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EVALUATION

OF

FPC-3 COMBUSTION FUEL CATALYST

on

Cold End Acid Attack

Vanadium Pentoxide Deposits

and

Boiler Efficiency

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August 9, 1983

ABSTRACT

Serious corrosion, fouling and acid soot problems frequently occur in the flue gases of power generation and process steam boilers when sulfur- and vanadium-bearing No. 6 fuel is burned. With sulfur, this is due to the condensation of sulfuric acid (H_2SO_4) on surfaces of the boiler, flue, economizer or stack that are at a temperature below the acid dewpoint temperature. For vanadium in the fuel, the oxidation of vanadium to vanadium pentoxide (V_2O_5) results in deposits on all surfaces and reduces heat transfer.

Using a Land Dewpoint Meter in conjunction with flue gas analysis for O_2, CO_2, CO and temperature, followed by physical boiler inspections, an evaluation of FPC-3 fuel oil combustion catalyst was performed to determine the effect of FPC-3-treated fuel on corrosion, fouling and acid soot emissions.

FPC-3 is an iron-based catalyst in a toluene carrier, which promotes the reaction of carbon and oxygen, and thereby allows for more complete combustion of fuel.

This report shows conclusively that FPC-3 was found to be effective in the reduction of problems related to vanadium and sulfur, and at the same time reduced excess air requirements for proper combustion. Therefore, FPC-3 has the ability to improve boiler efficiency from 1 to 4%, as well as reduce boiler system maintenance and boiler deterioration.

FPC-3 was also compared to the typical magnesium oxide (MgO)-base additives for acid and vanadium problems. Findings show FPC-3 to be 50% more effective in reducing sulfuric acid problems, and equal to magnesium oxide in reducing vanadium pentoxide fireside deposits. Refer to Figures 1 through 4 in the Results section, showing the rate of acid buildup (RBU) -vs- temperatures for No. 6 fuel in firetube and watertube boilers.

INTRODUCTION

The main objective in boiler operation is to obtain maximum efficiency with minimum maintenance. With the reduction in overall oil quality, it is becoming more evident that fuel oil additives have a role to play in boiler operation in conjunction with development of state-of-the-art mechanical equipment. As time goes on, and oil quality deteriorates, problems will increase.

Typically, fuel oil additives can be broken down into subgroups such as:

1) Preburner conditioners to prevent sludge and water formation in storage tanks.

2) Combustion catalysts acting directly on the combustion process to improve combustion efficiency.

3) Slag inhibitors acting on the products of combustion to minimize fireside deposits, corrosion and reduce atmospheric pollution.

FPC-3 has been found to work effectively in all three areas of liquid hydrocarbon combustion.

While the formation of sludge and water in storage tanks is a problem, combustion efficiency and fireside deposits are more critical with rising fuel costs. Fuel additives are mainly used to reduce fireside deposits that decrease the rate of heat transfer, resulting in increased stack temperatures and decreased fuel efficiency. Boiler failure caused by deposits and corrosion result in the loss of profit because of reduced production while making repairs. The magnitude of this loss is often underestimated. Loss of production for several days may cost as much as proper fuel treatment for several years.

Fireside fouling and corrosion are principally caused by impurities present in residual fuels. The most commonly found elements are sulfur, vanadium, sodium, nickle, and iron; with sulfur, vanadium, and sodium being the main problems. Typically, sulfur is related to low-temperature problems, such as acid attack in air heaters, economizers and breeching; while vanadium and sodium are high-temperature problems related to acid attack and deposits on boiler tubes.

METHODOLOGY

In testing for the effectiveness of FPC-3 fuel oil combustion catalyst, a simple and easily duplicated program was established. The same program will be used for further FPC-3 evaluations, as well as for comparative evaluations of other fuel treatments.

To insure consistent results, all boilers must be operated under identical load conditions, typically base-loaded with manual operation, if possible. Once testing starts, no changes are allowed or all test data becomes invalid. Normally, boilers were run base-loaded at low fire, high fire and average load.

With boilers manually set, the necessary information to determine boiler efficiency was gathered. The following data was recorded:

Steam flow & pressure
O_2 - CO
Fuel additive used
Stack temperature
Fuel type
Ambient temperature WB/DB
Oil temperature
Oil pressure
Atomization pressure
Control settings

With boiler operation constant, a Land Model 200 Acid Dewpoint Meter was used to evaluate the effect of the fuel oil additive by obtaining acid formation data. An acid film is a good conductor of electricity. Therefore, if a non-conducting surface bearing two electrodes is placed in the flue gas, any condensate forming on the surface will be detected by a current flowing between the electrodes.

The Land Meter employs a dewpoint detector with a thermocouple and a pair of electrodes fused into a detecting surface that is air cooled from the rear. This detector is mounted on the end of a stainless steel probe. The probe is inserted into the gas stream and the detector is gradually cooled by the flow of air which is controlled manually at the control unit. A thin film of acid begins to condense on the detector surface when the detector surface is sufficiently cooled. This creates a current flow across the electrodes which is monitored at the control unit. The air flow to the detector is then manually adjusted to maintain a constant electrode current. At this constant current, the rate of condensation and evaporation of acid are equal. The temperature at which this takes place is the acid dewpoint temperature (ADT). This temperature is measured by the thermocouple fused to the surface of the detector.

The corrosion potential of the flue gas can also be assessed by measuring the Rate of Acid Buildup (RBU) at temperatures below the ADT. By plotting a graph of RBU -vs- temperature, the peak rate of acid condensation can be equated to a particular temperature. Any metal surfaces at this temperature that are exposed to the flue gases will experience acid condensation, and therefore corrosion.

By utilizing the RBU data, the direct effect of a fuel catalyst can be evaluated. Fuel oil which is untreated will have a particular RBU profile over a temperature range. If this is compared to the identical boiler operation with treated fuel, the RBU graph will show any effect of the fuel treatment with respect to sulfur- and vanadium-related problems.

Test equipment consisted of the following:

Land Model 200 Acid Dewpoint Meter
Neotronics O_2 - CO Analyzer; Model PCO 961
IMC Instruments Model 6100 Digital Thermometer
Bacharach O_2 - CO_2 Analyzer; Model 10-5020

RESULTS

FPC-3 fuel oil combustion catalyst has shown itself to be effective in the following areas:

1. Reducing or eliminating cold-end acid attack.
2. Stopping the formation of slag deposits.
3. Improving boiler combustion efficiency.
4. Eliminating sludge from strainers and fuel tanks.

The most significant results relate to FPC-3 reducing cold-end acid attack and fireside deposits. By reviewing the RBU -vs- temperature graphs, Figures 1, 2, 3, and 4, and noting the reduction in RBU, the following can be derived:

A. The use of FPC-3 substantially reduces the rate of H_2SO_4 and H_2SO_3 generation and potential acid corrosion.

B. If H_2SO_4 generation is reduced, it can be concluded that FPC-3 reduced the formation of SO_2 to SO_3.

C. Recalling that SO_2 oxidizes to SO_3 through the catalyzation of vanadium pentoxide and iron oxide:

$$SO_2 + 1/2O_2 \underset{Fe_2O_3}{\overset{V_2O_5}{\rightleftharpoons}} SO_3$$

it can further be concluded that the vanadium pentoxide formation has been greatly reduced, or even eliminated. At all test sites using FPC-3 to reduce vanadium pentoxide deposits, the normal hard, black deposits were replaced with a light gray dust which was found to be V_2O_4 and easy to remove with normal soot blowing. With FPC-3 as a oxidizing catalyst, which uses the free O_2 for more complete combustion, it follows that V_2O_3 and V_2O_4 cannot be oxidized to V_2O_5.

From the above equation, it is noted that iron oxide (Fe_3O_2) is also a catalyst, and therefore, the iron in FPC-3 could react to help form SO_3. However, the iron in the ferrous picrate of FPC-3 has a chemical valence of +2, compared to the valence of Fe_2O_3, which is +3. Thereby, the iron compounds in FPC-3 do not promote SO_3 formation, as with Fe_2O_3.

Figures 1, 2, 3, and 4 also demonstrate that the RBU related to H_2SO_4, SO_3 and V_2O_5 formation will vary depending upon the boiler type and size, and the burner design. Finally, the graphs show that the MgO-based fuel oil additives are not as effective as FPC-3 in reducing the RBU number, even though they did help control the slag deposits.

As a combustion catalyst, the primary desired effect is to reduce excess oxygen (O_2), and thereby improve boiler efficiency by lowering stack temperatures. However, a true combustion catalyst will also burn off carbon deposits and further reduce stack temperatures over a short time frame. In Table 1, all the test sites show improved combustion to a point where FPC-3 was cost-effective when considering only increased boiler efficiency.

TABLE #1

Boiler efficiency improvements due to FPC-3

	Boiler		Baseline			FPC-3			Efficiency	
Site	Rated #/hr	Average #/hr	Stack Temp.	$\%O_2$	Comb. Eff.	Stack Temp.	$\%O_2$	Comb. Eff.	Net Gain	% Gain
A*	100,000	40,000	520	4.2	81.7	495	3.1	83.0	1.3	1.6
B	40,000	20,000	625	4.6	78.4	590	3.4	80.0	1.6	2.1
C*	13,800	6,900	480	2.1	83.0	430	2.9	84.0	1.0	1.1
D*	10,350	3,200	440	5.5	82.3	430	4.8	83.2	.9	1.1
D**	10,350	3.200	440	5.5	82.3	400	4.6	84.2	1.9	2.3

* At Site A, C, and D, the FPC-3 $\%O_2$ levels were achieved in less than 24 hours of operation, while the stack temperatures remained at baseline. The FPC-3 stack temperatures were recorded at the completion of the program, and the FPC-3 $\%O_2$ remained the same over the entire test. This was caused by carbon burn-off.

** Site D compares baseline data to a complete mechanical cleaning during the test program. This demonstrates that over six weeks, FPC-3 recoverd 49% of lost boiler efficiency caused by carbon deposits and poor combustion

Finally, FPC-3 worked well as a preburner conditioner, as no sludge was found at any of the test sites. The strainers were found to be running much cleaner than any time in the past. The only problem was found at Site B, where for a short time after starting the FPC-3 program, the strainers had to be cleaned more often. Although more trash was being trapped, the strainers were cleaned in solvent, where in the past it had required a wire brush.

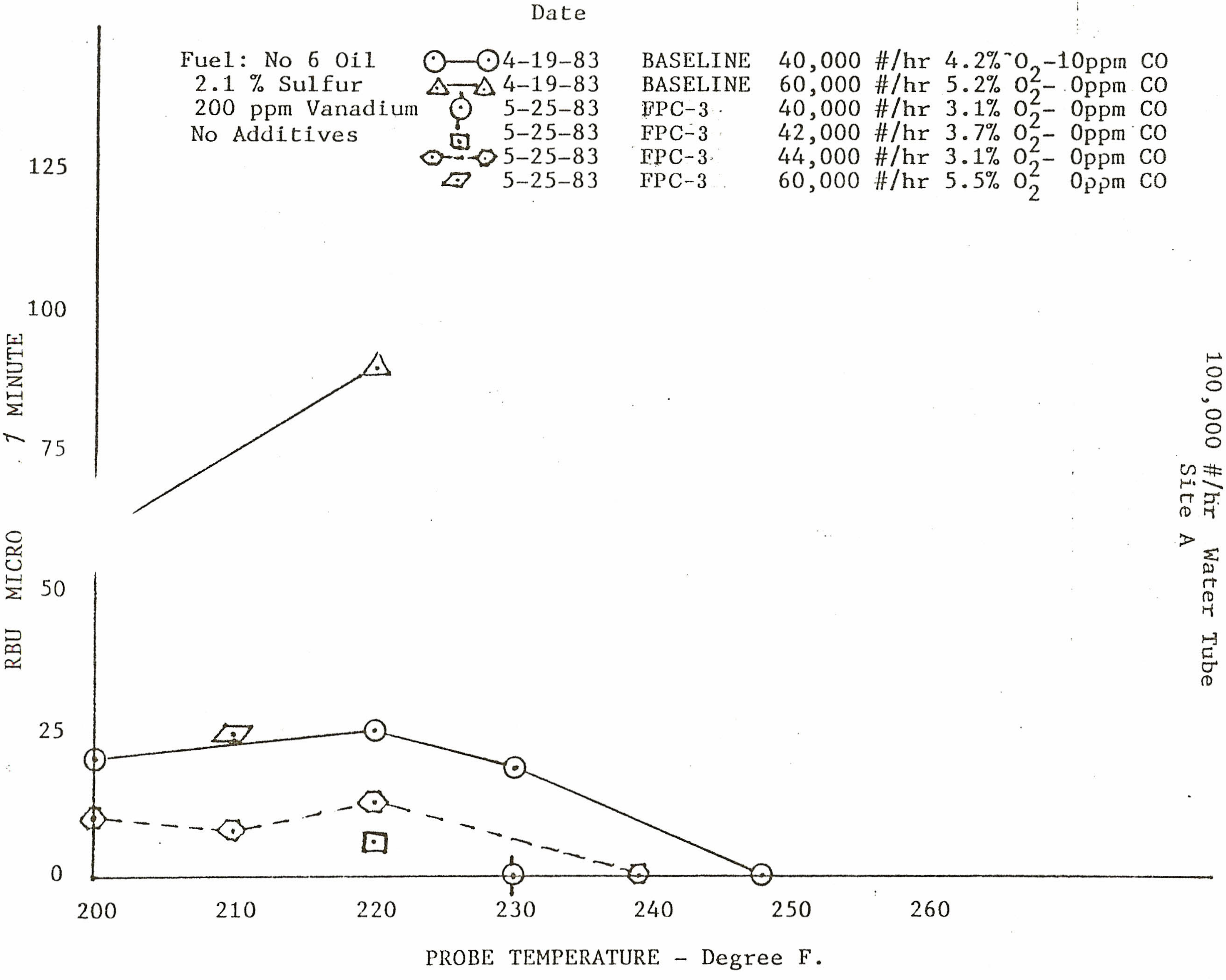

FIGURE 1

Corrosioin Potential -vs- Temperature

100,000 #/hr Water Tube

Site A

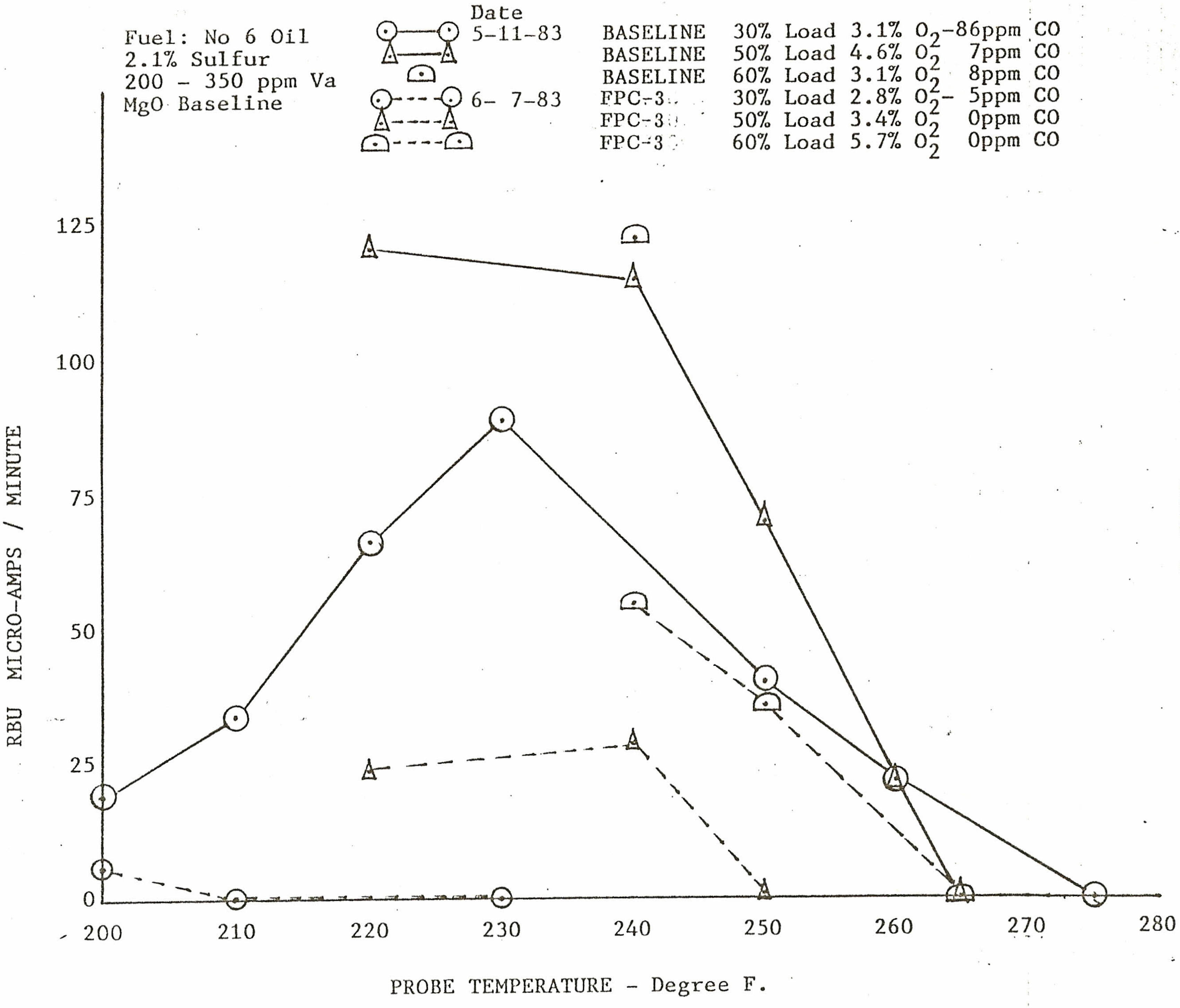

FIGURE 2

Corrosion Potential - vs - Temperature
40,000 #/hr Water tube
Site 'B'

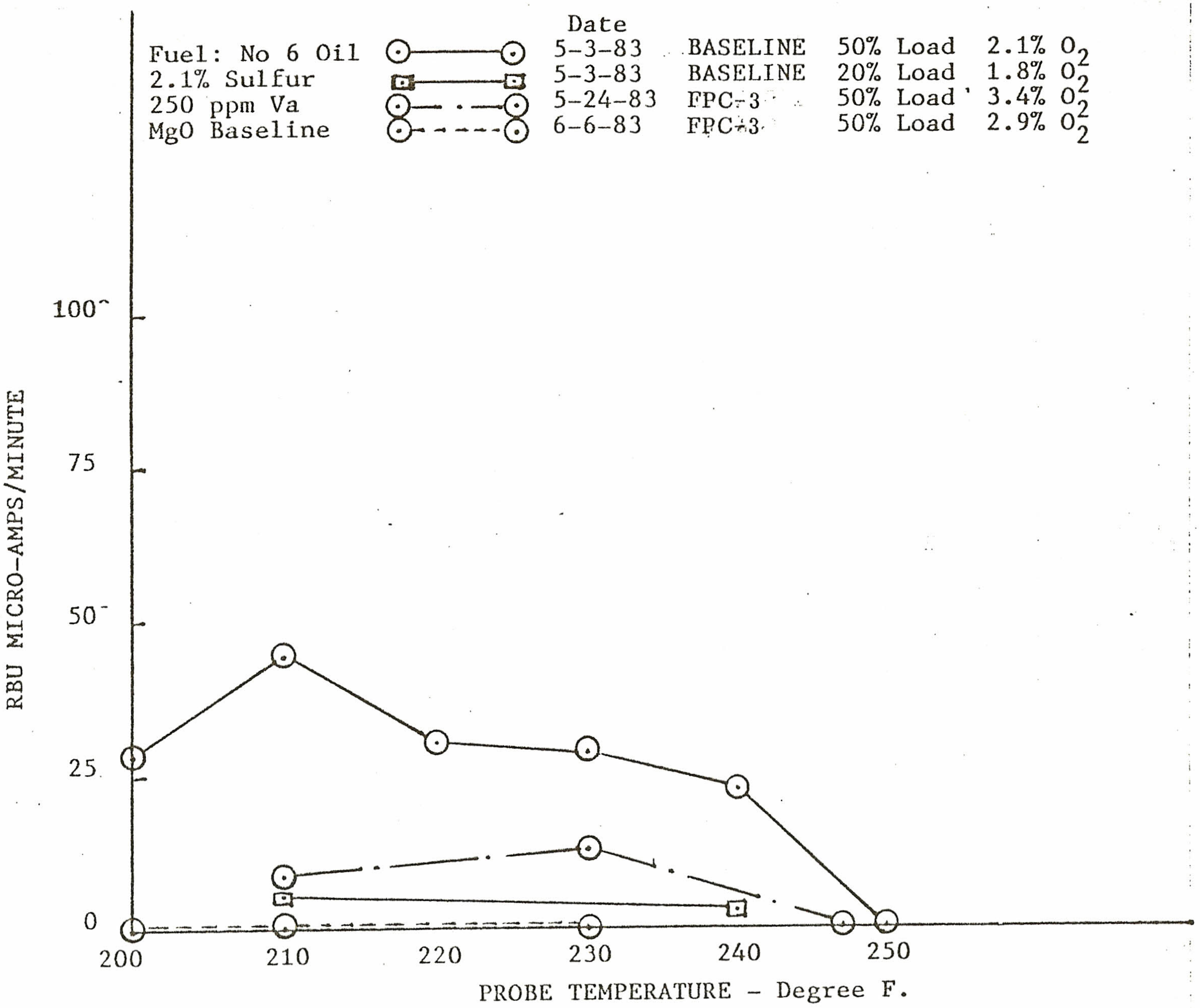

FIGURE 3

Corrosion Potential -Vs- Temperature
13,800 #/hr Firetube
Site 'C'

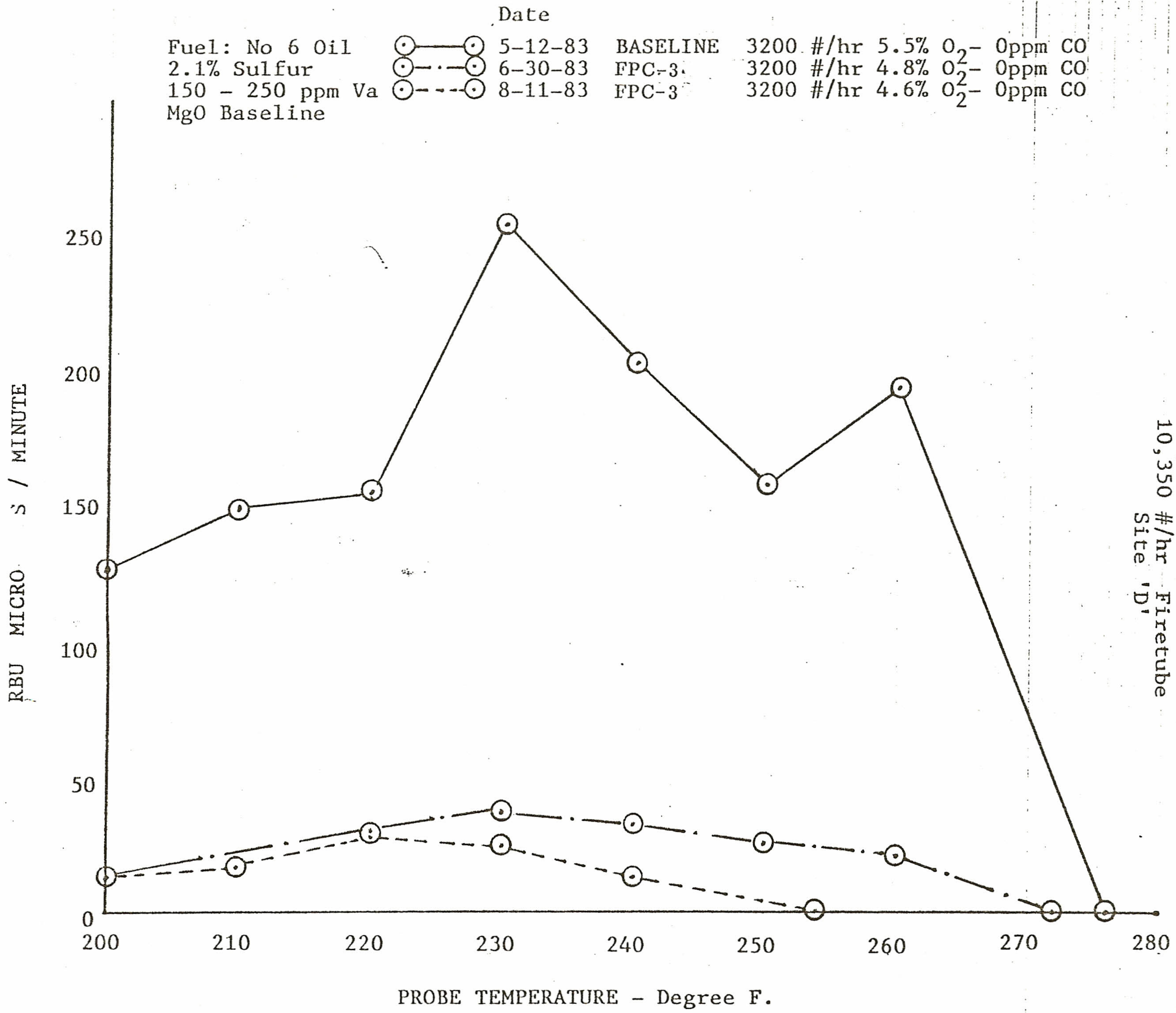

FIGURE 4

Corrosion Potential -vs- Temperature

10,350 #/hr Firetube
Site 'D'

DISCUSSION

Test results showing the effect of FPC-3 on RBU in oil-fired package boilers are given in Figures 1 and 2 for watertube boilers, and Figures 3 and 4 for firetube boilers. In all cases, FPC-3 substantially reduced the RBU at all temperatures, as compared to fuel without any treatment or with oil treated with MgO-base additives. The oil fired was typically No. 6 East Coast oil, with 2.1% sulfur and 150-350 ppm vanadium.

With the acid problem reduced or eliminated, the potential for improving boiler operation is tremendous. For the last 50 years, stack temperatures have been kept unnecessarily high in order to prevent cold-end acid attack. A typical summary of acceptable flue gas temperatures was presented in the April 1983 issue of Energy Management as follows:

Table 2

Propane or natural gas	250°F minimum
Low-sulfur oil	275
High-sulfur oil	320
Coal	325
Wood	310

The Land Dewpoint Meter can pinpoint the acid dewpoint and allow boiler operators to reduce stack temperatures, and save between 1% to 4% additional fuel. Further savings are possible by plotting an RBU -vs- temperature for each boiler system. In testing performed by Clark and Childs in Reference 1, experience indicates that appreciable corrosive tendencies do not become apparent until the RBU is over 100 microamps per minute. This means that for all sites tested, the use of FPC-3 has not only improved boiler efficiency, but has now made the boiler safe from appreciable corrosive attack at any boiler load or stack temperature.

Although the excessive corrosive tendencies have been stopped in all boilers by using FPC-3, there will still be some acid attack on boiler tubes, economizers and duct which must be explained. If the attack is not now from the low stack temperatures, where is the problem? The only remaining consideration is boiler operation. By operation, it is a question of operating 24 hours per day and 52 weeks a year, or shutting down the boiler system everyday or every weekend. Where boiler operation has been 24 hours a day, seven days a week, acid attack on feedwater economizers in particular is low with a life expectancy of five to seven years. However, with the same type boiler and fuel, and with only a six-day week, the economizer life drops to two to three years. The greatest damage, therefore, is not low stack temperatures, but rather allowing water and weak acid to condense on cold metal tubes and sit for one or two days. The solution is do not shut down the boiler, or change the shutdown procedure to thourghly dry out the complete boiler system.

With the use of FPC-3 combustion fuel catalyst, the corrosive tendencies within the boiler flue gas are minimized, and stack temperatures can be reduced to save fuel while not causing acid attack. The recommended temperatures are now as follows for typical package boiler systems, based on this test program:

Table 3

Propane or natural gas	150°F	NOT	250°F
Low-sulfur oil	200	NOT	275
High-sulfur oil	260	NOT	320
Coal	260	NOT	325
Wood	240	NOT	310

The Results section of this test program demonstrated that FPC-3 is effective in eliminating vanadium pentoxide deposits once the chemical process is understood. Prior to the introduction of FPC-3, FPC-2 was the recommended combustion catalyst. The only difference is that FPC-3 is a more concentrated mixture of iron, such that the mixing ratio is 7000:1 for FPC-3 and 4000 or 5000:1 for FPC-2. With FPC-3 and FPC-2 being essentially the same, Fig. 5 shows a complete chemical analyses of slag deposits taken from a 55,000 #/hr watertube boiler using FPC-3. The front sample was taken from the front wall of the boiler within two feet of the burner throat. This area will typically have zones of very poor combustion due to eddie currents during start-up and low fire operation. The rear sample was taken from the side wall immediately before entering the convection pass of the boiler. The significance of the report further demonstrates that V_2O_5 (vanadium pentoxide) has been eliminated, leaving only V_2O_4 (vanadium tetraoxide), a gray powder-dust which soot blowing can easily remove.

CHEM-BAC Laboratories, Inc.

• P. O. BOX 19198, CHARLOTTE, N. C. 28219
TEL. 394-6382

April 25, 1983

REF: 1325

ANalyses of Submitted Samples

MADE FOR: Adams Industrial Sales
Route 7 Box 712
Mooresville, N.C. 28115

ATTENTION: Gene Adams

MARKED: Samples received at Chem-Bac Labs, Inc. on 04/11/83

ANALYSIS:	Front	Rear
SiO_2	13.82	16.10
CaO	1.22	2.16
MgO	3.72	4.10
Fe_2O_3	7.63	8.95
NiO	5.43	6.78
MnO_2	.55	.67
ZnO	1.10	1.50
CuO	.10	.19
V_2O_4	8.75	35.35
V_2O_5	38.42	
Na_2O	14.16	17.70
K_2O	.48	1.05
Sulfates	3.47	3.75
PO_4	1.15	1.70

All data in percent(%).

Respectfully submitted,
CHEM-BAC LABORATORIES, INC.

J. C. H.

J.C. Hubbell
Supervising Chemist

JCH/th

REFERENCE

N.D. Clark and G.D. Childs, "Boiler Flue-Gas Measurements Using a Dewpoint Meter" (ASME Paper 63-WA-108)

"Energy Management Magazine", April 1983

The Babcock & Wilcox Company, "STEAM", 39th ed. (Babcock & Wilcox Co., New York, N.Y., 1978)