7.0 to 7.5 range to an alkaline 8.0 to 8.5 .

2) The concentration ratio was being increased from seven (7) to ten (10). A corresponding increase in dissolved and suspended solids levels was anticipated.

Laboratory testing had indicated that acceptable corrosion control results could be achieved with a reduced chromate level in the recirculating cooling water at the higher pH and concentration ratio targeted. Chromate levels in the recirculating cooling water were targeted for a reduction from the previous control range of 14 to 16 mg/l in the neutral pH range and lower concentration ratio range, to 10 to 12 mg/l in the alkaline pH control range and higher concentration ratio operation.

A blend of a sulfonated copolymer, with a polymer, phosphonate, and anionic surfactant provided scale and suspended solids control. The dispersant/scale control formulation had been selected based upon its ability to function in a water subject to contamination by coke fines. The coke fines had been observed to adsorb dispersants and scale control agents in laboratory studies and remove them from the cooling water, negating their effectiveness as chemical treatment agents. Loss of dispersant activity had been observed previously in the cooling system during periods of contamination. Onsite studies were chosen to verify the ability of the treatment programs proposed to operate in the presence of these suspended solids. The impact of the coke fine contamination was difficult to simulate in the laboratory. Onsite Pilot Cooling System studies were deemed the preferred method for evaluating proposed treatment programs due to the presence of this contamination.

The Pilot Cooling System was started up onsite in conjunction with the change in treatment program operating control ranges. The refinery cooling system had been operating on a neutral pH, high chromate treatment program. Refinery personnel desired to decrease the chromate control range while increasing the pH control range from a neutral 7.0 to 7.5 to an alkaline 8.0 to 8.5. It was desired to run the pilot cooling system in parallel to the operating system during this period to compare responsiveness of the systems to change as well as to correlate long term results. Table 2 outlines the cooling water treatment control guidelines during the transition from a neutral to an alkaline chromate program. Typical water chemistries for the makeup, Pilot Cooling System, and Refinery cooling system are outlined in Table 3. The water chemistry evaluated in the laboratory screening tests is also outlined in the table.

MONITORING

The Pilot Cooling System received the same monitoring and service as the refinery main cooling system. Water analysis and chemical feed rate adjustments were made a minimum of four times per week. Mild steel corrosion rates were monitored in both the pilot and refinery cooling systems using instantaneous corrosion rate measurement by linear polarization, and by corrosion coupons. Cooling water flow velocity across the coupons was set at 3.7 feet per second in both systems. Fouling rates were monitored in both systems using deposition monitors with annular space cooling water flow, mild steel heat transfer surfaces, and a heat input to provide a heat flux of 16,950 BTU/(Sq.Ft. Hr Deg F). A flow velocity of 3.7 feet/second was also used across the heat transfer surface of the deposition monitor. The flow velocity and heat transfer parameters were chosen to match the heat exchanger in the refinery system deemed most critical from a cooling water perspective. The flow velocity was selected to match the shear stress of the cooling water against the tubes in the critical exchanger. The heat flux setting was chosen to provide a comparable skin temperature to the critical exchanger. Critical exchanger heat transfer performance was also monitored.

The overall monitoring program was developed to provide indicators of treatment program performance on the Pilot Cooling System and refinery cooling system using industry standard test procedures and equipment, and to verify these results through monitoring of operating exchangers within the refinery cooling system.

OPERATION

The Pilot Cooling System ran without interruption for an eighty (80) day period with a minimum of supervision. It was able to maintain the twenty degree temperature rise desired and was able to operate with a ten (10) degree approach to ambient.

The Pilot Cooling System concentrated the makeup water at a rate comparable to the main system. It was able to achieve a concentration ratio of seven (7.0) in three (3) to five (5) days, and a concentration ratio of ten (10.0) in a one (1) week period (Figure 4). A major shortcoming of many pilot systems is their inability to concentrate cooling water in a reasonable period of time.

Comparable suspended solids levels were present in the Pilot Cooling System and the refinery cooling water, indicating that the airborne contamination effect was being simulated by the Pilot Cooling System (Figure 5).

TEST RESULTS

A close correlation of results was obtained during the validation phase of the study. Corrosion rates on mild steel were measured in the 0.2 to 0.4 mpy range on both the Pilot and refinery Cooling Systems. A slight tendency towards local attack was observed in both systems as measured by linear polarization. Corrosion rates on coupons were comparable in both systems and of the general etch type of attack with a slight tendency towards a shallow groove type of local attack. Corrosion control results achieved are summarized in Table 4. Instantaneous corrosion rate measurements versus time are presented in Table 5 for both systems.

Equilibrium fouling factors measured on the deposition monitors installed on both systems were comparable (0.00017 to 0.00019 (Sq.Ft.Hr. Deg F)/BTU) and well below that which would be of concern. Deposits are barely visible at these low fouling factors so no deposit samples could be obtained for analysis. No significant change in heat transfer performance was observed on the critical exchanger monitored in the refinery cooling system during the study. Alkalinity cycled comparably in both systems and equilibrium pH values attained were similar indicating that the Pilot Cooling System could simulate the carbon dioxide equilibrium between the air and the carbonate alkalinty in the cooling water found in typical open recirculating cooling systems.

Major ions cycled comparably in both systems with one exception. Lower silica levels were encountered in the Pilot Cooling System than would have been theoretically expected. No silica based deposits were observed in the Pilot system. It is believed that the brand new system may have exhibited a silica demand which was not satisfied during the study.

Table 6 summarizes analyzed water chemistries versus time for both the Pilot and refinery cooling systems. Key water chemistry control parameters are plotted in Figures 6, 7, and 8.

CONCLUSIONS

The Pilot Cooling System achieved the primary objectives for which it was designed. During this study:

1) The system was validated as a tool for simulating deposition and corrosion control in a side-by-side test. Corrosion rates and types, and fouling factors observed were comparable in both systems.

2) It was demonstrated that the system could operate for extended periods with a minimum of supervision.

FURTHER WORK

The Pilot Cooling System has been used onsite at the refinery to evaluate alternative treatment programs to the chromate-based approach currently in use. Results of the Pilot evaluations will be presented in the future, after the chromate alternative of choice has been implemented in the main cooling system.

TABLE 1
PILOT COOLING SYSTEM SPECIFICATIONS

Tower Type	Single Cell, Induced draft
Cooling Water Recirculation Rate	0.5 to 9.0 gpm Typical 0.5 to 20.0 gpm Available
Cooling Water Flow Regime	Laminar to fully developed Turbulent Flow
Heat Load	0 to 51,000 BTU/Hr from the Heat Load Exchanger 0 to 4,100 BTU/Hr from the Deposition Monitor
Heat Flux	0 to 31,000 BTU/(Sq Ft Hr) in Deposition Monitor
Temperature Rise	0 to 30 Deg F at all Flows
Holding Capacity	28 Gallons Maximum
Blowdown Control	Conductivity Controller
pH Control	Automatic pH Controller Acid and Alkali Feed Capability
Chemical Addition	Automatic Makeup Sensor Automatic Timed Addition
Monitors	Automatic pH, Conductivity, Temperature, Flow, Fouling Factor, and Corrosion Rate

TABLE 2
TREATMENT PROGRAM GUIDELINES

PARAMETER	LIMITS Initial	Transition	Target
pH	7.0-7.5	7.5-8.0	8.0-8.5
Conductivity(micromhos)	500-600	600-700	700-800
Calcium (as ppm CaCO3)	--------- 350 Maximum --------		
Chromate(as ppm CrO4)	14-16	12-14	10-12
Dispersant(ppm Product)	--- 50 ppm ---		
Total Residual Chlorine	As needed, 0.1 ppm TRC		

TABLE 3
WATER CHEMISTRY SUMMARIES

CONSTITUENT	PILOT COOLING SYSTEM	REFINERY COOLING SYSTEM	LABORATORY STUDY	MAKE UP WATER
Calcium Hardness(as CaCO3)	223	226	250	30
Total Hardness(as CaCO3)	325	331	300	42
Total Alkalinity(as CaCO3)	125	106	166	28
pH	8.2	8.3	8.0	7.25
Conductivity(micromhos)	703	749		100
Chromate(as CrO4)	13.9	13.8	8-20*	
Silica(as SiO2)	37.5	61.7	50	8.50
Iron(as Fe)	0.23	0.06		0.15
Copper(as Cu)	0.17	0.19		0.05
Total Residual Chlorine	0.42	0.34		0.00
Total Suspended Solids	11.4	14.8		0 - 2*
Bulk Water Temperature	95.0	99.8	90	
Temperature Rise	19	24		

Note: Values are 40 day averages in ppm with the exception of those with an asterisk (*). Asterisked values are ranges encountered during the evaluation.

TABLE 4
PERFORMANCE SUMMARY

	PILOT COOLING SYSTEM	REFINERY COOLING SYSTEM	LABORATORY SCREENING TESTS
Fouling Factor x 10000	1.89	1.72 1.79	
Average Corrosion Rates (on 1010 Carbon Steel)			
- By Linear Polarization			
General	0.40	0.30	0.43
Pitting	0.30	0.80	
- From Coupons	0.84	0.53	

NOTES: Fouling Factor Units are (Sq. Ft. Hr Deg F)/BTU
Corrosion Rates are in Mils per Year (mpy)

TABLE 5
MEASURED CORROSION RATES vs TIME

Days On Line	Pilot Cooling System General	Pilot Cooling System Pitting	Refinery Cooling System General	Refinery Cooling System Pitting
0	0.1	0.5	0.3	0.5
2			0.3	0.5
10	0.5	0.2	0.2	0.5
13	0.5	0.5		
16	0.3	0.0	0.3	0.8
21	0.2	0.3	0.5	0.8
27	0.4	0.2		
28	0.4	0.2	0.3	0.7
34	0.6	0.4	0.3	0.7
36	0.4	0.2		
37	0.6	0.3	0.4	0.9
Average	0.4	0.3	0.3	0.8
Standard Deviation	0.1	0.1	0.1	0.1

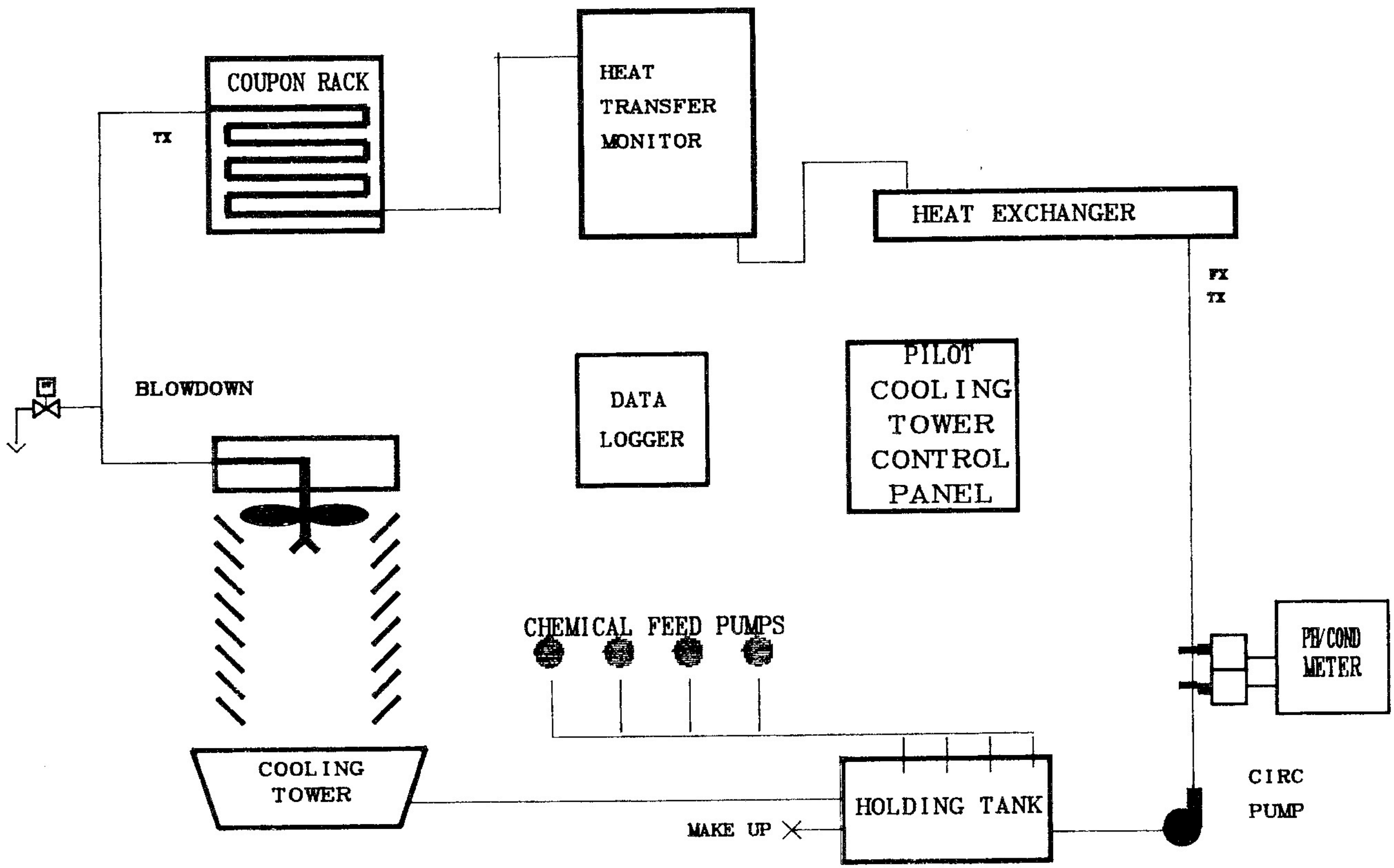

FIGURE 1

PILOT COOLING SYSTEM

Figure 2 Pilot Cooling System Front View

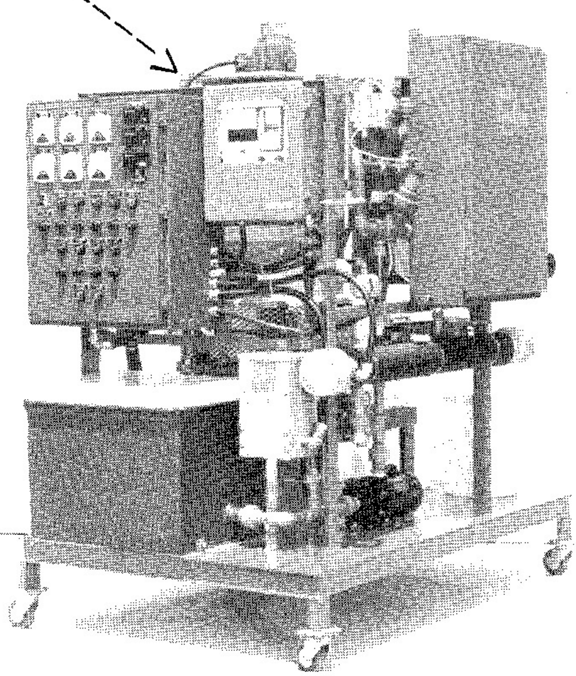

Figure 3 Pilot Cooling System Rear View

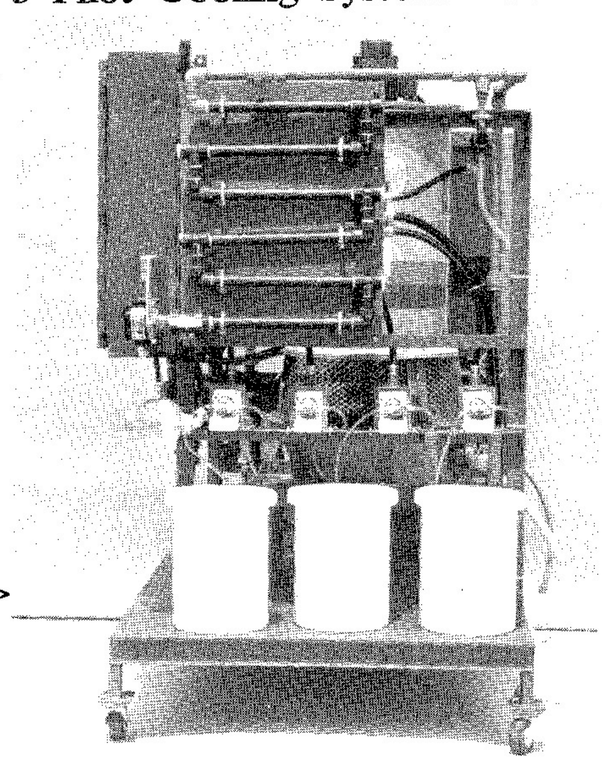

Figure 4 Concentration Ratio vs Time

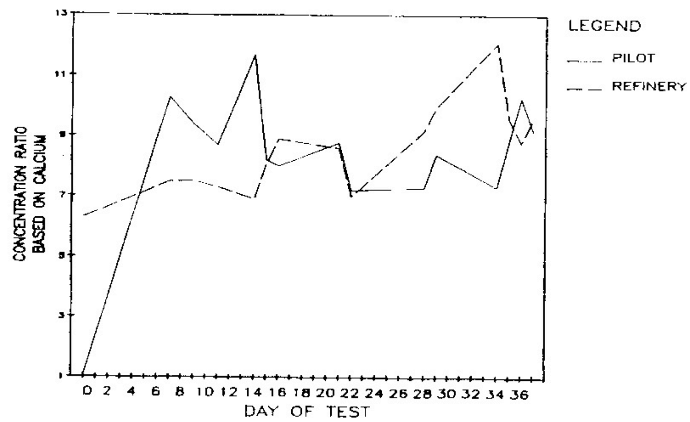

Figure 5 Total Suspended Solids vs Time

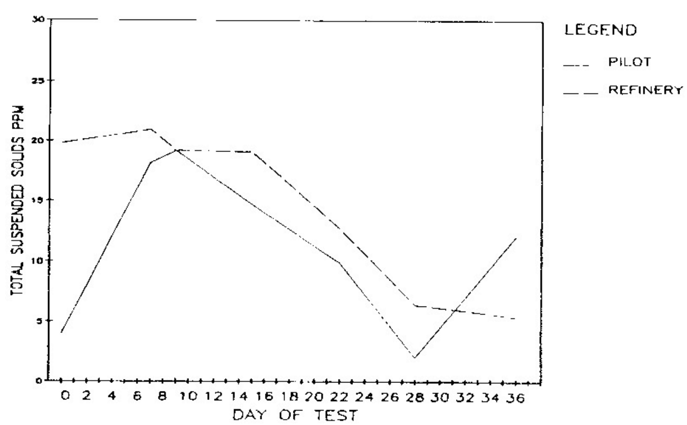

Figure 6 Calcium Levels vs Time

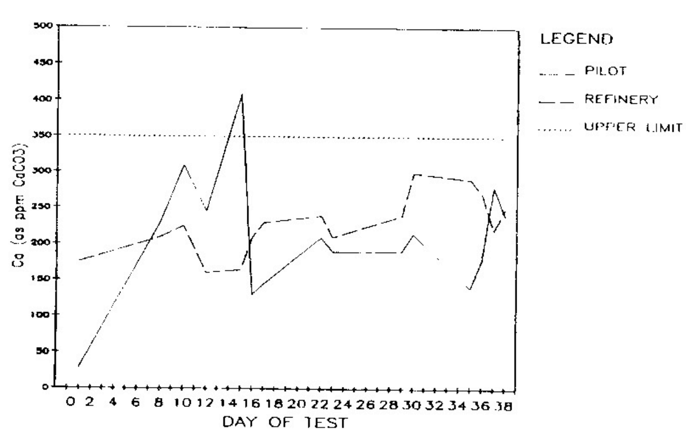

Figure 7 Conductivity vs Time

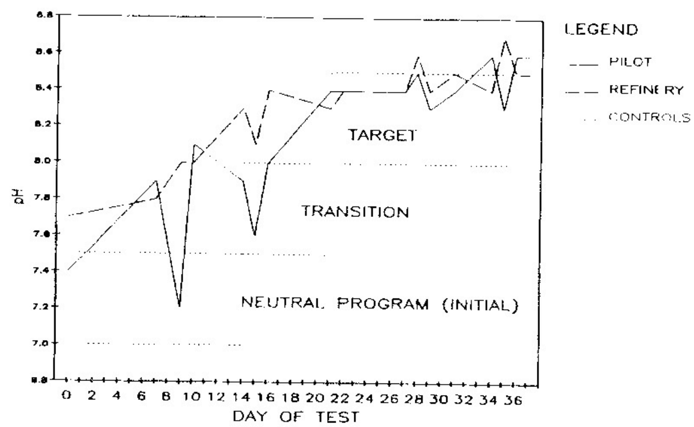

Figure 8 pH Control vs Time