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Preliminary Environmental Assessment of the Lignite-Fired CAFB

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Preliminary Environmental Assessment of the Lignite-Fired CAFB

by

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ABSTRACT

This document presents the results of a preliminary environmental assessment of the lignite-fired Chemically Active Fluid Bed (CAFB) process. This report is a follow-on to an earlier environmental assessment of the oil-fired CAFB. Waste streams contributing air and solid waste pollutants were evaluated in terms of emission rates and potential environmental effects. Particular emphasis is placed on flue gas emissions. As part of this investigation, a field sampling and laboratory analysis program was carried out to compile an emissions inventory of the CAFB pilot plant at the Esso Research Centre, Abingdon (ERCA), England. In addition to the environmental assessment, an economic evaluation of the oil-fired CAFB relative to alternative residual oil utilization techniques is presented. Finally, recommendations are made for further control needs and emissions testing to be carried out in conjunction with the CAFB demonstration plant in San Benito, Texas.

Particulate emissions were less than those from direct combustion of lignite using multiclones as a control. NO_x emissions were quite low with 0.09 lb/10^6 Btu being the highest measured. Light organics were equal to those from conventional units, while heavy (>C_6) organic emissions were lower. SO_x emissions were one-half the NSPS for coal-fired boilers.

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SECTION 1

EXECUTIVE SUMMARY

OVERVIEW

The Chemically Active Fluid Bed (CAFB) process is a technique whereby high sulfur, high metal residual oil or coal is vaporized in a fluidized bed of lime to produce a low Btu, low sulfur product gas which is then burned in a conventional boiler to generate electrical energy. Most of the sulfur and metals contained in the feed are captured by the lime. This spent lime is subsequently processed to recover sulfur.

At present, the only operating CAFB unit is a 2.93 MW pilot plant at the Esso Research Centre, Abingdon (ERCA), England facility.[1] Foster-Wheeler Energy Corporation (FW) is in the final construction stage of a 10 MW retrofit demonstration plant being installed in San Benito, Texas, at the La Palma Power Station of the Central Power and Light Company. This unit is scheduled for startup in early 1979.

The present study is an environmental assessment of the CAFB process for lignite gasification/combustion. This document is an update of GCA/Technology Division's 1976 environmental assessment of the oil-fired CAFB.[2]

The CAFB generates air, water and solid waste pollutants. The principal source of air emissions is the boiler stack which is equipped with a cyclone at both the pilot and demonstration plants. Fugitive emissions are produced by feed and waste handling and storage. At the demonstration plant these sources are contained by baghouses and, thus, will be minor contributors to total air emissions. Water effluents, such as boiler blowdown and cooling tower outputs, are similar to those produced by conventional combustion systems. Disposal of sulfided limestone with high metals content is an important environmental problem. In view of the extensive efforts[3] being conducted to develop environmentally sound methods of spent stone treatment and disposal, the program reported upon here was directed primarily toward the characterization and assessment of air emissions from the CAFB.

The data needed for the environmental assessment were acquired during an extensive sampling and analysis program of the emissions from the ERCA pilot plant. Measurement techniques included Level I of EPA's Phased Approach,[4] standard compliance methods and others selected to provide comparability of the results of this program to those of the oil-fired study.[2]

The evaluation of the results of the measurement program was accomplished by use of the Source Analysis Model SAM/IA,[5] comparison with standards of performance for coal-fired boilers and comparison with analogous results obtained by GCA for conventional lignite-fired combustion systems. Additional control requirements are noted and recommendations for additional testing at the CAFB demonstration plant are made.

In addition to the environmental analysis of the CAFB, the economic comparison between the oil-fired CAFB and alternate oil-fired energy production techniques has also been updated from the 1976 report. Eight new HDS processes are identified and described. Although the retrofit and fuel switching capability of the CAFB are not directly matched by HDS or FGD, the economic data are instructive for evaluating the marketability of the CAFB process.

CONCLUSIONS

Particulate Emissions

The most pressing environmental concern facing the CAFB is the need for additional control of particulate emissions. Particulate emission values determined at the ERCA pilot plant and reported here represent essentially uncontrolled emissions. The cyclone employed on the boiler stack was not designed for the CAFB and consequently cannot be assumed to have a collection efficiency of greater than 50 percent for total particulate nor greater than negligible reduction capability for particulate in the respirable size range. Emission values ranged from 2 to 4 $lb/10^6$ Btu, which represent a factor of 20 to 40 times higher than the New Source Performance Standard (NSPS) for coal-fired boilers. Ten to thirty percent of the total particulate emissions were in the respirable size range.

The CAFB particulate emission rate was about a factor of 3 lower than that measured for a conventional lignite-fired utility boiler employing multiclones for particulate control, but a factor of 2,000 higher than a boiler controlled by an ESP. To meet the current NSPS for coal-fired boilers and to comply with any potential standard for small particulate emissions, controls over and above the cyclones planned for the demonstration plant will be required.

Trace Element Emissions

Trace element emissions can be correlated directly with particulate emissions. From a SAM/IA evaluation of these emissions, 14 elements (Ba, As, Ni, Cr, Ti, P, Si, Mg, B, Be, Cd, Sr, Cu, Li) were identified which exceeded their health MATE. For these elements, the ratios of emission rate to MATE ranged from 1 to 500. Because almost all trace elements were found in particulate samples, reduction of CAFB particulate emissions by 99.8 percent would have the concommitant effect of lowering all trace element emissions to levels below their MATE values. However, because of the uncertainty of the MATE values employed in the SAM/IA analyses and the level of precision of ± 3 of the trace element emission values, such a stringent level of control may, in fact, not be required.

Trace element emissions from the conventional lignite-fired boiler are such that MATE values are exceeded by 12 elements by as much as a factor of 800. A comparison of actual emission rates with worst case values derived from lignite feed elemental composition for both the CAFB and conventional boilers supports the observation made for oil-fired CAFB operation that gasifier bed stone selectively adsorbs certain trace elements contained in the CAFB fuel.

Gaseous Emissions

As observed in the oil-fired CAFB study, NO_x emissions are significantly lower than the NSPS. The highest measured NO_x emission rate for lignite-firing was 0.09 lb/10^6 Btu. Although this value may be low by a factor of 2 (due to possible sample degradation) the NSPS value of 0.7 lb/10^6 Btu is well in excess of the actual emission rate.

The measured SO_2 emission rate corresponds to 0.55 lb/10^6 Btu, roughly half the NSPS requirement. Sulfur recovery efficiency (SRE) ranged from 30 to 80 percent for the 0.5 percent sulfur lignite fired. At the lower SRE, the SO_2 emission rate was equal to about the NSPS value. Clearly, if the CAFB process is to be capable of using high sulfur fuel, the conditions favoring capture of fuel sulfur by bed stone must be optimized.

Emissions of C_1 and C_2 hydrocarbons (the only gaseous hydrocarbons present at levels above the detection limit) were well below their respective health-based MATE values.

Organic Emissions

Organic emissions varied widely as a function of gasifier operating conditions. The principal conclusion which can be drawn from a comparison between CAFB emissions and those from six conventional lignite-fired boilers is that when operated efficiently, gaseous (C_1 - C_6) organic emissions from the CAFB are equivalent to those from conventional systems and emissions of heavier organics are lower than the average of those from conventional boilers.

Functional groups found in condensible CAFB air samples are esters, hydrocarbons, ketones, and amides. Other compounds provisionally identified are alcohols, phenols, amines, nitrocompounds, ethers, substituted aromatics, and organosilicon compounds. No SAM/IA analysis was performed for the organic emissions. Level II analysis of emissions from the demonstration plant will be required to generate the type of data necessary to perform a meaningful environmental assessment of organic emissions.

Economic Comparison of Oil-Fired CAFB, FGD and HDS

The CAFB is unique as a retrofit application to natural gas-fired boilers because the process can accept a wide variety of liquid and solid fuels including those with high sulfur and high metals contents. Although flue gas desulfurization (FGD) and hydrodesulfurization (HDS) are capable of providing desulfurization equivalent to the CAFB, they are in general less capable of demetallization and reduction of NO_x emissions. Consequently, any strict economic

comparison of the three oil-fired systems must be qualified by considering the attendant differences in technical capabilities of CAFB, FGD and HDS.

Regenerable CAFB and FGD systems are more expensive than their once-through counterparts. Projected capital costs for the CAFB are double those of the other two processes. Estimated operating costs are also significantly higher for CAFB, as compared to flue gas desulfurization systems. In order to operate the CAFB on a competitive basis with flue gas desulfurization systems, high sulfur, high metals crudes must be $2 to $3 per barrel cheaper than low metals, medium sulfur content residual or distillate oils. At present, this per barrel differential requirement is roughly twice the market situation.

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SECTION 2

INTRODUCTION

THE CHEMICALLY ACTIVE FLUID BED (CAFB) PROCESS

The Chemically Active Fluid Bed (CAFB) process was developed in the late 1960's by the Esso Research Centre, Abingdon (ERCA), England as a means to generate electrical energy from high sulfur, high metal heavy fuel oil.[1] During the early and mid 1970's, the process was demonstrated at the pilot plant stage to be capable of providing energy effectively while simultaneously limiting sulfur oxide, nitrogen oxide, vanadium and nickel air emissions to levels lower than those produced by conventional oil-firing techniques. With the realization that the supply of oil and natural gas available to the United States might soon be restricted, and that, consequently, coal would be the increasingly dominant fossil fuel source of energy in the coming decades, a decision was made to investigate the efficacy of the CAFB using coal as a retrofit for existing natural gas-fired boilers. To this end, a pilot plant test employing a Texas lignite was carried out at ERCA in early 1978.

In the CAFB process, oil or coal is fed continuously into a fluidized bed of limestone maintained at 850°C $\pm$70°C by preheated substoichiometric air. In this gasification unit fuel is successively vaporized, oxidized, cracked and reduced. Sulfur in the fuel forms various gaseous species which in turn react with the bed stone to form calcium sulfide coated lime. Some of the fuel bound trace elements are also bound to the lime particles. The low Btu, low sulfur product gas generated in the gasifier is passed through cyclones to a conventional natural gas boiler where it undergoes combustion. The sulfided stone left in the gasifier is cycled to a regenerator unit in which it is oxidized to produce lime which is returned to the gasifier and sulfur dioxide which is sent to a sulfur recovery unit.

The ERCA pilot plant is a 2.9 MW unit. Foster-Wheeler Energy Corporation is constructing a 10 MW retrofit demonstration plant in San Benito, Texas, at the La Palma Power Station of Central Power and Light Company.[2] This unit is scheduled for startup in early 1979.

BACKGROUND

In 1976 GCA/Technology Division prepared for EPA a report entitled "Preliminary Environmental Assessment of the CAFB."[3] The major part of that volume was devoted to an evaluation of the emission rates and potential environmental effects of the pollutants comprising all air, water and solid waste streams. This evaluation centered around a field sampling program

carried out at the ERCA pilot plant during oil gasification and subsequent laboratory analysis of samples collected during testing. Because this program was performed during the period in which EPA was developing the Phased Approach to Environmental Assessments, the sampling and analytical procedures employed included both standard EPA enforcement methods and elements from the evolving Level I procedures. In addition to the experimental measurement activities, the preliminary assessment included: an engineering evaluation of potential fugitive emissions from storage and handling of feedstocks and spent material; estimates of emissions associated with cooling and boiler water; and an air quality impact assessment for the oil-fired CAFB La Palma retrofit.

The major conclusions of the environmental assessment of the oil-fired CAFB are summarized below:

- Reduction of Stack Particulate Emissions - Total stack particulate emissions from oil-fired operation of the pilot plant, 30 percent of which are in the respirable size range, were only slightly lower than the New Source Performance Standard (NSPS) for oil-fired boilers. During stone feed-startup these emissions considerably exceeded the NSPS. The vanadium concentration of these particulates is such that the vanadium emission rate is only slightly lower than the Multi-Media Environmental Goal (MEG) for this element. Under coal-fired operation of the CAFB, proposed for the demonstration plant, the particulate emission problems may be even more pronounced. Foster-Wheeler is designing more efficient cyclones than were installed at the pilot plant. Extensive particulate emission rate measurements at the demonstration plant should be undertaken for all operating modes and for all fuels.

- Reduction of SO_2 Emissions During Abnormal Operating Conditions - Blockage of the gasifier-regenerator transfer duct causes saturation of gasifier bed stone and a resultant increase in SO_2 emissions. Operation of the CAFB in this mode for extended time periods should be avoided. Continuous SO_2 monitoring is recommended.

- NO_x Stack Emissions - Measurements of NO_x emissions for three separate runs were about 25 percent of the NSPS for oil-fired boilers.

- Trace Elements Other Than Vanadium - Stack emission rates of no element other than vanadium approached creating ambient levels on the order of the MEG for that element.

- Environmentally Acceptable Disposal of Spent Stone - The demonstration plant will generate 6000 kg/day (13,000 lb/day) and a 250 MW commercial size unit 79,000 kg/day (173,000 lb/day) of sulfided, metal-contaminated lime which must be treated before being disposed of by selling, landfilling, or ocean dumping.

- Detailed Investigation of Organic Stack Emissions - Flue gas analyses indicated the possible presence of quinone, carbonyl compounds and aliphatic hydrocarbons in sufficient quantities to produce ambient concentrations in the neighborhood of the MEG's for these species. Organic emissions are highly dependent on gasifier and boiler operating conditions and should be analyzed with greater specificity than was possible in the present study.

The 1976 report included an overview of other desulfurization technologies (hydrodesulfurization (HDS) and flue gas desulfurization (FGD)) and a comparative economic evaluation of CAFB, FGD and HDS. Sixteen HDS processes were identified as actual or potential commercial systems. The unit operations of each process were identified and the attendant environmental impacts of each unit operation were discussed.

PROGRAM OBJECTIVES

The goals of this program are to: evaluate the potential environmental impact of a lignite-fired CAFB; identify additional control needs for this process; provide recommendations for further environmental assessment of the CAFB; and update (from our 1976 report) capital and operating costs for the oil-fired CAFB and alternative oil-fired energy systems.

To collect the data necessary to the environmental assessment, an extensive sampling and analysis program of the emissions from the ERCA pilot plant was conducted. The measurement protocols closely followed Level I of EPA's Phased Approach to Environmental Assessments.[4] Additional measurements were conducted to ensure comparability of the results of this study with those of the oil-fired assessment and to provide specific data known to be required from the previous program and necessary for a clearer understanding of the CAFB process itself. Because of the extensive work on the environmental and economic implications of various solid waste disposal options being performed by other contractors,[5,6] in parallel with this study, this assessment focused primarily upon flue gas emissions from the CAFB.

The assessment of the environmental impact of the CAFB utilizes the results of the measurement program in conjunction with standards of performance for coal-fired power plants and the Source Analysis Model,[7] a scheme for ranking the relative hazards of pollutant emissions and waste streams. The output of this environmental assessment consists of the identification of control requirements for the CAFB and recommendations for follow-on assessment activities to be conducted at the demonstration plant.

In addition to the environmental analysis of the CAFB, the economic comparison between the oil-fired CAFB and alternate oil-fired energy production techniques has also been updated from the 1976 report. Eight new HDS processes are identified and described. Although the retrofit and fuel switching capability of the CAFB are not directly matched by HDS or FGD, the economic data are instructive for evaluating the marketability of the CAFB process.

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SECTION 3

PROCESS DESCRIPTION

INTRODUCTION

A description of three development stages of the CAFB process, as applied to residual oil gasification, is provided in GCA's preliminary environmental assessment of the CAFB.[1] These include the 2.93 MW pilot plant constructed at the Esso Research Center, Abingdon (ERCA), England, the 22 MW demonstration plant currently in the final stages of construction at Central Power and Light's La Palma, Texas, facility (a joint effort by Foster-Wheeler Equipment Corporation and Central Power and Light), and a conceptual full scale commercial unit based on the Foster-Wheeler design. Operating parameters noted in this section are based on the results of GCA's sampling effort conducted at the ESSO pilot plant during lignite gasification, data supplied by Foster-Wheeler, and simple mass balance calculations.

OVERVIEW

In the CAFB process, lignite is consecutively vaporized, oxidized, cracked and reduced in a fluidized bed of lime to produce a low Btu gas. This gas, from which a large portion of the sulfur has been removed by the lime, travels from the gasifier through cyclones for particulate removal and then into a conventional boiler for combustion. At the ESSO pilot plant the boiler flue gas encounters a knockout baffle and another cyclone before entering the stack. Under normal operating conditions, lime is continuously cycled between the gasifier and the regenerator where lime sulfided in the gasifier is oxidized to CaO. Sulfur dioxide produced in the regenerator is fed to the boiler stack (in the case of the pilot plant) or chemically treated to recover sulfur (for demonstration and larger designs). Spent lime is withdrawn from the regenerator for disposal on an intermittent or continuous basis. To maintain sulfur removal efficiency, an equivalent amount of limestone is added to the gasifier.

General Description and Chemistry of Gasification

The basic components of the CAFB process are the gasifier and regenerator. Figure 1 schematically illustrates the materials fed to and withdrawn from these unit operations. The quantity of limestone added to the gasifier is determined by the Ca/S molar feed ratio necessary to provide the desired level of SO_2 control. Air is fed into the gasifier at about 30 percent stoichiometric in order to partially oxidize the fuel oil and produce a temperature 871°C (1600°F)

suitable for vaporization and cracking of the fuel. Flue gas from the boiler at approximately 171°C (340°F) is recirculated to the gasifier for temperature control. A low Btu product gas is circulated from the gasifier to the boiler. The predominant reactions taking place in the gasifier are as follows:

$$\text{Fuel thermal cracking} \rightarrow C + H_2 + \text{hydrocarbons} + H_2S + CS_2 + COS$$

$$CaO + H_2S \rightleftharpoons CaS + H_2O$$

$$CaO + COS \rightleftharpoons CaS + CO_2$$

$$CaO + 1/2CS_2 \rightleftharpoons CaS + 1/2CO_2$$

The equilibria for these reactions are well to the right. Approximately 5 percent of the input limestone as calcium oxide is reduced to calcium sulfide on each pass of stone through the gasifier.

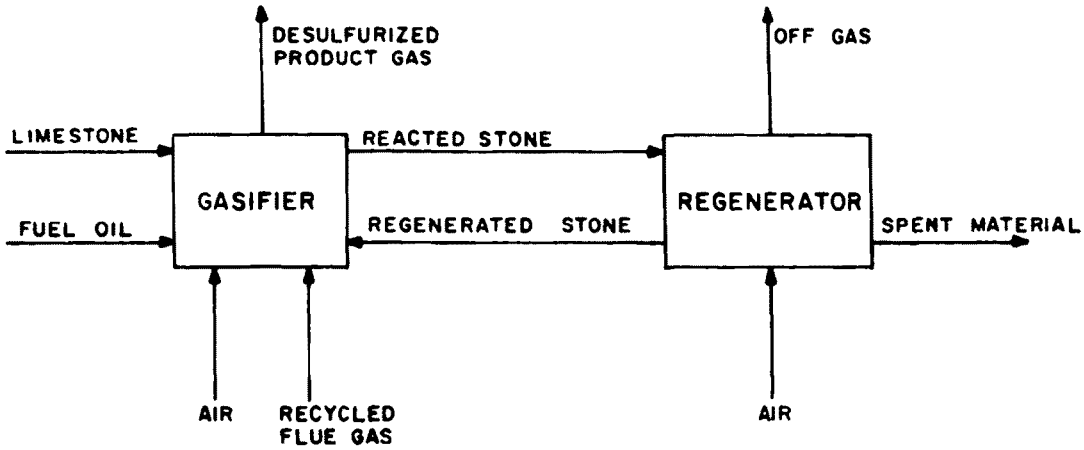

Figure 1. Gasifier-regenerator schematic.

General Description and Chemistry of Regeneration

The regeneration step is accomplished in a reaction vessel adjacent to the gasifier. Bed material comprised of CaO, CaS, carbon and ash is fed to the regenerator where it reacts with a stoichiometric quantity of air by the reactions:

$$CaS + 3/2\ O_2 \rightleftharpoons CaO + SO_2$$

$$CaS + 2O_2 \rightleftharpoons CaSO_4$$

$$CaS + 3CaSO_4 \rightleftharpoons 4CaO + 4SO_2$$

Carbon deposited on the stone during gasification is oxidized to CO_2. Regenerator solids analyzed by ESSO during the GCA sampling run ranged between 0.1 to 2.8 percent carbon.

The off-gas from the regenerator contains SO_2, CO_2 and N_2 derived from the influent air. Spent solid material consists of CaO, $CaSO_4$, CaS and ash. In the Foster-Wheeler demonstration plant and 250 MW unit, off-gas will be transported to the RESOX™ system for recovery of elemental sulfur, and spent solids will be conveyed to a solids cooler and storage bin. At the ESSO pilot plant regenerator off-gas passes through a cyclone and then into the boiler stack.

ESSO PILOT PLANT

Figure 2 is a schematic diagram of the ESSO pilot plant. Some physical modifications have been made since our first investigation to allow for solid fuel gasification. Input and output streams to and from each unit operation are labelled and their mass flow and characteristics are given in Table 1. The quantities listed in this table are those projected at steady-state conditions, based on recorded operating characteristics during the lignite sampling run. Parameters will vary during startup, shutdown, and atypical operating modes.

FOSTER-WHEELER DEMONSTRATION PLANT

The Foster-Wheeler demonstration plant shown schematically in Figure 3 contains, in addition to the basic gasifier and regenerator units, a RESOX™ system for sulfur recovery from the regenerator off-gas, a spent solids handling system and a coal storage and feed system for lignite gasification. Mass flows and stream conditions listed in Table 2 are based on FW design parameters and mass balance calculations by GCA. The extent of operations of the RESOX™ unit will depend upon fuel sulfur concentration. This sulfur recovery system is designed for maximal performance with 7 to 8 percent SO_2 input; thus, for CAFB gasification of low sulfur fuel the RESOX™ may be operated intermittently to allow for SO_2 buildup in the regenerator.

In GCA's oil-fired assessment report, auxiliary handling and storage unit operations were discussed in depth for both oil and coal-firing. Because these operations do not appear to present appreciable environmental problems and because they are similar to facilities used in conventional boilers, we have not updated the earlier treatment.

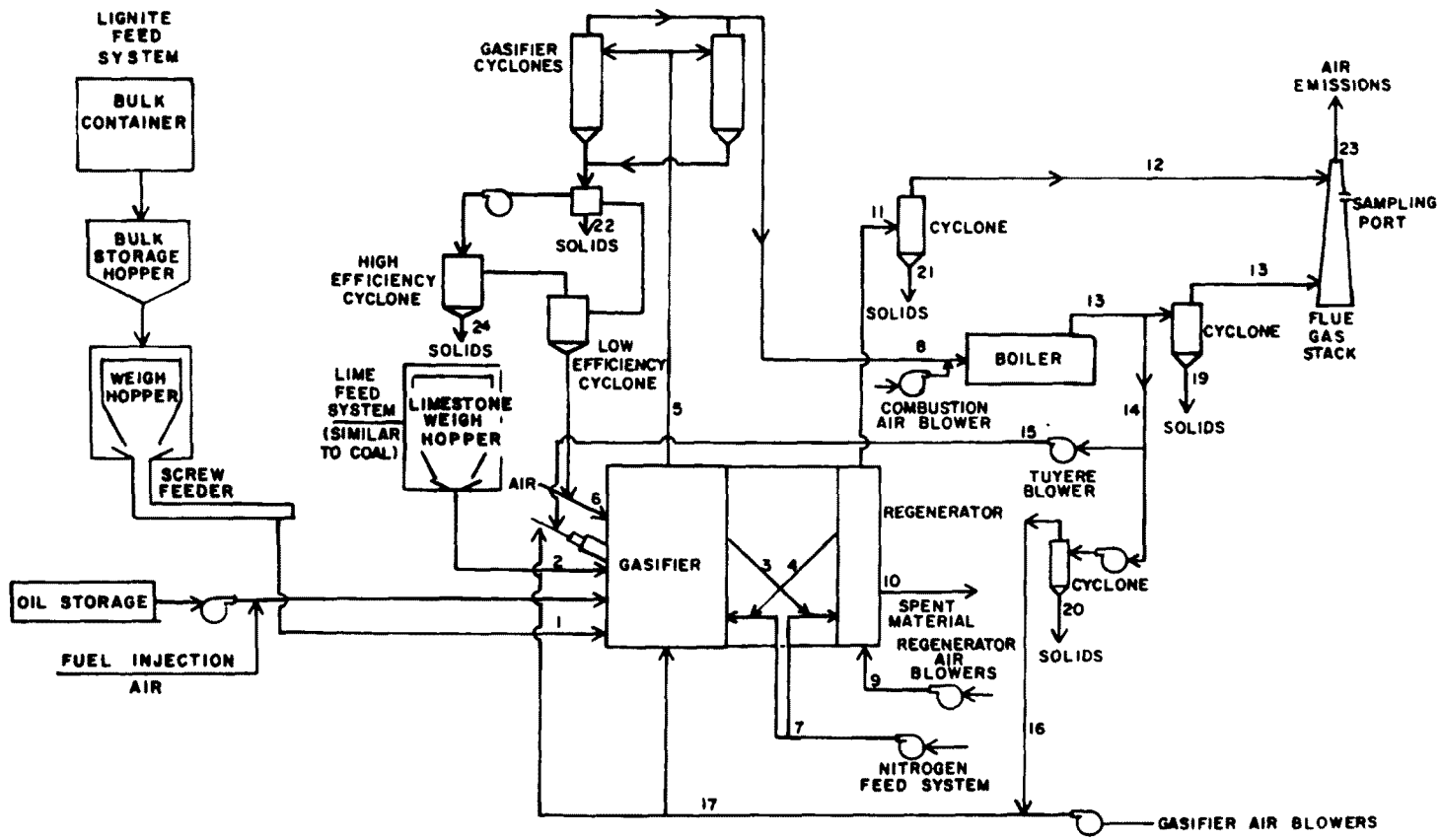

Figure 2. Unit operations flow diagram of the ESSO pilot plant.

TABLE 1. ESSO PILOT PLANT MASS FLOW RATES

	Process stream	Mass flow rate		Temperature	
		kg/sec	lb/hr	°C	°F
1.	Lignite feed to gasifier	0.04-0.07	(350-550)		
2.	Limestone feed to gasifier	0.001-0.003	(10-20)		
3.	Gasifier to regenerator stone transfer	Intermittent			
4.	Regenerator to gasifier stone transfer				
5.	Product gas to cyclones	0.09-0.18	(700-1,400)		
6.	Cyclone solids return to gasifier	Intermittent			
7.	N_2 gas to solids transfer lines				
8.	Product gas to boiler			792-913	(1,458-1,675)
9.	Air to regenerator	0.006-0.015	(45-115)		
10.	Spent solids from regenerator	Intermittent grab samples		1,055	(1,931)
11.	Regenerator off-gas to cyclone			1,055	(1,931)
12.	Regenerator off-gas, cyclone to stack				
13.	Flue gas from boiler				
14.	Flue gas recirculated to gasifier				
15.	Flue gas to Tuyere Blower				
16.	Recycled flue gas from cyclone				
17.	Air to gasifier	0.05-0.10	(400-800)		
18.	Flue gas to stack	0.66-0.71	(5,200-5,600)		
19.	Solids from boiler flue gas cyclone				
20.	Solids from recycled flue gas cyclone				
21.	Solids from regenerator off-gas cyclone				
22.	Solids from gasifier cyclones				
23.	Stack emissions				
24.	Solids from high efficiency cyclone				

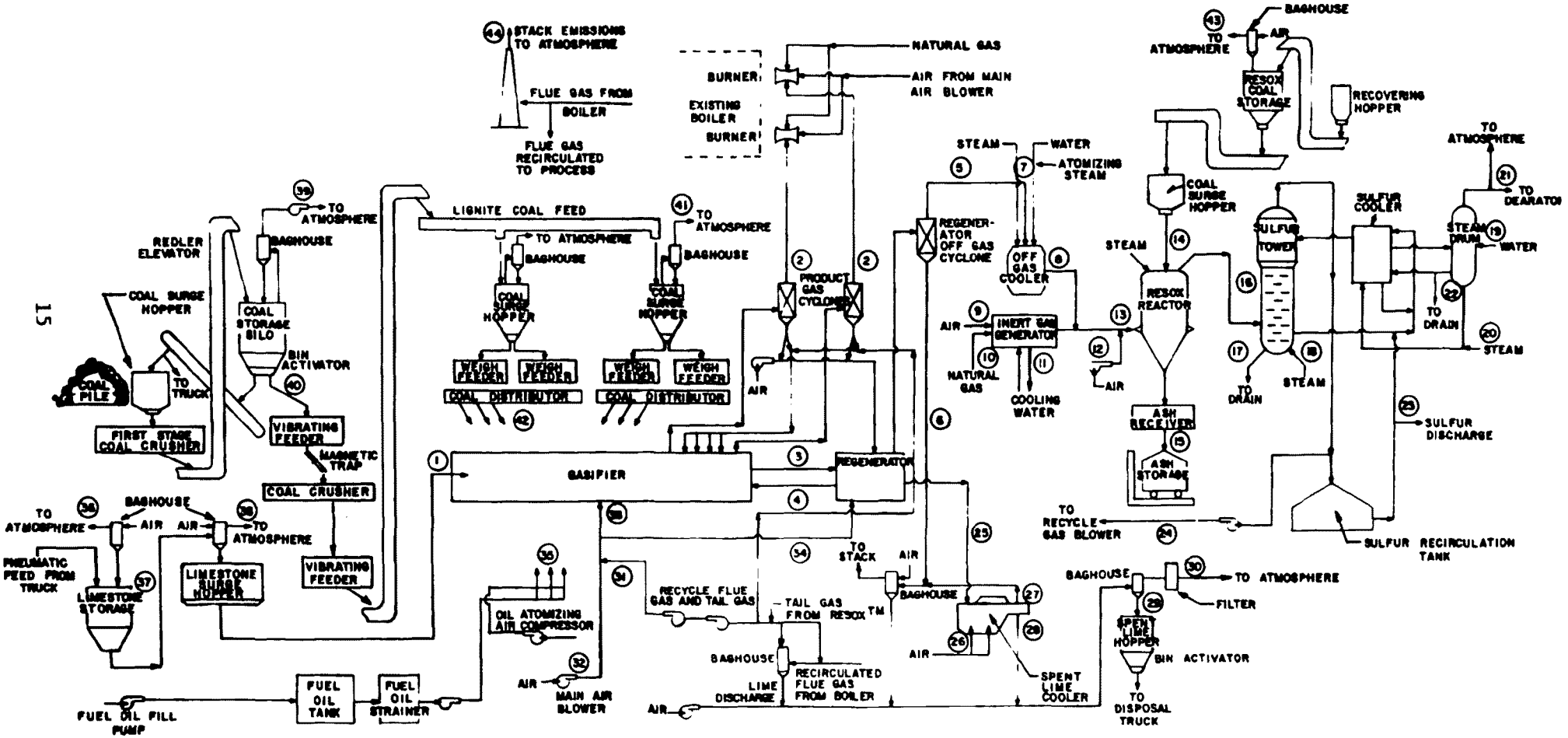

Figure 3. Unit operations flow diagram of the Foster-Wheeler CAFB demonstration plant.

TABLE 2. MASS FLOW RATES FOR FOSTER-WHEELER 22 MW CAFB DEMONSTRATION PLANT

	Process stream	Mass flow rate		Temperature	
		kg/sec	lb/hr	°C	°F
1.	Limestone to gasifier	0.06-0.11	(450-900)		
2.	Product gas to boiler	10.1-11.4	(80,000-90,000)*	871	(1,600)
3.	Gasifier to regenerator stone transfer	3.15-4.41	(25,000-35,000)		
4.	Regenerator to gasifier stone transfer	3.15-4.41	(25,000-35,000)		
5.	Regenerator off-gas: total	0.50-0.57	(4,500-4,500)	1,038	(1,900)
	SO_2				
	CO_2				
	N_2				
6.	Cyclone solids from regenerator to spent lime cooler baghouse				
7.	Water and steam to off-gas cooler				
8.	Off-gas from cooler to RESOX™			649	(1,200)
9.	Air to inert gas generator	0.67†	(5,300)		
10.	Natural gas to inert gas generator	0.05†	(360)		
11.	Cooling water for inert gas generator	22.7†	(180,000)		
12.	Air to RESOX™				
13.	Combined gas to RESOX™				
14.	Anthracite coal to RESOX™				
15.	RESOX™ ash to storage				
16.	Elemental sulfur from RESOX™ to sulfur tower			538†	(1,000)
17.	Drainage from sulfur tower				
18.	Steam to sulfur tower				
19.	Water to steam drum				
20.	Startup steam to sulfur cooler and steam drum				
21.	Steam purge from steam drum				
22.	Blowdown from steam drum and sulfur cooler				
23.	Sulfur discharge			154†	(310)
24.	RESOX™ tail gas			160†	(320)
25.	Spent solids from regenerator to cooler	0.02†	(122)	1,038†	(1,900)
26.	Air to spent lime cooler				

(Continued)

TABLE 2 (continued).

Process stream	Mass flow rate		Temperature	
	kg/sec	lb/hr	°C	°F
27. Spent lime cooler vent to baghouse				
28. Spent lime from cooler to hopper baghouse				
29. Spent lime from baghouse to spent lime hopper				
30. Air emissions from spent lime hopper baghouse				
31. Recycle flue gas and tail gas to gasifier and regenerator				
32. Air to gasifier and regenerator	6.52-6.58	(51,700-52,200)		
33. Combined air/flue/tail gas to gasifier	7.94	(63,000)		
34. Combined air/flue/tail gas to regenerator				
35. Fuel oil to gasifier (if used)				
36. Air emissions from limestone storage baghouse				
37. Fugitive emissions from limestone handling				
38. Air emissions from limestone surge hopper baghouse				
39. Air emissions from coal storage silo baghouse				
40. Fugitive emissions from coal handling				
41. Air emissions from coal surge hopper baghouse				
42. Lignite feed to gasifier	3.15	(25,000)		
43. Air emissions from RESOX™ coal storage baghouse				
44. Air emissions from main stack				

*Assuming flue gas recirculation to gasifier.

†Design capacity quantities based on Foster-Wheeler CAFB demonstration plant design drawings.

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SECTION 4

MEASUREMENT PROGRAM

INTRODUCTION

The experimental phase of the CAFB Environmental Assessment was designed to conform to the data and procedural requirements of an environmental assessment as defined by Level I of EPA's Phased Approach[1] and to provide data comparable to those acquired for the oil-fired study. Data on some internal process streams were also collected to assist in control design and implementation.

As noted previously, the measurement program emphasized emissions from the flue gas, although samples from the fuels, solid waste and process cyclones were also collected. The flue gas was sampled with SASS,* modified RAC, and in-stack impactor trains. The use of these three systems allowed comparison of total particulate collected by SASS and Method 5[2] RAC trains, and particle size distribution as determined by SASS and impactor. Tenax resin, used in a module incorporated into the Method 5 train, provided a measure of gaseous organic emissions in addition to those collected by XAD-2 resin in the SASS.

Organic analyses of SASS, Tenax, and solid samples followed the Level I procedures based on gas chromatography, liquid chromatography, and infrared spectroscopy. Level I inorganic analyses were based on spark source mass spectrometry, atomic absorption spectroscopy, and wet chemistry. Additional particulate analyses were performed with X-ray photoelectron spectroscopy.

This section presents the sampling and analytical procedures used in the measurement program and summarizes the field and laboratory results. Detailed field results are tabulated in Appendix C and laboratory results in Appendix D.

FIELD TESTS

Protocol

Field sampling of the ERCA CAFB pilot operation was conducted from January 24 through January 27, 1978. Testing was designed as a Level I Environmental Assessment of the flue gas and particulate emissions. Additionally, solid waste effluents, coal and limestone feeds and internal particulate and solid samples were collected for laboratory analysis. The principal purpose of the testing was to characterize the physical and chemical parameters of the stack emission through onsite analysis of specific chemical species and by the collection of flue gas samples for further laboratory analysis.

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*SASS - Source Assessment Sampling System.

The flue gas was sampled in the stack through the three ports installed approximately 6 diameters upstream from the flue gas entry into the stack. The ports were spaced 120 degrees apart and included two with a 3-inch BSP and one with a 5-inch BSP fitting. Multiple ports were necessary to allow simultaneous testing.

In-stack testing was by SASS train, Andersen impactor, modified RAC train, and integrated bag sampler. In addition to trains used for the chemical and particulate emissions testing, the physical parameters of the flue gas were measured by initial pitot traverses. In-stack thermocouples were used to monitor flue gas temperatures, and the flue gas moisture was determined by gravimetric analysis of moisture gain in the sampling trains. The results of the calculated physical parameters were used to determine the required nozzle sizes and sampling rates for the subsequent in-stack tests.

Particulate sampling was accomplished using a Method 5 train and a SASS train. The Method 5 train was also used to test simultaneously for SO_2/SO_3 by Method 8[3] in three of the five RAC train tests. The other two RAC tests used modified trains for the purpose of collecting gaseous organic species as well as total particulate.

Gaseous organic species were collected by the addition of a gas adsorbent column, shown in Figure 4, to the RAC train. This column contained preconditioned Tenax-GC, a porous polymer compound with the ability to adsorb organics heavier than C_6. In the modified RAC train the flue gas, after passing through the particulate filter, was cooled to slightly above its dewpoint by means of a thermostated cooling bath and water jacket. The gas then passed through the adsorbent cell which collected the organic constituents. Any condensate which filters through the cell was collected in a glass receiver (not shown). After completion of the sampling, the complete adsorbent column was capped and returned to the laboratory for extraction and analysis. Any condensed liquid can also be extracted and analyzed for organics. This modified train thus provided a sampling method for both organics and total particulate.

The SASS train, which is the train specified in the Level I assessment, also provides both particulate and organic testing of flue gas emissions. In addition, the SASS train allows determination of the particulate size distributions and also provides samples for inorganic analyses of volatiles in the flue gas emissions. For this program, two tests by SASS train were conducted. The methods used were according to those specified by the Level I Manual. A description of the SASS train and its operation may be found in that document. All SASS samples were recovered in the field laboratory provided by ERCA and then prepared for shipment to GCA's laboratory for analysis.

It was necessary to perform in-field analyses of the volatile gases. The tests for these included the Method 8 testing for SO_2/SO_3, gas chromatography analysis of hydrocarbons (C_1-C_6) and fixed inorganic gases, and chemiluminescent analysis of NO-NO_x emissions.

The Method 8 sampling was included with three of the particulate tests by modification of the standard RAC train. All solutions and standardizations

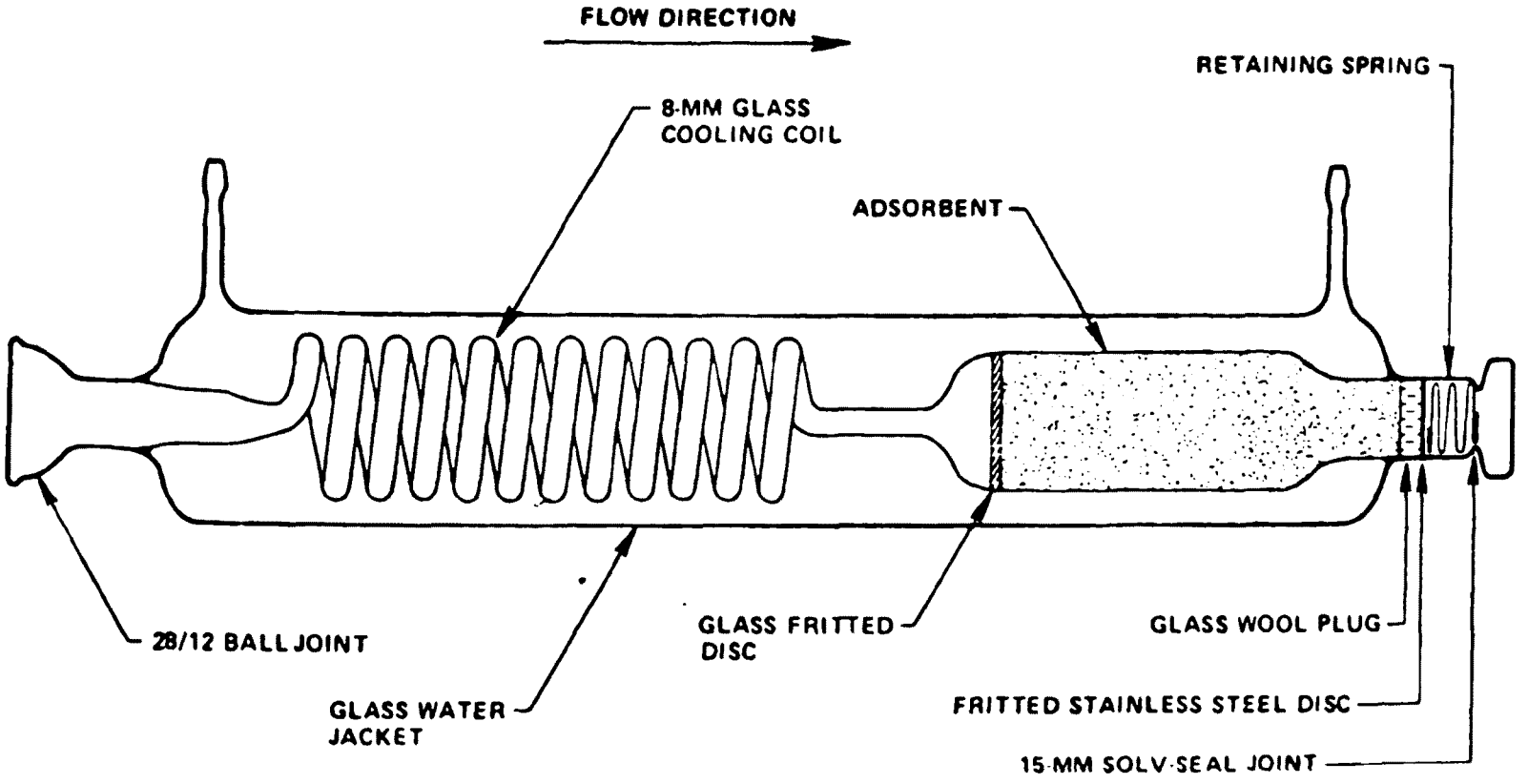

Figure 4. Adsorbent sampling system.

were performed in the field laboratory. Samples were analyzed after the completion of each test in order to prevent any degradation of samples.

Tests for C_1-C_6 hydrocarbons, fixed inorganic gases and NO-NO_x were performed in the field laboratory from integrated bag samples of the flue gas. Bag samples were taken with an integrated gaseous sampling train as described in the Level I Manual. Tedlar bags were used for samples. The bags were transported to the field laboratory, located approximately 100 yards from the stack, for analysis at the completion of the test.

Field testing for C_1-C_6 hydrocarbons was by gas chromatography. A Model 511 AID gas chromatograph equipped with FID detector, 6-ft stainless steel Poropak Q column, and heated 1-mℓ gas sampling valve was used for analysis. A recorder with an integrator was used to record the results of the analysis. Samples were compared against standard gas mixtures for qualitative and quantitative analysis.

The analysis of fixed inorganic gases, specifically CO_2, O_2, N_2 and CO, was by gas chromatography. The Model 511 AID equipped with a TCD detector and a 1-mℓ sampling valve was used for analysis of these components. The columns used in this instrument were a 2-ft chromosorb 102 with a 4-ft 13X molecular sieve. Samples were compared against standard gas mixtures for qualitative and quantitative analysis.

The bag sample was also used for NO-NO_x analysis. A Thermo Electron Model 10AR Chemiluminescent gas analyzer provided immediate analysis of the flue gas for both NO and NO_x.

It was intended that gas chromatography analysis of H_2S, SO_2, and COS by a flame photometric detector would also be used. This instrument was inoperative during this testing program.

When possible, analysis was performed on site to minimize transportation losses. These analyses included gravimetric analysis of filters and washes. The SO_2/SO_3 analyses were performed in the field laboratory with standard solutions prepared in the field. As described previously, the bag samples were analyzed in the field laboratory for gaseous components. Samples requiring more complex treatment and analysis were shipped to the home laboratory along with suitable blanks.

In addition to flue gas, samples of lignite, limestone, spent stone, gasifier bed, and cyclone catches were collected by ERCA at 6-hour intervals and provided to GCA for analysis.

Results

The field testing program was designed to provide an evaluation of the particulate and gaseous emissions from the CAFB unit. The results obtained from the field analysis include the particulate loading rates, the particulate size distributions, the physical parameters of the flue gas, and the gas analysis.

The data shown in Table 3 provide results of physical parameters from the two tests with the SASS train and the five tests with the modified RAC trains. The moisture determinations were obtained from gravimetric analysis of the moisture gain of each train. The reason for the variation in these values is unknown, but it should be noted that the exact temperature control and high volume of the SASS train would possibly provide a more representative value than the RAC values.

Particulate loadings as obtained from gravimetric analysis of the filter, cyclones, and washes of each test are also included in Table 3. There is some variation in the comparison of these results between trains which would be expected since each train was a single point sample. Also, it should be noted that while RAC train tests and SASS train tests were run simultaneously when possible, the test time duration and volume of gas sampled were significantly different. The results of these tests do provide an indication of the particulate loadings for the CAFB unit. The values obtained translate into 2 to 4 $lb/10^6$ Btu for total emissions.

The results of the particulate sampling by SASS train also provide a characterization of the particle size distributions. The results of this breakdown, along with the other measured parameters for each test, are included in Table 4.

The SASS train particle size distribution results are shown graphically in Figure 5. These graphs were obtained using the calculated cut diameters for each cyclone as determined by the cyclone equation $D_{P2} = D_{P1}\sqrt{\frac{\mu_2 Q_1}{\mu_1 Q_2}}$ where D_{P1} is calibrated aerodynamic particle diameter for Q_1 = 6.41 acfm at 400°F and μ_1 = 0.026 centipoise. The values for the percent weight were obtained from the values reported in Table 4, as calculated from the total particulate for each cyclone.

The results of the particle size distribution calculations indicate that 98 percent of the particulate was greater than 1 μm, with the mean particle diameter between 6 and 7 μm. These results show good correlation to the results of the three in-stack Andersen impactor runs which are presented by the conventional log normal plots of the particle size distributions shown in Figure 6.

Field analyses were also performed for gaseous species in the flue gas. As described previously, the RAC train was modified to provide determinations of SO_2 and SO_3. The measured parameters for these three tests are found in Table 3, and the results of the field analyses are included in Table 5.

Table 5 also includes the results of the field analyses of the bag samples. The bag samples were taken simultaneously with the train sampling on 3 of the 4 test days. The results of the fixed gas analysis show a large degree of variation presumably due to changes in operating conditions. The value for O_2 reported on January 27 appears abnormally low, but a check of calculations shows closed deviation of less than 3 percent.

TABLE 3. CAFB PARTICULATE TEST DATA

Test No.	Date	Q_s* (dscfm)	Q_a† (acfm)	Moisture (%)	E.A.‡ (%)	Part. loading (gr/dscf)	V_{mstd}§ (dscf)	Test design
RAC-1	1/24	1200.7	1463.3	7.1	39.9	1.0381	29.525	Part.; SO_2/SO_3
SASS-1	1/24	1100.3	1590.0	10.0	53.6	0.9632	919.167	SASS
RAC-2	1/25	1388.1	1891.6	6.6	67.1	1.5291	32.740	Part.; organics
SASS-2	1/26	1271.6	1878.0	12.1	53.6	1.1994	266.291	SASS
RAC-3	1/26	1346.7	1844.6	9.0	53.6	0.9906	32.876	Part.; SO_2/SO_3
RAC-4	1/27	1422.7	1972.8	4.5	29.4	0.8520	26.318	Part.; organics
RAC-5	1/27	1053.8	1536.0	9.4	28.0	0.7917	24.630	Part.; SO_2/SO_3

*Q_s - Stack flow rate at dry standard conditions.

†Q_a - Stack flow rate at actual stack conditions.

‡E.A. - Calculated excess air.

§V_{mstd} - Volume of flue gas sampled at dry standard conditions.

TABLE 4. CAFB PARTICULATE MASS AND SIZE EMISSIONS DATA MEASURED BY SASS TRAIN

SASS-1	
Parameter	Rate or value
Flue gas flow rate	1100.3 dscfm
Temperature at sampling port	214°F
Flue gas moisture	10.0%
Total particulate loading	0.9632 gr/dscf
Particle size fraction collected	Percent of total particulates
< 1 μm (filter)	1.2%
> 1 μm	26.9%
> 3 μm	50.3%
> 10 μm	21.6%

SASS-2	
Parameter	Rate or value
Flue gas flow rate	1271.6 dscfm
Temperature at sampling port	214°F
Flue gas moisture	12.0%
Total particulate loading	1.1994 gr/dscf
Particle size fraction collected	Percent of total particulates
< 1 μm (filter)	1.8%
> 1 μm	31.8%
> 3 μm	44.1%
> 10 μm	22.4%

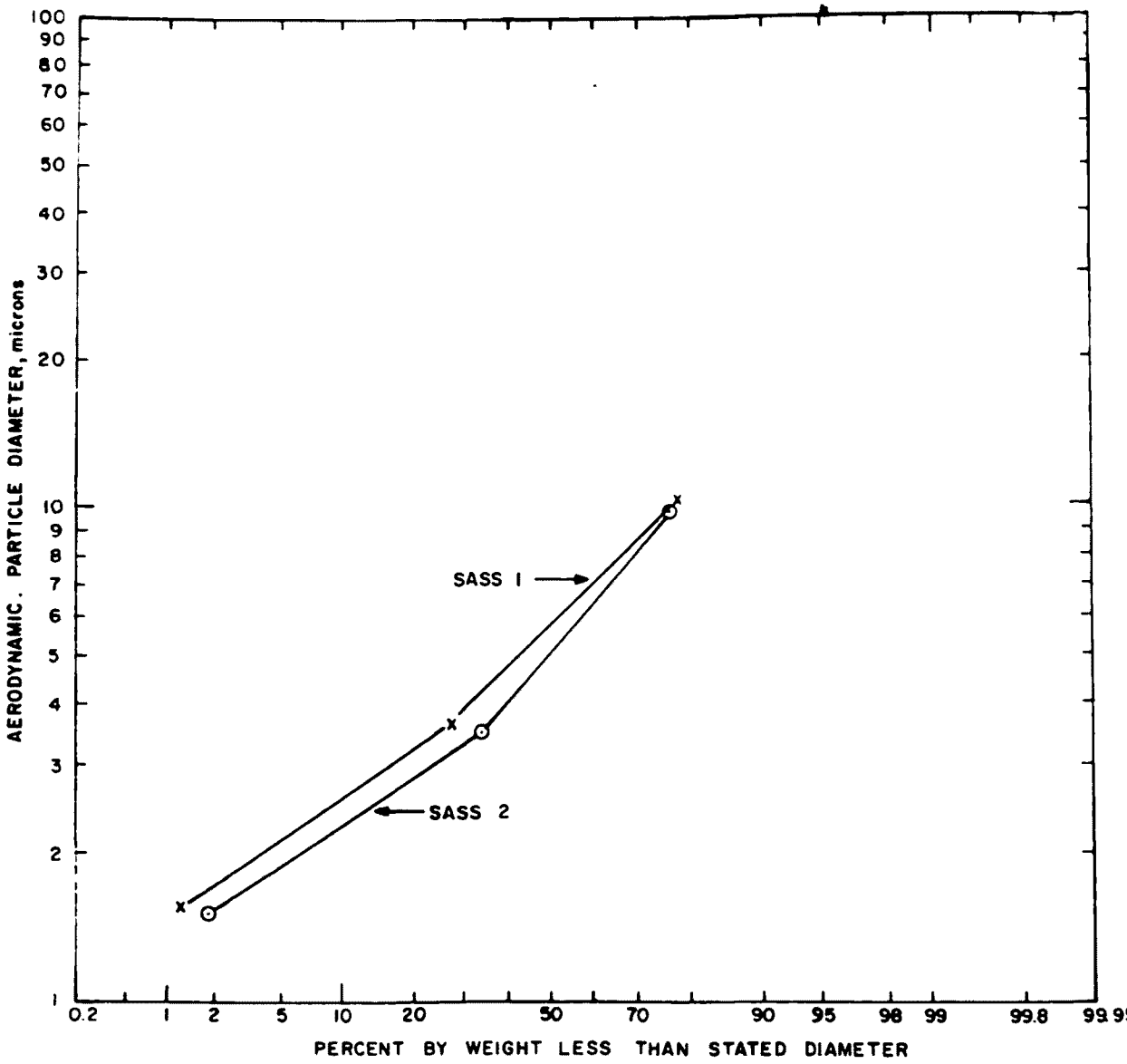

Figure 5. Particulate size distributions measured by SASS train.

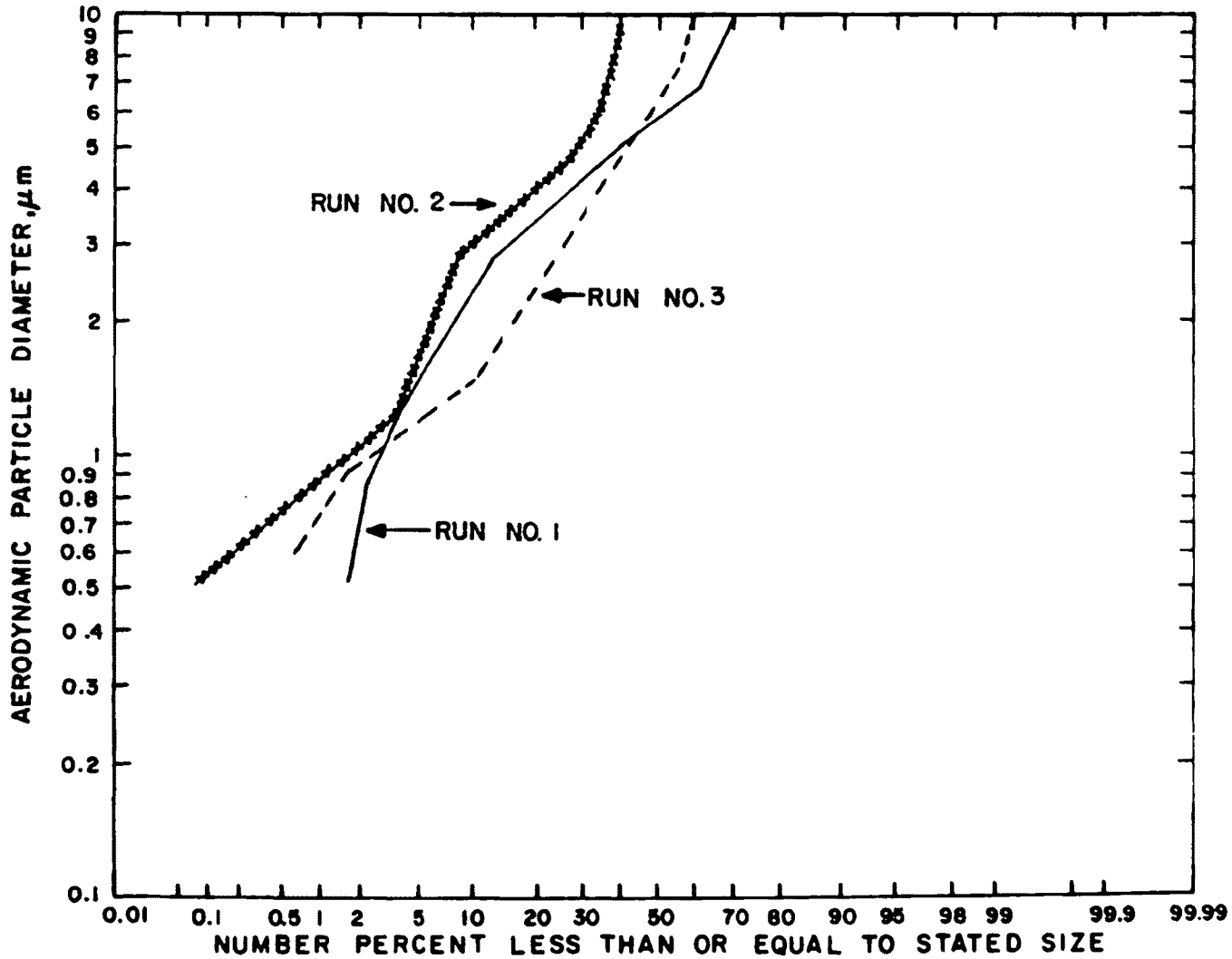

Figure 6. Particulate size distributions measured by in-stack impactor.

TABLE 5. CAFB GAS ANALYSIS

Test date	CO_2 (%)	O_2 (%)	CO (%)	NO (ppmv)	NO_x (ppmv)	SO_2 (ppmv)	SO_3 (ppmv)	C_1 (ppmv)	C_2* (ppmv)
1/24	10.1	9.1	<0.05	28	33	101.9	0.8	21.4	2.8
1/25	6.1	9.0	<0.05	14.5	15.7	—	—	6.5	<0.5
1/26	—	—	—	—	—	299.7	1.3	—	—
1/27	6.4	5.3	<0.05	26	42	185.0	0.9	<0.5	<0.5

*No hydrocarbons above C_2 detected, MDL 0.5 ppmv.

The results of hydrocarbon analysis on January 24 showed detectable hydrocarbons in the C_1 and C_2 boiling point range as determined according to the Level I method. The values of detectable hydrocarbon appeared to decrease during the testing, with no hydrocarbons detected above the 0.5 ppmv detectability limit of the instrument for the third bag sample taken January 27.

The values for NO and NO_x reported in Table 5 were obtained from analysis of bag samples by chemiluminescent instrument. The instrument was standardized against a standard NO gas and checked for standardization after being returned to the home laboratory. The results shown for the test on January 25 are abnormally low and may be the result of sample degradation due to a long holding time between sampling and analysis. Recent data gathered by other EPA contractors indicate that NO and NO_x collected in aluminized bags from streams containing air and moisture can degrade by a factor of 2 after a few hours. The runs completed on January 24 and January 27 were each analyzed within 2 hours of collection. Although Tedlar, not aluminized, bags were used in this study, it is possible that the NO/NO_x values reported in Table 5 could be low by as much as a factor of 2.

Discussion

The testing program was designed to comply with the EPA definition of an environmental assessment for the CAFB operation. In addition to the defined Level I environmental assessment, a number of other testing methods were included in this program to provide additional information on the physical and chemical properties of the emissions from the process.

Field tests with the RAC train and the SASS train were conducted simultaneously so that measurements could be compared. The results of the reported particulate loadings showed a variance of 4 percent and 12 percent for the tests No. 1 and No. 2. This variation is possibly due to the fact that SASS sampling was at a single point while RAC test No. 1 was traversed over 12 points. It was not possible to traverse with RAC test No. 2 since the addition of the organic sampling column prohibited the movement of the train. Sampling for RAC test No. 2 was thus at a single point.

The organic sampling column which was adapted to the RAC train used Tenax-GC as the organic adsorbent. The SASS train which is also designed to collect organic emissions used XAD-2 resin as the collection medium. This design allowed the comparison of the efficiencies of the two organic collecting resins. The result of this comparison is discussed in the Laboratory Analysis discussion of this report.

In addition to the organic emissions and total particulate emissions testing, the SASS train provided particle size information analysis of the three cyclone catches. These results, which are reported in the field analysis section, were compared to the particle size information which was obtained using Andersen impactors. The results of the two test designs showed good agreement with regard to size distributions and mean particle diameter.

The test program had been designed to provide comparison of sulfur species analysis methods. Unfortunately, the flame photometric gas

chromatograph was inoperative, and the results reported for SO_2 and SO_3 species were derived solely from the modified RAC train sampling.

There were other problems during the sampling program which required the alteration of the original plan. A principal problem was the sporadic operation of the CAFB unit, which resulted in schedule changes and shorter than specified SASS train sampling run time. The number of intended RAC train runs was reduced due to the changes in unit run schedule.

Other problems which were independent of the CAFB operation also caused delays and alteration of the intended schedule. Primary among these was the problem of power supply for the test equipment and laboratory instruments. Power for all of these instruments was provided by gasoline-powered generators. During testing one of the four generators was inoperative due to a short in the generator windings. As a result, the power supply for the laboratory was available only when one of the other three generators was not needed for the sampling equipment. This problem resulted in delays in some analyses performed by gas chromatography and NO_x analyzer.

Other problems were encountered during the test program, but on-site modifications and the cooperation of CAFB personnel remedied these situations to the satisfaction of the intent of the test program. The overall goals of program design were completed and the results reported are considered representative of the CAFB unit at the conditions tested.

LABORATORY ANALYSIS

Analysis Protocol

The laboratory analysis program was designed to characterize particulate and gaseous emissions from the CAFB pilot plant during operations with lignite. Using the Level I procedures for an environmental assessment as the framework for the analytical scheme, a program was developed which provided information on the CAFB process as well as information for an environmental assessment.

The types of sample analyses carried out are summarized in Table 6. SASS samples were analyzed for organics and inorganics by Level I methods with the exception that particulate samples were not combined (i.e., filter with 1μ cyclone, 3μ cyclone with 10μ cyclone). This provided a more complete analysis of the particulate size fractions which it was hoped would reveal information on their origin. Bulk samples were also analyzed by Level I methods to determine the composition of solid wastes generated by the CAFB and to provide information on the process which may aid in the design of controls.

Samples collected using the modified RAC train, in which particulate on a filter and gaseous organics on Tenax-GC resin were collected, were analyzed as shown. Because our experience has shown that most organic emissions are found on the resin samples, the particulate catches from RAC runs 1 to 5 were combined separately for organic compounds; therefore, a composite sample was made. Similarly, no inorganic analyses were performed on the Tenax resin. Two particulate samples were analyzed separately for bulk elemental composition.

TABLE 6. LABORATORY ANALYSIS PLAN FOR CAFB-LIGNITE STUDY

Organic Analysis

- SASS samples
  - Particulate
  - Resin (XAD-2)
  - Condensate
  - Rinses
- RAC samples
  - Particulate (composite of probe rinses; runs 1 to 5)
  - Tenax (runs 2 and 4)
- Bulk samples
  - Spent solids

Inorganic Analysis

- SASS samples
  - Particulate
  - Resin (XAD-2)
  - Condensate
  - Impingers
  - Rinses
- RAC samples
  - Particulate (runs 1, 3 and 5)
- Bulk samples
  - Lignite
  - Limestone
  - Spent solids
  - Cyclone fines
  - Gasifier bed

Surface Analysis

- SASS samples
  - Particulate
- RAC samples
  - Particulate
- Impactor substrates

Organic Analyses--

Level I organic analysis is designed to provide a semiquantitative (± 3×) determination of the classes and concentrations of organic substances contained in waste streams emitted by stationary energy and industrial processes. In this study, particulate, flue gas and solid waste were analyzed for organics.

In general, three categories of organic compounds are defined by Level I: gaseous, volatile and nonvolatile. Volatile organics are defined as those which boil between 90° and 300°C; nonvolatile organics boil above 300°C, and gaseous organics boil below 90°C. Gaseous organics which are measured in the field have been discussed earlier. Organic analyses were performed on all SASS train components except the impingers. All stainless steel components were rinsed with methylene chloride or a 50-50 (v/v) mixture of methylene chloride with acetone to recover organics. Organics in the condensate, particulate and XAD-2 resin were recovered by methylene chloride extraction. Tenax resin was extracted with pentane.

Because the extracts, in general, are too dilute to detect organic compounds using almost any instrumental technique available, all organic liquid and solvent extracts were concentrated to 10 mℓ via a Kuderna-Danish (K-D) concentrator. (The Kuderna-Danish concentrator is a glass apparatus which removes most of the solvent while minimizing the loss of the other volatile components.)

The concentrated samples were analyzed in two stages. The first stage of the analysis consists of four different methods. A sample aliquot is evaporated to dryness and weighed. The residue is then transferred to KBr plates and analyzed by a grating infrared spectrophotometer. The output of these steps is a measure of the amount of nonvolatile organic matter present in each sample and an indication of the functional groups which are present.

Another sample aliquot is injected into a gas chromatograph (GC). The instrument is calibrated so that the organic compounds boiling between 90° and 300°C (i.e., the total chromatographic organics or TCO) are quantified relative to n-decane. If the TCO is greater than 75 $\mu g/m^3$, the quantity of organics boiling within certain ranges is also determined. The volatile organics boiling within the ranges 90° to 110°, 110° to 140°, 140° to 160°, 160° to 180°, 180° to 200°, 200° to 220°, 220° to 240°, 240° to 260°, 260° to 280°, and 280° to 300°C were quantified relative to n-decane and reported as C_7, C_8, C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{14}, C_{15} and C_{16} alkane equivalents. The difference in the response of the GC detector between decane and the other hydrocarbons has been shown to be ±5 percent, which is well within the accuracy requirements of Level I analysis. The samples were not analyzed further if the total quantity of volatile and nonvolatile organic emissions (the sum of the TCO emissions and the gravimetric components) was less than 0.50 mg/m^3.

In the second stage of analysis, those samples with organic emission factors larger than 0.50 mg/m^3 were fractionated by liquid chromatography (LC). (The LC method used provides some separation of components according to polarity.) A sample aliquot was transferred to the top of a liquid chromatographic column packed with 6.5 gm silica gel in pentane. The column was

developed by gradient elution using the solvents given in Table 7, and seven fractions were collected. The fractions were analyzed by the gravimetric and infrared methods described previously. If the unfractionated sample contained more than 10 percent volatile organic material, each fraction was also analyzed by the gas chromatographic method discussed above.

TABLE 7. SOLVENTS USED FOR LIQUID CHROMATOGRAPHY

Fraction	Solvent
1	25 mℓ pentane
2	10 mℓ 20% CH_2Cl_2/pentane
3	10 mℓ 50% CH_2Cl_2/pentane
4	10 mℓ CH_2Cl_2
5	10 mℓ 5% CH_3OH/CH_2Cl_2
6	10 mℓ 20% CH_3OH/CH_2Cl_2
7	10 mℓ 50% CH_3OH/CH_2Cl_2

Inorganic Analysis--

Level I inorganic analysis consisted of a Spark Source Mass Spectrographic (SSMS) elemental survey along with specific analyses for mercury, fluoride, chloride, and sulfate. Both liquid and solid samples were received in the laboratory for analysis. Organic materials, both liquid and solid, were combusted in a Parr oxygen bomb to destroy the organic matrix. Solids that were primarily inorganic (with the exception of glass fiber particulate filters) were analyzed directly by SSMS, but were digested with aqua regia for mercury and fluoride analyses. Particulate filters were generally acid digested for the SSMS analysis as well, because of the cohesion and sparking problems that are associated with having glass filters in the graphite electrodes. All particulate samples for SSMS were run neat whenever possible. Samples for chloride and sulfate analysis were prepared by extraction with hot water. Table 8 summarizes the inorganic sample preparation scheme.

Mercury was analyzed by a cold vapor AA technique. The sulfate determination was a turbidimetric procedure and specific ion electrodes were used to analyze both fluoride and chloride. These analyses are described further in the following paragraphs.

Spark Source Mass Spectrography (SSMS)--SSMS was used to perform a semi-quantitative elemental survey analysis on the Level I samples taken. The analysis was performed using a JEOL Analytical Instruments, Inc. Model JMS-01BM-2 Mass Spectrograph. The JMS-01BM-2 is a high resolution, double focusing mass spectrometer with Mattauch-Herzog ion optics. The instrument is specially designed to carry out high sensitivity trace element analysis with the aid of an RF spark ion source and photoplate detection. An aliquot of each sample to be analyzed is incorporated into two electrodes which are

TABLE 8. INORGANIC SAMPLE PREPARATION SCHEME

Sample	Preparation	Analysis
Particulate filters	Aqua regia extraction	SSMS, Hg, F^-
	Hot water extraction	$SO_4^=$, Cl^-
Cyclone catches	Neat	SSMS
	Aqua regia extraction	Hg, F^-
	Hot water extraction	$SO_4^=$,Cl^-
Composite*	None required	SSMS, Hg, F^-, Cl^-
XAD-2 resin	Parr bomb	SSMS, Hg, F^-, Cl^-, $SO_4^=$
Impinger composite†	None required	Hg
Bulk samples		
Lignite	Parr bomb	SSMS, Hg, F^-, Cl^-, $SO_4^=$
Others	Aqua regia extraction	SSMS, Hg, F^-
	Hot water extraction	$SO_4^=$, Cl^-

*Composite of peroxide impinger, condensate, and acid module rinse.

†Composite of second and third impingers.

then mounted in the ion source of the mass spectrometer. These electrodes are "sparked" with a high voltage discharge which decomposes and ionizes the electrode material. Because of the high energy of the electrical discharge, most of the material is reduced to its elemental form. The ions formed are collected with focusing plates and subsequently measured in the mass spectrometer. Spark source mass spectrometry can be used to detect elemental concentrations down to 10^{-9} g (one nanogram). Although the sensitivity may vary somewhat from sample to sample, practically all elements (except H, C, N, O, and the inert gases) in the periodic table can be detected.

Interferences can result from the formation of multiply charged ions, ion clusters and molecular ions such as oxides, hydrides, hydroxides, and carbides. These interferences, coupled with the fact that the discharge conditions in the ion source are not easily reproduced, limit the accuracy of the technique. Spark source mass spectrometry, however, is very useful as a survey tool, and is capable of providing semiquantitative results (i.e., accurate to within a factor of 2 or 3).

Mercury - cold vapor--The cold vapor mercury analysis is based on the reduction of mercury species in acid solution with stannous chloride and the subsequent sparging of elemental mercury, with nitrogen, through a quartz cell where its absorption at 253.7 nm is monitored.

Sulfate - turbidimetric--The basis of the analysis is the formation of a barium sulfate precipitate in a hydrochloric acid medium with barium chloride in such manner as to form barium sulfate crystals of uniform size. The absorbance of the barium sulfate suspension was measured by a transmission photometer and the sulfate ion concentration determined by comparison of the reading with a standard curve.

Fluoride--Fluoride was determined potentiometrically using a selective ion fluoride electrode in conjunction with a standard single junction sleeve-type reference electrode and a pH meter having an expanded millivolt scale. Sample pH was between 5 and 9. Polyvalent cations of Si^{+4}, Fe^{+3} and Al^{+3} interfere by forming complexes with fluoride. The addition of a pH 5 total ionic strength adjustor buffer (TISAB II) containing a strong, chelating agent preferentially complexes aluminum (the most common interference), silicon, and iron and eliminates the pH problem.

The addition of TISAB II also provides a high total ionic strength background to help mask the difference in total ionic strengths between samples and standards. However, the TISAB II cannot entirely compensate for this difference due to the very high and variable level of ionic strength in the Level I SASS samples. Thus, a known addition technique is employed to eliminate the necessity of drawing different calibration curves for different types of samples.

Chloride--Chloride was determined potentiometrically using a solid state selective ion chloride electrode in conjunction with a double junction reference electrode and a pH meter having an expanded millivolt scale. The solid state electrode is used because it is not sensitive to the higher levels of nitrate, sulfate or bicarbonate which could be present in many of the samples.

This method does require that the sample and standards have the same total ionic strength. Because samples can have a very high and variable level total ionic strength, a known addition technique is employed to eliminate the necessity of drawing different calibration curves for different types of samples.

Surface analyses--Included as part of the analytical scheme of this study is surface analysis by X-ray photoelectron spectroscopy, or ESCA, which is not part of Level I. ESCA is capable of surface ($\leq$ 20Å depth) elemental analysis of solid and particulate samples, with relative amounts of each element being reported as percent atomic. ESCA can also give information on the oxidation states of a number of elements, a capability which was applied to the study of carbon and sulfur species in this program. Coupled with the use of argon ion etching to remove surface layers, ESCA can provide profiling to supplement surface and SSMS bulk analyses. Further information on the technique is provided in the report of the CAFB-fuel oil study.[4]

Results of Laboratory Analyses

Organic Results--

To determine organic flue gas emissions, samples collected by both SASS and RAC trains were analyzed. Table 9 summarizes the volatile, nonvolatile and total organic emissions determined for SASS runs 1 and 2, Tenax RAC runs 2 and 4, and the aggregate content of the five particulate catches from RAC runs 1 to 5. As noted in Table 3, the runs represented by the first four columns in Table 9 were performed on different days, thus precluding any direct comparison between the SASS and RAC-Tenax collection efficiencies.

TABLE 9. TOTAL $>C_6$ ORGANIC EMISSIONS ($\mu g/m^3$)

	SASS No.1	SASS No. 2	Tenax RAC No. 2	Tenax RAC No. 4	Particulate RAC Nos. 1-5
TCO*	221	307	290	1,070	360
Gravimetric	565	21,725	5,050	17,200	2,540
Total	786	22,032	5,340	18,270	2,900

*Total Chromatographable Organics (C_7-C_{16} B.P. Equivalents).

The low total organic emissions found in SASS No. 1, relative to the other runs, may be attributable to recycle of fines from the gasifier cyclone to the gasifier. This recycle operation was suspended after SASS No. 1 to alleviate particulate accumulation in the boiler. Although the excess air values for SASS 1 and 2 were identical, the factor of three difference between the SO_2 emissions (see Table 5) during these runs indicates that during SASS No. 1 the CAFB was more "chemically active" than during SASS No. 2. The high C_1 and C_2 emissions determined by gas chromatography during SASS No. 1 may be indicative of more efficient gasification and pyrolysis of heavy lignite organic matter during that run.

Tables 10 and 11 display the distribution of organic emissions among the SASS components for runs 1 and 2. Emissions called individual alkane equivalents refer to compounds boiling in the ranges C_7-C_{16}. As can also be noted in Table 9, SASS No. 1 has a high proportion of TCO material. Again, this is consistent with the relatively large C_1 and C_2 values and with the inference that the gasifier was particularly effective during SASS No. 1. Consistent with the oil-fired results, most of the capturable organics are found in the resin module (XAD-2, module rinse and condensate).

Table 12 contains a similar summary of individual alkane equivalents (IAE's), TCO and gravimetric weights for Tenax RAC 2 and 4 and the particulate composite RAC 1-5 samples. As with the SASS samples, a peak in the IAE region occurs around C_9. The sizable quantity of extractable organics found in the RAC particulate is somewhat surprising. The composite nature of this sample precludes assignment of high organic emissions to any one run. These results do suggest, however, that higher total organic emissions may have occurred during RAC runs 1, 3 or 4 than during either SASS or Tenax runs.

Infrared spectra of all samples listed in Tables 9 to 12 were obtained to discern the functional groups contained in each sample. All spectra are contained in Appendix D. Tables 13 and 14 contain interpretations of spectra taken of samples comprising SASS 1 and 2. Figures 7 and 8 are spectra of XAD-2 resin extracts from SASS 1 and 2, respectively. The resin extract from SASS No. 1 contains a significant contribution from saturated hydrocarbons while the spectrum contained in Figure 8 is dominated by oxygenated compounds. Summary Tables 13 and 14 show a wide variety of hydrocarbons and heteroatom groups. The inability to obtain meaningful spectra from some particulate extracts may be due to evaporation losses occurring as a result of heat lamp drying of KBr plates. The use of a heat lamp for rapid evaporation of methylene chloride solvent was instituted to prevent condensation of water vapor on the IR plates which would result in masking the spectrum.

Table 15 summarizes the IR interpretations of RAC Tenax and particulate extracts. The groups identified in these samples are similar to those found in the SASS samples. The indication of major amide emissions in the Tenax samples may indicate a higher collection efficiency for these compounds by this resin over XAD-2. Additional experimental work needs to be carried out to determine if this is in fact the case or if amides may be present as impurities in Tenax, more easily extracted by pentane (used with Tenax) than by methylene chloride (used with XAD-2) or formed in secondary reactions.

Three samples met the Level I weight criterion (gravimetric plus TCO) for liquid chromatography (LC) separation: XAD and module rinse from SASS No. 2 and Tenax from RAC No. 4. Tables 16, 17 and 18 list the distribution of material in the seven fractions and the functional groups found by IR in each fraction. From the fractional distributions and functional group identifications shown in these tables it is apparent that esters, ketones and aliphatic hydrocarbons are the principal organic emissions from the CAFB. Following in importance are substituted aromatics and possibly amines, ethers, amides, alcohols, phenols and nitrosubstituted compounds.

TABLE 10. ORGANIC EMISSIONS IN CAFB SASS SAMPLES, RUN No. 1 ($\mu g/m^3$)

IAE*	10μ cyclone	3μ cyclone	1μ cyclone	Particulate filter	Probe rinse	XAD-2 resin	Module rinse	Condensate
7	-	-	-	-	-	-	-	-
8	-	-	-	-	4.66	11.2	8.95	4.88
9	2.49	7.44	5.78	-	-	2.00	-	91.4
10	1.07	1.90	2.98	-	-	22.5	-	-
11	-	-	-	-	-	b.r.†	-	-
12	-	-	-	0.599	-	22.8	-	0.232
13	-	-	0.624	2.66	-	4.57	-	-
14	-	-	-	-	-	7.06	-	-
15	-	-	-	5.39	0.131	1.26	-	-
16	-	-	-	4.69	-	3.60	-	-
TCO	3.56	9.34	9.38	13.3	4.79	75.0	8.95	96.5
Grav.	b.r.†	b.r.†	b.r.†	28.7	b.r.†	467	69.3	b.r.†
TO	3.56	9.34	9.38	42.0	4.79	542	78.3	96.5

*Individual alkane equivalents.

†b.r. - blank removes; sample less than or equal to blank.

TABLE 11. ORGANIC EMISSIONS IN CAFB SASS SAMPLES, RUN No. 2 ($\mu g/m^3$)

IAE*	10μ cyclone	3μ cyclone	1μ cyclone	Particulate filter	Probe rinse	XAD-2 resin	Module rinse	Condensate
7	-	-	-	-	-	-	19.4	-
8	-	-	-	-	-	-	6.20	9.62
9	6.31	31.1	6.24	-	-	-	-	158
10	-	-	-	-	0.659	b.r.†	-	-
11	-	-	-	-	0.838	b.r.†	-	-
12	-	-	-	-	-	b.r.†	-	-
13	-	-	-	-	-	-	4.12	-
14	-	-	-	-	-	-	-	-
15	-	-	14.6	-	2.86	b.r.†	28.3	18.4
16	-	-	-	-	-	-	-	-
TCO	6.31	31.1	20.8	-	4.35	b.r.†	58.0	186
Grav.	80.1	303	102	b.r.†	b.r.†	3240‡	18000‡	b.r.†
TO	86.4	334	123	b.r.†	4.35	3240‡	18100‡	186

*Individual alkane equivalents.

†b.r. - blank removes; sample less than or equal to blank.

‡Only the first three digits are significant.

TABLE 12. ORGANIC EMISSIONS IN CAFB RAC SAMPLES ($\mu g/m^3$)

IAE*	Tenax: RAC-2	Tenax: RAC-4	Particulate: RAC 1-5
7	-	5.53	-
8	-	-	28.8
9	41.8	230	324
10	115	731	-
11	-	13.4	7.17
12	32.4	17.4	-
13	8.53	-	-
14	12.7	-	-
15	82.7	60.7	-
16	-	10.5	-
TCO	290	1070	360
Grav.	5050	17200	2540
TO	5340	18300	2900

*Individual alkane equivalents.

TABLE 13. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF UNFRACTIONATED SAMPLES, SASS RUN No. 1

Sample code	Medium	Minor	Trace
XAD-2 resin	Esters,* saturated hydrocarbons	Possible nitrosubstituted compounds, ethers	
Condensate	Aliphatic hydrocarbons	Esters,* ketones;* possible: ethers,* organosilicon compounds, nitrocompounds, substituted aromatics	
Module rinse		Esters*	Possible: aliphatic ethers
Probe rinse†			
Particulate filter†			
1μ cyclone		Saturated esters, saturated hydrocarbons	Possible: aryl or unsaturated esters or ethers
3μ cyclone			Saturated esters; possible: aryl or unsaturated esters or ethers, organosilicon compounds
10μ cyclone†			

*May be saturated, unsaturated, aryl.

†Blank removes IR spectrum.

TABLE 14. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF UNFRACTIONATED SAMPLES, SASS RUN No. 2

Sample code	Medium	Minor	Trace
XAD-2 resin	Aryl or unsaturated esters; ketones* hydrocarbons	Possible: nitrocompounds, ethers	
Module rinse		Aliphatic hydrocarbons esters;* possible: aromatic hydrocarbons	Saturated ketones; possible ethers
Condensate			Aliphatic ethers
Probe rinse	Saturated hydrocarbons, saturated esters	Aryl esters; possible: substituted aromatics, aliphatic ethers	
Particulate filter†			
1μ cyclone†			
3μ cyclone†			
10μ cyclone†			

*May be saturated, unsaturated and/or aryl.

†Blank removes IR spectrum.

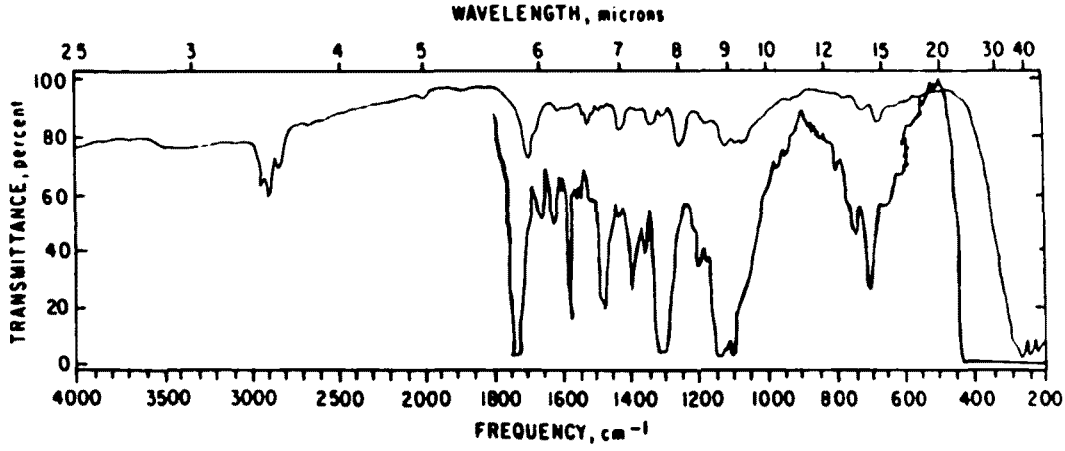

Figure 7. IR spectrum of XAD-2 resin from SASS-1. Major peaks indicate esters, saturated hydrocarbons; possible ethers and nitrosubstituted compounds.

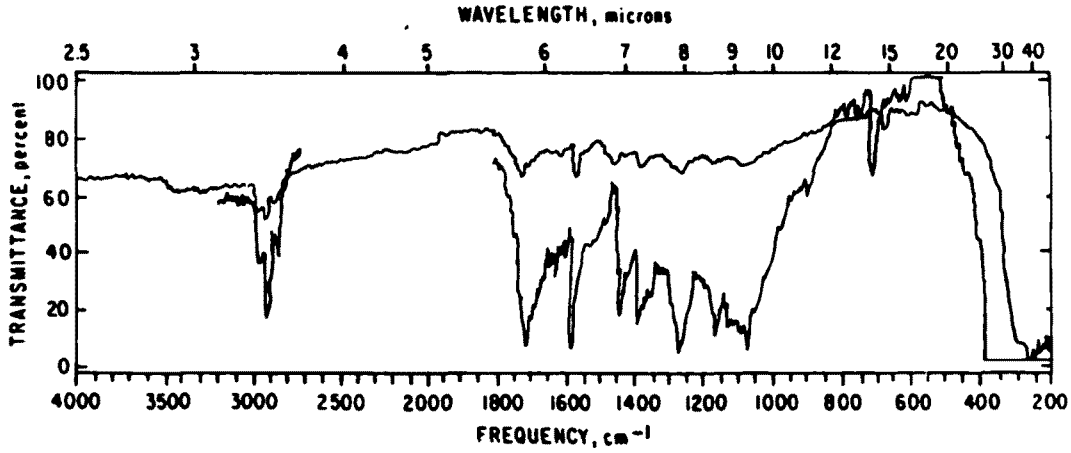

Figure 8. IR spectrum of XAD-2 resin from SASS-2. Major peaks indicate aryl or unsaturated esters, ketones, hydrocarbons; possible ethers and nitrocompounds.

TABLE 15. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF RAC SAMPLE EXTRACTS WITHOUT LC FRACTIONS

Sample code	Major	Medium	Minor	Trace
RAC-2, Tenax	Amides* (primary, secondary)	Ethers,* hydrocarbons;* possible: amines,* alcohols/phenols	Possible: organo-silicon compounds	Possible: esters,* ketones*
RAC-4, Tenax	Hydrocarbons,* esters,* ketones;* possible: alcohols/phenols, amines,* amides		Possible: ethers*	
RAC 1-5, Particulate		Esters,* ketones* saturated hydrocarbons; possible: ethers,* organosilicon compounds, substituted aromatics		

*May be saturated, unsaturated, aryl.

TABLE 16. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF XAD-2 RESIN EXTRACT AND ITS LC FRACTIONS, SASS RUN No. 2

Sample code	Major	Medium	Minor	Trace	Weight distribution (percent)
XAD-2 resin*		Aryl or unsaturated esters; ketones,† hydrocarbons	Possible: nitro-compounds, ethers		100‡
LC-1		Aliphatic hydrocarbons	Aromatic hydrocarbons	Esters (aryl or unsaturated); possible; ethers	6.2
LC-2				Hydrocarbons;† possible: saturated ethers	0.4
LC-3			Esters†	Possible: saturated hydrocarbons, ethers	3.8
LC-4§					20.8
LC-5§					6.7
LC-6	Esters,† ketones†	Possible: amines,† alcohols/phenols, ethers,† nitrocompounds,† amines†			54.9
LC-7		Unsaturated esters; saturated and unsaturated ketones	Possible: ethers, nitro-compounds		7.3

*The spectra of some fractions are stronger than the spectrum of the unfractionated sample. Therefore, some compounds may show up in the spectrum of a fraction, but not in the spectrum of the unfractionated sample.

†May be saturated, unsaturated, and/or aryl.

‡Column percent recovery: 91 percent.

§Blank removes IR spectra.

TABLE 17. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF MODULE RINSE AND ITS LC FRACTIONS, SASS RUN No. 2

Sample code	Major	Medium	Minor	Trace	Weight distribution (percent)
2-MR			Aliphatic hydrocarbons esters (saturated, unsaturated, aryl); possible: aromatic hydrocarbons	Saturated ketones; possible: ethers	100†
LC-1				Aliphatic hydrocarbons	46.9
LC-2*					13.5
LC-3*					5.1
LC-4		Esters (saturated)	Esters (unsaturated, aryl)	Possible: ethers	16.4
LC-5			Esters (saturated)	Esters (unsaturated, aryl)	1.6
LC-6			Esters (saturated)	Esters (unsaturated, aryl)	14.4
LC-7				Ethers (saturated)	3.0

*Blank removes IR spectrum.

†Column percent recovery: 51 percent.

TABLE 18. INTERPRETATION OF IR SPECTRA FROM GRAVIMETRIC RESIDUES OF TENAX RESIN EXTRACT AND ITS LC FRACTIONS, RAC RUN No. 4

Sample code	Major	Medium	Minor	Trace	Weight distribution (percent)
RAC, Tenax	Hydrocarbons,* esters,* ketones;* possible: alcohols/phenols, amines,* amides,* ethers‡				100†
LC-1		Saturated hydrocarbons	Aromatic hydrocarbons	Aryl or vinyl ethers	8.8
LC-2		Saturated hydrocarbons		Unsaturated hydrocarbons	0.2
LC-3		Substituted aromatics, esters;* possible: amines,* amides,* ethers,* unsaturated alcohols	Possible: nitro-substituted compounds, phenols		11.4
LC-4		Esters;* possible: amides,* amines,* ethers*	Possible: unsaturated alcohols, nitrosubstituted compounds		21.6
LC-5		Esters,* ketones;* possible: amides,*,‡ amines,*,† ethers,*,‡ alcohols/phenols†			36.6
LC-6		Esters,* ketones;* possible: amides,*,† amines,*,† ethers,*,† alcohols/phenols†			18.3
LC-7			Ketones,* esters;* possible: ethers,* phenols, amines,*,†		3.0

*May be saturated, unsaturated, and/or aryl.

†Column percent recovery: 114 percent.

‡May possess an isopropyl group attached to N or O.

These data indicate that XAD-2 used in the SASS train and Tenax used in a modified RAC train produce qualitatively similar results. Differences in operating conditions over the several days of testing preclude quantitative comparison of the organic emissions data. In Section 5 the organic emissions data from the CAFB are compared with emissions from conventional lignite-fired boilers and with CAFB emissions during oil-firing.

Table 19 summarizes the organic composition of spent stone withdrawn from the regenerator. Over 99 percent of extractable material is nonvolatile. The esters and ethers contained in the material reflect the highly oxidizing nature of the regenerator. It is not unreasonable to assume that high molecular weight tars also remain on the stone; however, these compounds are probably insoluble in methylene chloride and, hence, undetectable in the Level I scheme.

TABLE 19. ORGANIC COMPOSITION OF SPENT STONE (mg/kg)

TCO*	Gravimetric†	Total
0.80	195	196

*Individual Alkane Equivalents: C_{14} = 0.60 C_{16} = 0.2

†Infrared analysis shows minor amounts of aryl and unsaturated esters and ethers.

Inorganic and Trace Element Results--

The inorganic analysis program centered upon Spark Source Mass Spectrographic (SSMS) analysis of stack particulate, bed material, internal solids and vapor species collected on resin and in solution. Appendix D contains tabulations of the elemental compositions of each sample analyzed. In addition to SSMS, wet chemical methods and X-ray photoelectron spectroscopy (ESCA) were used to determine mercury, sulfate, fluoride, chloride and particulate surface species. The elemental compositions of lignite and limestone feeds are reported in Tables 20 and 21. Elements present in appreciable concentrations in one feed are also present in the other, thus no indicator elements are apparent.

Tables 22 and 23 contain trace element amounts and emission factors, determined by SSMS, for all SASS fractions for runs 1 and 2. The emission factors listed in the last column of each table are compared with MATE values and with emissions from conventional lignite-fired sources in Section 5. The milligram quantities tabulated under each sample designation refer to the total number of milligrams of each element determined to be in each sample. Ranges of values reported under "Total SASS" have as minima the sum of all real

TABLE 20. SSMS ANALYSIS OF CAFB LIGNITE*

Element	Value (ppm)	Element	Value (ppm)	Element	Value (ppm)
U	1.2	Pr	1.4	Ge	< 3.0
Th	3.8	Ce	3.4	Ga	14
Bi	< 0.33	La	10	Zn	11
Pb	13	Ba	320	Cu	19
Tl	< 0.47	Cs	0.86	Ni	10
Au	< 0.23	I	0.16	Co	2.2
Pt	< 0.64	Te	4.9	Fe	0.57%
Ir	< 0.35	Sb	0.38	Mn	100
Os	< 0.40	Sn	1.9	Cr	13
Re	< 0.25	In	IS†	V	28
W	< 0.60	Cd	0.69	Ti	0.14%
Hf	< 0.75	Pd	< 0.18	Ca	MC‡
Lu	< 0.17	Rh	< 0.064	K	0.49%
Yb	< 0.27	Ru	< 0.23	S	0.86%
Tm	< 0.16	Mo	0.73	P	76
Er	< 0.25	Nb	6.9	Si	MC
Ho	< 0.15	Zr	65	Al	MC
Dy	< 0.26	Y	8.2	Mg	0.44%
Tb	< 0.16	Sr	230	Na	80
Gd	< 0.43	Rb	7.8	F	92
Eu	< 0.12	Br	11	B	88
Sm	< 0.73	Se	< 9.3	Be	0.55
Nd	1.1	As	< 57		

*Concentrations based on "as received" lignite weight.

†IS - Internal Standard.

‡MC - Major Component.

TABLE 21. SSMS ANALYSIS OF CAFB LIMESTONE FEED

Element	Value (ppm)	Element	Value (ppm)	Element	Value (ppm)
U	< 0.63	Pr	0.21	Ga	< 0.07
Th	< 0.63	Ce	0.43	Zn	< 1.4
Bi	< 0.28	La	0.95	Cu	3.8
Pb	8.3	Ba	160	Ni	4.4
Tl	< 0.33	Cs	0.06	Co	0.23
Au	< 0.43	I	19	Fe	590
Pt	< 1.2	Te	< 0.35	Mn	7.5
Ir	< 0.65	Sb	0.95	Cr	0.63
Os	< 0.74	Sn	5.5	V	3.6
Re	< 0.46	In	IS*	Ti	40
W	< 0.61	Pd	< 0.34	Ca	MC†
Hf	< 0.75	Rh	< 0.12	K	230
Lu	< 0.17	Ru	< 0.43	S	400
Yb	< 0.27	Mo	0.87	P	27
Tm	< 0.16	Nb	< 0.05	Si	400
Er	< 0.46	Zr	0.55	Al	150
Ho	< 0.15	Y	0.24	Mg	0.36%
Dy	< 0.26	Sr	210	Na	110
Tb	< 0.07	Rb	1.7	F	150
Gd	< 0.28	Br	< 21	B	5.5
Eu	< 0.12	Se	< 4.4	Be	0.003
Sm	< 0.48	As	< 328	Li	0.09
Nd	< 0.50	Ge	< 0.17		

*IS - Internal Standard.

†MC - Major Component.

TABLE 22. TRACE ELEMENT EMISSIONS IN SASS SAMPLES, RUN No. 1

CARD #1: [illegible] SAMPLED = 26.93 DSCM

ELEMENT	100% CYCLONE (UG)	30% CYCLONE (UG)	10% CYCLONE (UG)	FILTER CATCH (UG)	XAD RESIN (UG)	COMPOSITE SAMPLE (UG)	TOTAL SASS (UG)	EMISSION FOUND (MG/DSCM)
U	0.065	0.28	0.087	0.0085	< 0.018	< 0.013	0.44	0.017
TH	0.16	0.57	0.35	0.012	< 0.026	< 0.020	1.1	0.043
BI	< 0.056	< 0.48	< 0.30	0.014	< 0.0081	< 0.0061	0.014 TO 0.85	0.0005 TO 0.033
PB	0.77	1.4	2.5	0.12	< 0.28	< 0.070	4.8	0.18
TL	< 0.0076	< 0.0068	< 0.011	< 0.0040	< 0.0100	< 0.0076	< 0.051	< 0.0020
AU	< 0.0025	< 0.011	< 0.013	< 0.0002	< 0.014	< 0.0100	< 0.050	< 0.0019
IR	< 0.0038	< 0.016	< 0.020	< 0.0003	< 0.021	< 0.016	< 0.077	< 0.0030
OS	< 0.0041	< 0.018	< 0.022	< 0.0003	< 0.023	< 0.017	< 0.084	< 0.0032
RE	< 0.0026	< 0.011	< 0.014	< 0.0002	< 0.014	< 0.011	< 0.053	< 0.0020
W	< 0.014	< 0.042	< 0.052	< 0.0032	< 0.019	< 0.014	< 0.15	< 0.0056
HF	< 0.062	< 0.13	< 0.33	< 0.0034	< 0.024	< 0.018	< 0.57	< 0.022
LU	< 0.025	< 0.052	< 0.063	< 0.0003	< 0.0056	< 0.0042	< 0.15	< 0.0058
YB	< 0.019	< 0.055	< 0.051	< 0.0021	< 0.0082	< 0.0061	< 0.14	< 0.0055
TM	< 0.0075	< 0.0039	< 0.0048	< 0.0006	< 0.0050	< 0.0037	< 0.026	< 0.0010
ER	< 0.027	< 0.012	< 0.099	< 0.0021	< 0.015	< 0.011	< 0.17	< 0.0064
HO	< 0.0051	< 0.022	< 0.019	0.0006	< 0.0048	< 0.0036	0.0006 TO 0.055	< 0.0001 TO 0.0021
DY	< 0.072	< 0.0066	< 0.13	0.0041	< 0.0084	< 0.0062	0.0041 TO 0.23	0.0002 TO 0.0087
TH	< 0.0003	< 0.0013	< 0.0016	< 0.0001	< 0.0023	< 0.0017	< 0.0072	< 0.0003
GD	< 0.036	< 0.0066	< 0.051	< 0.0027	< 0.0083	< 0.0062	< 0.11	< 0.0042
EU	0.013	< 0.041	< 0.034	0.0010	< 0.0038	< 0.0028	0.014 TO 0.082	0.0005 TO 0.0031
SM	0.075	< 0.16	< 0.20	0.0048	< 0.015	< 0.011	0.080 TO 0.39	0.0031 TO 0.015
ND	0.17	0.36	0.22	0.013	< 0.018	< 0.014	0.76	0.029
PR	0.051	0.12	0.073	0.0040	< 0.0032	< 0.0024	0.25	0.0095
CE	0.40	0.85	1.1	0.060	< 0.0043	< 0.0032	2.4	0.091
LA	0.56	1.2	3.0	0.033	< 0.0047	< 0.0035	4.8	0.18
BA	4.3	21.	39.	0.35	< 0.076	0.013	69.	2.6
CS	0.024	0.038	0.024	0.0031	< 0.0008	< 0.0006	0.090	0.0034
I	0.032	< 0.025	< 0.0075	< 0.0002	< 0.013	< 0.0093	0.032	0.0012
TE	< 0.039	< 0.048	< 0.100	< 0.0053	< 0.011	< 0.0076	< 0.21	< 0.0081
SB	0.026	0.067	0.079	0.0050	< 0.0073	< 0.0054	0.17	0.0067
SN	0.072	0.15	0.13	< 0.025	0.039	1.3	1.7	0.066
CD	0.019	0.028	0.027	0.027	< 0.013	0.029	0.13	0.0050
PD	< 0.042	< 0.091	< 0.036	< 0.0018	< 0.0100	< 0.0076	< 0.19	< 0.0074
RH	< 0.0078	< 0.0029	< 0.0035	< 0.0012	< 0.0037	< 0.0027	< 0.022	< 0.0008

TABLE 22 (continued)

CARD 31: . LINE SAMPLED = 20.03 DSCM

ELEMENT	100M CYCLONE (MG)	30M CYCLONE (MG)	10M CYCLONE (MG)	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
RU	< 0.0021	< 0.0089	< 0.011	< 0.0002	< 0.013	< 0.0100	< 0.046	< 0.0018
MO	0.030	0.080	0.079	0.012	< 0.012	< 0.0093	0.20	0.0077
NB	0.33	0.72	0.89	0.0026	< 0.0016	< 0.0012	1.9	0.075
ZR	1.4	5.4	5.0	0.062	< 0.0059	< 0.0044	12.	0.47
Y	0.67	1.0	1.3	0.012	< 0.0024	< 0.0018	3.0	0.12
SR	11.	30.	20.	0.53	< 0.21	0.0079	62.	2.4
RB	0.23	0.50	0.44	0.015	< 0.0061	< 0.0031	1.2	0.046
BR	1.0	1.6	1.4	< 0.025	< 0.87	< 0.075	4.0	0.15
SE	< 0.67	< 0.39	< 0.68	< 0.020	< 0.060	0.013	0.013 TO 1.8	0.0005 TO 0.070
AS	2.4	5.9	7.3	0.065	0.0056	< 0.012	16.	0.60
GE	0.15	< 0.47	< 0.30	< 0.0066	< 0.0050	< 0.0037	0.15 TO 0.79	0.0056 TO 0.030
GA	0.39	1.7	1.9	0.100	< 0.0021	< 0.0015	4.1	0.16
ZN	8.2	6.8	5.3	< 0.66	< 1.6	0.45	21.	0.80
CU	1.2	0.93	1.6	< 0.25	< 2.5	0.60	4.3	0.17
NI	0.57	2.4	2.1	< 0.13	< 1.5	0.35	5.5	0.21
CO	0.26	0.40	0.49	0.012	< 0.047	< 0.025	1.2	0.045
FE	MC	480.	350.	5.4	1.7	3.8	-	-
MN	24.	10.	7.0	0.25	< 0.15	0.15	41.	1.6
CR	0.50	0.73	1.0	0.15	< 0.090	0.32	2.7	0.100
V	1.1	2.8	3.4	0.083	< 0.020	0.0077	7.4	0.28
TI	79.	100.	130.	1.8	< 0.067	< 0.035	310.	12.
CA	810.	**	**	44.	< 9.2	170.	**	190.
K	21.	140.	99.	4.4	< 4.8	< 0.68	260.	10.
S	MC	260.	450.	17.	<120.	120.	-	-
P	2.7	21.	18.	0.34	< 1.6	< 4.0	38.	1.5
SI	830.	**	790.	< 5.0	< 14.	0.38	**	210.
AL	MC	560.	290.	14.	< 2.0	0.23	-	-
MG	59.	210.	98.	8.8	< 6.2	0.26	380.	14.
NA	11.	89.	25.	MC	< 25.	< 3.4	-	-
B	4.2	31.	69.	< 0.60	0.11	0.11	100.	4.0
BE	0.044	0.068	0.24	0.0010	< 0.0012	0.0001	0.35	0.013

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL SEC EMISSION VALUES WERE NOT CALCULATED DUE TO THE PRESENCE OF AN MC CONCENTRATION.

** INDICATES A VALUE EXCEEDING ONE GRAM.

TABLE 23. TRACE ELEMENT EMISSIONS IN SASS SAMPLES, RUN No. 2

CAFB #2: VOLUME SAMPLED = 7.541 DSCM

ELEMENT	100M CYCLONE (MG)	30M CYCLONE (MG)	10M CYCLONE (MG)	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
U	0.029	0.050	0.018	0.0023	< 0.100	< 0.022	0.100	0.013
TH	0.081	0.14	0.035	0.0033	< 0.15	< 0.031	0.26	0.035
BI	< 0.035	< 0.12	< 0.0026	0.0039	< 0.046	< 0.0097	0.0039 TO 0.21	0.0005 TO 0.028
PB	0.21	1.0	1.0	0.046	< 0.27	< 0.020	2.3	0.31
TL	< 0.0014	< 0.0016	< 0.022	< 0.0015	< 0.057	< 0.012	< 0.096	< 0.013
AU	< 0.0022	< 0.0019	< 0.0009	< 0.0001	< 0.076	< 0.016	< 0.098	< 0.013
IR	< 0.0034	< 0.0029	< 0.0015	< 0.0002	< 0.12	< 0.025	< 0.15	< 0.020
OS	< 0.0037	< 0.0032	< 0.0016	< 0.0002	< 0.13	< 0.027	< 0.16	< 0.022
RE	< 0.0023	< 0.0020	< 0.0010	< 0.0010	< 0.081	< 0.017	< 0.100	< 0.014
W	< 0.0087	< 0.022	< 0.0079	< 0.0012	< 0.11	< 0.023	< 0.17	< 0.023
HF	< 0.11	< 0.071	< 0.024	< 0.0013	< 0.14	< 0.029	< 0.37	< 0.049
LU	< 0.031	< 0.027	< 0.0046	< 0.0001	< 0.032	< 0.0067	< 0.100	< 0.013
YB	< 0.011	< 0.020	< 0.0053	< 0.0007	< 0.046	< 0.0097	< 0.094	< 0.012
TM	< 0.0045	< 0.0007	< 0.0041	< 0.0002	< 0.028	< 0.0060	< 0.044	< 0.0058
ER	< 0.016	< 0.014	< 0.0072	< 0.0009	< 0.083	< 0.018	< 0.14	< 0.018
HO	< 0.0032	< 0.0079	< 0.0020	< 0.0006	< 0.027	< 0.0057	< 0.047	< 0.0062
DY	< 0.022	< 0.039	< 0.020	< 0.0067	< 0.047	< 0.0100	< 0.15	< 0.019
TB	< 0.0003	< 0.0002	< 0.0001	< 0.0003	< 0.013	< 0.0027	< 0.016	< 0.0022
GD	< 0.016	< 0.023	< 0.0068	< 0.0012	< 0.047	< 0.0099	< 0.100	< 0.014
EU	< 0.011	< 0.021	< 0.0037	0.0002	< 0.021	< 0.0045	0.0002 TO 0.061	< 0.0001 TO 0.0081
SM	< 0.055	< 0.082	0.0072	0.0013	< 0.082	< 0.017	0.0085 TO 0.24	0.0011 TO 0.031
ND	< 0.20	0.089	0.032	0.0074	< 0.100	< 0.022	0.13 TO 0.33	0.017 TO 0.044
PR	0.024	0.029	0.028	0.0011	< 0.018	< 0.0038	0.082	0.011
CE	0.35	0.15	0.21	0.016	< 0.025	< 0.0052	0.73	0.097
LA	0.35	0.86	0.31	0.0089	< 0.027	< 0.0056	1.5	0.20
BA	6.5	21.	11.	< 0.69	0.051	0.011	38.	5.1
CS	0.0078	0.0093	0.0093	< 0.0020	< 0.0043	< 0.0009	0.026	0.0035
I	0.021	< 0.0032	< 0.0023	< 0.0002	< 0.071	< 0.015	0.021 TO 0.091	0.0027 TO 0.012
TE	< 0.017	< 0.018	< 0.0090	0.0010	< 0.059	< 0.013	0.0010 TO 0.12	0.0001 TO 0.015
SB	0.037	0.052	0.061	0.0052	< 0.041	< 0.0087	0.14	0.018
SN	0.035	0.043	0.060	< 0.037	< 0.058	< 2.9	0.14 TO 3.0	0.018 TO 0.40
CD	0.0038	0.0070	0.0044	< 0.017	< 0.073	< 0.12	0.015 TO 0.21	0.0020 TO 0.028
PD	< 0.019	< 0.016	< 0.012	< 0.0007	< 0.059	< 0.012	< 0.12	< 0.016
RH	< 0.0033	< 0.0005	< 0.0003	< 0.0002	< 0.021	< 0.0044	< 0.029	< 0.0039

TABLE 23 (continued)

CAPB #21 VOLUME SAMPLED = 7.541 DSCM

ELEMENT	100M CYCLONE (MG)	30M CYCLONE (MG)	10M CYCLONE (MG)	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
RU	< 0.0018	< 0.0016	< 0.0008	< 0.0015	< 0.076	< 0.016	< 0.098	< 0.013
MO	0.019	0.023	0.016	0.0063	< 0.070	0.030	0.094	0.012
NB	0.15	0.18	0.26	0.0014	< 0.0088	0.0026	0.59	0.079
ZR	1.0	1.8	1.3	0.011	< 0.033	< 0.0070	4.1	0.54
Y	0.21	0.19	0.26	0.0045	< 0.014	< 0.0029	0.66	0.088
SR	20.	9.9	7.2	0.43	< 0.28	0.0050	38.	5.0
RB	0.21	0.18	0.090	< 0.011	< 0.048	0.0009	0.48	0.063
BR	0.65	0.57	0.19	< 0.0091	< 1.7	< 0.062	1.4	0.19
SE	< 0.42	< 0.52	< 0.26	0.029	< 0.040	0.077	0.11 TO 1.2	0.014 TO 0.16
AS	3.6	1.1	2.9	0.024	< 0.016	0.0033	7.6	1.0
GE	< 0.13	0.081	0.23	0.0009	< 0.028	< 0.0060	0.31	0.041
GA	0.34	0.60	0.97	0.064	< 0.012	< 0.0024	2.0	0.26
ZN	11.	1.7	1.2	< 0.27	< 2.0	< 0.47	14.	1.9
CU	0.53	0.66	0.46	< 0.18	< 2.6	0.28	1.9	0.26
NI	0.25	0.44	0.32	< 0.033	< 4.3	< 0.48	1.0 TO 4.8	0.13 TO 0.64
CO	0.082	0.14	0.100	< 0.0038	< 0.032	0.0070	0.33	0.044
FE	MC	160.	140.	1.1	< 6.5	< 1.9	-	-
MN	12.	1.8	1.7	0.055	< 0.22	< 0.095	15.	2.0
CR	0.24	0.13	1.9	0.052	< 0.11	0.14	2.5	0.33
V	1.0	0.87	1.3	0.014	< 0.014	< 0.0057	3.2	0.43
TI	38.	33.	31.	0.53	< 0.19	< 0.098	100.	14.
CA	240.	820.	MC	24.	< 17.	< 2.2	-	-
K	22.	25.	12.	< 0.92	< 10.	< 0.76	58.	7.7
S	690.	200.	55.	8.5	560.	160.	**	220.
P	4.3	2.1	5.6	0.074	< 4.5	< 6.4	12.	1.6
SI	MC	400.	320.	< 1.7	< 9.9	< 1.5	-	-
AL	MC	120.	MC	11.	< 3.9	< 0.58	-	-
MG	46.	21.	46.	1.4	< 6.2	< 0.70	110.	15.
NA	14.	9.9	14.	< 26.	< 76.	< 5.4	38. TO 110.	5.0 TO 14.
B	11.	5.5	5.0	< 0.18	0.40	0.97	23.	3.1
BE	0.0070	0.0085	0.012	< 0.0004	0.0012	< 0.0001	0.029	0.0038
LI	0.25	0.12	0.062	< 0.0037	0.018	< 0.014	0.46	0.060

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

** INDICATES A VALUE EXCEEDING ONE GRAM.

quantities. Upper limits are sums of real values and "less thans." Quantities reported as "less than" mean that either an element was not present at values above its detection limit (in which case the detection limit is the "less than" value employed) or that the elemental value did not exceed its value in the appropriate blank (in which case the blank value is the "less than"). "Major component" is used for concentrations exceeding a few percent.

The bulk of the trace elements are found in the stack particulate, with only a few elements present at greater than their blank values after the filter. The composite sample is a combination of the first impinger, a nitric acid module rinse and the module condensate.

Tables 24 and 25 list trace element totals and emission factors determined from cyclone and filter catches from RAC runs 1 and 2. Although neither Tenax nor impingers were analyzed for trace elements, the distribution found in SASS samples (see Tables 22 and 23) indicates that most trace elements are found in the particulate catches. In general, the emission factors from the RAC and SASS samples agree within the factor of 3 noted earlier, although the RAC values are consistently lower. There is no evidence for contamination of SASS collected samples by iron, chromium or manganese from the stainless steel probe or cyclones. One major difference between the SASS and RAC emission factors is arsenic, with the RAC values for this element lower by a factor of 20 to 40. The higher oven temperature of the SASS would suggest that the volatile element arsenic would be more readily collected on RAC particulates; however, the opposite is true.

Analysis of SASS train samples for mercury, fluoride, chloride, and sulfate resulted in the sample concentrations displayed in Table 26. As with the SSMS data, these results show that most of the inorganic substances are in the particulate rather than the gaseous portions of the CAFB emissions even for the volatile element mercury.

Mercury emission rates for SASS runs 1 and 2 are 2.02 $\mu g/m^3$ and 4.00 $\mu g/m^3$ which represent 10.5 percent and 24.1 percent, respectively, of the mercury in the lignite. Fluoride emission rates are 1.01 mg/m^3 and 2.35 mg/m^3 corresponding to 9.2 percent and 24.8 percent, respectively, of the fluoride in the lignite. Chloride emission rates are 0.53 mg/m^3 and 3.25 mg/m^3 which correspond to 0.2 percent and 1.8 percent, respectively, of the chloride in the lignite.

A combination of laboratory and field data (SO_2-SO_3 emissions) is necessary for a complete evaluation of sulfur emissions. Such a combination shows:

- The SO_x emissions measured corresponding to the SASS-1 run are SO_2, 101.9 ppmv, or 407.3 mg/m^3 sulfate, and SO_3, 0.8 ppmv, or 3.1 mg/m^3 sulfate. Combined with the SASS-1 measurements, these total 470 mg/m^3 or 21.5 percent of the total sulfur in the lignite.

- The SO_x emissions corresponding to SASS-2 were SO_2, 299.7 ppmv, or 1197.9 mg/m^3 of sulfate, and SO_3, 1.3 ppmv, or 5.1 mg/m^3 of

TABLE 24. RAC-1 TRACE ELEMENT EMISSIONS

ELEMENT	CYCLONE CATCH (MG)	FILTER CATCH (MG)	TOTAL RAC (MG)	EMISSION FOUND (MG/DSCM)
U	0.0032	< 0.0088	0.0032 TO 0.0088	0.0038 TO 0.011
TH	0.0063	< 0.018	0.0063 TO 0.018	0.0075 TO 0.021
BI	0.0005	< 0.0053	0.0005 TO 0.0053	0.0006 TO 0.0063
PB	0.017	0.040	0.056	0.067
TL	0.0065	< 0.0003	0.0065	0.0078
AU	< 0.0002	< 0.0003	< 0.0005	< 0.0006
IR	< 0.0003	< 0.0005	< 0.0008	< 0.0009
OS	< 0.0003	< 0.0006	< 0.0008	< 0.0010
RE	0.0005	< 0.0029	0.0005 TO 0.0029	0.0006 TO 0.0035
W	0.0002	< 0.0028	0.0002 TO 0.0028	0.0003 TO 0.0033
HF	< 0.0030	< 0.0060	< 0.0090	< 0.011
LU	< 0.0008	< 0.0034	< 0.0042	< 0.0050
YB	< 0.0013	< 0.0017	< 0.0029	< 0.0035
TM	< 0.0005	< 0.0007	< 0.0012	< 0.0014
ER	< 0.0013	< 0.0030	< 0.0042	< 0.0051
HO	< 0.0001	< 0.0010	< 0.0011	< 0.0013
DY	< 0.0009	< 0.0078	< 0.0087	< 0.0100
TB	< 0.0002	< 0.0001	< 0.0003	< 0.0003
GD	< 0.0006	< 0.0020	< 0.0026	< 0.0031
EU	< 0.0006	< 0.0036	< 0.0043	< 0.0051
SM	0.0013	0.0036	0.0049	0.0058
ND	0.0028	0.012	0.014	0.017
PR	0.0009	0.0051	0.0060	0.0071
CE	0.0095	0.027	0.036	0.043
LA	0.013	0.038	0.051	0.061
BA	0.19	0.71	0.89	1.1
CS	0.0003	0.0012	0.0015	0.0018
I	0.0016	< 0.0011	0.0016	0.0019
TE	< 0.0013	< 0.0025	< 0.0038	< 0.0046
SB	0.0007	0.0015	0.0022	0.0027
SN	0.0012	0.0068	0.0080	0.0095
CD	0.0002	0.0008	0.0011	0.0013
PD	< 0.0014	< 0.0019	< 0.0034	< 0.0040
RH	< 0.0002	< 0.0001	< 0.0003	< 0.0003
RU	< 0.0001	< 0.0003	< 0.0004	< 0.0005
MO	0.0009	0.0018	0.0027	0.0032
NB	0.0057	0.016	0.022	0.026
ZR	0.065	0.22	0.29	0.34
Y	0.012	0.016	0.028	0.033
SR	0.44	0.61	1.0	1.2
RB	0.0057	0.016	0.022	0.026
BR	0.012	< 0.0093	0.012	0.015
SE	0.0044	< 0.0086	0.0044	0.0052
AS	0.014	0.0070	0.021	0.025
GE	< 0.0075	< 0.0077	< 0.015	< 0.018
GA	0.012	< 0.068	0.012 TO 0.068	0.015 TO 0.081
ZN	0.56	0.093	0.66	0.78
CU	0.020	0.040	0.061	0.072
NI	0.79	0.035	0.82	0.98
CO	0.0044	0.0043	0.0087	0.0100
FE	25.	15.	40.	48.
MN	0.53	0.18	0.71	0.84
CR	0.018	0.015	0.033	0.039
V	0.044	0.086	0.13	0.15
TI	1.6	11.	12.	15.
CA	33.	110.	140.	170.
K	1.3	4.3	5.6	6.6
S	29.	8.1	37.	44.
P	0.033	0.20	0.23	0.27
SI	15.	90.	100.	120.
AL	2.3	MC	-	-
MG	1.2	4.2	5.4	6.4
NA	0.100	1.2	1.3	1.5
B	0.15	0.96	1.1	1.3
BE	0.0004	0.0007	0.0011	0.0013
LI	0.0060	0.0065	0.013	0.015

MC INDICATES A MAJOR COMPONENT OF THE SAMPLE.

- INDICATES THAT THE TOTAL AND EMISSION VALUES WERE NOT CALCULATED OWING TO THE PRESENCE OF AN MC CONCENTRATION.

TABLE 25. RAC-2 TRACE ELEMENT EMISSIONS

ELEMENT	CYCLONE CATCH (MG)	FILTER CATCH (MG)	TOTAL RAC (MG)	EMISSION FOUND (MG/DSCM)
U	0.0026	0.0050	0.0076	0.0079
TH	0.0038	0.015	0.018	0.019
HI	0.0005	0.0046	0.0050	0.0052
PB	0.049	0.083	0.13	0.14
TL	< 0.0006	< 0.0033	< 0.0039	< 0.0041
AU	< 0.0001	< 0.0005	< 0.0006	< 0.0006
IR	< 0.0002	< 0.0007	< 0.0009	< 0.0009
OS	< 0.0002	< 0.0008	< 0.0010	< 0.0010
RE	0.0003	< 0.0040	0.0003 TO 0.0040	0.0003 TO 0.0042
W	0.0004	0.0018	0.0022	0.0023
HF	< 0.0003	< 0.0008	< 0.0011	< 0.0011
LU	< 0.0001	< 0.0005	< 0.0007	< 0.0007
YB	< 0.0006	< 0.0030	< 0.0036	< 0.0038
TM	< 0.0001	< 0.0014	< 0.0015	< 0.0016
ER	< 0.0007	< 0.0051	< 0.0057	< 0.0060
HO	< 0.0003	< 0.0027	< 0.0030	< 0.0031
DY	< 0.0006	< 0.0011	< 0.0018	< 0.0018
TB	0.0001	< 0.0026	0.0001 TO 0.0026	0.0001 TO 0.0027
GD	< 0.0004	< 0.0028	< 0.0032	< 0.0034
EU	0.0002	0.0008	0.0010	0.0010
SM	0.0009	0.0048	0.0057	0.0059
ND	0.0035	0.034	0.037	0.039
PR	0.0010	0.0069	0.0079	0.0082
CE	0.014	0.051	0.065	0.068
LA	0.0069	0.040	0.047	0.049
BA	0.24	1.5	1.8	1.8
CS	0.0004	0.0016	0.0021	0.0021
I	0.0020	0.0025	0.0044	0.0046
TE	< 0.0005	< 0.0045	< 0.0049	< 0.0051
SB	0.0011	0.011	0.012	0.013
SN	0.0014	0.016	0.017	0.018
CD	0.0008	0.0099	0.011	0.011
PD	< 0.0001	< 0.0020	< 0.0021	< 0.0022
RH	< 0.0001	< 0.0002	< 0.0003	< 0.0003
RU	< 0.0001	< 0.0004	< 0.0006	< 0.0006
MO	0.0008	0.0087	0.0095	0.0099
NB	0.0031	0.0092	0.012	0.013
ZR	0.036	0.14	0.17	0.18
Y	< 0.0001	0.020	0.020	0.021
SR	0.19	2.0	2.2	2.2
RB	0.0036	0.024	0.028	0.029
BR	0.0079	0.0100	0.018	0.019
SE	0.0041	0.018	0.022	0.023
AS	0.0070	0.047	0.054	0.057
GE	0.011	0.013	0.024	0.025
GA	0.0092	0.12	0.13	0.14
ZN	0.36	0.16	0.52	0.54
CU	0.031	0.16	0.20	0.20
NI	0.0051	0.012	0.017	0.018
CO	0.0021	0.0083	0.0100	0.011
FE	9.0	12.	21.	21.
MN	0.20	0.41	0.61	0.63
CR	0.0059	0.062	0.068	0.071
V	0.041	0.20	0.24	0.25
TI	0.45	7.9	8.3	8.7
CA	33.	110.	140.	150.
K	0.36	3.2	3.6	3.7
S	47.	11.	58.	60.
P	0.042	0.49	0.53	0.55
SI	6.9	67.	74.	77.
AL	1.1	12.	13.	14.
MG	0.54	28.	28.	29.
NA	0.13	0.84	0.97	1.0
B	0.046	0.37	0.42	0.43
BE	0.0002	0.0012	0.0014	0.0015
LI	0.0024	0.027	0.029	0.031

TABLE 26. CONCENTRATIONS OF SELECTED INORGANIC SPECIES IN SASS SAMPLES FROM THE CAFB-LIGNITE PROCESS*

Sample	Mercury (μg/g)	Sulfate (mg/g)	Fluoride (mg/g)	Chloride (mg/g)
SASS Run No. 1				
filter	1.24	59	0.59	ND
1μ cyclone	0.80	8.2	0.42	0.005
3μ cyclone	0.70	7.4	0.09	0.10
10μ cyclone	1.12	75	0.35	-
XAD	< 0.072	1.8	0.02	ND
CH†	0.014 μg/mℓ	-	0.05 mg/mℓ	0.008 mg/mℓ
IC‡	0.003 μg/mℓ	-	-	-
SASS Run No. 2				
filter	12.67	110	1.06	ND
1μ cyclone	1.87	22	0.50	0.38
3μ cyclone	1.19	21	0.23	0.38
10μ cyclone	0.79	74	1.30	0.77
XAD	< 0.081	0.32	-	0.14
CH†	0.034 μg/mℓ	-	-	0.015 mg/mℓ
IC‡	0.003 μg/mℓ	-	-	-

*All values blank corrected.

†Combination of first impinger, condensate, and acid module rinse.

‡Combination of second and third impingers.

ND = none detected; sample is less than or equal to blank.

sulfate. Added to the SASS train catch, this results in 1297 mg/m^3 sulfate or 68.6 percent of the sulfur in the lignite.

These sulfur balances point out the extremely poor sulfur removal efficiency of the gasifier bed during SASS No. 2 and the relatively better performance during SASS No. 1. These conclusions are consistent with the observations made concerning the organic emissions data that the CAFB was more "chemically active" during SASS No. 1 than during SASS No. 2.

Table 27 lists concentrations of mercury, sulfate, fluoride and chloride for various nonstack samples collected during SASS No. 2. In general, fly ash and bed material from the same unit operation (regenerator bed and cyclone; gasifier bed and main cyclone) have similar concentrations of these species indicating that fly ash is representative of the bed material. The mercury and sulfate concentrations in the stack cyclone and knockout baffle pass readily through the hot gasifier and boiler and condense in the cooler stack region.

TABLE 27. CONCENTRATIONS OF SELECTED INORGANIC SPECIES IN SOLID SAMPLES COLLECTED FOR THE CAFB-LIGNITE STUDY

Sample	Mercury (μg/g)	Sulfate (mg/g)	Fluoride (mg/g)	Chloride (mg/g)
Gasifier bed	0.037	1.2	0.08	2.0
Main cyclone	0.029	1.0	0.13	0.78
Regenerator bed	0.029	2.2	0.09	0.14
Regenerator cyclone	0.054	1.8	0.21	2.0
Stack cyclone	0.129	2.0	0.15	0.054
Stack knockout baffle	0.833	3.4	0.19	0.2
Lignite	0.158	18.0	0.09	1.75

Surface analysis of particulate samples was performed using ESCA. For SASS samples, these samples included cyclone and filter catches and for the RAC train, the particulate filter. Filter samples were analyzed by placing a small piece of the filter into the instrument's sample holder. Cyclone and other particulate were crushed, if necessary, and spread onto sintered steel substrates for subsequent analysis. Data were discarded if the resultant spectra displayed peaks characteristic of the substrate material. Regenerator bed material was also analyzed as a "particulate" sample to determine the fluid bed's effectiveness in removing sulfur from the coal. Lignite and limestone feed samples were also crushed and analyzed by ESCA. Analysis of impactor substrates was attempted, but due to the light particulate covering, no spectra could be obtained.

All samples analyzed by ESCA in this study were first scanned over the entire electron binding energy range (broadband scan) to identify those elements present in concentrations greater than 0.1 to 1 percent (the sensitivity of ESCA to any one element is a function of the photoionization cross-section of the most intense core electron emission of that element). These broadband spectra were then analyzed to yield surface concentrations of all identifiable elements. Representative broadband spectra appear in Figures 9 and 10. Quantification data for RAC particulate appear in Table 28; those for SASS samples in Table 29.

TABLE 28. QUANTIFICATION DATA FROM ESCA ANALYSES OF RAC TRAIN PARTICULATE FILTERS (RESULTS IN PERCENT ATOMIC)

Element	RAC-1	RAC-2	RAC-3	RAC-4	RAC-5
O	55.5	49.1	54.6	51.9	51.4
C	19.3	24.1	23.4	23.9	27.4
Ca	5.3	4.8	4.2	3.5	5.0
Na	-	1.3	-	-	-
S	4.1	3.9	4.9	3.5	3.2
Si	6.8	5.9	5.4	7.9	6.6
Al	9.0	10.9	7.5	9.3	6.3

As can be seen from the quantification data, the particulate samples have very similar surface compositions, with oxygen and carbon being particularly abundant. Substantial portions of this carbon, which the carbon 1s short scans showed to be mostly hydrocarbon, and oxygen are due to unavoidable adsorption of these ubiquitous species on the sample surfaces. Such contamination is a common problem in surface analysis and makes absolute (rather than relative) quantification of the samples impossible.

The composition of particulate from lignite firing is quite different from that found in the oil-fired CAFB. Samples collected during oil runs contained no detectable aluminum or silicon; they had more sulfur and sodium and also contained vanadium due to the different compositions of the fuels. Analysis of fuel oil showed 20 ppm silicon and 2.1 ppm aluminum, while in lignite these elements are listed as major components of greater than 1 percent (10,000 ppm). Vanadium is present in lignite at 28 ppm and in fuel oil at 307 ppm.

Short scans over the binding energy range of the carbon 1s electron showed several distinct carbon species. Figures 11 and 12 are C_{1s} spectra of SASS No. 1 filter and SASS No. 2 1μ particulate, respectively. Hydrocarbons are the dominant carbon species in both samples, and both show small amounts of surface carbonate. The tailing between the hydrocarbon and carbonate binding energies,

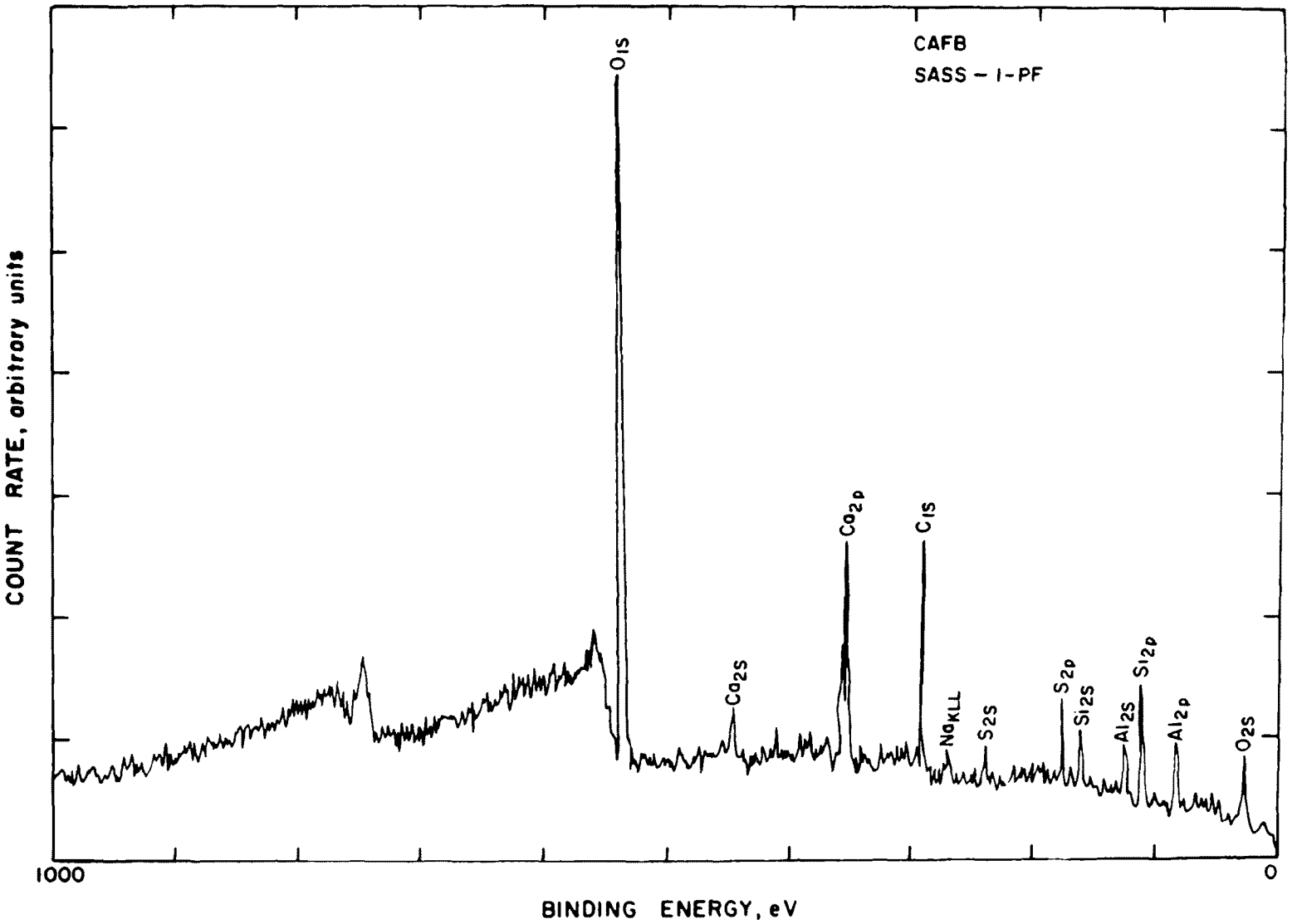

Figure 9. Broadband ESCA spectrum of SASS-1 filter particulate.

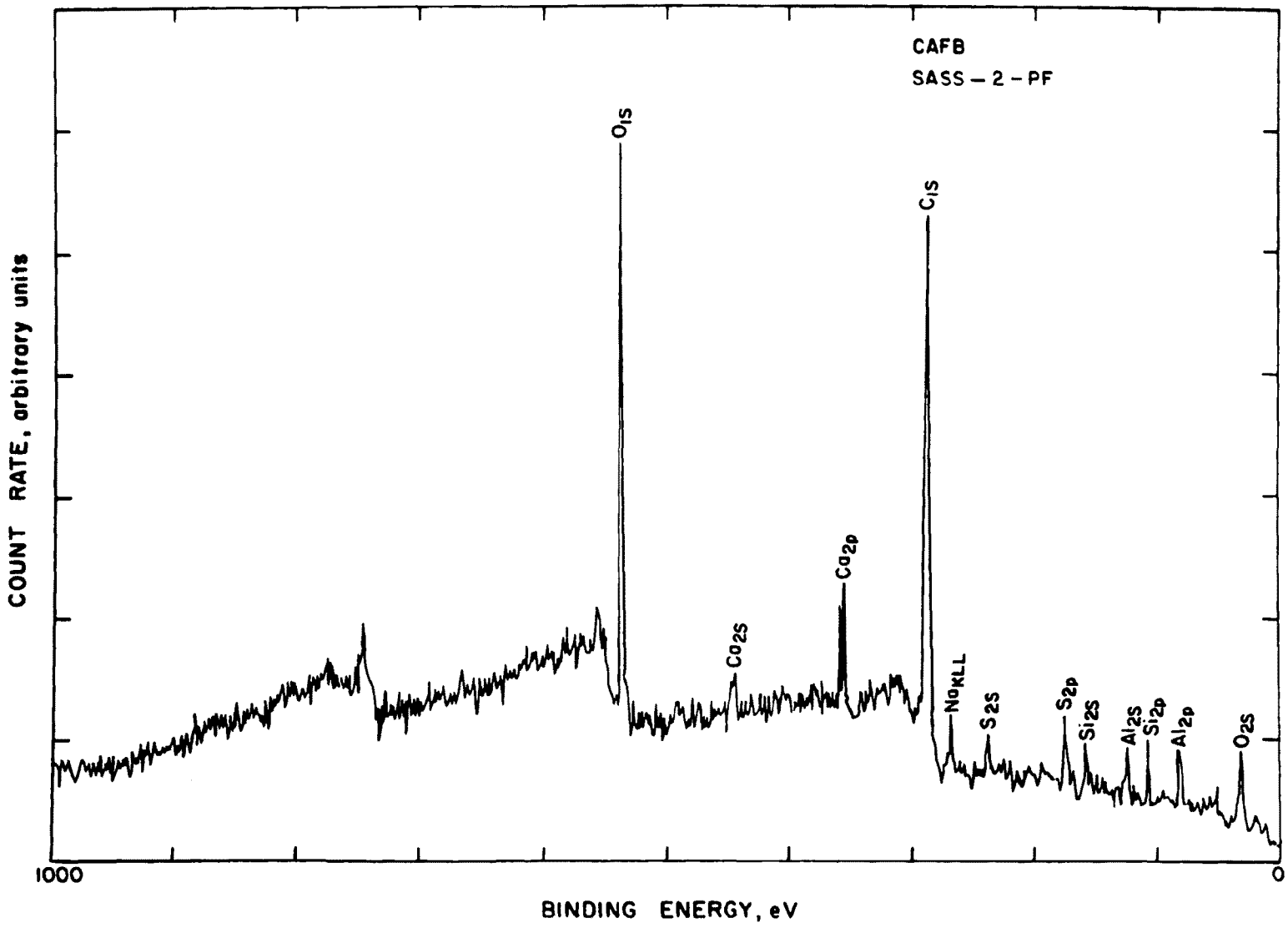

Figure 10. Broadband ESCA spectrum of SASS-2 filter particulate.

TABLE 29. ELEMENTAL QUANTIFICATION DATA FOR SASS PARTICULATE SAMPLES FROM ESCA ANALYSIS; RESULTS IN PERCENT ATOMIC

Element	SASS run No. 1				SASS run No. 2			
	Particulate filter	1μ cyclone	3μ cyclone	10μ cyclone	Particulate filter	1μ cyclone	3μ cyclone	10μ cyclone
O	43.1	44.5	47.3	48.6	33.0	*	55.0	53.9
C	26.9	28.9	29.4	30.0	52.3	*	25.8	24.4
Ca	12.8	9.2	4.3	3.3	2.8	*	3.3	4.8
Na	0.6	0.7	0.8	0.6	1.0	*	0.8	-
S	4.7	6.9	6.1	7.7	3.7	*	6.3	10.5
Si	5.7	4.8	6.1	4.4	2.5	*	4.2	2.4
Al	6.3	5.0	6.0	5.4	4.6	*	4.7	4.0

*Calculations were not made due to high background in spectrum attributed to substrate.

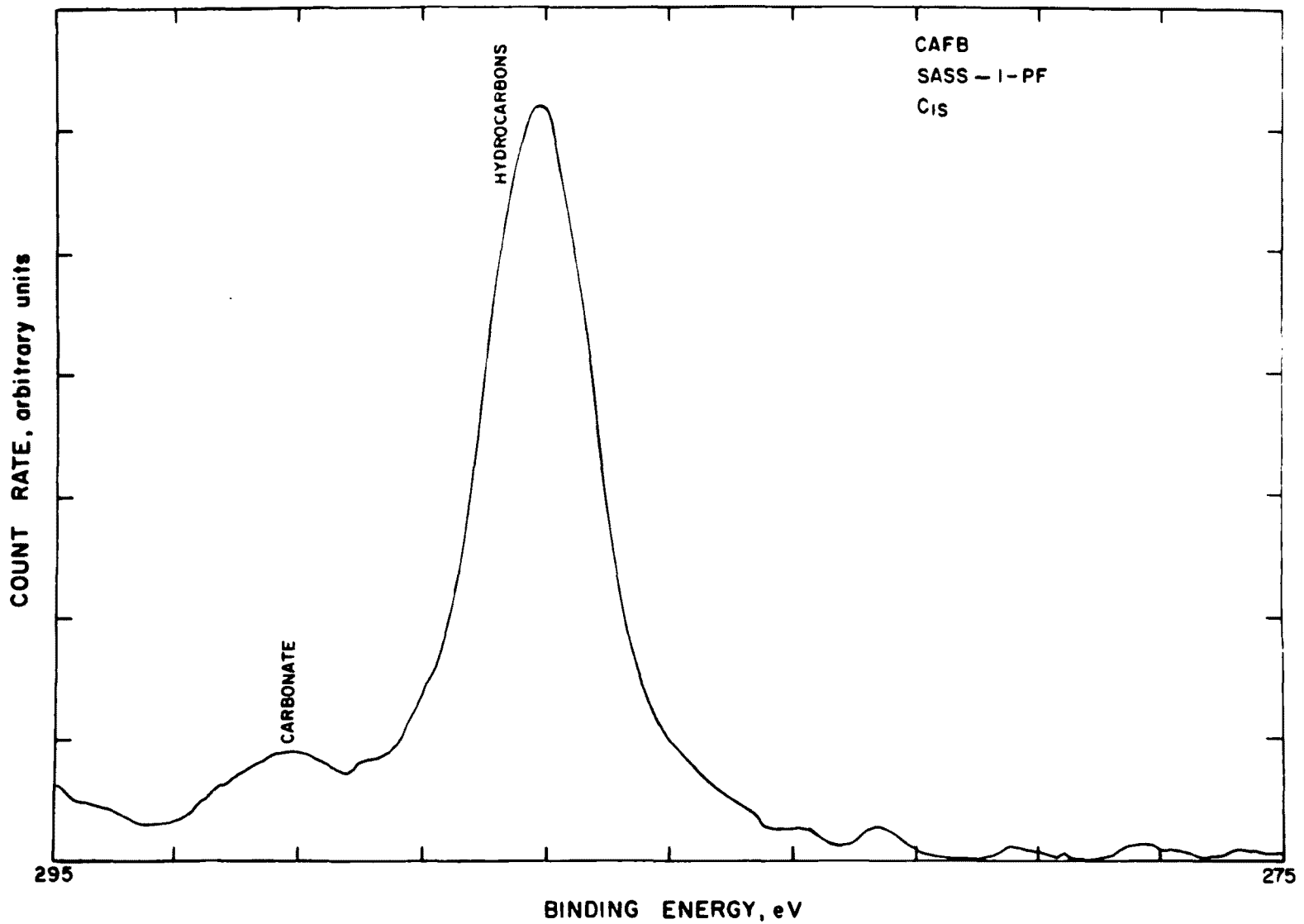

Figure 11. Carbon 1s spectrum of SASS-1 filter particulate.

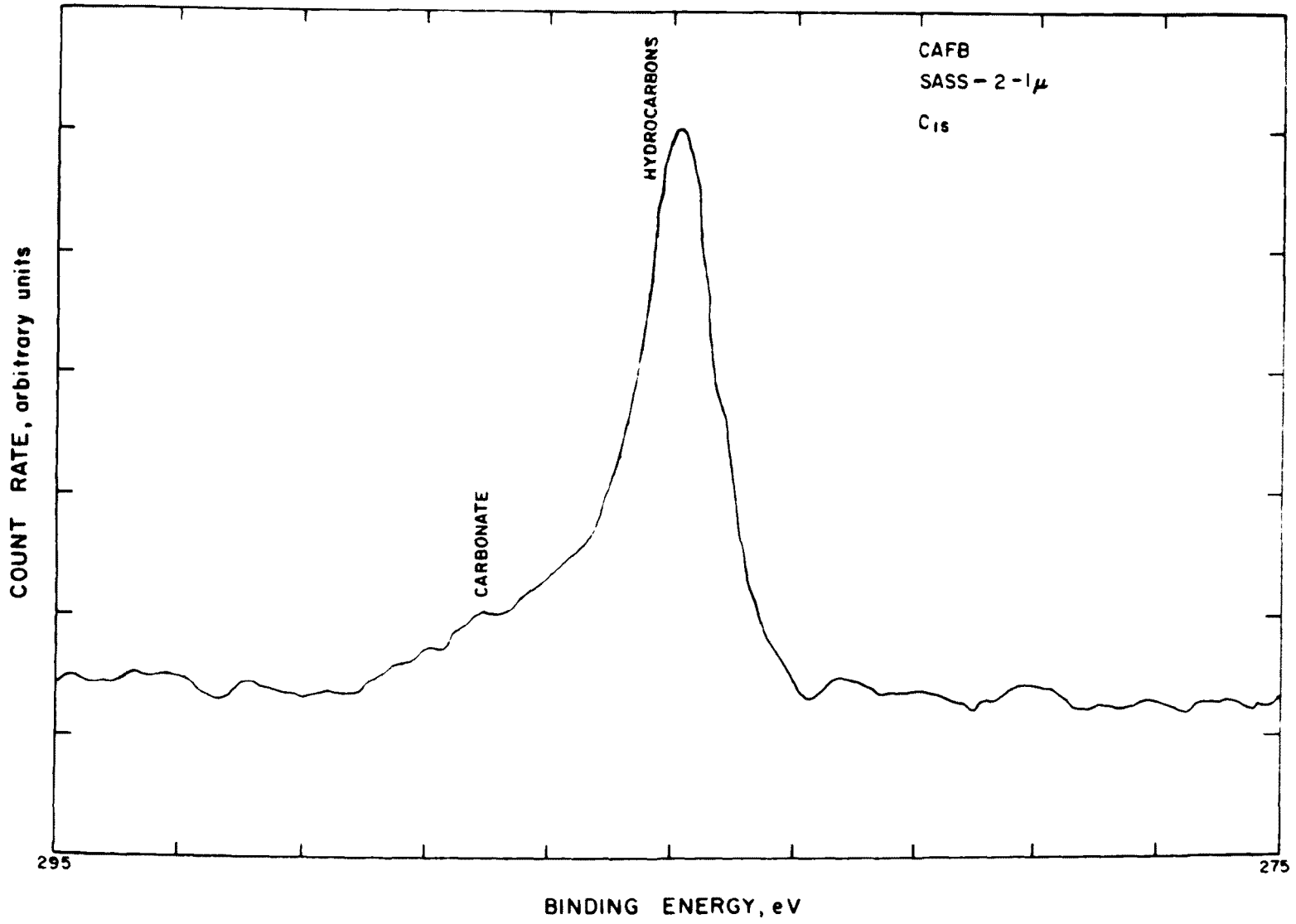

Figure 12. Carbon 1s spectrum of SASS-2 1μ cyclone particulate.

particularly evident in Figure 12, could be attributable to carbonyl or alcohol. The C_{1s} spectra of RAC 1 and 5 filters displayed in Figures 13 and 14 show, in addition to hydrocarbon and carbonate, the presence of reduced carbon species, possibly coke. No reduced carbon species were found on RAC filters collected during CAFB oil-firing.

Sulfur found in all particulate samples analyzed was, for the most part, sulfate with only the SASS-2 filter showing any sulfide (Figure 15). In this sample the sulfide was approximately 10 percent of the surface sulfur; the rest, sulfate. The depth profile of sulfur on the two SASS filters was determined by measuring the sulfur-calcium ratio after argon ion etching the samples for successive periods of time up to 20 minutes. Changes in the spectra with depth are shown in Figures 15 to 17. These figures show the tendency of etching to reduce the sample surface. Calcium was chosen as the internal standard or constant by which to measure sulfur because there is no evidence that its concentration changes with depth. For SASS-1 the S/Ca ratio decreased by a factor of 4.5 between the surface and a depth of approximately 200 Å. The S/Ca ratio for SASS-2 decreased at roughly half that rate. Both depth profiles are plotted in Figures 18 and 19 as S/Ca versus depth as minutes etched. This depth profile shows a surface enhancement of sulfur on the particulate which is probably due to condensation of moisture onto particulate in the cooler stack region.

ESCA analysis of the gasifier bed material collected during SASS No. 2 revealed only carbon, oxygen, and calcium in detectable quantities. If the system were working efficiently, we would expect to see detectable quantities of sulfur in the bed. A failure to see sulfur may, however, be partially attributable to particle size. When received, the bed particles were perhaps as large as 1 mm in diameter. Crushing these to a powder for ESCA analysis would expose a large amount of previously unexposed area. Since any expected sulfur would be that adsorbed on the surface, this pulverizing could make the sulfur undetectable.

Carbon in the bed sample (Figure 20) was in three distinct forms: hydrocarbon, carbonate and an unidentified reduced species, possibly coke. Hydrocarbons are due to unburned fuel and ambient surface contamination; carbonate is limestone bed material; and the coke is a deposit from pyrolysis.

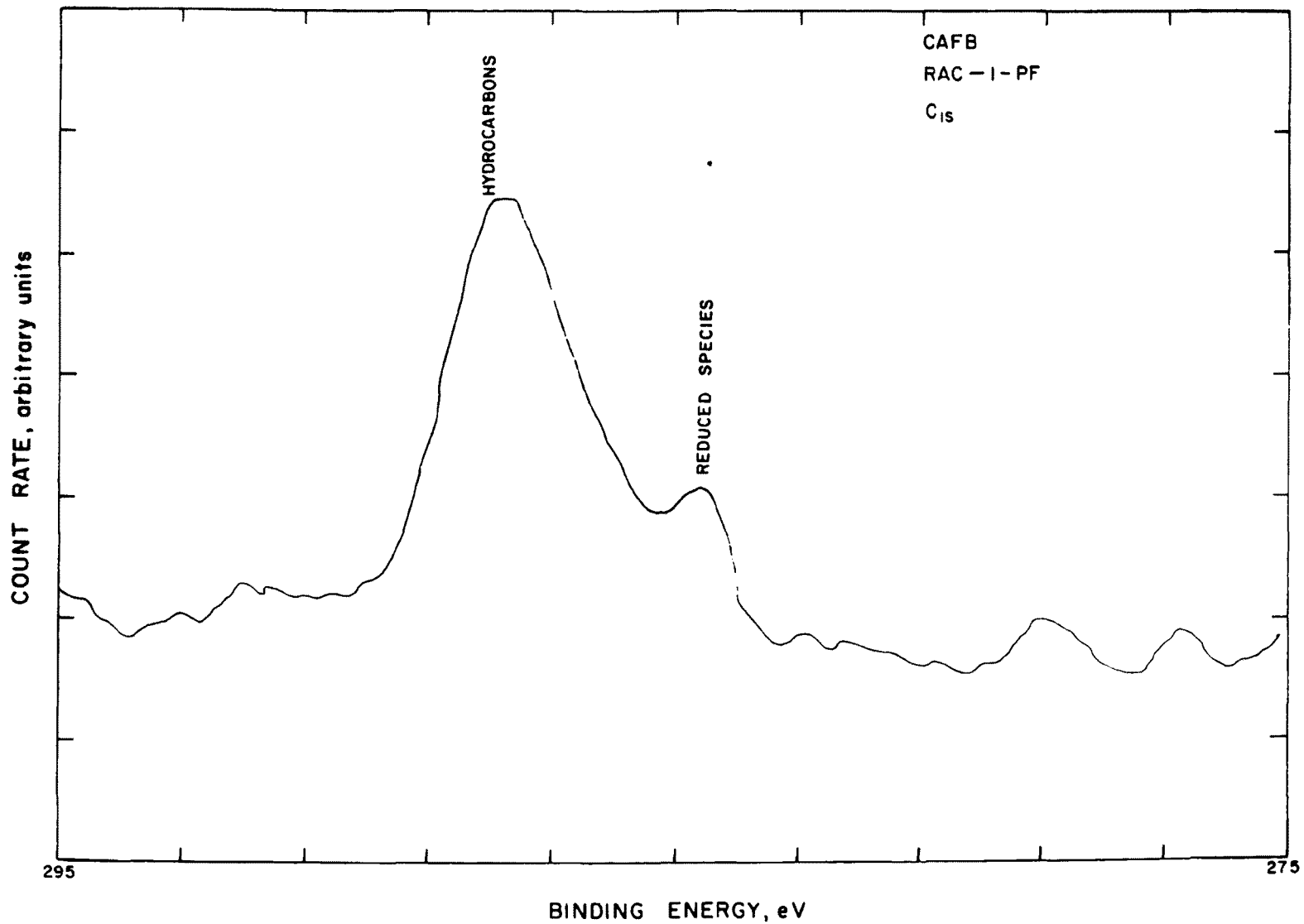

Figure 13. Carbon 1s spectrum of RAC-1 filter particulate.

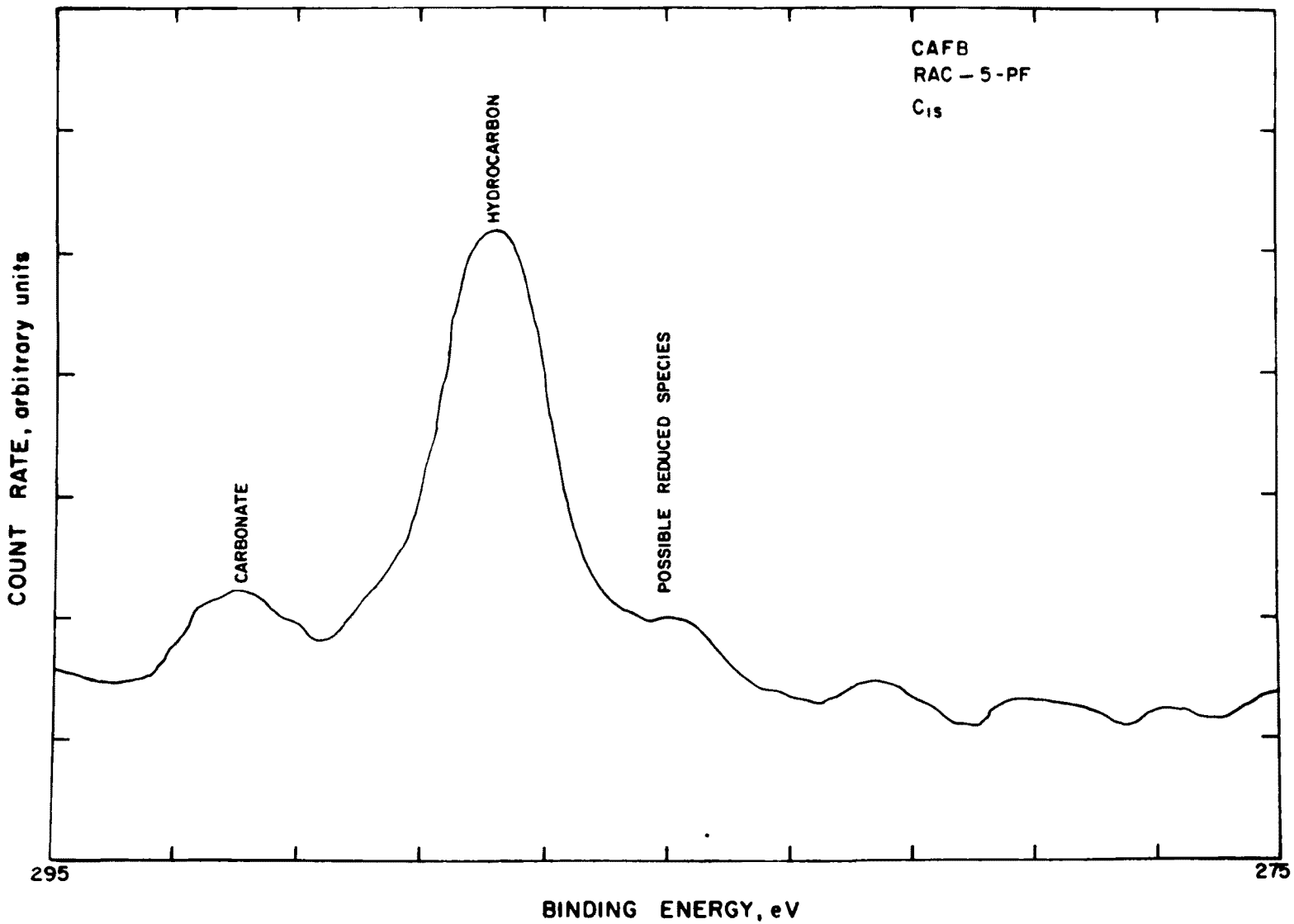

Figure 14. Carbon 1s spectrum of RAC-5 filter particulate.

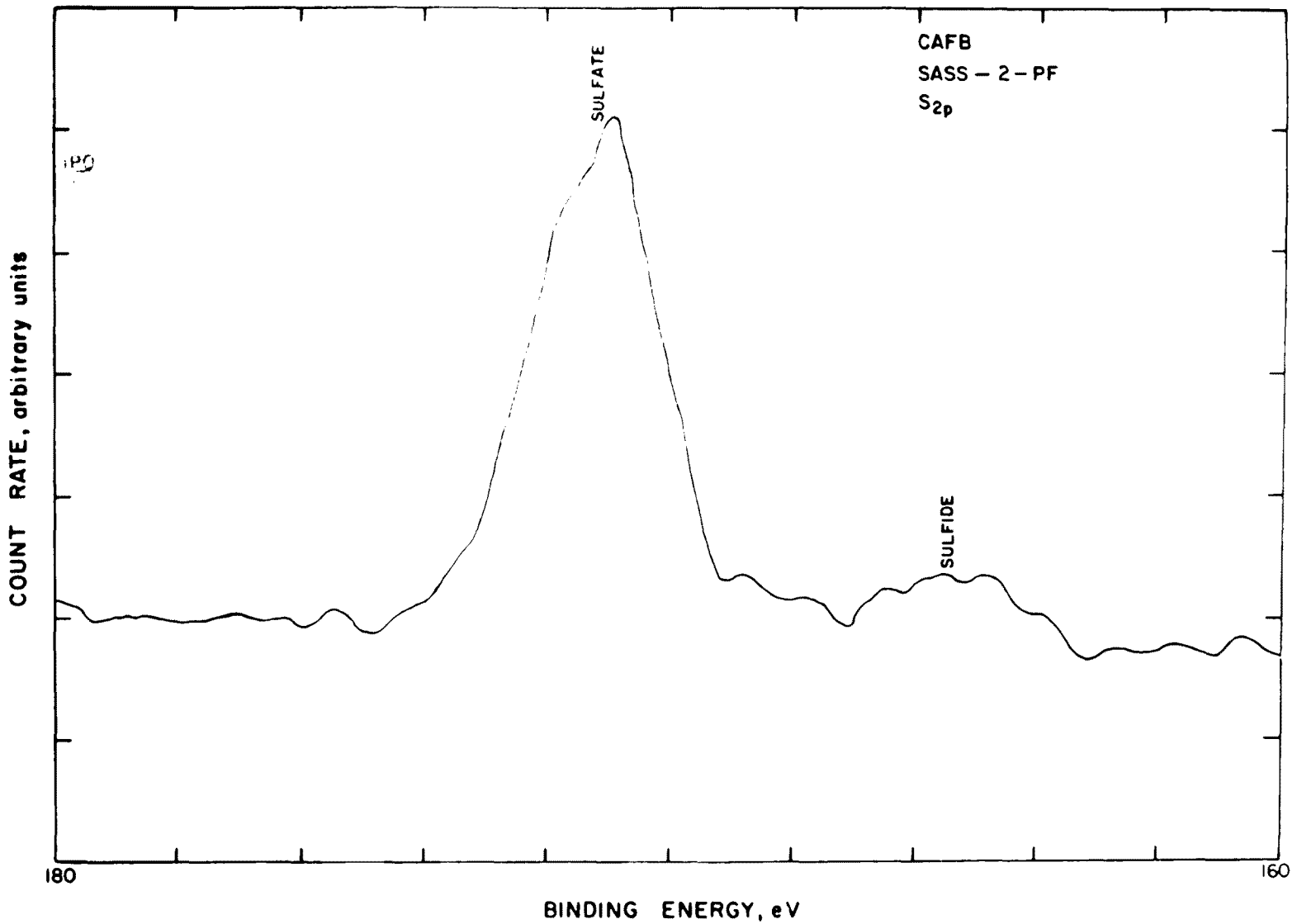

Figure 15. Sulfur 2p spectrum of SASS-2 filter particulate.

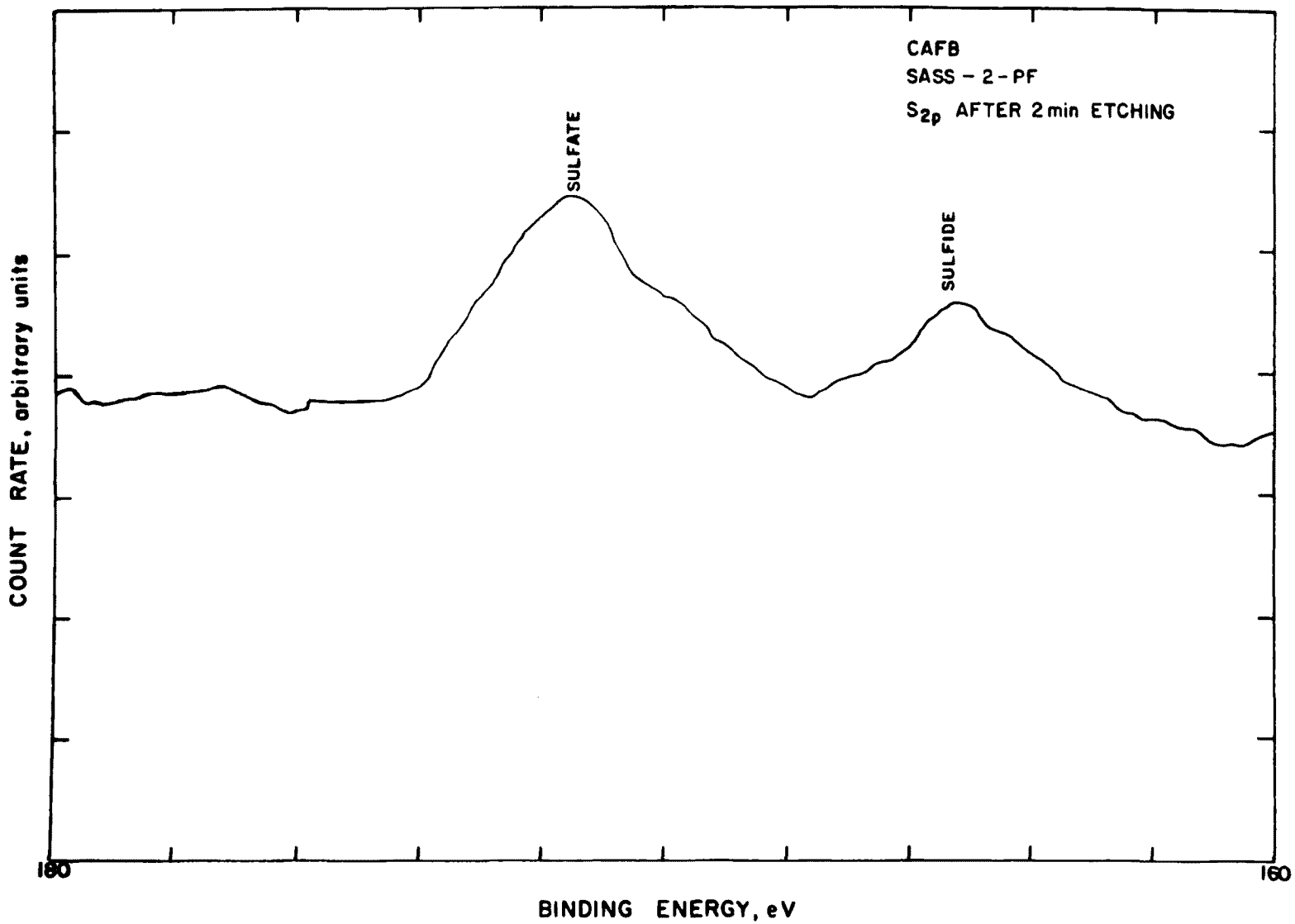

Figure 16. Sulfur 2p spectrum of SASS-2 particulate filter with argon ion etching: after 2 minutes of etching.

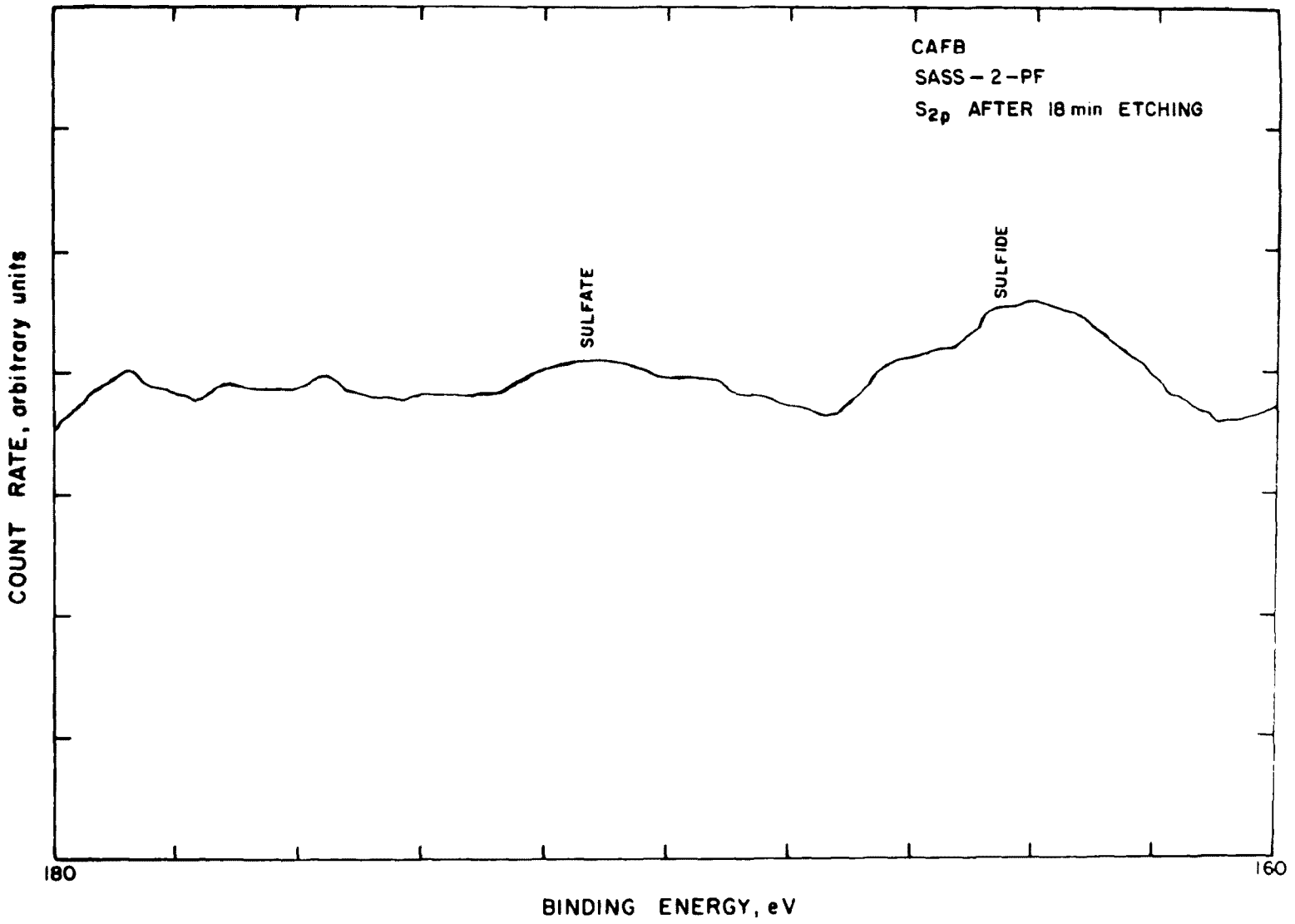

Figure 17. Sulfur 2p spectrum of SASS-2 particulate filter with argon ion etching: after 18 minutes of etching.

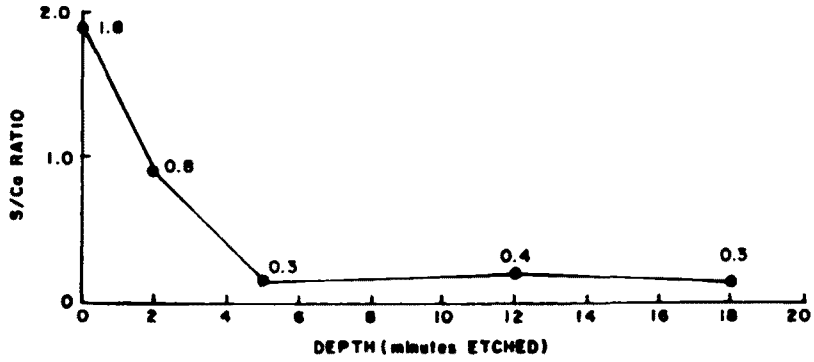

Figure 18. Depth profile of sulfur in SASS-1 filter particulate.

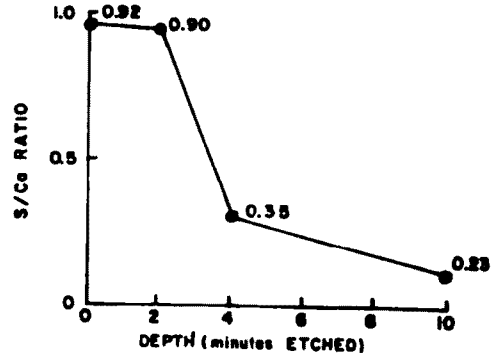

Figure 19. Depth profile of sulfur in SASS-2 filter particulate.

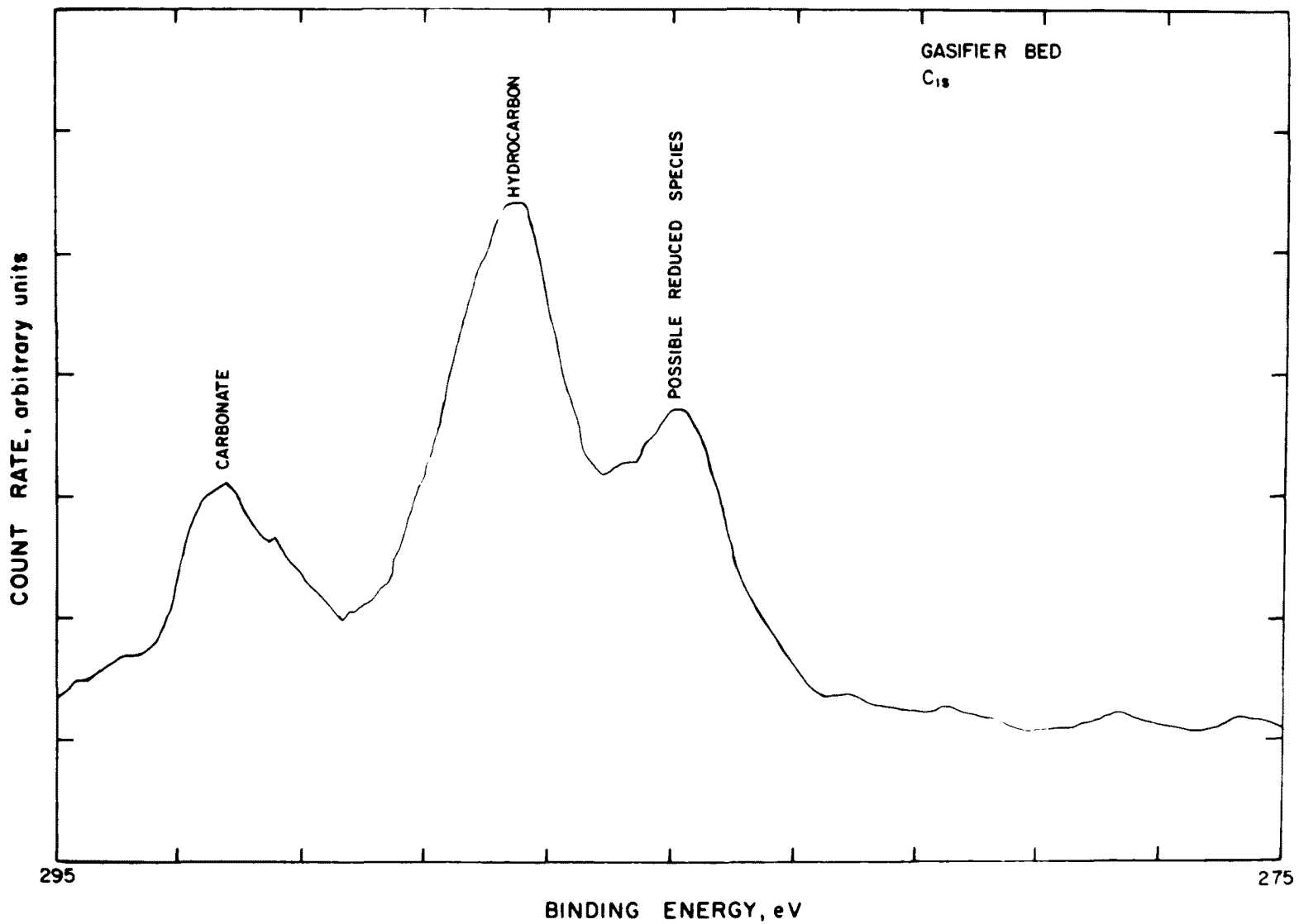

Figure 20. Carbon 1s spectrum of gasifier bed sample collected during SASS-2.

REFERENCES

1. Dorsey, J. A., L. D. Johnson, R. M. Statnick, and C. H. Lochmuller. Environmental Assessment Sampling and Analysis: Phased Approach and Techniques for Level I. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-600/2-77-115. June 1977. 38 pp.

2. 40 CFR 60, Appendix A (42 FR 41754-41782), 1977.

3. 40 CFR 60, Appendix A (42 FR 41786-41789), 1977.

4. Werner, A. S., C. W. Young, M. I. Bornstein, R. M. Bradway, M. T. Mills, and D. F. Durocher. Preliminary Environmental Assessment of the CAFB. GCA/Technology Division, Bedford, Massachusetts. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-600/7-76-017. October 1976. 324 pp. (NTIS No. PB 262-001/AS).

SECTION 5

ENVIRONMENTAL ASSESSMENT

INTRODUCTION

The Industrial Environmental Research Laboratory (IERL) of EPA is currently involved in formalizing and standardizing environmental assessment methods to allow for comparison of environmental impact associated with different energy and industrial processes. Source Analysis Models (SAM) have been developed by Acurex for EPA as a systematic procedure for investigating environmental impact.[1]

In conducting environmental assessments, it is necessary to perform one or more of the following tasks:

1. rank individual effluent streams by the expected toxicity of their discharges,

2. establish sampling priorities,

3. determine problem pollutants,

4. recommend best multimedia control technology alternatives,

5. recommend control/disposal technology development programs.

Three Source Analysis Models (SAM/IA, SAM/I, SAM/II) have been developed as a series of methods to aid in accomplishing these five tasks. GCA has employed the simplest method of the sequence, SAM/IA, to provide a rapid screening of flue gas emissions from the lignite-fired CAFB. SAM/IA compares actual emission and effluent concentrations with a series of Minimum Acute Toxicity Effluent (MATE) values established by EPA. The model is appropriate for analysis of Level I and Level II data and provides some input to each of the five elements above; most specifically: identification of further sampling needs, problem pollutants, and recommendations for applicable control technology. The objective in evaluating the CAFB by this procedure is to compare results with similar data derived for six conventional lignite-fired boilers located in the western U.S. The final goal is to recommend sampling procedures and control technology that would be appropriate for operation of the CAFB demonstration plant in San Benito, Texas.

SAM/IA is implemented by use of a tabular format for simple comparison of estimated pollutant discharge rates with effluent and emission goals. The emission goal used with SAM/IA is the MATE, with values established for most

of the 650 substances on the Multimedia Environmental Goal (MEG) list based upon health or ecological effects reference data. The assumption is made that the concentrations of pollutants in gas, liquid or solid effluent streams should not exceed MATE values which are estimated to minimize acute (short-term exposure) toxic effects.

MATE's describe very approximate concentrations of components or species in air, water or land effluents which may evoke significant damage response in exposed humans or the ecology from limited duration exposures (i.e., less than 8 hours per day).

MATE's are derived from TLV's, NIOSH recommendations, LD_{50}'s, LD_{LO}'s, LC_{50}'s, TD_{LO}'s, TLM's, Water Quality Criteria and Drinking Water Regulations.

As many as six MATE's can be listed for each pollutant species or sample fraction in the worksheets:

- Air (health and ecology based)
- Water (health and ecology based)
- Land (health and ecology based).

This allows for comparison of emissions to MATE's for air, water or land for studies of health or ecological effects.

The steps included in the SAM/IA approach are:

1. Identify specific sources within the overall system or process.

2. Identify the various effluent streams from that source. For complete analysis, each gas, liquid or solid waste discharge is included as a separate effluent stream.

3. Determine the concentration of each sample fraction (Level I) or specific pollutant species (Level II) to be considered in each effluent stream. In Level I assessments, the set of species potentially present which would lead to environmental hazard is established at this point for each sample fraction.

4. Each sample fraction or specific pollutant concentration in a given effluent stream is then divided by its corresponding health-based MATE. This quantity is, henceforth, called a "degree of hazard" (H). A second quotient is formed using the corresponding ecological MATE.

5. At this point, flags (i.e., checkmarks) are noted on the form for each pollutant entry whose health or ecological degree of hazard (H) is greater than unity. This provides for ease in spotting potential problem pollutants. Their presence should be noted and assessed in any report.

6. The final calculation for each pollutant species or sample fraction in each stream utilizes the product of its degree of hazard (H) and the effluent stream flow rate to establish health (or ecological) toxic unit discharge rates (TUDR).

7. The total stream degree of hazard is then calculated as the sum of the H's for each pollutant. Further, the total stream TUDR is calculated by summing the individual pollutant entry toxic unit discharge rates.

8. Degrees of Hazard and Toxic Unit Discharge Rates are then grouped and summed by discharge media (i.e., the H's and TUDR's for all gaseous, water and solid effluent streams are listed and summed for each medium).

GASEOUS EMISSIONS

SAM/IA is being used to assess air emissions from the CAFB as compared to several conventionally-fired lignite boilers in the Western U.S. Particulate and trace element and anion species are compared based on sampling by SASS and RAC train methods and analysis by spark source mass spectroscopy (SSMS), atomic absorption spectroscopy (AAS), and wet chemical techniques. Other air emissions which are assessed in the SAM/IA model include: C_1-C_6 hydrocarbons, NO_x, SO_2 and SO_3.

Table 30 illustrates the format of the SAM/IA procedure and an analysis of gaseous emissions measured during lignite gasification and combustion. No hydrocarbons with higher boiling points than C_2 were detected, and hydrocarbons which did exist were in very low concentrations. Comparison of actual hydrocarbon concentrations with health MATE values shows degrees of hazard significantly less than 1. However, the ecological degree of hazard for C_1 hydrocarbons, 9,000, indicates that flue gas ethylene concentrations may have an adverse effect on vegetation. The ecological C_1 hydrocarbon MATE value was probably set at 1 $\mu g/m^3$ due to the reported harmful effect of ethylene on plants at relatively low concentrations. The SAM/IA analysis indicates that C_2 hydrocarbons (acetylene, ethane, propylene) emitted from the CAFB during lignite gasification are low and of minor significance in producing adverse health or ecological impacts.

The health hazard factors associated with NO and NO_x emissions range from 3.1 to 4.1, respectively. This indicates a somewhat excessive emission of nitrogen oxides, however, on a fuel-related basis NO_x emissions are well below the new source performance standards (NSPS) for coal-fired steam generators $> 250 \times 10^6$ Btu/hr capacity. The actual NO_x emission rate is 0.09 lb/10^6 Btu as compared to the standard of 0.7 lb/10^6 Btu, lower by a factor of 10. This suggests that the health MATE value for NO_x may require revision to make it more representative of existing standards.

TABLE 30. SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT

SAM/IA WORKSHEET FOR LEVEL 1 — **Form IA02 Level 1**

1 SOURCE/CONTROL OPTION — Page 1

ESSO, England, CAFB Pilot Plant

2 EFFLUENT STREAM

101 (CODE #) — Flue Gas (NAME)

3 EFFLUENT STREAM FLOW RATE

Q = 0.6 m^3/sec

(gas = m^3/sec — liquid = l/sec — solid waste = g/sec)

4 COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/m^3	μg/m^3	μg/m^3	–	–	–	–	–	–		
C_1	9.0E3	3.3E5	1.0	0.03	-	9,000	2		✓	0.02	5,355
C_2	2.0E3	5.3E6	1.1E5	0.0004	-	0.02	2			0.0002	0.01
NO	2.8E4	9.0E3	N	3.1				✓		1.84	
NO_x	3.7E4	9.0E3	N	4.1				✓		2.44	
SO_2	5.1E5	1.3E4	N	39.2				✓		23.52	
SO_3	3.2E3	N	N								
CO	<5.7E5	4.0E4	1.2E5	<14.3		4.75		✓	✓	8.51	2.83
CO_2	1.4E8	9.0E6	N	15.6				✓		9.28	

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5 EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL E) 5a 76.3

ECOLOGICAL MATE BASED (Σ COL G) 5b 9,005

(ENTER HERE AND AT LINE 8, FORM IA01)

6 NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 7

ECOLOGICAL 6b 3

7 TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL K) 7a 45.6

ECOLOGICAL MATE BASED (Σ COL L) 7b 5,358

(ENTER HERE AND AT LINE 8, FORM IA01)

The same argument holds for the SAM/IA results for SO_2 emissions. Although the health hazard factor is 39.2, the total SO_2 emission was found to be 0.55 lb/10^6 Btu or less than half of the NSPS (1.2 lb/10^6 Btu) for large steam generators. The emission of CO_2 and attendant hazard factor is fairly meaningless because high CO_2 flue gas concentrations are indicative of high combustion efficiency.

TRACE ELEMENT AIR EMISSIONS

The SAM/IA procedure was used to assess the impact of trace element emissions measured during the lignite run at the ESSO pilot plant. Tables 31 and 32 present a listing of trace element concentrations measured by spark source mass spectrometry (SSMS) from particulate samples collected during the two SASS runs. As for the gaseous emission analysis, emissions and MATE values are presented in $\mu g/m^3$. A check mark is placed in column I or J if the Health or Ecology MATE value is exceeded by the actual emission. For the first SASS run (SASS-1), the emissions of concern, according to the SAM/IA analysis, include Ba, As, Ni, Cr, V (Ecology MATE exceeded), Ti, P, Si, Mg, B, and Be. Except for Ti, Si, Mg, and B, these emissions may have severe effects. RTI's research of background information for MEG (multimedia environmental goal) development reports the following potential effects associated with the aforementioned hazardous trace elements:[2]

- Barium - soluble barium compounds are highly toxic when ingested; 0.8 to 0.9 g of $BaCl_2$ is reported as a lethal dose; BaO and $BaCO_3$ have caused respiratory damage in man.

- Arsenic - trivalent species is most toxic; compounds absorbed by inhalation, ingestion, and through skin; cumulative poison producing chronic effects in mammals.

- Nickel - nickel absorbed through inhalation may be associated with nasal, sinus, and lung cancer; dietary intake of nickel apparently not harmful; nickel salts may be highly toxic.

- Chromium - all chromium compounds are considered poisonous, with hexavalent chromium considered more hazardous than trivalent form; inhalation may cause injury or cancer in the respiratory tract; laboratory tests have shown carcinogenic response in rats and mice with lowest dosage of 1 mg/kg.

- Vanadium - toxic to humans by all routes of absorption, with pentavalent species being most highly toxic; inhalation causes respiratory system effects, including tracheitis, pulmonary edema, and bronchial pneumonia; 0.2 to 0.5 mg/m^3 has caused effects on respiratory systems; 0.5 to 1.0 $\mu g/m^3$ has produced noticeable effects in plants.

- Phosphorus - white phosphorus is most hazardous allotropic form; chronic effects include liver injury, necrosis of jaw bone, anemia, brittle bones, and tooth and eye damage; may be absorbed by all

TABLE 31. SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-1

SAM/IA WORKSHEET FOR LEVEL 1 — Form IA02 Level 1

1 SOURCE/CONTROL OPTION — Page 1 /

ESSO, England, CAFB Pilot Plant, SASS-1

2. EFFLUENT STREAM

101 (CODE #) Flue gas (NAME)

3 EFFLUENT STREAM FLOW RATE

Q = 0.52 m^3/sec

(gas = m^3/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	✓ IF HEALTH MATE EXCEEDED	✓ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/m^3			–	–	–	–	–	–		
U	18										
Th	46										
Bi	0.6-35	4.1E2	N	.001-.085						.0005-.04	
Pb	200										
Tl	< 2.1	1.5E2	N	<0.014						<0.01	
Au	< 2.1	N	N								
Ir	< 3.2										
Os	< 3.5										
Re	< 2.2										
W	< 6.1	1.0E3	N	<0.006						<0.003	
Hf	<24										
Lu	< 6.2										
Yb	< 5.9										
Tm	< 1.1										

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5 EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL E) 5a ~513

ECOLOGICAL MATE BASED (Σ COL G) 5b 310

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 31

ECOLOGICAL 6b 1

7 TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL K) 7a ~267

ECOLOGICAL MATE BASED (Σ COL L) 7b 161

(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE 31 (continued). SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-1

CONTINUATION SHEET FOR ITEM NO. 4 FORM IA02, LEVEL 1 Page

SOURCE/CONTROL OPTION ESSO, England, CAFB Pilot Plant, SASS-1 EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	✓ IF HEALTH MATE EXCEEDED	✓ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	μg/m³			—	—	—	—	—	—		
Er	< 6.9										
Ho	<0.1-2.3										
Dy	0.2-9.4	9.3E3	N	<0.001						<0.0005	
Tb	< 0.3										
Gd	< 4.6										
Eu	0.6-3.4										
Sm	3.3-16.0	5.3E4	N	<0.0003						<0.00002	
Nd	31	N	N								
Pr	10	5.1E4	N	0.0002						0.0001	
Ce	98	3.7E4	N	0.0026						0.0014	
La	200	1.1E5	N	0.0018						0.0009	
Ba	2,800	5.0E2	N	5.6				✓		2.91	
Cs	3.7										
I	1.3										
Te	8.8	1.0E2	N	0.088						0.046	
Sb	7.2	5.0E2	N	0.014						0.007	
Sn	71	N	N								
Cd	5.4	1.0E1	N	0.54						0.281	
Pd	7.9										
Rh	0.9										
Ru	< 1.9										
Mo	8.4	5.0E3	N	0.002						0.001	
Nb	81										
Zr	510										
Y	120										

TABLE 31 (continued). SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-1

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page

SOURCE/CONTROL OPTION ESSO, England, CAFB Pilot Plant, SASS-1 EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/m³			—	—	—	—	—	—		
Sr	2,600	3.1E3	N	0.839						0.436	
Rb	50										
Br	160										
Se	0.6-75	2.0E2	N	.003-.375						<0.195	
As	650	2.0	N	325				√		169	
Ge	6.2-33	5.6E2	N	.011-.059						<0.031	
Ga	170	5.0E3	N	0.034						0.018	
Zn	860	4.0E3	N	0.215						0.112	
Cu	180	2.0E2	N	0.90						0.468	
Ni	230	1.5E1	N	15.33				√		7.97	
Co	48	5.0E1	N	0.96						0.50	
Fe	-										
Mn	1,700	5.0E3	N	0.34						0.177	
Cr	110	1	N	110				√		57.2	
V	310	5.0E2	1	0.62		310			√	0.322	161
Ti	13,000	6.0E3	N	2.17				√		1.128	
Ca	210,000										
K	11,000	N	N								
S	-										
P	1,600	1.0E2	N	16				√		8.32	
Si	230,000	1.0E4	N	23				√		11.96	
Al	-	5.2E3	N								
Mg	16,000	6.0E3	N	2.67				√		1.388	
Na	-	5.3E4	N								
B	4,300	3.1E3	N	1.387				√		0.721	
Be	14	2.0	N	7				√		3.64	

TABLE 32. SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-2

SAM/IA WORKSHEET FOR LEVEL 1 — **Form IA02 Level 1**

1 SOURCE/CONTROL OPTION — Page 1

ESSO, England, CAFB Pilot Plant, SASS-2

2 EFFLUENT STREAM

101 (CODE #) — Flue gas (NAME)

3 EFFLUENT STREAM FLOW RATE

Q = 0.60 m^3/sec

(gas = m³/sec — liquid = l/sec — solid waste = g/sec)

4 COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	Y IF HEALTH MATE EXCEEDED	Y IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	ug/m³			–	–	–	–	–	–		
U	13										
Th	35										
Bi	0.5-28	4.1E2	N	.001-.068						<0.041	
Pb	310										
Tl	< 13	1.5E2	N	<0.087						<0.052	
Au	< 13	N	N								
Ir	< 20										
Os	< 22										
Re	< 14										
W	< 23	1.0E3	N	<0.023						<0.014	
Hf	< 49										
Lu	< 13										
Yb	< 12										
Tm	< 5.8										

IF MORE SPACE IS NEEDED USE A CONTINUATION SHEET

5 EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL E) 5a -920

ECOLOGICAL MATE BASED (Σ COL G) 5b 430

(ENTER HERE AND AT LINE 8 FORM IA01)

6 NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 31

ECOLOGICAL 6b 1

7 TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL K) 7a -551

ECOLOGICAL MATE BASED (Σ COL L) 7b 258

(ENTER HERE AND AT LINE 8 FORM IA01)

TABLE 32 (continued). SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-2

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page

SOURCE/CONTROL OPTION ESSO, England, CAFB Pilot Plant, SASS-2 EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	✓ IF HEALTH MATE EXCEEDED	✓ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E = LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G = LINE 3)
UNITS	μg/m³			—	—	—	—	—	—		
Er	< 18										
Ho	< 6.2										
Dy	< 19	9.3E3	N	<0.002						<0.0012	
Tb	< 2.2										
Gd	< 14										
Eu	<0.1-8.1										
Sm	1.1-31	5.3E4	N	<0.001						<0.0006	
Nd	17-44	N	N								
Pr	11	5.1E4	N	0.0002						0.00012	
Ce	97	3.7E4	N	0.003						0.00018	
La	200	1.1E5	N	0.002						0.00012	
Ba	5,100	5.0E2	N	10.2				✓		6.12	
Cs	3.5										
I	2.7-12										
Te	0.1-15	1.0E2	N	.001-.15						<0.09	
Sb	18	5.0E2	N	0.036						0.022	
Sn	18-400	N	N								
Cd	2.0-27	1.0E1	N	0.2-2.7				✓		<1.62	
Pd	< 16										
Rh	< 3.9										
Ru	< 13										
Mo	12	5.0E3	N	0.002						0.0012	
Nb	78										
Zr	540										
Y	87										
Sr	5,000	3.1E3	N	1.613				✓		0.968	

TABLE 32 (continued). SAM/IA WORKSHEET FOR LEVEL I - ESSO, ENGLAND, CAFB PILOT PLANT, SASS-2

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page

SOURCE CONTROL OPTION ESSO, England, CAFB Pilot Plant, SASS-2 EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	✓ IF HEALTH MATE EXCEEDED	✓ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	μg/m³			—	—	—	—	—	—		
Rb	63										
Br	190										
Se	14-160	2.0E2	N	.07-0.80						<0.48	
As	1,000	2.0	N	500				✓		300	
Ge	41	5.6E2	N								
Ga	260	5.0E3	N	0.052						0.031	
Zn	1,900	4.0E3	N	0.475						0.285	
Cu	260	2.0E2	N	1.30				✓		0.78	
Ni	130-630	1.5E1	N	8.67-42				✓		<25.2	
Co	44	5.0E1	N	0.88						0.528	
Fe	-										
Mn	2,000	5.0E3	N	0.4						0.24	
Cr	330	1	N	330				✓		198	
V	430	5.0E2	1	0.86		430				0.516	258
Ti	14,000	6.0E3	N	2.33				✓		1.398	
Ca	-										
K	7,700	N	N								
S	220,000										
P	1,600	1.0E2	N	16				✓		9.6	
Si	-	1.0E4	N								
Al	-	5.2E3	N								
Mg	15,000	6.0E3	N	2.5				✓		1.5	
Na	5000-14,000	5.3E4	N	.094-.264						<0.158	
B	3,100	3.1E3	N	1				✓		0.6	
Be	3.8	2.0	N	1.9				✓		1.14	
Li	60	2.2E1	N	2.73				✓		1.638	

routes; lowest reported lethal dose to humans is 1.4 mg/kg administered orally.

- Beryllium - toxic through all routes of absorption, with major health hazard via inhalation; chronic exposure causes berylliosis, with particle size being critical factor; lowest toxic concentration reported for humans is 0.1 mg/m^3; beryllium and 5 beryllium compounds reported to cause cancer in animals with lowest dose producing carcinogenic response being 35 $\mu g/m^3$ as $BeSO_4 \cdot 4H_2O$ in laboratory testing.

Because the toxicities of the elements reported are high, it is important to assure highly efficient control in actual commercial CAFB systems. It is expected that these trace elements are emitted in particulate form, but further Level II testing is required to identify actual compounds and the probability of escape in the vapor phase.

Using the SAM/IA procedure, analysis of particulate emitted during the second SASS run (SASS-2), during which emissions exceeded SASS-1 values by 25 percent, indicates some additional trace elements with health hazard factors greater than 1; namely, Cd, Sr, Cu, and Li. The naturally occurring isotope of Sr is not highly toxic, but the other three elements are, giving further support to the need for appropriate emission control in commercial systems.

The health hazard factors for the trace elements discussed above range from approximately 1 to 500 (covering SASS-1 and SASS-2); the highest value is for arsenic. The only trace element compared with an ecology MATE is vanadium, with ecology hazard factors of 310 and 430 for SASS-1 and SASS-2, respectively. These high hazard factors indicate that particulate control efficiency of 99.8 percent is required to lower the arsenic hazard factor to 1. Due to inconsistencies between MATE values and standards (e.g., the previous discussion of NO_x and SO_2), it would be inappropriate to base control efficiency objectives solely on the results of the SAM/IA analysis. Therefore, we have evaluated (through application of the SAM/IA method) trace element emission data representing lignite-fired conventional boilers controlled with multiclones or electrostatic precipitators to compare conventional systems with the CAFB. These sites are located in the midwest and were recently monitored as part of another EPA contract.[3]

Site A is a conventional lignite-fired boiler using multiclones for particulate control. The total measured particulate emission at Site A is $\sim$8.5 gm/m^3 as compared to $\sim$2.5 gm/m^3 at the ESSO pilot plant. The results of the SAM/IA analysis of trace element emissions from the boiler are itemized in Table 33. The trace elements with hazard factors greater than 1 are the same as those noted during the SASS-1 and SASS-2 sampling runs at the ESSO pilot plant. Cobalt and manganese are also shown as having health hazard factors greater than 1. Overall, the hazard factors for these important elements range between 1 and 800, which is very similar to the CAFB results. It is important to note that the accuracy of the SSMS technique is within a factor of 2 or 3 so that differences of an order of magnitude are necessary to be significant. Overall, the ESSO pilot plant trace element emissions present no

TABLE 33. SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH MULTICLONE - SITE A

SAM/IA WORKSHEET FOR LEVEL 1 — **Form IA02 Level 1**

1 SOURCE/CONTROL OPTION — Page 1 .

Conventional Lignite Boiler With Multiclone - Site A

2 EFFLUENT STREAM

101 (CODE #) Flue Gas (NAME)

3 EFFLUENT STREAM FLOW RATE

Q = 27.9 m^3/sec

(gas = m /sec — liquid = l/sec — solid waste = g/sec)

4 COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	Y IF HEALTH MATE EXCEEDED	Y IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	ug/m^3	ug/m^3		–	–	–	–	–	–		
U	56										
Th	74										
Bi	2.6	4.1E2	N	0.006						.167	
Pb	320										
Tl	< 8.3	1.5E2	N	<.055						<1.535	
Au	< 4.1	N	N								
Ir	< 6.3										
Os	< 7.0										
Re	< 4.5										
W	6.2-33	1.0E3	N	.006-.033						< .921	
Hf	<13										
Lv	< 3										
Yb	< 3.2										
Tm	< 2.5										

IF MORE SPACE IS NEEDED USE A CONTINUATION SHEET

5 EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL E) 5a < 2032

ECOLOGICAL MATE BASED (Σ COL G) 5b 470

(ENTER HERE AND AT LINE 8, FORM IA01)

6 NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 30

ECOLOGICAL 6b 1

7 TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL K) 7a < 56,700

ECOLOGICAL MATE BASED (Σ COL L) 7b 13,113

(ENTER HERE AND AT LINE 8 FORM IA01)

TABLE 33 (continued). SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH MULTICLONE - SITE A

CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02. LEVEL 1

Page 2

SOURCE/CONTROL OPTION Conventional Lignite Boiler With Multiclone EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN-TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS	ug/m^3	ug/m^3		—	—	—	—	—	—		
Er	< 4.8										
Ho	< 1.1										
Dy	< 3.2	9.3E3	N	.0003						< .008	
Tb	< 0.7										
Gd	< 3.2										
Eu	< 1.8										
Sm	< 5.4	5.3E4	N	<.0001						< .003	
Nd	13	N	N								
Pr	29	5.1E4	N	.0006						.017	
Ce	240	3.7E4	N	.0065						.181	
La	320	1.1E5	N	.0029						.081	
Ba	200,000	5.0E2	N	400						11,160	
Cs	18										
I	3.3										
Te	< 3.3	1.0E2	N	<.033						< .921	
Sb	40	5.0E2	N	.08						2.232	
Sn	23	N	N								
Cd	33	1.0E1	N	3.3						92.07	
Pd	< 6.7										
Rh	6.6										
Ru	< 3.6										
Mo	38	5.0E3	N	.0076						0.212	
Nb	67										
Zr	1300										
Y	190										
Sr	41,000	3.1E3	N	13.23				√		369.1	

TABLE 33 (continued). SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH MULTICLONE - SITE A

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

Page 3

SOURCE CONTROL OPTION Conventional Lignite Boiler With Multiclone EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	IF HEALTH MATE EXCEEDED	IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS				—	—	—	—	—	—		
Rb	290										
Br	210										
Se	83	2.0E2	N	.415				✓		11.58	
As	1,600	2.0	N	800						22,320	
Ge	7.2	5.6E2	N	.0129						.360	
Ga	240	5.0E3	N	.048						1.34	
Zn	880	4.0E3	N	.220						6.138	
Cu	470	2.0E2	N	2.35				✓		65.57	
Ni	1,400	1.5E1	N	93.33				✓		2604	
Co	100	5.0E1	N	2.0				✓		55.8	
Fe	---										
Mn	27,000	5.0E3	N	5.4				✓		150.7	
Cr	470	1	N	470				✓		13,113	
V	470	5.0E2	1	.94		470				26.23	13,113
Ti	28,000	6.0E3	N	4.67				✓		130.3	
Ca	---										
K	39,000	N	N								
S	160,000										
P	16,000	1.0E2	N	160				✓		4,464	
Si	---	1.0E4	N								
Al	---	5.2E3	N								
Mg	---	6.0E3	N								
Na	---	5.3E4	N								
B	140,000	3.1E3	N	45.16				✓		1,260	
Be	10	2.0	N	5.0				✓		139.5	
Li	570	2.2E1	N	25.91				✓		722.9	

greater ambient hazard than the emissions from Site A. This indicates that the gasifier cyclones and boiler cyclone in use at ERCA have a combined performance at least equal to the multiclones in use at Site A.

Site B is a lignite-fired conventional power plant boiler using an ESP for particulate control. The measured emission at the stack is 0.0012 gm/m^3, a factor of 2000 less than the total particulate emissions indicated by the two SASS runs at the ESSO pilot plant. Table 34 indicates the results of the SAM/IA analysis of trace element emissions from this site. The only elements with hazard factors greater than 1 are arsenic, nickel, chromium, and vanadium (ecology); and these values are all reported as upper limits. The accuracy of the SSMS analysis in this case is quite low because of the very small amount of material collected in the sampling train. The data are presented to demonstrate the capability of an available control device to lower trace element emissions to acceptable levels.

A summary of trace element emission data representing the two conventional sites and the ESSO pilot plant is presented in Table 35. All elements with hazard factors > 1 at any of the three sites are included. In addition, some other trace elements (namely, Pb, Sb, Zr, Br, Zn) and sulfur are included for the purpose of discussion. Lignite trace element concentrations are presented to indicate comparative amounts processed by each of the three systems. One immediately apparent feature is that the trace element emissions measured at the CAFB and Site A are very similar, considering the accuracy of the SSMS analysis technique. This seems to be true regardless of the input quantity of each trace element. The most striking differences in feed quantities between CAFB and Site A exist for the elements Zr, Cr, V, Ti, Mg, Be, and Co. The feed concentration to the CAFB is at least an order of magnitude higher than the feed concentration at Site A for these six elements. However, the flue gas emissions of these elements are all higher at Site A than the CAFB, except for beryllium. This is partially explained by the fact that total particulate emissions at Site A are higher than at the ESSO pilot plant by a factor of 3.4 (8.5 gm/m^3 versus 2.5 gm/m^3). This being the case, there must be some factor that explains why emissions of these elements from the CAFB pilot plant are generally lower than measured at Site A by a factor of about 1.5 to 2 instead of being higher by a factor of > 10/3.4. Apparently, as noted for residual oil gasification, there is significant adsorption of these trace elements by the bed material. Trace elements may also be retained in the system in association with nonelutriated ash particles.

Trace element emission concentrations noted for Site B, where an ESP is used for final particulate control, are generally about two orders of magnitude less than emissions from the pilot plant and Site A. Since trace element feed concentrations are similar for Sites A and B, it is projected that application of a high efficiency control device at a commercial CAFB installation would provide very adequate control of trace element emissions.

TABLE 34. SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH ESP - SITE B

SAM/IA WORKSHEET FOR LEVEL 1 — **Form IA02 Level 1**

1 SOURCE/CONTROL OPTION — Page 1

Conventional Lignite Boiler With ESP - Site B

2. EFFLUENT STREAM

101 (CODE #) — Flue Gas (NAME)

3 EFFLUENT STREAM FLOW RATE

Q = 40.5 m^3/sec

(gas = m^3/sec — liquid = l/sec — solid waste = g/sec)

4 COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	Y IF HEALTH MATE EXCEEDED	Y IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS				–	–	–	–	–	–		
U	< 1.2										
Th	< 1.7										
Bi	< .5	4.1E2	N	< .0012						< .049	
Pb	1.1 - 8.5										
Tl	< .7	1.5E2	N	< .0047						< .190	
Au	< .9	N	N								
Ir	< 1.4										
Os	< 1.5										
Re	< .9										
W	< 1.3	1.0E3	N	< .0013						< .053	
Hf	< 1.6										
Lv	< .4										
Yb	< .5										
Tm	< .3										

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5 EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL E) 5a < 12.1

ECOLOGICAL MATE BASED (Σ COL G) 5b < 1.1

(ENTER HERE AND AT LINE 8 FORM IA01)

6 NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a 34

ECOLOGICAL 6b 1

7 TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL K) 7a < 490.8

ECOLOGICAL MATE BASED (Σ COL L) 7b < 44.55

(ENTER HERE AND AT LINE 8 FORM IA01)

TABLE 34 (continued). SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH ESP - SITE B

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page 2

SOURCE/CONTROL OPTION Conventional Lignite Boiler With ESP EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN-TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS				—	—	—	—	—	—		
Er	< 1										
Ho	< .3										
Dy	< .5	9.3E3	N	.00005						.002	
Tr	< .1										
Gd	< .5										
Eu	< .2										
Sm	< .9	5.3E4	N	.00002						.001	
Nd	< 1.2	N	N								
Pr	< .2	5.1E4	N	<.00001						< .0004	
Ce	< .3	3.7E4	N	<.00001						< .0004	
La	< .3	1.1E5	N	<.00001						< .0004	
Ba	< 28	5.0E2	N	.056						<2.268	
Cs	< .1										
I	< .8										
Te	< .7	1.0E2	N	<.007						< .284	
Sb	< .5	5.0E2	N	<.001						< .041	
Sn	1.3-16	N	N								
Cd	.9-2.1	1.0E1	N	.09-.21						<8.505	
Pd	< .7										
Rh	< .2										
Ru	< .9										
Mo	.8	5.0E3	N	.0002						.008	
Nb	< .1										
Zr	.3										
Y	< .1-.1										
Sr	<10	3.1E3	N	<.0032						< .130	

TABLE 34 (continued). SAM/1A WORKSHEET FOR LEVEL I - CONVENTIONAL LIGNITE BOILER WITH ESP - SITE B

CONTINUATION SHEET FOR ITEM NO. 4. FORM IA02, LEVEL 1 Page 3

SOURCE/CONTROL OPTION Conventional Lignite Boiler With ESP EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	✓ IF HEALTH MATE EXCEEDED	✓ IF ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E x LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G x LINE 3)
UNITS				—	—	—	—	—	—		
Rb	< .1-.4										
Br	< 43										
Se	9.7	2.0E2	N	.0485						1.964	
As	< 4.2	2.0	N	< 2.1				✓		< 85.05	
Ge	< .1-.3	5.6E2	N	<.0005						< .02	
Ga	< .1-.1	5.0E3	N	<.00002						< .001	
Zn	13-31	4.0E3	N	<.0078						< .316	
Cu	< 36	2.0E2	N	<.18						< 7.29	
Ni	< 69	1.5E1	N	< 4.6				✓		< 186.6	
Co	< .8	5.0E1	N	<.016						< .648	
Fe	<170										
Mn	< 7.8	5.0E3	N	<.0016						< .065	
Cr	< 4.2	1	N	<4.2				✓		<170.1	
V	< 1.1	5.0E2	1	<.0022		1.1			✓	< .089	< 44.55
Ti	< 3.5	6.0E3	N	<.0006						< .024	
Ca	40-390										
K	560	N	N								
S	1400-7700										
P	< 46	1.0E2	N	<.46						< 18.63	
Si	180	1.0E4	N	.0180						.729	
Al	36-88	5.2E3	N	<.0169						< .684	
Mg	160	6.0E3	N	.0267						1.081	
Na	680	5.3E4	N	.0128						.518	
B	64	3.1E3	N	.0206						.834	
Be	.2	2.0	N	.1						4.05	
Li	< .3	2.2E1	N	.0136						.551	

TABLE 35. SUMMARY OF TRACE ELEMENT DATA

Trace element	Lignite fuel feed data (ppm)			Flue gas emissions (μg/m³)				Solid basis (ppm)		
	CAFB 1197	Site A	Site B	CAFB SASS-1	CAFB SASS-2	Site A	Site B	CAFB SASS-1	CAFB SASS-2	Site A
Pb	9.6	1.7	2.3	200	310	320	1.1 to 8.5	90.5	113	37.7
Ba	38	110	7.0	2,800	5,100	200,000	<28	1,268	1,018	23,585
Sb	0.30	0.055	<0.22	7.2	18	40	< 0.5	3.3	2.6	4.7
Cd	0.17	0.28	<0.39	5.4	15	33	0.9 to 2.1	2.4	2.0	3.9
Zr	5.9	0.37	0.35	510	540	1,300	0.3	231	196	153
Sr	37	38	46	2,600	5,000	41,000	<10	1,177	1,818	4,835
Br	0.23	3.3	3.2	160	190	210	<43	72.4	69.1	24.8
As	1.5	2.6	0.48	650	1,000	1,600	< 4.2	294	364	189
Zn	13	10	15.0	860	1,900	880	13 to 31	389	691	104
Cu	15	62	7.1	180	260	470	<36	81.5	94.6	55.4
Ni	23	4	48	230	380	1,400	<69	104	138	165
Cr	2.7	0.48	0.61	110	330	470	< 4.2	49.8	120	55.4
V	14	0.56	0.87	310	430	470	< 1.1	140	156	55.4
Ti	230	9.3	15.0	13,000	14,000	28,000	< 3.5	5,885	5,091	3,302
S	0.23%	0.23%	1.4%	-	220,000	160,000	1400 to 7700	-	80,000	18,868
P	42	14	8.6	1,600	1,600	16,000	<46	724	582	1,887
Si	MC	170	420	230,000	-	-	180	104,100	-	-
Mg	130%	420	840	16,000	15,000	MC	160	7,243	5,455	-
B	21	6.3	8.9	4,300	3,100	140,000	64	1,946	1,127	16,509
Be	0.03	0.018	0.037	14	3.8	10	0.2	6.3	1.4	1.2
Li	0.82	0.26		ND	60	570	<0.3		21.8	67.2
Co	0.50	0.089	0.17	48	44	100	<0.8			
Mn	22	11.0	13.0	1,700	2,000	27,000	<7.8			

Note: ND = not determined; MC = major component.

ORGANIC EMISSIONS

The variability of the distribution of organic emissions among the gaseous, volatile and condensable samples collected during the two SASS and two Tenax RAC runs is demonstrated by the emissions summary presented in Table 36. As noted in Section 4, SASS No. 1 measurements were made during reinjection of gasifier fines with the apparent result that lignite gasification efficiency was higher than during subsequent runs.

To establish a basis for evaluation of the potential environmental impact of organic emissions from the CAFB, Table 37 summarizes emissions determined by GCA from six conventional lignite-fired boilers. Comparison between the data in Tables 36 and 37 shows that the total organic emissions from the CAFB fall in the middle of the range found for conventional systems. The > C_6 emissions from the CAFB during SASS No. 1 is on the low end of the distribution, while the emissions from SASS No. 2 and RAC No. 4 are higher than any found from conventional systems.

The principal conclusions which can be drawn from a comparison between CAFB and conventional organic emissions is that when operated efficiently, gaseous (C_1 - C_6) organic emissions from the CAFB are equivalent to those from conventional systems and emissions of heavier organics are lower than the average from conventional boilers. The large number of organic functional groups identified by infrared spectroscopy indicates that Level II organic analyses should be performed to definitize the specific compound nature of the organic emissions.

TABLE 36. TOTAL CAFB ORGANIC EMISSIONS ($\mu g/m^3$)

	SASS No. 1	SASS No. 2	RAC No. 2	RAC No. 4
C_1 - C_6	17,770-23,192	No data	4,337-10,384	< 6,380
C_7 - C_{16}	221	307	650*	1,430*
> C_{16}	565	21,725	7,590*	19,740*
Total	18,556-23,978	> 21,725	12,577-18,624	21,170-27,550

*Average RAC 1-5 particulate emissions plus Tenax captured emissions.

TABLE 37. ORGANIC EMISSIONS FROM CONVENTIONAL LIGNITE-FIRED UTILITY BOILERS

Boiler type	Organic emissions ($\mu g/m^3$)			Total organic emissions ($\mu g/m^3$)
	$C_1 - C_6$	$C_7 - C_{16}$	$> C_{16}$	
Pulverized dry bottom (front fired)	39,020-44,520	434	9,800	49,300-54,800
Pulverized dry bottom (front fired)	5,340-17,430	936	6,930	13,200-25,300
Pulverized dry bottom (front fired)	4,000-13,000	558	64	4,600-13,600
Cyclone	10,680-22,770	382	2,410	13,500-25,600
Spreader stoker	1,780-13,870	643	1,745	4,200-16,300
Spreader stoker	No data	27	332	> 359

EMISSIONS FROM OIL-FIRED HDS AND FGD PROCESSES

Potential emissions from these sources have been discussed in an earlier report.[3] Pollutant streams emanating from limestone FGD and Flexicoking HDS will be specified here.

Limestone FGD

This is a "throwaway" FGD method which uses a circulating $CaCO_3$ scrubbing solution for SO_2 removal by the following reactions:[4]

$$CaCO_3 + SO_2 + \tfrac{1}{2} H_2O \rightarrow CaSO_3 \cdot \tfrac{1}{2} H_2O \downarrow + CO_2$$

$$CaSO_3 \cdot \tfrac{1}{2} H_2O + 3/2\ H_2O + \tfrac{1}{2} O_2 \rightarrow 2\ H_2O \downarrow$$

The calcium sulfite/sulfate solid waste generated amounts to approximately four times the weight of sulfur removed from the flue gas stream.[5] The waste slurry is generally discharged to a large pond for solids separation or it can be dewatered by mechanical means such as centrifugation or filtration. The chemical pollutants in FGD sludges originate from process ingredients, fuel, combustion products, absorbents, and process makeup water. Trace elements exist in the slurry liquor in the range of 0.01 to 1.0 mg/ℓ and in the solid phase at a concentration approximately two orders of magnitude higher.[6] (See Table 38.) The limestone scrubbing system operates at the lowest pH in comparison to other FGD systems and, therefore, has the highest distribution of trace elements in liquor. Typically, trace element distribution will be 1 to 2 percent in liquid and 98 to 99 percent in the solids. The low pH in the limestone process apparently causes a greater degree of trace element leaching from the fly ash. Table 39 illustrates the chemical characteristics of limestone FGD solids at a number of coal-fired plants.

It is reported that the most persistent pollution potential associated with limestone FGD waste disposal is by water percolation through the sludge and subsoil into the subterranean water table. Three methods of reducing the environmental impact of limestone FGD waste disposal are:[4]

- decreasing the permeability of solid wastes to reduce water seepage
- reducing leachability through a reduction of solubility
- managing seepage and runoff to limit the excess of waste constituents to ground-water or surface-water

An effective embodiment of these ideas is sluicing of waste sludge to an underdrained pond so that excess liquor can be returned to the scrubber while reducing seepage and overflow by minimizing supernatant hydraulic head.[6]

TABLE 38. RANGE OF CONCENTRATIONS OF CHEMICAL CONSTITUENTS IN FGD SLUDGES

Scrubber constituent	Sludge concentration range			
	Liquor (mg/ℓ, except pH)*		Solid (ppm)†	
Aluminum	0.03	- 2.0	-	-
Arsenic	<0.004	- 1.8	0.6	- 52
Beryllium	<0.002	- 0.18	0.05	- 6
Cadmium	0.004	- 0.11	0.08	- 4
Calcium	180	- 2600	105,000	- 268,000
Chromium	0.015	- 0.5	10	- 250
Copper	<0.002	- 0.56	8	- 76
Lead	0.01	- 0.52	0.23	- 21
Magnesium	4.0	- 2750	-	-
Mercury	0.0004	- 0.07	0.001	- 5
Potassium	5.9	- 100	-	-
Selenium	<0.0006	- 2.7	2	- 17
Sodium	10.0	- 29,000	-	- (4.8)
Zinc	0.01	- 0.59	45	- 430
Chloride	420	- 33,000	-	- (0.9)
Fluoride	0.6	- 58	-	-
Sulfate	600	- 35,000	35,000	- 473,000
Sulfite	0.9	- 3500	1600	- 302,000
Chemical oxygen demand	<1	- 390	-	-
Total dissolved solids	2800	- 92,500	-	-
pH	4.3	- 12.7		

*Liquor analyses were conducted on 13 samples from seven power plants burning eastern or western coal and using lime, limestone, or double-alkali absorbents.

†Solids analyses were conducted on six samples from six power plants burning eastern or western coal and using lime, limestone, or double alkali.

TABLE 39. PHASE COMPOSITION OF FGD WASTE SOLIDS IN WEIGHT PERCENT[6]

Atomic formula	TVA Shawnee limestone, 2/1/73	TVA Shawnee limestone, 7/12/73	TVA Shawnee limestone, 6/15/74	SCE Mohave limestone, 3/30/73	APS Cholla limestone, 4/1/74
$CaSO_4 \cdot 2H_2O$	21.9	15.4	31.2	84.6	17.3
$CaSO_3 \cdot 1/2H_2O$	18.5	21.4	21.8	8.0	10.8
$CaCO_3$	38.7	20.2	4.5	6.3	2.5
$MgSO_4 \cdot 6H_2O$	4.6	3.7	1.9	-	-
NaCl	-	-	-	1.5	-
Fly ash	20.1	40.9	40.1	3.0	58.7
Total	103.8	101.6	99.5	103.4	89.3

Flexicoking

This process was developed by EXXON Research and Engineering Company as a method of producing low sulfur fuel oil blendstocks from a wide range of residual feedstocks.[3] A schematic process diagram is shown in Figure 21.[8] The major pollutant sources include the purge coke, the venturi scrubber and cyclones fines, and the fractionator wastewater. Minor fugitive emissions may escape from equipment and piping joints. The coke purge quantity ranges between 1 and 2 percent of the total feed weight. Approximately 99 percent of the trace metals in the feedstock are concentrated in the coke purge, cyclone fines and venturi scrubber fines.[7] Table 40 illustrates the chemical characteristics of these three streams during processing of West Texas sour asphalt, and documents the system's capability for trace metal removal.[8] Table 41 shows a materials balance for vanadium based on a feedstock concentration of 160 ppm.[7]

The Flexicoking system is also efficient in generating a coke gas with low nitrogen content typically less than 3 ppm. This minimizes the formation of nitrogen compounds during combustion of the product gas.

Fractionator scrubber wastewater is the major source of liquid waste within the Flexicoking process. In general, this stream will contain organics, solids, trace elements, and sulfur compounds. A recent publication[8] indicates that conventional biological treatment or some form of activated carbon filtration would be suitable for producing a water stream with effluent quality within the limits of current regulations.

Fugitive leakage at pipe joints or other equipment connections would discharge a minor quantity of hydrocarbon compounds.

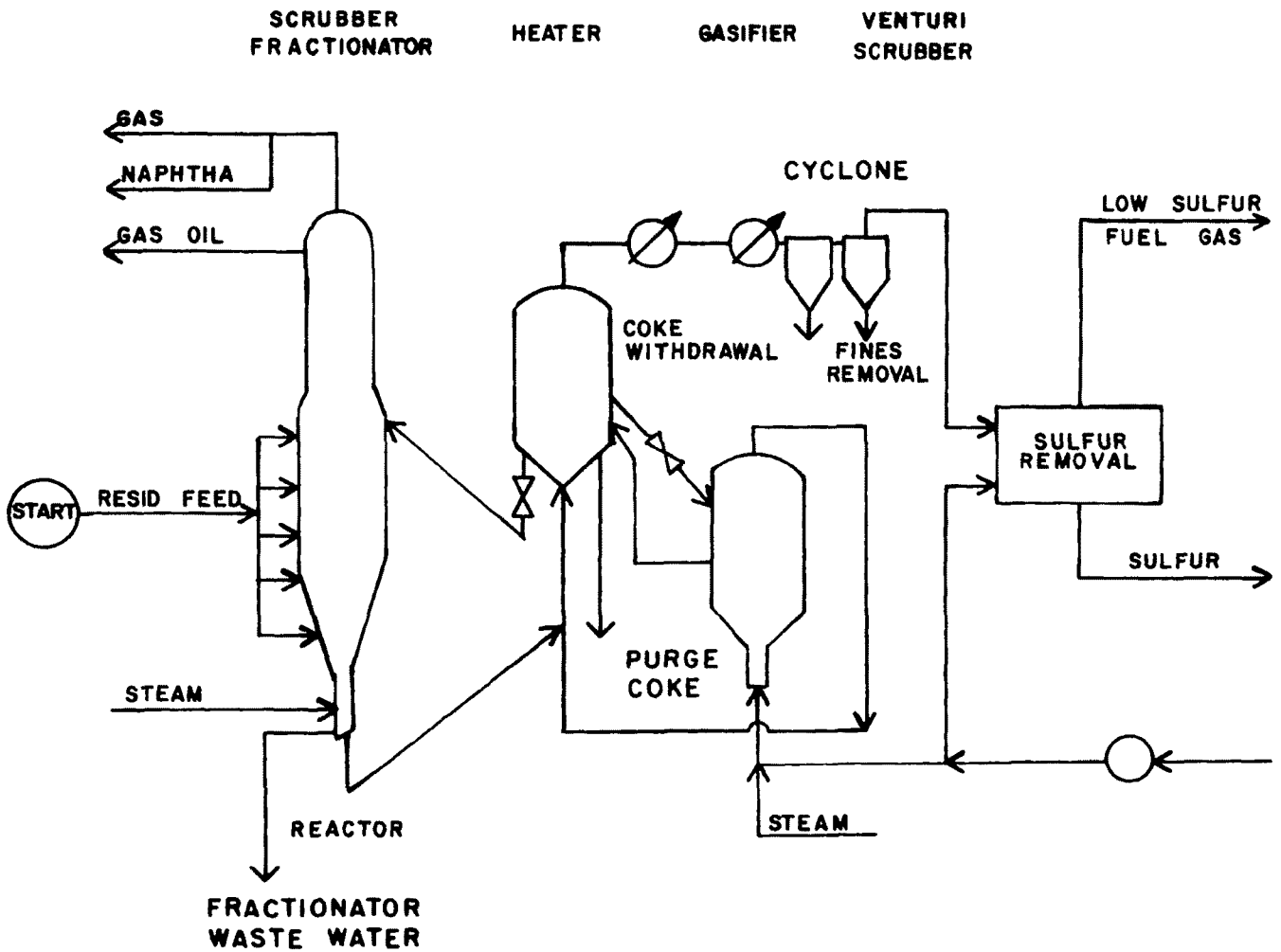

Figure 21. Flexicoking Unit.[8]

TABLE 40. PROPERTIES OF COKE PRODUCTS FROM WEST TEXAS SOUR ASPHALT OPERATION*[6]

Coke product	Bed purge	Tertiary fines	Venturi fines
Percent of reactor product coke	1	2	2
Weight average particle size, microns	105	25	5
Sulfur, weight percent	2.08	2.60	3.15
Vanadium, wppm	4,990	5,400	10,800
Nickel, wppm	380	295	590
Ash, weight percent	2.0	2.6	5.2

*95 percent gasification operation without fines recycle.

TABLE 41. PROTOTYPE FLEXICOKER DISPOSITION OF VANADIUM AMONG PRODUCTS*

	Vanadium concentration (wppm)	Vanadium rate (lbs/day)	Percent of feed vanadium
Fresh feed	160	37	100
Reactor liquid product	-	0.5	1.3
Bed coke purge	5,800	6.1	16.5
Tertiary cyclone fines	9,000	14.0	37.8
Venturi scrubber fines	11,000	18.7	50.5
Total output		39.3	106.1†

*Vanadium balance obtained during the West Texas resid/asphalt operation.

†Percent of feed vanadium as total output indicative of vanadium balance closure.

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APPENDIX A

PROCESS DESCRIPTIONS AND ECONOMICS OF RESIDUAL OIL DESULFURIZATION TECHNIQUES

Several refinery processes exist for the desulfurization of fuel feedstock. A number of these systems have been discussed in an earlier report, and include the following:[1]

- Flexicoking
- Gulf HDS
- RCD Isomax
- Residue Desulfurization (BP)
- Resid Hydroprocessing (Standard Oil)
- LC Fining
- Resid Ultrafining
- Go Fining
- Residfining
- Residue Hydrodesulfurization
- Hydrodesulfurization, Trickle Flow
- IFP Resid and VGO Hydrodesulfurization
- Demetallization/Desulfurization
- Delayed Coking
- VGO/VRDS Isomax
- Shell Gasification

The purpose of this discussion is to update the technical and economic information which was presented for these processes and to report upon new processes which have been identified since the initial study. These additional processes include:

- Autofining
- Gulfining
- Shell Residual Oil Hydrodesulfurization
- Exxon Hydrofining
- BP Hydrofining
- Ultrafining
- Unicracking/HDS
- Unionfining

Literature review and correspondence with developers have indicated that technical modifications instituted since the initial report[1] have little economic impact. The major point of technical advance seems to be catalyst improvement, which enhances demetallization and desulfurization, extends catalyst life, and reduces catalyst replacement cost.

THE GENERAL HYDRODESULFURIZATION PROCESS

The hydrodesulfurization process is used to remove sulfur, nitrogen and metals from petroleum feedstocks. In most cases, the feedstock is mixed with hydrogen-rich gas, preheated, and sent to a fixed bed reactor where the mixture comes into contact with a cobalt or nickel-molybdenum catalyst. Fuel sulfur is converted to H_2S, nitrogen to NH_3, and metals are picked up by the catalyst. The reactor products are cooled and travel to a separator where H_2S and hydrogen are removed. Hydrogen is recycled to the head of the process and H_2S is treated further for sulfur recovery. The liquid product is steam-stripped to remove residual contaminants and may be fractionated depending upon the desired end products. A typical schematic process flow diagram appears in Figure A-1.

In some cases, an ebullating bed or continuous catalyst feed and withdrawal system is used. The design and operation of each system is dependent upon the feedstock and desired end products.

ECONOMIC FORECAST

In order to develop a basis of cost comparison among the various hydrodesulfurization processes, all economic data has been forecasted to the year 1980. Published capital and operating costs were updated by use of the Nelson Refinery Inflation Index and the Nelson Refinery Operating Index. In addition, 1980 unit operating costs were estimated by reference to literature concerning refinery processes.[2-4] The 1980 Nelson Refinery Index values and the unit operating costs used for the analysis are as follows:

- Nelson Refinery Inflation Index 760
- Nelson Refinery Operating Index 295

1980 Unit Operating Costs:

- Electricity $0.03/kWh
- Supplemental fuel $3.25/MMBtu
- Cooling water $0.05/Mgal
- High pressure steam $4.50/Mlbs
- Medium pressure steam $3.25/Mlbs
- Low pressure steam $2.00/Mlbs
- Process (boiler feed) water $1.50/Mgal
- Hydrogen $1.00/Mscf

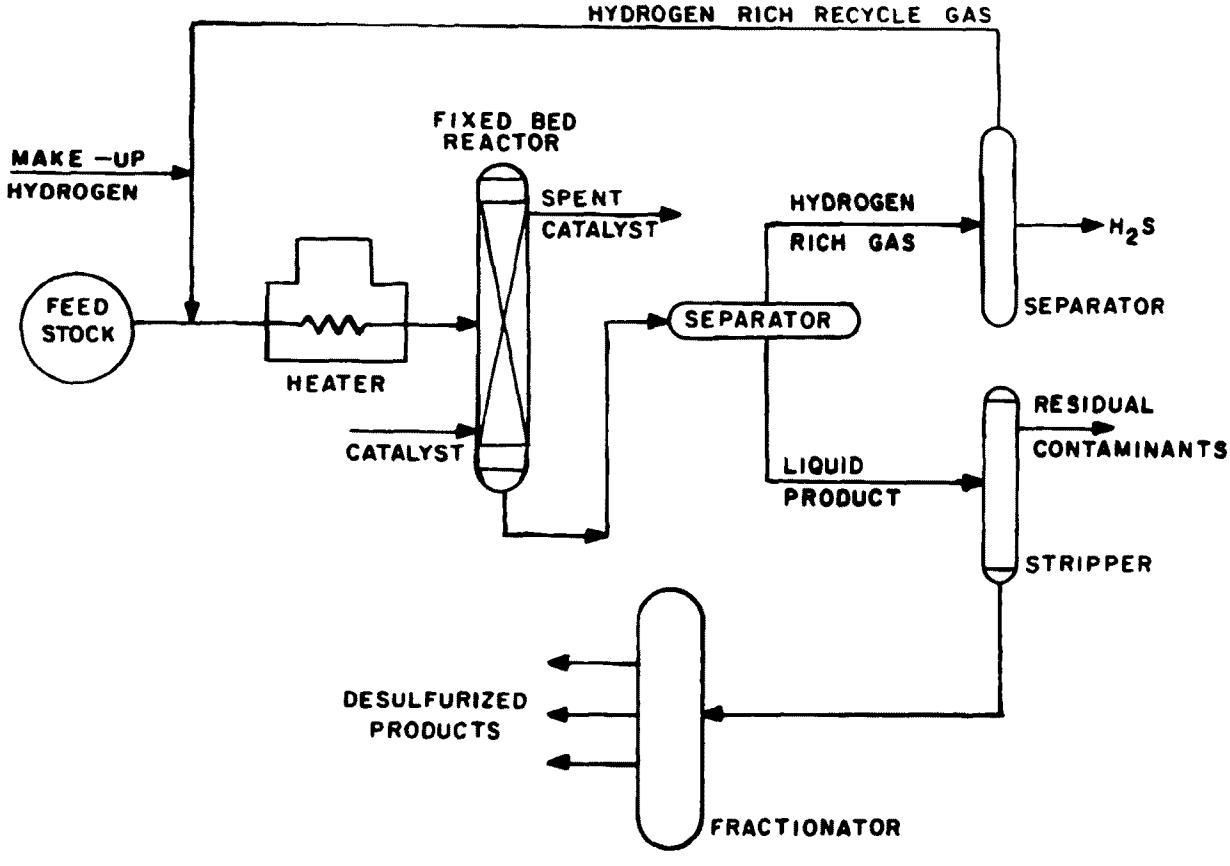

Figure A-1. Generalized schematic hydrodesulfurization flow diagram.

These unit operating costs are identified here for use below, because, in most cases, actual utility requirements are published by licensors, rather than total operating costs for a given year. A discussion of the engineering and economic aspects of the newly identified residual oil desulfurization systems follows.

AUTOFINING[5]

This process is licensed by British Petroleum Trading Limited and is used to desulfurize distillate stocks, such as feed to SNG plants, without an external source of hydrogen.

Process Description

The process flow diagram is shown in Figure A-2. The system operates in the temperature range of 730 to 760°F and at a pressure of approximately 300 psig. The catalyst is regenerated through contact with air/steam or inert gas/air mixtures. The advantages of the system are:

- No external source of hydrogen required
- High desulfurization capacity
- Easily regenerable catalyst.

Stage of Development

Four units have been installed as follows:

Location	Capacity (bpsd)*
Wales	3,500
Aden	3,500
Scotland	500
France	2,300

Thirteen other BP hydrotreaters have been operated as Autofiners in the absence of process hydrogen.

Economic Forecast

The economic data given in Table A-1 are based on estimates for March 1976. The estimated 1980 investment cost was projected through the use of a Nelson Refinery Inflation Index of 760. Electricity and fuel costs were calculated based on estimated 1980 unit costs of $0.03/kWh and $3.25/MMBtu, respectively. The catalyst replacement cost was projected by use of a 1980 Nelson Refinery Operating Index of 295.

*Barrels per stream day.

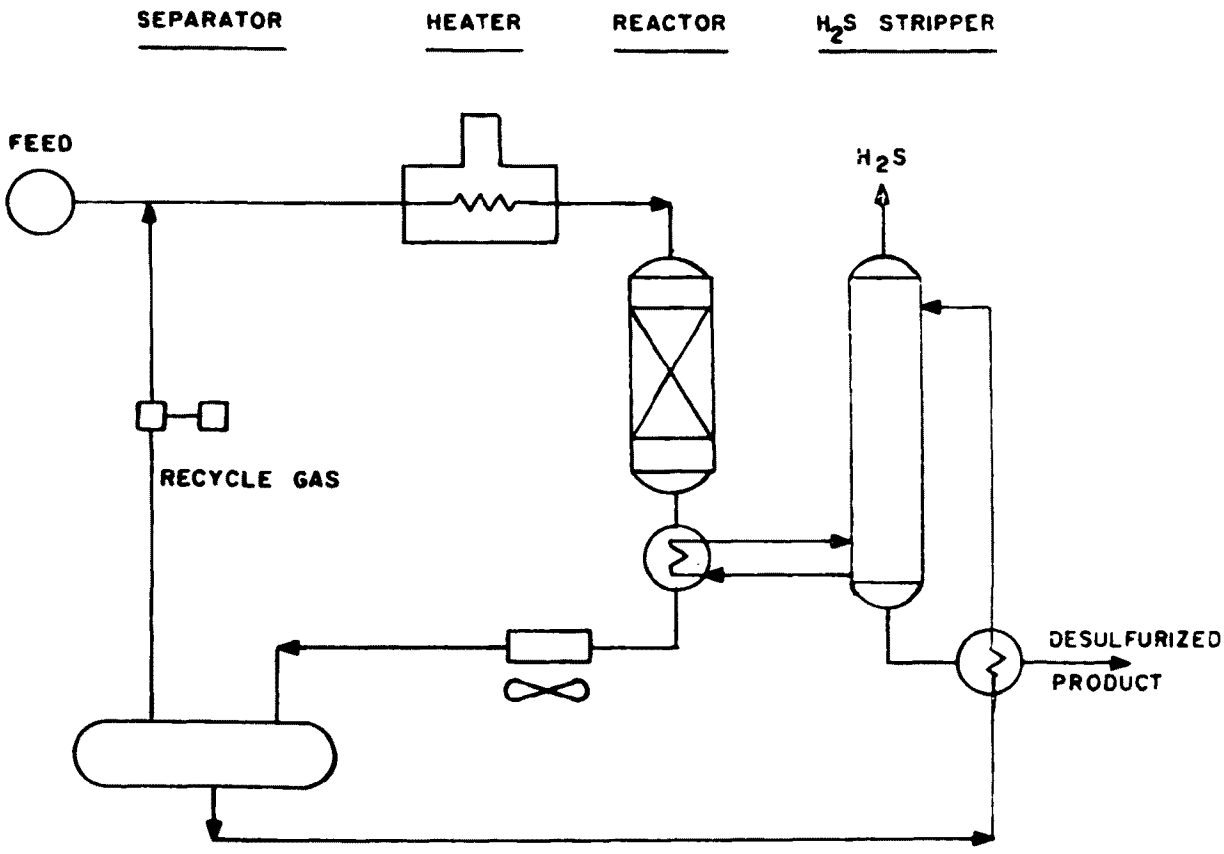

Figure A-2. Autofining process.

TABLE A-1. ESTIMATED COST OF AUTOFINING, 1980

		Cost, $ per bpsd
Investment:		
Basis: 45,000 bpsd unit, estimated erected cost, excluding initial catalyst charge.		95
Operating Requirements, per bbl of feed		Cost, ¢ per bbl feed
Electricity	1.2 kWh	3.6
Fuel	45.5 MBtu	14.8
Catalyst replacement		0.3
Steam		2.0
Cooling water		1.0
Annualized capital		4.3
Maintenance		0.9
Property tax and insurance		0.6
Operating labor and supervision		4.5
Administration, misc. supply, and overhead		0.9
Total operating cost, ¢/bbl		32.9

GULFINING[6]

This system is used for hydrodesulfurization of heavy distillate gas oils including vacuum distillate.

Process Description

The feedstock gas oil is mixed with fresh and recirculating hydrogen and heated prior to entering the Gulfining reactor, where sulfur compounds are converted to hydrogen sulfide. Cooled reactor effluent is sent to a flash drum where liquid oil is withdrawn from the bottom. High pressure flash drum liquid passes to the low pressure flash drum where hydrogen sulfide and additional fuel gas is flashed off. Liquid from the low pressure separator passes to the stripper tower where the desulfurized gas oil is stabilized. Figure A-3 shows the process diagram of the system.

Typical yields for Gulfining Middle East vacuum gas oil at 90 percent desulfurization are presented in Table A-2.

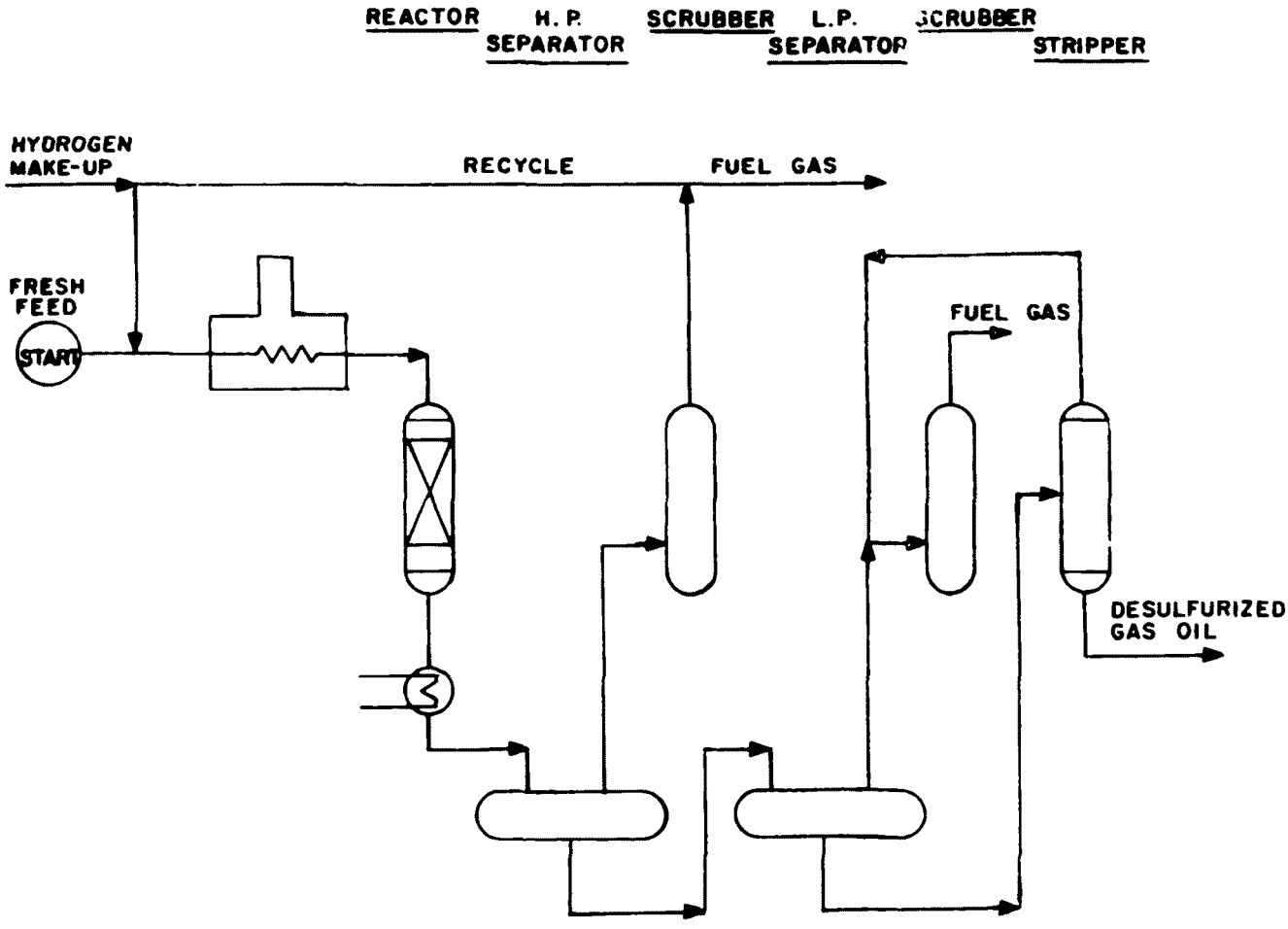

Figure A-3. Gulfining process.

TABLE A-2. YIELDS FROM GULFINING PROCESS

Characteristic	Feedstock	Product
Gravity, °API	24.0	29.0
ASTM Distillation, °F		
1 BP	410	
10%	622	
50%	870	
90%	1,020	
EP	1,090	
Sulfur, wt. %	2.20	0.2
Carbon residue, wt. %	0.7	0.2
Nickel and vanadium, ppm	2	—
Viscosity, cs at 122°F	20	16

TABLE A-3. ESTIMATED COST OF GULFINING, 1980

Investment			Cost, $ per bpsd
Basis: 35,000 bpsd			416
Utilities	Requirement	Unit Cost	Cost, ¢ per bbl feed
Electricity	1.7 kWh/bbl	$0.03/kWh	5.1
Fuel	55 MBtu/bbl	$3.25/MMBtu	17.9
Steam	6 lbs/bbl	$3.25/Mlbs	2.0
Cooling Water	160 gal/bbl	$0.05/1000 gal	0.8
Hydrogen	350 scf/bbl	$1.00/1000 scf	35.0
Catalyst replacement			0.3
Annualized capital			19.0
Maintenance			3.8
Property tax and insurance			2.6
Operating labor and supervision			3.5
Administration, misc. supply, and overhead			3.8
Total operating cost, ¢/bbl			93.8

Economic Forecast

The economics of the Gulfining Process are illustrated in Table A-3 and are based on the operating parameters shown in Table A-2.

HYDRODESULFURIZATION, RESIDUAL OIL (SHELL DEVELOPMENT CO.)[7]

The process is used to improve the quality of residual oils by removing sulfur, metals, and asphaltenes. Use of various catalysts makes the system capable of treating a wide range of feedstocks, including those which are high in metals and/or asphaltenes.

Process Description

Feedstock is combined with hydrogen rich makeup and recycle gas and heated in heat exchangers and a furnace and then passes through the reactor in trickle flow. Reactor products are cooled and separated into a desulfurized product, a sour gas, and a hydrogen rich gas which is recirculated after H_2S removal. A bunker reactor can be used for catalyst addition and withdrawal and is especially suited to treating high metals feedstocks. A process flow diagram appears in Figure A-4.

Stage of Development

As of 1976, two units were in operation, one demonstration plant of 3,000 bpsd capacity and one commercial facility of 47,000 bpsd capacity.

Economic Forecast

The economics of the process are based on the operating parameters shown in Table A-4.

TABLE A-4. TYPICAL OPERATING PARAMETERS SHELL RESIDUAL OIL HYDRODESULFURIZATION

Properties	Feed (660^oF^+)	Product (330^oF^+)
Specific gravity, d $^{15/40^oF}$	0.967	0.917
Viscosity, cs at 122^oF	580	61
Sulfur, wt. %	4.18	0.50
Vanadium, ppm wt.	50	12
C_7 asphaltenes, % wt.	2.5	1.2

Chemical H_2 consumption: 1.2% wt. on feed

Breakdown of products, % wt. on feed:

H_2S	3.9
C_1-C_4	0.9
C_5-165^oC	1.0
165^oC^+	95.4

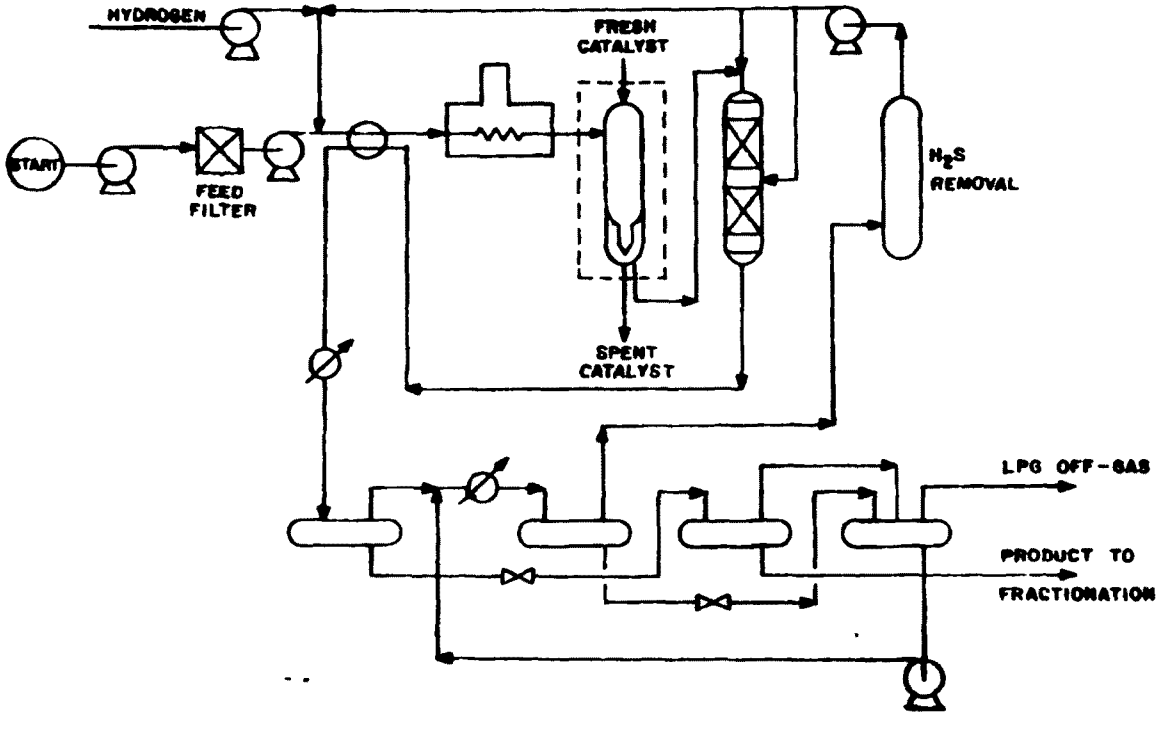

Figure A-4. Shell residual oil hydrodesulfurization.

The estimated cost of utility requirements for this Shell hydrodesulfurization process are given in Table A-5. The catalyst cost has been forecasted through use of a Nelson Refinery Operating Index of 295 for the year 1980.

TABLE A-5. ESTIMATED OPERATING COST OF THE SHELL RESIDUAL OIL HYDRODESULFURIZATION PROCESS, 1980

Utilities	Requirement, per bbl feed	Unit cost	Cost, ¢ per bbl feed
Hydrogen	1020 scf	$1.00/Mscf	102
Electricity	6 kWh	$0.03/kWh	18
Fuel	65.5 MBtu	$3.25/MMBtu	21.3
Steam, med. pres.	15 lbs	$3.25/Mlbs	4.9
Cooling water	225 gal	$0.05/1000 gal	1.1
Catalyst			21.0

HYDROFINING (EXXON)[8]

This system improves the quality of a wide variety of petroleum feedstocks by catalytic treatment with hydrogen. The process can be used to remove sulfur and nitrogen as well as improve the odor, color, stability, and burning characteristics of feeds ranging from light ends to heavy distillate gas oil and lube stocks.

Process Description

The petroleum feedstock is heated to a temperature between 400 and 700°F, and then passed to a fixed bed reactor along with hydrogen rich gas. The feedstock is treated at pressures between 200 to 500 psig in the presence of a regenerable metal oxide catalyst. The reactor effluent is cooled and the hydrogen rich gas is separated for use in other operations. After separation, the product is stripped for removal of residual hydrogen sulfide. The process flow diagram is shown in Figure A-5.

Stage of Development

Approximately 225 units are in operation or are being designed with a total capacity of 4,000,000 bpsd.

Economic Forecast

The economics of the Exxon Hydrofining Process are given in Table A-6.

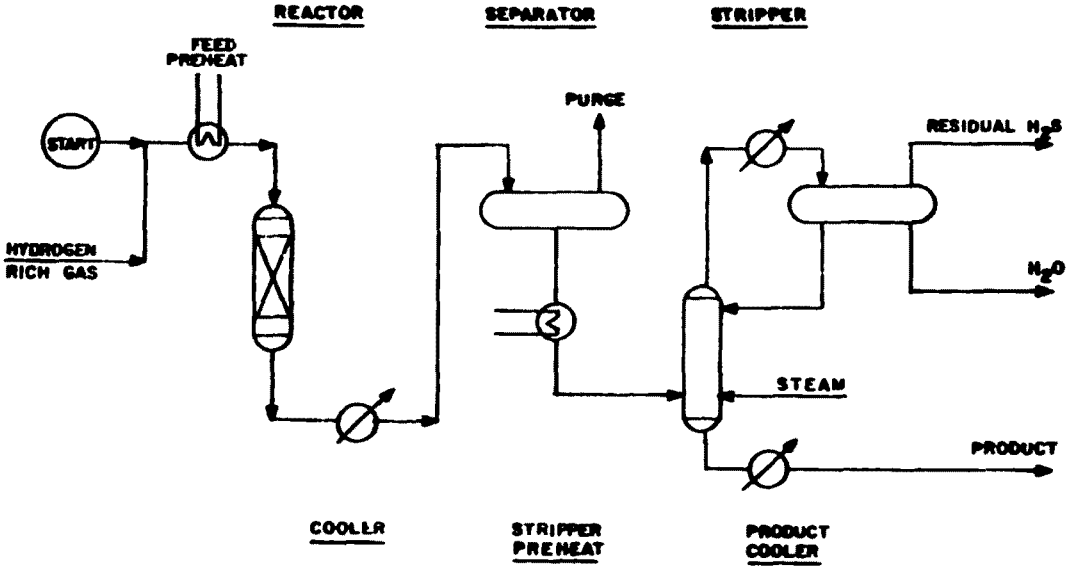

Figure A-5. Exxon Hydrofining Process.

TABLE A-6. ESTIMATED COST OF EXXON HYDROFINING, 1980

Investment*			Cost, $ per bpsd
Basis: Direct material and labor			102 - 384
Utilities	Requirements	Unit Cost	Cost, ¢ per bbl feed
Electricity	0.3 to 1.0 kWh/bbl	$0.03/kWh	0.9 to 3
Steam, low pressure	5 to 12 lb/bbl	$2.00/Mlbs	1 to 2.4
Fuel	0 to 30 MBtu/bbl	$3.25/MMBtu	0 to 9.8
Cooling water	0 to 70 gal/bbl	$0.05/Mgal	0 to 0.4
Catalyst replacement			0.3
Hydrogen			60.0
Annualized capital			4.6 to 17.6
Maintenance			0.9 to 3.5
Property tax and insurance			0.6 to 2.4
Operating labor and supervision			3.0 to 4.0
Administration, misc. supply, and overhead			0.9 to 3.5
Total operating cost, ¢/bbl			78.4 to 105.9

*Wide range of investment cost due to variety of applications; large virgin feed units tend to be in the lower cost range while small cracked stock feed units are covered by the higher cost range.

HYDROFINING (BP)[9]

The system is used to remove sulfur from a wide range of distillate feedstocks by catalytic hydrogenation. Feedstock can range from light gasolines to vacuum gas oils up to 1020°F end point, including catalytic cracker cycle oil or coke gas oil components.

Process Description

Feedstock is mixed with hydrogen rich gas, heated, and passed through a fixed bed desulfurization catalyst reactor. The hot reactor effluent is cooled and separated into liquid and gaseous streams at high pressure. The separated gas stream is recycled to minimize makeup hydrogen requirements. The liquid product stream passes to a low pressure separator for dissolved gas removal prior to entering a stripper column where hydrogen sulfide and light ends are removed. The advantages of the process include:

- Easily regenerable catalyst
- Low operating cost
- High yield

A schematic process diagram is shown in Figure A-6.

Stage of Development

A total of 49 units are in operation or under construction, with a cumulative capacity of 720,000 bpsd.

Economic Forecast

Economic figures for 1980, considering four different feedstocks, are given in Table A-7. The catalyst cost was updated by using a Nelson Refinery Operating Index of 295.

ULTRAFINING[10]

The system is used to desulfurize, denitrogenate, and hydrogenate various oils. Typical charges are virgin and cracked stocks including naphthas, kerosene and diesel fractions, and heavy gas oils including vacuum gas oils, decanted oils and lubricating oils.

Process Description

The process utilizes cobalt-molybdenum or nickel-molybdenum on alumina catalysts for hydrogenation. The catalyst can be regenerated with a cycle life of approximately 1 year. Desulfurization occurs in a single reactor section, followed by fractionation into the desired product streams. A process flow diagram appears in Figure A-7.

Stage of Development

A total of approximately 550,000 bpsd of capacity is operating or under construction by Standard Oil, and its affiliates and licensees.

Economic Forecast

Economic data for the Ultrafining Process is given in Table A-8.

UNICRACKING/HDS[11,12]

The process is used to treat atmospheric and vacuum resids. It is a fixed bed catalytic system which removes sulfur, nitrogen, and metals.

Process Description[11]

Feedstock and hydrogen rich gas are mixed and heated and sent to a guard chamber for removal of particulate matter and residual salt content. The mixture then enters the main reactors for contact with the catalyst. Reactor

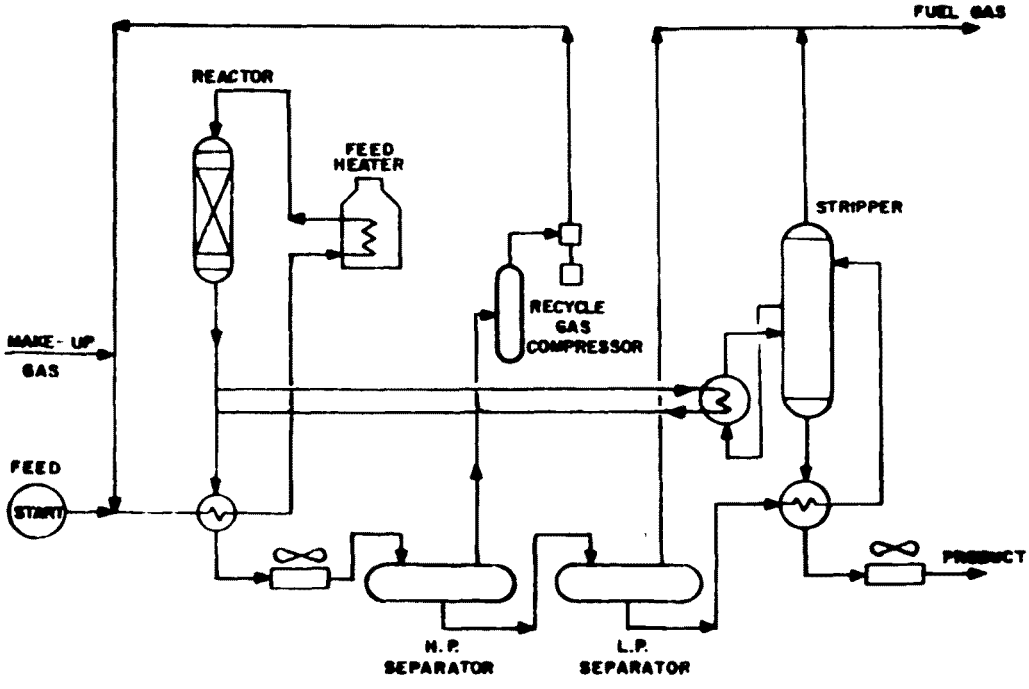

Figure A-6. BP Hydrofining Process.

TABLE A-7. ESTIMATED COST OF BP HYDROFINING, 1980

	Type of feedstock			
	Naphtha	Kerosene	Gas oil	Vacuum gas oil
Investment, erected cost excluding initial catalyst $ per bpsd	27	146	171	191
Utilities				
Cost, ¢ per bbl				
Electricity	1.6	1.8	2.8	4.2
Steam (25 psig)	-	-	-	1.6
Cooling water	-	-	0.2	0.1
Fuel	9.1	9.8	15.0	24.0
Catalyst replacement	0.15	0.15	0.2	1.0
Hydrogen	60.0	60.0	60.0	60.0
Annualized capital	5.8	6.7	7.8	8.7
Maintenance	1.2	1.3	1.6	1.7
Property tax and insurance	0.8	0.9	1.1	1.1
Operating labor and supervision	3.0	3.0	3.0	3.0
Administration, misc. supply and overhead	1.2	1.3	1.6	1.7
Total operating cost, ¢/bbl	82.9	85.0	93.3	107.1

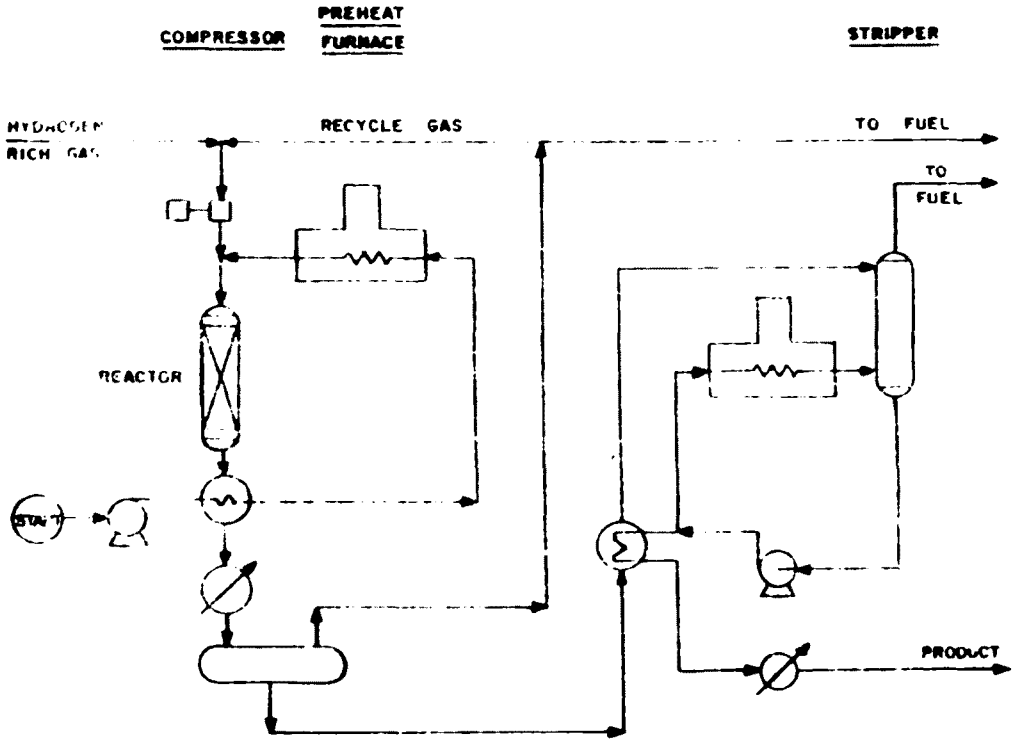

Figure A-7. Ultrafining process.

TABLE A-8. ESTIMATED COST OF ULTRAFINING, 1980

			Cost, $ per bpsd
Investment			
Basis: 10,000 to 30,000 bpsd distillate ultrafiner			192 - 294
Utilities	Requirements	Unit cost	Cost, ¢ bbl feed
Electricity	1.3 kWh/bbl	$0.03/kWh	3.9
Fuel	70 MBtu/bbl	$3.25/MMBtu	22.8
Cooling water	215 gal/bbl	$0.05/Mgal	1.1
Catalyst	0.004 lbs/bbl		0.3
Hydrogen	125 scf/bbl	$1.00/Mscf	12.5
Steam			2.0
Annualized capital			8.8 to 13.4
Maintenance			1.8 to 2.7
Property tax and insurance			1.2 to 1.8
Operating labor and supervision			1.0 to 3.0
Administration, misc. supply and overhead			1.8 to 2.7
Total operating cost ¢/bbl			57.2 to 66.2

product is cooled, separated from recycle gas, and stripped to provide the proper flash point. The recycle gas is treated for H_2S removal and combined with the makeup gas. The schematic process flow diagram is shown in Figure A-8.

Stage of Development

This process is Union Oil's successor to the Residfining system. One 60,000 bpsd Unicracking HDS facility is in operation.

Economics

Table A-9 lists the investment and operating costs forecasted to 1980. These figures are updated from a recent article which appeared in Hydrogen Processing.[12] The per barrel utility costs were increased from the original publication to reflect the fact that the authors used a cost of $2.00/MMBtu for fuel as opposed to our projected unit cost of $3.25/MMBtu in 1980.

TABLE A-9. ESTIMATED COST OF UNICRACKING/HDS, 1980[12]

Cost Basis: 40,000 bpsd North Slope crude charge	
Capital Investment, onsite including initial catalyst	$61.8 × 10^6
$ per bpsd	1545
Direct Operating Costs, ¢/bbl feed	
Operating labor and supervision	4.0
Maintenance	16.0
Utilities and catalyst	83.0*
Property tax and insurance	8.0
Annualized capital	71.0
Administration, misc. supply, and overhead	16.0
Total operating cost, ¢/bbl	198.0

*Increased from $0.74 to reflect estimated 1980 fuel cost of $3.25/MMBtu.

UNIONFINING[13]

This process is used to accomplish hydrodesulfurization, hydrodenitrogenation, and hydrogenation of a wide variety of petroleum stocks. It is used for upgrading naphthas, kerosene, turbine fuel, and diesel fuel and for desulfurization of vacuum gas oils.

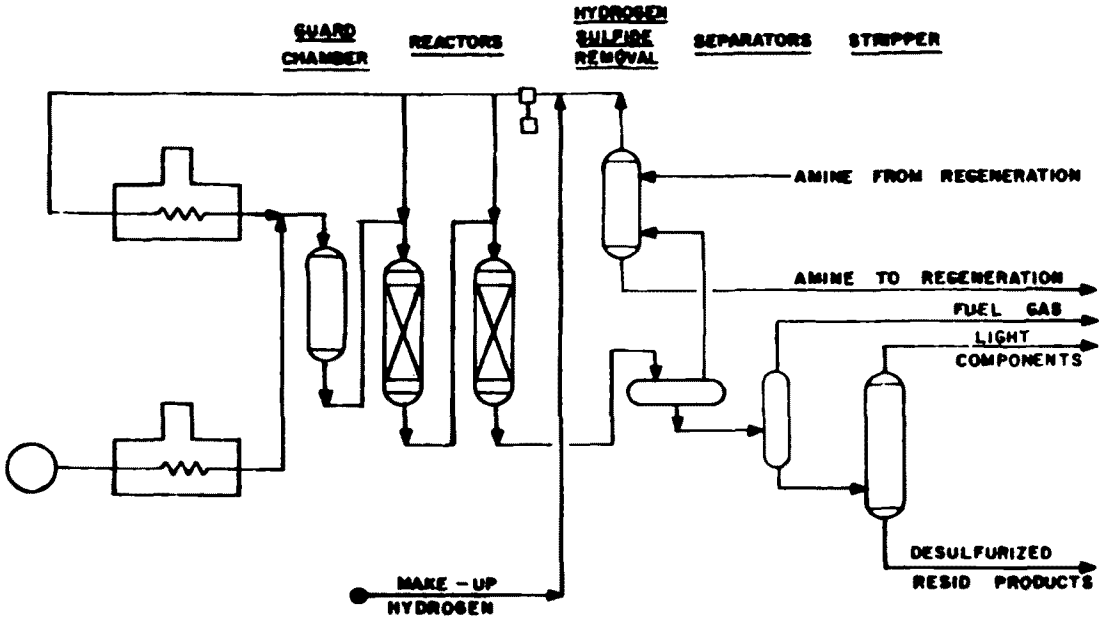

Figure A-8. Unicracking/HDS process.

Process Description

Feedstock and hydrogen rich gas are mixed, heated, and sent to a fixed bed reactor where the mixture is contacted with a high activity catalyst. The catalyst is regenerable with mixtures of air and steam or inert gas. Effluent from the reactor is cooled and passes to a separator where hydrogen rich gas is withdrawn for recycling. Liquid product passes to a stripper for removal of light components and residual hydrogen sulfide, or to a fractionator for splitting into multiple products. A schematic diagram of the process appears in Figure A-9.

Stage of Development

The process is based on 35 years of hydrotreating experience including more than 75 units in Union Oil and licensee refineries.

Economic Forecast

The economics of the Unionfining process are given in Table A-10. Catalyst cost is based upon a 1980 Nelson Refinery Operating Index of 295.

TABLE A-10. ESTIMATED COST OF UNIONFINING, 1980

Investment			Cost, $ per bpsd
			224 to 544
Utilities	Requirement	Unit Cost	Cost, ¢ per bbl feed
Electricity	0.5 to 1.5 kWh/bbl	$0.03/kWh	1.5 to 4.5
Fuel	40 to 100 MBtu/bbl	$3.25/MMBtu	13 to 32.5
Catalyst			0.3 to 3.0
Cooling water			1.0
Low pressure steam			2.0
Hydrogen			60.0
Annualized capital			10.2 to 24.8
Maintenance			2.0 to 5.0
Property tax and insurance			1.3 to 3.4
Operating labor, and supervision			2.0 to 4.0
Administration, misc. supply and overhead			2.0 to 5.0
Total operating cost, ¢/bbl			95.3 to 145.2

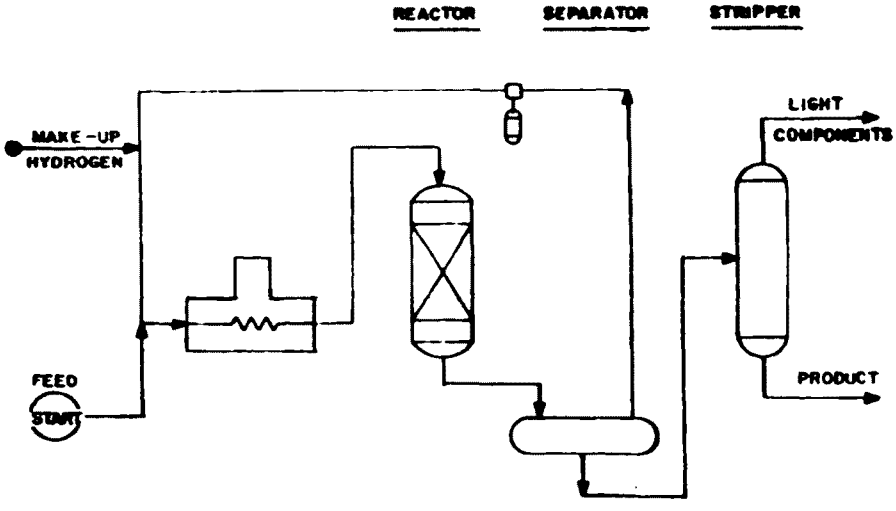

Figure A-9. Unionfining process.

SUMMARY

Table A-11 summarizes 1980 capital and operating costs for the HDS processes previously outlined and for systems discussed in the aforementioned environmental assessment.[1] The capital costs presented in Table A-11 have been updated based on information provided in various publications. The basis of individual capital estimates is variable and, in some instances, undefined. In most cases, the published values are battery limit figures. The total annualized costs presented for Flexicoking and LC Fining include allowances for the following additional capital costs; construction management and overhead, engineering and procurement, contingency, fee, new burner cost allowance, startup, and interest during construction. This allows for economic comparison of these two HDS systems with FGD and CAFB systems, as discussed in Appendix B. Therefore, the Flexicoking and LC Fining costs are not on a comparable basis with other HDS systems presented in Table A-11. Finally, some of the operating costs have been estimated by GCA as shown in the footnotes to the table.

TABLE A-11. SUMMARY OF ESTIMATED 1980 CAPITAL AND OPERATING COSTS ASSOCIATED WITH ALTERNATIVE HYDRODESULFURIZATION PROCESSES

Process	Licensor	Capacity (bpsd)	Feedstock	Capital[a] cost ($/bpsd)	Operating costs - all values in c/bbl of feedstock					
						Material costs				
					Estimated[b] total utility costs	Supplemental fuel[c]	Steam		Cooling[f] water	Process[g] water
							Medium[d]	Low[e]		
Autofining	BP	45,000	distillate	95		14.8		2.0[r]	1.0[r]	
Gulfining	Gulf	35,000	heavy dist. gas oils	416		17.9	2.0		0.8	
Hydrofining	Exxon	large	virgin feed	100		5.0[r]		1.0	0.2[r]	
		small	cracked stock	385		9.8		2.4	0.4	
Hydrofining	BP	30,000	naphtha	127		9.1		-		
		30,000	kerosene	146		9.8		-	-	
		30,000	gas oil	171		15.0		-	0.2	
		30,000	vacuum gas oil	191		24.0		1.6	0.1	
Ultrafining	Standard Oil	10,000	distillate	192		22.8		2.0[r]	1.1	
		30,000	distillate	294		22.8		2.0[r]	1.1	
Unicracking/HDS	Union Oil	40,000	North slope crude	1,545	83.0					
Unisulfining	Union Oil			224		13.0		2.0[r]	1.0[r]	
				554		32.5		2.0[r]	1.0[r]	
Flexicoking	Exxon	10,700	vacuum resid 0.3% S prod.	2,500		20.0	75.0	14.9	0.3	6.8
Residue Desulfurization	BP	50,000	Kuwait atm. res. 1.0% S prod.	545		21.5	18.5		0.7	0.1
			0.5% S prod.	570		20.2	20.5		0.8	0.1
Resid Ultrafining	Amoco	40,000	West Texas sour	535	32.3					
LC Fining	CE Lummus Cities Service	10,700	Gach Saran atm. resid. 0.5% S prod.	2,215	32.3					
Resid. Oil Hydrodesulfurization	Shell					21.3	4.9		1.1	
HCD Unibon	UOP	50,000 0.3% prod.	Kuwait crude	1,025	26.1					
Gulf HDS-III	Gulf	50,000	53% Kuwait	1,100		27.0		23.0	0.9	0.2
Gulf HDS-IV	Gulf	50,000	53% Kuwait	1,380		27.0		26.4	1.1	0.2
IFP Fuel Hydrodesulfurization	IFP	45,000	residual feedstocks	1,120		81.9		10.1	2.4	1.1
Shell Gasification	Shell	59,000	vacuum residue	9,600						
Demetallization/ Desulfurization	Cities Service	25,000	Venezuela medium metals atm. resid.	1,332		20.0		2.0[r]	1.0[r]	
		25,000	Venezuelan high metals crude, Boscan	1,264		20.0[r]		2.0[r]	1.0[r]	
Residfining	Exxon	40,000[k]	heavy resids	1,690		32.5		2.0[r]	1.5	
Gas-fining	Exxon	40,000[k]	virgin and cracked gas oils	420		16.3		2.0[r]	0.3	
Resid Hydroprocessing	Standard Oil	40,000	Kuwait atm. resid.	1,050		28.0		0.5	0.8	0.6

Footnotes to Table:

[a]Capital costs are projected from figures presented by current journal articles or direct correspondence. A Nelson Refinery Capital Cost Index (NRC) of 760 was used to represent the year 1980. Past NRC's are published in the Oil and Gas Journal.

[b]Total utility costs which were not available in itemized form from published information; updated by OCA.

[c]Operating cost for supplemental fuel use based on $3.25/MMBtu.

[d]Operating cost for medium pressure steam based on $3.25/M lbs.

[e]Operating cost for low pressure steam based on $2.00/M lbs.

[f]Operating cost for cooling water use based on $0.05/M gal.

[g]Operating cost for process water use based on $1.50/1000 gal.

[h]Operating cost for electricity fuel use based on 3c/kWh.

[i]Catalyst replacement costs were updated from published data based on a projected Nelson Refinery Operating Cost index of 295 in 1980.

[j]Operating cost for hydrogen requirements is based on $1.00/M scf.

[k]Based on 15 percent of total capital investment per year.

[m]Based on 3 percent of total capital investment per year.

[n]Based on 2 percent of total capital investment per year.

[p]Based on 1.0c/10,000 bpsd capacity.

[q]Based on 3 percent of total capital investment per year.

[r]Unit operating costs estimated by OCA.

TABLE A-11 (continued)

Operating costs - all values in c/bbl of feedstock								
Material costs			Annualized costs					Total operating cost (c/bbl)
Electricity[h]	Catalyst replacement[j]	Hydrogen[k]	Capital investment[l]	Maintenance[m]	Property tax and insurance[n]	Operating labor and supervision[p]	Administration misc. supply overhead[q]	
3.6	0.3	-	4.3	0.9	0.6	4.5	0.9	32.9
5.1	0.3[r]	35.0	19.0	3.8	2.6	3.5	3.8	93.8
0.9	0.3[r]	60.0[r]	4.6	0.9	0.6	4.0[r]	0.9	78.4
3.0	0.3[r]	60.0[r]	17.6	3.5	2.4	3.0[r]	3.5	105.9
1.6	0.15	60.0[r]	5.8	1.2	0.8	3.0	1.2	82.9
1.8	0.15	60.0[r]	6.7	1.3	0.9	3.0	1.3	85.0
2.8	0.2	60.0[r]	7.8	1.6	1.1	3.0	1.6	93.3
4.2	1.0	60.0[r]	8.7	1.7	1.1	3.0	1.7	107.1
3.9	0.3	12.5	8.8	1.8	1.2	1.0	1.8	57.2
3.9	0.3	12.5	13.4	2.7	1.8	3.0	2.7	66.2
			71.0	16.0	8.0	4.0	16.0	198.0
1.5	0.3	60.0[r]	10.2	2.0	1.3	2.0[r]	2.0	95.3
4.5	3.0	60.0[r]	24.8	5.0	3.4	4.0[r]	5.0	145.2
45.0	0.3		114.0	23.0	15.0	7.0[r]	23.0	345.0
10.2	16.0	60.0[r]	24.9	5.0	3.4	5.0	5.0	170.3
15.6	27.0	60.0[r]	26.0	5.2	3.5	5.0	5.2	189.1
	12.0	60.2	24.4	4.9	3.3	4.0	4.9	146.0
	49.3	140.0	101.0	20.2	13.5	7.0[r]	20.2	384.0
18.0	21.0	102.0						
	21.6	85.0	46.8	9.4	6.3	5.0	9.4	209.6
23.0	26.9	66.3	50.2	10.0	6.7	5.0	10.0	249.2
29.3	54.8	81.0	63.0	12.6	8.4	5.0	12.6	321.4
10.7	11.0		51.1	10.2	6.8	4.5	10.2	200.0
			415.00	83.0	55.6	5.9	83.0	> 500.0[r]
10.0[r]	20.0	68.0	60.8	12.2	8.2	2.5	12.2	216.9
10.0[r]	17.0	103.0	57.7	11.5	7.7	2.5	11.5	243.9
8.0	45.0	60.0[r]	77.2	15.4	10.3	4.0	15.4	271.3
6.0	4.5	60.0[r]	19.2	3.8	2.6	4.0	3.8	122.5
13.2	20.0	56.0	48.0	9.6	6.4	4.0	9.6	196.7

(continued)

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APPENDIX B

ECONOMIC COMPARISON OF RESIDUAL OIL UTILIZATION: CAFB, FGD, HDS

INTRODUCTION

The CAFB is unique as a retrofit application to a natural gas-fired utility. The process can desulfurize and gasify a wide variety of fuels, including high sulfur, high metals, crude oils and high sulfur coals, and produce a low Btu gas suitable for combustion in a conventional gas-fired boiler.

One objective of this study is to update the economic comparison of residual oil desulfurization processes presented in our earlier report.[1] The processes include the emerging technology of chemically active fluid bed (CAFB) gasification, and the existing technologies of flue gas desulfurization (FGD), and hydrodesulfurization (HDS). By comparing CAFB with existing systems, some idea of potential marketability can be determined as compared to conventional systems. Although the conventional systems are capable of providing equivalent desulfurization, they are somewhat limited in matching other inherent capabilities of CAFB, such as demetalization, and reduction of NO_x emissions. Figure B-1 illustrates how the three systems would interface with a conventional utility for combustion of a residual oil feed.

Emissions of NO_x are lower from CAFB, partially due to lower flame temperatures and potentially due to some catalytic fixation of nitrogen in the fuel. The use of HDS and FGD will provide minimal reduction of NO_x emissions because they are associated with conventional combustion temperatures, but will provide SO_2 reduction comparable to CAFB. Some HDS systems are capable of demetalizing, but FGD is inferior to both HDS and CAFB in this respect.

A workable total cost comparison of these three systems is difficult to generate due to wide variation in published budget cost estimates. For instance, a recent reference reported unit capital costs for regenerable FGD ranging between \$50 and \$240/kW capacity.[2] Determining representative HDS costs is open to question due to uncertainty in design of the HDS processes. These processes are rarely used to produce only one uniform liquid product so that a larger system might be necessary to produce the same heat input of low sulfur fuel being processed by CAFB. However, the three systems have been compared on the basis of processing 10,700 bpsd of 2.5 to 3.0 percent S residual feed, or the amount required to generate 250 MW of power.

In summary, the utility of the following cost comparison must be assessed on the following basis.

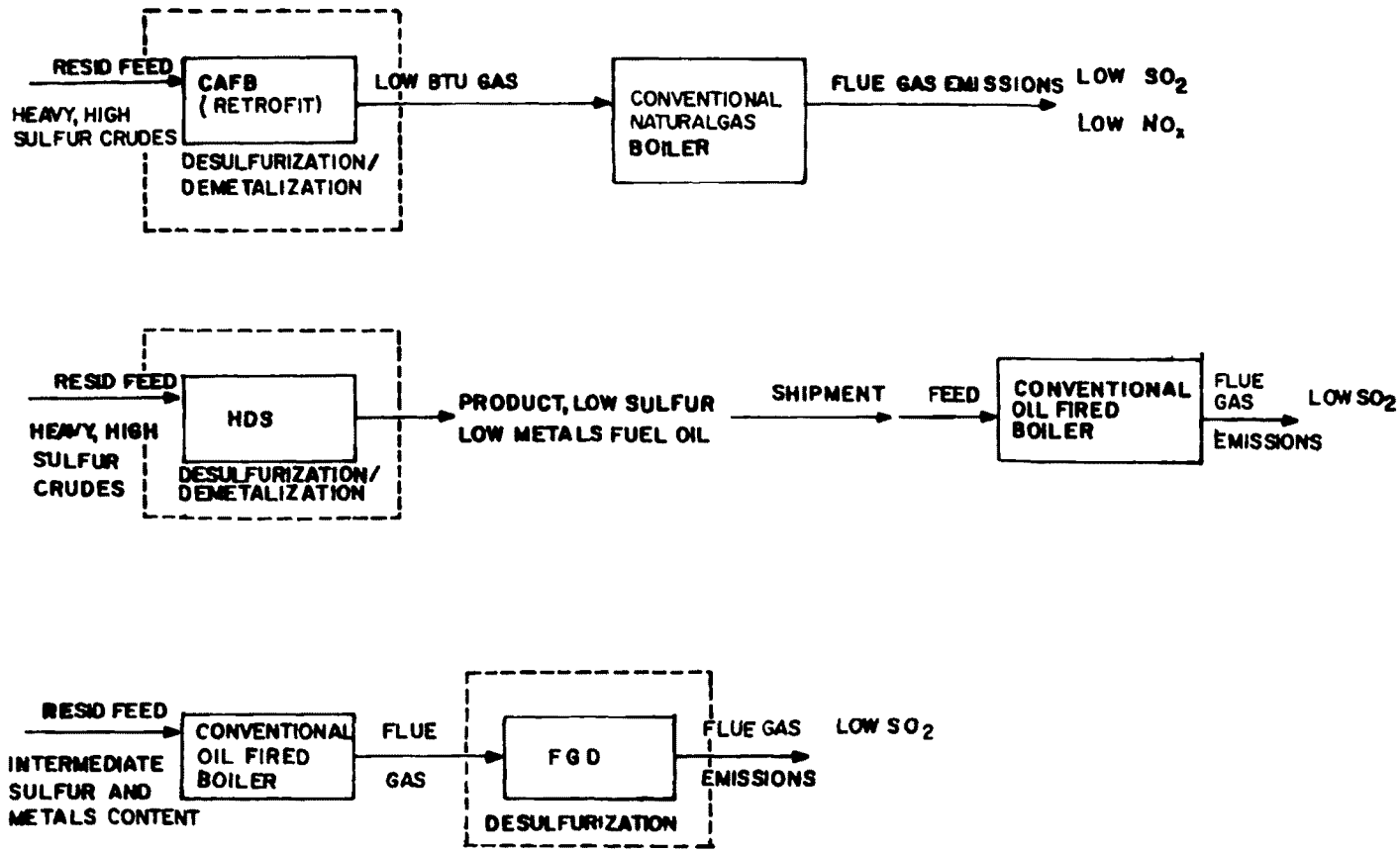

Figure B-1. Application of CAFB, HDS, and FGD systems at conventional power plants.

Items which are comparable:

- All three systems have equivalent desulfurization capacity.
- All three systems process residual feed at the same rate. (In many HDS applications, it may be desirable to produce other than one end product. Any limitation of production of low sulfur residual oil would necessarily require a larger system to maintain production of 10,700 bpsd of low sulfur fuel. This would increase capital and operating costs.)

Items which are not comparable:

- CAFB generates very low NO_x emissions as compared to equivalent applications of HDS and FGD.
- CAFB and certain HDS systems are equivalent in demetalization capacity; i.e., limitation of trace element air emissions. However, FGD has no demonstrated flue gas demetalizing capacity.
- A wide variety of fuels can be gasified by the CAFB.
- CAFB is a prototype system as opposed to FGD and HDS which are commercially proven.

Another critical factor which complicates an economic comparison based on residual oil utilization is that CAFB and FGD are more aptly suited to coal processing. Considering the current national emphasis on coal utilization as opposed to use of residual and distillate oil, CAFB and FGD are potentially important options for environmentally suitable combustion of coal.

Finally, comparing the three systems exclusively, without considering the cost of the power production train, obscures any cost advantage that gas-firing may have over oil-firing. Gas-firing has negligible requirements for soot blowing and ash handling. In the 250 MW category, this advantage may amount to 5 or 10 percent of the total capital cost.

BASIS OF COST ESTIMATES

Cost figures were developed for regenerable and nonregenerable (once-through) CAFB and FGD systems. In regenerable systems, sulfur is recovered in elemental or other useful form (such as H_2SO_4) and sorbent material is regenerated for reuse, with attendant reduction in solid waste quantities. Regenerable systems require additional processing equipment which add to total capital and operating cost.

The Foster Wheeler Equipment Corporation's design of the CAFB incorporates a RESOX™ processing system which reduces SO_2 formed in the regenerator to elemental sulfur. This system is shown in Figure 2 in the main body of the text. It is compared economically with a regenerable magnesium oxide (MgO) FGD scrubbing system. This is currently the only known regenerable FGD system applied at a conventional oil-fired power plant.

A recirculating slurry of MgO or $Mg(OH)_2$ absorbs sulfur dioxide from the flue gas yielding a solution of magnesium sulfite, magnesium sulfate, and unreacted magnesium oxide. The sulfite and sulfate crystals are filtered from the slurry and dried and calcined to regenerate magnesium oxide. Coke is added to reduce the residual magnesium sulfate to MgO and SO_2. The recovered SO_2 can be processed in an acid plant to yield sulfuric acid or in a Claus unit to produce elemental sulfur. The regenerated MgO is then used as makeup in the FGD system.

The once-through CAFB system is based on use of a dry sulfation technique developed by Westinghouse. In this process, SO_2 from the regenerator is contacted with spent stone and boiler cyclone fines to produce a highly sulfated byproduct stone. No byproduct stone regeneration is practiced. A low concentration of SO_2 is circulated from the dry sulfation reactor to the gasifier.

The CAFB system with dry sulfation is compared with once-through limestone flue gas desulfurization. A recirculating slurry of limestone is used to scrub SO_2 from the flue gas. A waste slurry of calcium sulfate and sulfite is produced and can be dried or disposed of in a liquid state. The costs for limestone FGD include solid waste disposal by discharge to settling ponds.

HDS economics are based on construction and operation of an LC Fining or Flexicoking refining process. These units are licensed by Cities Service and EXXON, respectively. The two processes are representative of demonstrated refinery systems which are capable of desulfurizing and demetalizing petroleum crudes and heavy residual oil. The HDS cost figures presented here are on a once-through nonregenerable basis, although certain HDS processes can operate in a regenerable mode. For instance, a Claus reactor could be added to a Flexicoking installation to convert H_2S to elemental sulfur. Complete operating information on the LC Fining and Flexicoking processes is presented in our initial assessment of the CAFB.[1]

The basis of the cost estimates and final comparison is presented in Table B-1. Some of the background references presented gross costs such as capital costs in terms of $/bpsd, or operating costs without any indication of quantitative material requirements. Such costs were projected to 1980 by use of the Nelson Refinery Construction Cost Index and the Nelson Refinery Operating Cost Index.[3]

SUMMARY

The comparative costs for the six systems are presented in Tables B-2 and B-3. The overall format used for presenting capital and operating costs is based on that presented by Westinghouse in their evaluation of fluidized bed combustion.[4]

It is important to note that cost information on these different processes is very limited, and published data tend to vary greatly. The comparison given here may have quantitative inconsistencies based on differing

TABLE B-1. BASIS OF COST COMPARISON

General

1. All costs represent projections to the year 1980.
2. CAFB and FGD costs are based on battery limits retrofit, and HDS systems are battery limits new.
3. Each system processes liquid fuel at 10,700 bpsd (equivalent to 250 MW capacity).

Capital Costs

1. Direct costs (equipment and labor).
2. Distributable costs (construction management and overhead) at 15 percent of direct costs.
3. Indirect costs (engineering and procurement) at 13.5 percent of direct costs.
4. Contingencies at 7.7 percent of total directs, indirects, and distributables.
5. Fee at 50 percent of contingency.
6. Startup at 8 percent of total investment.
7. Interest during construction at 8 percent of total investment.

Operating Costs

1. Limestone at $25/ton, FOB works.
2. Hydrogen at $1.00/1000 scf.
3. Supplemental fuel at $3.25/MM Btu.
4. Steam, high pressure at $3.25/1000 lbs.
   low pressure at $2.00/1000 lbs.
5. Cooling water at 5¢/1000 gal.
6. Process water at $1.50/1000 gal.
7. Power at 3¢/kWh.
8. Annualized capital at 15 percent/year of total capital investment.
9. Maintenance at 3 percent/year of total capital investment.
10. Property tax and insurance at 2 percent/year of total capital investment.
11. Labor and supervision at 7¢/bbl processed.
12. Administration, miscellaneous supply, and overhead at 3 percent/year of total investment.

(continued)

TABLE B-1 (continued).

CAFB and RESOX™

1. Capital costs based on mid-1975 equipment costs developed by Foster Wheeler.[a]

2. Operating costs are based on:

   - Limestone at 6.3 ton/hour.
   - Anthracite coal to RESOX™ at 2 ton/hour and $50/ton.
   - Electricity at 3¢/kWh, assumed equal to electricity requirements noted for CAFB and dry sulfation, updated from Westinghouse study.[b]

CAFB and Dry Sulfation, Limestone FGD

- Capital and Operating costs interpolated and updated directly from the Westinghouse study.[b]

MgO FGD

- Capital and Operating costs based on latest FGD cost study prepared by McGlamery and Torstrick of TVA.[c]

Flexicoking

- Capital and Operating costs based on published data and additional information provided by EXXON.[d,e,f]

LC Fining

- Capital and Operating costs based on published data and additional information provided by Cities Service.[g,h]

[a]Chemically Active Fluid Bed Process. Preliminary Process Design Manual. Foster-Wheeler Energy Corp., Livingston, New Jersey. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Contract No. 68-02-2106. 185 p. December 1975.

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(continued)

TABLE B-1 (continued).

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[f]Correspondence with Mr. Lamont E. Hill, EXXON Research and Engineering Company. October 26, 1977.

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[h]LC Fining. Hydrocarbon Processing. September 1976.

TABLE B-2. ESTIMATED 1980 CAPITAL COSTS FOR REGENERABLE AND NONREGENERABLE CAFB AND FGD SYSTEMS, 250 MW OIL-FIRED POWER PLANTS

Cost items	Regenerable CAFB and FGD systems		Nonregenerable CAFB and FGD systems		Nonregenerable HDS systems	
	CAFB and RESOX™	MgO FGD	CAFB and Dry sulfation	Limestone FGD	Flexicoking	LC Fining
Process equipment in place	23,044,300	6,916,250	11,815,600	5,162,500	7,918,000	7,008,500
Process materials and labor	15,439,700	6,916,250	15,893,600	6,898,600	7,918,000	7,008,500
Total directs	38,484,000	13,832,500	27,709,200	12,061,100	15,836,000	14,017,000
Distributables (15% directs)	5,772,600	2,074,900	4,156,400	1,829,200	2,375,000	2,102,600
Subtotal	44,256,600	15,907,400	31,865,600	13,890,300	18,211,000	16,119,600
Indirects (13.5% directs)	5,195,300	1,867,300	3,740,700	1,649,800	2,137,900	1,892,300
Subtotal base costs	49,451,900	17,774,700	35,606,300	15,540,100	20,348,900	18,011,900
Contingency (7.7% base costs)	3,840,900	1,368,600	2,741,700	1,210,500	1,580,300	1,386,900
Fee (50% contingency)	1,920,500	684,300	1,370,900	605,900	790,200	693,500
Subtotal process investment	55,213,300	19,827,600	39,718,900	17,356,500	22,719,400	20,092,300
New ID fan	342,000	-	342,000	-	-	-
Burner costs	477,000	-	477,000	-	330,000	330,000
Subtotal investment	56,032,300	19,827,600	40,537,900	17,356,500	23,049,400	20,422,300
Startup (8% investment)	4,482,600	1,586,200	3,243,000	1,392,600	1,844,000	1,633,800
Interest during construction (8% investment)	4,482,600	1,586,200	3,243,000	1,392,600	1,844,000	1,633,800
Total	64,997,500	23,000,000	47,023,900	20,141,700	26,737,000	23,689,900
$/kW	260	92	188	81	107	95

TABLE B-3. ESTIMATED 1980 OPERATING COSTS FOR CAFB, FGD AND HDS SYSTEMS, 250 MW OIL-FIRED POWER PLANTS

Cost items	Regenerable CAFB and FGD systems		Nonregenerable CAFB and FGD systems		Nonregenerable HDS systems	
	CAFB and RESOX™	MgO FGD	CAFB and Dry sulfation	Limestone FGD	Flexicoking	LC Fining
Limestone	1,242,800		1,242,800	1,562,500	-	-
Catalyst	-		-	-	11,000	1,732,900
Hydrogen	-		-	-	-	4,920,900
Supplemental Fuel	1,180,000[a]	3,715,000	-	-	703,000	
Steam	-		-	800,900	3,163,500	
Cooling Water	-		-		11,000	1,135,300
Process Water	-			17,500	239,000	
Power	3,100,000		3,100,000	1,181,200	1,581,700	
Annualized capital	9,747,200	3,450,000	7,053,600	3,021,300	4,010,600	3,553,500
Maintenance	1,949,400	690,000	1,410,700	604,300	802,100	710,700
Property tax and insurance	1,306,100	462,300	945,900	404,900	537,400	473,800
Labor and supervision	250,000	250,000	250,000	250,000	250,000	250,000
Administration, miscellaneous supply, and overhead	1,949,400	690,000	1,410,700	604,300	802,100	710,700
Total	20,724,900	9,257,300	15,410,800	8,446,900	12,111,400	13,487,800
$/bbl	5.90	2.63	4.38	2.40	3.45	3.84

[a]Anthracite coal for RESOX™ system.

basic assumptions in the references cited. However, the more important inconsistencies are technical differences with respect to system comparability as pointed out in the introductory section of this Appendix.

This cost summary indicates that regenerable CAFB and FGD systems are more expensive than their once-through counterparts. The CAFB with RESOX™ has the highest capital and operating cost, at $260/kW and $5.90/bbl, respectively. These values are more than double the equivalent MgO FGD control costs. CAFB with dry sulfation is a more cost effective CAFB operation, with operating costs only slightly higher than those associated with the Flexicoking and LC Fining HDS processes. However, capital costs for CAFB, whether regenerable or once-through, are double any other system.

Estimated operating costs are also significantly higher for CAFB, as compared to flue gas desulfurization systems. The CAFB with RESOX™ is $3/bbl more expensive than MgO FGD. CAFB with dry sulfation has an attendant operating cost $2/bbl higher than limestone FGD. In order to operate the CAFB on a competitive basis with flue gas desulfurization systems, high sulfur, high metals crudes must be $2 to $3 per barrel cheaper than low metals, medium sulfur content residual or distillate oils. At present this per barrel differential requirement is roughly twice the market situation.

COAL UTILIZATION

The total capital cost (design, equipment, and construction) of a 250 MW coal-fired regenerable CAFB is estimated to be approximately 8 to 10 percent greater than an equivalent oil-fired regenerable CAFB system.[5] The additional cost is due to the coal handling system, which adds about 15 percent to the total equipment cost. Similar incremental costs would be applicable for a coal-fired conventional boiler with flue gas desulfurization, so that the overall cost comparison of the two technologies is unchanged. Operating costs for the two systems would also be somewhat higher because of added electricity needs for coal handling. Conventional pulverized coal boilers would have a slightly higher additional operating cost than the coal-fired CAFB system due to greater coal crushing needs.

REFERENCES

1. Werner, A. S., C. W. Young, M. I. Bornstein, R. M. Bradway, M. T. Mills, and D. F. Durocher. Preliminary Environmental Assessment of the CAFB. GCA/Technology Division, Bedford, Massachusetts. Prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-600/7-76-017. October 1976. 324 pp. (NTIS No. PB 262-001/AS).

2. Princiotta, F. T. Advances in SO_2 Stack Gas Scrubbing. Chemical Engineering Progress. 74(2):58-64. February 1978.

3. Nelson, W. L., Technical Editor and Petroleum Consultant. Nelson Indexes. The Oil and Gas Journal. Published Weekly.

4. Keairns, D. L., et al. Fluidized Bed Combustion Process Evaluation (Phase I - Residual Oil Gasification/Desulfurization Demonstration at Atmospheric Pressure). Volume I - Summary. Prepared for the U.S. Environmental Protection Agency, Office of Research and Development. Publication No. EPA-650/2-75-027a. March 1975. (NTIS No. PB 241-834/AS).

5. Letter correspondence from Mr. Frank D. Zoldak, Foster-Wheeler Energy Corporation, to Mr. Samuel L. Rakes, U.S. Environmental Protection Agency. December 13, 1978.

APPENDIX C

RAW DATA FROM FIELD MEASUREMENTS

Sample Control No. RAC#1

ANALYTICAL TRAVELER

Inorganic Gases

(Special Instructions Attached____)

Sample Site CAFB

Type of Source

Test Number RAC#1 Sample Number BAG#1

Sample Description

Responsible Analyst

Date Taken 1/23/78 Date Analyzed 1/23/78

Analyst Signature

Workup

1. Column flow rate (mℓ/min) 20 2. Recorder speed 2CM/m

3. Full scale (mv)_____ 4. Column pressure (psi)_____

5. Electrometer set (A/mv)_____ 6. Calibration date_____

7. Sample size (mℓ) 1 8. Oven temperature ~~(°C)~~ 35°F

9. Attenuation 1024/64 10. Range_____

11. Observations TCD

Results

12. Param	13. Sum of peak areas	14. Concentration (%)	15. Q.
O_2		9.1%	
CO_2		10.1%	
CO		—	
N_2			

Sample Control No._____

ANALYTICAL TRAVELER

Inorganic Gases

(Special Instructions Attached____)

Sample Site CAF13

Type of Source

Test Number GHSS#1 Sample Number BH6#2

Sample Description

Responsible Analyst

Date Taken 11/24/78 Date Analyzed 11/25/78

Analyst Signature

Workup

1. Column flow rate (mℓ/min) 30 2. Recorder speed 2 CM/MIN

3. Full scale (mv) 4. Column pressure (psi) 28

5. Electrometer set (A/mv) 6. Calibration date

7. Sample size (mℓ) 1ml 8. Oven temperature ~~(°C)~~ 40°

9. Attenuation 1624/ 64 10. Range

11. Observations TCD

Results

12. Param	13. Sum of peak areas	14. Concentration (%)	15. Q. A.
O_2		90%	
CO_2		6.1%	
CO		0%	
N_2			

Sample Control No. BAG #2

ANALYTICAL TRAVELER

$C_1 - C_6$

(Special Instructions Attached____)

Sample Site CAFB

Type of Source

Test Number SASS 1 Sample Number BAG #2

Sample Description

Responsible Analyst

Date Taken 11/24/78 Date Analyzed

Analyst Signature

Workup

1. Column flow rate (mℓ/min) 30 2. Recorder speed 4 cm/min

3. Full scale (mv) 4. Column pressure (psi) 28

5. Electrometer set (A/mv) 6. Calibration date

7. Sample size (mℓ) 1 ml 8. Oven temperature (°C) 105° F

9. Flame flow rates (mℓ/min): H_2 Air

10. Attenuation 8 11. Range

12. Observations FID

Results

13. Param	14. Sum of peak areas	15. Concentration ~~(µg/µℓ)~~ ppmv	16. Q. A.
C_1		6.5	
C_2			
C_3			
C_4			
C_5			
C_6			

Page 1 of

Sample Control No. RAC #1

ANALYTICAL TRAVELER

$C_1 - C_6$

(Special Instructions Attached____)

Sample Site CAFB

Type of Source

Test Number RAC#1 Sample Number BAG #1

Sample Description

Responsible Analyst

Date Taken 1/23/78 Date Analyzed 1/23/78

Analyst Signature

Workup

1. Column flow rate (mℓ/min) 32 ml/min 2. Recorder speed 2 cm/min

3. Full scale (mv) 4. Column pressure (psi) 30

5. Electrometer set (A/mv) 6. Calibration date

7. Sample size (mℓ) 1 8. Oven temperature (°C) 107°

9. Flame flow rates (mℓ/min): H_2 Air

10. Attenuation 16 11. Range

12. Observations FID

Results

13. Param	14. Sum of peak areas	15. Concentration ~~(μg/μ²)~~ ppm	16. Q. A.
C_1		21.4	
C_2		2.8	
C_3			
C_4			
C_5			
C_6			

Page 1 of 1

Sample Control No._____

ANALYTICAL TRAVELER

Inorganic Gases

(Special Instructions Attached____)

Sample Site CAFB

Type of Source_____

Test Number_____ Sample Number Bag #3

Sample Description bag samp'

Responsible Analyst a.b

Date Taken 1/22/78 Date Analyzed_____

Analyst Signature_____

Workup

1. Column flow rate (mℓ/min) 10 2. Recorder speed 2

3. Full scale (mv)_____ 4. Column pressure (psi) 9

5. Electrometer set (A/mv)_____ 6. Calibration date 1/22/78

7. Sample size (mℓ) 1 ml 8. Oven temperature (°C)_____

9. Attenuation_____ 10. Range_____

11. Observations_____

Results

12. Param	13. Sum of peak areas	14. Concentration (%)	15. Q.
O_2		5.3	
CO_2		6.4	
CO		0	
N_2		88.1	

Sample Control No._____

ANALYTICAL TRAVELER

$C_1 - C_6$

(Special Instructions Attached____)

Sample Site CAFB

Type of Source_____

Test Number_____ Sample Number Bag sample 3

Sample Description Integrated bag sample

Responsible Analyst LP

Date Taken 1/27/78 Date Analyzed 1/27/78

Analyst Signature_____

Workup

1. Column flow rate (mℓ/min) 30 2. Recorder speed 2

3. Full scale (mv)_____ 4. Column pressure (psi) 22

5. Electrometer set (A/mv)_____ 6. Calibration date 1/27/78

7. Sample size (mℓ) 1 ml 8. Oven temperature (°C) 104

9. Flame flow rates (mℓ/min): H_2_____ Air_____

10. Attenuation X 8 11. Range 1

12. Observations_____

Results

13. Param	14. Sum of peak areas	15. Concentration (μg/μℓ)	16. Q. A.
C_1	0	0	
C_2	0	0	
C_3	0	0	
C_4	0	0	
C_5	0	0	
C_6	0	0	

Page 1 of 1

% M 8.968

ANDERSEN IMPACTOR FIELD DATA

PLANT CAPB

LOCATION

BOILER

DATE 1/20/

TIME

RUN NO.

IMPACTOR LOCATION

ORIFICE

NOZZLE DIA.

ΔH = .77

STAGE NO.	0	1	2	3	4	5	6	7	F
SUBSTRATE NO.	48	50	87	54	49	46	52	47	28

Leak test = .005

TRAVERSE POINT	ELAPSED TIME	ORIFICE Δh "H_2O	ORIFICE T °F	ORIFICE S.P. - "Hg
	0	.77	38 38	.8
	2 min	.77	38 38	1.2

Final = 799.708
Initial = 799.056
.642

ANDERSEN IMPACTOR FIELD DATA

PLANT LAFB

LOCATION

BOILER

DATE 1-27-78

TIME 15:0

RUN NO. Impactor Run #3

IMPACTOR LOCATION

ORIFICE

NOZZLE DIA.

STAGE NO.	0	1	2	3	4	5	6	7	F
SUBSTRATE NO.	67	88	73	53	55	5[illegible]	95	82	30

TRAVERSE POINT	ELAPSED TIME	ORIFICE Δh "H_2O	ORIFICE IT °F	ORIFICE S.P. - "Hg
	0	.77	48 48	.6
	2.5	.77	48 48	.61
	5	.77	48 48	.6
	8			

Final = 804.6[illegible]

Initial = 802.[illegible]

1.981

Nozzle [illegible]

2.5 min

ANDERSEN IMPACTOR FIELD DATA

PLANT CFB

LOCATION

BOILER

DATE 6/24/77

Desired ΔH .77

TIME

RUN NO. 1

IMPACTOR LOCATION

ORIFICE DGM [illegible]

NOZZLE DIA.

STAGE NO.	0	1	2	3	4	5	6	7	F
SUBSTRATE NO.	81	80	75	45	79	74	44	76	32

Leak Rate = .0040 @ 5.5" Hg / 60 sec.

TRAVERSE POINT	ELAPSED TIME	ORIFICE Δh "H_2O	ORIFICE T °F I	ORIFICE T °F O	ORIFICE S.P. - "Hg
1830	0	.77	50	49	.8
	2.5	.77	49	49	.8
	5	.77	49	49	.9

Final = 798.916

Initial = 797.163

1.753

Location CAFB

Run # SHCS #1

Date 1/24/78

INPUT		OUTPUT	
$\overline{\Delta H}$ (H_2O)	1.73	Vw^{Std}	94.71
Vw (ml)	2466.4	Vm^{Std}	919.167
Vm (Ft^3)	932.936	9^r/DSCF	.9632
Tm (^oR)	525.29	% M	9.34
Pb ("Hg)	29.20	% Dry Gas	90.66
Mg. Partic.	57492.09	M. W. (Wet)	28.44
% CO_2	7.53	D ($^{Lbs.}/Ft^3$)	.0564
% O_2	7.8	% EA	53.40
% CO	0	Vs (fpm)	400.124
TS (^oR)	675.16	Qs (ft^3)	110[illegible].32
PST ("H_2O)	.08	Wp ($^{lbs.}$part/hr)	9.08
$\Delta P^{1/2}$	.10	% I	96.59
Cp	.865		
TT (min)	250		
A_{noz} (ft^2)	.01227		
AST (ft^2)	3.976		

SASS ANALYTICAL DATA

PLANT CIFA

DATE 1/24/71

SAMPLING LOCATION

~~SOURCE I.D.~~ S

RUN NUMBER SASS-1

RECOVERY BY

RECORDED

COMMENTS:

FILTER # 1.3130

TOTAL = .6776 g.

CYCLONES USED:

	10μ	3μ	1μ
Net.	12.43855g	28.89202g	15.4837

VOLUME

	INITIAL	FINAL
FIRST IMPINGER	500 ml	1,218 ml
SECOND IMPINGER	500 ml	927 ml
THIRD IMPINGER	500 ml	490 ml
TOTAL	1500 ml	2635 ml

GAIN 1135

CONDENSATE - TRAP GAIN 691

SILICA GEL INITIAL WEIGHT	SILICA GEL FINAL WEIGHT
1018.00 g	1198.6 g
g	g
g	g
TOTAL g	TOTAL g

GAIN 180.6

TOTAL 2006.60

ADDITIONAL COMMENTS:

SASS FIELD DATA

PLANT CAFB
DATE 1/24
SAMPLING LOCATION
SOURCE I.D.
RUN NUMBER SASS-1
OPERATOR
AMBIENT TEMPERATURE
BAROMETRIC PRESSURE 29.13
STATIC PRESSURE, (P_s)
FILTER NUMBER(S)

PROBE LENGTH AND TYPE 6'
NOZZLE I.D. 1.5
ASSUMED MOISTURE, % 10%
XAD-2 MODULE NUMBER
METER BOX NUMBER OVEN NUMBER
METER ΔH@
C FACTOR
PROBE HEATER SETTING
OVEN SETTING
REFERENCE ΔP

SCHEMATIC OF TRAVERSE POINT LAYOUT
READ AND RECORD ALL DATA EVERY ____ MINUTES

TRAVERSE POINT NUMBER	SAMPLING TIME, MIN	CLOCK TIME (24 HR CLOCK)	GAS METER READING (V_M), FT^3	VELOCITY HEAD (ΔP_S), IN. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN H_2O ACTUAL	STACK TEMPERATURE (T_S), °F	DRY GAS METER TEMPERATURE INLET ($T_{M_{IN}}$) °F	DRY GAS METER TEMPERATURE OUTLET ($T_{M_{OUT}}$) °F	PUMP VACUUM IN Hg	OVEN TEMPERATURE °F	IMPINGER TEMPERATURE °F	SORBENT TRAP TEMPERATURE °F	PROBE TEMPERATURE °F
	0	1825	478.075	–	1.77	1.77	203	49	49	0	380	49		257
stop →	2		484.440											
start →	2		484.440		1.77	1.77	207	51	49	12	379	75	42	261
	15		[illegible]		1.77	1.77	204	64	53	12	376	[illegible]	47	254
	30	1835	571.873		1.77	1.77	204	69	57	13	43	150	52	257
	45		624.952		1.77	1.77	206	71	61	14	373	56	67	259
	60	[illegible]	678.350		1.77	1.77	209	73	67	14.5	388	56	62	259
	75		731.345		1.77	1.77	212	72	65	14.5	391	54	63	255
	90	1915	785.190		1.77	1.77	213	72	65	14.5	393	56	62	263
	105		837.246		1.77	1.77	214	72	65	15.0	[illegible]	[illegible]	63	[illegible]
	120	2000												
	135	2020			1.77	1.77	215	70	64	16.0	409	57	66	258
	150	2035	[illegible]	[illegible]	1.77	1.77	216	70	64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	165	2050	007.[illegible]		[illegible]	[illegible]	[illegible]	71	64	17.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	180	21[illegible]	063.[illegible]		1.77	1.77	220	73	65	18.3	409	55	65	255
	195	21[illegible]	116.[illegible]		1.77	1.77	221	72	66	18.8	409	54	64	[illegible]
	210	21[illegible]	175.035		1.77	1.77	223	72	65	19.0	408	49	64	263
	225	21[illegible]	221.[illegible]		1.77	1.77	[illegible]	72	66	20.5	410	46	62	[illegible]
	240	[illegible]	265.[illegible]		1.77	1.65	225	72	65	20.5	410	47	63	260
	255	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	66	20.5	411	47	64	[illegible]
TOTAL		●	860.935	●	●	●	●	●	●	●	●	●	●	●
AVERAGE	●	●	●	●	●			65.250		●	●	●	●	●

Temps & vac/meet all accuracy, pulse, weight

COMMENTS

SASS FIELD DATA

PLANT _____
DATE _____
SAMPLING LOCATION _____
SOURCE I.D. _____
RUN NUMBER _____
OPERATOR _____
AMBIENT TEMPERATURE _____
BAROMETRIC PRESSURE _____
STATIC PRESSURE, (P_s) _____
FILTER NUMBER(s) _____

PROBE LENGTH AND TYPE _____
NOZZLE I.D. _____
ASSUMED MOISTURE, % _____
XAD-2 MODULE NUMBER _____
METER BOX NUMBER _____ OVEN NUMBER _____
METER $\Delta H@$ _____
C FACTOR _____
PROBE HEATER SETTING _____
OVEN SETTING _____
REFERENCE ΔP _____

SCHEMATIC OF TRAVERSE POINT LAYOUT
READ AND RECORD ALL DATA EVERY ____ MINUTES

TRAVERSE POINT NUMBER	SAMPLING TIME, MIN	CLOCK TIME (24 HR CLOCK)	GAS METER READING (V_M), FT^3	VELOCITY HEAD (ΔP_s) IN. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{M_{IN}}$) °F	DRY GAS METER TEMPERATURE OUTLET ($T_{M_{OUT}}$) °F	PUMP VACUUM IN Hg	OVEN TEMPERATURE °F	IMPINGER TEMPERATURE °F	SORBENT TRAP TEMPERATURE °F	PROBE TEMPERATURE °F
	270	22[illegible]	403.2[illegible]		1.71	1.53	335	65	[illegible]	[illegible]	47	47	53	2[illegible]
	280	2240	411.011		1.71	1.50								
							215.160	65 28						
			932.936			1.731								
TOTAL														
AVERAGE														

COMMENTS

Location CAFB

Run # SASS #2

Date 11/26/78

INPUT		OUTPUT	
$\overline{\Delta H}$ (H_2O)	1.78	Vw^{Std}	36.73
Vw (ml)	778.2	Vm^{Std}	266.248
Vm (Ft^3)	268.168	9^r/DSCF	1.1994
Tm (^oR)	525.6	% M	12.09%
Pb ("Hg)	29.44	% Dry Gas	87.88
Mg. Partic.	10736.2	M. W. (Wet)	28.12
% CO_2	7.53	D ($^{Lbs.}/Ft^3$)	.0563
% O_2	7.8	% EA	53.6
% CO	0	Vs (fpm)	472.62
TS (^oR)	674.4	Qs (ft^3)	1271.6
PST ("H_2O)	.08	Wp ($^{lbs.}$part/hr)	13.07
$\Delta P^{1/2}$	.118	% I	86.91
Cp	.865		
TT (min)	78		
A_{noz} (ft^2)	.01227		
AST (ft^2)	3.976		

SASS ANALYTICAL DATA

PLANT CAFB

DATE 1/26/78

SAMPLING LOCATION

~~SOURCE I.D.~~

RUN NUMBER SASS-2

RECOVERY BY

RECORDED

COMMENTS:

FILTER # 1.31023 wet.dust

TOTAL = .365 g

CYCLONES USED:

10μ 4.64813 3μ 9.13672 1μ 6.5854

VOLUME

	INITIAL	FINAL
FIRST IMPINGER	500 ml	565 ml
SECOND IMPINGER	500 ml	574 ml
THIRD IMPINGER	500 ml	592 ml
TOTAL	ml	231 ml

GAIN 231.0

CONDENSATE - TRAP GAIN 470 g

SILICA GEL + CON WEIGHT INITIAL	FINAL	
10195 g	10967 g	(750.0 g)
g	g	
g	g	
TOTAL g	TOTAL 77.2 g	GAIN 77.2
		TOTAL 778.2

ADDITIONAL COMMENTS:

SASS FIELD DATA

PLANT CAFB
DATE 1-26-77
SAMPLING LOCATION CAFB/ESSO
SOURCE I.D.
RUN NUMBER 2
OPERATOR
AMBIENT TEMPERATURE 42°F
BAROMETRIC PRESSURE
STATIC PRESSURE, (P_s)
FILTER NUMBER(S)

PROBE LENGTH AND TYPE 6'
NOZZLE I.D. 1.5
ASSUMED MOISTURE, % 8
XAD-2 MODULE NUMBER
METER BOX NUMBER OVEN NUMBER
METER ΔH@
C FACTOR
PROBE HEATER SETTING 250
OVEN SETTING 400
REFERENCE ΔP

SCHEMATIC OF TRAVERSE POINT LAYOUT
READ AND RECORD ALL DATA EVERY 15 MINUTES

TRAVERSE POINT NUMBER	SAMPLING TIME, MIN	CLOCK TIME (24 HR CLOCK)	GAS METER READING (V_M), FT^3	VELOCITY HEAD (ΔP_s) IN. H_2O	ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN H_2O DESIRED	ORIFICE PRESSURE DIFFERENTIAL (ΔH), IN H_2O ACTUAL	STACK TEMPERATURE (T_s), °F	DRY GAS METER TEMPERATURE INLET ($T_{M_{IN}}$) °F	DRY GAS METER TEMPERATURE OUTLET ($T_{M_{OUT}}$) °F	PUMP VACUUM IN Hg	OVEN TEMPERATURE °F	IMPINGER TEMPERATURE °F	SORBENT TRAP TEMPERATURE °F	PROBE TEMPERATURE °F
	0	14:05	421.630	-	1.78	1.78	220	55	55	13	406	48	53	257
	15	14:20	473.698		1.78	1.78	220	70	59	13.5	401	54	70	262
	30	14:35	525.5[illegible]		1.78	1.78	218	74	66	14.0	403	60	70	260
	45	14:50	580.34[illegible]	[illegible]	1.78	1.78	207	76	68	14.0	404	59	62	258
STACK IS DOWN		14:[illegible]	583.472	161.842										
STACK UP:		15:15	583.610		1.78	1.78	207	61	63	15.0	407	55	57	257
	60	15:30	637.575		1.78	1.78	220	71	64	16.0	401	54	70	253
	75	15:45	692.290	-	1.78	1.78	209	72	65	16.0	400	52	63	261
STACK DOWN		15:48	701.888	118.278										
			280.120											
	— Leak Rate		12.09					68.429	62.857					
TOTAL	78	●	268.168	●	●	●	●	●	●	●	●	●	●	
AVERAGE	●	●	●	●	●	1.78	214.429	65.643		●	●	●	●	

COMMENTS Leak Rate = .155 CFM @ 20" Hg / 60 sec.

45
8
C-17
58341
42163

Location CAFB

Run # 1 (RAC)

Date 1/28/78

INPUT		OUTPUT	
$\overline{\Delta H}$ (H_2O)	.88	Vw^{Std}	2.26
Vw (ml)	47.95	Vm^{Std}	29.53
Vm (Ft^3)	30.1678	g^r/DSCF	1.038
Tm (^oR)	536.6	% M	7.12
Pb ("Hg)	29.20	% Dry Gas	92.88
Mg. Partic.	1990.35	M. W. (Wet)	29.016
% CO_2	9.1	D ($^{Lbs.}/Ft^3$)	.06067
% O_2	10.1	% EA	89.93
% CO	0	Vs (fpm)	368.20
TS (^oR)	5833	Qs (ft^3)	12067
PST ("H_2O)	.08	Wp ($^{lbs.}$part/hr)	10.68
$\Delta P^{1/2}$	.1	% I	119.7
Cp	.865		
TT (min)	60		
A_{noz} (ft^2)	.001364		
AST (ft^2)	3.976		

PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: 1/23/77 Client: CAFB

Run No.: RAC #1 W. O. No.:

Sample Box No. Plant: ESSO

Operator: Sampling Location:

FRONT HALF

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Lab No. Residue mg

Cyclone and Flask-Acetone Wash Lab No. Residue mg

Laboratory Results

Filter No.	Lab No.	Weight Results
G-61		1.03036 g
Cyclone		0.81014 g
		.14985 mg
	TOT.	1.99035 g

Filter particulate weight (+cyclone) 18405 mg

FRONT HALF Sub Total mg

BACK HALF

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder

Lab No.

Collected on 0.22μ Filter mg

Aqueous Residue mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash

Lab No. Residue mg

BACK HALF Sub Total mg

TOTAL WEIGHT mg

MOISTURE

Impingers	w + filter	w + c + f
1	583.01	576.11
2	587.93	[illegible]
3	587.52	599.15
		1797.27

Final Volume 1797.27

Initial Volume 1758.01

Net Volume 39.26

Silica Gel

Weight after test: 254.09

Weight before test: 245.4

Net Weight 8.69

Container No.: 1. 2. 3. 4.

TOTAL WEIGHT-Silica Gel 8.69 gm

TOTAL VOLUME-Impingers 39.26 ml

TOTAL MOISTURE 47.95 gm

Comments:

LAB: DATE RECEIVED

DATE REPORTED

ANALYTICAL CHEMIST

HFS/5/77

PLANT CAFB

DATE 23-1-78

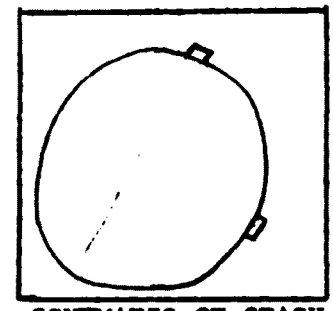
RUN NO. 1

STACK DIAMETER, in. 29.95

BAROMETRIC PRESSURE, in.Hg. 29.20

STATIC PRESSURE IN STACK(P_g), in. Hg.

OPERATORS



SCHEMATIC OF STACK CROSS SECTION

Traverse point number	Velocity head, in. H_2O	$\sqrt{\Delta_p}$	Stack Temperature(T_S), °F
1	.007	.084	114
2	.007	.084	114
3	.01	1.10	114
4	.007	.084	114
5	.007	.084	114
6	.01	1.10	115
7	.01	1.10	116
8	.01	1.05	113
9	.01	1.10	105
10	.01	1.10	96
11	.012	1.11	91
12	.017	1.13	69
AVERAGE:		.098	106

$$V_S = 5130 \times C_p \times \sqrt{\Delta p} \times \sqrt{T_S} \left[\frac{1}{P_S \times M_w}\right]^{\frac{1}{2}}$$

$$V_S = (5130)(.865)(.098)(23.8) \left[\frac{1}{29.20 \times 29.0}\right]^{\frac{1}{2}}$$

V_S = 355.7 AFPM

Sheet 1 o. 2

Client CAFB

W. O. No. _____

Plant _____

Run No. 1

Location _____

Date 1-24-77

Operator _____

Sample Box No. _____

Meter Box No. 2257

Meter△H _____

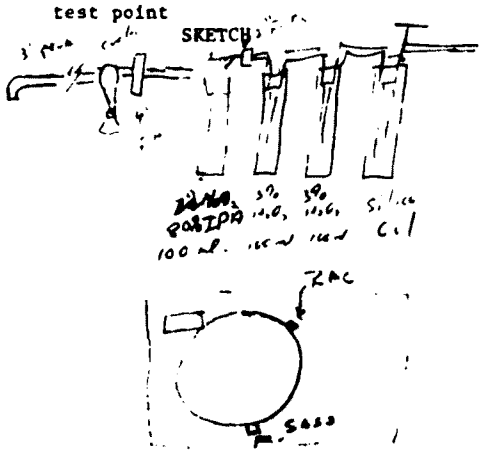
C Factor _____

PARTICULATE FIELD DATA

VERY IMPORTANT - FILL IN ALL BLANKS

Read and record at the start of each test point

SKETCH



Pitot Number & Side _____

Pitot tube CP _____

Filter No. _____

Ambient Temp. °F _____

Bar. Press. "Hg 29.20

Assumed Moisture % 10

Heater Box Setting, °F _____

Nozzle #/Dia., In. 1/2

Probe Length 3

Probe Heater Setting 300°

Avg.△P _____ Avg. △H _____

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H_2O △P	ORIFICE △H IN. H_2O DESIRED	ORIFICE △H IN. H_2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP. °F	IMPINGER TEMP. °F	STACK PRESS IN. Hg.	STACK TEMP. °F
1	1	1840	0	112.067	.01	.60	.60	76	66	3	231	36		108
2			5	114.665	.01	.65	.65	76	68	4	226	36		117
3			10	116.265	.01	.85	.85	80	68	4	238	35		121
4			20		.01	.9	.9	82	66	4	297	34		122
5			20		.01	.95	.95	86	64	4	222	34		123
6			25		.01	.95	.95	86	68	4.5	277	34		123
7			30	127.185	.01	.95	.95	86	68		225	34		115
8			35	129.810	.01	.95	.95	86	68	4.5				110
9			40		.01	.95	.95	86	70	5	206	35		87
10			45		.01	.87	.87	90	70	5	210	36		163
11			50	137.750	.01	.92	.92	90	70	5.5	176	56		161

Meter leak check: TOTAL

Before test: _____ CF _____ Sec _____ in.Hg

After test: _____ CF _____ Sec _____ in.Hg

Static Pressure (PST) Port _____ in.H_2O _____

COMMENTS:

impinger 3 = 587.52

impinger 2 587.48

impinger 1 583.01

impinger 4

Client CAFB

W.O. No.

Plant [illegible]

Run No. 1

PARTICULATE FIELD DATA
(continued)

Sheet 2 of 2

Location

Date 1-23-77

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H_2O ΔP	ORIFICE ΔH IN. H_2O DESIRED	ORIFICE ΔH IN. H_2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP °F	IMPINGER TEMP °F	STACK PRESS IN. Hg	STACK TEMP. °F
	12		55	140.-	.01	.92	.92	90	70	5.5	200	35		140
			60	143.046										
			Avg.	30.978	.01	0.89	0.89	84.67	68.6		235	35		123.333
		Leak		.3				76	6					
		Total =		30.678										

TOTAL

Meter leak check during test:

			Meter stop	Reading start
____CF	____Sec	____in.Hg's	____	____
____CF	____Sec	____in.Hg's	____	____

Static Pressure: Port ____ ____ ____
in.H_2O ____ ____ ____

COMMENTS:

GASEOUS SAMPLING
IMPINGER TRAIN

Client: CAFB

Personnel:

Location:

Sample location: Esso

W.O. No.

Date: 1/23/77

Barometric Pressure:

Pollutant and Run No.		SO2/SO3				
Time	F.	60 MIN				
	S.	0				
	T.	60 MIN				
Gas Meter	F.	143.045				
	S.	112.067				
Total ft.^{3}		30.978				
Vacuum In. Hg.	F.	5.5				
	S.	3.0				
	Av.	4.25				
Inlet Dry Gas Meter Temp. °F.	F.	90				
	S.	76				
	Av.	83				
Outlet Dry Gas Meter Temp. °F	F.	70				
	S.	66				
	Av.	68				
Impinger Volumes Sol'n A	F.					
	S.					
	Net.					
Impinger Volumes Sol'n B	F.					
	S.					
	Net.					
Silca Gel gms	F	254.09				
	S	245.4				
	N	8.69				
Filter or Thimble #						

NOTES: ten set up as combination method 5/method 6

Location CAFB

Run # RAC #2

Date 11/25/78

INPUT		OUTPUT	
$\overline{\Delta H}$ (H_2O)	1.20	Vw^{Std}	2.315
Vw (ml)	49.050	Vm^{Std}	32.740
Vm (Ft^3)	33.804	9^r/DSCF	1.529
Tm (^oR)	539.83	% M	6.604
Pb ("Hg)	29.54	% Dry Gas	93.40
Mg. Partic.	3250.97	M. W. (Wet)	28.59
% CO_2	6.1	D ($^{Lbs.}/Ft^3$)	.058
% O_2	9.0	% EA	67.096
% CO	0	Vs (fpm)	~~475.196~~ 475.
TS (^oR)	663.5	Qs (ft^3)	~~1388.15~~ 1388.
PST ("H_2O)	.08	Wp ($^{lbs.}$part/hr)	18.20
$\Delta P^{1/2}$	.121	% I	~~113.0~~ ~~112.0~~ 114.3
Cp	.865		
TT (min)	60		
A_{noz} (ft^2)	.001364		
AST (ft^2)	3.976		

Sheet 1 of _____

Client CGFB

W. O. No. _____

Plant CAFC / [illegible]

Run No. TNA

Location _____

Date 1-25-78

Operator _____

Sample Box No. _____

Meter Box No. 2257

Meter ΔH _____

C Factor _____

PARTICULATE FIELD DATA

VERY IMPORTANT - FILL IN ALL BLANKS

Read and record at the start of each test point

SKETCH

Pitot Number & Side _____

Pitot tube CP _____

Filter No. _____

Ambient Temp. °F ~ 54

Bar. Press. "Hg 29.54

Assumed Moisture % 8%

Heater Box Setting, °F _____

Nozzle #/Dia., In. 1/2"

Probe Length 3'

Probe Heater Setting _____

Avg. ΔP _____ Avg. ΔH _____

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H_2O ΔP	ORIFICE ΔH IN. H_2O DESIRED	ORIFICE ΔH IN. H_2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP. °F	IMPINGER TEMP. °F	IMPINGER TEMP. °F	STACK PRESS IN. Hg.	STACK TEMP. °F
9		1730	0	149.060	.013 .114	1.2	1.2	70	65	7	239	53			216
9			5		.014 .118	1.1	1.1	80	66	10	[illegible]	52	19C		208
9			10		.015 .122	1.2	1.2	88	68	10	271	56			208
9			15		.015 .122	1.2	1.2	90	68	11.5	280	58	16C		207
9			20		.015 .122	1.2	1.2	92	70	11.5	282	60			206
9			25		.015 .122	1.2	1.2	94	70	12.0	278	60	18C		207
9			30	165.665	.015 .122	1.2	1.2	94	70	12.0	281	60	18		207
9			35		.015 .122	1.2	1.2	94	71	12.0	282	60	17C		207
9			40	171.50	.015 .122	1.2	1.2	94	72	12.5	282	60			194
9			45	178.402	.015 .122	1.2	1.2	94	72	12.5	279	60	16C		194
9		1820	50		.015 .122	1.2	1.2	95	72	13.0	288	60			194
Meter leak check:				TOTAL	.116										207

Before test: _____ CF _____ Sec _____ in.Hg

After test: _____ CF _____ Sec _____ in.Hg

Static Pressure (PST) Port _____ in.H_2O _____

COMMENTS:

LEAK RATE = .007 CFM @ 15" Hg / 30 sec

Set RAC leak @ point 9 to R. test.

Could not traverse because TEN-X filter would exceed 200F.

Client _____ **PARTICULATE FIELD DATA (continued)** Sheet ____ of ____

W.O. No. _____

Plant _____ Location _____

Run No. _____ Date _____

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H_2O ΔP	ORIFICE ΔH IN. H_2O DESIRED	ORIFICE ΔH IN. H_2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP °F	IMPINGER TEMP. °F		STACK PRESS IN. Hg	STACK TEMP. °F
9			55		.015	1.3	1.3	75	72	14	293	61	16 C		194
		Stop	60	183.284											
								90	69.67						203.5
				33.804	.121	1.208		79.5	93						
				TOTAL											

COMMENTS:

Meter leak check during test: Meter stop / Reading start

_____ CF _____ Sec _____ in.Hg's _____ _____

_____ CF _____ Sec _____ in.Hg's _____ _____

Static Pressure: Port _____ _____ _____

in.H_2O _____ _____ _____

PLANT CAFB

DATE 1-25-78

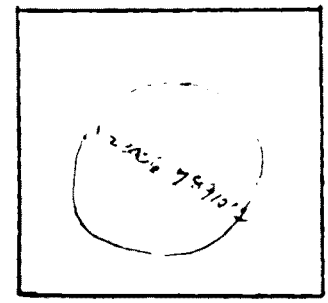
RUN NO. 2

STACK DIAMETER, in.

BAROMETRIC PRESSURE, in.Hg. 29.54

STATIC PRESSURE IN STACK(P_g), in. Hg.

OPERATORS



SCHEMATIC OF STACK CROSS SECTION

Traverse point number	Velocity head, in. H_2O	$\sqrt{\Delta_p}$	Stack Temperature(T_S), °F
1	.01	.100	191
2	.01	.100	192
3	.01	.100	194
4	.01	.100	196
5	.01	.100	197
6	.01	.100	197
STATIC	.08		196
7	.013	.114	195
8	.015	.122	196
9	.015	.122	190
10	.015	.122	185
11	.017	.130	181
12	.020	.141	169
AVERAGE:		.113	190.2
	AV. .013	.113	

$$V_s = 85.48\ C_p\ \sqrt{\Delta p_{avg}}\ \sqrt{\frac{T_{s\,avg} + 460}{P_s M_s}}$$

$$V_s = 85.48\,(.865)\,(.113)\,\sqrt{\frac{190 + 460}{(29.54)\ 29.3}}$$

$$V_s = 7.24\ ft/sec$$

PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: 1/25/78 Client:

Run No.: RAC-2 W. O. No.:

Sample Box No. Plant:

Operator: Sampling Location: CAFB

FRONT HALF

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Lab No. Residue mg

Cyclone and Flask-Acetone Wash Lab No. Residue mg

Laboratory Results

Filter No.	Lab No.	Weight Results
6-82		2.18645 mg
Cyclon		0.69625 mg
RINSE		.36827 mg
		3.25097 mg

Filter particulate weight 2882.7 mg

FRONT HALF Sub Total mg

BACK HALF

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder Lab No.

Collected on 0.22μ Filter mg

Aqueous Residue mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash Lab No. Residue mg

BACK HALF Sub Total mg

TOTAL WEIGHT mg

MOISTURE

Impingers

100 - 138		38
100 - 100		0
0		0

Final Volume

Initial Volume

Net Volume 38 ml

Silica Gel

Weight after test:	263.25			
Weight before test:	252.2			
Net Weight	11.050			

Container No.: 1. 2. 3. 4.

TOTAL WEIGHT-Silica Gel 11.050 gm

TOTAL VOLUME-Impingers 38.0 ml

TOTAL MOISTURE 49.050 gm

Comments:

LAB: DATE RECEIVED

DATE REPORTED

ANALYTICAL CHEMIST

HFS/5/77

Location CAFB

Run # RAC #3

Date 2/26/78

INPUT		OUTPUT	
$\overline{\Delta H}$ (H_2O)	1.12	Vw^{Std}	3.23
Vw (ml)	68.48	Vm^{Std}	32.876
Vm (Ft^3)	33.77	9^r/DSCF	.990
Tm (^oR)	535.154	% M	8.95
Pb ("Hg)	29.44	% Dry Gas	91.05
Mg. Partic.	2114.68	M. W. (Wet)	28.436
% CO_2	7.53	D ($^{Lbs.}/Ft^3$)	.059
% O_2	7.8	% EA	53.60
% CO	0	Vs (fpm)	464.23
TS (^oR)	~~#9~~ 648.08	Qs (ft^3)	1346.7 ~~1342.00~~
PST ("H_2O)	.08	Wp ($^{lbs.}$part/hr)	11.43
$\Delta P^{1/2}$	.119	% I	118.94
Cp	.865		
TT (min)	60		
A_{noz} (ft^2)	.001367		
AST (ft^2)	3.976		

Sheet No. 2

Client CAFB

W. O. No. _____

Plant _____

Run No. ~~[illegible]~~ RAC #3

Location CAFB

Date 11/26/78

Operator _____

Sample Box No. _____

Meter Box No. _____

Meter ΔH _____

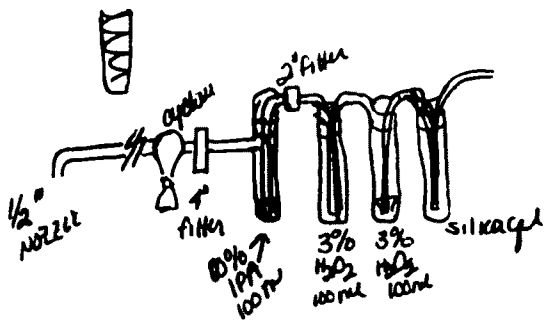
C Factor _____

PARTICULATE FIELD DATA

VERY IMPORTANT - FILL IN ALL BLANKS

Read and record at the start of each test point

SKETCH



Pitot Number & Side _____

Pitot tube CP _____

Filter No. 5169

Ambient Temp. °F _____

Bar. Press. "Hg 29.44

Assumed Moisture % _____

Heater Box Setting, °F _____

Nozzle #/Dia., In. 1/2"

Probe Length 3'

Probe Heater Setting _____

Avg. ΔP _____ Avg. ΔH _____

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H2O ΔP	ORIFICE ΔH IN. H2O DESIRED	ORIFICE ΔH IN. H2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP. °F	IMPINGER TEMP. °F	STACK PRESS IN. Hg	STACK TEMP. °F
1		1034	0	183.532	.016	.66	.66	55	55	[illegible]	[illegible]	46		204
2		[illegible]	5	[illegible]	.012	.80	.80	62	56	5	265	45		213
3		10	10	188.25	.014	.93	.93	74	58	5	261	46		217
4		15	15	190.93	.009	.97	.97	81	60	4	255	46		219
5		20	20	193.97	.013	.86	.86	83	63	5	251	43		221
6		25	25	195.50	.019	1.6	1.6	86	65	6	255	49		221
7		30	30	198.70	.017	1.4	1.4	89	68	6	276	50		219
8		40	35	201.8	.014	1.0	1.0	91	70	5	310	53		212
9		45	40	204.6	.018	1.5	1.5	91	72	7	264	51		209
10			45	207.6	.016	1.0	1.0	94	74	5	270	57		
11	STOP	1450	46.19	208.798										

Meter leak check: 25.26 TOTAL

Before test: _____ CF _____ Sec [illegible] in.Hg

After test: _____ CF _____ Sec _____ in.Hg

Static Pressure (PST) Port _____ in.H2O _____

COMMENTS:

IMP #1 584.70

#2 588.38

#3 588.90

Silicagel 136 255.959,

Leak Pol. - .006 [illegible] 15" Hg [illegible]

1450 - CAIB Unit went Down

Client _____

W.O. No. _____

Plant [illegible] Location _____

Run No. [illegible]-3 Date 1/20/7[illegible]

PARTICULATE FIELD DATA
(continued)

Sheet 2 of 2

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H_2O ΔP	ORIFICE ΔH IN. H_2O DESIRED	ORIFICE ΔH IN. H_2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP °F	IMPINGER TEMP °F	STACK PRESS IN. Hg	STACK TEMP. °F
Start		[illegible]	46:19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	267	45		[illegible]
11		[illegible]	50	211.4	[illegible]	1.5	1.5	[illegible]	[illegible]	7	260	44		172
12			55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
Stop		[illegible]	60	217.662										
				6.864										
		TOTAL		34.130				82.923	~~[illegible]~~					
				-.360										
				33.770	.118	1.122		~~76.964~~						188.077
									67.38					
				TOTAL								67.38		

Meter leak check during test:

CF	Sec	in.Hg's	Meter stop	Reading start

Static Pressure: Port _____ in.H_2O _____

COMMENTS:

.387 CFm to 4' [illegible]

.001 CFm to [illegible]

.132 CFm to [illegible]

PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: 1/26/78 Client: _____

Run No.: RAC #3 W. O. No.: _____

Sample Box No. _____ Plant: CAFB

Operator: _____ Sampling Location: _____

FRONT HALF

Nozzle and Probe (Cyclone Bypass)-Acetone Wash,
Cyclone and Flask-Acetone Wash

Filter No.	Lab No.	Weight Results
G69		1.51072 g
Cyclon.		0.41236 g
RINSE		.19160 mg
		2.11468 mg

Laboratory Results

Lab No. _____ Residue _____ mg

Lab No. _____ Residue _____ mg

Filter particulate weight 1923.1 mg

FRONT HALF Sub Total _____ mg

BACK HALF

Impinger Content and Water Wash of Impingers
Connectors and Back Half of Filter Holder

TAKEN AS METHOD 8 - SEE SHEET

Impinger, Connectors and Back Half of
Filter Holder - Acetone Wash

Lab No. _____

Collected on 0.22μ Filter _____ mg

Aqueous Residue _____ mg

Lab No. _____ Residue _____ mg

BACK HALF Sub Total _____ mg

TOTAL WEIGHT _____ mg

MOISTURE

Impingers	I	F
#1	584.70	577.60
#2	588.38	631.42
#3	588.90	603.81

Final Volume	1812.83
Initial Volume	1761.98
Net Volume	50.85

Silica Gel

Weight after test:	273.58			
Weight before test:	255.95			
Net Weight	17.63			
Container No.:	1.	2.	3.	4.

TOTAL WEIGHT-Silica Gel 17.63 g

TOTAL VOLUME-Impingers 50.85 ml

TOTAL MOISTURE 68.48 g

Comments: _____

LAB: DATE RECEIVED _____

DATE REPORTED _____

ANALYTICAL CHEMIST

HPS/5/77

Location CAFB

Run # RAC #4

Date 1/27/78

INPUT		OUTPUT	
$\overline{\Delta H}$ (H_2O)	.698	Vw^{Std}	1.23
Vw (ml)	26.1	Vm^{Std}	26.318
Vm (Ft^3)	27.132	9^r/DSCF	.8520
Tm (^oR)	536.54	% M	4.47
Pb ("Hg)	29.47	% Dry Gas	95.53
Mg. Partic.	1456.06	M. W. (Wet)	28.73
% CO_2	6.4	D ($^{Lbs.}/Ft^3$)	.056
% O_2	5.3	% EA	29.426
% CO	0	Vs (fpm)	496.37
TS (^oR)	688.3	Qs (ft^3)	1422.45
PST ("H_2O)	.08	Wp ($^{lbs.}$part/hr)	10.38
$\Delta P^{1/2}$	.124	% I	88.58
Cp	.865		
TT (min)	60		
A_{noz} (ft^2)	.00134		
AST (ft^2)	3.976		

Sheet 1 of _____

Client CAFB

W. O. No. _____

Plant _____

Run No. AHC #4

Location _____

Date 11/27/78

Operator _____

Sample Box No. _____

Meter Box No. _____

Meter ΔH _____

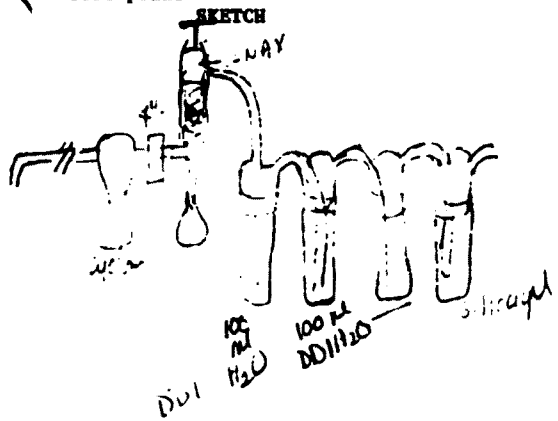
C Factor _____

PARTICULATE FIELD DATA

VERY IMPORTANT - FILL IN ALL BLANKS

Read and record at the start of each test point

SKETCH



Pitot Number & Side _____

Pitot tube CP _____

Filter No. 371

Ambient Temp. °F _____

Bar. Press. "Hg _____

Assumed Moisture % _____

Heater Box Setting, °F _____

Nozzle #/Dia., [redacted]

Probe Length _____

Probe Heater Setting _____

Avg. ΔP _____ Avg. ΔH _____

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H2O ΔP	ORIFICE ΔH IN. H2O DESIRED	ORIFICE ΔH IN. H2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP. °F	IMPINGER TEMP. °F Ice	IMPINGER TEMP. °F 10	STACK PRESS IN. Hg.	STACK TEMP. °F
1		1515	0	725.536	.21	.58	.58	[illegible]	60	5.5	527	57	55		228
2			5		.01	.58	.58	78	64	6	285	55			226
3			10		.01	.58	.58	80	66	6.5	271	54	32		227
4			15		.012	.70	.70	82	67	7.5	275	54			228
5			20		.015	1.0	1.0	84	[illegible]	7.5	303	54	27		228
6			25		.013	.83	.82	88	70	8.5	322	54	25		229
1			30		[illegible]	[illegible]	[illegible]	90	70	8.0	310	54	22		228
2			35		.017	.55	[illegible]	86	72	[illegible]	[illegible]	54	22		228
3			40		.017	.74	.74	88	72	8.5	315	54	23		228
4			45	27.852	.01	.54	.54	88	72	9.0	284	53	22		230
5			50		.012	.77	.77	88	72	8.5	285	54	23		231
					.013	.83	.83	88	74	7.5	276	55	22		231
								84.167	68.917			54.333	8.15		228.333

Meter leak check: 5.5 / 60 TOTAL 28.388

Before test: _____ CF _____ Sec _____ in. Hg

After test: _____ CF _____ Sec _____ in. Hg

Static Pressure (PST) Port _____ in. H_2O _____

COMMENTS: .698

[illegible] B-2 254.19

Leak [illegible]

PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: Jan 27 1978 Client:

Run No.: Run #4 W. O. No.:

Sample Box No. Plant: CAFB

Operator: Sampling Location:

FRONT HALF

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Cyclone and Flask-Acetone Wash

Laboratory Results

Lab No. Residue mg

Lab No. Residue mg

Filter No.	Lab No.	Weight Results
71		1.34237 g
Cyclone		0.03738 g
		.07631 mg
		1.45606 mg

Filter particulate weight 1379.8 mg

FRONT HALF Sub Total mg

BACK HALF

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder

Lab No.

Collected on 0.22μ Filter mg

Aqueous Residue mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash

Lab No. Residue mg

BACK HALF Sub Total mg

TOTAL WEIGHT mg

MOISTURE

Impingers

Final Volume 218

Initial Volume 200

Net Volume 18 ml

Silica Gel

Weight after test: 254.5

Weight before test: 254.4

Net Weight 8.1

Container No.: 1. 2. 3. 4.

TOTAL WEIGHT-Silica Gel 8.1 gm

TOTAL VOLUME-Impingers 18.0 ml

TOTAL MOISTURE 26.1 gm

Comments:

LAB: DATE RECEIVED

DATE REPORTED

ANALYTICAL CHEMIST

NFS/5/77

NOMOGRAPH SETUP DATA SHEET

CLIENT CAFB

GCA WORK ORDER NO. _____ DATE: 1-25-78

PLANT CAFB / ESSO

SAMPLING LOCATION _____

METER BOX NO. _____ METER BOX ΔH@ 2.104

MOISTURE VOL. % 8% BAR. PRESSURE (PB)(PM) 29.54 in. Hg

STATIC PRESSURE SAMPLING POINT (PST) .08 in. H_2O x 0.735 = .0059

PRESSURE STACK (PS) PB±(PST) = 29.54 + _____ = 29.55 in. Hg

PS/PM = _____ = 1.00 PITOT TUBE NO. _____

C_p = .865 ; $(C_p/0.85)^2$ = (1.017)^2 = 1.035 Cpc ; Cc = C x cpc

Δp LOW .01 ; Δp AVERAGE .013 ; Δp HIGH .017

NOZZLE DIAMETER 5/8 in. ; TS min 169 TS avg 190.2 TS high 197

K FACTOR CHART

C	1.08	1.1		1.11		1.15				
CC	1.09	1.14		1.14		1.19				
TS \ TM	60	70		80		90				
150	.79	.81		.81		.85				
160	.79	.80		.86		.82				
170	.79	.79		.79		.84				
180	.78	.78		.78		.82				
190	.78	.77		.77		.81				
200	.76	.76		.76		.80				
210	.75	.76		.76		.79				
220	.75	.75		.75		.79				
230	.75	.74		.74		.78				
240	.74	.74		.74		.77				

K FACTOR REFERENCE ON Δp SCALE

Location CAFB

Run # RAC #5

Date 11.27.78

INPUT		OUTPUT	
$\overline{\Delta H}$ (H_2O)	.552	Vw^{Std}	2.54
Vw (ml)	53.8	Vm^{Std}	24.63
Vm (Ft^3)	25.20	g^r/DSCF	.7917
Tm (^oR)	532.28	% M	~~9.36~~ 9.36
Pb ("Hg)	29.44	% Dry Gas	90.65
Mg. Partic.	1266.25	M. W. (Wet)	28.186
% CO_2	6.4	D ($^{Lbs.}/Ft^3$)	.0552
% O_2	5.3	% EA	29.43
% CO	0	Vs (fpm)	388.50
TS (^oR)	690.08	Qs (ft^3)	1053.8
PST ("H_2O)	.08	Wp ($^{lbs.}$part/hr)	7.15
$\Delta P^{1/2}$	.096	% I	~~111.7~~ 113.1
Cp	.865		
TT (min)	60		
A_{noz} (ft^2)	.001364		
AST (ft^2)	3.976		

Sheet 1 of _____

PARTICULATE FIELD DATA

VERY IMPORTANT - FILL IN ALL BLANKS

Client _____

W. O. No. _____

Plant CAFB/E000

Run No. RAC #5

Location _____

Date 1/27/78

Operator _____

Sample Box No. 2267

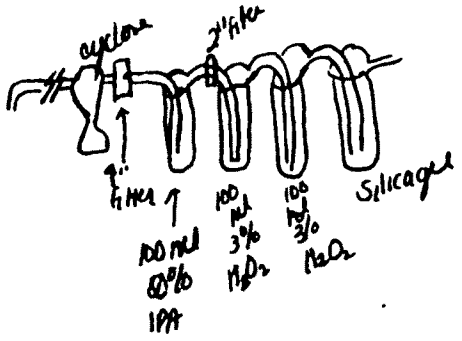
Meter Box No. 2257

Meter ΔH _____

Operator _____

Read and record at the start of each test point

SKETCH



Pitot Number & Side _____

Pitot tube CP _____

Filter No. G87

Ambient Temp. °F _____

Bar. Press. "Hg 29.44

Assumed Moisture % _____

Heater Box Setting, °F _____

Nozzle #/Dia., In. _____

Probe Length 3'

Probe Heater Setting _____

Avg. ΔP _____ Avg. ΔH _____

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H_2O ΔP	ORIFICE Δ H IN. H_2O DESIRED	ORIFICE Δ H IN. H_2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP. °F	IMPINGER TEMP. °F	STACK PRESS IN. Hg.	STACK TEMP. °F
1		1725	0	253.562	.01 .1	.54	.53	55	55	2	230	44		232
2			5		.011 .105	.70	.70	72	63	2.5	316	44		234
3			10		.01 .1	.55	.55	76	60	2.5	234	45		235
4			15		.01 .105	.70	.70	80	62	2.5	231	47		236
5			20		.008 [illegible]	.38	.38	82	64	2	243	47		234
6			25		.01 .1	.57	.57	83	66	2.5	230	50		235
7			30		.008 .08	.38	.38	84	66	2	233	49		234
8			35		.009 .08	.44	.41	85	68	2	235	48		240
9			40		.01 .1	.57	.59	85	68	2.5	232	48		244
10			45		.011 .105	.74	.74	85	70	4.0	249	47		237
11			50		.01 .1	.72	.72	85	70	4.0	242	47		176
Meter leak check:				TOTAL	1.087		.679	81	72					170

Before test: _____ CF _____ Sec _____ in. Hg .098

After test: _____ CF _____ Sec _____ in. Hg

Static Pressure (PST) Port _____ in. H_2O _____

COMMENTS:

SILICA GEL D-1 298.6 g.

I 1 586.30

I 2 589.98

I 3 588.18

230.08

64.4

Client _____

W.O. No. _____

Plant _____ Location _____

Run No. _____ Date _____

PARTICULATE FIELD DATA
(continued)

Sheet ____ of ____

POINT	DISTANCE IN INCHES	CLOCK TIME ACTUAL	CLOCK TIME RUN	DRY GAS METER, CF	PITOT IN. H_2O ΔP	ORIFICE ΔH IN. H_2O DESIRED	ORIFICE ΔH IN. H_2O ACTUAL	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM IN. Hg GAUGE	BOX TEMP °F	IMPINGER TEMP °F	STACK PRESS IN. Hg	STACK TEMP. °F
12			55		.005	5	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]		[illegible]
				total										
			60	278.763										
	[illegible]			25.20	[illegible]		.552	72.28			230.08			
TOTAL														

Meter leak check during test:

				Meter stop	Reading start
____ CF	____ Sec	____ in.Hg's		____	____
____ CF	____ Sec	____ in.Hg's		____	____

Pressure: Port ____ ____ ____
in.H_2O ____ ____ ____

COMMENTS:

PARTICULATE CLEAN UP AND REPORT SHEET

Run Date: 1/27/78 Client:

Run No.: RAC #5 W. O. No.:

Sample Box No. Plant: CAFB/ESSO

Operator: Sampling Location:

FRONT HALF

Nozzle and Probe (Cyclone Bypass)-Acetone Wash, Lab No. Residue mg

Cyclone and Flask-Acetone Wash Lab No. Residue mg

Filter No.	Lab No.	Weight Results
G87		1.17512 g
Cyclone		0.03176 g
RINSE		.05930 g
		1.26625 mg

Filter particulate weight 1266.9 mg

FRONT HALF Sub Total mg

BACK HALF

Impinger Content and Water Wash of Impingers Connectors and Back Half of Filter Holder Lab No.

Collected on 0.22μ Filter mg

Aqueous Residue mg

Impinger, Connectors and Back Half of Filter Holder - Acetone Wash Lab No. Residue mg

BACK HALF Sub Total mg

TOTAL WEIGHT mg

MOISTURE

Impingers	I Wt	F Wt.	
I1	586.30	586.95	
I2	589.98	623.77	33.79
I3	588.18	589.28	1.18
			34.92

Final Volume

Initial Volume

Net Volume

Silica Gel

Weight after test: 257.5

Weight before test: 248.6

Net Weight

Container No.: 1. 89 2. 3. 4.

TOTAL WEIGHT-Silica Gel 89 gm

TOTAL VOLUME-Impingers 49.9 ml

TOTAL MOISTURE 53.8 gm

Comments:

LAB: DATE RECEIVED

DATE REPORTED

ANALYTICAL CHEMIST

HPS/5/77

APPENDIX D

DATA FROM LABORATORY ANALYSES OF CAFB SAMPLES

TABLE D-1. SAMPLE ABBREVIATION CODE

Sample code	Sample description
PF	Particulate filter
1c, 1 μc	1 micron cyclone
3c, 3 μc	3 micron cyclone
10c, 10 μc	10 micron cyclone
PR	Solvent probe rinse
XR	XAD-2 resin
MR	Solvent module rinse
CD	Module condensate
CH	Composite of acid module rinse, condensate, and first impinger
IC	Composite of second and third impingers
RB	Regenerator bed
GB	Gasifier bed
FR	Fines return
RC	Regenerator cyclone
MC	Main cyclone
SC	Stack cyclone
KO	Knockout
BB	Boiler back
BS	Boiler sides
CF, Lig.	Coal feed (Lignite)
Lim.	Limestone

TABLE D-2. SSMS ANALYSIS OF 10μ CYCLONE CATCH FROM SASS-1

SAMPLE ID: CAFB#1-10C-0-1 0.1058G

ELEMENT	VALUE(PPM)
U	5.3
TH	15.
BI	< 2.3
PB	62.
TL	< 0.38
AU	< 0.099
IR	< 0.15
OS	< 0.17
RE	< 0.11
W	< 0.58
HF	< 2.5
LU	< 1.0
YB	< 0.78
TM	< 0.30
ER	< 1.1
HO	< 0.21
DY	< 2.9
TB	< 0.012
GD	< 1.4
EU	1.1
SM	6.0
ND	13.
PR	4.1
CE	32.
LA	45.
BA	660.
CS	1.9
I	2.6
TE	< 1.6
SB	1.8
SN	5.7
IN	$ 140.
CD	1.5
PD	< 1.7
RH	< 0.31
RU	< 0.083
MO	2.4
NB	27.
ZR	150.
Y	54.
SR	850.
RB	19.
BR	83.
SE	< 27.
AS	200.
GE	12.
GA	31.
ZN	660.
CU	97.
NI	46.
CO	21.
FE	MC
MN	0.19 (%)
CR	40.
V	91.
TI	0.64 (%)
CA	6.5 (%)
K	0.17 (%)
S	MC
P	210.
SI	6.7 (%)
AL	MC
MG	0.48 (%)
NA	850.
B	340.
BE	3.6

TABLE D-3. SSMS ANALYSIS OF 3μ CYCLONE CATCH FROM SASS-1

SAMPLE ID: CAFB#1-3C-0-1 0.1003G

ELEMENT	VALUE(PPM)
U	9.8
TH	20.
BI	< 8.4
PB	50.
TL	< 0.15
AU	< 0.18
IR	< 0.28
OS	< 0.31
RE	< 0.20
W	< 0.73
HF	< 2.3
LU	< 0.89
YB	< 0.95
TM	< 0.068
ER	< 0.20
HO	< 0.38
DY	< 0.11
TB	< 0.022
GD	< 0.11
EU	< 0.71
SM	< 2.8
ND	12.
PR	4.1
CE	30.
LA	42.
BA	720.
CS	1.3
I	< 0.44
TE	< 0.83
SB	2.3
SN	5.3
IN	3 140.
CD	0.98
PD	< 1.6
RH	< 0.050
RU	< 0.15
MO	2.8
NB	25.
ZR	190.
Y	36.
SR	0.100(%)
RB	17.
BR	54.
SE	< 6.8
AS	210.
GE	< 8.1
GA	58.
ZN	230.
CU	32.
NI	85.
CO	14.
FE	1.7 (%)
MN	360.
CR	25.
V	96.
TI	0.36 (%)
CA	9.0 (%)
K	0.47 (%)
S	0.90 (%)
P	730.
SI	13. (%)
AL	1.9 (%)
MG	0.74 (%)
NA	0.31 (%)
B	0.11 (%)
BE	2.4
LI	24.

TABLE D-4. SSMS ANALYSIS OF 1μ CYCLONE CATCH FROM SASS-1

SAMPLE ID: CAFB#1-1C-0-1 0.1030G

ELEMENT	VALUE(PPM)
U	5.6
TH	23.
BI	< 9.7
PB	160.
TL	< 0.35
AU	< 0.42
IR	< 0.65
OS	< 0.71
RE	< 0.45
W	< 1.7
HF	< 11.
LU	< 2.1
YB	< 1.7
TM	< 0.16
ER	< 3.2
HO	< 0.62
DY	< 4.3
TB	< 0.051
GD	< 1.7
EU	< 1.1
SM	< 6.4
ND	14.
PR	4.7
CE	68.
LA	190.
BA	0.25 (%)
CS	1.6
I	< 0.24
TE	< 3.2
SB	5.1
SN	8.6
IN	$ 140.
CD	1.8
PD	< 1.2
RH	< 0.11
RU	< 0.35
MO	5.1
NB	57.
ZR	320.
Y	83.
SR	0.13 (%)
RB	29.
BR	89.
SE	< 22.
AS	470.
GE	< 9.8
GA	120.
ZN	340.
CU	100.
NI	140.
CO	32.
FE	2.2 (%)
MN	450.
CR	65.
V	220.
TI	0.81 (%)
CA	9.3 (%)
K	0.64 (%)
S	2.9 (%)
P	910.
SI	5.1 (%)
AL	1.9 (%)
MG	0.61 (%)
NA	0.16 (%)
B	0.45 (%)
BE	15.
LI	55.

TABLE D-5. SSMS ANALYSIS OF PARTICULATE FILTER FROM SASS-1

SAMPLE ID: CAFB#1-PF-A-1 0.0739G (10.96%)

ELEMENT	VALUE(UG)
U	0.93
TH	1.4
BI	1.5
PB	15.
TL	< 0.22
AU	< 0.010
IR	< 0.016
OS	< 0.018
RE	< 0.011
W	< 0.17
HF	< 0.19
LU	< 0.017
YB	< 0.11
TM	< 0.032
ER	< 0.12
HO	0.061
DY	0.45
TB	< 0.002
GD	< 0.15
EU	0.11
SM	0.53
ND	1.5
PR	0.44
CE	6.6
LA	3.6
BA	70.
CS	0.41
I	< 0.010
TE	< 0.29
SB	0.71
SN	1.4
IN	< 14.
CD	3.5
PD	< 0.098
RH	< 0.066
RU	< 0.010
MO	1.6
NB	0.30
ZR	7.4
Y	1.3
SR	59.
RB	2.0
BR	1.3
SE	< 1.1
AS	7.8
GE	< 0.36
GA	11.
ZN	36.
CU	14.
NI	7.0
CO	1.5
FE	680.
MN	31.
CR	17.
V	9.3
TI	200.
CA	4.9 (MG)
K	510.
S	2.1 (MG)
P	41.
SI	270.
AL	1.6 (MG)
MG	1000.
NA	MC
B	33.
BE	0.16
LI	0.68

TABLE D-6. SSMS ANALYSIS OF PARTICULATE FILTER BLANK FOR SASS-1 AND SASS-2

SAMPLE ID: CAFB-PFB-A-1 11.56% (305-)

ELEMENT	VALUE(UG)
U	< 0.025
TH	< 0.036
BI	< 0.011
PB	2.1
TL	< 0.014
AU	< 0.018
IR	< 0.028
OS	< 0.031
RE	< 0.020
W	< 0.026
HF	< 0.033
LU	< 0.008
YB	< 0.011
TM	< 0.007
ER	< 0.020
HO	< 0.007
DY	< 0.011
TB	< 0.003
GD	< 0.011
EU	< 0.005
SM	< 0.020
ND	< 0.025
PR	< 0.004
CE	0.049
LA	< 0.006
BA	32.
CS	0.069
I	0.096
TE	< 0.014
SB	0.16
SN	2.4
IN	$ 14.
CD	0.54
PD	< 0.014
RH	< 0.005
RU	< 0.018
MO	0.24
NB	0.012
ZR	0.54
Y	0.009
SR	1.4
RB	0.35
BR	1.2
SE	0.25
AS	0.67
GE	< 0.056
GA	< 0.100
ZN	37.
CU	19.
NI	11.
CO	0.24
FE	92.
MN	3.3
CR	0.70
V	0.21
TI	0.68
CA	73.
K	36.
S	230.
P	4.4
SI	170.
AL	16.
MG	35.
NA	1.7 (MG)
B	32.
BE	0.050
LI	0.13

TABLE D-7. SSMS ANALYSIS OF XAD-2 RESIN FROM SASS-1

SAMPLE ID: CAFB#1-XR-P-1 0.6928G

ELEMENT	VALUE(PPM)
U	< 0.084
TH	< 0.12
BI	< 0.038
PB	1.3
TL	< 0.047
AU	< 0.063
IR	< 0.097
OS	< 0.11
RE	< 0.067
W	< 0.090
HF	< 0.11
LU	< 0.026
YB	< 0.038
TM	< 0.023
ER	< 0.068
HO	< 0.022
DY	< 0.039
TB	< 0.011
GD	< 0.039
EU	< 0.018
SM	< 0.068
ND	< 0.085
PR	< 0.015
CE	< 0.020
LA	< 0.022
BA	< 0.35
CS	< 0.003
I	< 0.058
TE	< 0.049
SB	< 0.034
SN	0.37
IN	3 21.
CD	< 0.061
PD	< 0.049
RH	< 0.017
RU	< 0.063
MO	< 0.058
NB	< 0.007
ZR	< 0.027
Y	< 0.011
SR	0.96
RB	0.028
BR	4.1
SE	< 0.28
AS	0.052
GE	< 0.023
GA	< 0.009
ZN	7.3
CU	12.
NI	7.1
CO	< 0.22
FE	31.
MN	0.70
CR	0.42
V	0.094
TI	< 0.31
CA	43.
K	22.
S	570.
P	7.5
SI	65.
AL	9.4
MG	29.
NA	110.
B	1.4
BE	< 0.006
LI	0.040

TABLE D-8. SSMS ANALYSIS OF XAD-2 RESIN BLANK FOR SASS-1 AND SASS-2

SAMPLE ID: CAFB-XRB-P-1 0.6674G FROM 4.1G

ELEMENT	VALUE (PPM)
U	< 0.25
TH	< 0.36
BI	< 0.11
PB	1.3
TL	< 0.14
AU	< 0.18
IR	< 0.28
OS	< 0.31
RE	< 0.20
W	< 0.26
HF	< 0.33
LU	< 0.077
YB	< 0.11
TM	< 0.068
ER	< 0.20
HO	< 0.066
DY	< 0.11
TB	< 0.031
GD	< 0.11
EU	< 0.052
SM	< 0.20
ND	< 0.25
PR	< 0.044
CE	< 0.059
LA	< 0.064
BA	< 2.1
CS	< 0.010
I	< 0.17
TE	< 0.14
SB	< 0.100
SN	< 0.14
IN	$ 21.
CD	< 0.18
PD	< 0.14
RH	< 0.050
RU	< 0.18
MO	< 0.17
NB	< 0.021
ZR	< 0.080
Y	< 0.033
SR	1.4
RB	0.12
BR	12.
SE	0.82
AS	< 0.038
GE	< 0.069
GA	< 0.028
ZN	6.8
CU	8.7
NI	11.
CO	0.16
FE	16.
MN	2.0
CR	0.29
V	0.097
TI	0.91
CA	120.
K	120.
S	500.
P	22.
SI	46.
AL	16.
MG	15.
NA	180.
B	0.38
BE	< 0.001
LI	0.060

TABLE D-9. SSMS ANALYSIS OF COMPOSITE SAMPLE (CH) FROM SASS-1

SAMPLE ID: CAFR#1-CH-0-1 20ML

ELEMENT	VALUE(PPM)
U	< 0.003
TH	< 0.004
BI	< 0.001
PB	0.016
TL	< 0.002
AU	< 0.002
IR	< 0.004
OS	< 0.004
RE	< 0.002
W	< 0.003
HF	< 0.004
LU	< 0.001
YB	< 0.001
TM	< 0.001
ER	< 0.002
HO	< 0.001
DY	< 0.001
TB	< 0.001
GD	< 0.001
EU	< 0.001
SM	< 0.002
ND	< 0.003
PR	< 0.001
CE	< 0.001
LA	< 0.001
BA	0.006
CS	< 0.001
I	< 0.002
TE	< 0.002
SB	< 0.001
SN	0.84
IN	1.8
CD	0.018
PD	< 0.002
RH	< 0.001
RU	< 0.002
MO	< 0.002
NB	< 0.001
ZR	< 0.001
Y	< 0.001
SR	0.006
RB	0.001
BR	0.017
SE	0.010
AS	0.003
GE	< 0.001
GA	< 0.001
ZN	0.32
CU	0.30
NI	0.18
CO	0.006
FE	2.0
MN	0.073
CR	0.15
V	0.005
TI	0.008
CA	81.
K	0.16
S	57.
P	0.92
SI	0.30
AL	0.15
MG	0.14
NA	0.77
B	0.050
BE	0.000
LI	0.001

TABLE D-10. SSMS ANALYSIS OF COMPOSITE SAMPLE BLANK (CHB) FROM SASS-1

SAMPLE ID: CAFR#1-CHB-0-1 20ML

ELEMENT	VALUE(PPM)
U	< 0.002
TH	< 0.002
BI	< 0.001
PB	0.009
TL	< 0.001
AU	< 0.001
TR	< 0.002
OS	< 0.002
RE	< 0.001
W	< 0.002
HF	< 0.002
LU	< 0.001
YB	< 0.001
TM	< 0.001
ER	< 0.001
HO	< 0.001
DY	< 0.001
TB	< 0.001
GD	< 0.001
EU	< 0.001
SM	< 0.001
ND	< 0.002
PR	< 0.001
CE	< 0.001
LA	< 0.001
BA	< 0.007
CS	< 0.001
I	< 0.001
TE	< 0.001
SB	< 0.001
SN	0.24
IN	$ 1.8
CD	0.005
PD	< 0.001
RH	< 0.002
RU	< 0.001
MO	< 0.001
NB	< 0.001
ZR	< 0.001
Y	< 0.001
SR	0.002
RB	0.001
BR	0.12
SE	0.004
AS	0.003
GE	< 0.001
GA	< 0.001
ZN	0.11
CU	0.023
NI	0.020
CO	0.003
FE	0.22
MN	0.005
CR	0.003
V	0.001
TI	0.007
CA	3.0
K	0.085
S	3.6
P	0.52
SI	0.13
AL	0.047
MG	0.022
NA	1.3
B	0.001
BE	< 0.000
LI	0.001

TABLE D-11. SSMS ANALYSIS OF 10μ CYCLONE CATCH FROM SASS-2

SAMPLE ID: CAF8#2-10C-0-1 0.10246

ELEMENT	VALUE(PPM)
U	6.2
TH	17.
BI	< 3.7
PB	46.
TL	< 0.19
AU	< 0.23
IR	< 0.36
OS	< 0.39
RE	< 0.25
W	< 0.93
HF	< 12.
LU	< 3.3
YB	< 1.2
TM	< 0.48
ER	< 1.8
HO	< 0.34
DY	< 2.4
TB	< 0.028
GD	< 1.7
EU	< 1.2
SM	< 5.9
ND	< 22.
PR	5.2
CE	75.
LA	76.
BA	0.14 (%)
CS	1.7
I	4.5
TE	< 1.8
SB	8.0
SN	7.5
IN	$ 140.
CD	0.82
PD	< 2.0
RH	< 0.35
RU	< 0.20
MO	4.0
NB	32.
ZR	220.
Y	46.
SR	0.43 (%)
RB	44.
BR	140.
SE	< 45.
AS	780.
GE	< 14.
GA	74.
ZN	0.24 (%)
CU	110.
NI	53.
CO	18.
FE	MC
MN	0.25 (%)
CR	51.
V	210.
TI	0.82 (%)
CA	5.1 (%)
K	0.46 (%)
S	15. (%)
P	930.
SI	MC
AL	MC
MG	0.98 (%)
NA	0.30 (%)
B	0.25 (%)
BE	1.5
LI	54.

TABLE D-12. SSMS ANALYSIS OF 3μ CYCLONE CATCH FROM SASS-2

SAMPLE ID: CAFB#2-3C-0-1 0.1005G

ELEMENT	VALUE(PPM)
U	5.5
TH	16.
BI	< 6.7
PB	110.
TL	< 0.086
AU	< 0.100
IR	< 0.16
OS	< 0.17
RE	< 0.11
W	< 1.2
HF	< 3.9
LU	< 1.5
YB	< 1.1
TM	< 0.039
ER	< 0.79
HO	< 0.43
DY	< 2.2
TB	< 0.013
GD	< 1.3
EU	< 1.1
SM	< 4.5
ND	9.8
PR	3.2
CE	17.
LA	95.
BA	0.23 (%)
CS	1.0
I	< 0.17
TE	< 0.98
SB	3.6
SN	4.7
IN	$ 140.
CD	0.77
PD	< 0.89
RH	< 0.028
RU	< 0.087
MO	2.5
NB	20.
ZR	190.
Y	20.
SR	0.11 (%)
RB	20.
BR	62.
SE	< 28.
AS	120.
GE	8.9
GA	66.
ZN	190.
CU	72.
NI	48.
CO	16.
FE	1.7 (%)
MN	200.
CR	14.
V	96.
TI	0.37 (%)
CA	9.0 (%)
K	0.27 (%)
S	2.2 (%)
P	230.
SI	4.4 (%)
AL	1.3 (%)
MG	0.23 (%)
NA	0.11 (%)
B	600.
BE	0.94
LI	14.

TABLE D-13. SSMS ANALYSIS OF 1μ CYCLONE CATCH FROM SASS-2

SAMPLE ID: CAFB#2-1C-0-1 0.1007G

ELEMENT	VALUE(PPM)
U	3.9
TH	7.7
BI	< 0.28
PB	220.
TL	< 2.4
AU	< 0.100
IR	< 0.16
OS	< 0.17
RE	< 0.11
W	< 0.86
HF	< 2.6
LU	< 0.50
YB	< 0.58
TM	< 0.45
ER	< 0.78
HO	< 0.22
DY	< 2.2
TB	< 0.012
GD	< 0.75
EU	< 0.40
SM	1.6
ND	7.0
PR	6.1
CE	47.
LA	67.
BA	0.23 (%)
CS	2.0
I	< 0.25
TE	< 0.98
SB	13.
SN	13.
IN	$ 140.
CD	0.95
PD	< 1.3
RH	< 0.028
RU	< 0.087
MO	3.6
NB	56.
ZR	270.
Y	57.
SR	0.16 (%)
RB	20.
BR	42.
SE	< 28.
AS	630.
GE	50.
GA	210.
ZN	260.
CU	100.
NI	70.
CO	22.
FE	3.1 (%)
MN	370.
CR	420.
V	290.
TI	0.67 (%)
CA	MC
K	0.27 (%)
S	1.2 (%)
P	0.12 (%)
SI	7.0 (%)
AL	MC
MG	0.99 (%)
NA	0.30 (%)
B	0.11 (%)
BE	2.6
LI	14.

TABLE D-14. SSMS ANALYSIS OF PARTICULATE FILTER FROM SASS-2

SAMPLE ID: CAFB#2-PF-A-1 0.0438G

ELEMENT	VALUE(UG)
U	0.27
TH	0.40
HI	0.47
PB	7.7
TL	< 0.091
AU	< 0.006
IR	< 0.009
OS	< 0.010
RE	< 0.061
W	< 0.072
HF	< 0.079
LU	< 0.007
YB	< 0.041
TM	< 0.013
ER	< 0.055
HO	< 0.036
DY	< 0.40
TB	< 0.017
GD	< 0.074
EU	0.022
SM	0.15
ND	0.89
PR	0.14
CE	2.0
LA	1.1
BA	41.
CS	0.12
I	0.011
TE	0.12
SB	0.79
SN	2.2
IN	$ 14.
CD	1.0
PD	< 0.039
RH	< 0.009
RU	< 0.095
MO	0.99
NB	0.18
ZR	1.9
Y	0.55
SR	53.
RB	0.66
BR	0.54
SE	3.7
AS	3.6
GE	0.11
GA	7.7
ZN	16.
CU	11.
NI	2.0
CO	0.23
FE	220.
MN	9.9
CR	6.9
V	1.8
TI	64.
CA	2.9 (MG)
K	55.
S	1.3 (MG)
P	13.
SI	100.
AL	1.3 (MG)
MG	200.
NA	1.5 (MG)
B	11.
BE	0.024
LI	0.22

TABLE D-15. SSMS ANALYSIS OF XAD-2 RESIN FROM SASS-2

SAMPLE ID: CAFB#2-XR-P-1 0.6787G FORM 6.5G

ELEMENT	VALUE(PPM)
U	< 0.49
TH	< 0.70
BI	< 0.22
PB	1.3
TL	< 0.27
AU	< 0.36
IR	< 0.56
OS	< 0.61
RE	< 0.38
W	< 0.52
HF	< 0.64
LU	< 0.15
YB	< 0.22
TM	< 0.13
ER	< 0.39
HO	< 0.13
DY	< 0.22
TB	< 0.061
GD	< 0.22
EU	< 0.100
SM	< 0.39
ND	< 0.49
PR	< 0.086
CE	< 0.12
LA	< 0.13
BA	0.48
CS	< 0.020
I	< 0.34
TE	< 0.28
SB	< 0.20
SN	< 0.28
IN	21.
CD	< 0.35
PD	< 0.28
RH	< 0.098
RU	< 0.36
MO	< 0.33
NB	< 0.042
ZR	< 0.16
Y	< 0.065
SR	1.3
RB	0.23
BR	8.2
SE	< 0.19
AS	< 0.075
GE	< 0.13
GA	< 0.055
ZN	9.4
CU	12.
NI	20.
CO	0.15
FE	31.
MN	1.1
CR	0.54
V	0.064
TI	0.89
CA	82.
K	49.
S	0.58 (%)
P	22.
SI	47.
AL	18.
MG	29.
NA	360.
B	4.2
BE	0.011
LI	0.23

TABLE D-16. SSMS ANALYSIS OF COMPOSITE SAMPLE (CH) FROM SASS-2

SAMPLE ID: CAFB#2-CH-0-1 20ML

ELEMENT	VALUE (PPM)
U	< 0.008
TH	< 0.012
BI	< 0.004
PB	< 0.008
TL	< 0.005
AU	< 0.006
IR	< 0.009
OS	< 0.010
RE	< 0.007
W	< 0.009
HF	< 0.011
LU	< 0.003
YB	< 0.004
TM	< 0.002
ER	< 0.007
HO	< 0.002
DY	< 0.004
TB	< 0.001
GD	< 0.004
EU	< 0.002
SM	< 0.007
ND	< 0.008
PR	< 0.001
CE	< 0.002
LA	< 0.002
BA	0.008
CS	< 0.001
I	< 0.006
TE	< 0.005
SB	< 0.003
SN	1.1
IN	$ 0.72
CD	0.045
PD	< 0.005
RH	< 0.002
RU	< 0.006
MO	0.023
NB	0.002
ZR	< 0.003
Y	< 0.001
SR	0.004
RB	0.001
BR	0.024
SE	0.059
AS	0.002
GE	< 0.002
GA	< 0.001
ZN	0.18
CU	0.29
NI	0.19
CO	0.005
FE	0.74
MN	0.036
CR	0.12
V	0.002
TI	0.038
CA	0.84
K	0.29
S	130.
P	2.4
SI	0.59
AL	0.22
MG	0.27
NA	2.1
B	0.77
BE	< 0.001
LI	0.005

TABLE D-17. SSMS ANALYSIS OF COMPOSITE SAMPLE BLANK (CHB) FROM SASS-2

SAMPLE ID: CAFA#2-CHB-0-1 20ML

ELEMENT	VALUE(PPM)
U	< 0.024
TH	< 0.034
BI	< 0.011
PB	< 0.022
TL	< 0.013
AU	< 0.018
IR	< 0.027
OS	< 0.030
RE	< 0.019
W	< 0.025
HF	< 0.031
LU	< 0.007
YB	< 0.011
TM	< 0.006
ER	< 0.019
HO	< 0.006
DY	< 0.011
TB	< 0.003
GD	< 0.011
EU	< 0.005
SM	< 0.019
ND	< 0.024
PR	< 0.004
CE	< 0.006
LA	< 0.006
BA	< 0.008
CS	< 0.001
I	< 0.016
TE	< 0.014
SB	< 0.009
SN	1.3
IN	$ 0.72
CD	0.039
PD	< 0.014
RH	< 0.005
RU	< 0.018
MO	< 0.016
NB	< 0.002
ZR	< 0.008
Y	< 0.003
SR	< 0.004
RB	< 0.001
BR	0.13
SE	< 0.009
AS	< 0.004
GE	< 0.006
GA	< 0.003
ZN	1.0
CU	0.076
NI	0.38
CO	< 0.001
FE	0.53
MN	0.026
CR	0.009
V	0.002
TI	0.021
CA	0.85
K	0.16
S	9.6
P	2.1
SI	2.3
AL	0.22
MG	0.21
NA	5.9
B	0.025
BE	0.000
LI	0.003

TABLE D-18. SSMS ANALYSIS OF CYCLONE CATCH FROM RAC-1

SAMPLE ID: CAFB-RAC 1 CYCLONE 0.10360

ELEMENT	VALUE (PPM)
U	4.5
TH	8.5
BI	0.64
PB	22.
TL	8.8
AU	< 0.11
IR	< 0.18
OS	< 0.19
RE	0.67
W	0.32
HF	< 2.0
LU	< 0.55
YB	< 0.84
TM	< 0.35
ER	< 0.86
HO	< 0.057
DY	< 0.64
TB	< 0.16
GD	< 0.39
EU	< 0.44
SM	1.7
ND	3.8
PR	1.3
CE	13.
LA	18.
BA	250.
CS	0.42
I	2.2
TE	< 0.87
SB	1.0
SN	1.6
IN	> 68.
CD	0.33
PD	< 0.97
RH	< 0.12
RU	< 0.095
MO	1.2
NB	7.7
ZR	87.
Y	15.
SR	590.
RB	7.7
BR	17.
SE	5.9
AS	19.
GE	< 5.0
GA	17.
ZN	760.
CU	28.
NI	0.11 (%)
CO	6.0
FE	3.4 (%)
MN	710.
CR	25.
V	59.
TI	0.22 (%)
CA	4.4 (%)
K	0.17 (%)
S	3.9 (%)
P	45.
SI	2.0 (%)
AL	0.31 (%)
MG	0.16 (%)
NA	150.
B	220.
BE	0.51
LI	8.1

TABLE D-19. SSMS ANALYSIS OF NEAT FILTER PARTICULATE FROM RAC-1

SAMPLE ID: CAFH-RAC 1-0-1 0.11896

ELEMENT	VALUE(PPM)
U	< 4.8
TH	< 9.6
BI	< 2.9
PB	43.
TL	< 0.15
AU	< 0.18
IR	< 0.28
OS	< 0.50
RE	< 1.6
W	< 1.5
HF	< 3.5
LU	< 1.8
YB	< 0.90
TM	< 0.57
ER	< 1.6
HO	< 0.55
DY	< 4.2
TB	< 0.022
GD	< 1.1
EU	< 2.0
SM	5.9
ND	15.
PR	5.5
CE	29.
LA	41.
BA	760.
CS	1.5
I	< 0.60
TE	< 1.4
SB	1.6
SN	7.5
IN	5 59.
CD	0.92
PD	< 1.0
RH	< 0.049
RU	< 0.15
MO	1.9
NB	17.
ZR	240.
Y	17.
SR	660.
RB	17.
BR	< 5.0
SE	< 4.6
AS	7.5
GE	< 4.2
GA	< 37.
ZN	100.
CU	44.
NI	41.
CO	4.7
FE	1.6 (%)
MN	190.
CR	17.
V	95.
TI	1.2 (%)
CA	12. (%)
K	0.46 (%)
S	0.88 (%)
P	210.
SI	9.7 (%)
AL	MC
MG	0.46 (%)
NA	0.13 (%)
B	0.100(%)
BE	0.81
LI	7.1

TABLE D-20. SSMS ANALYSIS OF NEAT FILTER PARTICULATE FROM RAC-3

SAMPLE ID: CAFH-RAC 3-0-1 0.11076

ELEMENT	VALUE (PPM)
U	< 1.7
TH	< 5.1
BI	< 2.2
PB	65.
TL	< 0.22
AU	< 0.27
IR	< 0.42
OS	< 0.46
RE	< 0.29
W	< 2.3
HF	< 0.95
LU	< 0.94
YB	< 0.95
TM	< 0.100
ER	< 2.1
HO	< 0.049
DY	< 2.8
TB	< 0.035
GD	< 0.94
EU	0.71
SM	2.9
ND	9.0
PR	5.0
CE	31.
LA	31.
BA	580.
CS	1.0
I	< 0.46
TE	< 1.0
SB	4.9
SN	5.5
IN	< 65.
CD	0.57
PD	< 0.28
RH	< 0.074
RU	< 0.23
MO	2.0
NB	13.
ZR	110.
Y	19.
SR	700.
RB	15.
BR	7.6
SE	< 15.
AS	35.
GE	< 15.
GA	< 78.
ZN	110.
CU	48.
NI	44.
CO	7.2
FE	1.4 (%)
MN	290.
CR	15.
V	140.
TI	0.31 (%)
CA	6.0 (%)
K	0.41 (%)
CL	< 0.062
S	1.3 (%)
P	590.
SI	12. (%)
AL	MC
MG	0.83 (%)
NA	MC
F	< 0.058
H	0.16 (%)

TABLE D-21. SSMS ANALYSIS OF CAFB LIGNITE

SAMPLE ID: LIGNITE (S/N50010/77) 0.6757G

ELEMENT	VALUE(PPM)
U	0.23
TH	0.32
BI	0.20
PB	9.6
TL	< 0.029
AU	< 0.036
IR	< 0.055
OS	< 0.060
RE	< 0.038
W	0.100
HF	< 0.12
LU	< 0.031
YB	< 0.090
TM	< 0.013
ER	< 0.039
HO	< 0.006
DY	0.20
TB	0.024
GD	0.061
EU	< 0.015
SM	0.18
ND	0.60
PR	0.14
CE	1.1
LA	1.5
BA	38.
CS	0.046
I	0.040
TE	0.075
SB	0.30
SN	2.1
IN	3 21.
CD	0.17
PD	< 0.037
RH	< 0.010
RU	< 0.030
MO	0.43
NB	0.64
ZR	5.9
Y	0.65
SR	37.
RB	0.59
BR	0.23
SE	2.8
AS	1.5
GE	0.20
GA	2.6
ZN	13.
CU	15.
NI	23.
CO	0.50
FE	0.19 (%)
MN	22.
CR	2.7
V	14.
TI	230.
CA	0.17 (%)
K	92.
S	0.23 (%)
P	42.
SI	1.3 (%)
AL	0.23 (%)
MG	130.
NA	180.
B	21.
BE	0.030
LI	0.82

TABLE D-22. SSMS ANALYSIS OF CAFB LIMESTONE

SAMPLE ID: LIMESTONE (LS2) 0.13246

ELEMENT	VALUE(PPM)
U	< 0.37
TH	< 0.53
HI	< 0.23
PB	12.
TL	< 0.27
AU	< 0.33
IR	< 0.51
OS	< 0.55
RE	< 0.35
W	< 0.24
HF	< 1.2
LU	< 0.29
YB	< 0.21
TM	< 0.12
ER	< 0.36
HO	< 0.059
DY	< 0.20
TB	< 0.040
GD	< 0.20
EU	< 0.14
SM	< 0.43
ND	< 0.30
PR	0.22
CE	0.42
LA	1.8
BA	160.
CS	0.052
I	4.5
TE	< 0.25
SB	0.96
SN	4.7
IN	110.
CD	< 0.059
PD	< 0.34
RH	< 0.089
RU	< 0.28
MO	0.48
NB	< 0.13
ZR	1.2
Y	0.52
SR	210.
RB	2.1
BR	< 18.
SE	< 4.3
AS	< 0.079
GE	< 0.11
GA	< 0.048
ZN	2.1
CU	4.7
NI	14.
CO	0.58
FE	0.15 (%)
MN	8.8
CR	0.76
V	6.4
TI	80.
CA	16. (%)
K	220.
S	530.
P	39.
SI	430.
AL	130.
MG	0.22 (%)
NA	110.
B	17.
BE	0.012
LI	0.086

TABLE D-23. SSMS ANALYSIS OF CAFB FINES RETURN

SAMPLE ID: CAFB FINES RET 0.0709G

ELEMENT	VALUE(PPM)
U	5.1
TH	10.
BI	< 0.093
PB	27.
TL	< 0.11
AU	< 0.14
IR	< 0.21
OS	< 0.23
RE	< 0.14
W	< 0.54
HF	< 2.5
LU	< 1.4
YB	< 0.70
TM	< 0.14
ER	< 1.0
HO	0.20
DY	< 2.8
TB	< 0.016
GD	< 0.98
EU	0.52
SM	< 3.4
ND	9.1
PR	4.1
CE	44.
LA	44.
BA	910.
CS	1.9
I	0.45
TE	< 0.74
SB	3.3
SN	5.5
IN	< 190.
CD	0.45
PD	< 0.79
RH	< 0.21
RU	< 0.11
MO	2.9
NB	< 37.
ZR	180.
Y	26.
SR	900.
RB	26.
BR	110.
SE	< 19.
AS	270.
GE	< 2.9
GA	21.
ZN	< 0.041
CU	47.
NI	21.
CO	10.
FE	4.1 (%)
MN	260.
CR	59.
V	120.
TI	0.87 (%)
CA	MC
K	0.35 (%)
S	0.94 (%)
P	540.
SI	MC
AL	MC
MG	0.50 (%)
NA	640.
B	140.
BE	0.30
LI	3.1

TABLE D-24. SSMS ANALYSIS OF CAFB BOILER BACK

SAMPLE ID: CAFB BOILER BACK 0.09616

ELEMENT	VALUE(PPM)
U	4.1
TH	16.
BI	< 0.074
PB	29.
TL	< 0.85
AU	< 0.11
IR	< 0.17
OS	< 0.18
RE	< 0.12
W	< 0.90
HF	< 5.4
LU	< 0.77
YB	< 0.43
TM	< 0.33
ER	< 1.7
HO	< 0.45
DY	< 2.2
TB	< 0.013
GD	< 0.67
EU	< 0.77
SM	< 4.7
ND	15.
PR	4.5
CE	35.
LA	49.
BA	430.
CS	3.0
I	< 0.12
TE	< 0.83
SB	1.8
SN	6.3
IN	$ 150.
CD	0.77
PD	< 1.3
RH	< 0.029
RU	< 0.091
MO	1.9
NB	59.
ZR	200.
Y	30.
SR	0.11 (%)
RB	21.
BR	46.
SE	< 15.
AS	120.
GE	< 4.8
GA	34.
ZN	62.
CU	75.
NI	50.
CO	5.7
FE	3.3 (%)
MN	210.
CR	25.
V	100.
TI	0.38 (%)
CA	7.1 (%)
K	0.51 (%)
S	0.75 (%)
P	230.
SI	MC
AL	MC
MG	0.35 (%)
NA	960.
B	210.
BE	0.49
LI	14.

TABLE D-25. SSMS ANALYSIS OF CAFB BOILER SIDES

SAMPLE ID: CAFB BOILER SIDES 0.09826

ELEMENT	VALUE(PPM)
U	14.
TH	20.
BI	< 0.72
PB	71.
TL	< 1.5
AU	< 0.19
IR	< 0.29
OS	< 0.31
RE	< 0.20
W	< 1.6
HF	< 39.
LU	< 1.3
YB	< 1.4
TM	< 0.069
ER	< 2.1
HO	< 0.78
DY	< 5.4
TB	< 0.023
GD	< 1.9
EU	< 1.0
SM	< 5.7
ND	18.
PR	5.7
CE	60.
LA	85.
BA	0.11 (%)
CS	5.3
I	< 0.63
TE	< 2.5
SB	6.8
SN	12.
IN	> 150.
CD	4.0
PD	< 6.7
RH	< 0.59
RU	< 0.16
MO	31.
NB	73.
ZR	640.
Y	51.
SR	0.11 (%)
RB	36.
BR	79.
SE	< 9.7
AS	370.
GE	< 23.
GA	59.
ZN	100.
CU	92.
NI	0.14 (%)
CO	28.
FE	MC
MN	0.20 (%)
CR	120.
V	290.
TI	2.1 (%)
CA	MC
K	0.48 (%)
S	0.70 (%)
P	410.
SI	MC
AL	MC
MG	0.70 (%)
NA	830.
B	280.
BE	0.59
LI	25.

TABLE D-26. SSMS ANALYSIS OF CAFB STACK KNOCKOUT

SAMPLE ID: CAFB STACK KO 0.08806

ELEMENT	VALUE (PPM)
U	9.3
TH	37.
BI	< 0.67
PB	120.
TL	< 1.9
AU	< 0.35
IR	< 0.54
OS	< 0.59
RE	< 0.37
W	< 1.4
HF	< 13.
LU	< 1.7
YB	< 2.7
TM	< 1.1
ER	< 3.1
HO	< 1.0
DY	< 7.5
TB	< 0.042
GD	< 1.8
EU	< 1.8
SM	< 7.5
ND	34.
PR	11.
CE	160.
LA	110.
BA	0.15 (%)
CS	6.8
I	< 1.2
TE	< 2.7
SB	4.4
SN	14.
IN	$ 160.
CD	2.6
PD	< 2.0
RH	< 0.095
RU	< 0.29
MO	4.2
NB	47.
ZR	330.
Y	48.
SR	0.11 (%)
RB	66.
BR	100.
SE	< 36.
AS	120.
GE	< 7.4
GA	79.
ZN	140.
CU	120.
NI	220.
CO	18.
FE	1.8 (%)
MN	370.
CR	62.
V	320.
TI	1.1 (%)
CA	9.4 (%)
K	1.6 (%)
S	1.7 (%)
P	760.
SI	MC
AL	MC
MG	0.43 (%)
NA	0.100(%)
B	0.12 (%)
BE	1.6
LI	81.

TABLE D-27. SSMS ANALYSIS OF CAFB STACK CYCLONE

SAMPLE ID: CAFB STACK CYLCONE 0.1064G

ELEMENT	VALUE(PPM)
U	6.6
TH	19.
BI	< 2.0
PB	34.
TL	< 0.14
AU	< 0.17
IR	< 0.27
OS	< 0.29
RE	< 0.18
W	< 1.0
HF	< 9.4
LU	< 1.8
YB	< 1.4
TM	< 0.75
ER	< 2.7
HO	0.51
DY	5.3
TB	< 0.021
GD	< 2.5
EU	0.95
SM	< 8.9
ND	17.
PR	7.2
CE	56.
LA	110.
BA	680.
CS	1.2
I	0.83
TE	< 0.95
SB	3.1
SN	3.5
IN	8 130.
CD	1.0
PD	< 1.0
RH	< 0.19
RU	< 0.15
MO	2.6
NB	47.
ZR	230.
Y	68.
SR	0.12 (%)
RB	42.
BR	73.
SE	< 18.
AS	190.
GE	< 5.6
GA	39.
ZN	< 59.
CU	61.
NI	56.
CO	13.
FE	2.8 (%)
MN	620.
CR	31.
V	160.
TI	1.1 (%)
CA	6.7 (%)
K	0.82 (%)
S	0.43 (%)
P	690.
SI	MC
AL	MC
MG	0.64 (%)
NA	0.27 (%)
B	590.
BE	1.1
LI	68.

TABLE D-28. SSMS ANALYSIS OF CAFB REGENERATOR CYCLONE

SAMPLE ID: CAFB REG CYCLONE 0.0888G

ELEMENT	VALUE (PPM)
U	8.9
TH	24.
BI	< 0.45
PB	53.
TL	< 1.3
AU	< 0.12
IR	< 0.18
OS	< 0.20
RE	< 0.12
W	< 0.47
HF	< 8.7
LU	< 1.7
YB	< 0.92
TM	< 0.56
ER	< 1.8
HO	0.98
DY	< 3.8
TB	< 0.014
GD	< 1.7
EU	1.2
SM	< 6.0
ND	16.
PR	6.9
CE	53.
LA	38.
BA	0.14 (%)
CS	2.3
I	2.2
TE	< 0.90
SB	3.0
SN	3.7
IN	> 160.
CD	1.3
PD	< 1.5
RH	< 0.37
RU	< 0.098
MO	2.8
NB	32.
ZR	510.
Y	64.
SR	0.100(%)
RB	16.
BR	70.
SE	< 32.
AS	710.
GE	< 6.8
GA	52.
ZN	67.
CU	57.
NI	54.
CO	12.
FE	1.9 (%)
MN	230.
CR	48.
V	180.
TI	0.41 (%)
CA	7.7 (%)
K	0.100(%)
S	2.5 (%)
P	250.
SI	7.9 (%)
AL	MC
MG	0.56 (%)
NA	0.100(%)
B	400.
BE	1.1
LI	8.4

TABLE D-29. SSMS ANALYSIS OF CAFB GASIFIER BED

SAMPLE ID: CAFB GAS BED #1179 0.09496

ELEMENT	VALUE(PPM)
U	< 0.74
TH	< 1.0
BI	< 0.44
PB	< 2.8
TL	< 0.54
AU	< 0.65
IR	< 1.0
OS	< 1.1
RE	< 0.69
W	< 0.46
HF	< 2.3
LU	< 0.56
YB	< 0.41
TM	< 0.24
ER	< 0.70
HO	< 0.12
DY	< 0.40
TB	< 0.078
GD	< 0.40
EU	< 0.28
SM	< 0.84
ND	< 0.58
PR	< 0.86
CE	9.7
LA	14.
BA	150.
CS	0.60
I	< 0.13
TE	< 0.49
SB	23.
SN	19.
IN	$ 150.
CD	< 0.12
RH	< 0.18
RU	< 0.54
MO	< 0.33
NB	12.
ZR	110.
Y	17.
SR	290.
RB	15.
BR	72.
SE	< 48.
AS	720.
GE	< 15.
GA	47.
ZN	67.
CU	40.
NI	36.
CO	9.1
FE	2.5 (%)
MN	180.
CR	11.
V	100.
TI	0.18 (%)
CA	MC
K	0.56 (%)
S	3.2 (%)
P	260.
SI	MC
AL	0.41 (%)
MG	1.4 (%)
NA	390.
B	960.
BE	0.77
LI	25.

TABLE D-30. SSMS ANALYSIS OF CAFB REGENERATOR BED

SAMPLE ID: CAFB REG BED #1181 0.0865G

ELEMENT	VALUE(PPM)
U	1.1
TH	2.3
BI	< 0.083
PB	2.4
TL	< 0.100
AU	< 0.12
IR	< 0.19
OS	< 0.20
RE	< 0.13
W	< 0.24
HF	< 1.5
LU	< 0.100
YB	< 0.077
TM	< 0.25
ER	< 0.13
HO	< 0.12
DY	< 0.44
TB	< 0.015
GD	< 0.42
EU	< 0.052
SM	< 0.16
ND	2.0
PR	0.47
CE	6.8
LA	7.3
BA	130.
CS	0.45
I	0.20
TE	< 0.091
SB	6.1
SN	9.8
IN	$ 170.
CD	0.041
PD	< 1.0
RH	< 0.18
RU	< 0.100
MO	1.3
NB	8.2
ZR	35.
Y	4.4
SR	220.
RB	29.
BR	36.
SE	< 6.2
AS	240.
GE	5.3
GA	14.
ZN	24.
CU	21.
NI	18.
CO	3.2
FE	0.36 (%)
MN	76.
CR	4.2
V	38.
TI	0.23 (%)
CA	MC
K	0.31 (%)
S	0.30 (%)
P	85.
SI	3.2 (%)
AL	3.0 (%)
MG	0.48 (%)
NA	0.11 (%)
B	140.
BE	0.20
LI	16.

TABLE D-31. SSMS ANALYSIS OF CAFB OIL FEED

SAMPLE 101 FOS OIL 0.8556G

ELEMENT	VALUE(PPM)
U	< 0.049
TH	< 0.071
BI	0.12
PB	11.
TL	< 0.028
AU	< 0.037
IR	< 0.057
OS	< 0.062
RE	< 0.034
W	< 0.052
HF	< 0.065
LU	< 0.015
YB	< 0.022
TM	< 0.014
ER	< 0.040
HO	< 0.013
DY	< 0.023
TB	< 0.006
GD	< 0.023
EU	< 0.010
SM	< 0.040
ND	< 0.050
PR	< 0.009
CE	< 0.012
LA	< 0.013
BA	0.41
CS	0.006
I	0.067
TE	< 0.029
SB	0.15
SN	0.45
IN	5 17.
CD	0.82
PD	< 0.029
RH	< 0.23
RU	< 0.037
MO	0.79
NB	0.924
ZR	0.045
Y	< 0.007
SR	0.38
RB	0.093
BR	0.28
SE	< 0.019
AS	1.3
GE	< 0.014
GA	< 0.006
ZN	48.
CU	28.
NI	97.
CO	0.67
FE	33.
MN	2.3
CR	0.98
V	49.
TI	0.32
CA	83.
K	99.
S	0.42 (%)
P	15.
SI	110.
AL	31.
MG	31.
NA	150.
H	0.11
BE	0.001
LI	0.34

TABLE D-32. SSMS ANALYSIS OF CAFB BITUMEN

SAMPLE ID: BITUMEN 0.9791G

ELEMENT	VALUE (PPM)
U	< 0.060
TH	< 0.087
BI	< 0.027
PB	3.7
TL	< 0.034
AU	< 0.045
IR	< 0.069
OS	< 0.075
RE	< 0.047
W	< 0.064
HF	< 0.079
LU	< 0.019
YB	< 0.027
TM	< 0.016
ER	< 0.048
HO	< 0.016
DY	< 0.028
TB	< 0.007
GD	< 0.028
EU	< 0.012
SM	< 0.048
ND	< 0.060
PR	< 0.011
CE	0.040
LA	< 0.016
BA	1.4
CS	0.007
I	< 0.041
TE	< 0.035
SB	0.091
SN	0.76
IN	> 15.
CD	0.24
PD	< 0.035
RH	< 0.012
RU	< 0.044
MO	0.23
NB	0.014
ZR	< 0.019
Y	< 0.008
SR	0.33
RB	0.056
BR	< 0.059
SE	1.3
AS	4.6
GE	< 0.017
GA	0.056
ZN	110.
CU	20.
NI	110.
CO	0.58
FE	40.
MN	2.0
CR	1.2
V	150.
TI	0.39
CA	59.
K	24.
S	0.28 (%)
P	18.
SI	140.
AL	11.
MG	29.
NA	19.
B	1.9
BE	0.016
LI	0.53

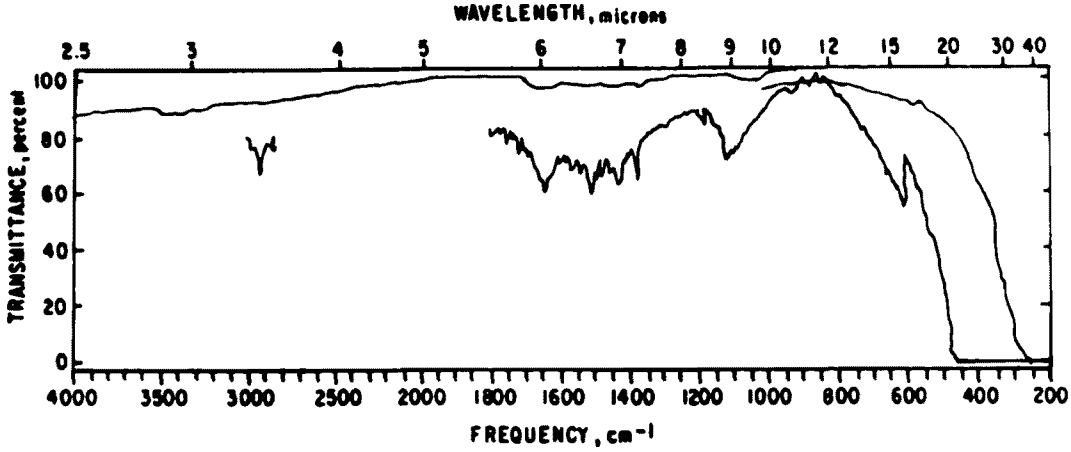


Figure D-1. IR spectrum of 10μ cyclone catch from SASS-1. Content of spectrum is less than or equal to that of blank.

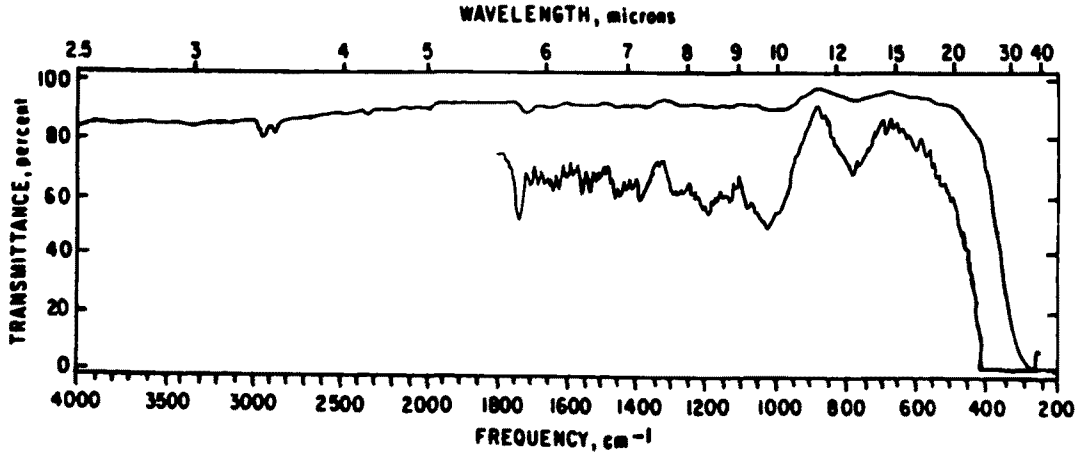


Figure D-2. IR spectrum of 3μ cyclone catch from SASS-1. Peaks indicate saturated esters; possible aryl or unsaturated esters or ethers, organosilicon compounds.

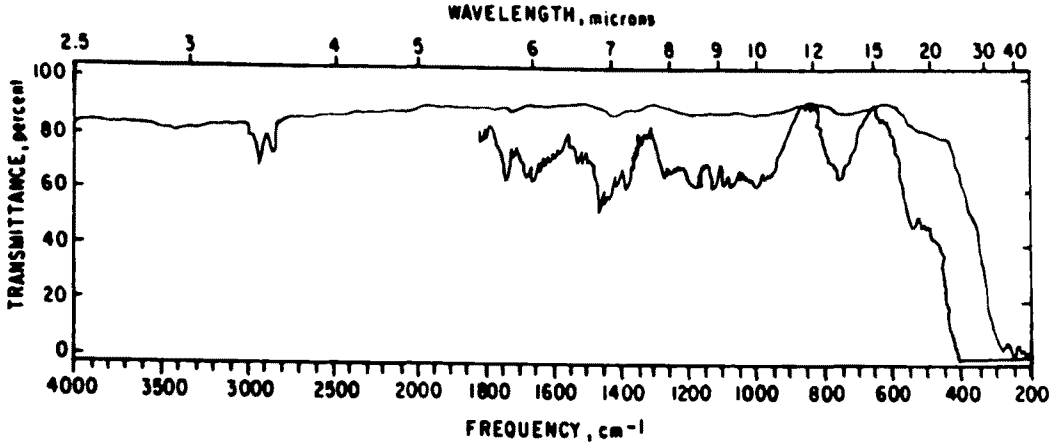


Figure D-3. IR spectrum of 1μ cyclone catch from SASS-1. Peaks indicate saturated esters and hydrocarbons; possible aryl or unsaturated esters or ethers.

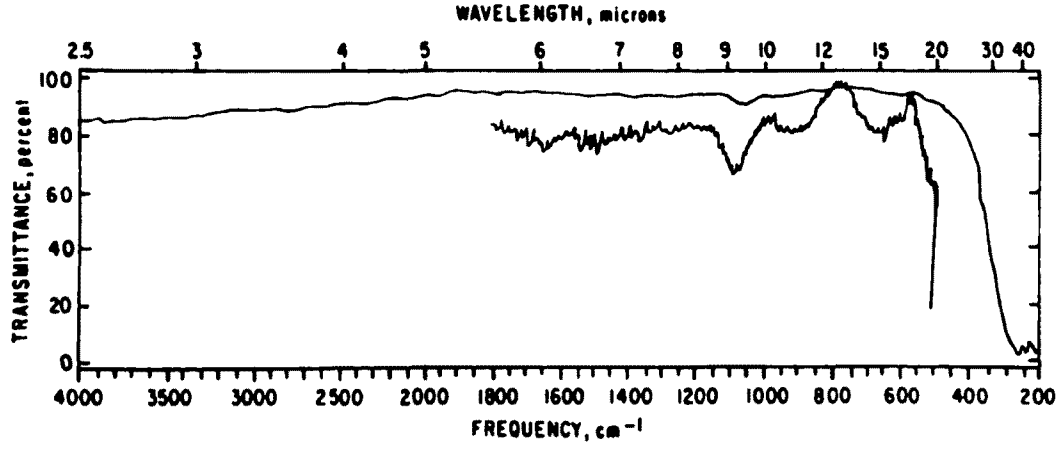


Figure D-4. IR spectrum of particulate filter from SASS-1. Content of spectrum is less than or equal to that of blank.

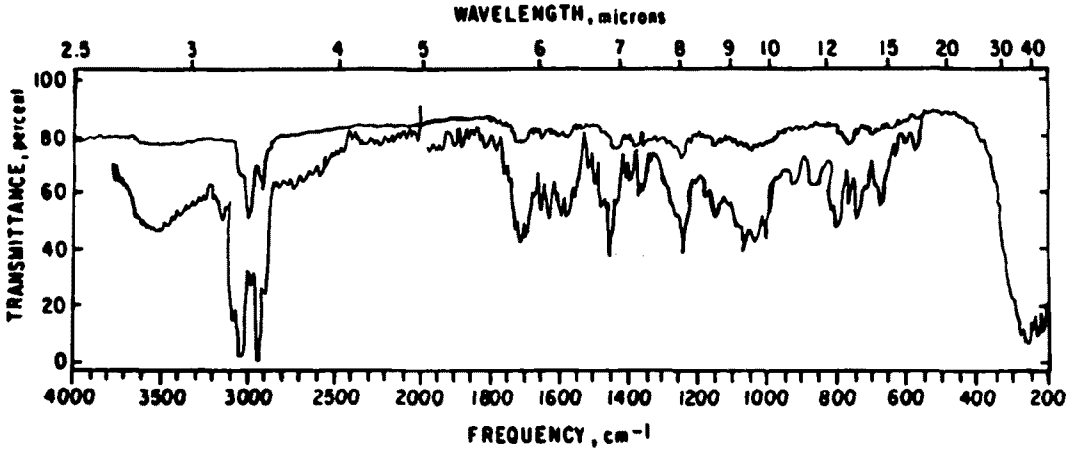


Figure D-5. IR spectrum of condensate extract from SASS-1. Major peaks indicate aliphatic hydrocarbons, esters, ketones; possible ethers, substituted aromatics, nitrocompounds and organosilicon compounds.

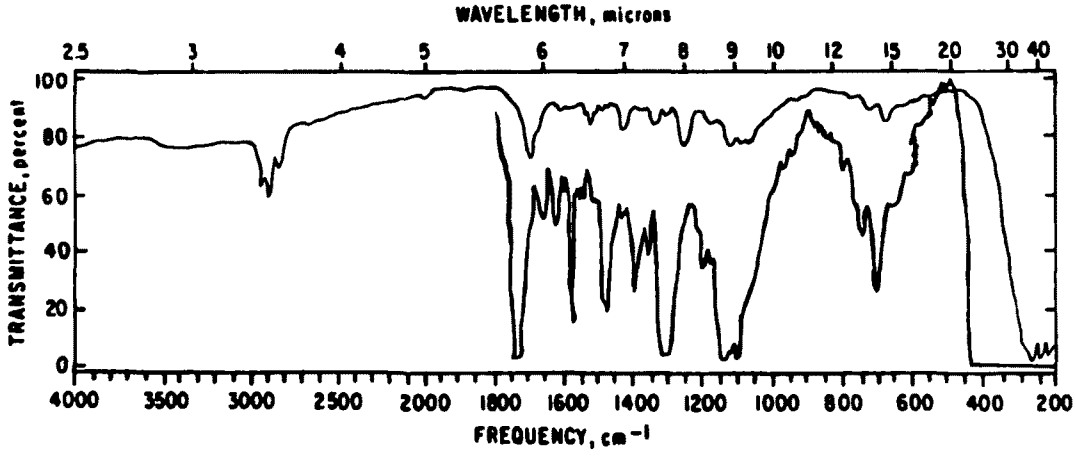


Figure D-6. IR spectrum of XAD-2 resin from SASS-1. Major peaks indicate esters, saturated hydrocarbons; possible ethers and nitrosubstituted compounds.

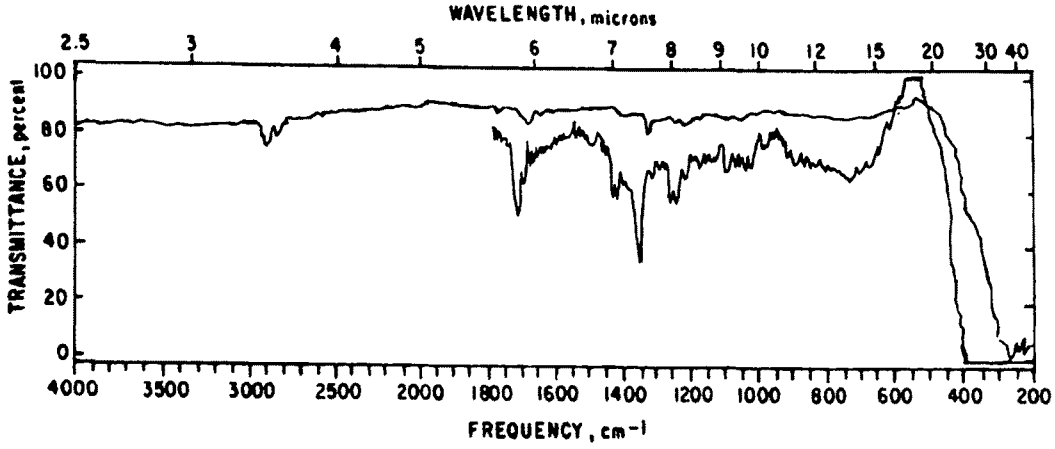


Figure D-7. IR spectrum of module rinse from SASS-1. Peaks indicate esters and aliphatic ethers.

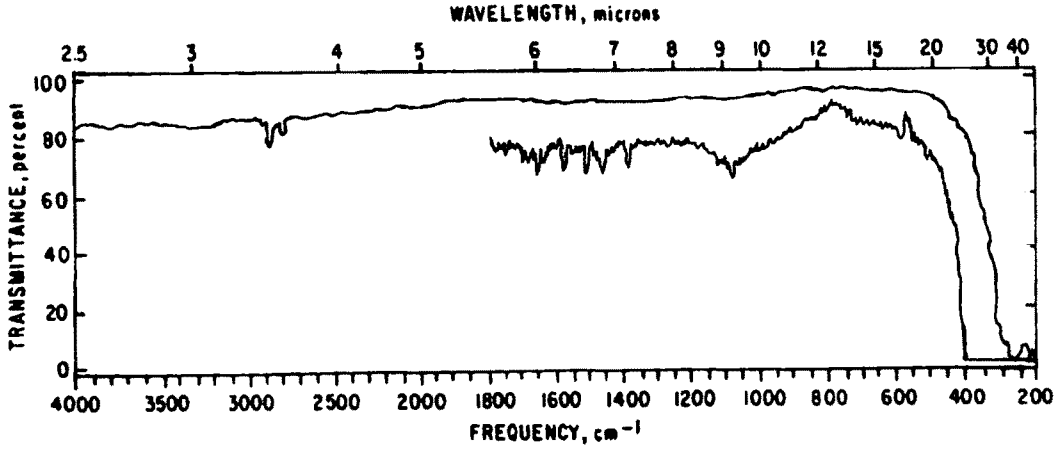


Figure D-8. IR spectrum of probe rinse from SASS-1. Content of spectrum is less than or equal to that of blank.

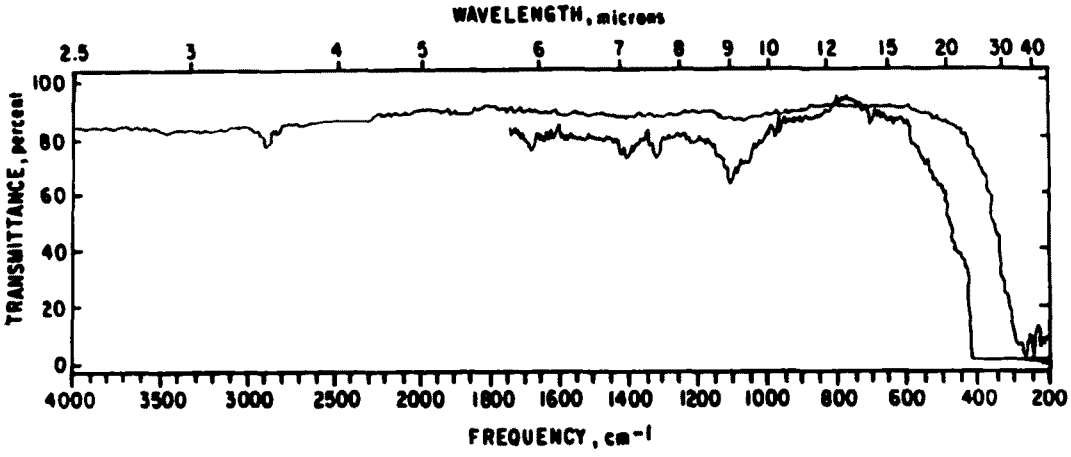


Figure D-9. IR spectrum of 10μ cyclone catch from SASS-2. Content of spectrum is less than or equal to that of blank.

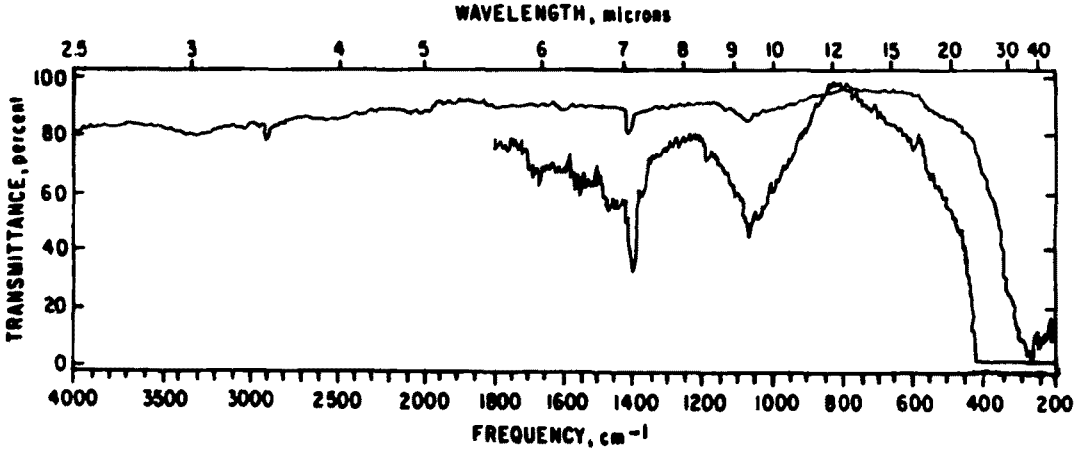


Figure D-10. IR spectrum of 3μ cyclone catch from SASS-2. Content of spectrum is less than or equal to that of blank.

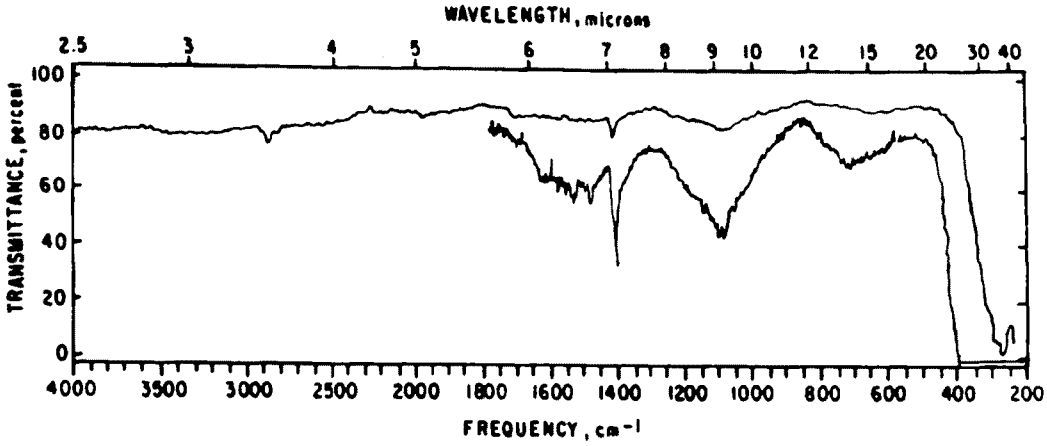


Figure D-11. IR spectrum of 1μ cyclone catch from SASS-2. Content of spectrum is less than or equal to that of blank.

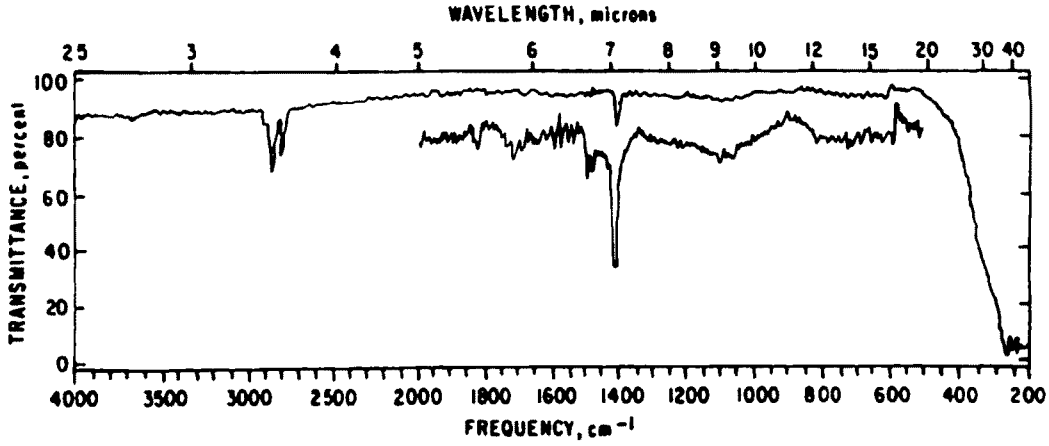


Figure D-12. IR spectrum of particulate filter from SASS-2. Content of spectrum is less than or equal to that of blank.

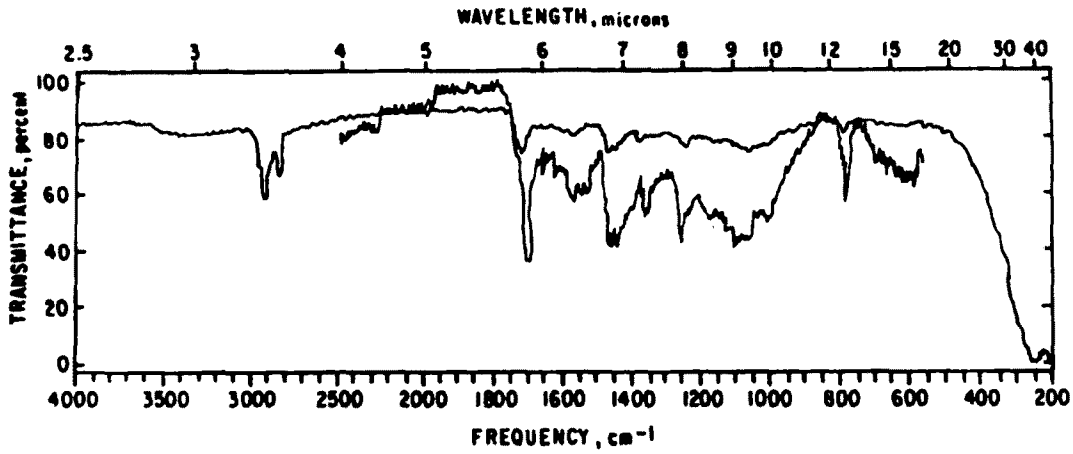


Figure D-13. IR spectrum of probe rinse from SASS-2. Major peaks indicate saturated hydrocarbons, esters and aryl esters; possible substituted aromatics and aliphatic ethers.

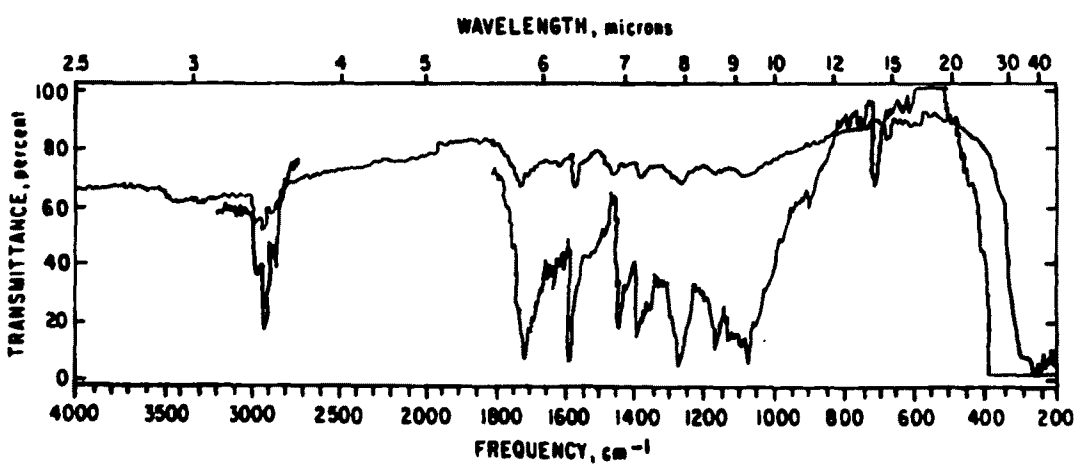


Figure D-14. IR spectrum of XAD-2 resin from SASS-2. Major peaks indicate aryl or unsaturated esters, ketones, hydrocarbons; possible ethers and nitrocompounds.

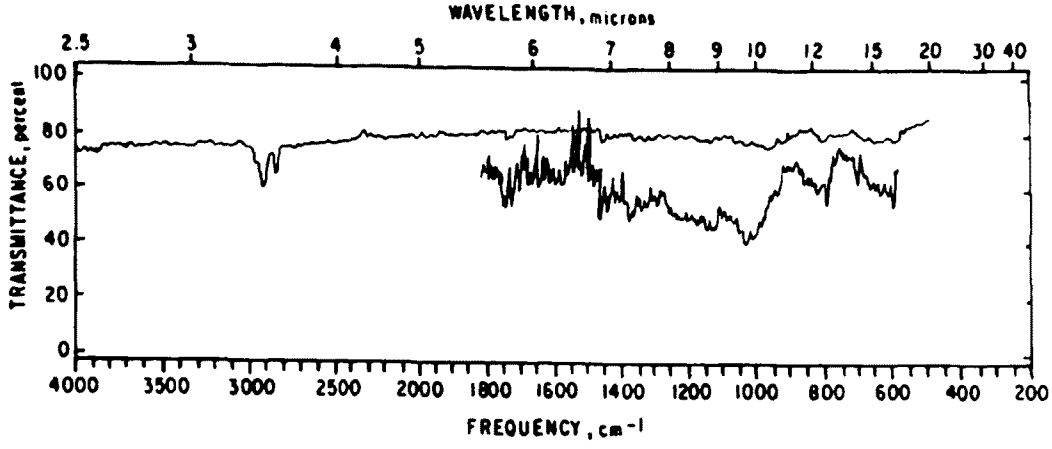


Figure D-15. IR spectrum of XAD-2 resin from SASS-2, LC fraction 1. Peaks indicate aliphatic and aromatic hydrocarbons; trace esters and ethers.

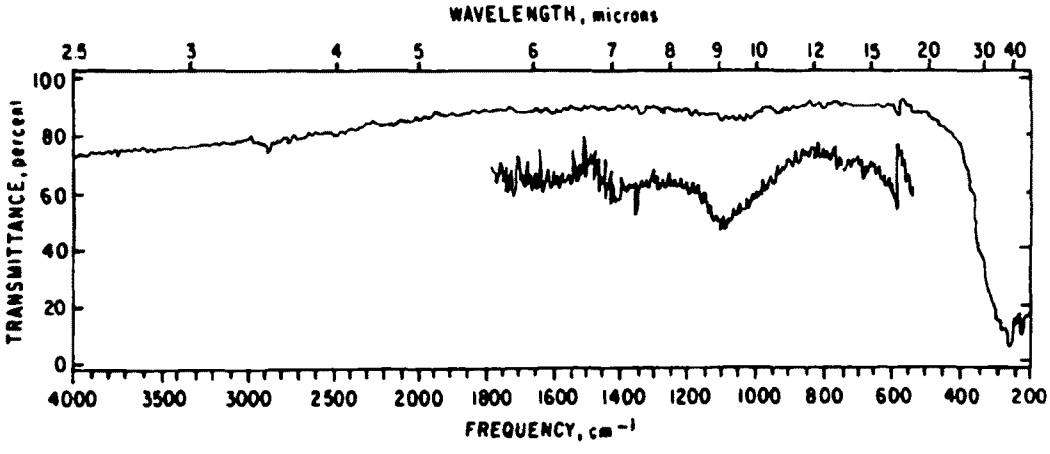


Figure D-16. IR spectrum of XAD-2 resin from SASS-2, LC fraction 2. Peaks indicate hydrocarbons and possible ethers.

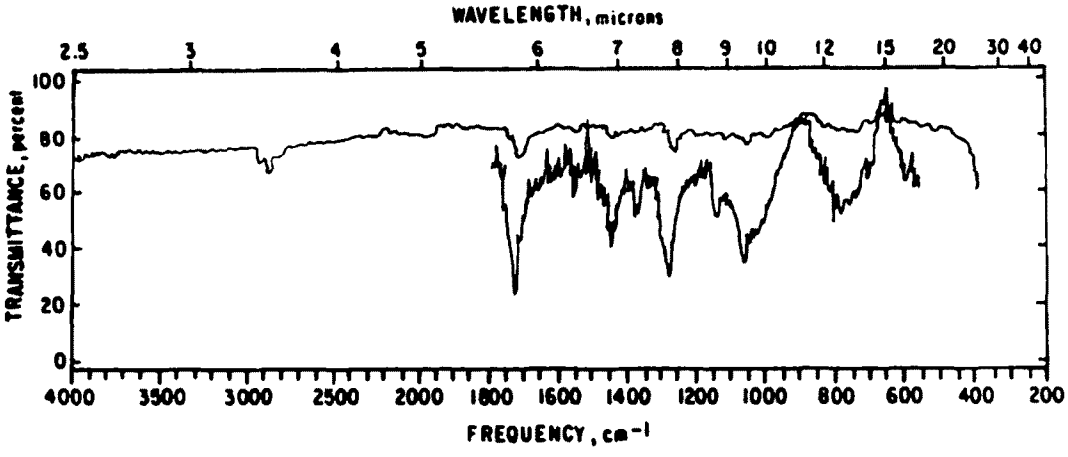


Figure D-17. IR spectrum of XAD-2 resin from SASS-2, LC fraction 3. Peaks indicate esters and trace saturated hydrocarbons and ethers.

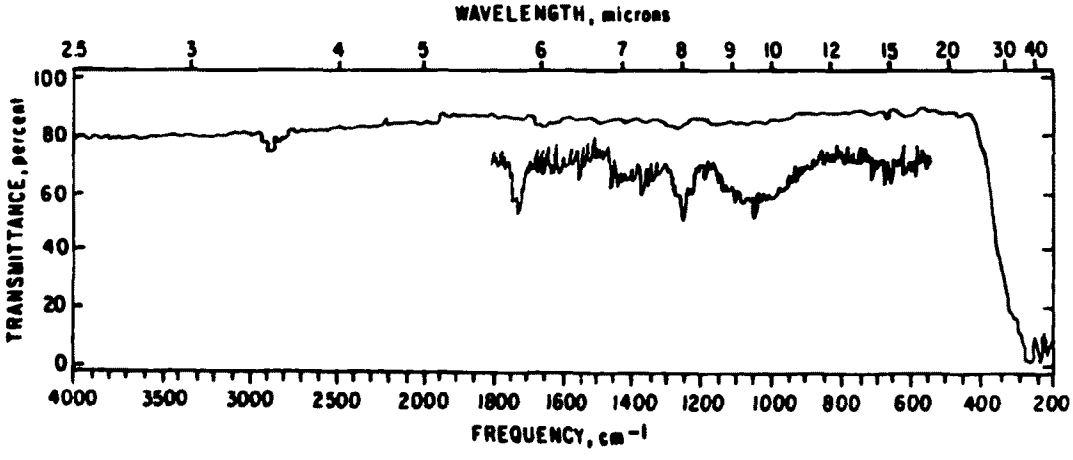


Figure D-18. IR spectrum of XAD-2 resin from SASS-2, LC fraction 4. Content of spectrum is less than or equal to that of blank.

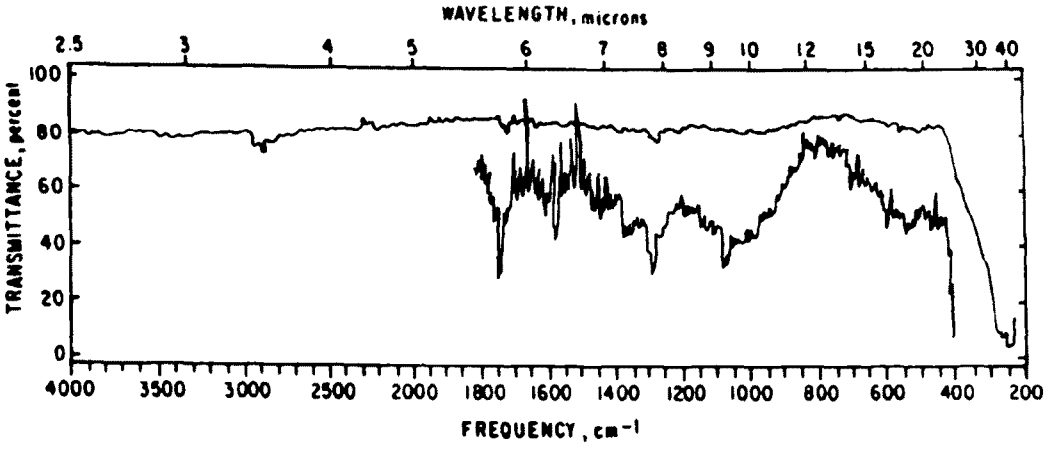


Figure D-19. IR spectrum of XAD-2 resin from SASS-2, LC fraction 5. Content of spectrum is less than or equal to that of blank.

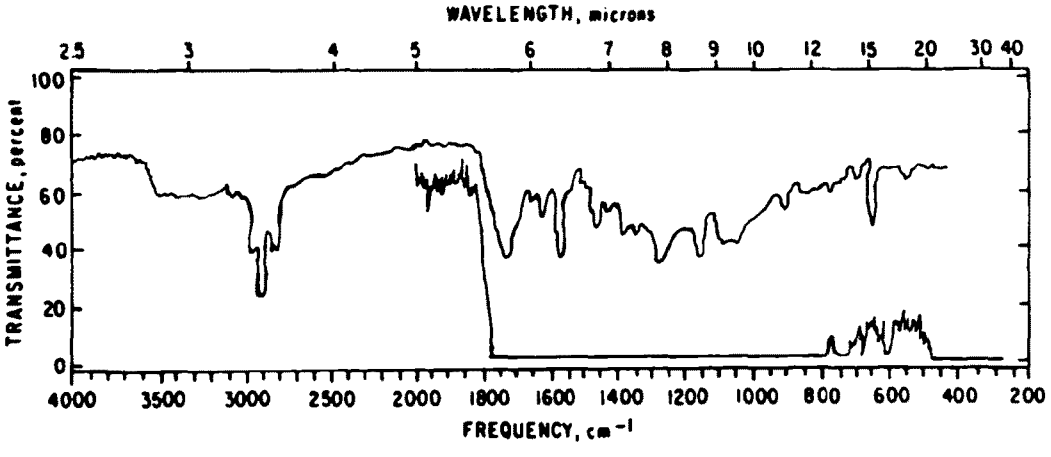


Figure D-20. IR spectrum of XAD-2 resin from SASS-2, LC fraction 6. Major peaks indicate esters, ketones; possible amines, alcohols, phenols, ethers and nitrocompounds.

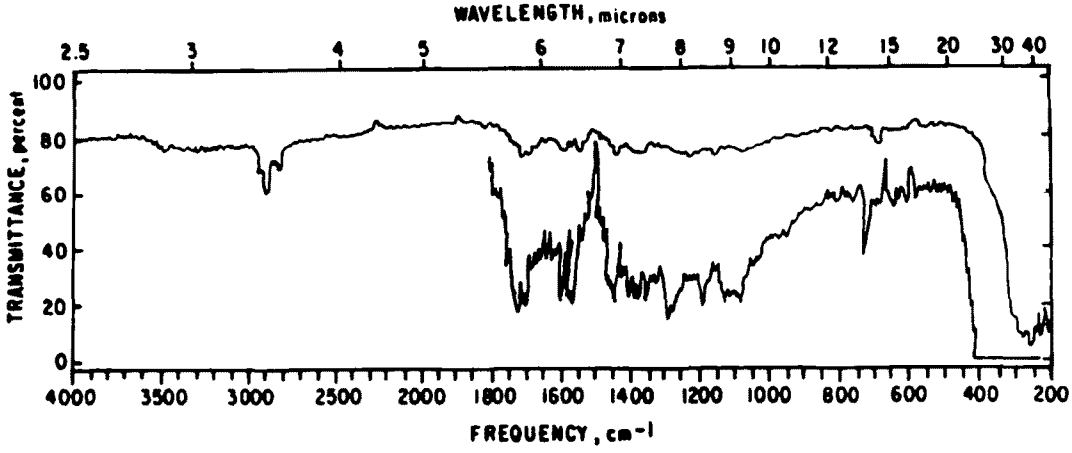


Figure D-21. IR spectrum of XAD-2 resin from SASS-2, LC fraction 7. Major peaks indicate unsaturated esters, saturated and unsaturated ketones; possible ethers and nitrocompounds.

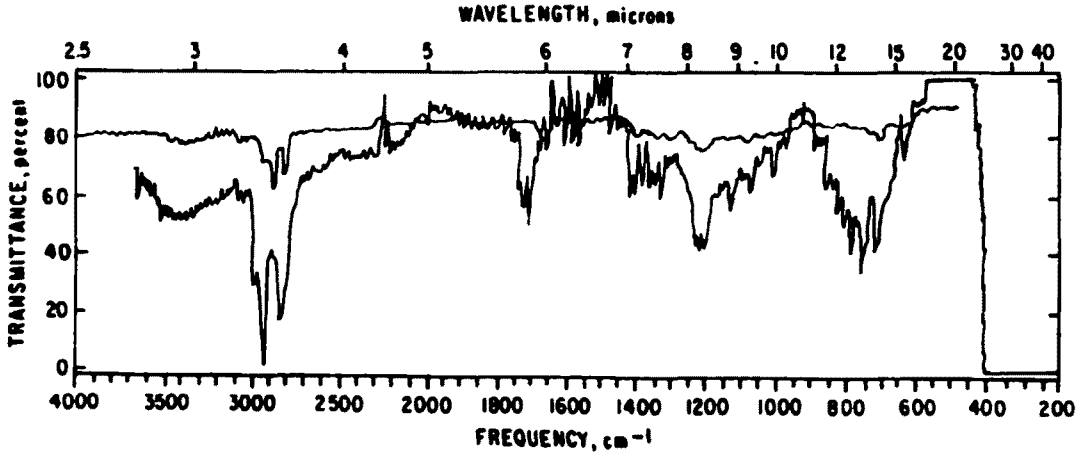


Figure D-22. IR spectrum of module rinse from SASS-2. Major peaks indicate aliphatic and aromatic hydrocarbons; saturated, unsaturated and aryl esters; possible ethers and saturated ketones.

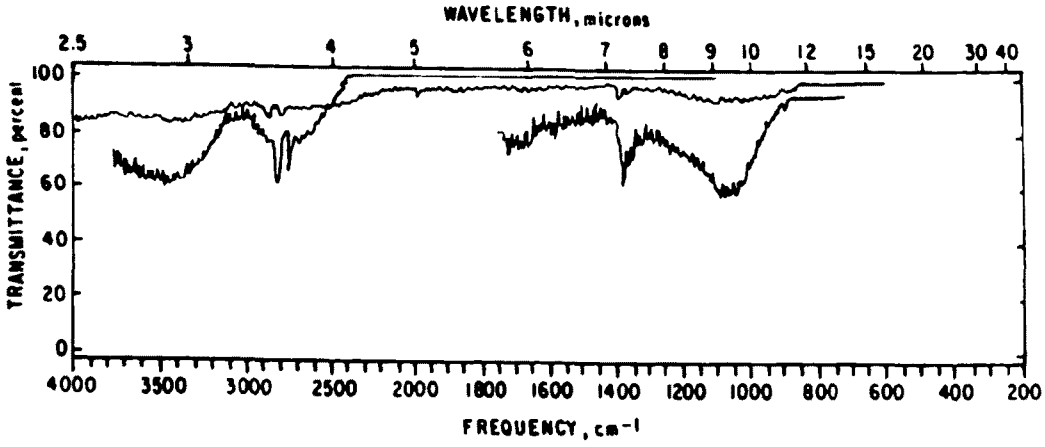


Figure D-23. IR spectrum of module rinse from SASS-2, LC fraction 1. Content of spectrum is less than or equal to that of blank.

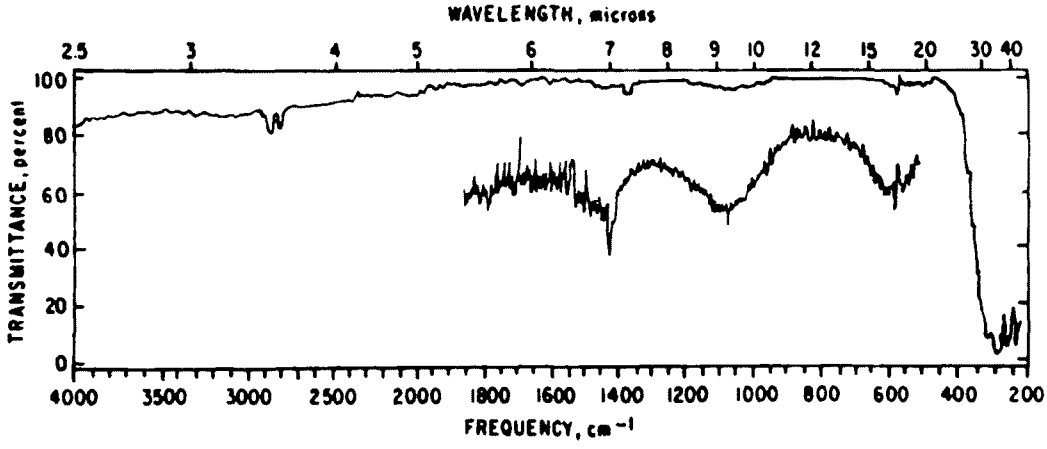


Figure D-24. IR spectrum of module rinse from SASS-2, LC fraction 2. Spectrum indicates aliphatic hydrocarbons.

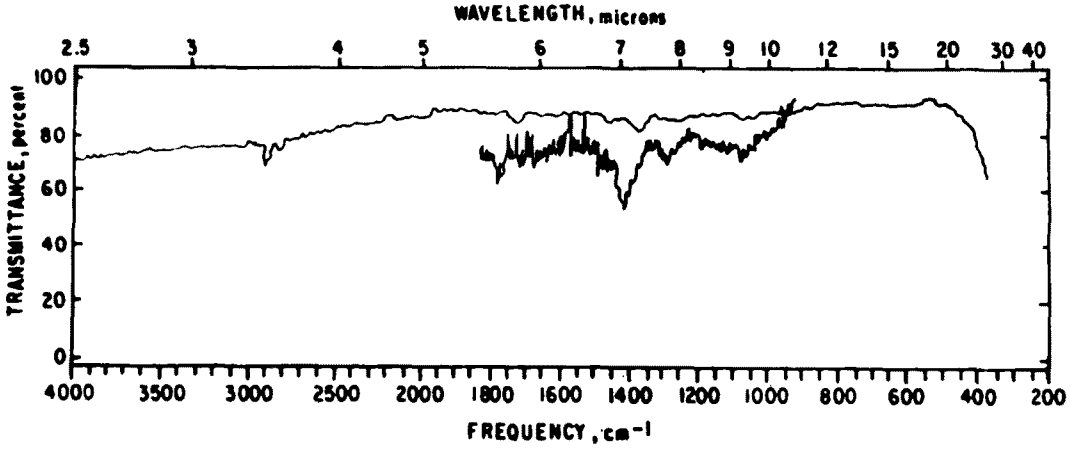


Figure D-25. IR spectrum of module rinse from SASS-2, LC fraction 3. Content of spectrum is less than or equal to that of blank.

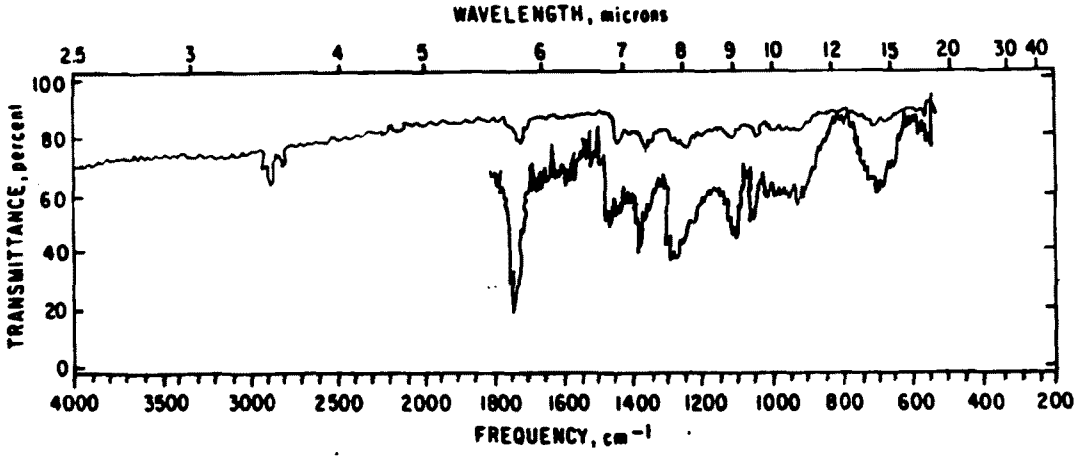


Figure D-26. IR spectrum of module rinse from SASS-2, LC fraction 4. Major peaks indicate saturated, unsaturated and aryl esters; possible ethers.

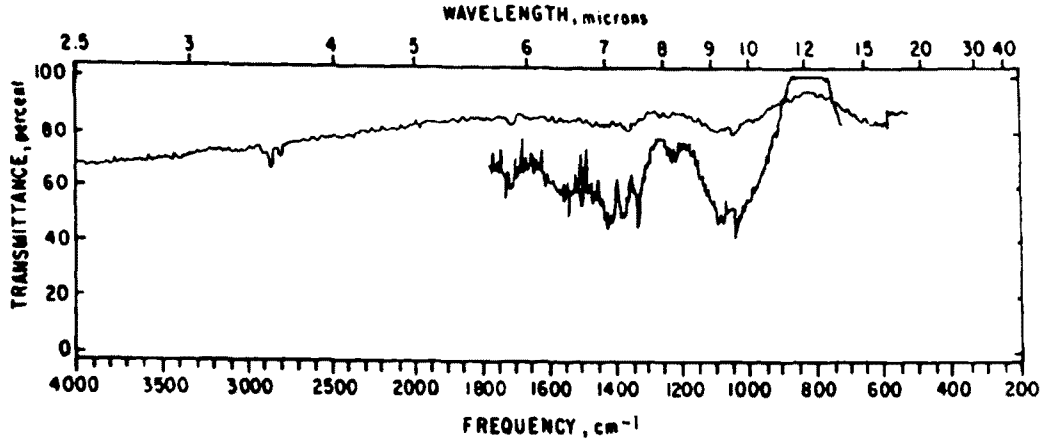


Figure D-27. IR spectrum of module rinse from SASS-2, LC fraction 5. Peaks indicate saturated, unsaturated and aryl esters.

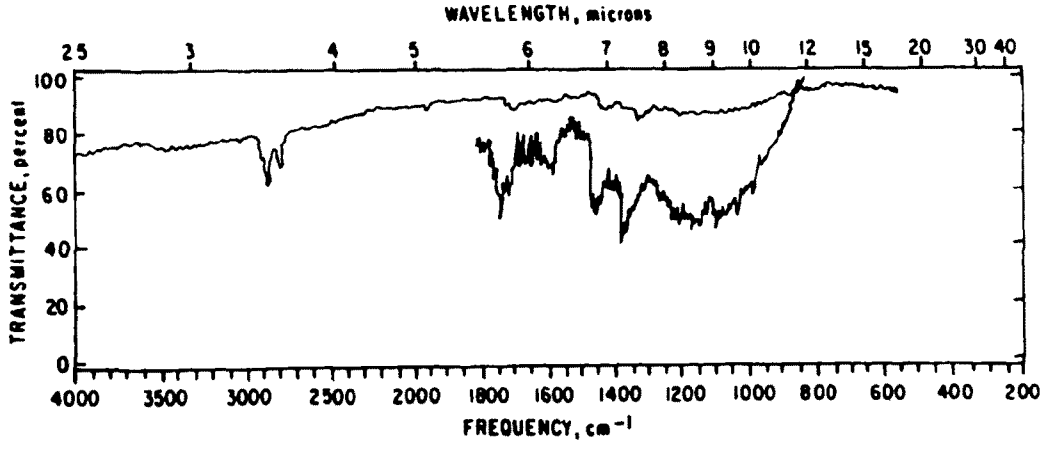


Figure D-28. IR spectrum of module rinse from SASS-2, LC fraction 6. Peaks indicate saturated, unsaturated and aryl esters.

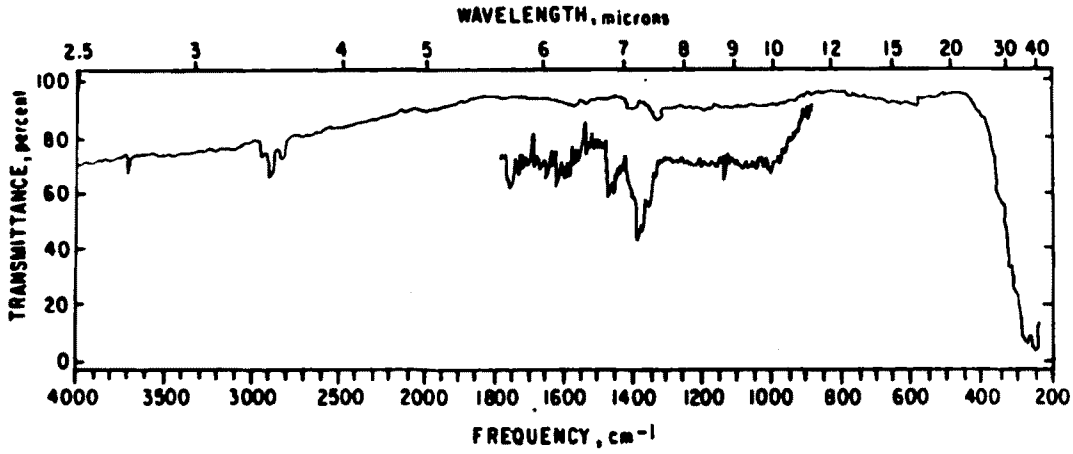


Figure D-29. IR spectrum of module rinse from SASS-2, LC fraction 7. Spectrum indicates saturated ethers.

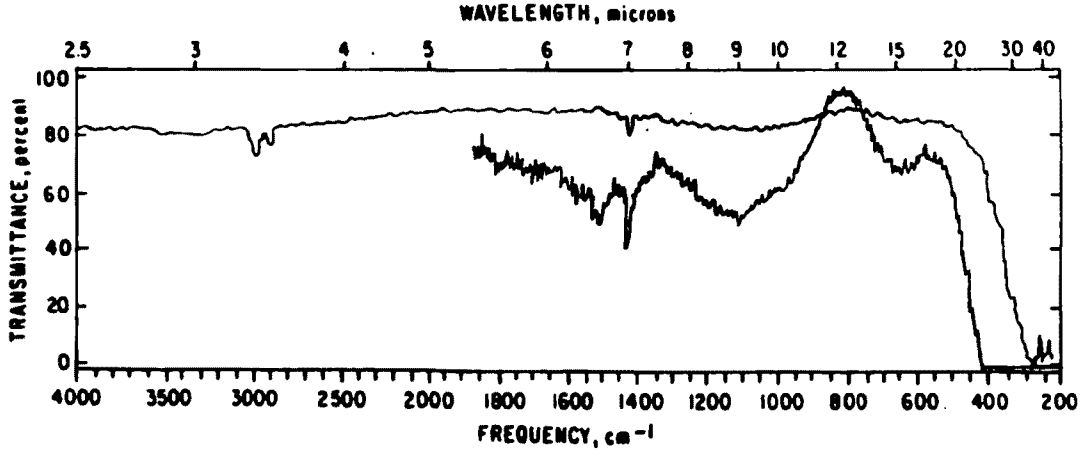


Figure D-30. IR spectrum of condensate extract from SASS-2. Peaks indicate trace aliphatic ethers.

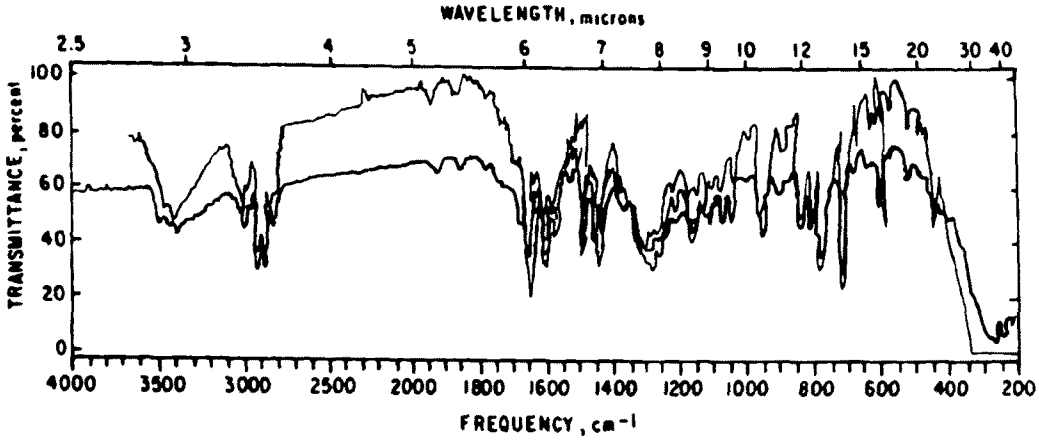


Figure D-31. IR spectrum of Tenax resin from RAC-2. Major peaks indicate primary and secondary amides, ethers, hydrocarbons; possible amines, alcohols and phenols.

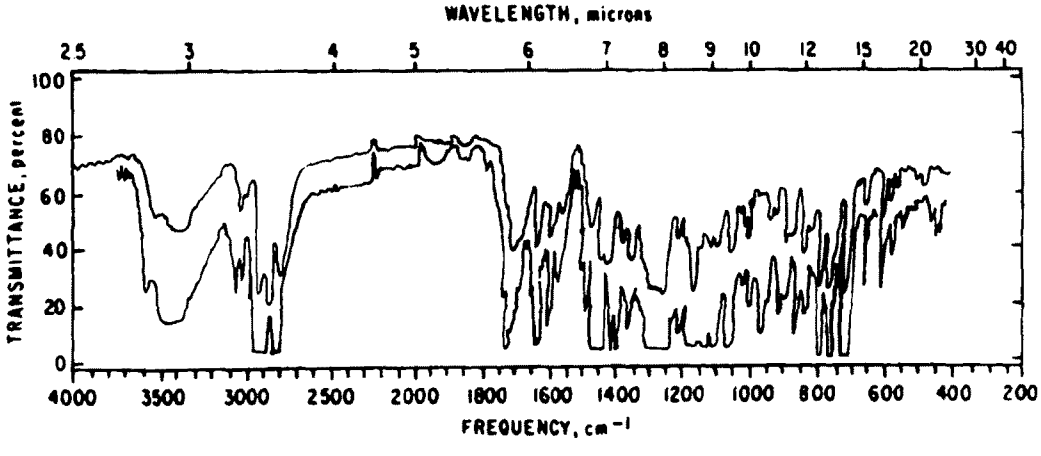


Figure D-32. IR spectrum of Tenax resin from RAC-4. Major peaks indicate hydrocarbons, esters, ketones; possible phenols and alcohols, amines, amides and ethers.

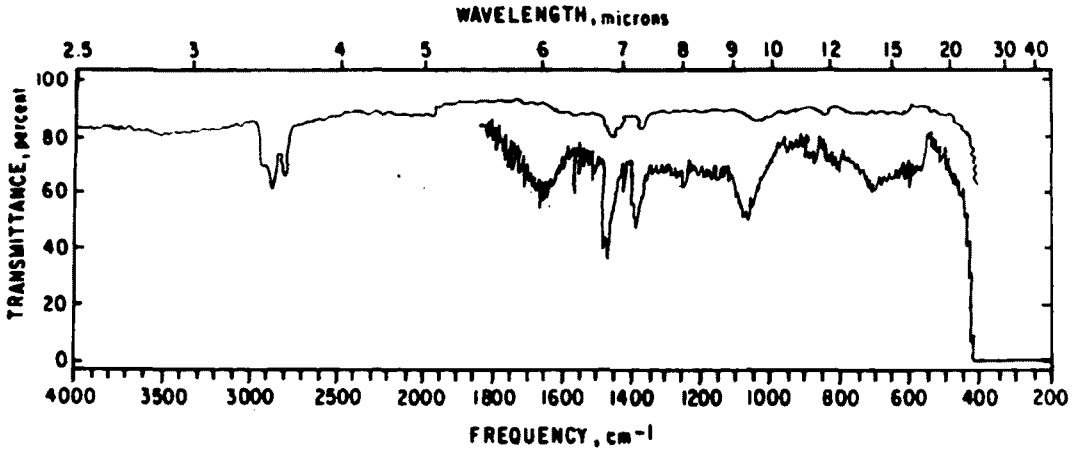


Figure D-33. IR spectrum of Tenax resin from RAC-4, LC fraction 1. Spectrum indicates saturated and aromatic hydrocarbons.

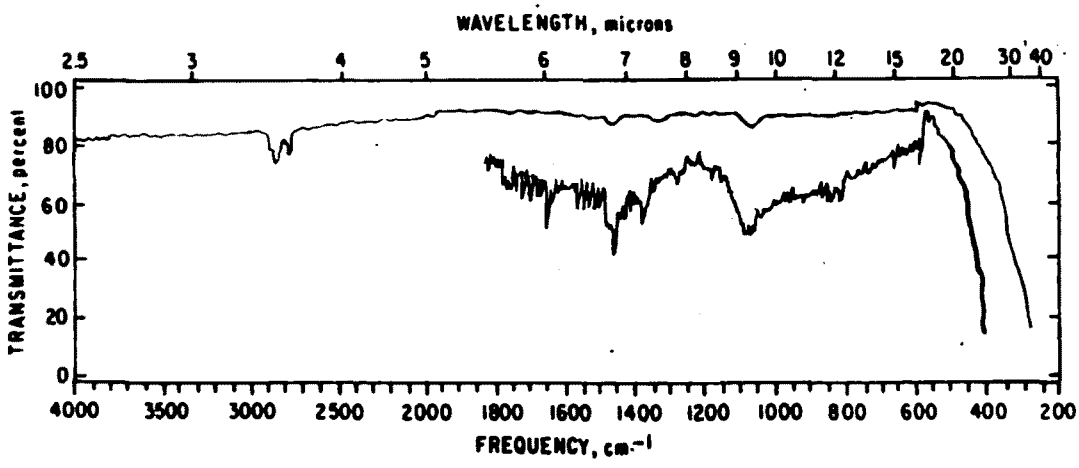


Figure D-34. IR spectrum of Tenax resin from RAC-4, LC fraction 2. Peaks indicate saturated and unsaturated hydrocarbons.

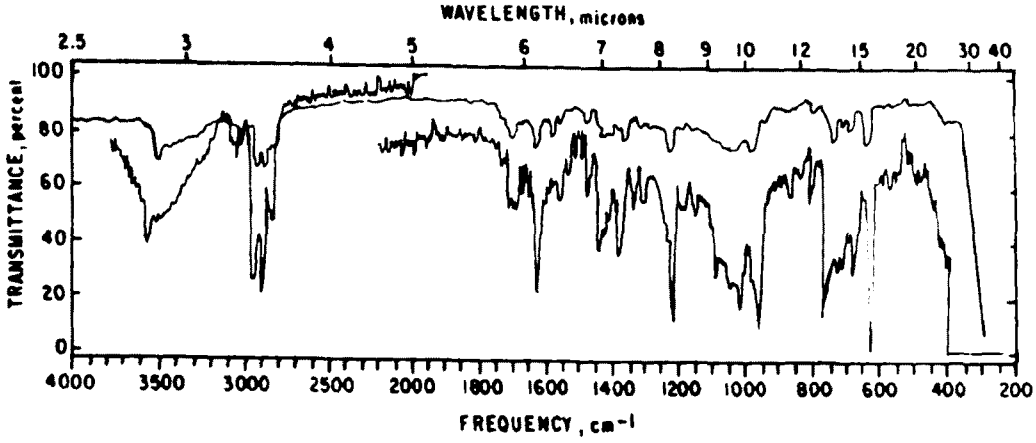


Figure D-35. IR spectrum of Tenax resin from RAC-4, LC fraction 3. Major peaks indicate substituted aromatics, esters; possible amines, amides, ethers and unsaturated alcohols.

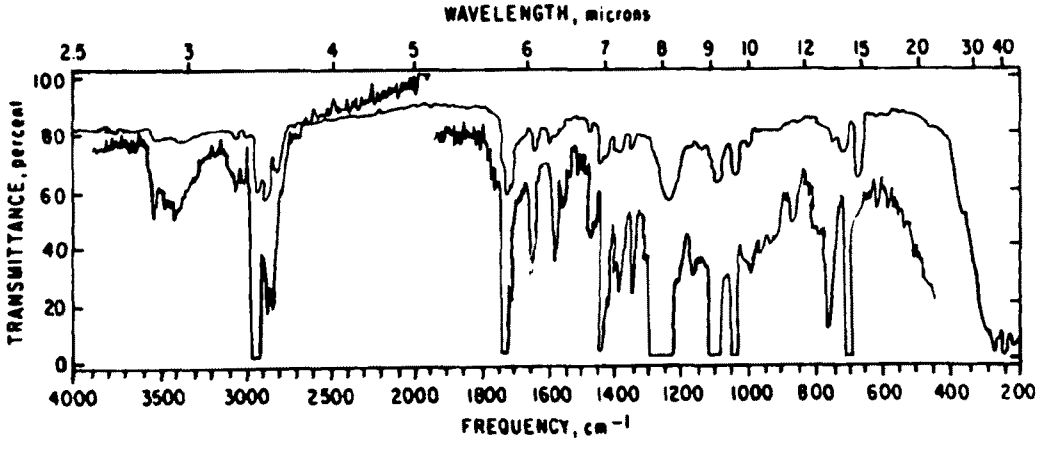


Figure D-36. IR spectrum of Tenax resin from RAC-4, LC fraction 4. Peaks indicate esters, ethers, amines and amides; possible unsaturated alcohols and nitrosubstituted compounds.

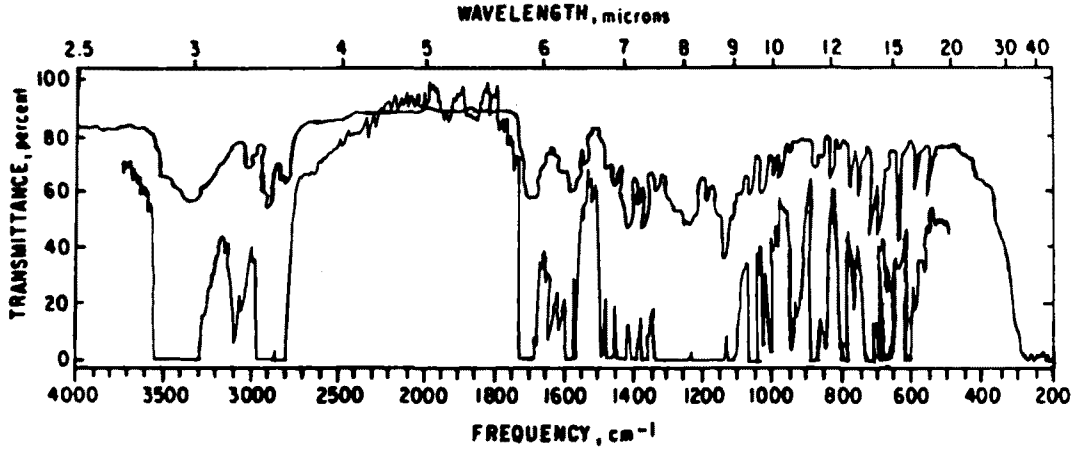


Figure D-37. IR spectrum of Tenax resin from RAC-4, LC fraction 5. Spectrum indicates esters, ketones; possible amides, amines, ethers, alcohols and phenols.

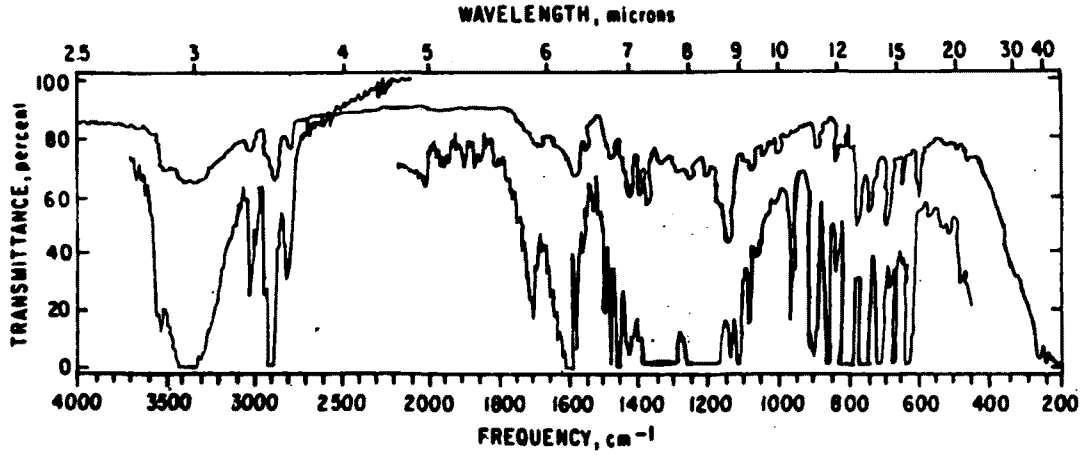


Figure D-38. IR spectrum of Tenax resin from RAC-4, LC fraction 6. Peaks indicate esters and ketones; possible amides, amines, ethers, alcohols and phenols.

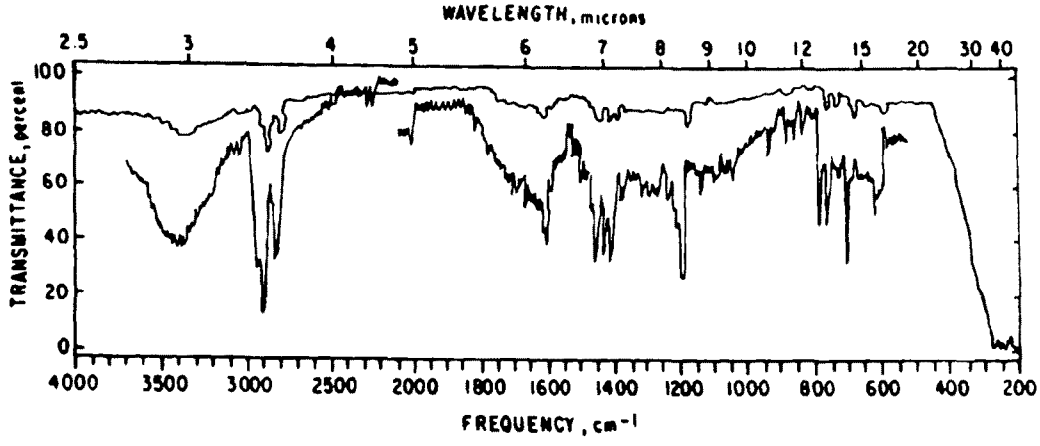


Figure D-39. IR spectrum of Tenax resin from RAC-4, LC fraction 7. Spectrum indicates ketones and esters; possible ethers, phenols, amines and amides.

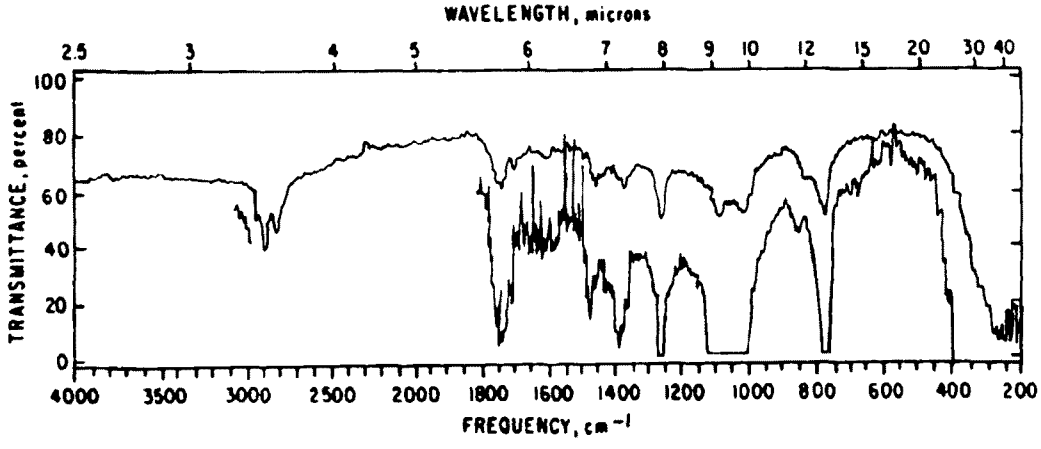


Figure D-40. IR spectrum of RAC 1-5 particulate sample. Major peaks indicate esters, ketones, saturated hydrocarbons; possible ethers, substituted aromatics and organosilicon compounds.

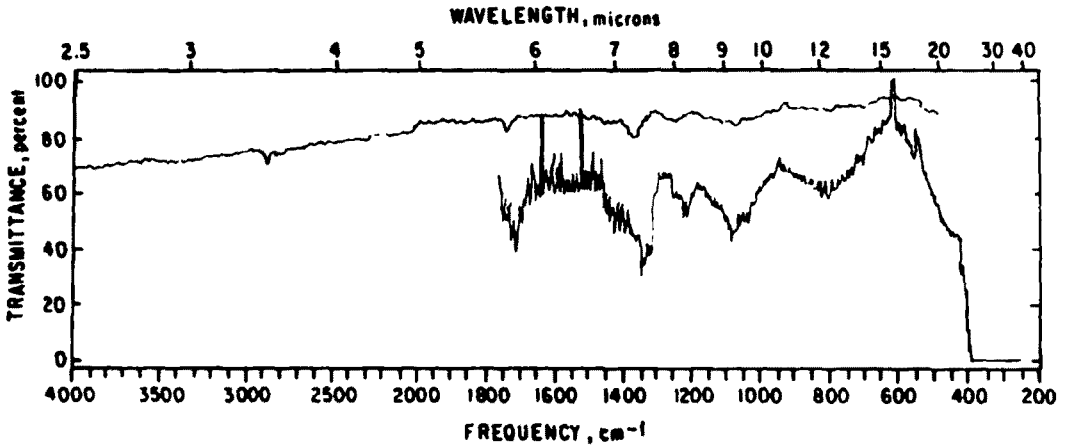


Figure D-41. IR spectrum of regenerator bed sample. Spectrum indicates aryl and unsaturated esters and ethers.

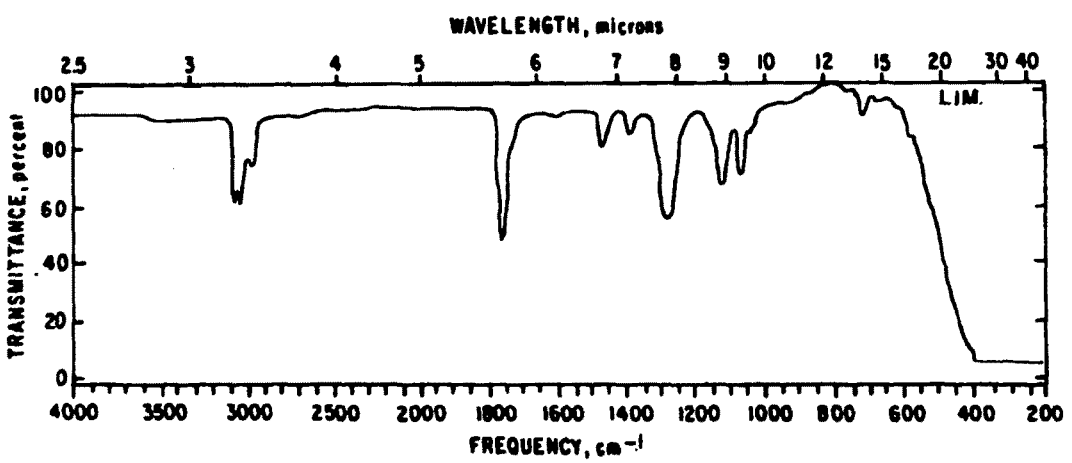


Figure D-42. IR spectrum of limestone, total methylene chloride extract. Functional groups present include methyl and methylene, carbonyl, and aromatic esters.

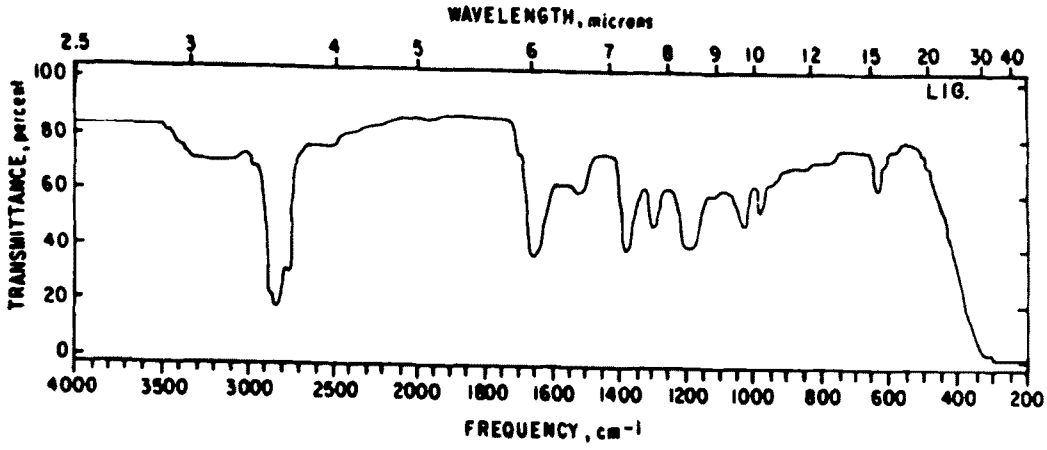


Figure D-43. IR spectrum of lignite, total methylene chloride extract. Spectrum indicates presence of alcohols and/or amines, methyl and methylene groups, carbonyls and aromatics.

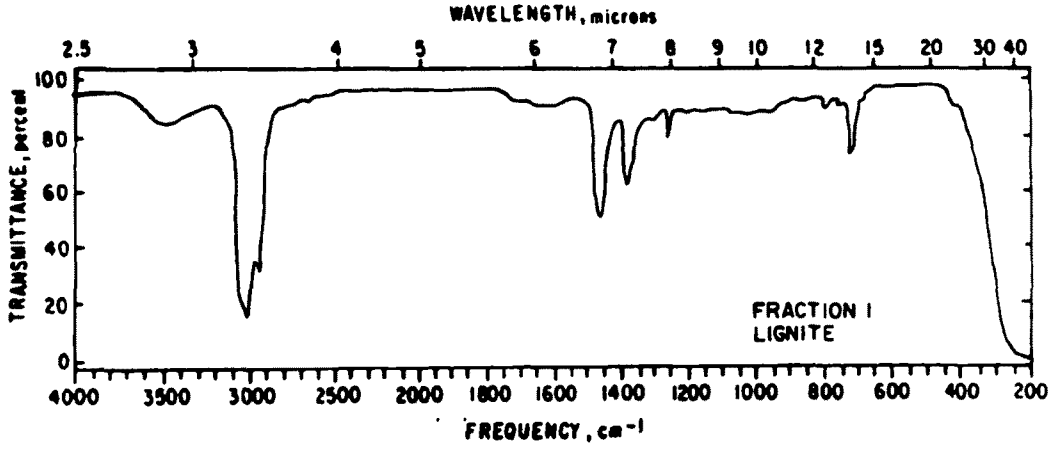


Figure D-44. IR spectrum of lignite, LC fraction 1. Groups found are aliphatics and possibly phenols.

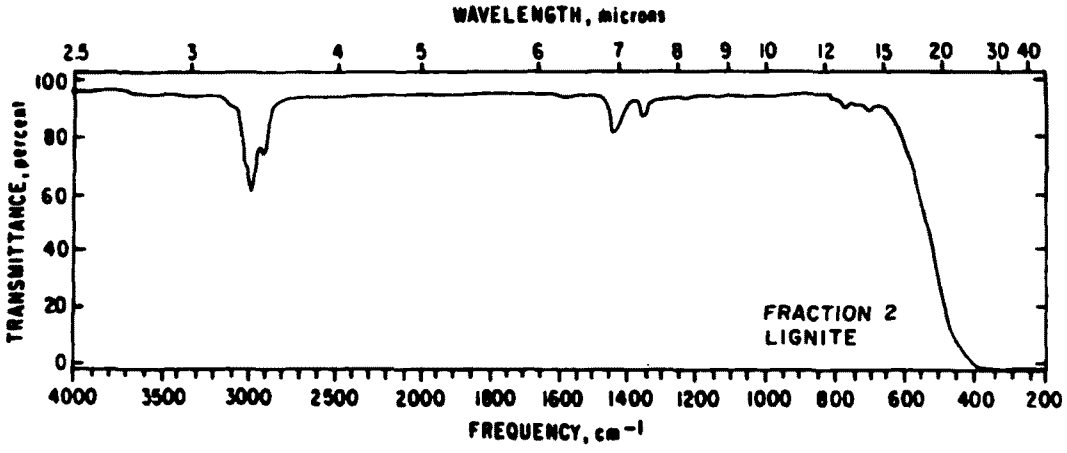


Figure D-45. IR spectrum of lignite, LC fraction 2. Presence of polycyclic organic hydrocarbon is indicated.

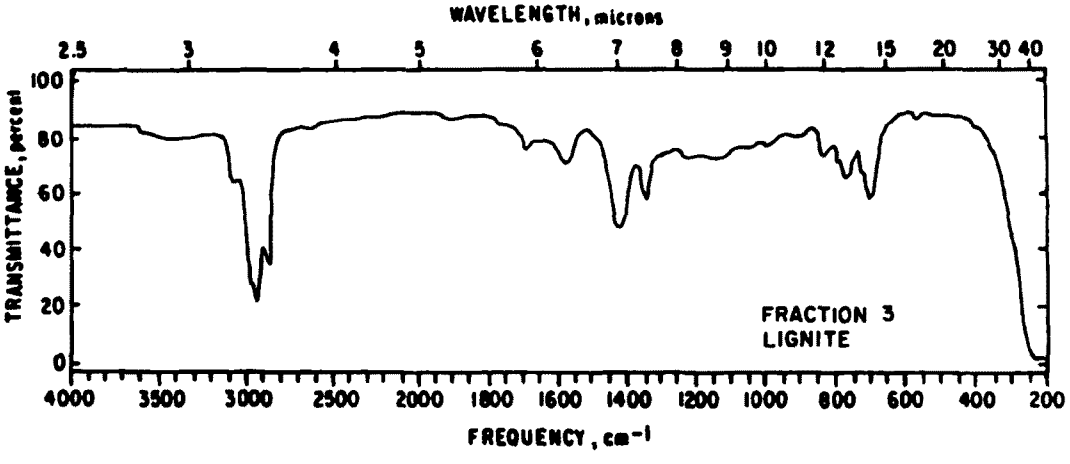


Figure D-46. IR spectrum of lignite, LC fraction 3. Spectrum indicates that halo substituted aromatics, amines and carbonyl functional groups are present.

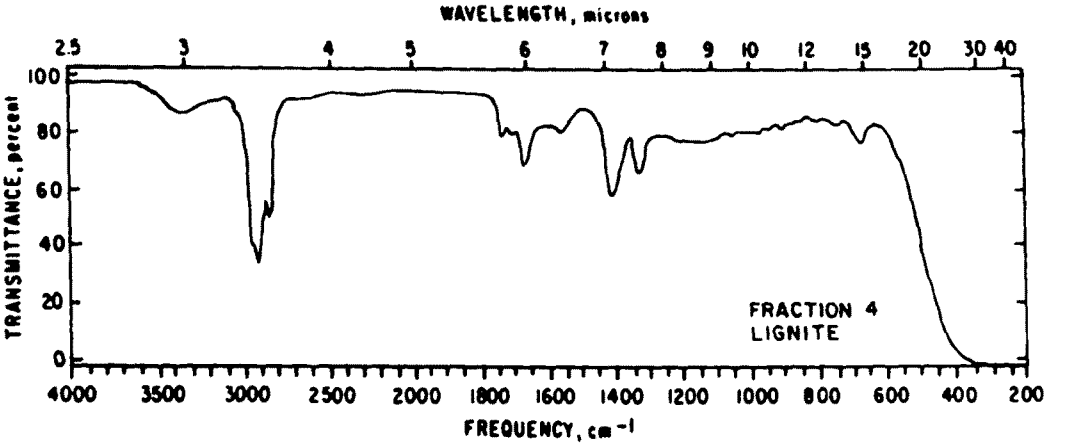


Figure D-47. IR spectrum of lignite, LC fraction 4. Presence of carbonyls detected.

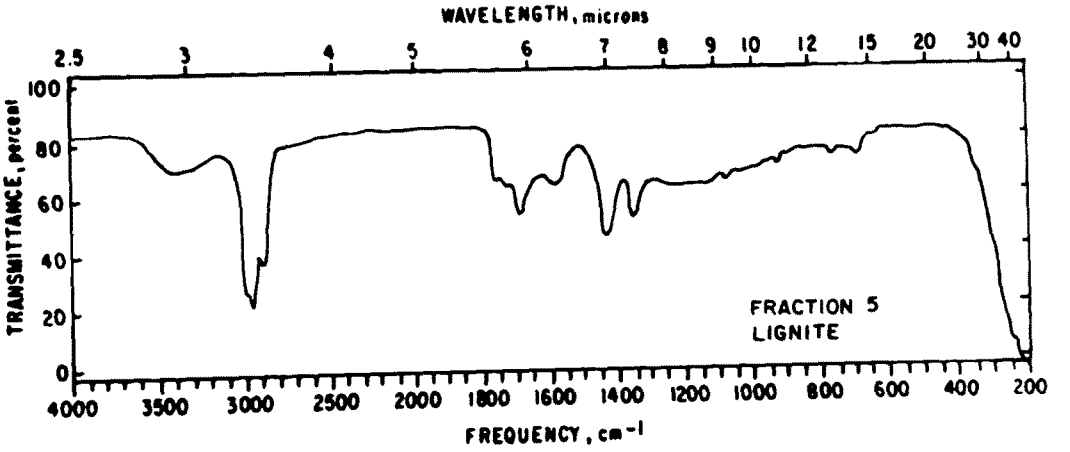


Figure D-48. IR spectrum of lignite, LC fraction 5. Presence of carbonyls detected.

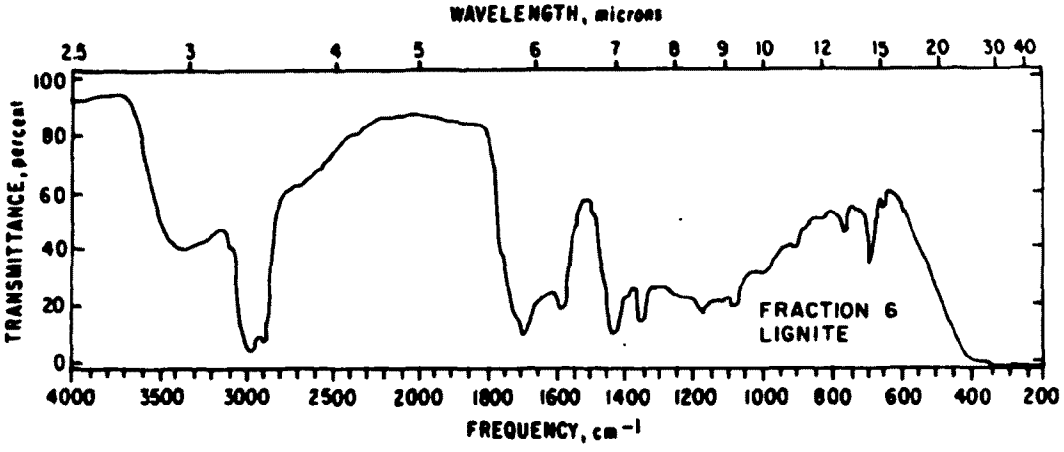


Figure D-49. IR spectrum of lignite, LC fraction 6. Aliphatic amines and possibly phenols present.

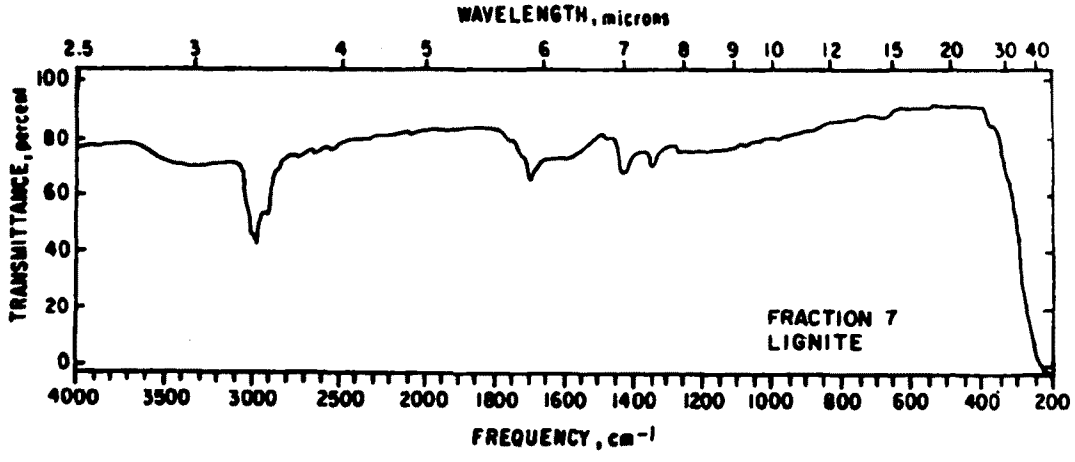


Figure D-50. IR spectrum of lignite, LC fraction 7. Carbonyls are indicated.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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		6. PERFORMING ORGANIZATION CODE
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16. ABSTRACT The report gives results of a preliminary environmental assessment (EA) of the lignite-fired Chemically Active Fluid-Bed (CAFB) process. It follows an earlier EA of the oil-fired CAFB. Waste streams contributing air and solid waste pollutants were evaluated in terms of emission rates and potential environmental effects. Emphasis is placed on flue gas emissions. As part of the investigation, a field sampling and laboratory analysis program was carried out to compile an emissions inventory of the CAFB pilot plant at the Esso Research Centre in Abingdon, England. In addition to the EA, an economic evaluation of the oil-fired CAFB is presented relative to alternative residual oil utilization techniques. Finally, recommendations are made for further control needs and emissions testing to be carried out in conjunction with the CAFB demonstration plant in San Benito, Texas. Particulate emissions were less than those from direct combustion of lignite using multiclones as a control. NOx emissions were quite low: 0.09 lb/million Btu was the highest measured. Light organics were equal to those from conventional units; heavy (> C6) emissions were lower. SOx emissions were half the New Source Performance Standard for coal-fired boilers.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Fuel Oil	Pollution Control	13B	11H
Assessments	Residual Oils	Stationary Sources	14B	
Lignite	Coal	Environmental Assessment	21D,08G	
Combustion	Sulfur Oxides		21B	07B
Fluidized Bed Processing		CAFB Process	13H,07A	
Flue Gases	Organic Compounds	Fluidized-Bed Combustion		07C

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