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A COMPENDIUM

OF SYNFUEL END-USE

TESTING PROGRAMS

Prepared for

EPA Program Offices

EPA Regional Offices

Prepared by

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

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EPA REVIEW NOTICE

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A COMPENDIUM OF SYNFUEL END USE TESTING PROGRAMS

by

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ABSTRACT

This "Compendium of Synfuel End Use Testing Programs" provides information on major recently-completed, current and planned synfuel end use testing projects. The compendium is intended to promote flow of information among various synfuel testing programs, thereby reducing chances for duplication of effort and enabling design and implementation of cost-effective and systematic approaches to the collection of appropriate environmental data in conjunction with on-going and planned performance testing projects. It is EPA's intention to update this compendium to include results from current and future testing programs.

Projects described in the compendium involve testing of shale-derived fuels, SRC-II middle distillates, EDS fuel oils, H-coal liquids and methanol-indolene mixtures in various equipment such as utility boilers, steam generators, diesel engines (lab-scale and full-scale), auto engines, and various other combustors.

A separate "data sheet" is devoted to each of the major projects covered. In general, each data sheet provides the following information on a project: type of fuel tested (both synfuel and the reference fuel), test equipment used, test site, test objectives, sponsoring agency, contractor, test conditions, environmental monitoring, project status, summary of results, and references. A table summarizing the information in the data sheets and an overview of the synfuel testing programs are also included.

Based on the data presented in this compendium, the thrust of the synfuel testing program which has been carried out to date has been to assess equipment performance and fuel handling characteristics. Where some emissions monitoring has been conducted, such efforts have been limited in scope and have primarily emphasized measurement of criteria pollutants (NO_X, SO_X, particulates, etc.). Essentially no data have been collected on emissions of non-criteria/non-regulated pollutants.

Published reports on various testing efforts and discussions with test sponsors/contractors are the sources of data for the compendium. Agencies/organizations providing input include DOD, DOE, NASA, EPRI, private synfuel developers, and engine manufacturers.

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ACKNOWLEDGMENTS

Gratitude is expressed to the EPA Project Officer, Mr. Joe McSorley, for suggesting the subject study and for his advice and guidance during the course of the effort.

This compendium is based on information and documents provided to the study by individuals/organizations engaged in synfuel characterization and end use testing; those on the project staff wish to express their gratitude to the supporting individuals/organizations, particularly to those listed in Table 1, to whom the project is deeply indebted.

Special thanks are due to Mrs. Monique Tholke for typing the manuscript and for her invaluable secretarial support to the project. Mr. Robert Scofield and Mrs. Anne Takata assisted in the preparation of data sheets on the projects covered.

1.0 INTRODUCTION AND OBJECTIVES OF THE DOCUMENT

A recently-completed synfuel utilization background study* identified a great need for better coordination among various agencies involved in synfuel end use testing programs so as to promote more systematic approaches to the collection of environmental data in connection with such programs and to reduce chances for duplication of effort. This compendium of synfuel end use testing programs, which has been developed per recommendation of the background study, is intended as an information source on major recently-completed, on-going, and planned synfuel end use testing programs. The dissemination of the document among agencies/organizations engaged in various aspects of synfuel production, testing, utilization, and regulation, coupled with holding regular symposia/workshops on synfuel utilization and end use testing, should greatly enhance coordination and flow of information among various programs and, in the long run, contribute to the goal of more rapid establishment of an environmentally acceptable commercial synfuel industry in the U.S. It is EPA's intention to periodically update this document to include the results from current and future testing programs.

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*M. Ghassemi and R. Iyer, "Environmental Aspects of Synfuel Utilization", EPA Report No. EPA-600/7-81-025, March 1981.

2.0 DATA BASE USED AND DATA PRESENTATION

Information presented in this document on the recently-completed, on-going and planned synfuel testing programs has been obtained from published documents and via telephone calls and/or interviews with organizations involved in the testing programs. The key individuals/agencies providing most of the reports and data used in this document are listed in Table 1.

A separate "data sheet" has been devoted to each project covered in this compendium to permit periodic updating of the document to include additional projects and incorporation of further results from on-going studies. The data sheets are grouped into four categories, covering projects for which the key sponsors/participants are Electric Power Research Institute (EPRI), Department of Defense (DOD), Department of Energy (DOE), and Miscellaneous agencies (e.g., EPA). Data sheets are presented for a total of 45 projects, of which 7 are in the EPRI-sponsored category, 16 in the DOD category, 13 in the DOE category, and 9 in the Miscellaneous category.

Where data have been available, each data sheet provides the following information on a test project: type of fuel tested (both synfuel and the reference petrofuel, where indicated), test equipment used, test site, test objectives, sponsoring agency, contractor, test conditions, environmental monitoring, project status, summary of results, and references (where a report or reports have been published on a project).

A summary of the data contained in the data sheets is presented in Table 2. Tables 3 and 4 present brief descriptions of some of the recently initiated and tentatively planned synfuel testing programs.

TABLE 1. LIST OF ORGANIZATIONS/INDIVIDUALS PROVIDING INFORMATION USED IN THE DEVELOPMENT OF THE COMPENDIUM

Electric Power Research Institute
3412 Hillview Drive
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DOE, Office of Coal Utilization
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Mr. Gavin McGurdy

Energy and Environmental Research
Corporation
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Santa Ana, CA 92705
Mr. Dave Pershing

Ford Motor Company
Scientific Research Laboratory
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Vulcan Cincinnati, Inc.
2900 Vernon Place
Cincinnati, OH 45219
Mr. R. W. Duhl

TABLE 2. SYNFUELS-COMBUSTION SYSTEM COMBINATIONS TESTED AND EMISSIONS MONITORED

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
1	EPRI	SRC-II fuel oil	No. 6 fuel oil	Tangentially-fired utility boiler	NO_x, CO, THC, SO_3, POM, particulates, particle size, particulate composition	• No adverse boiler performance effects with SRC-II fuel. • NO_x emissions nominally 70% higher than No. 6 fuel.
2	EPRI	SRC-II fuel oil H-Coal EDS oil	No. 6 and No. 2 fuel oils	Scaled-down utility boiler	NO, CO_2, CO, SO_2, SO_3, THC, smoke, particulates, particle size	• Higher fuel nitrogen content of SRC-II fuels produced higher NO emissions than reference fuels. • NO emissions from H-Coal and EDS liquids were lower than SRC-II. • No unique differences in combustion or emission characteristics of SRC-II fuel blends.
3	EPRI	SRC-II fuel oil	No. 2 and No. 5 fuel oil	Babcock & Wilcox package boiler	NO_x, CO, CO_2, SO_2, hydrocarbons, O_2, and dust	• NO_x emissions consistent with fuel nitrogen content. • Combustion performance of SRC-II fuel oil was similar to No. 2 and No. 5 fuel oils.
4	EPRI	SRC-II, H-Coal	No. 2 diesel fuel	Three catalytic reactors	NO_x and CO	• Coal-derived liquids can be burned catalytically but SRC-II, and to a lesser degree H-Coal, appeared to degrade reactor performance significantly as evidenced by higher CO emissions. • NO_x emissions were consistent with fuel nitrogen content.
5	EPRI	Hydrogenated shale oil and various liquid fuels for SRC-I, H-Coal, EDS, and SRC-II	No. 2 distillate fuel	Full-scale and sub-scale turbine combustors	NO_x, CO, UHC, particulates, and smoke	• A selected number of coal liquids and shale oil fuels can be used in current turbines. • Emission levels of CO, UHC, and particulates for synfuels were about the same as for No. 2 fuel - not significant. • Significant quantities of FBN are converted to NO_x causing emissions higher than EPA limits.
6	EPRI	Solvent refined coal	Bituminous coal	Utility boiler	NO_x, SO_2, CO_2, particulates, particulate composition	• The boiler stayed much cleaner with SRC than with coal, producing an equivalent boiler efficiency as coal at full load. • The quantity of SRC flyash was 10 to 15% of that of coal flyash with no bottom ash accumulation from SRC. • Particulates, SO_2 and NO_x emissions from SRC were all under EPA limits.
7	EPRI	*	Jet-A fuel, natural gas, methanol	Two utility gas turbines	NO_x, CO, SO_2, THC, POM, sulfates, particulates, aldehydes, opacity	• Methanol is a suitable fuel for gas turbines; turbine performance and NO_x and particulate emissions are improved over the other fuels.

(Continued)

TABLE 2. (Continued)

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
8	DOD	Shale-derived JP-5 and blends with petroleum JP-5	Petroleum JP-5	DOD helicopter engine: Allison T63-A-5A turbo-shaft	NO_x, CO, CO_2, and THC	• NO_x emissions increased with increasing fuel nitrogen content; conversion efficiency was about 45%. • No significant effects were noted on engine performance or CO, CO_2, and THC emissions due to the presence of high levels of fuel bound nitrogen.
9	DOD	Shale-derived DFM	Petroleum diesel fuel (MIL-F-16884G)	U.S. Navy LM2500 turbine engine	NO_x, CO, THC, and smoke	• Combustor and engine operating characteristics were identical when using marine diesel or DFM shale oil; thus, DFM shale oil would be suitable for use in LM2500 engines. • NO_x emissions followed fuel nitrogen content; CO and THC levels were essentially the same for both fuels.
10	DOD	JP-5 from oil shale, coal, and tar sands	Jet-A, JP-5, diesel marine fuel, leaded gasoline, and blends of the above	Two high temperature/pressure research combustors	NO_x, CO, UHC, and smoke	• In all performance areas, the synfuels correlated in the same manner as petroleum-derived fuels except for NO_x emissions from the shale oil fuel. • Smoke formation was dependent on hydrogen content; combustion efficiency, CO, and UHC depend more on higher boiling point components than fuel viscosity.
11	DOD	Shale fuel oil	Petroleum diesel fuel marine (DFM)	Steam generator diesel engine	Particulates and particulate composition	• No significant differences between particulate emission products measured in the study from the combustion of DFM or shale fuel oil.
12	DOD	Shale-derived diesel fuel	Petroleum distillate	Lab-scale diesel engine	NO_x, THC, and smoke	• There was no significant difference in performance or emissions with the shale-derived fuel.
13-15	DOD	Shale-derived DFM	Petroleum DFM	3 different types of prototype steam generators	NO_x, SO_2, CO, CO_2, THC, O_2, and smoke	• There were no significant differences in measured pollutant emissions resulting from the combustion of petroleum DFM or shale-derived DFM on the CVA-60, DDG-15, and the FF-1040 boilers. In each case, SO_2, NO_x, and smoke were below levels set by EPA.
16	DOD	Oil shale-derived JP-5 fuel	Petroleum-derived JP-5 fuel	DOD helicopter engine: Allison T62-A-5A turbo-shaft	NO_x, CO, and THC	• Performance, CO, and THC emissions were equivalent for both fuels. • NO_x emissions followed fuel nitrogen content.

(Continued)

TABLE 2. (Continued)

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
17	DOD	Unifined kerosene derived from tar sands	Petroleum-derived JP-5 fuel	DOD helicopter engine: Allison T63-A-5A turbo-shaft	NO_x, CO, and UHC	• Unifined kerosene was a satisfactory substitute for petroleum JP-5 fuel. • NO_x emissions were slightly higher when using unifined kerosene than with JP-5.
18	DOD	Distillate, aviation, turbine, and diesel fuels derived from coal, tar sands and oil shale	Various petroleum-derived fuels	Wide variety of Army power-plant systems	Various pollutants	• Product quality of many synfuels tested and other results are described in individual abstracts.
19	DOD	Shale-drived JP-5, JP-8, and DFM	JP-5, diesel fuel No. 2, and Jet A	DOD helicopter engines: Allison T-63 gas turbine, Detroit Diesel 6V-53T, LDT-465-1C diesel engine, Teledyne-Continental AVDS-1790 diesel engine, and Detroit Diesel 3-53	CO, NO_x, unburned hydrocarbons, and smoke	• The carbon monoxide emissions followed the same trend as combustion efficiency. At the lower power points, DFM showed slightly higher CO than JP-5 and Jet A. There were no fuel property effects on the emissions of unburned hydrocarbons and NO_x. The flame radiation and exhaust smoke levels for the synfuels were higher than those of Jet A and are attributed to differences in hydrogen content. • The shale JP-5 in the DD6V-53T engine showed a 6% average loss in maximum power output when compared to the reference diesel fuel which approximates the 6.5% power loss observed in the same engine with petroleum-derived JP-5. The shale-derived JP-5 and DFM performed in the CUE-1790 engine like similar petroleum-derived fuels. Evaluation of DFM from shale in the LDT-465-1C engine resulted in no difference between the maximum power produced by this fuel and that of a petroleum No. 2 diesel fuel. • The results from the 210-hour test in the DD 3-53 engine are indistinguishable from those that may result from tests with conventional petroleum-derived diesel fuel with similar properties. • Shale-derived fuels met virtually every military specification with the exception of the failure of JP-5 to meet copper corrosion requirement and DFM to meet maximum pour point limit.
20-22	DOD	*	13 petroleum derived fuels: JP-4, JP-8, diesel No. 2 & various blends	General Electric F101 turbofan, J79-17C turbojet, and J79 turbojet engines	NO_x, CO, UHC, and smoke	• In all three engines, fuel hydrogen content strongly affected smoke and NO_x emissions. NO_x emissions were also highly dependent upon combustor operating conditions.

(Continued)

TABLE 2. (Continued)

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
23	DOE	*	12 petroleum-derived fuels: JP-4, JP-8, and various blends	TF41 turbofan combustor	NO_x, CO, UHC, and smoke	• All pollutant emissions measured were highly dependent upon operating conditions. CO and smoke levels were also strongly affected by hydrogen and aromatic content of fuels.
24	DOE	SRC-II middle distillate	Low quality residual oil, and petroleum reference distillate fuel	Combustor sized for use with industrial gas turbine	NO_x, CO, CO_2, THC, and smoke	• The combustor was able to achieve low NO_x with all fuels. • CO and smoke varied directly with rich zone equivalence ratio and inversely with lean zone equivalence ratio.
25	DOE	SRC-II middle distillate	Petroleum distillate	Various combustor concepts	NO_x, smoke	• Values of NO_x were reduced for the smaller diameter quench zone and increased for larger diameter quench zone. • Rich-lean burn stage combustion system can meet EPA emission standards.
26	DOE	SRC-II middle distillate	Low quality residual oil and distillate fuel	Seven combustors of varying designs for use in utility gas turbine engines	NO_x, smoke, CO, unburned HC	• A lean-lean combustor has potential for achieving ultra-low NO_x emissions with distillate, residual or other fuels containing up to 0.25% (wt.) fuel nitrogen. CO and smoke met program goals from this combustor also.
27	DOE	SRC-II middle distillate	Low quality residual oil, petroleum reference distillate oil, and natural gas	Combustors for use in utility gas turbine engines	NO_x, CO, THC, smoke	• Lean-lean combustor NO_x emission levels were higher than emission goals using SRC-II fuel. CO emissions remained low using SRC-II fuel, while no smoke was detectable and UHC levels were negligible throughout these tests. • Rich-lean combustor NO_x emissions appeared to reach a minimum below the NO_x emission goal for rich primary zone condition.
28	DOE	SRC-II middle distillate	Low quality residual oil, petroleum reference distillate oil	Experimental combustor for use with utility gas turbine engines	NO_x, CO, UHC, smoke	• Five combustors have been found adequate for further development: rich-lean diffusion flame venturi quench, burner ceramic lined pipe lean burner, multiannular swirl burner, Rolls-Royce combustor, and lean catalytic combustor. These meet NO_x emission limits set by EPA with petroleum distillate and/or residual oils. • SRC-II fuel NO_x emissions were close to meeting EPA limits in only two combustors: rich-lean diffusion and ceramic lined pipe lean burners.

(Continued)

TABLE 2. (Continued)

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
29	DOE	SRC-II middle and heavy distillate, fuel oils & three blends of the above	No. 2 and No. 6 petroleum-based fuel oils	A 20-hp Johnston, fire-tube boiler	NO_x, SO_2, CO, HC and polynuclear aromatic hydrocarbons	• The levels of NO_x and SO_2 produced were proportional to the amount of nitrogen and sulfur in the fuel. • There appear to be two sources of trace organics in the exhaust gases: small amounts of the fuel itself not burned during combustion, and the products of combustion. For the petroleum fuels, n-alkanes and polynuclear aromatic hydrocarbons are seen in the exhaust gas; for the SRC-II fuels, the alkanes are absent or present at very low levels, and polynuclear aromatic hydrocarbons not seen in the petroleum exhaust gases are present.
30	DOE	*	Indolene and 10% methanol/90% indolene	Two light duty vehicles	Evaporative emissions (hydrocarbons and methanol)	• Using methanol 10% blend increased evaporative emissions by 130% for short term use and 220% for long term use.
31	DOE	*	Unleaded gasoline and methanol/indolene mixtures	Auto engines (10)	NO_x, CO, THC, aldehydes, and methanol	• Aldehyde, methanol, and hydrocarbon emissions increased with higher concentration of methanol in the fuel. • CO was reduced by the addition of methanol to the base fuel.
32	DOE	*	10% methanol/90% gasoline blends	Auto engines (7)	NO_x, CO, and evaporative emissions (HC and methanol)	• Data show consistent reduction in CO emissions with use of methanol blends. • Significant increases in evaporative emissions with methanol blends.
33-35	DOE	*	Ethanol, methanol, and gasoline blends	Fleet vehicles	Evaporative and tailpipe hydrocarbon emissions	• 75% increase in evaporative emissions with methanol blends over a straight gasoline. • Emissions were lower for vehicles fueled with gasohol but data was inadequate to conclude a significant difference.
36	DOE	*	Indolene, indolene/methanol blends and ethanol/indolene blends	Pontiac 4-cylinder modified engine	Total aldehydes and specific organics	• Total aldehydes increased 25% in going from indolene to ethanol/indolene and methanol/indolene blends. • Formaldehyde is the largest component of the total aldehydes (up to 90 mole percent of the total).
37	Vulcan Cincinnati	*	No. 6 residual oil, natural gas, and methanol	Small scale boiler test stand and a 49 MW utility boiler	NO_x, CO, and aldehydes	• In the utility boiler, methanol NO_x levels were 7-14% of those measured during residual oil combustion. • CO emission levels of methanol were less than 100 ppm and generally less than those observed for the residual oil. • Aldehyde emissions during methanol combustion were generally less than 1 ppm.

(Continued)

TABLE 2. (Continued)

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
38	Ford Motor Co.	*	Methanol, indolene, and blends	Ford 400 CID engine and 1975 Ford LTD with 400 CID engine	Total hydrocarbons and specific organics	• Methanol/indolene blends gave significantly higher hydrocarbon and aromatic emissions than indolene without a catalyst, but only slightly higher emissions with a catalyst.
39	DOT	Shale-derived DFM	No. 2 diesel fuel	VW Rabbit engine	NO_x, CO, THC, particulates, Ames test on particulates	• HC and CO emissions were found to be lower and NO_x levels higher for the shale-derived fuel as compared to the petroleum-derived fuel. Particulate emissions were similar for both fuels. • Mutagenic activity of the organics from the particulate matter was similar for the two fuels.
40	Bank of America	*	Methanol/gasoline blends	Fleet vehicles	NO, CO, unburned hydrocarbons	• Blends of 2 to 18% methanol decrease emissions of CO and unburned hydrocarbons and result in improved mileage in new cars. • Certain blends result in operating cost decreases of 1¢/mile.
41	EPA	Shale-derived DFM	No. 2 fuel, and No. 2 fuel with 0.5% nitrogen	Two configurations of a full-scale prototype (25-MW engine-size) gas turbine combustor utilizing a Rich burn/Quick Quench combustor concept	NO_x, CO, unburned hydrocarbons	• Both combustor configurations met program emissions goals using both reference fuels and synfuel. • Unburned HC emissions from one combustor ranged from 0.9 to 7.3 ppmv for No. 2 fuel; 1.1 to 21.8 ppm for No. 2 fuel with 0.5% nitrogen; and 1.3 to 15.3 ppmv for shale-derived DFM at 15% O_2.
42	EPA	SRC-II middle distillate fuel oil and shale-derived residual oil	No. 2 fuel oil and Indonesian/Malaysian residual oil	Prototype full-scale (25-MW engine-size) Rich Burn/Quick Quench gas turbine with two combustor configurations	NO_x, CO, unburned hydrocarbon, and smoke	• All emissions exhaust goals met. • Relationship demonstrated between primary zone residence time and attainable NO_x emission concentrations.
43	EPA	*	Residual and distillate oils, natural gas, propane, isopropanol, methanol	Experimental wall furnace and prototype industrial boiler	NO_x, NO, CO, HC, and aldehydes.	• NO emission levels for the five fuels were as follows: distillate oil > propane > isopropanol > alcohol mixture > methanol. • Although there was considerable scatter in the data, aldehyde concentrations were around 10 ppm for methanol. • NO emissions for all fuels decreased with increasing fraction of flue gas recirculation. • CO and hydrocarbon emissions were always below 50 ppm and smoke was not observed for any fuel.

(Continued)

TABLE 2. (Continued)

Test No.	Agency	Synfuel	Reference Fuel	Combustion System	Emissions Monitored	General Conclusions
44	EPA	*	No. 5 residual oil, natural gas, and methanol	Industrial water-tube and fire-tube boilers	NO_x	• Flue gas recirculation was capable of reducing NO_x emissions during methanol combustion. • Methanol NO_x emissions were significantly lower than during residual oil combustion and were also less than during natural gas combustion.
45	EPA	*	Indolene and ethanol blends	Two light duty vehicles	NO_x, CO, THC, ethanol, and evaporative emissions	• The addition of ethanol to indolene reduced tailpipe emissions of THC and CO, but increased NO_x. • Use of gasohol increased evaporative emissions substantially.

*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

TABLE 3. ON-GOING SYNFUEL TESTING PROGRAMS

Sponsoring Agency	Test Fuels	Schedule*	Project Description*
EPA, Motor Vehicle Emission Laboratory	Shale-derived diesel fuel and SRC-II fuel versus National Average Baseline Diesel Fuel, and Mobil-M gasoline	1981 to late 1982	Volkswagen Rabbit diesel engine testing. Emissions monitored to include particulates, NO_x, CO/CO_2, hydrocarbons, and aldehydes.
	EDS and H-coal liquids	Late 1981 to September 1982	Large standing diesel engines and a GE research engine. Emissions monitoring includes collection of particulates.
	SRC-II fuel	1982	Electronically controlled internal combustion engine at Southwest Research Institute, San Antonio, TX.
EPA, Combustion Research Laboratory	SRC-II middle and heavy distillates, EDS middle distillates, and shale-derived No. 2 fuels	November 1981-April 1982	North American package boiler and Caterpillar Model D334 stationary diesel engine testing. Package boiler represents small-to-medium sized fire-tube boiler for industrial and commercial applications; boiler can be equipped with low NO_x burner which may be tested with synfuels. The stationary diesel represents medium-sized industrial and commercial engine used for backup power generation, pumping and other applications. Emissions monitored include particulates, NO_x, CO/CO_2, SO_2, and hydrocarbons.
DOE, Bartlesville Energy Technology Center; Contractor/test site:			
A. General Electric, Erie, PA	SRC-II middle distillate and oil shale distillate	1981-early 1982	Testing of GE EDI-8, 8-cylinder "V" configuration, 5344 cu. in. standing diesel engine for electric power, rail and marine applications. Parameters evaluated include: starting ability, injection timing, fuel rate variation effects and internal engine temperatures. Emissions monitored include O_2, CO/CO_2, NO_x, SO_2, HC, H_2SO_4, and particulates.
	H-coal liquids	January to April 1982	Limited testing with single cylinder diesel engine. Emissions monitored include O_2, CO/CO_2, NO_x, SO_2, and HC.
B. Transamerica Delaval, Oakland, CA	SRC-II middle distillate	1981-early 1982	Testing of Delaval DSR 46, 6-cylinder in-line configuration, 28,600 cu. in. standing diesel engine for electric power, compressor and marine applications. Performance parameters being evaluated include starting ability, precombustion chamber effects, ignition delay, and other engine parameters. The engine has been operated at full load using a pre-mixed blend of 60% SRC-II liquid and 40% diesel oil which had been injected into the combustion chamber with no modification of the engine, followed by increasing proportions of SRC-II liquid up to 100%. Emissions monitored include O_2, CO/CO_2, NO_x, SO_2, THC, and smoke.

(Continued)

TABLE 3. (Continued)

Sponsoring Agency	Test Fuels	Schedule*	Project Description*
C. A. D. Little, Beloit, WI	SRC-II middle distillate	1981-1982	Fairbank-Morse 38 to 8-1/8, 6-cylinder opposed piston design, 3108 cu. in. standing diesel engine for electric power and marine applications, compressors and pumps being tested. Parameters evaluated include effects of load variations, combustion pressure vs. time, and engine delay. Emissions monitored include CO/CO_2, NO, NO_2, SO_2, SO_4, HC, PAH, particulates, and oxidants.
	Various H-coal and EDS liquids	March to November 1982	Testing of Fairbanks piston engine at NAVSSES test facility, Philadelphia, PA. Emissions monitoring to include gaseous pollutants and collection of sizable (i.e., 5 g) quantities of particulate matter.
D. Energy and Environmental Research, Springfield, OH	Shale-derived distillate oil	1981-early 1982	Testing of Superior 6-cylinder in-line configuration turbo-charged 4120 cu. in. standing diesel engine for use in compressors, pumping and electrical power generation. The purpose of the tests is to compare engine performance parameters during synfuel and conventional fuel combustion. Tests with shale-derived distillate oil and a baseline No. 2 diesel fuel include SASS train sampling for PAH and particulates. Other emissions monitored include CO, HC, NO_x, and smoke†.
E. Acurex, Shoreham-by-the-Sea, England	Shale oil residuals	1981-early 1982	Testing of A.F.E. Allen BSC 128 6-cylinder, in-line configuration, 5101 cu. in. standing diesel engine for marine, pumping, compressor and electric power applications. Tests include injection, starting, combustion duration and steadiness. Emissions monitored include CO/CO_2, NO_x, NO_2, THC, and smoke‡.
DOE, Conservation and Solar Energy Division	Various shale- and coal-derived fuels	1978-1984	Auto engine dynamometer testing being conducted at SwRI. Particulates, NO_x, CO/CO_2, hydrocarbons, and aldehydes being monitored.
	SRC-II distillates and shale-derived JP-5 and DFM mixed with powdered carbon, sawdust, or other cellulosic material	1981 to ---	Slurry/fuel project involving diesel engine testing. Particulates, NO_x, and other emissions being monitored.
	Coal-derived methanol and gasohol	1981 to ---	Testing in 1,000 fleet vehicles; program currently constrained for lack of fuel samples.
DOE, Office of Coal Utilization	SRC-II and shale-derived fuels	1980 to ---	Medium speed diesel engine testing conducted by SEMT-Pielstich, Paris; Baumester Wain, Copenhagen; Grandi Motori Trieste, Trieste; and Selzer of Switzerland.

(Continued)

TABLE 3. (Continued)

Sponsoring Agency	Test Fuels	Schedule*	Project Description*
DOE, Office of Coal Utilization (Continued)	SRC-II middle distillates, a 2.9 to 1 blend of SRC-II middle and heavy distillate, and shale-derived fuels	1980 to ---	Program conducted at Norwegian Technical Institute in various ships.
	SRC-II middle distillate	1981 to ---	Continuation of low NO_x fuel combustor concept program (see Tests 24-28). Several combustors to be tested by Westinghouse; staged combustor to be tested at several operating loads at Detroit Diesel Allison; testing of 5 combustors planned at GE.
DOE, Pittsburgh Energy Technology Center	Biomass fuel, H-coal, Exxon Donor Solvent, and shale fuel oils	1981 to October 1982	Continuation of small scale combustion of synthetic fuels program (see Test 29). A 20-hp firetube boiler is to be tested with the above synfuels using No. 2 and No. 6 fuel oils as a baseline. The purpose of the program is to assess the possible environmental impact of substituting synfuels for petroleum in utility and industrial boilers.
Air Force/Navy/FAA (under the direction of Capt. H. Cewell, USAF Civil Engineering and Services Center, Tyndall AFB)	Shale-derived JP-4 and JP-8	1982-1984	Testing of CF-6 and CFM-56 turbine engines. Emissions monitoring to include NO_x, SO_x, CO/CO_2, hydrocarbons, and particulates. Limited Ames mutagenicity testing to be performed on particulate samples, as well as photochemical reactivity testing on exhaust gases.
Department of Transportation and Rutgers University	Coal- and shale-derived diesel fuel	1981 to 1982	Testing of a recently-designed and constructed one cylinder diesel engine, including collection of particulates and other combustion products.
Sandia Laboratories	Petroleum-derived synfuel simulation fuels, with higher hydrocarbon/aromatic content than conventional fuels	1981 to ---	Testing being conducted in single cylinder diesel systems and auto/truck engines from Cummins Engine Co. Emphasis on measurement of flame fronts and other engine/burn parameters. Limited emissions monitoring performed.
Bank of America	Methanol/gasoline blends	1980 to ---	Testing being conducted in blends ranging from 2 to 18% methanol in fleet vehicles, with emphasis on blends of 2 and 4%. CO, NO, and unburned hydrocarbons being monitored.

*The schedules and some of the activities listed under the Project Description are somewhat tentative and subject to modification.

†Test results obtained to date have indicated that the performance of the shale-derived fuel was comparable to the No. 2 diesel fuel, although easier atomization and lower fuel consumption were observed with the shale-derived fuel.

‡The test engine satisfactorily burned residual shale oil when heated above the wax melting point and with agitation; emissions were comparable to a No. 2 diesel fuel except for an increase of cylinder deposits of fine carbon.

TABLE 4. TENTATIVE SYNFUEL TESTING PROGRAMS

Sponsoring Agency	Fuels to be Tested	Time Period*	Project Description
Army, MERADCOM, Ft. Belvoir, VA	Diesel fuels and other synfuels (high aromatic content fuels, low lubricity fuels)	1982 to ---	Development of accelerated fuel qualification test procedures, including matrix of specific Army equipment components and candidate fuels; project is part of Army Alternative Fuels Program.
Navy Air Propulsion Test Center, Trenton, NJ	Various shale-derived fuels	1982 to ---	Testing of synfuels in various test burners and aviation equipment.
AF Wright Aeronautical Lab, Aero Propulsion Laboratory, Wright-Patterson AFB, Cincinnati, OH	Various shale-derived fuels	1982 to 1983	Engine augmenter tests and whole engine tests on 3 engines; emissions monitoring for NO_x, CO/CO_2, and hydrocarbons.
EPRI	Various liquid and solid synfuels, including shale-derived heavy and middle residuals, and methanol	Fall 1982 - 1986	Testing of synfuels in various diesel engines, turbines, and boilers; limited emissions monitoring for SO_x, NO_x, CO/CO_2, O_2 and/or particulates.

*Tests pending receipt of synfuel samples.

3.0 OVERVIEW OF SYNFUEL TESTING PROGRAMS

Based on the data presented in the test program data sheets and summarized in Table 2, and on the discussions which have been held with a number of synfuel developers, trade associations and potential major users of synfuels, the following are some general observations on the status, nature, and thrust of the synfuel testing programs:

- Since the primary use of synfuel products is expected to be as combustion fuels, nearly all synfuel end use testing programs have involved evaluation of fuel suitability for use in existing combustion systems (auto engines, industrial/utility boilers, turbines, etc.).

- Reflecting the developmental status of the synfuel technologies, the thrust of the synfuel testing programs which have been carried out to date has been to assess equipment performance and fuel handling characteristics. Where some emissions monitoring has been conducted, such monitoring efforts have been limited in scope and have primarily emphasized measurements of gross parameters such as particulates, NO_x, SO_x, etc., emissions. The limited scope of the monitoring programs has also been in part due to: (a) an absence of a clear definition of the specific environmental data which would be required on synfuel products by regulatory agencies (e.g., by EPA's Office of Pesticides and Toxic Substances in connection with the Premanufacturing Notification Section of the Toxic Substances Control Act); and (b) lack of a standard protocol for testing for environmental data acquisition.

- Most of the synfuel end use testing programs have been, or are being, conducted/funded by DOD, EPRI, and DOE. The programs of these organizations have, respectively, emphasized use of shale oil products in military aviation and ship equipment; use of coal liquids in boilers; and testing of methanol and methanol-gasoline blends in auto engines and use of coal and shale-derived fuels in stationary diesel engines.

- Many synfuel developers appear to have in-house synfuel testing programs; the emphasis of these programs is primarily on synfuel characterization and not on end use testing. The data generated in these programs are generally considered company proprietary and are not published.

- Nearly all the refined shale oil products which have been used in combustion testing to date have been from the refining of the 100,000 barrels of Paraho shale oil at Sohio's Toledo (Ohio) refinery. Since this refining operation apparently did not involve the use of typical unit operations which would be employed in commercial refining of shale oil, the refined products from this operation are not considered to be representative of products from any future commercial refining of the shale oil.

- To date the synfuel testing effort has been severely curtailed by lack of adequate quantities of fuel for testing. Some of the planned testing programs will utilize shale oil products from the forthcoming refining of 50,000 barrels of shale oil by Union Oil for the Defense Fuels Supply Center.

- Synfuel products (specially the shale-derived materials) which will be marketed in the future will most likely be blends and not 100 percent pure products. The use of 100 percent pure products in the initial synfuel testing programs has been justified on grounds that it would simulate a possible "extreme/worst" case condition (at least) from the standpoint of emissions and their environmental implications).

- Although the performance testing is continuing, the limited data which have been gathered to date indicate that the tested synfuels are generally comparable to petrofuels and do not present any unique problems from the standpoint of fuel handling and combustion characteristics. Potential problems with long-term fuel storage stability (observed with certain shale- and petroleum-derived middle distillates) and durability and material compatibility problems (e.g., possible increase in the engine wear with methanol use) are under investigation.

- The very limited data which have been collected on the emission of criteria pollutants (particulates, NO_X, SO_X, etc.) indicate that, except for a higher emission of NO_X with synfuels having a higher content of fuel-bound nitrogen, the emissions of such criteria pollutants are similar for both synfuel and their petrofuel counterparts. For most synfuels, however, no data have been collected on emissions of non-criteria pollutants such as polycyclic organic matter (POM's), primary aromatic amines, nitropyrenes and other organics. There is also very limited data on overall trace element composition of emissions.

APPENDIX

DATA SHEETS ON INDIVIDUAL PROJECTS

TEST 1

COMBUSTION DEMONSTRATION OF SRC-II FUEL OIL IN A TANGENTIALLY-FIRED BOILER

1. FUELS TESTED (see Table A-1)

   Synfuel: SRC-II distillate fuel oil

   Reference fuel: No. 6 fuel oil

2. TEST EQUIPMENT (See Figure A-1)

   Combustion Engineering, Inc., tangentially-fired boiler with a rated steam flow of 450,000 lb/hr.

3. TEST SITE

   74th Street Generating Station of the Consolidated Edison Company of New York.

4. TEST OBJECTIVES

   - Demonstrate the use of SRC-II fuel oil in a utility boiler system of a design typical of a large fraction of utility generation capacity, yet consistent with the limited availability of the synthetic liquid fuel;
   - Compare the boiler performance with that obtained firing conventional petroleum fuel oil;
   - Assess the potential for minimizing NO_X emissions from high nitrogen, coal-derived liquids through choice of operating conditions;
   - Obtain comparative information on the quantity and composition of particulates and organic compounds present in the combustion products of SRC-II fuel oil and No. 6 petroleum fuel oil under comparable boiler operations.

5. SPONSORING AGENCIES

   Electric Power Research Institute
   3412 Hillview Avenue
   Palo Alto, CA 94304

   EPRI Project Manager: W.C. Rovesti
   Telephone No: 415 - 855-2519

   New York State ERDA

   U.S. Department of Energy

   Consolidated Edison Company of New York

TABLE A-1. AVERAGE FUEL PROPERTIES

	No. 6 Fuel Oil	SRC II Fuel Oil
API Gravity at 60°F	25.0	11.0
H_2O % by Volume	0.20	0.28
Sulfur % by Weight	0.24	0.22
Carbon % by Weight	87.02	85.50
Hydrogen % by Weight	12.49	8.86
Nitrogen % by Weight	0.23	1.02
Oxygen % by Weight	--	4.38
Heating Value (Btu/lb)	19,200	17,081
Ash % by Weight	0.02	0.02
Viscosity (sec.) Saybolt Universal at 100°F		40
Viscosity (sec.) Saybolt Universal at 122°F	300 - 700	
Pour Point (°F)	95	-30
Flash Point (°F)	>200	150

Note: Because of sulfur content limitations in New York City, the No. 6 oil utilized by Con Edison exhibits properties close to a No. 5 residual oil.

6. CONTRACTOR

KVB Incorporated
246 North Central Avenue
Hartsdale, New York 10530

Principal Investigators: B.F. Piper
S. Hersh
W. Nazimowitz

7. TEST CONDITIONS

Tests conducted at full load (∿450 klb/hr steam flow rate), half load, and three-quarter load. Tests also included variations designed to reduce NO_x emissions, including reducing the number of burners used and redistributing admitted air (see Table A-2).

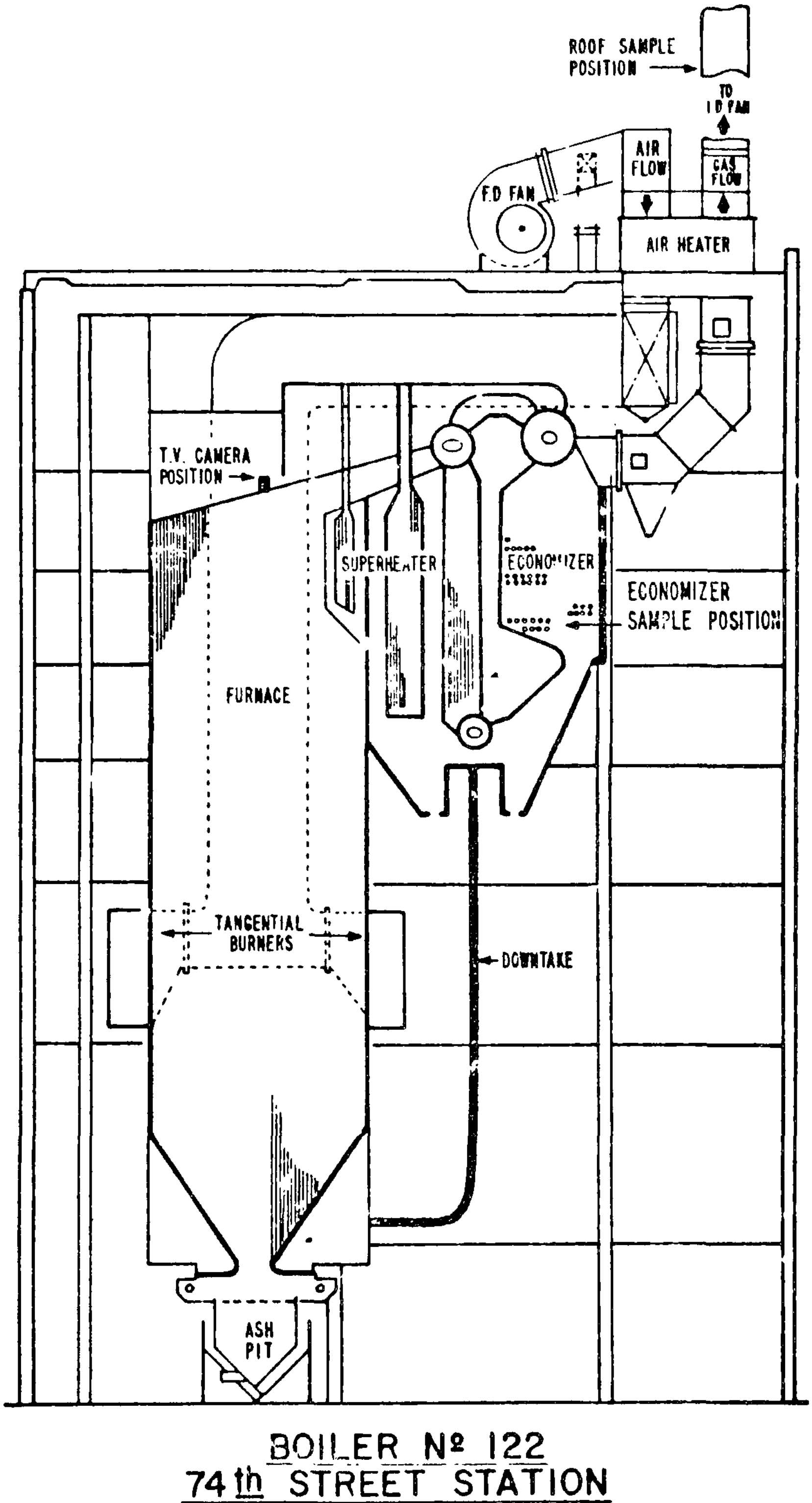

Figure A-1. Boiler 122 Cross Section

TABLE A-2. SRC II FUEL OIL - EMISSIONS TEST SUMMARY

TEST NO.	DATE	TEST CONDITIONS	BOILER PERFORMANCE STM FLOW (klb/hr)	SH TEMP (°F)	BOILER EFF. (%)	GASEOUS EMISSIONS SO_3 (ppm)	NO_2 (ppm Dry @ 3% O_2)	NO (ppm Dry @ 3% O_2)	NOx (lbs NO_2/ 10^6Btu)	O_2 (%)	CO (ppm)	THC (ppm)	PARTICULATE EMISSIONS (lb/10^6 Btu)
II-1	9/11/78	Full Load/Baseline	435	955		0.3,0.9	2	258	.341	3.6	6	2	
II-2	9/11/78	Full Load/Low NOx/6 Burner	430	925	85.7		1	212	.280	3.7	9	1	
II-3	9/11/78	Full Load/Low NOx/6 Burner	425	955			1	236	.311	3.4	9	1	
II-4	9/12/78	Full Load/Baseline	430	962			-	298	.391	3.9	9	2	
II-5	9/12/78	Full Load/Low NOx/8 Burner	440	938			-	228	.299	2.5	17	2	
II-6	9/12/78	Full Load/Low NOx/8 Burner	436	930	86.3		-	232	.305	2.7	24	2	.017,.016,.016,(.021)**
II-7	9/13/78	Half Load/Baseline	251	935			2	261	.345	4.7	5	1	
II-8	9/13/78	Half Load/3 Burners	246	939	87.8		1	287	.378	4.1	15	0	
II-9	9/13/78	Half Load/4 Burners	240	948			1	279	.368	5.0	19	1	
II-10	9/13/78	Half Load/Baseline	230	905			2	301	.397	4.8	6	0	.007,.006
II-11	9/14/78	Full Load/Baseline*	477	955	86.0		0	239	.313	2.7	25	1	.018,.019
II-12	9/14/78	Full Load/Low NOx/6 Burner	472	943			0	194	.255	3.5	65	0	
II-13	9/14/78	3/4 Load/Low NOx/6 Burner	340	900			2	159	.211	3.9	12	0	
II-14	9/14/78	3/4 Load/Low NOx/J-14	305	890			-	186	.244	3.1	16	-	
II-15	9/15/78	Half Load/Low NOx/N30	243	870	87.1		0	188	.247	4.1	6	1	.009,.010
II-16	9/15/78	Half Load/Upper/Lower Pattern	245	865			0	188	.247	4.0	5	2	
II-17	9/15/78	Full Load/Low NOx/6 Burner	492	935	86.2		0	175	.230	2.7	22	2	.024,.026

* Boiler setup not typical of usual baseline operation - refer to Section 7

** (Value) from ASME in-stack thimble

8. ENVIRONMENTAL MONITORING

Nitric oxides, oxygen, carbon monoxide, polycyclic organic matter, total unburned hydrocarbons, sulfur trioxide, particulate mass and particle size distribution.

9. PROJECT STATUS

This effort is an element of EPRI's ongoing R&D program directed at gaining operating experience in utility boilers firing various liquid and solid coal-derived synthetic fuels. Additional tests are planned in various-scale equipment using fuels from the solvent refined coal (SRC-I and SRC-II), H-Coal, Exxon EDS and other advanced liquefaction processes as adequate fuels from these processes become available for testing.

10. RESULTS

The results of the test program are highlighted below and summarized in Table A-2.

- No major operational problems or adverse boiler performance effects encountered with SRC-II fuel oil. Nitrogen oxide emissions nominally 70 percent higher than with the No. 6 fuel oil currently used by Consolidated Edison. Reductions in NO_x levels on the order of 35 percent demonstrated through combustion modifications with both fuels.

- Particulate mass emissions were lower for the SRC-II fuel oil than for the No. 6 fuel oil. At full load, the SRC II fuel oil particulate emissions exhibit a bi-modal size distribution; many were $\leq$0.05 microns and others were >0.1 microns. Particulate mass composition is also reported.

- Total hydrocarbon emissions were <3ppm under all operating consitions with both fuels.

- Total POM for both fuels were low, $<6\times10^{-6}$ lb/10^6 Btu.

11. REFERENCE

B.P. Piper, et al., "Combustion Demonstration of SRC-II Fuel Oil in a Tangentially Fired Boiler", Final Report, May 1979, EPRI Projects 1235-5 and 1412-2, prepared by KVB, Incorporated, Hartsdale, New York.

TEST 2

COMBUSTION AND EMISSION CHARACTERISTICS OF COAL-DERIVED LIQUID FUELS

1. FUELS TESTED

Synfuels: SRC-II fuel (5 ratios of medium and heavy boiling range components); H-Coal (syncrude mode of operation, full-range distillate); EDS (full-range distillate).

Reference fuel: No. 6 and No. 2 petroleum-derived fuels.

2. TEST EQUIPMENT

An 80-HP firetube boiler system extensively modified to simulate a utility boiler including an indirectly fired air preheater, a scaled-down utility boiler burner, radiation shields to increase the thermal environment in the combustion chamber, and capabilities to implement staged combustion.

3. TEST SITE

KVB Combustion Research Laboratory, Tustin, California.

4. TEST OBJECTIVES

- Develop an understanding of the effect of compositional variations of a particular coal liquid and the resulting effects on the implementation of combustion modifications for pollutant emission reductions;
- Establish an understanding of the difference in the combustion and emission characteristics of coal liquids produced from various processes--specifically the SRC-II Process, the Exxon Donor Solvent Process, and the H-Coal Process;
- Establish a standard test method, using a small-scale facility, to predict the response to changes in operation of smoking tendency, CO, and NO_x. This will be used to differentiate various fuel properties and the performance of each fuel in a large variety of commercial boilers.

5. SPONSORING AGENCY

Electric Power Research Institute (EPRI)
Power Generation Program
Advanced Power Systems Division
Palo Alto, California

EPRI Project Manager: W.C. Rovesti
Telephone No: 415-855-2519

6. CONTRACTOR

KVB Inc.
Irvine, California

Principal investigators: L.J. Muzio, J.K. Arand
Telephone No. 714-641-6200

7. TEST CONDITIONS

A systematic set of experiments was conducted which investigated the following variables: excess air with single stage combustion, burner stoichiometry with two-staged combustion, firing rate, air preheat temperature, fuel temperature (viscosity), and atomizer (mechanical, steam).

8. ENVIRONMENTAL MONITORING

O_2, CO_2, CO, NO, SO_2, SO_3, unburned hydrocarbons, smoke number, particulate size distribution.

9. PROJECT STATUS

Completed.

10. RESULTS

Emissions from the various synfuels combustion tests in this program are summarized in Table A-3. A brief description of other emission test results are shown below.

SRC II

Particle size data indicate that SRC-II fuel blends produced finer-size-distribution particulate than No. 6 oil, the exception being SRC-II heavy distillate component under single-stage combustion. Measured SO_2 emissions were consistent with the fuel sulfur content, with nearly all fuel sulfur emitted as SO_2. An SO_3 concentration of 2 ppm for heavy distillate component was the only SRC-II test detecting this pollutant. Reference fuel No. 6 oil burn test also emitted 2ppm SO_3. Unburned hydrocarbon concentrations measured for SRC-II combustion tests ranged from 1 to 14 ppm.

H-Coal

Average particle size of particulate matter proved to be less than 0.4 microns. Measured SO_2 emissions were consistent with fuel sulfur content in that the SO_2 emissions were the lowest of all synfuels tested.

TABLE A-3. SUMMARY OF EMISSIONS

Fuel Type	Fuel Ash Content lb/10^6 Btu	Single-Stage O_2 %	Single-Stage Part. lb/10^6 Btu	Single-Stage NO ppm @ 3% O_2	Two-Stage (Low O_2) O_2 %	Two-Stage (Low O_2) Part. lb/10^6 Btu	Two-Stage (Low O_2) NO ppm @ 3% O_2	Two-Stage (High O_2) O_2 %	Two-Stage (High O_2) Part. lb/10^6 Btu	Two-Stage (High O_2) NO ppm @ 3% O_2
No. 6 oil	0.0045	3.7	0.024	270	3.6	0.037	199	---	---	---
SRC-II 5.75/1*	0.0017	3.8	0.014	400	3.2	0.022	303	4.9	0.020	382
SRC-II Medium Distillate	0.0012	4.0	0.011	476	3.1	0.017	307	4.2	0.012	342
SRC-II 2.9/1*	0.0041	3.3	0.012	361	2.9	0.015	308	4.5	0.017	371
SRC-II 0.4/1*	0.018	3.4	0.031	509	3.3	0.039	279	4.7	0.039	375
SRC-II Heavy Distillate	0.034	3.3 3.8	0.029 0.037	381 392	3.5	0.184	249	4.6	0.090	269
SRC-II Heavy Distillate (210°F Fuel Temperature)	0.034	---	---	---	3.2	0.065	339	---	---	---
H-Coal	0.0095	2.8	0.022	247	3.1	0.037	226	4.95	0.034	202
EDS Fuel	0.0045	2.8	0.022	259	3.2	0.0184	270	5.15	0.0154	216

*Middle to heavy distillate ratio.

SO_3 was not detected, Unburned hydrocarbon emissions ranged from 1 to 4 ppm.

EDS

Two particle sizing tests showed the average particle size to be less than 0.4 microns. Measured SO_2 emissions were consistent with the fuel sulfur content. EDS flue gas samples showed no detectable levels of SO_3. Measured unburned hydrocarbon emissions were 1 and 2 ppm.

11. REFERENCE

Muzio, L.J. and J.K Arand. Combustion and Emission Characteristics of Coal-Derived Liquid Fuels. EPRI AP-1878, Electric Power Research Institute, Palo Alto, Calif., 1981.

TEST 3

CHARACTERIZATION AND COMBUSTION OF SRC-II FUEL OIL

1. FUELS TESTED

Synfuel: SRC-II fuel oil, 5.75/1 blend of medium/heavy distillate with nominal boiling range of 350-850°F.

Reference fuels: No. 2 fuel oil, No. 5 fuel oil.

2. TEST EQUIPMENT

Babcock & Wilcox FM boiler (Model FM 1070) designed to the following specifications:

Steam Capacity	50,000 lbs/hr
Design Pressure	1050 psig
Operating Pressure	150 to 1000 psig
Heating Surface	4410 Ft^2
Furnace Volume	1065 Ft^3
Furnace Dimensions	20' x 6'-4" x 8'-6"
Fuel	Nat. gas/No. 6 fuel oil/ No. 2 fuel oil.

Modifications to the boiler facility included:

- Connection of an existing air heater to supply combustion air at 400°F.
- Revamping of the boiler controls to permit biasing of the fuel/ air ratio.
- Installation of a high pressure mechanical return flow pumping & atomization system.
- Various piping and pump modifications.
- Installation of various gas and particulate analysis instrumentation.

3. TEST SITE

Alliance Research Center of
Babcock and Wilcox Co.
Alliance, Ohio

4. TEST OBJECTIVES

- To obtain a detailed analysis and characterization of a portion of the same SRC II distillate fuel oil product scheduled for subsequent field testing in a utility boiler.
- To carry out combustion tests in a modified water tube package boiler using a conventional circular burner (to provide data for comparing emissions and combustion performance of the test fuels).
- To determine the effectiveness of using a dual register burner in order to control NO_x emissions from the combustion of SRC II fuel oil in the test boiler.

5. SPONSORING AGENCY

Electric Power Research Institute
Fossil Fuel and Advanced Systems Division
Palo Alto, California

Project Manager: W.C. Rovesti
Telephone No: (415) 855-2519

6. CONTRACTOR

The Babcock & Wilcox Company
Alliance Research Center
Research and Development Division
Alliance, Ohio

Principal Investigators: W. Downs and A.J. Kubasco

7. TEST CONDITIONS

The test program was conducted in three phases. The first involved detailed fuel analyses of SRC fuel oil, No. 2 fuel oil, and No. 5 fuel oil The second involved combustion tests on the FM boiler using a conventional circular burner. Operating variables included excess air, load, and burner register settings. Four fuel atomizers were tested: Y-jet, Racer, T-jet, and Return flow mechanical atomizer. The third test involved combustion studies with a Babcock & Wilcox dual register burner on the FM package boiler.

8. ENVIRONMENTAL MONITORING

NO_x, CO, CO_2, SO_2, H_xC_y, O_2, and stack capacity. Dust loadings were taken by EPA's Method 5.

9. PROJECT STATUS

Project completed; final report dated June, 1979.

10. RESULTS

NO_x emissions and combustion performance were the principal variables studied. The quantifiable aspects of combustion performance are stack opacity and CO measurements. The interactions between minimum excess air, flame appearance, flame impingement, burner stability, and furnace rumble played a role in assessing combustion performance. In this context, the influence of the various operating parameters upon NO_x emissions and combustion performance are listed as follows:

- NO_xemissions increased moderately with increases in O_2.
- Oxidation of fuel-bound nitrogen in the SRC fuel oil was the predominant factor attributing to NO_x emissions.
- Combustion performance for SRC fuel oil was similar to No. 2 and No. 5 fuel oils.
- At full boiler load, the type of fuel atomizer had a substantial affect upon NO_x emissions and combustion performance. At reduced loads, the type of fuel atomizer had a lesser impact on either variable.
- Combustion performance improved slightly at reduced loads.
- Burner register settings had little affect on NO_x emissions.
- Burner register settings had a substantial impact upon combustion performance at minimum excess air conditions.
- Combustion and boiler efficiency were similar for both SRC fuel oil and No. 5 fuel oi.

Several conclusions were drawn regarding emissions and combustion of SRC fuel oil:

- Although the capability to burn SRC fuel oil in such a way as to limit NO_x emissions to less than EPA's proposed New Source Performance Standard of 0.5 pound NO_2/million Btu was not demonstrated, it appears that this new limit could be met on the typical wall-fired utility boiler by the use of two stage combustion and by the proper matching of burner and atomizer designs.
- The ineffectiveness of the dual register oil burner to control NO_x resulted from a design error which prevented controllability over fuel-air mixing. Schedule restraints negated the opportunity to correct that problem.

- The fuel nitrogen in SRC fuel oil appears to oxidize more readily than does the fuel nitrogen in other fuels.
- The interaction between fuel and air mixing appears to have a predominating influence upon NO_x formation and emissions. Most of the potential for reducing NO_x emissions lies in the control of fuel nitrogen oxidation with a lesser potential existing for reducing thermally derived NO_x. Therefore, the influence of air preheat temperature and the flame temperature parameter Ha/Sc should have only a minor impact upon NO_x emissions. Boiler load may have some influence upon NO_x emissions and control.
- SRC fuel oil produced no significant smoking tendencies. Flame Appearance, as well as stack opacity, with SRC fuel oil was slightly better than with No. 5 fuel oil.
- Neither combustion efficiency nor boiler efficiency were affected by conversion from No. 5 fuel oil to SRC fuel oil.
- Particulate emissions limits in compliance with EPA's proposed New Source Performance Standards of 0.03 pound/million Btu can be easily attained with SRC fuel oil.

11. REFERENCE

Downs, W. and A.J. Kubasco. Characterization and Combustion of SRC II Fuel Oil. EPRI FP-1028, Projects 1235-3,-4, 1412-1. Prepared for the Electric Power Research Institute, Palo Alto, California, June, 1979.

TEST 4

CATALYTIC COMBUSTION OF COAL-DERIVED LIQUID FUELS

1. FUELS TESTED

   Synfuels: SRC-II fuel oil blend (a blend of middle and heavy distillates in a 5:1 ratio with a nominal boiling range of 360-700°F); H-coal fuel oil (from distillation of atmospheric overhead products, nominal boiling range was 300-500°F).

   Reference fuel: No. 2 petroleum-derived diesel fuel.

2. TEST EQUIPMENT

   Three different catalytic reactors were combustion-tested with the three fuels: (1) a high dispersion washcoated precious metal catalyst made by UOP, (2) a high platinum loading catalyst made by Acurex, and (3) a proprietary monolith with platinum applied by Acurex.

3. TEST SITE

   Acurex Combustion Laboratory

4. TEST OBJECTIVES

   - Determine the combustion characteristics of coal-derived liquids in catalytic reactors.
   - Evaluate the potential poisoning effects of coal-derived liquids on state-of-the-art catalytic reactors.

5. SPONSORING AGENCY

   Electric Power Research Institute
   Power Generation Program
   Advanced Power Systems Division
   Palo Alto, California

   Project Manager: L.C. Angello
   Telephone No.: 415-855-2873

6. CONTRACTOR

Acurex Corporation
Energy and Environment Division
Mountain View, California

7. TEST CONDITIONS

This test program included a series of screening tests and a durability test. Screening tests were run with all three catalytic reactors at a pressure of one atmosphere and over a range of equivalence ratios nominally between 0.3 (fuel-lean) and 1.35 (fuel-rich). Nominal operating conditions were for an air preheat of 800°F, reactor temperature of 2100°F, and reference face velocities between 20 and 80 fps at the measured preheat temperature and chamber pressure.

A durability test series was also run using the UOP and H-Coal fuel oil. Durability tests were conducted at a pressure of three atmospheres. The combustor inlet face velocity was decreased by a factor of three, but the residence time was increased by a factor of three. Nominal reactor temperatures ranged from 2100-2370°F.

8. ENVIRONMENTAL MONITORING

CO and NO_x

9. PROJECT STATUS

This effort was conducted during the period November 1978 to February 1980.

10. RESULTS

The results of the screening tests are summarized in Table A-4. In the durability test with H-Coal, catalyst deactivation became substantially evident after about 26 hours; CO emissions increased from a baseline of about 10 ppm to about 24 ppm. After 40 hours on H-Coal, the combination was unstable and the reactor fractured. At this point, combustion testing was terminated.

11. REFERENCE

Chu, E.K., G.C. Snow, H. Tong. Catalytic Combustion of Coal-Derived Liquid Fuels. EPRI AP-1666, Electric Power Research Institute, Palo Alto, January 1981.

TABLE A-4. SUMMARY OF SCREENING TEST RESULTS

Lean Combustion

Reactor	CO (ppmv) SRC II	CO (ppmv) H-Coal	CO (ppmv) Diesel	NO_x (ppmv) 15% EO SRC-II	NO_x (ppmv) 15% EO H-Coal	NO_x (ppmv) 15% EO Diesel
UOP	100-200	50-100	25-50	390-440	140	4-9
Acurex Pt	250-800	50-100	40-60	450-590	140	2-10
Acurex Pt on proprietary monolith	Not active	80-200	--	Not active	140-167	--

Rich Combustion

Reactor	SRC II Combustion	SRC II FN Conversion	H-Coal Combustion	H-Coal FN Conversion	Diesel Combustion	Diesel FN Conversion
UOP	Stable	17%	Stable	30%	Stable	--
Acurex Pt	Inactive	--	Inactive	--	--	--
Acurex Pt on proprietary monolith	--	--	Inactive	--	--	--

TEST 5

GAS TURBINE COMBUSTOR PERFORMANCE ON SYNTHETIC FUELS

1. FUELS TESTED

Synfuels: the 18 synfuels tested are described in Table A-5 below.

TABLE A-5. FUEL DESCRIPTION

Fuel #	Name	%N*	%Ca*	%H*
1	SRC-I Light Organic Liquid	0.29	28	12.18
2	H-Coal (210-480°F)	0.15	34	11.32
2A	H-Coal (300-500°F)	0.16	29	11.19
3	H-Coal (450-650°F)	0.33	43	10.03
4	H-Coal, ATM. Bottoms	0.61	57	9.27
5	EDS-Hydrogenated Recycle Solvent	0.08	48	9.95
5A	Reprocessed EDS (W/O 650° + Fraction)	0.04	47	10.16
6	SRC-I Wash Solvent	0.35	61	9.23
7	SRC-I Recycle Solvent	0.69	76	7.74
8	SRC-II Middle Distillates	0.91	63	8.83
9	SRC-II Heavy Distillates	0.98	77	7.13
9A	SRC-II Heavy Distillates (Second Batch)	0.94	71	7.22
10	SRC-II Blend (Medium)	0.91	63	8.70
10A	3:1 Mixture - #2 Dist. & SRC-II Blend	0.23 Est	--	11.6 Est
10B	1:1 Mixture - #2 Dist. & SRC-II Blend	0.45 Est	--	10.6 Est
11	Shale Oil - Paraho (Hydrogenated)	0.33	14	12.80
12	Shale Oil - Deashed	1.82	--	11.4
13	Shale Oil - Desulfurized	1.63	--	12.2

*%N - Percent Bound Nitrogen
%Ca- Percent Aromatic Carbon
%H - Percent Hydrogen

Reference fuel: No. 2 petroleum distillate oil.

2. TEST EQUIPMENT

Two combustors were used, including a full-scale Westinghouse commercial unit (0.3 m diameter) typical of those used in Westinghouse W-251 and W-501 combustion turbine engines and a half-diameter (0.14 m) version.

3. TEST SITES

Full scale: Westinghouse Combustion Turbine System Division Laboratory, Lester, Pennsylvania.

Subscale tests: Westinghouse Research and Development Center, Pittsburgh, Pennsylvania.

4. TEST OBJECTIVES

- Identify problems that will arise in using these synfuels on current engines.
- Determine fuel properties that lead to a fuel suitable for current engines.
- Determine which synthetic fuels now available are suitable for use.
- Determine combustor/engine improvements needed to use the synthetic fuels that do not meet these specifications.

5. SPONSORING AGENCIES

Electric Power Research Institute
Power Generation Program
Advanced Power Systems Division
Palo Alto, California

Project Manager: A. Cohn
Telephone No: 415 - 855-2519

6. CONTRACTOR

Westinghouse Electric Corporation
Combustion Turbine Systems Division
Long-range Development Department
Concordville, Pennsylvania

Subcontract support for fuel analysis was provided by Mobil Research and Development Corporation.

7. TEST CONDITIONS

Typical combustor test conditions were as follows:

	Full-scale Combustor	Subscale Combustor
Inlet air temperature	600°F	600°F
Pressure Level	8 ATM	4 ATM
Air Flow	33 lb/sec	1.5 lb/sec
Fuel/test	2,000 gal	100 gal

8. ENVIRONMENTAL MONITORING

NO_x, CO, CO_2, smoke, unburned hydrocarbons (UHC), particulates.

9. PROJECT STATUS

Testing was completed July 1980, and the final report is dated November 1980.

10. RESULTS

NO_x

- Figures A-2 and A-3 show NO_x vs. burner outlet temperature curves derived from subscale and full-scale tests. Because of their high fuel-bound-nitrogen (FBN) content, the synfuels produced higher NO_x emissions than No. 2 baseline fuel. Each curve indicates the fuel type and number, and the percent weight FBN. Detailed graphs of NO_x response to each fuel under all test conditions are documented in the referenced report.
- Synfuels with hydrogen content greater than 10% (by wt.) and nitrogen content less than 0.2% should be satisfactory for engines of current design.

Smoke

- Smoke increased with increasing combustor burner outlet temperature. Level of smoke was dependent on fuel quality; fuels of better quality (higher % H_2, lower aromaticity) tended to smoke less. Smoke emissions may be a problem with some of the poorer fuels, especially at idle conditions.

Other Emissions

- Particulates were measured during full-scale tests on H-Coal (fuel No. 2) and baseline fuel No. 2. All measured concentrations were below 0.5 $lb/10^6$ $ft.^3$, which is quite low. It was concluded that particulate emissions are no different for coal derived and petroleum derived fuels.
- In all cases, CO emissions were below 100 ppm; measured results are shown in Figure A-4.

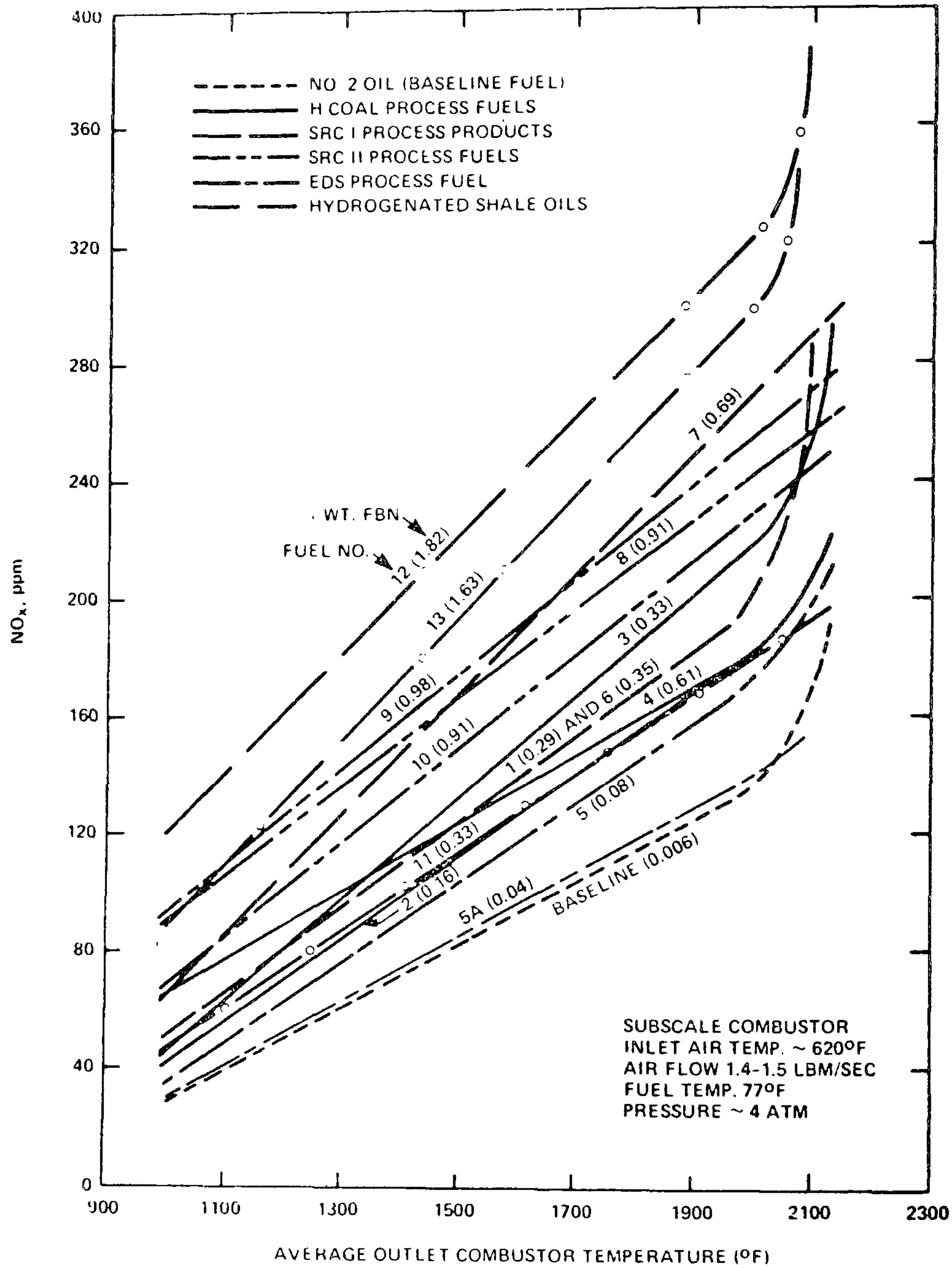

Figure A-2. NO_x Emissions for Synthetic Fuels and No. 2 Oil, Subscale Combustor Tests

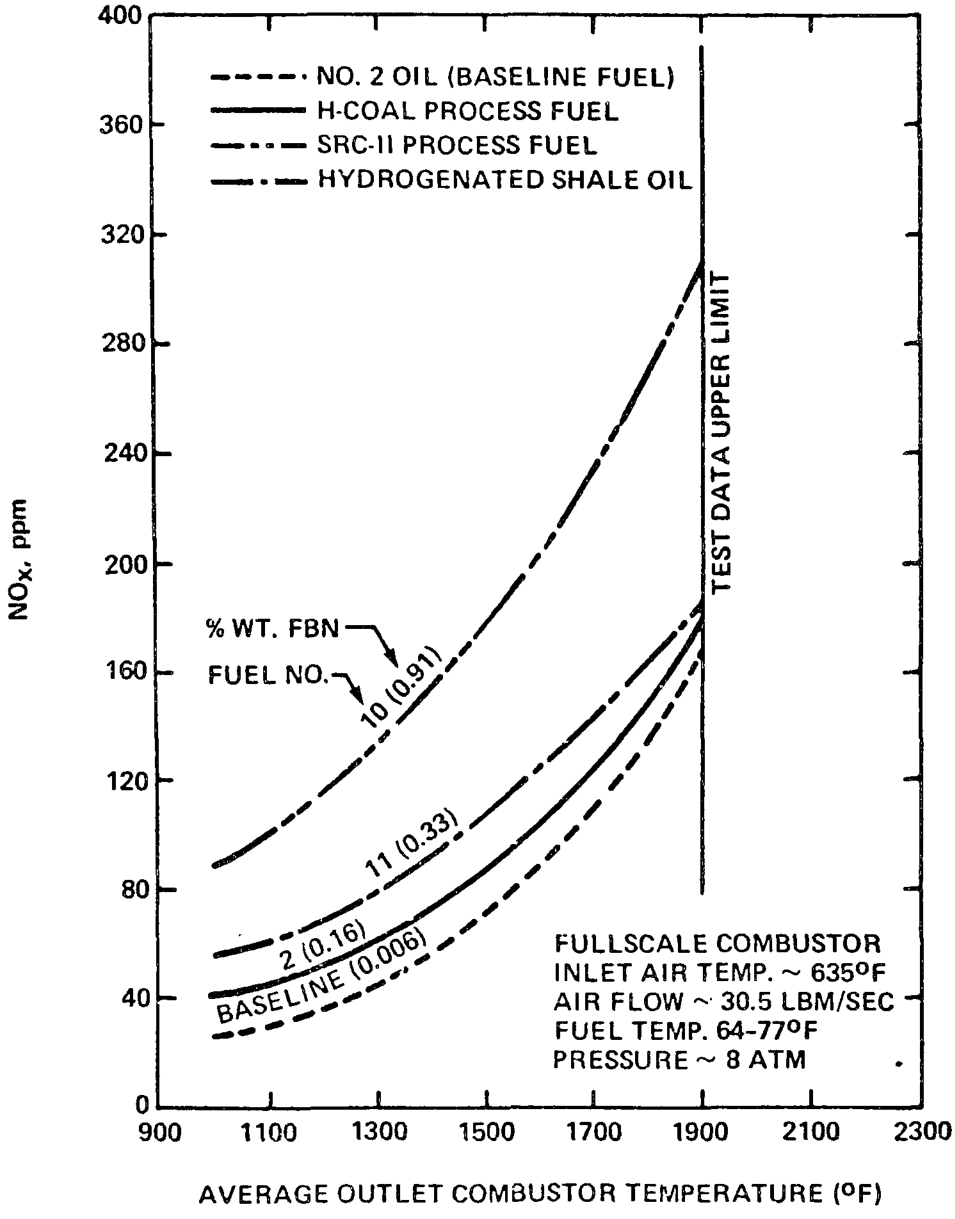

Figure A-3. NO_X Emissions for Synthetic Fuels and No. 2 Oil, Full-Scale Combustor Tests

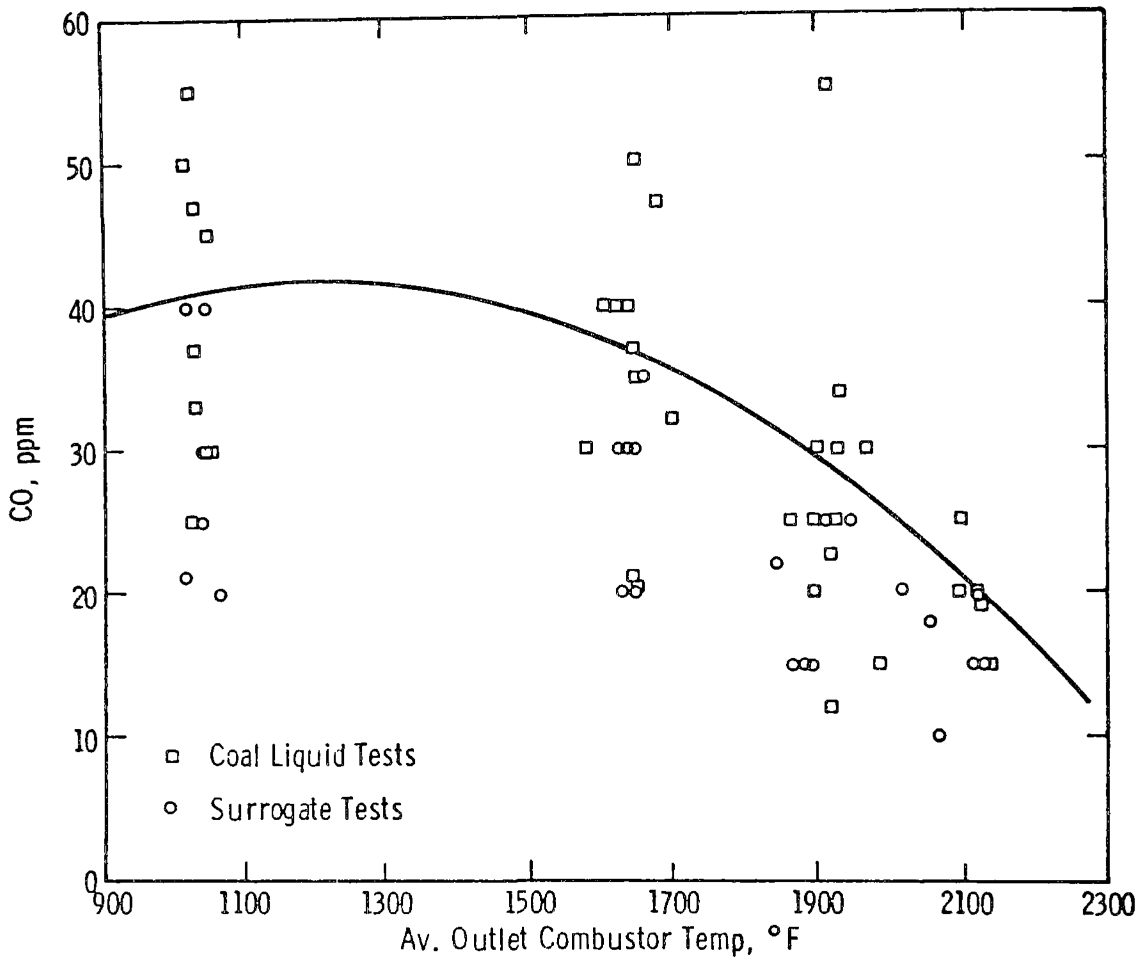

Figure A-4. Baseline CO Emissions With No. 2 Fuel Oil

- In general, unburned hydrocarbon levels were found to be ≤ 10 ppm.
- CO_2 data are displayed in Figure A-5 for combustion information only.

11. REFERENCE

DeCorso, S.M., P.W. Pillsburn, G. Bauserman, P.R. Mulik, and T.R. Stein. Gas Turbine Combustor Performance on Synthetic Fuels, Volumes I and II. EPRI AP-1623. Prepared for the Electric Power Research Institute, Palo Alto, California, November 1980.

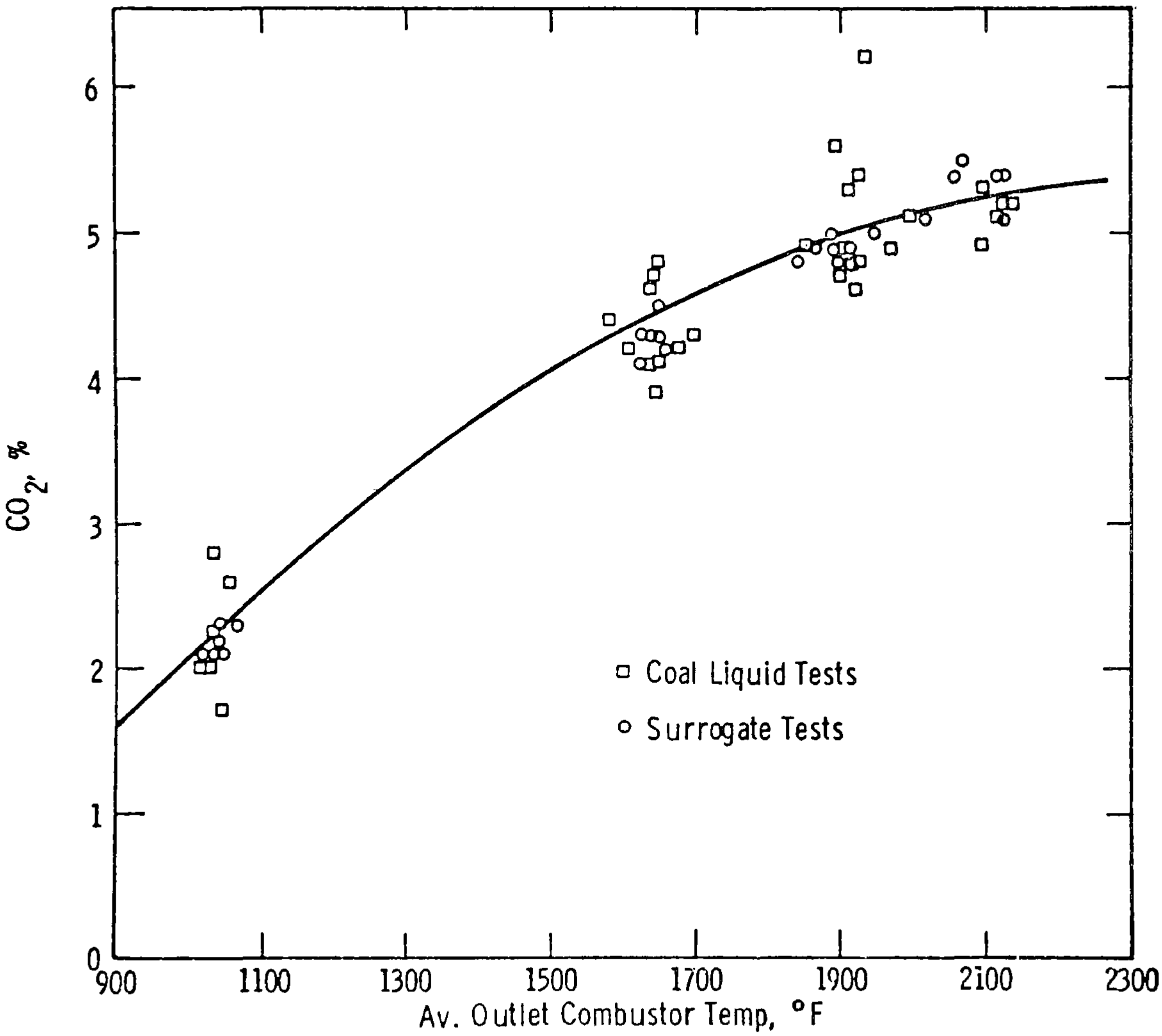

Figure A-5. Baseline CO_2 Emissions With No. 2 Fuel Oil

TEST 6

SOLVENT REFINED COAL BURN TEST

1. FUELS TESTED

Synfuel: Solvent Refined Coal (SRC) fuel.

Reference fuel: Bituminous coal.

2. TEST EQUIPMENT

Babcock & Wilcox F-type 22.5 MW power plant boiler using a specially designed dual register, water-cooled burner.

3. TEST SITE

Georgia Power Company's Plant Mitchell near Albany, Georgia.

4. TEST OBJECTIVES

- To evaluate the shipping, handling, boiler-performance, and combustion-emission characteristics of SRC.

5. SPONSORING AGENCY

U.S. Department of Energy
DOE project support: Nueworth, M.G.

6. CONTRACTOR

Southern Company Services, Inc.
Research and Development Department
Birmingham, Alabama

Project Managers: Dr. W.B. Harrison and Mr. S.R. Hart, Jr.
Telephone No: (205) 870-6011

Many other organizations also provided technical support.

7. TEST CONDITIONS

Tests were run in three phases. Phase I was to operate and test the boiler under normal conditions firing coal. For Phase II, new burners and pulverizer feeders were installed, and the boiler was tested against firing coal. During Phase III, when SRC was fired, hot air to pulverizers was closed off, pulverizer spring pressure was reduced, and the boiler was tested for a third time. For each phase, tests were run at unit loads of approximately 7, 14, and 21 MWe. Usually two tests, each of 4-hours duration, were run at each load in each phase (see Table A-6).

8. ENVIRONMENTAL MONITORING

Particulates, SO_2, and NO_x were monitored using EPA and ASME procedures. Also, continuous monitors analyzed flue gas for opacity, SO_2, NO_x, CO_2, and O_2.

9. PROJECT STATUS

Project completed; final report dated July 1979.

10. RESULTS

Boiler efficiency measurements performed throughout all phases of the burn test indicated that efficiency at full load was essentially the same when either SRC or coal was burned. The boiler stayed much cleaner with SRC than with coal, eliminating the need for deslagging the burner front or the use of soot blowers during the entire 18-day burn test. Typical SRC emissions and current EPA requirements (in lb/10^6 Btu) are shown below.

	EPA Requirements	SRC
SO_2	1.2	1.00
NO_x	0.7	0.45
Particulates	0.1	0.04

The quantity of fly ash generated while burning SRC was nominally 10 to 15 percent of that generated when firing coal, and bottom ash was virtually nonexistent. Boiler conditions and emissions are summarized in Table A-6.

11. REFERENCE

Southern Services Company. Solvent Refined Coal Burn Test, Final Report. Prepared for the U.S. Department of Energy. The Research and Development Department of Southern Services, Inc., Birmingham, Alabama, July 1979. 214 pp.

TABLE A-6. OPERATION AND EMISSIONS DATA

	Phase I			Phase II				Phase III			
Load, MW	22.5	15	7.5	21	14	7.5	21*	21	14	7.5	21*
Fuel Rate, lb/hour	23,880	16,143	9,010	20,676	14,784	9,510	20.065	17,714	12,178	7,311	17,678
Excess O_2, %	4.7	6.0	11.0	4.4	6.2	11.6	4.6	6.0	7.5	11.3	6.2
Particulate Loading In, $lb/10^6$ Btu	9.90	10.84	9.81	7.39	9.09	8.96	4.72	1.04	1.91	1.77	0.96
Particulate Loading Out, $lb/10^6$ Btu	2.30	0.46	0.11	1.66	0.81	0.32	0.07	0.90	1.42	0.93	0.04
Carbon in Ash, %	13.9	14.5	19.5	22.33	20.6	16.9	28.1	77.4	88.7	89.4	74.8
Carbon Efficiency, %	97.70	97.47	97.07	98.00	97.18	97.18	97.87	98.51	96.98	97.07	98.60
SO_2, $lb/10^6$ Btu	1.94	2.15	2.44	1.20	1.57	1.80	0.94	0.95	0.98	1.06	0.93
NO_x, $lb/10^6$ Btu	1.01	0.46	0.89	0.49	0.47	0.49	0.47	0.43	0.45	0.42	0.46
Average Opacity, %	41	18	7	30	22	12	66	32	29	15	40
$kWh/10^6$ Btu	78.05	78.67	67.85	79.30	75.81	64.97	80.22	78.98	76.18	65.77	78.88
Average CO_2, %		8.88			8.27				8.76		

* Secondary precipitator tests.

TEST 7

TEST AND EVALUATION OF METHANOL IN A GAS TURBINE SYSTEM

1. FUELS TESTED*

Reference fuels: distillate fuel (Jet-A); natural gas; and chemical grade methanol derived from natural gas.

2. TEST EQUIPMENT

Two Turbo Power and Marine Systems, Inc. (TPM) gas turbines combined with an electric generator in a TP-4 Twin Pac configuration.

3. TEST SITE

SCE's Ellwood Energy Support Facility at Goleta, California.

4. TEST OBJECTIVES

- Compare gas turbine emissions and performance characteristics operating on distillate, methanol, and natural gas fuel.
- Evaluate the handling and storage of methanol.
- Compare maintenance requirements operating the gas turbines on methanol or distillate fuel.
- Determine emissions operating the gas turbines on distillate fuel with and without water injection.
- Determine the performance and emissions operating the methanol fueled gas turbine with water injection.
- Determine the necessity of a lubricant additive to the methanol fuel system.

5. SPONSORING AGENCY

Electric Power Research Institute
Power Generation Program
Advanced Power Systems Division

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

Project Managers: R.L. Duncan and H. Schreiber
Telephone No: 415-455-2502

6. CONTRACTOR

Southern California Edison Company (SCE)
Research and Development
Rosemead, California

Principal Investigators: A. Weir, Jr., W.H. Von Kleinsmid, and E.A. Danko.

Emissions testing was performed by KVB, Inc., Irvine, California

7. TEST CONDITIONS

Emissions were measured at base load (25 MW), 75 percent load (18 MW), and 50 percent load (13 MW).

The effects on gaseous emissions of using water injection for NO_x control were also investigated.

8. ENVIRONMENTAL MONITORING

NO_x, NO, CO, CO_2, SO_2, total hydrocarbons, particulates (including sulfates and POM), aldehydes, and opacity.

9. PROJECT STATUS

The methanol program was begun on 6/25/79 and was completed in 12/79. Report is dated 2/81.

10. RESULTS

The major emissions and performance results are summarized in Table A-7 for baseload conditions.

11. REFERENCE

Weir, A., W.H. VonKleinsmid, and E.A. Danko. Test and Evaluation of Methanol in a Gas Turbine System. EPRI AP-1712, Research Project 988-1. Prepared for the Electric Power Research Institute, Palo Alto, California, February 1981.

TABLE A-7. EMISSIONS AND PERFORMANCE RESULTS

	Methanol (dry*)	Jet A (dry*)	Jet A (wet*)	Natural Gas (dry*)	Natural Gas (wet*)
NO_x†	45	207	56	124	65
NO_2†	10	10	10	50	40
CO†	70	50	60	175	220
Hydrocarbons†	10	5	5-6	216	280
Aldehydes†	1.8	---	0.05	10.6	12.1
SO_2†	0	13	13	0	0
Particulates, $lb/10^6$ Btu					
Solid	0.003	---	0.008	---	---
Condensible	0.011	---	0.017	---	---
Total POM, µg/SCM	1.22	---	1.07	---	---
Opacity, %	0	0	0	0	0
Heat rate, Btu/kW-hr	11,722	11,863	12,014	11,863	---
Fuel consumption @ 24 MW					
Liquid (GPM)	82.4	37.4	38.0	---	---
Gas (SCFM)	---	---	---	4,860	---

*"Dry" and "wet" refer to water injected and nonwater injected.

†Measured at 15 percent O_2, dry, ppm.

TEST 8

EFFECT OF FUEL BOUND NITROGEN ON OXIDES OF NITROGEN EMISSIONS FROM A GAS TURBINE ENGINE

1. FUELS TESTED

Synfuel: JP-5 type fuel derived from crude shale oil.

Reference fuel: JP-5 derived from petroleum.

2. TEST EQUIPMENT

Allison T63-A-5A turboshaft engine (free turbine type used in Army OH-58A and Navy TF-57A helicopters).

3. TEST SITE

Naval Air Propulsion Test Center
Trenton, New Jersey

4. TEST OBJECTIVES

- Confirm the presence of high levels of NO_x in engine exhaust;
- Obtain information on conversion efficiency of fuel bound nitrogen into NO_x;
- Assess the impacts of high nitrogen fuel on meeting pollution control regulations.

5. SPONSORING AGENCY

Deputy Chief of Naval Material (Development)
Department of the Navy
Washington, D.C. 20361

Project Officer: L. Maggitti
Telephone No: 202 - 545-6700

6. CONTRACTOR

Naval Air Propulsion Center
Fuels and Fluid Systems Division, PE71
Trenton, New Jersey 08628

Authors: A. F. Klarman, A. J. Rollo
Telephone No: 609 - 896-5841

7. TEST CONDITIONS

The T63-A-5A engine was installed in a sea level test cell using a three-point mounting system. A flywheel and an Industrial Engineering Water Brake, Type 400, were connected to the engine gearbox assembly at the forward power output pad to absorb the engine power. The brake reaction was measured by a Baldwin load cell. All parameters to determine the engine starting and steady-state performance with the fuels were measured using standard test cell instrumentation. Engine performance data is contained in the reference report.

Fuels of varying nitrogen content were tested in a T63-A-5A engine to measure their effects on exhaust gas emissions. Five test fuels varying in fuel bound nitrogen content from 3 μg (nitrogen)/g (fuel) to 902 μg (nitrogen)/g (fuel) were evaluated. The nitrogen content in the fuel was adjusted by mixing a JP-5 type fuel derived from shale oil (902 μg (nitrogen)/g (fuel)) and regular petroleum JP-5 fuel (3 μg/ (nitrogen)/g (fuel)).

8. ENVIRONMENTAL MONITORING

Hydrocarbons, carbon dioxide, carbon monoxide, and nitrogen oxides.

9. PROJECT STATUS

Project report completed November 1977. This is part of an on-going Naval program to evaluate fuel products derived from alternate sources.

10. RESULTS

Table A-8 shows the results of the exhaust gas measurements performed during the test program. Additional results include the following:

- NO_x emissions for the same engine power rating increased with increasing fuel nitrogen content.
- The conversion efficiency of fuel bound nitrogen to NO and NO_x was approximately 45 percent for the test data in which the NO and NO_x values could be accurately measured.
- No significant effects were noted on engine performance or carbon monoxide (CO) and unburned hydrocarbons (HC) emissions due to the presence of high levels of fuel bound nitrogen.

TABLE A-8. EMISSION DATA SUMMARY

Fuel Nitrogen µg/g fuel	Engine Power Rate	CO_2	CO			NO			NO_x (as NO_2)			HC			F/A (calculated)
			ppm	g/s	g/kg fuel	ppm	g/s	g/kg fuel	ppm	g/s	g/kg fuel	ppm	g/s	g/kg fuel	
	IDLE	1.98	1035	0.714	99.2	6.7	0.00495	0.688	6.7	0.00690	1.06	157	0.0503	6.99	0.00979
3	60% NR	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	MIL	3.03	140	0.227	9.25	23.9	0.0416	1.69	23.9	0.0637	2.59	5.6	0.00422	0.172	0.0146
	IDLE	2.08	985	0.692	90.5	7.7	0.00579	0.758	7.3	0.00887	1.16	131	0.0427	5.59	0.0105
47	60% NR	2.43	430	0.482	35.0	12.7	0.0152	1.11	13.1	0.0241	1.75	18.3	0.00952	0.692	0.0119
	MIL	3.03	130	0.207	8.60	24.3	0.0415	1.72	24.3	0.0635	2.64	8.4	0.00621	0.258	0.0146
	IDLE	2.08	1005	0.698	92.3	9.1	0.00677	0.895	9.4	0.0108	1.42	134	0.0432	5.71	0.0105
267	60% NR	2.43	380	0.438	31.0	16.5	0.0204	1.44	16.7	0.0315	2.24	14.5	0.00775	0.549	0.0119
	MIL	3.03	140	0.224	9.26	27.6	0.0473	1.96	27.6	0.0726	3.00	11.1	0.00825	0.341	0.0146
	IDLE	2.10	950	0.688	86.7	11.6	0.00900	1.13	12.3	0.0146	1.85	109.6	0.0368	4.65	0.0106
515	60% NR	2.43	445	0.482	36.2	17.8	0.0206	1.55	18.4	0.0327	2.47	18.6	0.00935	0.702	0.0119
	MIL	3.03	130	0.210	8.60	31.6	0.0547	2.24	31.6	0.0838	3.44	8.7	0.00652	0.267	0.0146
	IDLE	2.10	992	0.710	90.4	14.9	0.0114	1.45	16.0	0.0188	2.39	116	0.0385	4.91	0.0106
902	60% NR	2.43	460	0.500	37.4	22.1	0.0257	1.92	22.5	0.0401	3.01	18.2	0.00918	0.687	0.0119
	MIL	3.03	135	0.218	8.93	35.9	0.0621	2.55	36.3	0.0962	3.95	8.4	0.00629	0.258	0.0146

- The use of shale derived JP-5 fuel with a high nitrogen content will make it more difficult to meet the EPA NO_X standards for aircraft gas turbine engines.

11. REFERENCE

Klarman, A.F. and A.J. Rollo. "Effect of Fuel Bound Nitrogen on Oxides of Nitrogen Emission From a Gas Turbine Engine", Naval Air Propulsion Center, Trenton, New Jersey, NAPC-PE-1, November 1977, 32 pp.

TEST 9

SHALE-DERIVED FUEL OIL ENGINE SUITABILITY INVESTIGATION

1. FUELS TESTED

Synfuel: Shale-derived diesel fuel marine (MIL-F-16884G).

Reference fuel: Petroleum-derived diesel fuel marine (MIL-F-16884G).

2. TEST EQUIPMENT

U.S. Navy LM2500 gas turbine engine configured as a gas generator with a fixed conical nozzle replacing the standard power turbine.

3. TEST SITE

General Electric, Evendale, Ohio

4. TEST OBJECTIVES

- To determine the suitability of using shale-derived DFM in the LM2500 engine.
- Compare performance, exhaust emissions, smoke level, and combustion liner temperatures of the two fuels.

5. SPONSORING AGENCY

U.S. Navy
David W. Taylor Naval Ship Research and
Development Center, Code 2705, Annapolis Laboratory
Annapolis, MD 21402

Contract Technical Monitors:

Mr. Robert M. Giannini
Mr. Carlton H. Hershner
Telephone No: (301) 267-2674

6. CONTRACTOR

General Electric Company
Aircraft Engine Group
Evendale, Ohio

Program Manager: Mr. A.F. Pyatt
Telephone No: 513-243-2000

7. TEST CONDITIONS

Both fuels were tested in a one atmosphere annular combustor test rig. Determinations were made of pattern factor, temperature profiles, light off characteristics, lean blow out characteristics, and low power efficiencies. Following the one atmosphere testing, back-to-back engine testing throughout the power rating of the engine was conducted using both fuels. Engine performance, outer combustor liner temperatures and exhaust emissions were measured. All testing was done under essentially identical ambient conditions.

8. ENVIRONMENTAL MONITORING

NO_x, CO, hydrocarbons, and smoke.

9. PROJECT STATUS

This program was conducted November-December, 1979. Final report is dated January 22, 1980.

10. RESULTS

All testing indicated that the combustor and engine operating characteristics were identical when using petroleum-derived or shale-derived DFM. From exhaust emissions analysis it was determined that shale-derived DFM gave consistently lower NO_x levels (which could only be due to nitrogen content in the fuel) throughout the engine operating range.

CO, hydrocarbon, and smoke emission levels are summarized in Table A-9. Shale-derived DFM yielded slightly higher CO and HC levels at the lower power settings, but within current acceptable limits. At higher power, CO and HC levels were essentially the same for both fuels.

11. REFERENCE

General Electric Company, Marine and Industrial Projects Division. Shale-Derived Fuel Oil Engine Suitability Investigation. Document No.: NSRDC-02, Naval Ship Research and Development Center, Annapolis Laboratory, Annapolis, Maryland, January 22, 1980. 91 pp.

TABLE A-9. TEST DATA SUMMARY LM2500, NOV. 1979

Date/Run	Fuel	NG* RPM	F/A Ratio FAR 39	Emission Index (LB/1000 LB Fuel) CO	HC	NO_x †	Smoke No.
11/17/79	Petroleum-Derived DFM	5015	.01385	102.2	52.3	1.88	5.54
	↓	5550	.01365	86.0	41.0	2.16	1.43
		6000	.01259	77.7	33.3	2.42	4.86
		7016	.01208	58.8	21.7	3.29	5.54
		7500	.01236	47.3	13.3	4.38	4.84
		7964	.01557	15.9	2.7	7.81	1.80
		8466	.02152	2.3	0.9	15.11	1.95
		8710	.02363	1.6	0.6	17.9	4.56
11/19/79	Shale-Derived DFM	4980	.01268	102.9	63.8	1.524	2.72
	↓	5500	.01364	94.5	54.0	1.7	1.97
		6018	.01238	78.7	38.9	2.0	3.37
		7023	.01203	60.4	22.9	2.9	11.42
		7529	.01216	45.2	11.8	4.35	3.10
		8016	.01557	13.0	1.9	8.45	1.25
		8510	.02152	1.8	0.5	14.58	9.89
		8752	.02357	1.5	0.4	17.9	9.06

*Gas generator speed.

†NO_x emissions corrected to humidity = 44 GR/LB

TEST 10

FUEL PROPERTY EFFECTS ON COMBUSTOR PERFORMANCE

1. FUELS TESTED

Synfuels: JP-5 from oil shale, coal, and tar sands.

Reference fuels: Fifteen (15) fuels (see Table A-10).

2. TEST EQUIPMENT

Two 2-inch-diameter, high-temperature/pressure research combustors of varying designs. Figure A-6 shows design of the Phillips Combustor, and Figure A-7 shows the design of the T-63 Combustor.

3. TEST SITE

U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas

4. TEST OBJECTIVES

- Study the sensitivity of combustor performance to the physical and chemical properties of fuels.
- Determine the impact of broadening fuel specifications and of using nonspecification fuels in emergencies.

5. SPONSORING AGENCIES

U.S. Naval Air Propulsion Center
Trenton, New Jersey

Project Manager: Mr. Larry Maggitti
Contract Number: N00140-77-C-1345
Telephone No: 609 -896-5841

6. CONTRACTOR

Mobile Energy Division
Southwest Research Institute
P. O. Drawer 28510
San Antonio, Texas 78284

TABLE A-10. FUEL BLEND CHARACTERISTICS

Fuel No.	Description
1	Jet A - Used for adjusting combustor operating conditions.
2	Base Fuel - JP-5 with 1 to 2 percent olefins, 2 to 3 percent naphthalenes and 10-15 percent aromatics. Fuels 3 to 7 are derived by adding materials to this fuel.
3	16-mm smoke point obtained by adding dicyclic polynuclear aromatics to base fuel.
4	16-mm smoke point obtained by increasing naphthalene to 4 percent and adding monocyclic aromatics as necessary to JP-5 base fuel.
5	Addition of 40 percent aromatics typical of petroleum distillates in JP-5 distillation range (smoke point must be less than 19 mm).
6.	Specification maximum for aromatics (25 percent) and olefins (5 percent) typical of petroleum distillates in the JP-5 distillation range (smoke point below 19 mm permissible).
7.	Distillation end point of 580°F, achieved by adding compounds typical of petroleum distillates in the required range (variations in other specification limits permissible - except aromatic content).
8.	Synthetic JP-5 from Oil Shale.
9.	Synthetic JP-5 from Coal.
10.	Synthetic JP-5 from Tar Sands.
11.	JP-5 Base Fuel for blending Fuels 12-14.
12.	JP-5 plus 10 percent diesel marine fuel (1).
13.	JP-5 plus 20 percent.
14.	JP-5 plus 40 percent.
15.	Diesel marine fuel (1).
16.	Leaded gasoline.
17.	Diesel marine fuel (2).
18.	Diesel marine fuel (1) plus 30 percent leaded gasoline.

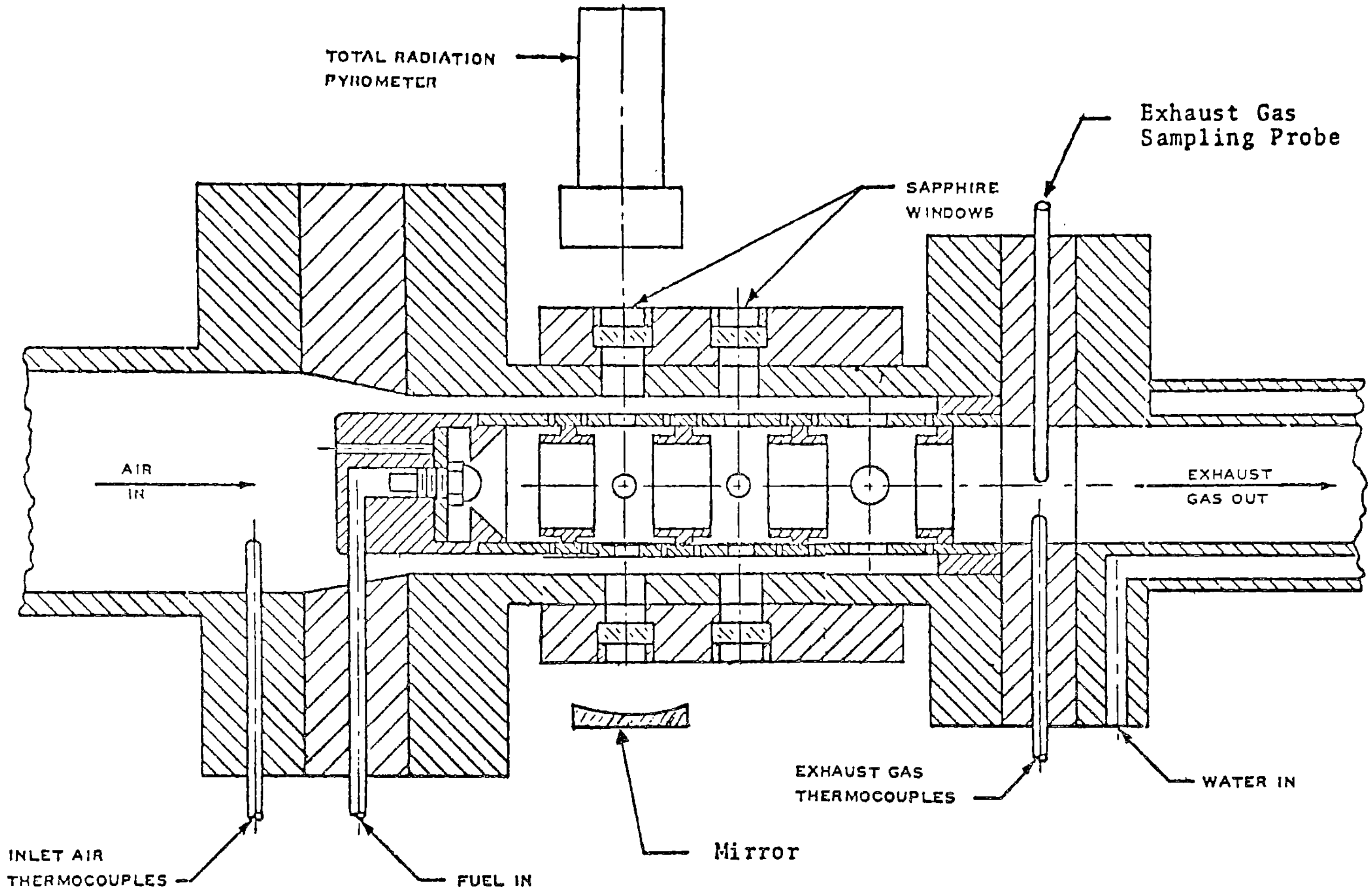

Figure A-6. Phillips 2-inch Combustor

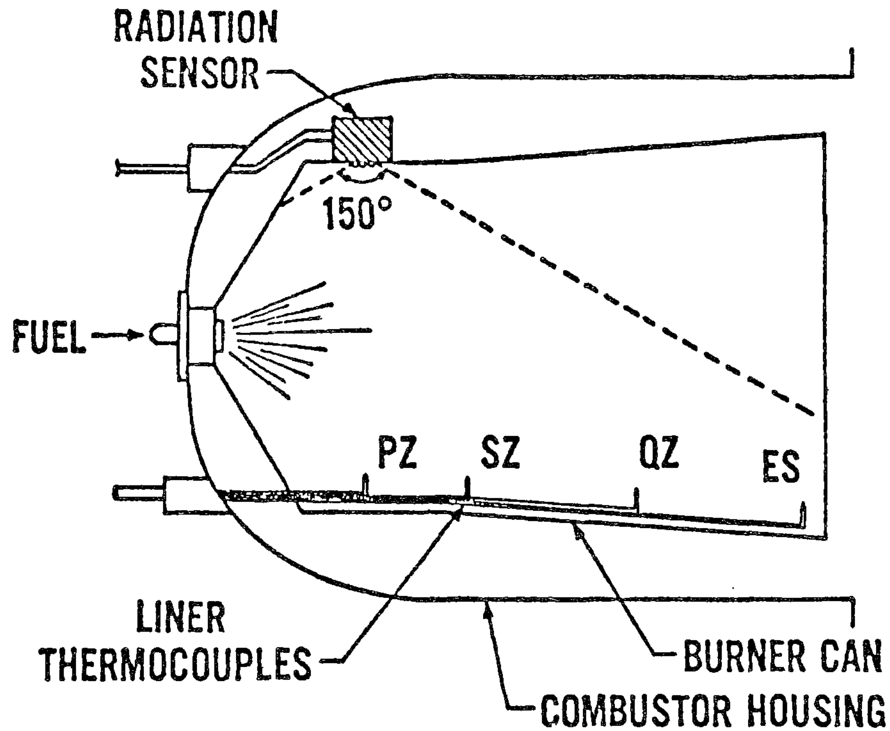

Figure A-7. T-63 Combustor

Authors: C. A. Moses, D. W. Naegeli
Telephone No: 512 - 684-5111

7. TEST CONDITIONS

Both two-inch research combustors were operated at various air flow and heat input conditions as described in the referenced report.

8. ENVIRONMENTAL MONITORING

Exhaust smoke, CO, NO_x, and UHC.

9. PROJECT STATUS

This document is the final project report dated March 1980. The first phase of this program was reported in Interim Report AFLRL No. 101, AD No. A054229, entitled "Effect of High Availability Fuels on Combustor Properties", was performed under Contract No. DAAK70-78-C-0001 and was monitored by U.S. Army Mobility Equipment Research and Development Command, DRDME-GL, Fort Belvoir, VA.

10. RESULTS

- Gaseous emissions and combustion efficiency were not significantly affected by fuel properties although some sensitivity to boiling point distribution was evident.
- In all performance areas, the syncrude fuels correlated in the same ways as the petroleum-derived fuels except for the NO_x emissions from the nitrogen-containing shale oil fuel.
- Flame radiation and smoke were best correlated by hydrogen content rather than hydrocarbon structure; the soot formation was due to gas-phase reactions.
- Lean-blowout conditions were about the same for all fuels except that gasoline could be burned leaner at idle conditions.
- Ignition limits were more sensitive to volatility than viscosity.

11. REFERENCE

Moses, C.A. and D.W. Naegeli. "Fuel Property Effects on Combustor Performance", Mobile Energy Division, Southwest Research Institute, San Antonio, TX, AD A084017, March 1980, 52 pp.

TEST 11

SHALE-DERIVED DFM PARTICULATE EMISSIONS MEASUREMENT

1. FUELS TESTED

Synfuel: shale-derived diesel fuel marine (MIL-F-16884G).

Reference fuel: petroleum-derived diesel fuel marine (MIL-F-16884G).

2. TEST EQUIPMENT

U.S. Navy DDG-15 Class ship's propulsion steam generator.

3. TEST SITE

Navy Ship Systems Engineering Station, Philadelphis, Pennsylvania.

4. TEST OBJECTIVE

- To make comparative particulate emissions measurements between petroleum-derived and shale-derived diesel fuel marine (DFM).

5. SPONSORING AGENCY

U.S. Navy
David W. Taylor Naval Ship Research and
Development Center, Code 2705, Annapolis Laboratory
Annapolis, MD 21402

Contract Technical Monitors:

Mr. Robert M. Giannini
Mr. Carlton H. Hershner
TelephoneNo: 301-267-2674

6. CONTRACTOR

NAVSSES (Materials Branch 053).

7. TEST CONDITIONS

All test runs were conducted in triplicate at nominal 100 percent, 35 percent, and 20 percent of full power with both fuels.

8. ENVIRONMENTAL MONITORING

Particulates and particulate matter composition.

9. PROJECT STATUS

The study was conducted in January 1981.

10. RESULTS

There were no significant differences between the particulate emission products described and measured in this study resulting from the combustion of petroleum-derived or shale-derived DFM on the DDG-15 boiler (utilizing steam-atomized burners). Particulate emissions from both petroleum-derived and shale-derived DFM were below the EPA limit of 0.1 lbs/10^6 Btu.

Results of emission spectroscopy (qualitative analysis) of particulate matter retained on filter paper are given as follows:

	Trace Element				
	Zinc	Lead	Iron	Tin	Copper
Shale-derived DFM	major	trace	trace	trace	trace
Petroleum-derived DFM	major	trace	not detected	not detected	not detected

11. REFERENCE

E.A. Dixon. Memorandum for File. Shale Oil Fuel, Particulate Emissions Measurement; DDG-15 Boiler. U.S. Navy, NAVSSES (Materials Branch 053) 053C:ED:amt, 6240(A2797), Ser. 3151, undated, 7 pp.

TEST 12
DIESEL ENGINE TEST

1. FUELS TESTED (See Table A-11)

   Synfuel: shale-derived diesel fuel marine (MIL-F-16884G).

   Reference fuel: petroleum-derived distillate fuel No. 2.

2. TEST EQUIPMENT

   A single cylinder, turbocharged, prechambered, four stroke cycle, laboratory diesel engine (supplied by a Navy diesel engine manufacturer).

3. TEST SITE

   Diesel engine manufacturer's facility.

4. TEST OBJECTIVE

   - To compare the performance and emissions of the shale-derived diesel fuel marine (DFM) with those of the petroleum-derived No. 2 fuel.

5. SPONSORING AGENCY

   David W. Taylor Naval Ship R&D Center
   Annapolis Laboratory, Code 2705
   Annapolis, MD 21402

   Project Officers: Carl H. Hershner and Robert M. Giannini
   Telephone No: 301-267-2674

6. CONTRACTOR

   Same as sponsoring agency (see above).

7. TEST CONDITIONS

   See Table A-12 for Test Plan.

8. ENVIRONMENTAL MONITORING

   Nitrogen oxides, hydrocarbons, and smoke.

TABLE A-11. COMPARISON OF FUEL CHARACTERISTICS

	ASTM Test Method	Petroleum-Derived Diesel No. 2	Shale-Derived DFM
Gravity			
API	D287	35	38.2
Specific gravity		.85	.8338
lb/gal		7.0923	6.9585
Cetane Index	D975	42-43	50-53
Low Heat Value			
Btu/lb		18,330	18,980
Btu/gal		130,000	132,060
Btu increase by wt.			3.5%
Btu increase by vol.			1.6%
Viscosity @ 100°F (SUS)	D445	33-40	34.8
Aniline Pt.	D611		150.5°F
Pour Point	D97	0°F	-5°F
Cloud Point	D97	10°F	-2°F
Flash Point	D93		146°F
Distillation			
IBP (°F)	D86	430	372
90% (°F)	D86	625	560
EP (°F)	D86	675	580
Water and Sediment, %	D1796		0
Sulphur	D1552	.35-.45	Nil
Ash %	D482	.02	<.001
C %, wt.			86.28
H %, wt.			13.40
Ca, ppm			12
Na, ppm			<1
Ni, ppm			<1
V, ppm			<1
Pb, ppm			<10
Corrosion, Copper Strip (3 hr @ 210°F)	D130		1
Aromatics %	D1319		32.4
Olefins %	D1319		1.3
Carbon Residue (10% bottoms), %			0.08

TABLE A-12. TEST PLAN

I. Baseline performance with petroleum fuel.

A. Engine break-in.
B. Run engine to determine mechanical and pumping losses for correlation of data.
C. Collect part load and emissions data at:

1. 2200 RPM - rated speed
2. 1400 RPM - peak torque

Data taken at load points equivalent to the 0, 50%, and 100% BMEP points.

II. Performance with shale-derived DFM - repeat step I-C.

A. With same timing and rack setting.
B. With rack and timing adjusted to the same power as in step I-3.

III. "OBSERVED" shale-derived DFM comparison - steps I-C and II repeated for personnel from Naval Ship Research and Development Center.

9. PROJECT STATUS

Testing conducted in April 1980; results documented on 12 May 1980.

10. RESULTS

Performance and emissions for both fuels were compared and found to be the same with the exception of 2.5 to 4.0 percent lower thermal efficiency with the shale-derived DFM. Results are presented in Table A-13. Additional part load performance tests and advanced timing performance tests also showed no significant differences in either performance or emissions for both fuels.

11. REFERENCES

"Diesel Engine Test, 12 May 1980", supplied by C. H. Hershner, David W. Taylor Naval Ship R&D Center, Annapolis Laboratory (Code 2705). Annapolis, MD, 12 pp.

Telephone communication to C. H. Hershner, U.S. Department of the Navy, David W. Taylor Naval Ship R&D Center, Annapolis, MD, to S. Quinlivan, 17 March 1981.

TABLE A-13. SUMMARY OF TEST RESULTS

	Petroleum	Shale
I. 2200 rpm - max load (fixed rack @ .440)		
BMEP* (psi)	125	126
BSFC† (lb/bhp-hr)	.447	.448
BSEC‡ (btu/bhp-hr)	8,194	8,503 (3.8%>)
Smoke	.03	.03
HC (gr/bhp-hr)	.09	.03
NO_x (gr/bhp-hr)	1.17	1.25
II. 2200 rpm - idle		
HC (gr/bhp-hr)	.09	.15
NO_x (gr/bhp-hr)	.22	.16
III. 1400 rpm - max load (fixed rack @ .440)		
BMEP* (psi)	142	142
BSFC† (lb/bhp-hr)	.411	.406
BSEC‡ (btu/bhp-hr)	7,534	7,706 (2.3%>)
Smoke	.08	.11
HC (gr/bhp-hr)	.12	.12
NO_x (gr/bhp-hr)	.57	.51
IV. 1400 rpm - idle		
HC (gr/bhp-hr)	.05	.06
NO_x (gr/bhp-hr)	.12	.11

*BMEP = brake mean effective pressure.

†BSFC = brake specific fuel consumption.

‡BSEC = brake specific energy consumption.

TEST 13

NAVY CV-60 CLASS BOILER EMISSION MEASUREMENTS

1. FUELS TESTED

Synfuel: shale-derived diesel fuel marine (MIL-F-16884G).

Reference fuel: petroleum-derived diesel fuel marine (DFM).

2. TEST EQUIPMENT

U.S. Navy CV-60 Class ship's propulsion steam generator (see Table A-14 for description).

TABLE A-14. CV-60 STEAM GENERATOR-OPERATIONAL PARAMETERS

Number Class	1 CV-60
Boiler Manufacturer	Babcock & Wilcox (B&W)
Operating Pressure	1200 psig
Superheated Steam Temperature	950°F
Steam Generated @ Full Power	261,450 lb/hr
Oil Burner @ Full Power	20,000 lb/hr
Combustion Gas Pressure	2 psig
Boiler Type	Natural Circulation
Water Cooled Furnace	Yes
Furnace Frontwall and Floor Materials	Refractory
Superheater Type	Horizontal
Number of oil Burners	7
Burner Type	*
Automatic Combustion Control	Yes

*B&W Iowa Registers with mechanical vented plunger atomizers.

3. TEST SITE

Naval Ship Systems Engineering Station, Philadelphia, Pennsylvania.

4. TEST OBJECTIVE

- To perform comparative emissions measurements between petroleum-derived diesel fuel marine (DFM) and shale-derived DFM for comparison with EPA stationary source steam generator standards.

5. SPONSORING AGENCY

David W. Taylor Naval Ship R&D Center
Annapolis Laboratory, Code 2705
Annapolis, MD 21402

Project Officers: Carl H. Hershner and Robert M. Giannini
Telephone No: 301-267-2674

6. CONTRACTOR

NAVSSES, Philadelphia, Pennsylvania.

7. TEST CONDITIONS

Boiler operating conditions presented in Table A-15. It was originally intended to conduct the emissions testing at boiler loading conditions of 10, 25, 50, 75, 100, and 120 percent of full power. However, due to lack of a full complement of forced draft blowers, rates of 63 percent or lower were obtained (see Table A-15).

8. ENVIRONMENTAL MONITORING (See Figure A-8)

SO_2, NO_x, CO, HC, CO_2, O_2, and smoke.

9. PROJECT STATUS

Project began in March 1980 and completed in September 1980.

10. RESULTS

Pollutant emission results summarized in Table A-15. No significant differences observed between emissions resulting from use of petroleum-derived DFM or shale-derived DFM for any boiler load condition. It is noteworthy that:

- Shale-derived DFM sulfur oxide emissions were generally somewhat lower than petroleum-derived DFM at the same operating rates, due to the lower initial sulfur content of the shale DFM vs. petroleum DFM (0.02 v 0.16 percent).
- Petroleum-derived DFM oxides of nitrogen exceeded those of shale-derived DFM.

TABLE A-15. CV-60, PETROLEUM-DERIVED/SHALE-DERIVED DFM EMISSIONS COMPARISON

Operating Rate, %	11		12			25				28	40	54	50	62	63	62
	DFM	DFM	Shale	Shale	Shale	DFM	DFM	Shale	Shale	Shale	DFM	DFM	Shale	DFM	DFM	Shale
Sulfur Dioxide, PPM, Measured	2	3	0	0	0	10	1	0	0	0	2	3	0	10	10	0
Theoretical Sulfur, PPM	-	93.5	11.7	12.01	11.80	99	99	12.4	12.2	12.0	100	99.8	12.7	100	100	12.5
EPA - Units, lbs Per 10^6 BTU	-	0.005	0	0	0	0.016	0.002	0	0	0	0.003	0.005	0	0.016	0.016	0
Oxides of Nitrogen, PPM, Measured	9	10	9	50	15	60	-	22	35	50	20	27	105	160	220	180
EPA - Units, lbs Per 10^6 BTU	-	0.012	0.011	0.060	0.018	0.071	-	0.026	0.041	0.060	0.023	0.031	0.121	0.185	0.253	0.205
Carbon Monoxide, PPM	1500	800	200	200	350	30	0	250	200	200	800	230	1500	0	2500	1500
Hydrocarbons, PPM, as Methane	140	30	15	20	15	-	3	0	8	60	8	0	0	-	-	0
Carbon Dioxide, %	1.2	1.2	3.5	4.5	3.6	-	0	8.8	4.6	4.0	2.6	1.1	10	-	-	5.6
Smoke, Ringelmann Number	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	1	<1	<1	<1	<1	<1
Oxygen, %	14.2	11.6	11.4	10.2	11.1	7.1	7.3	7.3	8.0	10.2	5.2	6.5	4.5	5.9	5.6	4.3
Excess Air	-	112	109	83	100	48	50	50	58	83	30	41	29	37	33	26
DFG	-	207	206	201	205	195	195	195	197	201	192	194	191	193	192	191
lbs Fuel Oil Pressure	65	65	64	65	64	120	100	95	97	112	125	165	159	203	206	193
Fuel Oil Rate, HR	2137	2137	2400	2400	2400	5150	5150	5040	5000	5940	7100	10140	10000	12740	12640	12290
% of Full Power	11	11	12	12	12	25	25	25	25	28	40	54	50	62	63	62
Time/Date	1030 5/16/80	1100 5/16/80	1200 5/29/80	1430 5/29/80	1500 5/29/30	1110- 5/9/80	1100- 5/13/80	1500- 5/23/80	1100- 5/29/80	1300- 5/29/80	1415- 5/13/80	1235- 5/13/80	1200- 5/23/80	1255- 5/9/80	1325- 5/9/80	1100- 5/23/80
Comment	White Smoke	Trace Stack	Normal Operation	Normal Operation	Normal Operation	Normal Operation	→	→	→	Clear Stack Not set	→	Normal Operation		Normal Operation	Trace Stack	Steady

Note: - = instrument in operation.

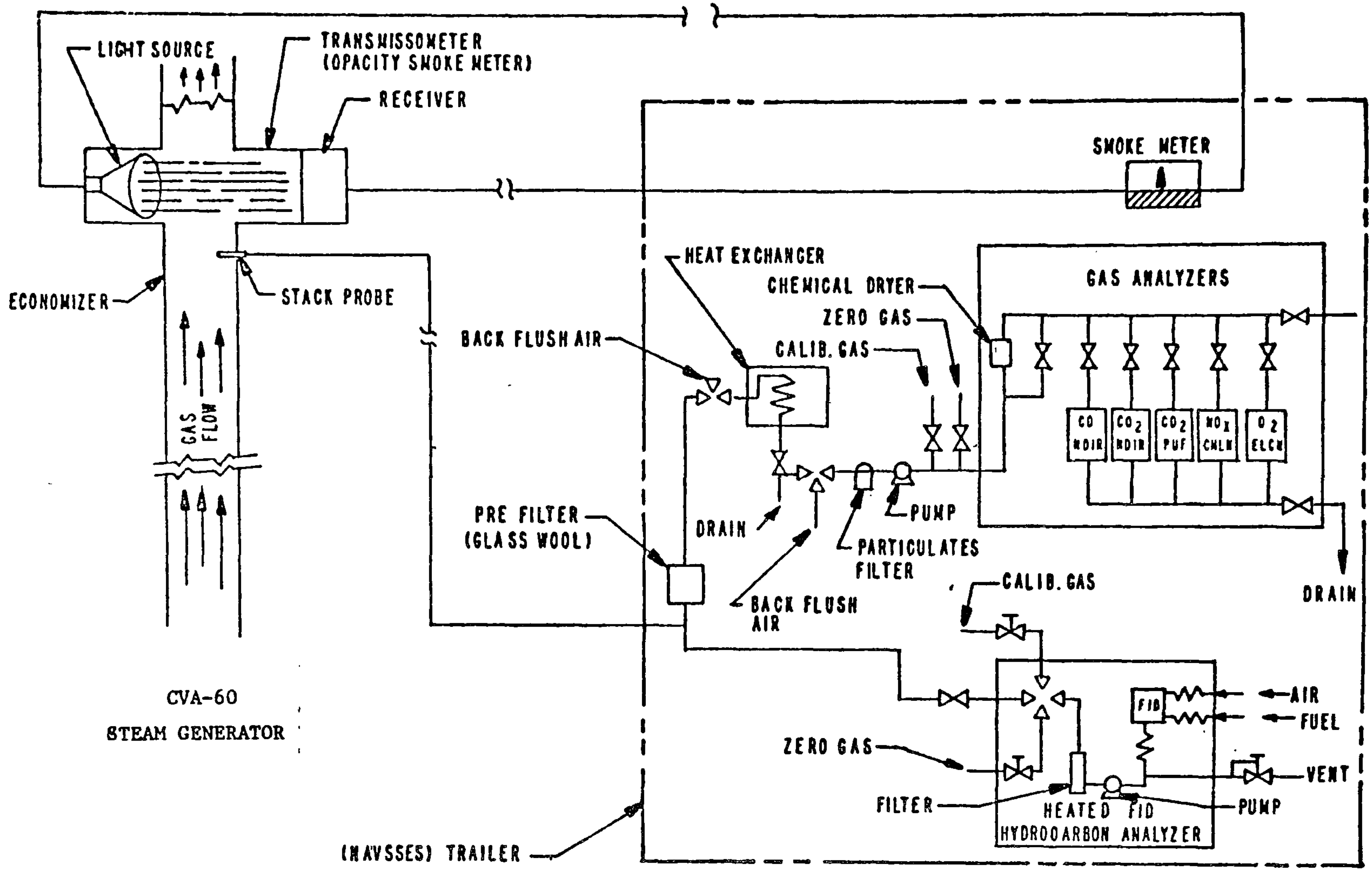

Figure A-8. Source Emissions Instrumentation Schematic Diagram

Pollutant levels (i.e., sulfur oxides, nitrogen oxides, and smoke) were all found to be below EPA stationary source standards.

11. REFERENCES

"Shale Fuel Oil Emissions Measurement: Interim Report", Memorandum Series 3242, 24 August 1980, supplied by C. H. Hershner, David W. Taylor Naval Ship R&D Center, Annapolis Laboratory (Code 2705), Annapolis, Maryland, 12 pp.

Telephone communication of C. H. Hershner, U.S. Department of Navy, David W. Taylor Naval Ship R&D Center, Annapolis, Maryland, to S. Quinlivan, TRW, 17 March 1981.

TEST 14

U.S. NAVY DDG-15 CLASS BOILER EMISSIONS MEASUREMENTS

1. FUEL TESTED

Synfuel: shale-derived diesel fuel marine (DFM), MIL-F-16884G.

Reference fuel: petroleum-derived diesel fuel marine (DFM), MIL-F-16884G.

2. TEST EQUIPMENT

U.S. Navy DDG-15 Class propulsion steam generator (see Table A-16 for description).

3. TEST SITE

Naval Ship Systems Engineering Station, Philadelphia, Pennsylvania.

4. TEST OBJECTIVE

- To perform comparative emissions measurements between petroleum-derived diesel fuel marine and shale-derived DFM for comparison with EPA stationary source steam generator standards.

5. SPONSORING AGENCY

David W. Taylor Naval Ship R&D Center
Annapolis Laboratory, Code 2705
Annapolis, MD 21402

Project Officers: Carl H. Hershner and Robert M. Giannini
Telephone No: 301-267-2674

6. CONTRACTOR

NAVSSES, Philadelphia, Pennsylvania.

7. TEST CONDITIONS

Comparative emissions data on petroleum-derived and shale-derived DFM obtained over an operating range of 12 to 106 percent of full power. Other boiler operating conditions presented in Table A-17.

TABLE A-16. GENERAL DDG-15 BOILER DESCRIPTION

Class	DDG-15
Boiler Manufacturer	Combustion Engineering
Operating Pressure	1200 psig
Superheated Steam Temperature	950°F
Steam Generated @ Full Power	137,500 lb/hr
Oil Burner @ Full Power	10,980 lb/hr
Combustion Gas Pressure	2 psig
Boiler Type	Natural Circulation
Water Cooled Furnace	Yes
Furnace Frontwall and Floor Materials	Refractory
Superheater Type	Vertical
Number of Oil Burners	4
Burner Type	C.E./Wallsend Steam Assist Burner
Automatic Combustion Control	Yes

TABLE A-17. DDG-15, PETROLEUM-DERIVED/SHALE-DERIVED DFM EMISSIONS COMPARISON

Operating Rate, %	17 DFM			17 SHALE					25 DFM				29 SHALE				40 DFM				40 SHALE			
Sulfur Dioxide, ppm, measured	10	10	9	6	6	6	6	6	9	8.5	9	8.5	5	5	5	5	10	11	10	10	5	5	5	5
Theoritical Sulfur, ppm	58	58	57	6.5	6	6.5	6.5	-	53	52	52	50	6	6	6	6	51	61	59	57	-	7	-	7
EPA-Units, lbs Per 10^6 BTU	0.027	0.027	0.026	0.018	0.019	0.018	0.019	-	0.028	0.029	0.029	0.028	0.015	0.016	0.016	0.016	0.027	0.032	0.028	0.029	-	0.014	-	0.015
Oxides of Nitrogen, ppm, measured	25	25	28	27	27	25	30	36	40	40	30	43	35	38	42	42	-	23	28	28	38	37	32	33
EPA-Units, lbs Per 10^6 BTU	0.051	0.051	0.057	0.060	0.061	0.060	0.067	-	0.089	0.092	0.092	0.10	0.080	0.090	0.090	0.090	-	0.047	0.056	0.056	-	0.076	-	0.071
Carbon Monoxide, ppm	200	200	200	0	0	0	0	0	2500	1500	1500	30	0	0	100	100	100	neg	neg	neg	neg	neg	neg	neg
Hydrocarbons, ppm, as methane	5	5	-	5	5	6	2	2	35	35	30	-	1	1	1	1	5	5	5	10	1	1	2	1
Carbon Dioxide, %	-	8.0	8.0	4.0	3.8	4.2	4.2	-	6.4	-	-	-	5.0	5.0	5.8	5.8	9.0	9.6	9.6	7.4	4.0	4.0	4.0	4.0
Smoke, Ringelmann Number	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Trace Stack				Clear	Clear	Clear	Clear	Clear	Trace Stack	Trace Stack	Clear	Clear	Clear		Clear
Oxygen, %	9.8	10.0	10.1	11.8	12.1	11.8	12.0	-	11.7	12.0	12.0	12.7	12.0	12.8	12.8	12.8	9.2	10.1	9.7	10.1	-	10.2	-	10.6
Excess Air	80	81	83	97	102	97	100	-	98	103	103	110	100	110	110	110	71	83	77	83	-	83	-	88
DFC	336	338	341	368	378	368	373	-	370	379	379	392	373	392	392	392	319	342	330	341	-	342	-	351

(Continued)

TABLE A-17. (Continued)

Operating Rate, %	12 → DFM			SHALE					25 DFM				29 SHALE				40 → DFM				SHALE			
lbs Fuel Oil Pressure	37	37	37	36	36	36	36	36	61	61	61	61	61	61	61	61	87	87	87	87	98	98	98	98
Fuel Oil Rate, Hr	1264	1264	1264	1400	1400	1400	1400	1400	2740	2740	2740	2740	2778	2778	2778	2778	4180	4180	4180	4393	4393	4393	4393	4393
% of Full Power	12	12	12	12	12	12	12	12	25	25	25	25	27	27	27	27	40	40	40	40	40	40	40	40
Time/ Date	1115 6/23/80	1130	1145	1100 9/5/80	1145	1245	1315	1500	1200 7/1/80	1215	1230	1245	1330 9/11/80	1335	1340	1345	1410 6/23/80	1435	1445	1510	1425 9/11/80	1430	1440	1445
# of Burners	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Comment	NOTE: – = instrument not in operation n.c.= not calculated								not quite clear stack				clear stack				rate not quite set				clear stack			

(Continued)

TABLE A-17. (Continued)

Operating Rate, %	70 DFM →				68 SHALE			100 DFM			106 SHALE	
Sulfur Dioxide ppm, measured	5	2	2	8	6	5.5	5.5	5	4	6	6	6
Theoretical Sulfur, ppm	55	57	55	53	-	6	6	52	53	51	6	6
EPA-Units, lbs Per 10^6 BTU	0.015	0.006	0.006	0.025	-	0.020	0.020	0.016	0.012	0.019	0.022	0.022
Oxides of Nitrogen, ppm, measured	50	38	52	55	35	38	35	62	53	60	46	40
EPA-Units, lbs Per 10^6 BTU	0.110	0.080	0.110	0.130	-	0.099	0.091	0.140	0.190	0.140	0.120	0.100
Carbon Monoxide, ppm	200	-	310	350	0	0	0	neg	neg	neg	100	100
Hydrocarbons, ppm, as methane	5	10	20	10	1	1	0	5	5	5	10	10
Carbon Dioxide, %	7.2	8.8	9.4	9.1	5.0	4.8	4.9	5.4	4.8	-	5.0	5.0
Smoke, Ringelmann Number	Trace	Clear <1	Clear <1	Clear <1	Clear <1	Clear <1	Clear <1	Clear <1	Clear <1	Clear <1	Clear <1	Clear <1
Oxygen, %	10.9	10.2	10.9	12.0	-	14.8	14.8	12.0	11.9	12.2	14.8	14.8

(Continued)

TABLE A-17. (Continued)

Operating Rate, %	70 DFM →				68 SHALE →			100 DFM			106 SHALE	
Excess Air	92	83	92	100	-	132	132	100	98	107	132	132
DFG	358	341	358	373	-	434	434	374	370	387	434	434
lbs Fuel Oil Pressure	7073	7073	7073	7073	7453	7453	7453	10830	10830	10830	11790	11790
% of Full Power	70	70	70	70	68	68	68	100	100	100	106	106
Time/ Date	0950 6/25/80	1000	1015	1100	1045 9/10/80	1055	1105	1310 6/25/80	1330	1400	1435 9/3/80	1445
# of Burners	4	4	4	4	4	4	4	4	4	4	4	4
Comment	Trace Stack										Light Trace Stack	

NOTE: - = Instrument not in operation
n.c.= not calculated

8. ENVIRONMENTAL MONITORING

SO_2, CO, CO_2, NO_x, HC, O_2, and smoke emission levels were monitored by the NAVSSES Mobile Source Emissions Unit (see Figure A-9 for schematic) which was positioned adjacent to the DDG-15 boiler.

9. PROJECT STATUS

Testing performed intermittently between June and September 1980.

10. RESULTS

Pollutant emission results summarized in Table A-17. No significant differences observed between emission resulting from use of petroleum-derived DFM or shale-derived DFM for any boiler load condition. However:

- Shale-derived DFM, sulfur oxides emissions were generally lower than those of petroleum-derived DFM at the same operating rates due to lower initial sulfur content of shale fuel versus petroleum (0.02 percent vs. 0.16 percent). In addition, shale DFM excess air values tended to be higher than those of petroleum DFM, consequently diluting stack sulfur dioxide emissions further.
- Petroleum-derived DFM oxides of nitrogen emissions were slightly higher than those of shale-derived DFM, at the same rate of combustion.
- Hydrocarbon emissions were generally low. Carbon dioxide emissions from petroleum-derived DFM tended to be unusually higher than those of shale-derived DFM at 12, 50, and 70 percent of full power, due in part to incomplete setting of boiler operating condition and the adjustment of excess air settings after the onset of data taking. Carbon monoxide emissions from the petroleum fuel were also higher than those from shale fuel which were in most cases negligible.

Pollutant levels all found to be below EPA stationary source standard.

11. REFERENCES

"Shale Oil Fuel Measurement, DDG-15 Boiler Interim Report", 18 February 1981, supplied by C. H. Hershner, David W. Taylor Naval Ship R&D Center, Annapolis Laboratory (Code 2705), Annapolis, MD. 7 pp.

Telephone communication of C. H. Hershner, David W. Taylor Naval Ship R&D Center, Annapolis, MD, to S. Quinlivan, 17 March 1981.

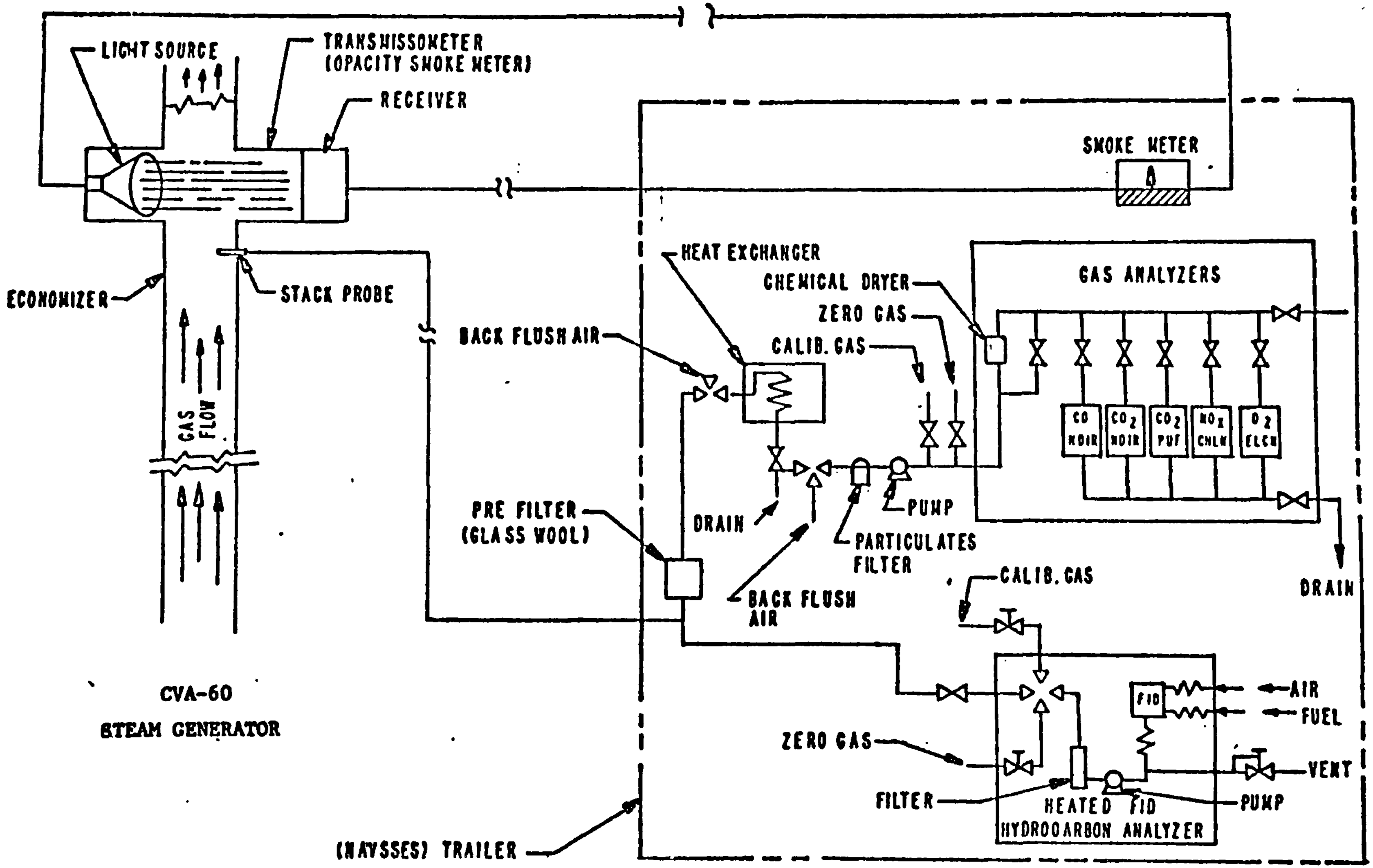

Figure A-9. Source Emissions Instrumentation Schematic Diagram

TEST 15
U.S. NAVY FF-1040 CLASS BOILER
PRESSURE-FIRED EXHAUST EMISSIONS MEASUREMENTS

1. FUELS TESTED

Synfuel: shale-derived diesel fuel marine (DFM), MIL-F-16884G.

Reference fuel: petroleum-derived fuel marine (DFM), MIL-F-16884G.

2. TEST EQUIPMENT

U.S. Navy FF-1040 Class pressure-fired steam generator (see Table A-18 for description).

3. TEST SITE

Naval Ship Systems Engineering Station, Philadelphia, Pennsylvania.

4. TEST OBJECTIVE

- To perform comparative emissions measurements between petroleum-derived and shale-derived DFM for comparison with EPA stationary source steam generator standards.

5. SPONSORING AGENCY

David W. Taylor Naval Ship R&D Center
Annapolis Laboratory, Code 2705
Annapolis, MD 21402

6. CONTRACTOR

NAVSSES, Philadelphia, Pennsylvania.

7. TEST CONDITIONS

Boiler conditions are presented in Table A-19. It was originally intended to conduct the emissions testing over the full operating range of the FF-1040; due to mechanical problems, data acquisition was limited to the operating condition 20 to 60 percent of full power.

TABLE A-18. GENERAL BOILER DATA

Class	FF-1040
Boiler Manufacturer	Foster-Wheeler
Operating Pressure	1200 psig
Superheated Steam Temp.	950°F
Steam Generated @ Full Power	126,000 lb/hr
Oil Burner @ Full Power	9,740 lb/hr
Combustion Gas Pressure	up to 60 psig
Boiler Type	Pressure Fired
Water Cooled Furnace	Yes
Furnace Frontwall and Floor Materials	Can type - refractory No Frontwall
Superheater Type	Horizontal - Ring Tube Type
Number of Oil Burners	3
Burner Type	TODD triplex mechanical pressure atomizer
Automatic Combustion Control	Yes

TABLE A-19. FF-1040, PETROLEUM-DERIVED/SHALE-DERIVED DFM EMISSIONS COMPARISON

Operating	DFM		SHALE →				DFM	SHALE	DFM	SHALE	DFM	SHALE	DFM		SHALE
Rate, %	19.5	20	19	19	20	20	25	26	33	33	45	48	56	56	58
Sulfur Dioxide, ppm, measured	2	0	0	0	1	0	0	0	2.5	0.5	2	2	3	4	2
Theoretical Sulfur, ppm	-	57	8	7	8	7	61	7	64	6	61	7	64	64	8
EPA-Units, lbs per 10^6 BTU	-	-	-	-	0.027	-	-	-	0.068	0.015	0.054	0.058	0.076	0.102	0.052
Oxides of Nitrogen, ppm	23	62	66	65	64	61	60	67	63	72	65	77	92	92	120
EPA-Units, lbs per 10^6 BTU	-	0.090	0.120	0.133	0.125	0.125	0.110	0.130	0.110	0.156	0.125	0.160	0.170	0.170	0.227
Carbon Monoxide, ppm	200	10	0	0	0	0	10	200	0	0	0	100	0	0	50
Hydrocarbons, ppm, as methane	5	3	8	7	-	10	0	125	0	45	0	285	0	0	200
Carbon Dioxide, %	5.4	7.2	10.0	8.8	-	-	9.0	8.8	8.7	14.0	10.0	8.6	-	10.5	9.2
Smoke, Ringelmann Number	Trace White	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Oxygen, %	13.3	10.1	8.9	9.8	9.2	9.7	9.0	9.0	8.7	10.9	9.2	10.3	8.7	8.7	8.9
Excess Air	-	83	68	81	71	79	70	70	63	92	71	85	63	63	68

(Continued)

TABLE A-19. (Continued)

Operating Rate, %	DFM 19.5	20	SHALE 19	19	20	20	DFM 25	SHALE 26	DFM 33	SHALE 33	DFM 45	SHALE 48	DFM 56	56	SHALE 58
DFG	-	341	314	338	319	334	318	318	304	359	319	346	304	304	314
Fuel Oil Rate, Hr	1906	1964	1880	1880	2000	2000	2448	2527	3252	3136	4391	4681	5515	5515	5617
3-Stage Burner Pressure	550/55	550/50	550/40	550/40	550/50	550/50	545/98	548/105	552/195	546/185	575/365	562/440	560/545 135	560/545 135	555/545 135
% of Full Power	19.5	20	19	19	20	20	25	26	33	33	45	48	56	56	58
Time/ Date	1455 9/17/80	1440 9/17/80	1245 9/23/80	1345 9/23/80	1200 9/23/80	1215 9/23/80	1400 9/17/80	1245 9/18/80	1326 9/17/80	1200 9/18/80	1250 9/1[illegible]/80	1130 9/1[illegible]/80	1135 9/17/80	1200 9/17/80	1045 9/18/80

Comments: Trace White Smoke From Stack

(-) = Instrument Inoperative

8. ENVIRONMENTAL MONITORING (See Figure A-10)

SO_2, NO_x, CO, HC, and smoke.

9. PROJECT STATUS

Data acquired on three operating days (17, 18, and 23 September 1980).

10. RESULTS

Pollutant emissions summarized in Table A-19. No significant differences observed between emissions resulting from use of petroleum-derived or shale-derived DFM for any boiler load condition. It is noteworthy that:

- Petroleum-derived DFM sulfur emissions slightly exceeded shale fuel emissions under the same operating conditions.
- Shale fuel nitrogen oxide emissions slightly exceeded petroleum-derived emissions under the same operating conditions.

Pollutant levels (i.e., sulfur oxides, nitrogen oxides, and smoke) all found to be below EPA stationary source standards.

11. REFERENCES

"Shale Fuel Oil Emissions Measurement, FF-1040 Boiler, Interim Report", 18 February 1981, Memorandum Series 3037, supplied by C. H. Hershner, David W. Taylor Naval Ship R&D Center, Annapolis Laboratory (Code 2705), Annapolis, MD. 6 pp.

Telephone communication of C. H. Hershner, U.S. Department of Navy, David W. Taylor Naval Ship R&D Center, Annapolis, MD, to S. Quinlivan, 17 March 1981.

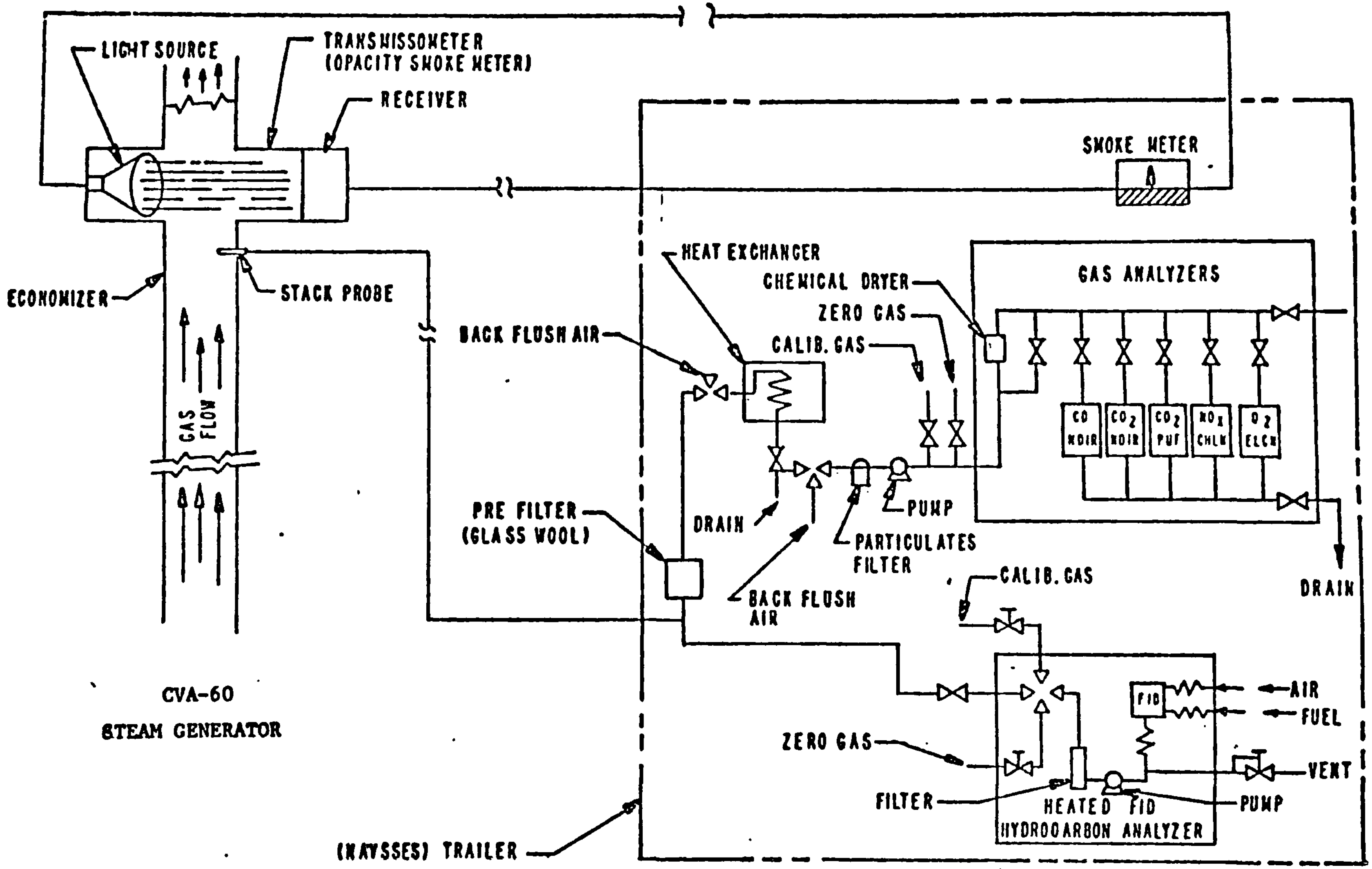

Figure A-10. Source Emissions Instrumentation Schematic Diagram

TEST 16

EVALUATION OF SHALE-DERIVED JP-5 TYPE FUEL IN AN ALLISON T63-A-5A ENGINE

1. FUELS TESTED

Synfuel: JP-5 fuel derived from shale oil (see Table A-20).

Reference fuel: JP-5 petroleum-derived fuel (see Table A-21).

2. TEST EQUIPMENT

Allison T63-A-5A turboshaft engine used in Army OH-58A and Navy TH-57A helicopters. Consists of a combination six-stage axial flow, one-stage centrifugal flow compressor directly coupled to a two-stage free turbine which is coupled to a gas producer turbine.

3. TEST SITE

Naval Air Propulsion Test Center, Trenton, New Jersey.

4. TEST OBJECTIVE

- To evaluate the performance and emissions of JP-5 type fuel derived from shale oil compared to petroleum-derived JP-5 in the sea level operation of a T63-A-5A helicopter engine.

5. SPONSORING AGENCY

U.S. Navy
Naval Air Systems Command
Washington, D.C.

6. CONTRACTOR

Naval Air Propulsion Test Center
Fuels and Fluid Systems Division
Trenton, N.J.

Project Officer: J. Solash
Telephone No: 609-896-5841

7. TEST CONDITIONS

Emissions test cycle parameters are presented in Table A-22. This sequence

TABLE A-20. LABORATORY ANALYSIS OF SHALE OIL DERIVED JP-5

	Oil Shale Derived JP-5	Average JP-5 (a)	MIL-T-5624J Requirements Minimum	Maximum
Gravity, Specific 15.5/15.5°C (60/60°F)	0.8058	0.8170	0.788	0.845
Gravity, °API, 15.5/15.5°C (60/60°F)	44.1	41.7	36.0	48.0
Distillation, IBP, °C (°F)	171.1 (340)	-	-	-
5% Over °C (°F)	185.5 (366)	-	-	-
10% Over °C (°F)	191.0 (376)	197.0 (387)	-	204.5 (400)
20% Over °C (°F)	199.0 (390)	-	-	-
30% Over °C (°F)	205.5 (402)	-	-	-
40% Over °C (°F)	212.0 (414)	-	-	-
50% Over °C (°F)	219.0 (426)	216.5 (422)	-	-
60% Over °C (°F)	225.5 (438)	-	-	-
70% Over °C (°F)	233.5 (452)	-	-	-
80% Over °C (°F)	242.0 (468)	-	-	-
90% Over °C (°F)	254.5 (490)	243.0 (469)	-	-
95% Over °C (°F)	265.5 (510)	-	-	-
End Point, °F	282.0 (540)	263.5 (506)	-	288.0 (550)
Recovery % Vol.	97.8	-	-	-
Residue % Vol.	1.0	-	-	1.5
Loss, % Vol.	1.2	-	-	1.5
Gum, Existent, mg/100 ml	81.7	1.3	-	7
Sulfur, % Wt.	0.05	0.096	-	0.4
F.I.A Saturates, % Vol.	71.76	-	-	-
Olefins, % Vol.	2.29	0.8	-	5.0
Aromatics, % Vol.	25.95	16.0	-	25.0
Aniline Point, °C	61.8	62.5	-	-
Aniline Gravity, Constant	6,315	6.059	4,500	-
Heat of Combustion, MJ Kg^{-1} (BTU/lb)	43.105 (18,532)	43.091 (18,526)	42.565 (18,300)	-
Corrosion, Copper Strip	1-a	-	-	1-b
Smoke Point, mm	22	22.2	19	-
Freeze Point, °C (°F)	-22.5 (-28)	-49.0 (-56)	-	-46.0 (-51)
Flash Point, °C (°F)	65.5 (150)	-	60.0 (140)	-
Viscosity, m^2s^{-1} X 10^{-6} (cks), -34.5°C (-30°F)	Frozen	10.5	-	16.5
Contamination, mgl^{-1}	164.20	-	-	1.0
Thermal Stability @ 260.0°C (500°F) (JFTOT)	Fail	Pass	-	Pass
Water Separometer Test, Modified	76	94	85	-

(a) Mineral Industry Surveys, Aviation Turbine Fuels, 1973 Reference.

TABLE A-21. LABORATORY ANALYSIS OF PETROLEUM-DERIVED JP-5 FOR T63-A-5A ENGINE TEST

	JP-5 Used	Average JP-5 (a)	MIL-T-5624J Requirements Minimum	MIL-T-5624J Requirements Maximum
Gravity, Specific 15.5/15.5°C (60/60°F)	0.8114	0.8170	0.788	0.845
Gravity, °API, 15.5/15.5°C (60/60°F)	42.9	41.7	36.0	48.0
Distillation, IBP, °C (°F)	176.5 (350)	-	-	-
5% Over °C (°F)	188.0 (370)	-	-	-
10% Over °C (°F)	192.0 (378)	197.0 (387)	-	204.5 (400)
20% Over °C (°F)	198.0 (388)	-	-	-
30% Over °C (°F)	202.0 (396)	-	-	-
40% Over °C (°F)	208.0 (406)	-	-	-
50% Over °C (°F)	213.5 (416)	216.5 (422)	-	-
60% Over °C (°F)	216.5 (422)	-	-	-
70% Over °C (°F)	223.5 (434)	-	-	-
80% Over °C (°F)	229.0 (444)	-	-	-
90% Over °C (°F)	238.0 (460)	243.0 (469)	-	-
95% Over °C (°F)	245.5 (474)	-	-	-
End Point, °F	258.0 (496)	263.5 (506)	-	288.0 (550)
Recovery % Vol.	98.5	-	-	-
Residue % Vol.	1.0	-	-	1.5
Loss, % Vol.	0.5	-	-	1.5
Gum, Existent, mg/100 ml	0	1.3	-	7
Sulfur, % Wt.	0.06	0.096	-	0.4
F.I.A Saturates, % Vol.	80.86	-	-	-
Olefins, % Vol.	0.95	0.8	-	5.0
Aromatics, % Vol.	18.10	16.0	-	25.0
Aniline Point, °C	61.7	62.5	-	-
Aniline Gravity, Constant	6,139	6,059	4,500	-
Heat of Combustion, MJ Kg^{-1} (BTU/lb)	43.170 (18,560)	43.091 (18,526)	42.565 (18,300)	-
Corrosion, Copper Strip	1-a	-	-	1-b
Smoke Point, mm	28	22.2	19	-
Freeze Point, °C (°F)	-50.0 (-58)	-49.0 (-56)	-	-46.0 (-51)
Flash Point, °C (°F)	63.5 (146)	-	60.0 (140)	-
Viscosity, $m^2s^{-1} \times 10^{-6}$ (cks), 38.0°C (100°F)	1.55	-	-	-
Viscosity, $m^2s^{-1} \times 10^{-6}$ (cks), -34.5°C (-30°F)	9.40	10.5	-	16.5
Contamination, mgl^{-1}	1.80	-	-	1.0
Thermal Stability @ 260.0°C (500°F) (JFTOT)	Pass	Pass	-	Pass
Water Separometer Test, Modified	98	94	85	-

(a) Mineral Industry Surveys, Aviation Turbine Fuels, 1973 Reference.

TABLE A-22. EMISSIONS TEST CYCLE

Engine Power Rating		Time (Minutes)
Cold Start		--
Maximum Power (mil)		10
Normal Rated Power (NR)		10
90% NR		10
60% NR		10
40% NR		10
Flight Idle		10
Ground Idle		10
	TOTAL TIME	70

was repeated to provide duplicate data. Throughout the test program, the power turbine was kept at 538 RPS (35,000 RPM) except at ground idle.

8. ENVIRONMENTAL MONITORING

CO, CO_2, NO, NO_2, and total hydrocarbons (THC).

9. PROJECT STATUS

The study was completed in May 1976. It was recommended that other laboratory tests should be initiated to measure other performance factors of the shale derived JP-5 (e.g., material compatibility, cleanliness, additive requirements, flammability, etc.).

10. RESULTS

- The performance of the JP-5 type fuel derived from oil shale was equivalent to that of petroleum-derived JP-5. Although the shale oil

JP-5 was highly contaminated with solid particles, no effect on engine performance was observed. Most of the solid matter was collected by two in-line filters and a filter upstream of the engine fuel pump.

- The CO and THC emissions were equivalent for both fuels. NO_x emission levels were higher for the oil shale derived JP-5, due to the higher levels of organic nitrogen compounds present in the oil shale derived JP-5 (see Figure A-11).
- The shale oil JP-5 was not recommended for use in flight operations, due to failure to meet standard specifications.

12. REFERENCES

Solash, J., C.J. Nowack, and R.J. Delfosse. "Evaluation of a JP-5 Type Fuel Derived from Oil Shale", Navy Air Propulsion Test Center, Trenton, NJ. NAPTC-PE-82, May 1976, 44 pp.

Telephone communication of C.J. Nowack, Navy Air Propulsiton Center, with S. Quinlivan, TRW, 3 March 1981.

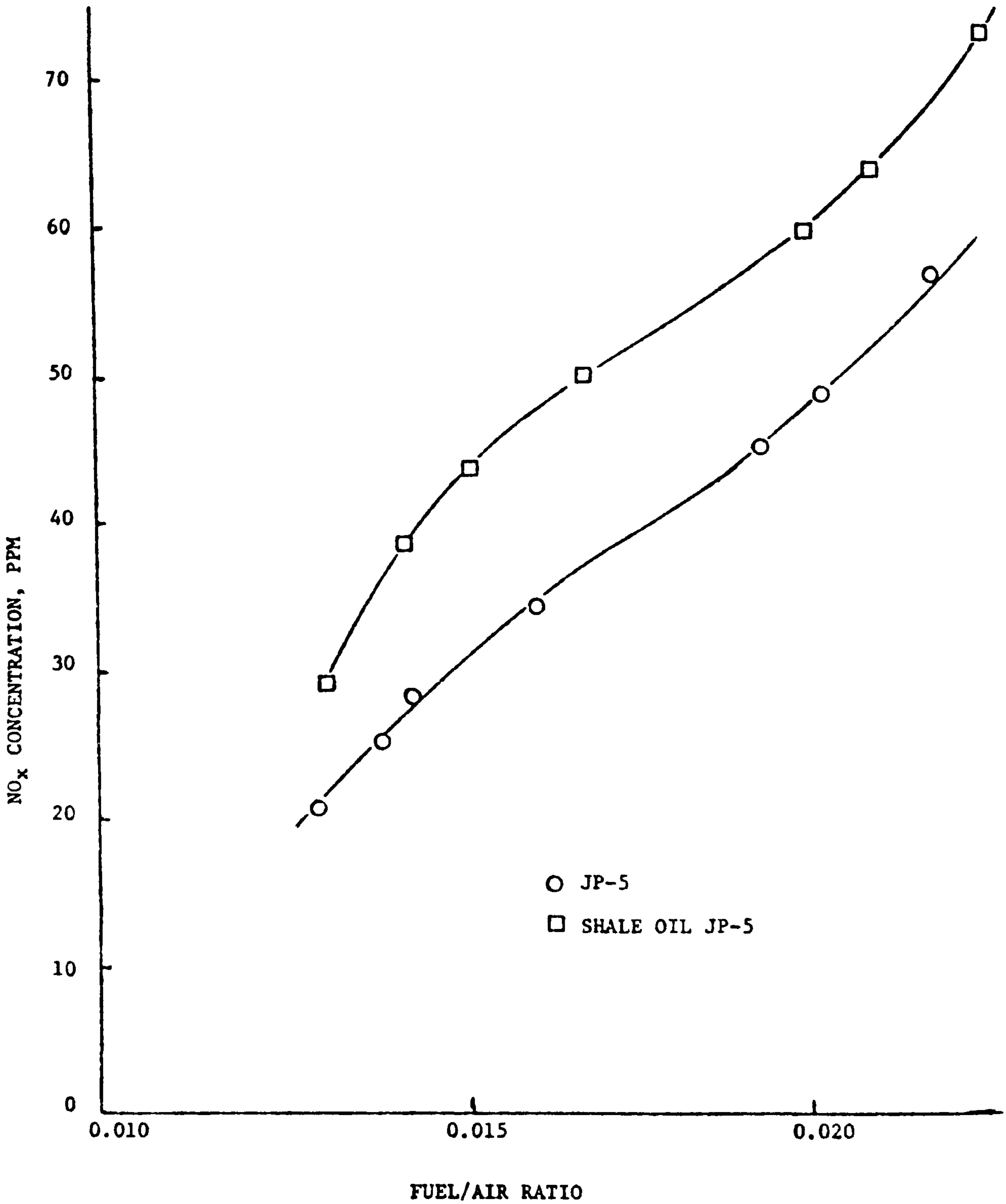

Figure A-11. Exhaust Emissions of Oxides of Nitrogen (NO_x) for T63-A-5A ENGINE.

TEST 17

DEVELOPMENT OF ALTERNATE SOURCES OF JP-5 FUEL, ENDURANCE AND EMISSION TESTS OF A T63-A-5A ENGINE USING A TAR SANDS DERIVED JP-5

1. FUELS TESTED (see Table A-23)

Synfuel: unifined kerosene-derived from Athabascan Tar Sands.

Reference fuel: petroleum-derived JP-5 fuel.

2. TEST EQUIPMENT

An Allison T63-A-5A turboshaft engine. Free turbine type used in the Army OH-58A and Navy TH-57A helicopters.

3. TEST SITE

Naval Air Propulsion Test Center,
Trenton, New Jersey

4. TEST OBJECTIVES

- Investigation of the suitability of JP-5 fuel derived from alternate sources for Navy use.

5. SPONSORING AGENCY

Department of the Navy
Naval Air Propulsion Test Center
Trenton, New Jersey

Prepared by: C. J. Nowack
Telephone No: 609 -896-5841

6. CONTRACTOR

Department of the Navy
Naval Air Propulsion Test Center
Trenton, New Jersey

Author: C. J. Nowack
Telephone No: 609 - 896-5841

7. TEST CONDITIONS

The T63-A-5A engine was installed in a sea level test cell using a three-point mounting system. Engine inlet air and fuel temperatures during the

TABLE A-23. PROPERTIES OF UNIFINED KEROSENE, AVERAGE JP-5 AND NAPTC JP-5 (T63 ENGINE CALIBRATION FUEL)

	Unified Kerosene	NAPTC JP-5	MIL-T-5624J Requirements	
			Min	Max
Gravity, Specific, 60/60 °F	0.8328	0.8142	0.788	0.845
Gravity, °API, 60/60 °F	38.4	42.3	36.0	48.0
Reid Vapor Pressure, lb/in^2	0.00	--	--	--
Distillation, I.B.P. °F	366	356	--	--
5% over °F	380	374	--	--
10% over °F	388	380	--	400
20% over °F	398	386	--	--
30% over °F	408	394	--	--
40% over °F	418	400	--	--
50% over °F	428	410	--	--
60% over °F	436	418	--	--
70% over °F	448	430	--	--
80% over °F	462	442	--	--
90% over °F	480	460	--	--
95% over °F	500	480	--	--
End poing °F	546	508	--	550
Recovery % vol.	98.1	99.0	--	--
Residue % vol.	1.4	1.0	--	1.5
Loss % vol.	0.5	0.0	--	1.5
Gum, Existent, mg/100 ml	1.2	--	--	7
Sulfur, % wt.	0.01	0.05	--	0.4
F.I.A. Saturates, % vol.	77.06	75.98	--	--
Olefins, % vol.	3.67	3.65	--	5.0
Aromatics, % vol.	19.27	20.37	--	25.0
Aniline Point, °C	59.8	61.5	--	--
Aniline - Gravity Constant	5,361	6,036	4,500	--
Heat of Combustion, Btu/lb	18,436	18,551	18,300	--
Corrosion, Copper Strip	1a	1a	--	1b
Smoke Point, mm	20.0	21	19	--
Freeze Point, °F	-64	-58	--	-51
Flash Point, °F	154	154	140	--
Water Tolerance	#1 (1.0)	--	--	--
Viscosity, cks., 100°F	1.74	--	--	--
0°F	6.38	--	--	--
-30°F	12.85	9.34	--	16.5
Contamination, mg/liter	0.11	0.33	--	1.0
Thermal Stability (JFTOT)	Pass	Pass	--	Pass
Total Acid Number	0.007	--	--	0.15
Doctor Test	Sweet	--	--	Sweet
Water Separometer Test, Modified	95	--	85	--

program was between 70 and 90°F. The studies were conducted according to the following test sequences:

Fuel	Test Sequence	Time/Hours
JP-5	Pre-test Engine Calibration	3
Unifined Kerosene	Engine Performance/Endurance Studies	54
JP-5	Post-test Engine Calibration/Exhaust Emissions	1
Unifined Kerosene	Post-test Engine Exhaust Emissions	1

Throughout the test program, the power turbine was kept at a constant speed of 35,000 RPM except at ground idle. The engine power ratings designated for the emission survey were selected as being representative of a typical Army helicopter duty cycle. (Performance ratings are detailed in the reference report.)

8. ENVIRONMENTAL MONITORING

Carbon monoxide, nitrogen oxide and unburned hydrocarbon emissions.

9. PROJECT STATUS

The Naval Air Propulsion Test Center investigation of the suitability for Navy use of JP-5 derived from alternate sources was originally authorized on June 1974 under NAVAIR AIRTASK No. A330-33-C/052B/5F571-571-301. It was recommended that various laboratory tests be continued on a low priority basis and that further engine testing be delayed.

10. RESULTS

- Unifined Kerosene as derived from Athabascan Tar Sands by GCOS is a satisfactory substitute for petroleum derived JP-5 in the sea level operation of the T63-A-5A engine under the environmental conditions tested. There was no visual degradation of fuel system materials or hot end components after 55 hours of engine performance.

- The carbon monoxide (CO) and total unburned hydrocarbon (THC) emissions were higher at low engine fuel-air ratios (lower power) for JP-5 than were obtained with Unifined Kerosene (see Figures A-12 and A-13).

- The nitrogen oxide (NO_x) emission was slightly higher at all fuel-air ratios when using Unifined Kerosene than with JP-5 (see Figure A-14).

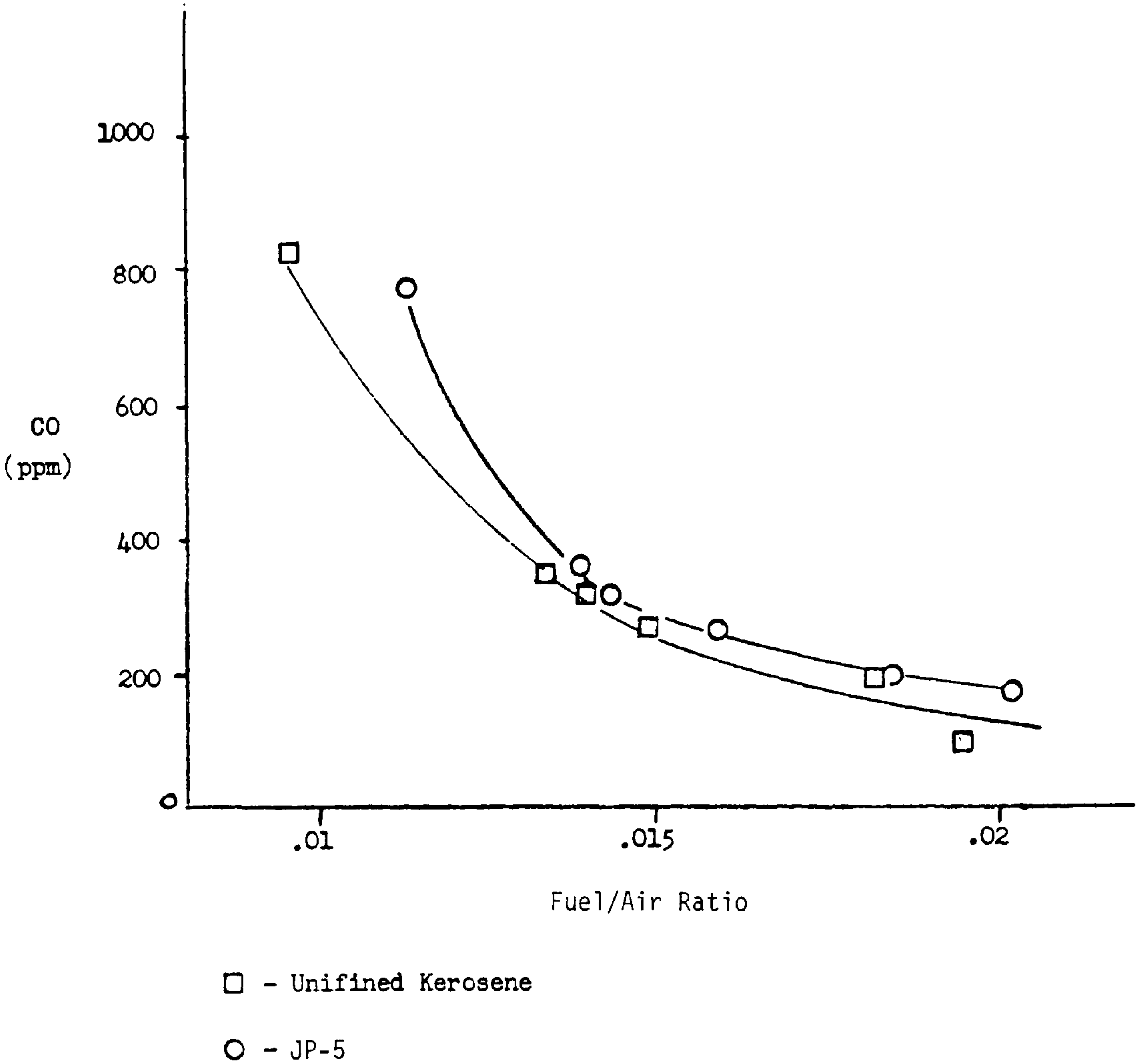

Figure A-12. Carbon Monoxide Emissions, ppm
T63-A-5A Engine (S/N 401331)

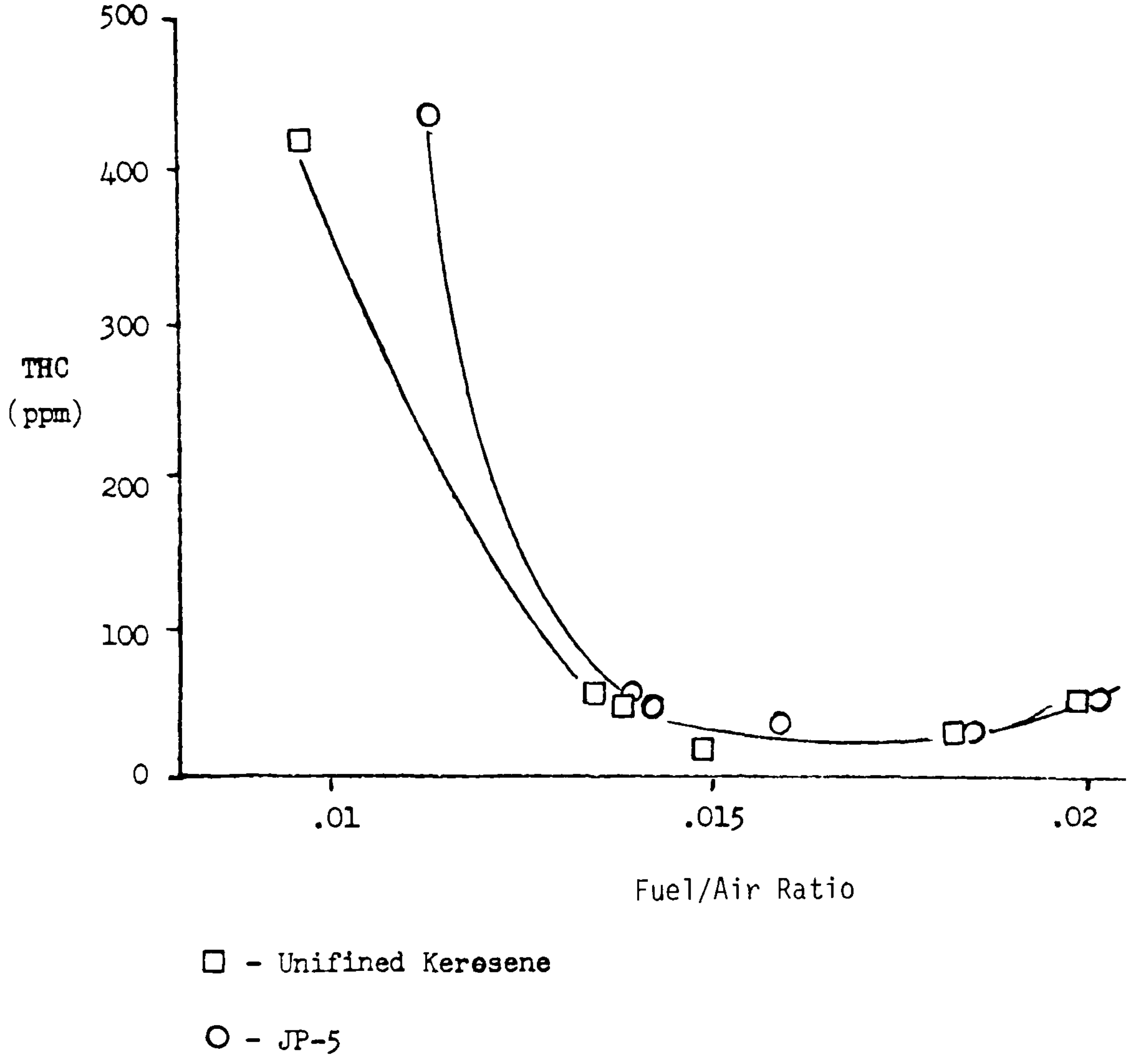

Figure A-13. Total Unburned Hydrocarbon Emissions T63-A-5A Engine (S/N 401331)

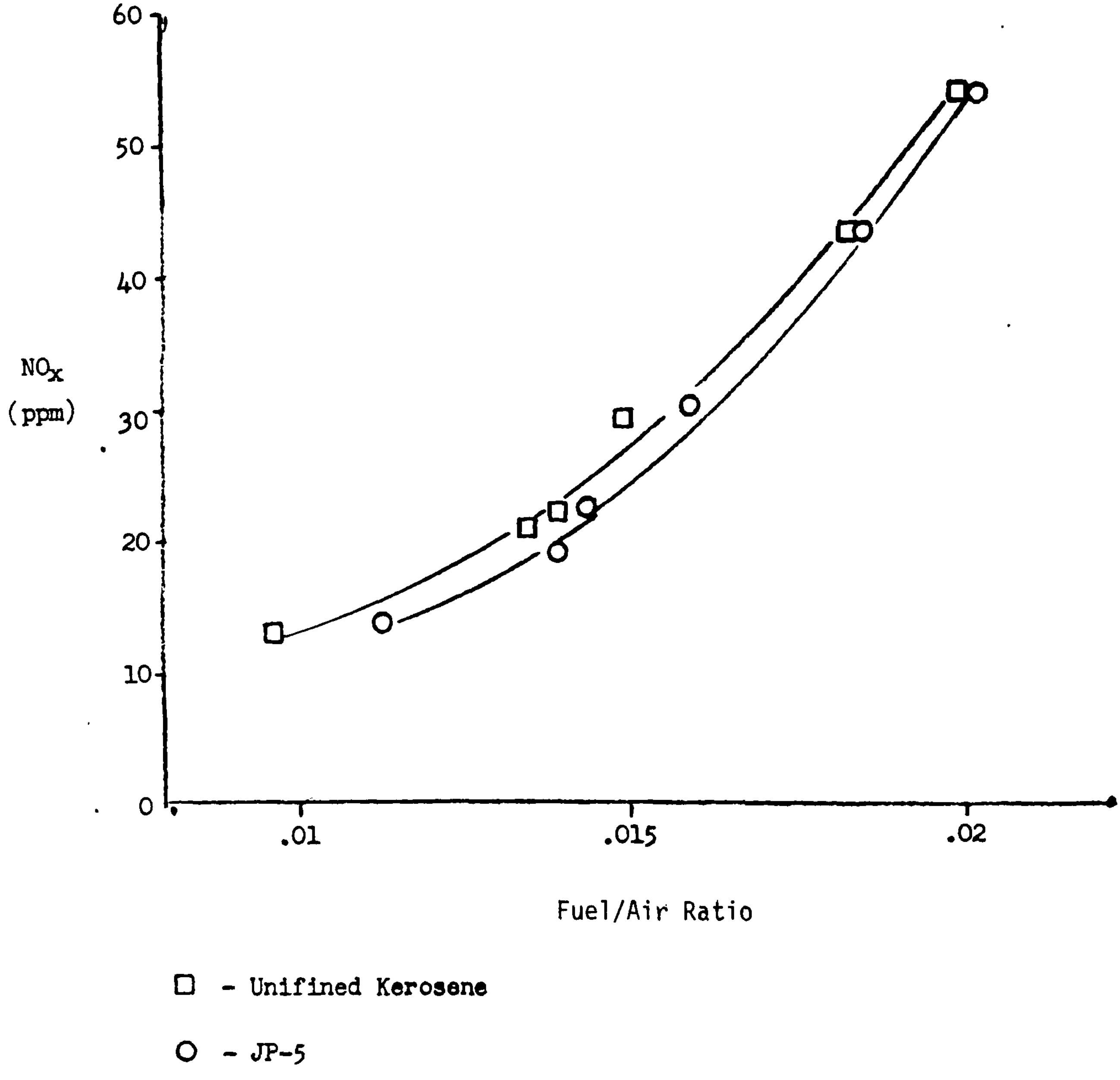

Figure A-14. Nitrogen Oxide Emissions
T63-A-5A Engine (S/N 401331)

11. REFERENCE

Memo No. PE71:CJN:er, 10340, Ser F1002, "NAVAIR Work Unit Plan No. NAPTC-812, Development of Alternate Sources of JP-5 Fuel, Report on Endurance and Emission Tests of a T63-A-5A Engine Using a Tar Sands Derived JP-5", 26 June 1975, 18 pp.

TEST 18

U.S. ARMY'S ENERGY AND SYNTHETIC FUELS PROGRAMS

1. FUELS TESTED

Previously tested fuels are shown in Table A-24. Future testing is scheduled to focus on fuels from oil shale, direct coal liquefaction, and biomass.

2. TEST EQUIPMENT

A wide variety of powerplant systems must be satisfied if synfuels are to be adopted. These range from 2-cycle spark-ignition engines to large 2-cycle and 4-cycle compression ignition engines found in self-propelled guns and tactical support equipment.

3. TEST OBJECTIVES

The Army Energy Plan establishes the basis for reducing energy consumption, reducing dependency on conventional hydrocarbon fuels, and tasks the Army to obtain a position of energy leadership. One of the major programs of the plan is the alternative fuels program, which is directed towards minimizing potential loss of military effectiveness from a disruption of energy supplied under foreigh control.

4. SPONSORING AGENCY

U.S. Army

5. CONTRACTOR

6. TEST SITE

7. TEST CONDITIONS

8. ENVIRONMENTAL MONITORING

This information for many individual tests are described in separate abstracts.

9. PROJECT STATUS

The Army has evaluated the suitability of several synfuels for use in Army equipment (Table A-24).

The current thrusts within the U.S. Army's Alternative and Synthetic Fuels Program encompasses the following efforts: Develop Capability for Using Synthetic and Alternative Fuels; Develop New, Accelerated Fuel-Engine Qualification Procedure Methodology; and Conduct Gasohol Evaluation in Tactical Equipment.

TABLE A-24. PREVIOUSLY EVALUATED SYNTHETIC FUELS

Syncrude Source:	Process:	Fuels:	When Tested:	Product Quality:
Coal	C.O.E.D.(Pyrolysis)	Gasoline Distillate	1973-74	Marginal Marginal
Tar Sands	Steam Extraction (Gulf Canada)	Aviation Turbine (JP-5)	1975	Excellent
Shale	Paraho (Above-Ground Retort)	Gasoline Diesel Aviation Turbine (JP-5/JET-A)	1976-77	Marginal Poor Marginal
Shale	Paraho (Above-Ground Retort)	Aviation Turbine (JP-5 & JP-8) Diesel	1979-80	Satisfactory

10. RESULTS

The product quality of fuels tested so far are shown in Table A-24. Test results from individual tests are described in separate abstracts.

11. MISCELLANEOUS

The file described in this abstract contains four documents: (1) Army Energy R&D Plan 1981, (2) a magazine article describing the Army's synfuel program, (3) a photocopies set of overhead-projector transparencies describing the Army Mobility Fuels Program, and (4) a progress report on fuels and lubricants research during 1980.

12. REFERENCES

Le Pera, Maurice E. The U.S. Army's Alternative and Synthetic Fuels Program. Army Research, Development, and Acquisition Magazine. September-October 1980. pp. 18-20.

Department of the Army. Progress of Fuels and Lubricants Research During FY 80. U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Fort Belvoir, Virginia. January 1981. 22 pp.

Department of the Army. Army Energy R&D Plan - 1981. U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia. March 12, 1981.

TEST 19

EVALUATION OF MILITARY FUELS REFINED FROM PARAHO-II SHALE OIL

1. FUELS TESTED

Synfuels: shale-derived JP-5, JP-8, and marine diesel fuel (DFM) (see Table A-25.

Reference fuels: JP-5, diesel fuel No. 2, and Jet A fuel derived from petroleum.

2. TEST EQUIPMENT

In the gas turbine combustion performance test, the combustor used is based on hardware from the Allison T-63 gas turbine engine used in several Army helicopters.

In the diesel engine performance test, the four diesel engines used represent critical and widespread engines in the military tactical fleet: the militarized version of the Detroit Diesel 6V-53T; the military-developed LDT-465-1C; a single cylinder from the Teledyne-Continental AVDS-1790 air-cooled diesel mounted on a CUE crankcase; and a commercially configured Detroit Diesel 3-53 diesel engine (see Table A-26 for test engine characteristics).

3. TEST SITE

U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas

4. TEST OBJECTIVES

- To evaluate JP-5, JP-8, and DFM produced from Paraho-II shale oil for specification requirements and other properties, and to ascertain their performance in Army engine systems as a part of the overall program to develop a capability for consuming multisource fuels within the Department of Defense.

TABLE A-25. PROPERTIES OF FUELS DERIVED FROM SHALE OIL

Properties	JP-8	JP-8 Requirements	JP-5	JP-5 Requirements	DFM	DFM Requirements
Specific Gravity, 15.6/15.6°C	0.8044	0.775-0.840	0.8081	0.788-0.845	0.8353	---
Gravity, °API	44.4	37-51	43.6	36-48	37.9	Record
Distillation, °C						
IBP	178	---	179	---	206	---
10% Recovered	187	205 max	189	205 max	233	---
20% Recovered	189	---	192	---	243	---
50% Recovered	201	---	202	---	264	---
90% Recovered	227	---	228	---	295	357 max
End Point	257	300 max	248	290 max	312	385 max
% Recovered	98.5	---	98.5	---	99	---
% Residue	1.0	1.5 max	1.5	1.5 max	1	3 max
% Loss	0.5	1.5 max	0	1.5 max	0	
Flash Point, °C	57	38 min	62	60 min	80	60 min
Viscosity at 37.8°C,cSt	1.30	---	1.38	---	2.71	1.8-4.5
Viscosity at -20°C,cSt	4.19	8.0 max	4.68	8.5 max	---	---
Aniline Point, °C	62.4	---	60.4	---	67.0	Record
Cloud Point, °C	---	---	---	---	10	-1 max
Pour Point, °C	---	---	---	---	-18	-7 max
Freezing Point, °C	-52	-50 max	-51	-46 max	---	---
Existent Gum, mg/100ml	0.4	7 max	0	7 max	0	---
Total Acid Number, mg KOH/g	0.01	0.015 max	0	0.015 max	0.001	0.3 max
Neutrality	---	---	---	---	Neutral	Neutral
Aromatics, vol% (FIA)	21	25 max	22	25 max	30	---
Olefins, vol% (FIA)	2	5 max	2	5 max	1	---
Carbon, wt%	86.05	---	85.92	---	86.54	---
Hydrogen, wt%	13.70	13.5 min	13.68	13.5 min	13.36	---
Nitrogen, ppm	0.31	---	<1	---	<1	---
Oxygen, wt%	0.40	---	0.38	---	0.37	---
Sulfur, wt%	0.002	0.30 max	0.005	0.40 max	0.004	1.00 max
Thermal Oxidation Stability (JFTOT) at 260°C						
ΔP, mm Hg	0	25 max	0	25 max	0	---
Tube rating, visual	2	<3	1	<3	3	---
TDR-spun	10.0	---	2.0	---	11.5	---
TDR-spot	12.0	---	8.0	---	19	---
Cu Corrosion at 100°C	1A	1B max	2C	1B max	1A	1 max
Net Heat of Combustion, MJ/kg	42.82	42.8 min	42.68	42.6 min	42.50	---
Smoke Point, mm	20.2	19 min	17.5	19 min	16.5	---
Aniline-Gravity Product	6,407	---	6,134	4,500 min	---	---
Visual Appearance	Straw, clear	---	White, clear	---	White, clear	Clear, bright
Color, ASTM Rating	0.5	---	<0.5	---	<0.5	3 max
Accelerated Stability, mg/100 ml	0.29	---	0.14	---	0.20	2.5 max
Particulate Matter, mg/l	0.3	1 max	0.1	1 max	0.5	8 max
Ash, wt%	---	---	---	---	0	0.005 max
Cetane Number	45	---	45	---	49	45 min
Carbon Residue on 10% bottoms, wt%	---	---	---	---	0.04	0.2 max
Demulsification, minutes	---	---	---	---	5	10 max
Ring Carbon						
Mono-aromatics, wt%	13.84	---	13.54	---	11.58	---
Di-aromatics, wt%	1.19	---	1.36	---	4.03	---
Tri-aromatics, wt%	0.003	---	0.002	---	0.045	---
GC Distillation, °C						
0.1 wt% off	120.1	---	136.5	---	103.4	---
1 wt% off	153.6	---	159.7	---	152.3	---
10 wt% off	170.4	186 max	174.5	185 max	214.0	---
20 wt% off	176.6	---	185.3	---	236.2	---
50 wt% off	203.1	---	208.9	---	271.8	---
90 wt% off	241.0	---	245.9	---	316.5	---
95 wt% off	252.2	---	255.0	---	323.3	---
99 wt% off	274.6	---	278.8	---	336.1	---
99.5 wt% off	285.7	330 max	291.6	320 max	342.1	---
HPLC Aromatics, wt%	23.5	---	24.9	---	27.8	---
HPLC Saturates, wt%	76.5	---	75.1	---	72.2	---

TABLE A-26. TEST ENGINE CHARACTERISTICS

Manufacturer	Detroit Diesel	Detroit Diesel	Teledyne Continental	Teledyne Continental*
Designation	6V-53T	3-53	LDT-465-1C	CUE-1790
Induction System	turbocharged	normally aspirated	turbocharged	simulated turbocharge
Combustion System	direct injection	direct injection	M.A.N.	direct injection
Strokes/Cycle	2	2	4	4
Number of Cylinders	6	3	6	1
Arrangement	60° V	in-line	in-line	---
Displacement	5.21L ($318\ in.^3$)	2.61L ($159\ in.^3$)	7.83L ($478\ in.^3$)	2.44L ($149.1\ in.^3$)
Bore and Stroke	9.84 x 11.43 cm (3-7/8x4-1/2in.)	9.84 x 11.43 cm (3-7/8x4-1/2in.)	18.0 x 19.2 (4.56x4.87 in.)	(5.75x5.75 in.)
Rated Power at Speed kW(Hp) at rpm	244(300) at 2800	67.1(90) at 2800	104(140) at 2600	---
Max Torque at Speed Nm(lb-ft) at rpm	834(615) at 2200	278(205) at 1800	556(410) at 1600	---
Compression Ratio	17	21	22	
Fuel System	N70 unit injector	N50 unit injector	Bosch PSB6A-90EH-5337A3 with ABD-355-124-7 nozzles	

*Single cylinder from Teledyne-Continental AVDS-1790-2D engine adapted to a CUE crankcase by others.

- Fuels were analyzed to determine their specification requirements, storage stability, additive response, compatibility with petroleum-based fuels, combustion performance, diesel engine performance, and microbiological growth susceptibility.

5. SPONSORING AGENCIES

U.S. Army Mobility Equipment Research and Development Command
Ft. Belvoir, Virginia 22060

Contract Monitor: F.W. Schaekel
Telephone No: 703-664-6071

U.S. Department of Energy
Bartlesville Energy Technology Center
Bartlesville, Oklahoma 74003

Project Officer: Dr. D.W. Brinkman
Telephone No: 918-336-2400

6. CONTRACTOR

Southwest Research Institute
Energy Systems Research Division
San Antonio, Texas 78284

Principal Investigator: John N. Bowden
Telephone No: 512-684-5111

7. TEST CONDITIONS

Table A-27 presents the operating conditions which represent the air flow rates in the actual engine for the six different power points (idle to full power) investigated. Emission data were recorded at each power point for each fuel.

Three diesel engines were used during maximum power output and specific fuel consumption testing: the 6V-53T, the LDT-465-K, and the AVDS-1790. The engines were mounted on dynamometer test stands and alternately operated on the shale-derived JP-5 and DFM and the petroleum-derived reference fuel - diesel fuel No. 2.

The 3-53 diesel engine was operated for 210 hours with shale-derived DFM according to the Army/CRC wheeled-vehicle endurance cycle to evaluate the wear and deposit formation tendencies of this fuel.

8. ENVIRONMENTAL MONITORING

CO, NO_x, unburned hydrocarbons, and smoke.

TABLE A-27. T-63 COMBUSTOR RIG OPERATING CONDITIONS

Mode	Percent Power	Burner Inlet Air Pressure, kpa	Burner Inlet Air Temperature, °K	Air Flow Rate, kg/s	Fuel Flow Rate, kg/m	Fuel/Air Ratio
Ground Idle	10	230	422	0.64	0.42	0.0109
---	25	283	452	0.75	0.54	0.0121
Descent	40	329	478	0.86	0.68	0.0131
Cruise	55	369	294	0.93	0.93	0.0145
Climb/Hover	75	418	518	1.02	1.01	0.0166
Takeoff	100	477	547	1.10	1.30	0.0198

9. PROJECT STATUS

Work was conducted from June 1979 through November 1980. Interim report dated March 1981. Additional tests planned for FY 82 using other types of army equipment.

10. RESULTS

Specification Analysis

- The shale-derived fuels met virtually all the military specifications with the exception of the failure of JP-5 to meet copper corrosion requirement and DFM to meet maximum limit for pour point as seen in Table A-25.

Storage Stability Tests

- Storage stability of the shale-derived fuels was equivalent to that of petroleum products at 43°C for 32 weeks. Accelerated stability at 80° and 150°C indicated instability at the lower temperature, but none at 150°C.

Compatibility, Additive Response, and Microbiological Growth Tests

- Compatibility tests with JP-5 and DFM petroleum- and shale-derived fuels indicated that the fuels are compatible with each other. JP-5 and DFM synfuels responded to the addition of a centane improver additive in a manner similar to that of a petroleum-based fuel. The addition of a corrosion inhibitor incrementally improved the corrosion tendencies of JP-5 and DFM but did not affect the JP-8. Microbiological growth susceptibility tests showed that growth of Cladosporium resinae was supported by shale-derived JP-5 and DFM.

Gas Turbine Combustion Performance

- In general, the combustion properties of synthetic JP-5 and DFM are not significantly different from the respective petroleum-derived fuel (see Table A-28).
- Combustion inefficiency is determined by CO and UHC in the exhaust. Figure A-15 shows that DFM gives slightly higher CO emissions than JP-5 and Jet A. Contrary to its fuel properties, DFM gave somewhat lower UHC emissions than the other fuels as seen in Figure A-16.
- NO_x emissions shown in Figure A-17 were essentially the same for both shale fuels and Jet A at all operating conditions.
- Exhaust smoke indices for the shale-derived fuels were higher than the respective Jet A fuel.

TABLE A-28. SUMMARY OF GAS TURBINE COMBUSTION RESULTS

Power Point	Fuel No.	Fuel Type	Flame Radia.	Smoke No.	Smoke mg/M^3	NO_x E.I.	CO E.I.	UBH E.I.	Combustion Efficiency
100	0	Jet A	42.8	28.9	4.3	7.2	9.5	0.2	99.79
100	1	JP-5	59.7	48.7	13.2	7.2	9.1	0.4	99.78
100	2	DFM	60.1	45.2	10.8	6.7	13.8	0.4	99.67
75	0	Jet A	37.0	32.1	5.1	5.5	30.3	2.0	99.31
75	1	JP-5	48.9	38.1	7.1	5.7	30.8	1.9	99.28
75	2	DFM	50.7	41.0	8.46	4.7	34.3	2.9	99.13
55	0	Jet A	31.9	15.8	1.8	4.7	48.3	7.1	98.64
55	1	JP-5	43.7	19.7	2.4	4.6	47.7	7.3	98.59
55	2	DFM	48.1	22.6	2.9	4.3	50.1	7.0	98.54
40	0	Jet A	26.7	12.0	1.3	4.7	59.6	11.7	98.14
40	1	JP-5	37.4	25.2	3.4	4.7	59.9	13.3	97.97
40	2	DFM	43.2	27.9	4.0	4.7	65.4	12.5	97.91
25	0	Jet A	23.3	11.7	1.27	3.1	82.3	35.9	95.57
25	1	JP-5	30.0	21.2	2.6	3.6	75.8	30.7	96.13
25	2	DFM	39.2	29.9	4.5	3.3	102.3	33.7	95.35
10	0	Jet A	17.8	7.9	0.84	1.3	113.6	71.5	92.37
10	1	JP-5	26.2	17.7	2.06	3.3	107.9	82.9	91.52
10	2	DFM	31.9	23.2	3.0	3.1	118.0	69.0	92.42

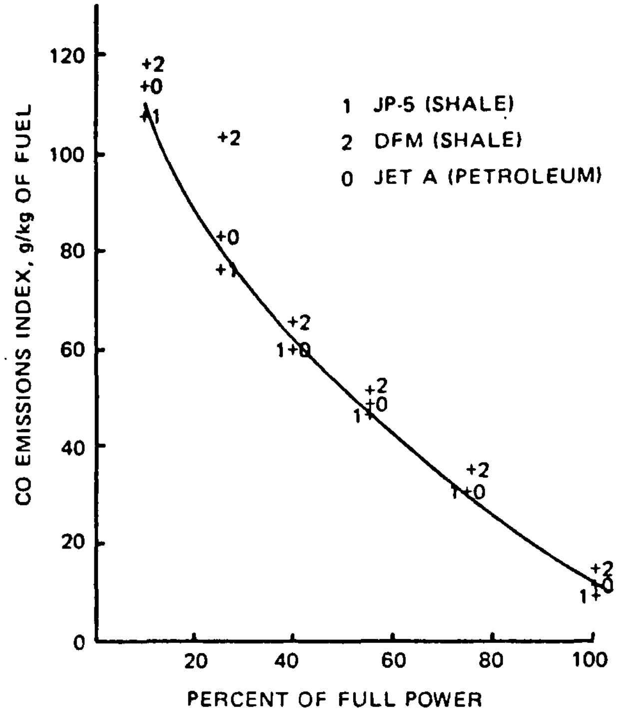

Figure A-15. Effect of Fuel on Carbon Monoxide Emissions

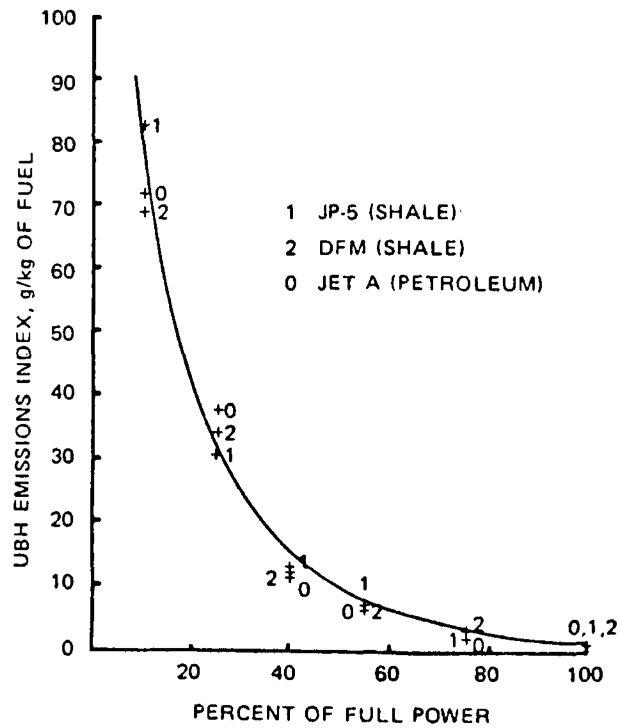

Figure A-16. Effect of Fuel on Unburned Hydrocarbon Emissions

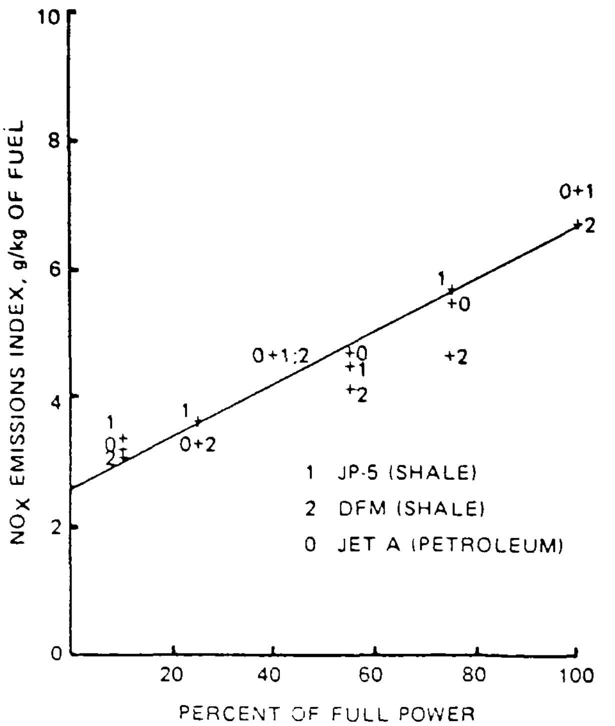

Figure A-17. Effect of Fuel on NO_x Emissions

Diesel Engine Performance

- In the power output and specific fuel consumption tests of the three diesel engines using shale-derived JP-5 and DFM and petroleum-derived diesel fuel, the only observable difference between the fuels were those attributed to differences in heat of combustion. The percent change in observed horsepower and volumetric fuel consumption for the three test engines are summarized in Tables A-29, A-30, and A-31.
- Results of the 210-hour endurance test showed no power loss during the test nor evidence of distress or component failure; and piston deposits and component wear were acceptable. The results of the shale-derived DFM in this test were indistinguishable from those obtained using a petroleum-derived diesel fuel.

11. REFERENCE

Bowden, J.N., et al. Military Fuels Refined From Paraho-II Shale Oil. Prepared by Southwest Research Institute for U.S. Army (MERADCOM), Interim Report AFLRL No. 131. March 1981.

TABLE A-29. PERCENT CHANGE IN OBSERVED HORSEPOWER AND VOLUMETRIC FUEL CONSUMPTION IN DETROIT DIESEL 6V-53T

Engine Speed	From DF-2 to DFM		From DF-2 to JP-5	
	Power	Fuel*	Power	Fuel*
1800	-0.8	1.5	-3.4	5.8
2000	-1.4	1.5	-5.1	4.2
2200	-1.8	1.1	-5.3	3.8
2400	-1.8	1.1	-6.2	5.5
2600	-1.5	1.2	-7.3	5.5
2800	-2.4	0.9	-8.4	6.6
Average	-1.7 ± 0.5	1.2 ± 1.0	-6.0 ± 0.5	5.2 ± 1.0

*Brake specific volumetric consumption (Gal/BHP-hr).

TABLE A-30. PERCENT CHANGE IN OBSERVED POWER AND VOLUMETRIC FUEL CONSUMPTION IN CUE-1790

Engine Speed, rpm	From DF-2 to DFM		From DF-2 to JP-5	
	Power	Fuel*	Power	Fuel*
1800	+2.7	-1.1	-2.9	7.0
2000	+1.4	-1.4	-4.6	0.3
2200	+3.7	-3.0	-1.1	1.8
2400	+1.8	-2.9	-2.3	3.8
Average	+2.4	-2.1	-2.7	3.2
Std Dev	1.0	1.0	1.5	2.9

*Brake specific volumetric consumption (Gal/BHP-hr).

TABLE A-31. PERCENT CHANGE IN OBSERVED POWER AND FUEL CONSUMPTION IN LDT-465-1C (From Diesel Fuel to DFM)

Engine Speed, rpm	Change in Max Power, %	Change in Fuel*, %	
		Full Power	3/4 of Full Power
1600	-1.9	+1.3	+0.8
2100	-0.6	-0.1	+1.8
2600	+0.4	+1.0	+2.7
Average	-0.7	+1.3	

*Brake specific volumetric consumption (Gal/BHP-hr).

TEST 20

EVALUATION OF FUEL CHARACTER EFFECTS ON F101 ENGINE COMBUSTION SYSTEM

1. FUELS TESTED

Reference fuels: thirteen non-synfuels were tested; i.e., a typical JP-4; five blends of JP-4 with a single ring aromatic concentrate; a double ring aromatic concentrate, and a light oil; a typical JP-8; five blends of JP-8 with the same three compounds used for the JP-4 blends; and a Number 2 diesel fuel. The thirteen fuels incorporated systematic variations in hydrogen content (12.0 to 14.0 weight percent), aromatic type (monocyclic or bicyclic), initial boiling point (285 to 393 K by gas chromatograph), final boiling point (532 to 679 K also by gas chromatograph), and viscosity (0.83 to 3.25 cSt at 300 K).

2. TEST EQUIPMENT

General Electric F101 turbofan engine main combustion system elements. A sector rig and a full-annular rig were used to generate the combustion data. Separate rigs were used to obtain carboning and nozzle fouling data on the fuels.

3. TEST SITE

General Electric test facility, Evendale, Ohio.

4. TEST OBJECTIVES

- To determine the effects of broad variations in fuel properties on the performance, emissions, and durability of the F101 combustion system.
- The rationale for selection of the test fuels was to span systematically the possible future variations in key properties that might be dictated by availability, cost, the use of nonpetroleum sources for jet fuel production, and the possible change from JP-4 to JP-8 as the prime USAF aviation turbine fuel.

5. SPONSORING AGENCIES

Air Force Aero Propulsion Laboratory (SFF)
Air Force Wright Aeronautical Laboratories
Wright-Patterson AFB, Ohio 45433

Government Project Engineer: T.A. Jackson
Telephone Number: 513-255-2008

Additional funding and technical guidance was provided by the Environmental Sciences Branch of the Environics Division in the Research and Development Directorate of HQ Air Force Engineering and Services Center located at Tyndall Air Force Base, Florida.

6. CONTRACTOR

General Electric Company
Aircraft Engine Group
Cincinnati, Ohio 45215

Project Officer: C.C. Gleason (and T.L. Oller)
Telephone Number: 513-243-3207

7. TEST CONDITIONS

Test fuels were evaluated in: (a) 13 high pressure/temperature full-annular combustor performance/emissions/durability tests; (b) 13 atmospheric pressure/high temperature full-annular combustor pattern factor performance tests; (c) 13 high pressure/temperature single fuel nozzle/swirl cup carbon deposition tests; (d) 14 low pressure/temperature 54-degree sector combustor cold day ground start/altitude relight tests; (e) 15 high temperature short duration fuel nozzle fouling tests; and (f) 8 high temperature longer cyclic fuel nozzle valve gumming tests.

8. ENVIRONMENTAL MONITORING

NO_x, CO, smoke, and unburned hydrocarbons.

9. PROJECT STATUS

Testing and analytic activity occurred from August 1977 through September 1978. Final report submitted June 1979.

10. RESULTS

- As expected, gaseous emissions and smoke levels were strongly dependent upon operating conditions for all fuels tested.

- Low power emissions of CO and UHC were only significant at idle, and decreased sharply with increasing power level. Levels of CO were readily correlated with power level; UHC exhibited more variability while following a similar trend.
- Oxides of nitrogen were primarily a high power emission and, for fuels with negligible amounts of fuel-bound nitrogen, correlated readily with power level.
- At high power conditions, fuel hydrogen content was found to have a very significant effect on annular liner temperature, smoke, and NO_X levels. While smoke levels decreased with increasing hydrogen content, the levels were very low with all the fuels (i.e., smoke levels of 0.4 to 3.2, which are on the threshold of smoke measurement system accuracy).
- At low power operation, CO and UHC correlated with the 10 percent distillation recovery temperature and with relative spray droplet size (a function of fuel viscosity, surface tension, and density).
- Cold day ground start and altitude relight correlated with fuel atomization/volatility parameters.
- Combustor liner life analyses yielded relative life predictions of 1.00, 0.72, 0.52, and 0.47 for fuel hydrogen contents of 14.5, 14.0, 13.0, and 12.0 percent, respectively. At the present state of turbine stator development, no fuel effect on life is predicted.
- Extended cyclic fuel nozzle valve gumming tests revealed significant effects of fuel type and temperature on nozzle life. The results correlated with laboratory thermal stability ratings of the fuels based on tube deposits alone.

11. REFERENCE

Gleason, C.C., T.L. Oller, M.W. Shayeson, and D.W. Bahr. Evaluation of Fuel Character Effects on the F101 Engine Combustion System. AFAPL-TR-79-2018, CEEDO-TR-79-07, U.S. Air Force, Wright-Patterson AFB, Ohio, June 1979. 199 pp.

TEST 21

EVALUATION OF FUEL CHARACTER EFFECTS ON J79 SMOKELESS COMBUSTOR

1. FUELS TESTED

Reference fuels: thirteen refined and blended non-synfuel fuels were tested; i.e., a current JP-4, five blends of the JP-4, a current JP-8, five blends of the JP-8, and a No. 2 diesel fuel. These fuels incorporated systematic variations in hydrogen content (11.9 to 14.5 weight percent), aromatic type (monocyclic or dicyclic), initial boiling point (298 to 409 K by gas chromatograph), final boiling point (554 to 646 K, also by gas chromatograph), kinematic viscosity (0.90 to 3.27 mm^2/s as 294.3 K), and thermal stability breakpoint (518 to 598 K by JFTOT) for evaluation.

2. TEST EQUIPMENT

The J79-17C turbojet engine main burner as represented by two single can combustor rigs and a fuel nozzle rig.

3. TEST SITE

General Electric test facility, Evendale, Ohio.

4. TEST OBJECTIVES

- To determine the effects of broad variations in fuel properties on the performance, emissions, and durability of the combustion system identified above.
- Compare results to those previously obtained in similar tests of the J79-17A and F101 combustion systems.
- Test fuels were selected to represent variations in properties that can be expected to affect the combustion system; ranges of property variations were set to represent broad limits that may be anticipated in using fuels refined from an expanded portion of the petroleum resource and from non-oetroleum hydrocarbon sources.
- The combustion system was selected because it represented a redesign of a system in wide usage by the USAF (as well as one which was tested under a preceeding fuels program, the J79 standard configuration).

This provided an opportunity to compare two different combustion systems designed for the same engine.

5. SPONSORING AGENCY

Aero Propulsion Laboratory (AFWAL/POSF)
Air Force Wright Aeronautical Laboratories (AFSC)
Wright-Patterson AFB, Ohio 45433

Government Project Engineer: Jeffrey S. Stutrud
Telephone No: 513-255-2008

Partial funding and technical support in the area of the measurement and analysis of gaseous emissions and smoke data were provided by the Environmental Sciences Branch of the Environics Division in the Research and Development Directorate of HQ Air Force Engineering and Services Center.

6. CONTRACTOR

General Electric Company
Aircraft Engine Business Group
Technology Programs and Performance Technology Dept.
Cincinnati, Ohio 45215

Principal Investigator: C.C. Gleason (and T.L. Oller)
Telephone No: 513-243-3207

7. TEST CONDITIONS

The fuels were evaluated in: (a) 14 high pressure/temperature combustor cold-day ground start/altitude relight tests; (b) 14 low pressure/temperature combustor cold-day ground start/altitude relight tests; and (c) 7 high temperature cyclic fuel nozzle fueling tests.

8. ENVIRONMENTAL MONITORING

NO_x, CO, smoke, and unburned hydrocarbons.

9. PROJECT STATUS

The period of performance for this effort, including testing and analysis, was July 1, 1979 through June 1, 1980. Final report is dated November 1980.

10. RESULTS

- As expected, gaseous emissions and smoke levels were strongly dependent upon operating conditions for all fuels tested.

- Low power emissions of CO and UHC were only significant at idle, decreasing sharply with increasing power level. Levels of CO were readily correlated with power level; UHC exhibited more variability while following similar trends.
- Oxides of nitrogen were primarily a high power emission and, for fuels with negligible amounts of fuel-bound nitrogen, correlated readily with power level.
- Smoke increased with power level but for the system tested (a low smoke combustor) the emission was below 20 Smoke Number. This is below visible and also in a range where the accuracy of the measurement system is suspect.
- At high power operating conditions, fuel hydrogen content was found to be a very significant fuel property with respect to liner temperature, flame radiation, smoke, and NO_x emission levels.
- At idle and cruise operating conditions, CO and HC emission levels were found to be dependent on both fuel hydrogen content and relative spray droplet size.
- At cold-day ground start conditions, lightoff correlated with the relative fuel droplet size.
- Altitude relight limits at low flight Mach numbers were fuel dependent and also correlated with the relative fuel droplet size.
- Combustor liner life analyses, based on the test data, yielded relative life predictions of 1.00, 0.93, 0.83, and 0.73 for fuel hydrogen contents of 14.5, 14.0, 13.0, and 12.0 percent, respectively.
- High temperature cyclic fuel nozzle fouling tests revealed significant effects of fuel quality and operating temperature on nozzle life. The results correlated with laboratory thermal stability rating of the fuels.

11. REFERENCE

Gleason, C.C., T.L. Oller, M.W. Shayeson, and M.J. Kenworthy. Evaluation of Fuel Character Effects on J79 Smokeless Combustor. AFWAL-TR-80-2092, ESL-TR-80-46, U.S. Air Force, Wright-Patterson AFB, Ohio, 1980. 178 pp.

TEST 22
EVALUATION OF FUEL CHARACTER EFFECTS ON J79 ENGINE COMBUSTION SYSTEM

1. FUELS TESTED

Reference fuels: thirteen non-synfuels were tested; i.e., a typical JP-4; five blends of JP-4 with a single ring aromatic concentrate, a double ring aromatic concentrate, and a light oil; a typical JP-8; five blends of JP-8 with the same three compounds used for the JP-4 blends; and a Number 2 Diesel fuel. The thirteen fuels incorporated systematic variations in hydrogen content (12.0 to 14.5 weight percent), aromatic type (monocyclic or bicyclic), initial boiling point (285 to 393 K by gas chromatograph), final boiling point (532 to 679 K also by gas chromatograph), and viscosity (0.83 to 3.25 cSt at 300 K).

2. TEST EQUIPMENT

J79 turbojet engine main combustion system elements. Two single can test rigs were used to generate combustion data at high and low pressure points A fuel nozzle rig was used to obtain nozzle fouling data on the test fuels.

3. TEST SITE

General Electric test facility, Evendale, Ohio.

4. TEST OBJECTIVES

- To determine the effects of broad variations in fuel properties on the performance, emissions, and durability of the J79 combustion system.
- The rationale for selection of the test fuels was to span systematically the possible future variations in key properties that might be dictated by availability, cost, the use of nonpetroleum sources for jet fuel production, and the possible change from JP-4 to JP-8 as the prime USAF aviation turbine fuel.

5. SPONSORING AGENCIES

Air Force Aero Propulsion Laboratory (AFWAL/POSF)
Air Force Wright Aeronautical Laboratories
Wright-Patterson AFB, Ohio 45433

Government Project Engineer: T.A. Jackson
Telephone No: 513-255-2008

Additional funding and technical guidance was provided by the Environmental Sciences Branch of the Environics Division in the Research and Development Directorate of HQ Air Force Engineering and Services Center located at Tyndall Air Force Base, Florida.

6. CONTRACTOR

General Electric Company
Aircraft Engine Group
Cincinnati, Ohio 45215

Project Officer: C.C. Gleason (or T.L. Oller)
Telephone No: 513-243-3207

7. TEST CONDITIONS

Test fuels were evaluated in: (a) 14 high pressure/temperature combustor performance/emissions/durability tests; (b) 14 low pressure/temperature combustor cold-day ground start/altitude relight tests; and (c) 18 high temperature fuel nozzle fouling tests.

8. ENVIRONMENTAL MONITORING

NO_x, CO, smoke, and unburned hydrocarbons.

9. PROJECT STATUS

Testing and analytical activity occurred from June 1977 through August 1978. Final report is dated June 1979.

10 RESULTS

- Fuel hydrogen content strongly affected smoke, carbon deposition, liner temperature, flame radiation and moderately affected NO_x emissions. Hydrogen content is, therefore, probably the single most important fuel property, particularly with respect to high power performance and emission characteristics and combustor durability (life).
- Fuel volatility (as indicated by initial boiling range) and viscosity effects became evident at low power operating conditions. Cold day

starting and altitude relight capability are highly dependent upon these properties.

- Within the range tested, neither aromatic type (monocyclic or bicyclic) nor final boiling range produced any direct effect on emissions or combustor performance.
- None of the fuel properties produced any measurable effect on combustor exit temperature distribution (profile and pattern factor), idle stability, fuel nozzle fouling tendency, or turbine life.
- The fuel nozzle fouling tests were indeterminate. More sophisticated long-term tests are needed to determine the effects of fuel thermal stability on fuel supply/injection system components.

11. REFERENCE

Gleason, C.C., T.L. Oller, M.W. Shayeson, and D.W. Bahr. Evaluation of Fuel Character Effects on J79 Engine Combustion System. AFAPL-TR-79-2015, CEEDO-TR-79-06, U.S. Air Force, Wright-Patterson AFB, Ohio, June 1979, 197 pp.

TEST 23

FUEL CHARACTER EFFECTS ON CURRENT, HIGH PRESSURE RATIO, CAN-TYPE TURBINE COMBUSTION SYSTEMS

1. FUELS TESTED

Reference fuels: twelve fuels were tested including a baseline JP-4, a baseline JP-8, and five blends of each baseline fuel. Hydrogen content, aromatic type, distillation range, and viscosity were varied by blending JP-4 and JP-8 fuels with a mineral seal oil and two types of aromatic solvents. The fuel matrix incorporated systematic variations in hydrogen content (12.0 to 14.4 percent wt.), aromatic type (single or multi-ring), 10 percent distillation point (353 to 464 K by gas chromatograph), final boiling point (541 to 612 K by gas chromatograph), and viscosity (0.888 to 2.305 centi-stokes at 298 K).

2. TEST EQUIPMENT

A single can combustor rig, simulating a 36° segment of the mainburner of the TF41 turbofan engine, was used to generate high and low pressure data. A special fuel nozzle rig was used to generate combustor carboning and nozzle fouling data.

3. TEST SITE

Detroit Diesel Allison, Indianapolis, Indiana.

4. TEST OBJECTIVES

- The purpose of this program was to determine the effects of fuel property variations on the performance, exhaust emission, and durability characteristics of the TF41 turbofan engine combustion system. The system was selected because it is one of two high pressure ratio, connular system in use by the Air Force.
- The rationale for selection and testing of test fuels was to study the operational and performance characteristics that might occur with the ultimate use of non-petroleum-derived fuels in the TF41 turbofan engine.

5. SPONSORING AGENCY

Air Force Aero Propulsion Laboratory
Air Force Wright Aeronautical Laboratory
Air Force Systems Command
Wright-Patterson AFB, Ohio 45433

Government Project Engineer: T.A. Jackson
Telephone No: 515-255-2008

Partial funding and technical support in the area of the measurement and analysis of gaseous emissions and smoke data were provided by the Environmental Sciences Branch of the Environics Division in the Research and Development Directorate of HQ Air Force Engineering and Services Center (HQ AFESC/RDVC).

6. CONTRACTOR

Detroit Diesel Allison (DDA)
Division of General Motors Corporation
Indianapolis, Indiana 46206

Project Officer: Dennis Troth
Telephone No: 317-242-5000

7. TEST CONDITIONS

Performance tests were accomplished at idle, altitude cruise, dash, and takeoff conditions. Sea level and altitude ignition tests were also completed. Carboning and fuel nozzle fouling tests were conducted under accelerated failure conditions.

8. ENVIRONMENTAL MONITORING

NO_x, CO, smoke, and unburned hydrocarbons.

9. PROJECT STATUS

Test and analytical activity were conducted from June 15, 1978 through June 15, 1979. Final report is dated April 1980.

10. RESULTS

- Fuel fouling and carboning characteristics were established. Combustor operating parameters such as liner temperature, pattern factor, ignition fuel/air ratio, lean blowout fuel/air ratio, and exhaust emissions were correlated to fuel properties.

- This program did have a problem with fuel-to-fuel contamination. As a result, two fuel data files were created: one file for high pressure tests, the other for low pressure tests. High pressure combustor data such as performance, exhaust emissions and durability were correlated with fuel information identified as high-pressure fuel data. Altitude relight and stability measurements were correlated with low-pressure fuel data.
- Hydrogen content, total aromatic content, and multi-ring aromatic content were found to strongly affect CO and smoke emissions, combustion efficiency, and liner wall temperatures at high power operation.
- None of the fuel property characteristics produced any measurable effect on combustor exit temperature distribution (pattern factor or radial profile), idle performance or emissions, or hot section hardware life.
- Maximum achievable ignition altitude was most strongly influenced by total aromatic content and hydrogen content. Once ignition was achieved, combustor stability was controlled by 10 percent boiling point, viscosity, vapor pressure, and surface tension.

11. REFERENCE

Vogel, R.E., D.L. Troth, and A.J. Verdouw. Fuel Character Effects on Current, High Pressure Tatio, Can-Type Turbine Combustion Systems. AFAPL-TR-79-2072, ESL-TR-79-29, U.S. Air Force, Wright-Patterson AFB, Ohio, 1980. 148 pp.

TEST 24

LOW NO_x HEAVY FUEL COMBUSTORS CONCEPT

1. FUELS TESTED

Synfuel: middle distillate SRC-II fuel.

Reference fuels: low quality petroleum residual, and petroleum reference distillate fuel (see Table A-32).

TABLE A-32. FUEL PROPERTIES

	Petroleum Distillate (ERBS)*	Petroleum Residual (RESID)	Synthetic-CDL (SRC-II)
Hydrogen, wt %	12.88	11.24	8.81
Carbon, wt %	87.05	87.39	85.84
Nitrogen (FBN) wt%	0.013	0.27	0.88
10%. Dist. °F (K)	375 (464)	572 (573)	410 (483)
End point °F (K)	645 (614)	1026 plus (825)	597 (587)
Pour point, °F (K)	-35 (236)	40 (278)	-50 (228)

*Experimental Referee Broad Specification

2. TEST EQUIPMENT

Air-staged combustor with rich burning zone followed by quench zone and a lean reaction and dilution zone; sized for use with Detroit Diesel Allison Model 570-K industrial gas turbine.

3. TEST SITE

Detroit Diesel Allison high pressure test facility, Indianapolis, Indiana.

4. TEST OBJECTIVES

- Assess the capability of Model 570-K turbine to function in an environmentally acceptable fashion on the three fuels described above.
- Emission and performance goals are shown in Table A-33.

TABLE A-33. EMISSIONS AND PERFORMANCE GOALS AND TEST RESULTS*

Emissions and Performance Parameters	Test Fuels		
	ERBS	Residual	SRC-II
FBN content, wt %	0.013	0.27	0.88
Maximum EPA NO_x, ppm at 15% O_2	180	230	230
Program NO_x goal, ppm at 15% O_2	90	230	230
Minimum NO_x measured, ppm at 15% O_2	49	53	50
Program smoke goal, SAE smoke number	20	20	20
Measured smoke, SAE smoke number	5	3	3
Program combustion efficiency goal, %	99	99	99
Demonstrated combustion efficiency, %	99.9	99.9	99.9
Rich-zone equivalence ratio at minimum measured NO_x	1.25	1.40	1.35
Measured CO, ppm at 15% O_2	22	25	25
Measured unburned hydrocarbons, ppm at 15% O_2	24	7	6
Rich-zone maximum metal temperature, °K (°F)	1,015 (1,366)	1,170 (1,644)	1,110 (1,541)

*Operating conditions: Rich/quench/lean (RQL) combustor
6% pressure drop
0.60 lean-zone equivalence ratio
Maximum continuous power conditions

5. SPONSORING AGENCIES

U.S. Department of Energy
Office of Coal Utilization
Heat Engine and Heat Recovery Division

Project Officer: Warren Bunker
Telephone No: 301-353-2816

NASA-Lewis Research Center (Technical Program Management)
Cleveland, Ohio 44135

Project Officer: J. Notardonato
Telephone No: 216-433-4300, Ext. 6132

6. CONTRACTOR

Detroit Diesel Allison
Indianapolis, Indiana

Project Manager: A.S. Novick
Telephone No: 317-242-5428

7. TEST CONDITIONS

Combustor inlet temperature: 300°F and 575°F

Lean zone equivalence ratios: 0.45 to 0.50, and 0.55 to 0.60

Total mass flow: rated airflow and 125% rated airflow

Combustor was operated at maximum continuous power, as well as idle power and 50% and 70% load power.

8. ENVIRONMENTAL MONITORING

Carbon monoxide, unburned hydrocarbons, nitrogen oxides, carbon dioxide, smoke.

9. PROJECT STATUS

Project was begun in 1980 and completed in October 1981.

10. RESULTS (See Table A-33)

- The combustor was able to achieve low NO_x with significantly different fuels and levels of fuel-bound nitrogen at 50% and 70% load power and maximum continuous power.
- High NO_x levels (approximately 260 ppm at 15% O_2) were obtained with SRC-II fuel at idle power due to burn-through in the combustor dome, which shifted the rich zone equivalent ratio below stoichiometric or to full lean conditions.

- Unburned hydrocarbons measured at all power levels were all below 25 ppm.
- Both CO and smoke varied directly with rich zone equivalence ratio and inversely with lean zone equivalence ratio. Higher inlet temperatures reduced CO and smoke emissions. Smoke levels were usually below 10 smoke number.

11. MISCELLANEOUS

Project is part of a multiple contract effort sponsored by DOE to develop low NO_x combustor technology. Other participating contractors are: Westinghouse, General Electric, United Technologies Corporation, and Solar Turbine International.

12. REFERENCE

Novick, A.S. and D.L. Troth. "Low NO_x Heavy Fuel Combustor Concept Program". Detroit Diesel Allison Division of General Motors. DOE-NASA-014B-1, NASA CR-165367, October 1981.

TEST 25

LOW NO_x HEAVY FUEL COMBUSTOR CONCEPT

1. FUELS TESTED

Synfuel: SRC-II fuel oil.

Reference fuels: low quality petroleum residual and petroleum reference distillate fuel.

2. TEST EQUIPMENT

The combustion configurations and their variations evaluated in this study are described below.

A. Rich Burn - Lean Burn Concept

The baseline configuration is the rich-lean (rich burn-quick quench) staged combustion system. This concept consists of a metered primary zone airflow tube which provides the capability of varying the burner front end equivalence ratio within a pre-mix pre-vaporized fuel preparation system or an airblast fuel nozzle centered in a 45-degree recessed air swirler fuel preparation device, a rich burning combustion zone where fuel and air are burned at equivalence ratios greater than 1.3, and a quench zone where secondary air is introduced and mixed for further oxidation in a lean combustion zone.

Variations to the rapid quench section were made by replacing the baseline hardware (3-in. diam.) with 2-inch or 4-inch diameter sections. A third variation addressed the feasibility of using uncooled non-metallic materials for the rich zone combustor. The material chosen for this section was a cylinder of carbon compound. Another variation to the baseline concept was the use of externally controlled plungers to vary the pressure drop in the rapid quench zone of the baseline combustor.

B. Graduated Air Addition Configuration

This configuration contains two rich zones of combustion (primary equivalence ratios of greater than 2.0 and about 1.6) followed by the lean burn zone.

C. Rich Product Recirculation

This configuration utilizes a large diameter mixing chamber as the rich combustion zone. Secondary air is then added by one of two methods. The first utilizes the rapid quench zone of the base rich burn-lean configuration. The second method uses a quenching tube where air is introduced into the center of the large mixing chamber through a necked down region at the chamber exit through a 60° swirler.

D. Pre-burner Fuel Preparation

The pre-burner configuration consists of a small chamber with an air boost fuel nozzle upstream of the primary zone in which a small amount of fuel is burned to supply heat to vaporize the remaining fuel injected in a necked down region of the pre-burner exit. The vaporized fuel then travels into an aerodynamic swirler where vigorous mixing takes place. Operation downstream of this section is the same as in the baseline rich burn-lean burn configuration.

E. Rich-Lean Annihilation Combustor

This configuration consists of an air boost nozzle for fuel atomization in the front end of the combustor, a rich burn module, a lean burn module, an annihilation module, a rapid quench module, and a lean burn module.

3. TEST SITE

Pratt and Whitney Aircraft, West Palm Beach, Florida.

4. TEST OBJECTIVE

- Computer evaluation of several combustor concepts for achieving low NO_X emissions with high-nitrogen fuels (including SRC-II) in utility gas turbine engines application without the use of water injection.

5. SPONSORING AGENCIES

U.S. Department of Energy
Office of Coal Utilization
Heat Engine and Heat Recovery Division

Project Officer: Warren Bunker
Telephone No: 301 - 353-2816

NASA-Lewis Research Center (Technical Program Management)
Cleveland, Ohio 44135

Project Officer: D. Schultz
Telephone No: 216 - 433-4000

6. CONTRACTOR

Power Systems Division
United Technologies Corporation at
Pratt and Whitney Aircraft
Government Products Division
West Palm Beach, Florida

Project Manager: G. W. Beal
Telephone No: 305 - 840-2000

7. TEST CONDITIONS

Conditions of the tests run are shown in Table A-34.

8. ENVIRONMENTAL MONITORING

NO_x, CO, and smoke.

9. PROJECT STATUS

Modeling of individual configurations has been completed and performance characteristics with respect to combustor flow fields and emission characteristics predicted. Preliminary test results for some configurations are available and are described in Table A-34. These only include tests with the baseline configuration and variations to the fuel preparation, primary rich zone length and quench zone diameter.

10. RESULTS

The results of tests completed as of this paper's publication date are shown in Table A-34. As predicted, the values of NO_x were reduced for the smaller diameter quench zone and increased for the larger diameter quench zone. The results indicate the rich burn-lean burn staged combustion system can meet the emissions goals of the EPA standard.

11. MISCELLANEOUS

Project is part of a multiple contract effort sponsored by DOE to develop

TABLE A-34. TEST SUMMARY

Configuration Description	Fuel	Min. NO_X/Rich Equiv. Ratio	Approximate Run Hours	Comments
1. • Rich-Lean Burn (Rich Burn Quick Quench)				
• 18-in. (45.7 cm) Rich Zone Length	ERBS	35/1.4	5	Burned hole in rich zone at high pressure.
• Premix Tube				
1A. • Rich-Lean Burn				
• 18-in. (45.7 cm) Rich Zone Length	SRC-II	35/1.8 25/1.9	7.5	Burned hole in rich zone.
• Recessed Air Swirler				
1B. • Rich-Lean Burn				
• 18-in. (45.7 cm) Rich Zone Length	ERBS	20/1.7	1	Burned hole in rich zone.
• Recessed Air Swirler				
• Copper Cooling Coil				
1C. • Rich-Lean Burn				
• 18-in (45.7 cm) Rich Zone Length	ERBS	25/1.6	8	S.A.E. Smoke numbers 5.0 to 8. Overheated Rich Zone
• Recessed Air Swirler	SRC-II	44/1.6		
• Thicker Liner Material	Resid.	78/1.7		
2A. • Rich-Lean Burn				
• 12-in. (30.5 cm) Rich Zone Length	SRC-11	52/1.6 74/1.6 50/1.7	13	S.A.E. Smoke numbers 2.0 3.0 on No. 2 & SRC-II. Overheated rich zone.
• Recessed Air Swirler				

(Continued)

TABLE A-34. (Continued)

Configuration Description	Fuel	Min. NO_X/Rich Equiv. Ratio	Approximate Run Hours	Comments
2B. • Rich-Lean Burn				
• 12-in. (30.5 cm) Rich Zone Length	ERBS	42/1.5	4	Burned hole in rich zone at high pressure due to loss of coolant flow.
• Recessed Air Swirler				
• Improved Liner Cooling				
2C. • Rich-Lean Burn	ERBS	58/1.8		
• 12-in (30.5 cm) Rich Zone Length	Resid. (0.3% FBN)	95/2.0	10	No cooling problems.
• Recessed Air Swirler	Resid. (0.4% FBN)	90/1.8		
• Improved Liner Cooling	Resid. (0.5% FBN)	100/1.9		
3A. • Rich-Lean Burn				
• 18-in. (45.7 cm) Rich Zone Length	Resid. (0.3% FBN)	58/1.6		
• Recessed Air Swirler	Resid. (0.4% FBN)	70/1.6	15	No cooling problems.
• Improved Liner Cooling	Resid. (0.5% FBN)	85/1.6		
• Small Dia. Quench Zone				
4A. • Rich-Lean Burn				
• 18-in. (45.7 cm) Rich Zone Length	Resid. (0.3% FBN)	57/1.6		No cooling problems.
• Recessed Air Swirler	Resid. (0.4% FBN)	49/1.6	15	Heavy coking at entrance of rich zone.

(Continued)

TABLE A-34. (Continued)

Configuration Description	Fuel	Min. NO_x/Rich Equiv. Ratio	Approximate Run Hours	Comments
• Improved Liner Cooling	Resid. (0.5% FBN)	58/1.6		
• Large Dia. Quench Zone				
8A. • Rich-Lean Burn	ERBS	184/1.54		
• 18-in (45.7 cm) Primary	Resid. (0.3% FBN)	250/1.60		No cooling problems. Variable area stuck at low temps.
• Recessed Air Swirler	Resid. (0.4% FBN)	73/1.59	12	
• Improved Liner Cooling	Resid. (0.5% FBN)	108/1.56		
• Variable Quench Zone	SRC-II	78/1.60		Fuel Nozzle Tip Bent.
5A. • Rich-Lean Burn				
• 18 Inch (45.7 cm) Primary	ERBS	36/1.55 30/2.09		Smoke Number 13.8 @ ϕ_{pri} = 2.0
• Recessed Air Swirler	ERBS	26/1.57	13 (2 Hr. High Pressure)	No Cooling Problems (600°F Inlet) (315°C).
• Non-Metallic Liner	ERBS	39/1.65		180 PSIA (1290 kPa).
	50/50 ERBS/Resid.	50/1.60		Smoke Number 21.9 A ϕ_{pri} = 2.0
	Resid. (.3% FBN)	77/1.66		Non-Metallic Liner Ablated. Started in Cone Exit ~6 Hrs. into Testing After Blow Out Instability at 300°F (150°C) Inlet Condition with Residual Fuel.
	Resid. (.5% FBN)	80/1.54		

low NO_x combustor technology. Other participating contractors are: Westinghouse, Detroit Diesel Allison Division of General Motors, General Electric Company, and Solar Turbine International.

12. REFERENCE

Russell, P.L., G.W. Beal, R.A. Sederquist, and D. Schultz. "Evaluation of Concepts for Controlling Exhaust Emissions from Minimally Processed Petroleum and Synthetic Fuels", ASME Paper No. 81-GT-157. Paper presented at the Gas Turbine Conference and Products Show, March 9-12, 1981, Houston, Texas.

TEST 26

LOW NO_x HEAVY FUEL COMBUSTOR CONCEPT

1. FUELS TESTED

Synfuel: middle distillate SRC-II fuel oil.

Reference fuels: low quality petroleum residual, and petroleum reference distillate fuel (see Table A-35).

TABLE A-35. FUEL PROPERTIES

	ERBS*	SRC II	Residual
Spec. grav. @ 289/289 K	0.8377	0.9796	0.9440
Hydrogen content, percent	12.95	9.07	11.52
Sulfur content, percent	0.085	0.20	0.49
Net heat of combustion, MJ/kg	42.5	38.1	41.3
Viscosity, m^2/s @ 311 K	1.36×10^{-6}	3.55×10^{-6}	1.345×10^{-3}
Nitrogen content, percent	0.0054	0.87	0.23
Surface tension, N/M	---	---	3.29×10^{-2} @ 339 K
Surface tension, N/M	---	---	3.06×10^{-2} @ 366 K
Pour point, K	244	255	294
Vanadium, ppm by wt	---	---	26

*Experimental Referee Broad Specification (ERBS) petroleum distillate fuel.

2. TEST EQUIPMENT

Seven 20-cm diameter experimental combustors of varying designs (see Table A-36).

TABLE A-36. DESCRIPTION OF TEST COMBUSTORS

Combustor #	Type	Characteristics
1	Rich-Lean Combustor with Premixing	3-part combustor consisting of single-fuel nozzle and swirl cup in a premixing tube ahead of the rich stage to provide uniform mixing of fuel and air and avoid smoke production, a necked-down quench zone where secondary air is introduced, and a lean stage.
2	Rich-Lean Combustor with Multiple Nozzle	Consists of eight fuel nozzles and swirl cups in the head of a rich stage, followed by a quench zone and lean stage. Differs from Combustor 1 in multiple nozzle head end.
3	Rich-Lean Combustor	Same as Combustor 2 except for differences in design of the mixing passages between rich and lean stages, where secondary and dilution air are introduced and mixed with the products of combustion of the rich stage in minimum time to generate minimum additional NO_x.
4	Series-Staged Lean-Lean Combustor	Consists of pilot stage with single-air atomizing fuel injector and two-stage counter-rotating swirl cups, and main stage which employs eight single-stage swirlers and air atomizing fuel injectors. Design minimizes long gas residence times associated with recirculating zones that generate thermal NO_x.
5	Series-Staged Lean-Lean Combustor with Premixed Main Stage	Consists of pilot stage having six dual counter-rotating swirlers arranged in an annulus around a main stage premixing duct. Main stage fuel is introduced into the forward end of the duct and mixed with air prior to entering the combustion zone through twelve axial slots at the aft of the premixing duct.
6	Parallel-Staged Lean Combustor, Combustor 6	Has low velocity pilot stage with a single swirl cup and air atomizing fuel injector at the dome end. Main stage has annular high-velocity dome with six swirl cups and fuel injector in a concentric arrangement around the discharge end of the pilot stage.
7	Lean Burning Catalytic Combustor, Combustor 7	Designed to demonstrate ultra-low thermal NO_x performance. Includes a fuel preparation section preceding the catalytic reactor main stage containing seven fuel nozzles. Main stage catalytic reactor consists of an MCB-12 Zironia-spinel substrate coated with a proprietary VOP noble metal catalyst. Reactor is followed by a downstream pilot stage section for ignition, acceleration and part-load operation to 50 percent load, at which point lightoff occurs for further load increase to full power.

3. TEST SITE

General Electric test facilities, Evendale, Ohio.

4. TEST OBJECTIVES

- Evaluation of several combustor concepts for achieving low NO_x emissions with high-nitrogen fuels (including SRC-II fuels) in utility gas turbine engines application without the use of water injection.
- Emissions and performance goals presented in Table A-37.

TABLE A-37. EMISSIONS AND PERFORMANCE GOALS

Pollutant	Maximum Level	Operating Condition
(a) Emissions Goals		
Oxides of nitrogen	75 ppm at 15% 0	All
Sulfur dioxide	150 ppm at 15% 0	All
Smoke	S.A.E. no. = 20	All
(b) Performance Goals		
Combustion efficiency	>	99% at all operating conditions
Total pressure loss	<	6% at base power load
Outlet temperature pattern factor	=	0.25 at base load and load power
Combustor exit radial temperature profile	=	Equivalent to production comb. values

5. SPONSORING AGENCIES

U.S. Department of Energy
Office of Coal Utilization
Heat Engine and Heat Recovery Division

Project Officer: Warren Bunker
Telephone No: 301 - 353-2816

NASA-Lewis Research Center (Technical Program Management)
Cleveland, Ohio 44135

Project Officer: J. Notardonato
Telephone No: 216 -433-4000, Ext. 6132

6. CONTRACTOR

General Electric Company
Evendale, OH 45215

Project Manager: M. B. Cutrone
Telephone No: 513 - 243-2000, Ext. 3651

7. TEST CONDITIONS

Engine conditions (ignition to peak load): fuel-air ratios (0.0054 to 0.025), combustor inlet pressures (ambient to 1.166 mPa), combustor inlet temperature (ambient to 609°K), and reference velocity (11.3 to 43.6 m/sec).

8. ENVIRONMENTAL MONITORING

Carbon monoxide, nitrogen oxides, and unburned hydrocarbon (UHC) emissions.

9. PROJECT STATUS

Program begun in May 1979. To date, results available for testing performed on combustors 1, 2, 4, and 6 (see Table A-38); additional testing on combustors 1 and 2, as well as on combustors 3 and 5 recently completed; results will be published in August 1981. Combustor 7 currently being fabricated and tests planned for summer 1981. Program to be completed by November 1981.

10. RESULTS

Combustor 1 (only ERBS fuel tested)

- The high NO_x emissions (20.0 to 24.0 g/kg NO_x fuel) experienced due to nozzle misalignment; significant NO_x reduction experienced after nozzle correction and increased rich stage equivalence ratio (12.0 g/kg NO_x fuel).
- Smoke emissions exceptionally low (approximately 0-5 SAE smoke number).
- Combustible emissions (CO and UHC) were well within program goals (see Table A-37).

Combustor 2

- NO_x emissions with SRC-II and residual fuels higher than program goals (see Table A-37) (certain modifications reduced NO_x emissions considerably).

TABLE A-38. TEST MATRIX

Combustor No.*	ERBS	RESID	SRC II
4	X	X†	X
6	X†	X†	X
1	X†		
2	X†	X	X

*See Table A-36 for description of combustors.

†Fuel doped with pyridine to increase fuel-bound nitrogen.

- Excellent smoke performance with SRC-II fuel (SAE smoke number was 18 at an air/fuel ratio of 0.029).
- Combustible emissions (CO, UHC) within program goals (see Table A-37) for SRC-II and residual fuels; CO emissions were approximately 20 ppm at baseload conditions.

Combustor 4

- NO_x emissions approximately 10 percent above program goals (see Table A-37) at 4-1/2 percent pressure drop with the ERBS and residual fuels.
- With SRC-II fuel, NO_x emissions were well above program goals.
- Smoke levels well below goals (see Table A-37) at base and peak level conditions with all three types of fuel.

Combustor 6

- NO_x levels approximated program goals (see Table A-37) at base load conditions with ERBS fuel and residual fuel, but were 37 percent above the goal with SRC-II fuel.
- Low smoke levels observed for all fuels tested ($\sim$20 SAE smoke number).

11. MISCELLANEOUS

Project is part of a multiple contract effort sponsored by DOE to develop low NO_x combustor technology. Other participating contractors are: Westinghouse, Detroit Diesel Allison Division of General Motors, United Technologies Corporation, and Solar Turbine International.

12. REFERENCES

Cutrone, M.G., M.B. Hilt, et al. "Evaluation of Advanced Combustors for Dry NO_x Suppression with Nitrogen Bearing Fuels in Utility and Industrial Gas Turbines", ASME Paper No. 81-GT-125. Presented at 26th International Gas Turbine Conference, Houston, Texas, March 9-12, 1981. 10 pp.

Telephone communication to J. Fairbanks, U.S. DOE, Washington, D.C., with S. Quinlivan, TRW, March 24, 1981.

Telephone communication to J. Notardonato, NASA Lewis Research Center, with S. Quinlivan, TRW, May 20, 1981.

TEST 27

LOW NO_x HEAVY FUEL COMBUSTOR CONCEPT

1. FUELS TESTED

Synfuel: middle distillate SRC-II fuel.

Reference fuels: low quality petroleum residual and petroleum reference distillate fuel (ERBS)* and natural gas.

2. TEST EQUIPMENT

Two basic combustor approaches were tested including a staged combustor with a rich primary zone and a lean secondary zone, and a lean-lean combustion system. Three variations of the rich-lean combustor configuration were tested including a longer primary zone (Configuration 1), a shorter primary zone (Configuration 2), and a convectively cooled primary zone (Configuration 3). Only one configuration of the lean-lean combustor system was tested.

3. TEST SITE

Solar Turbine International, San Diego, California.

4. TEST OBJECTIVES

- Evaluation of several combustor concepts for achieving low NO_x emissions with high-nitrogen fuels (including SRC-II) in utility gas turbine engines application without the use of water injection.
- Emission goals and performance standards for this work are shown below in Table A-39.

5. SPONSORING AGENCIES

U.S. Department of Energy
Office of Coal Utilization
Heat Engine and Heat Recovery Division

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*Experimental Referee Broad Specification.

TABLE A-39. COMBUSTOR EMISSION GOALS AND PERFORMANCE STANDARDS

Goal/Standard	Level
NO_x	75 ppm corrected to 15 percent O_2 for FBN levels up to 1 percent (wt).
NO_x	37 ppm corrected to 15 percent O_2 for ERBS* fuel.
Combustion efficiency	>99 percent.
Pressure drop	<6 percent.
Pattern factor	0.25.

*Experimental Referee Broad Specification.

Project Officer: Warren Bunker
Telephone No: 301 - 353-2816

NASA-Lewis Research Center (Technical Program Management)
Cleveland, Ohio 44135

Project Officer: H.G. Yacobucci
Telephone No: 216 - 433-4000

6. CONTRACTOR

Solar Turbine International
San Diego, California

Telephone No: 714 - 238-5500

7. TEST CONDITIONS

<u>Lean-Lean</u>

ERBS Fuel:

Inlet Air Temperature	260 & 371°C (500 & 700°F)
Inlet Air Pressure	586, 793 & 1200 kPa (85, 115 & 161 psia)

SRC-II Fuel:

Inlet Air Temperature	260 & 371°F (500 & 700°F)
Inlet Air Pressure	308, 584 & 908 kPa (45, 85 & 132 psia)

<u>Rich-Lean</u>

Configuration 1 with Natural Gas:

Inlet Air Temperature	149, 177 & 204°C (300, 350 & 400°F)
Inlet Air Pressure	310 kPa (45 psia)

Configuration 2 with ERBS Fuel:

Inlet Air Temperature	143 & 260°C (290 & 500°F)
Inlet Air Pressure	310 & 379 kPa (45 & 55 psia)

Configuration 3 with ERBS & SRC-II Fuel

Inlet Air Temperature	143 & 260°C (290 & 500°F)
Inlet Air Pressure	586 to 910 kPa (85 to 132 psia)

8. ENVIRONMENTAL MONITORING

NO_x, CO, unburned hydrocarbons, and smoke.

9. PROJECT STATUS

The described combustor concepts were tested and recommendations for further testing were made. **Report presented in March 1981.**

10. RESULTS

Lean-Lean

ERBS Fuel:

- The high thermal NO_x is attributed to pre-mixing of the fuel and air. Higher inlet temperatures increased the NO_x emissions for a given equivalence ratio, as did higher inlet pressure.
- The CO emission levels were consistently low at all conditions evaluated.
- Unburned hydrocarbons were negligible and no smoke was detectable throughout these tests.

SRC-II Fuel:

- For rich primary zone conditions, NO_x emission levels were higher than the emission goals. Increasing inlet pressure resulted in a decrease in NO_x emissions.
- CO emissions remained low using the SRC-II middle distillate fuel.
- No smoke was detectable and unburned hydrocarbons were negligible throughout these tests.

Rich-Lean Combustor

Configuration 1 with Natural Gas:

- NO_x emissions were below 60 ppm and tended to decrease with decreasing inlet temperature.
- Low CO and negligible unburned hydrocarbon emissions were observed at all conditions evaluated.

Configuration 2 with ERBS Fuel:

- For rich primary zone conditions, NO_x emissions dropped below 75 ppm (corrected to 15 percent O_2) and increased sharply as stoichiometric primary zone conditions were approached.

- Low CO emissions were observed at all conditions evaluated.

Configuration 3 with ERBS Fuel:

- At each of four temperature and pressure conditions, the NO_x emissions appear to reach a minimum below the most stringent program goal, for rich primary zone conditions.
- CO emissions levels were consistently low.
- No smoke was detectable and unburned hydrocarbon emissions remained negligible throughout the tests.

Configuration 3 with SRC-II Fuel:

- At each of four inlet conditions evaluated, the NO_x emissions appear to reach a minimum below the lower (large engine) NO_x emission limit, for rich primary zone conditions.
- The CO emissions level was consistently low.
- No smoke was detectable and unburned hydrocarbon emissions remained negligible throughout these tests.

11. MISCELLANEOUS

Project is part of a multiple contract effort sponsored by DOE to develop low NO_x combustor technology. Other participating contractors are: Westinghouse, Detroit Diesel Allison Division of General Motors, United Technologies Corporation, and General Electric Company.

12. REFERENCE

White, D.J., A. Batakis, R.T. LeCren, and H.G. Yacobucci. "Low NO_x Combustion Systems for Burning Heavy Residual Fuels and High-Fuel-Bound Nitrogen Fuels", ASME Paper No. 81-GT-109. Presented at the Gas Turbine Conference and Products Show, March 9-12, 1981, Houston, Texas.

TEST 28

LOW NO_x HEAVY FUEL COMBUSTOR CONCEPT

. FUELS TESTED

Synfuel: middle distillate SRC-II fuel.

Reference fuels: low quality petroleum residual, and petroleum reference distillate fuel (see Table A-40), and various blends of these fuels.

TABLE A-40. FUEL PROPERTIES

	ERBS*	Petroleum Residual	SRC-II Middle Distillate
Gravity, °API (15.6°C)	38.2	---	13.3
Specific Gravity	.8338 @ 15.6°C	.9533 (@ 22°C)	.9772
Hydrogen, wt %	12.55	11.43	9.19
Nitrogen, wt %	.008	.22	.79-.8
Sulfur, wt %	.09	.48	.25
Ash, wt %	<.0002	.03	.0015
Pour Point, °C (°F)	-45.6(-50)	23.9(+75)	-59.4(-75)
Viscosity, cst @ 37.8°C(100°F)	1.87	>835 (furol sec)	4.03
Distillation Temp. °C (°F)			
IBP	126 (259)	180 (356)	110 (230)
10%	180 (356)	250 (482)	190 (374)
50%	224 (435)	358 (676)	242 (486)
90%	330 (620)	445 (833)	295 (563)
FBP	408 (766)	490 (914)	370 (698)
Net Heat of Combustion Btu/lb	18,343	17,609	16,674

*Experimental Referee Broad Specification (ERBS) petroleum distillate fuel

2. TEST EQUIPMENT

Several different combustion configurations were built for this test (Table A-41). The combustion configurations selected for development and design involved staged combustion (rich-lean) utilizing diffusion flames and stated catalytic combustion. Detailed descriptions and illustrations of each combustor are presented in the referenced report.

3. TEST SITE

Westinghouse Electric, Madison, PA.

4. TEST OBJECTIVES

- Evaluation of several combustor concepts for achieving low NO_x emissions with high-nitrogen fuels (including SRC-II) in utility gas turbine engines application without the use of water injection.
- Emissions and performance goals presented in Table A-42.

5. SPONSORING AGENCIES

U.S. Department of Energy
Office of Coal Utilization
Heat Engine and Heat Recovery Division

Project Officer: Warren Bunker
Telephone No: 301-353-2816

NASA-Lewis Research Center (Technical Program Management)
Cleveland, Ohio 44135

Project Officer: J. Notardonato
Telephone No: 216-433-4300, Ext. 6132

6. CONTRACTOR

Westinghouse Electric Co.
Synthetic Fuels Division
P. O. Box 158, Waltz Mill Site
Madison, PA 15665

Telephone No: 412-722-5716

7. TEST CONDITIONS

The reported test conditions for the configurations tested are shown in Table A-43.

TABLE A-41. COMBUSTOR CONFIGURATION DESIGNED AND BUILT FOR TESTING

Direct Injection - Rich-Lean

1. Direct Injection, Venturi Quench

2. Direct Injection, Vortex Quench

3. Direct Injection, Vortex Quench, Perforated Plate

4. Direct Injection, Vortex Quench, Catalyst

9. Multiannular Swirl Burner

11. Rolls-Royce Combustor

Premix Rich-Lean

5. Recirculating Counter Swirl, Venturi Quench

10. Perforated Plate, Venturi Quench

Rich Primary Catalytic - Lean Staged Combustion

7. Catalyst A, Venturi Quench

8. Catalyst B, Venturi Quench

Rich Hybrid Premix/Direct Injection

6. Hybrid Piloted Rich Burner, Venturi Quench

Lean Catalytic

12. Catalytic

Lean Hybrid Premix/Direct Injection

13. Hybrid Piloted Lean Burner

TABLE A-42. LOW NO_x HEAVY FUELS COMBUSTOR CONCEPT PROGRAM SUMMARY OF GOALS AND OBJECTIVES

A. Emissions Limits (All Operating Conditions)

1. Oxides of Nitrogen	-	75 ppm @ 15% O_2
2. Sulfur Dioxide	-	105 ppm @ 15% O_2
3. Smoke	-	S.A.E. No. = 20

B. Performance Specifications

1. Combustion Efficiency	>99%(@ all operating conditions)
2. Total Pressure Loss	<6% (@ base load power)
3. Outlet Temperature Pattern Factor	<0.25 (@ base load and load power)
4. Combustor Exit Temperature Profits	-Equivalent to typical production engine combustor values

C. General

1. Retrofitable to current production and field engines
2. Highly durable
3. Maintainable
4. Fuel Flexible - Capable of meeting emissions and performance specification on liquid fuels including petroleum distillates and residuals and synfuels from coal and shale

TABLE A-43. TEST CONDITIONS FOR BURNER CONFIGURATIONS TESTED

Direct Injection - Rich-Lean

Venturi Jet Quench/Lean Burner

Burner outlet pressure:	165 psia	(1.14 MPa)
Burner inlet temperatures:	600°F	(316°C)
Burner outlet temperatures:	1950°F	(1066°C)
Total air flow:	4.1 lb/sec	(1.86 kg/sec.)

Vortex Mixer/Lean Burner

Quench module with vortex mixer was tested under similar conditions to those described above.

Vortex Mixer/Catalytic Lean Burner (typical expected operating conditions at full pressure)

Catalyst inlet temperature:	1480°F	(804°C)
Catalyst outlet temperature:	2100°F	(1140°C)

Lean Catalytic Burner

Combustor inlet pressure:	180 psia	(1.24 MPa)
Air inlet temperature:	720°F	(382°C)

Rolls Royce Combustor (peak conditions)

Combustor inlet pressure:	163 psia	(1.13 MPa)
Air flow:	7.6 lb/sec.	(3.45 kg/sec)

Multiannular Swirl Burner

Combustor inlet pressure:	11.2 atmos	(1.19 MPa)
Combustor inlet temperature:	638°F	(338°C)
Air flow:	5.2 lb/sec.	(2.36 kg/sec.)

8. ENVIRONMENTAL MONITORING

Carbon monoxide, nitrogen oxides, unburned hydrocarbons, and smoke.

9. PROJECT STATUS

The combustion configurations which have been designed and built are shown in Table A-41. Combustion emission sampling results available so far are for configurations 1, 2, 4, 9, 11, and 12 using unblended fuels. The study results were presented in March 1981.

10. RESULTS

Direct Injection - Rich-Lean

Ventori Jet Quench/Lean Burner:

- Minimum NO_x values of 68-70 ppmv were obtained for the ERBS fuel.
- Minimum NO_x values of about 140 ppmv were obtained with SRC-II fuel.
- Smoke measurements for this configuration for the ERBS fuel show SAE smoke numbers of 20 and 26 for the primary equivalence ratio (1.6 which resulted in minimum NO_x emissions).
- Smoke numbers were higher for SRC-II fuel oil (29 at a primary equivalence ratio of 1.62).

Vortex Mixer/Lean Burner:

- NO_x emissions of approximately 195 ppmv were obtained with the SRC-II fuel.
- NO_x emissions of approximately 120 ppmv were obtained with the ERBS fuel.

Vortex/Mixer/Catalytic Lean Burner:

- NO_x emission buds were about the same as described above for the vortex mixer without the catalytic element for both fuels and did not appreciably change over the range of equivalence ratios considered.
- FBN* conversion in the SRC-II fuel was about 23 percent.

Lean Catalytic Burner

- NO_x emission for the ERBS fuel was 2 ppm.
- Approximate NO_x emissions and FBN conversions for the ERBS fuel with pyridine added are shown below:

*FBN - fuel bound nitrogen.

FBN, Wt %	NO_x, ppmv*	% Conversion of FBN
0.2	60	60
0.5	100	47
1.2	200	40

*Corrected to 15 percent oxygen.

- NO_x emissions from SRC-II fuel were 190 and 200 ppmv.
- Conversion efficiency of FBN from the SRC-II fuel in the lean catalytic combustor was about 50 percent.

Rolls-Royce Combustor

- Emissions for ERBS and SRC-II fuel at the peak design condition were as follows:

Emission Constituent	Emission Level-ERBS (ppm)	Emission Level-SRC-II (ppm)	Emission Level-Petroleum Residual (ppm)
NO_x	91	280	120
CO	8	16-37	
Unburned Hydrocarbon	2	2	
Smoke No.	5 & 11	7	

- Conversion rates of FBN were about 40 percent for SRC-II fuel and 30-40 percent for petroleum residual fuel.

Multiannolar Swirl Burner

- Preliminary results from this burner are shown below:

Fuel	Temperature, °F (°C)	NO_x (ppmv)	Remarks
ERBS	2035 (1113)	26	Central nozzle only
SRC-II	1948 (1064)	165	Central & radial nozzles
Petroleum Residual	1995 (1091)	127	Central & radial nozzles

- FBN conversion for SRC-II fuel was 20 percent, which is lower than that of a conventional burner.

11. REFERENCE

Lew, H.G., S.M. DeCorso, G. Vermes, D. Carl, W.J. Havener, J. Schwab, and J. Notardonato. "Low NO_x and Fuel Flexible Gas Turbine Combustors", ASME Paper No. 81-GT-99. Presented at the Gas Turbine Conference and Products Show, March 9-12, 1981, Houston, Texas.

TEST 29

SMALL SCALE COMBUSTION TESTING OF SYNTHETIC FUELS

1. FUELS TESTED (See Table A-44)

   Synfuel: SRC-II middle distillate, heavy distillate, and three blends of middle and heavy distillate fuel oils.

   Reference fuels: No. 2 and No. 6 fuel oils.

2. TEST EQUIPMENT

   A 20-hp, Johnston, three-pass, firetube boiler designed to transfer roughly 670,000 Btu/hr.

3. TEST SITE

   Combustion Technology Division, Pittsburgh Energy Technology Center, Pittsburgh, Pennsylvania.

4. TEST OBJECTIVE

   - To characterize exhaust emissions and boiler efficiencies from both synthetic fuels and petroleum-based fuels burned under identical combustion conditions, in order to assess any change in the environmental impact of industrial or utility boiler exhaust gases upon changing from petroleum-based fuels to synthetic fuels.

5. SPONSORING AGENCY

   U.S. Department of Energy
   Pittsburgh Energy Technology Center
   Analytical Chemistry Division and
   Combustion Technology Division
   Pittsburgh, Pennsylvania

   Principal Investigator: G. A. Gibbons
   Telephone No: 412-675-5804

6. CONTRACTOR

   None.

TABLE A-44. FUEL ANALYSIS

Fuel, %	No. 2 Fuel† Oil	No. 6 Fuel Oil	SRC-II "Blends"* Middle Distillate (M)	Blend No. 1 (3M:1H)	Blend No. 2 (2M:1H)	Blend No. 3 (1M:2H)	Heavy Distillate (H)
Carbon	87.3	87.0	85.9	86.2	87.5	99.1	88.9
Hydrogen	12.5	11.0	9.0	8.9	8.5	7.9	7.3
Nitrogen	--	0.30	0.9	0.9	0.9	1.0	1.1
Sulfur	0.21	0.70	0.3	0.2	0.4	0.4	0.5
Ash	--	0.10	0.10	--	0.60	0.3	0.6
Oxygen (diff)	--	1.9	3.8	3.8	2.1	1.3	1.6
Heating Value (Btu/lb)	19,840	18,610	17,260	17,590	17,140	17,130	17,050

*Typical analysis of No. 2 fuel oil.

†Mixtures of middle and heavy distillate; blend No. 1 received already mixed.

7. TEST CONDITIONS

To date, eight runs have been made with No. 6 oil: five at about 23 percent excess air and three at about 11 percent excess air. Two runs have been completed on No. 2 oil: one at 11 percent excess air and one at 20 percent excess air. Five SRC-II fuels have been tested: a heavy distillate, a middle distillate, and three blends. The initial blend of SRC-II was approximately three parts middle distillate to one part heavy distillate. Six runs, three at each of two conditions, were made with this blend. Subsequently, separate supplies of middle and heavy distillate were obtained, and two blends were prepared: one of two parts middle to one part heavy distillate and the second of one part middle to two parts heavy distillate. Three tests were run on each blend. Single tests were run on the middle distillate and heavy distillate alone (see Table A-45).

8. ENVIRONMENTAL MONITORING

NO_x, SO_2, CO, HC, particulates, and polynuclear aromatic hydrocarbons (qualitative).

9. PROJECT STATUS

Tests with SRC-II fuel oils and baseline petroleum fuel oils were conducted from October 1979 through October 1980. The Progress Report is dated 1981. Additional tests are planned with other synfuels - H-coal, Exxon Donor Solvent fuel, shale oil, and biomass fuel. The program will run until October 1982.

10. RESULTS

The results of the test program are highlighted below and in Tables A-46 through A-49.

- In general, combustion performance was good in all the test runs. Total particulate loadings in the stack were small, and CO and total hydrocarbon levels were below 100 and 1 ppm, respectively.
- The levels of NO_x and SO_2 produced were proportional to the amount of nitrogen and sulfur in the fuel.
- There appear to be two sources of trace organics in the exhaust gases: small amounts of the fuel itself not burned during combustion, and the

TABLE A-45. TEST CONDITIONS FOR THE SYNFUELS TEST PROGRAM

Run No.	Fuel	Excess % O_2 *	Fuel Rate† (Gal/Hr.)	Steam Production/ Gal Fuel‡ (lbs. Steam/Gal.)
LSF-20	No. 6 Fuel Oil	3.9	5.6	---
LSF-21	No. 6 Fuel Oil	2.1	5.4	---
LSF-22	No. 6 Fuel Oil	4.1	5.4	---
LSF-23	No. 6 Fuel Oil	4.4	5.4	---
LSF-24	SRC-II, Blend 1	3.9	5.4	---
LSF-25	SRC-II, Blend 1	2.2	5.4	---
LSF-26	SRC-II, Blend 1	3.9	5.4	---
LSF-27	SRC-II, Blend 1	2.3	5.6	107.5
LSF-28	SRC-II, Blend i	4.5	5.2	117.6
LSF-29	SRC-II, Blend 1	1.9	5.6	---
LSF-30	No. 6 Fuel Oil	2.3	5.4	111.2
LSF-31	No. 6 Fuel Oil	4.0	5.4	103.7
LSF-32	No. 6 Fuel Oil	2.1	5.4	108.3
LSF-34	No. 6 Fuel Oil	4.1	5.4	110.5
LSF-35	No. 2 Fuel Oil	4.6	5.2	106.1
LSF-36	No. 2 Fuel Oil	2.2	5.1	106.7
LSF-37	SRC-II, Mid. Dist.	4.4	5.3	111.7
LSF-38	SRC-II, Blend 3	2.5	5.6	115.7
LSF-39	SRC-II, Blend 3	4.2	5.7	114.0
LSF-40	SRC-II, Blend 3	2.2	5.3	115.7
LSF-41	SRC-II, Blend 2	2.5	5.6	109.8
LSF-42	SRC-II, Blend 2	3.9	5.3	108.7
LSF-43	SRC-II, Blend 2	2.6	5.6	109.4
LSF-44	SRC-II, Heavy Dist.	2.9	5.5	114.7

*Percent oxygen was set as an experimental condition; two levels were selected: 2.0-2.5 percent O_2 and 4.0-4.5 percent O_2.

†Fuel rates were set at approximately 5.4 gal/hr and adjusted slightly to maintain the same Btu/hr input for the fuel.

‡Pounds of steam produced per gallon of fuel fired.

TABLE A-46. NO_x EMISSIONS AS A FUNCTION OF FUEL NITROGEN CONTENT

Fuel	Run %	% Excess Air	% N (Fuel)	NO_x (ppm)*
No. 2 Fuel Oil	LSF 35	26.0	0	193
No. 2 Fuel Oil	LSF 36	11.0	0	178
No. 6 Fuel Oil	LSF 20	21.0	0.3	329
No. 6 Fuel Oil	LSF 21	10.5	0.3	261
No. 6 Fuel Oil	LSF 22	23.0	0.3	364
No. 6 Fuel Oil	LSF 23	25.0	0.3	353
No. 6 Fuel Oil	LSF 30	11.5	0.3	292
No. 6 Fuel Oil	LSF 31	22.0	0.3	350
No. 6 Fuel Oil	LSF 32	10.5	0.3	312
No. 6 Fuel Oil	LSF 34	23.0	0.3	331
SRC-II, Blend #1	LSF 24	21.5	0.9	599
SRC-II, Blend #1	LSF 25	11.0	0.9	456
SRC-II, Blend #1	LSF 26	21.5	0.9	493
SRC-II, Blend #1	LSF 27	11.5	0.9	517
SRC-II, Blend #1	LSF 28	26.0	0.9	548
SRC-II, Blend #1	LSF 29	9.5	0.9	434
SRC-II, Blend #2	LSF 41	13.0	0.9	480
SRC-II, Blend #2	LSF 42	21.5	0.9	604
SRC-II, Blend #2	LSF 43	13.5	0.9	528
SRC-II, Mid. Dist.	LSF 37	25.0	0.9	590
SRC-II, Blend #3	LSF 38	13.0	1.0	557
SRC-II, Blend #3	LSF 39	24.0	1.0	576
SRC-II, Blend #3	LSF 40	11.0	1.0	549
SRC-II, Blend #5	LSF 44	15.0	1.1	622

*Adjusted to a dry, 0% Excess Air Basis.

TABLE A-47. SO_2 EMISSIONS AS A FUNCTION OF FUEL SULFUR CONTENT

Fuel	Run %	% Excess Air	% S (Fuel)	SO_2 (ppm)*
No. 2 Fuel Oil	LSF 35	26.0	0.20	272
No. 2 Fuel Oil	LSF 36	11.0	0.20	194
SRC-II, Blend #1	LSF 24	21.5	0.20	233
SRC-II, Blend #1	LSF 25	11.0	0.20	204
SRC-II, Blend #1	LSF 26	21.5	0.20	221
SRC-II, Blend #1	LSF 27	11.5	0.20	203
SRC-II, Blend #1	LSF 28	26.0	0.20	200
SRC-II, Blend #1	LSF 29	9.5	0.20	---
SRC-II, Mid. Dist.	LSF 37	25.0	0.30	213
SRC-II, Blend #2	LSF 41	13.0	0.40	301
SRC-II, Blend #2	LSF 42	21.5	0.40	312
SRC-II, Blend #2	LSF 43	13.5	0.40	310
SRC-II, Blend #3	LSF 38	13.0	0.40	372
SRC-II, Blend #3	LSF 39	24.0	0.40	381
SRC-II, Blend #3	LSF 40	11.0	0.40	376
SRC-II, Heavy Dist.	LSF 44	15.0	0.50	463
No. 6 Fuel Oil	LSF 20	21.0	0.70	---
No. 6 Fuel Oil	LSF 21	10.5	0.70	---
No. 6 Fuel Oil	LSF 22	23.0	0.70	369
No. 6 Fuel Oil	LSF 23	25.0	0.70	446
No. 6 Fuel Oil	LSF 30	11.5	0.70	434
No. 6 Fuel Oil	LSF 31	22.0	0.70	421
No. 6 Fuel Oil	LSF 32	10.5	0.70	448
No. 6 Fuel Oil	LSF 34	23.0	0.70	364

*Adjusted to a dry, 0% Excess Air Basis.

TABLE A-48. CALCULATED EFFICIENCIES FOR SELECTED TESTS

Run #	Fuel	% (Δ Enthalpy Balance)	Efficiency % (Heat Loss)	Efficiency % (Input-Output)
LSF-32	No. 6	+1.2	83.1	81.2
LSF-34	No. 6	+1.5	78.7	77.4
LSF-35	No. 2	-0.32	74.8	75.1
LSF-36	No. 2	+5.0	80.0	74.0
LSF-37	SRC-II, Middle Distillate	+5.35	83.8	78.5
LSF-41	SRC-II, Blend of 2 Parts Middle Distillate to 1 Part Heavy Distillate	+2.4	78.4	75.6
LSF-42		+5.6	80.7	74.6
LSF-43		+5.8	82.5	76.4

TABLE A-49. SUMMARY OF GC-MS DATA OBTAINED FROM A SYNFUEL AS WELL AS A PETROLEUM BURN

Compound	Detected in Combustion Emission	
	SRC-II	No. 2 Fuel Oil
Naphthalene	L	M
2-Methylnaphthalene	L	H
1-Methylnaphthalene	L	L
Biphenyl	L	L
2-Ethylnaphthalene	L	L
2,6- & 2,7-Dimethylnaphthalene	L	L
1,3- & 1,7-Dimethylnaphthalene	L	L
1,5-Dimethylnaphthalene	L	L
1,2-Dimethylnaphthalene	L	L
Acenaphthene	L	L
Dibenzofuran	L	L
Fluorene	M	L
9-Methylfluorene	M	ND
2-Methylfluorene	M	ND
1-Methylfluorene	M	ND
Dibenzothiophene	M	L
Phenanthrene	H	H
Anthracene	L	L
Carbazole	L	ND
1-Phenylnaphthalene	L	ND
3-Methylphenanthrene	M	ND
2-Methylphenanthrene	M	ND
9- & 4-Methylphenanthrene	M	ND
1-Methylphenanthrene	M	ND
2-Phenylnaphthalene	L	ND
Fluoranthene	M	L
Benzo(def)dibenzothiophene	L	ND
Pyrene	H	L
Retene	L	ND
Benzo(b)fluorene	M	ND
4-Methylpyrene	L	ND
2-Methylpyrene	L	ND
Benzo(a)anthracene	L	ND
Chrysene/Triphenylene	L	ND
n-Alkanes	L	H

ND = Not Detected
H = High
M = Medium
L = Low
Total Hydrocarbon = 1 ppm.

products of combustion (note that No. 2 and No. 6 fuel oil are essentially aliphatic). For the petroleum fuels, n-alkanes and polynuclear aromatic hydrocarbons are seen in the exhaust gas; for the SRC-II fuels, the alkanes are absent or present at very low levels, and polynuclear aromatic hydrocarbons not seen in the petroleum exhaust gases are present.

11. REFERENCE

Gibbons, G.A., et al. Small Scale Combustion Testing of Synthetic Fuels. Progress Report prepared by Pittsburgh Energy Technology Center. 1981.

TEST 30

EVAPORATIVE EMISSIONS FROM VEHICLES

OPERATING ON METHANOL/GASOLINE BLENDS

1. FUELS TESTED*

Non-synfuel: 10 percent methanol/90 percent gasoline (Indolene) blend.

2. TEST EQUIPMENT

Two light duty vehicles were tested. Vehicle A was a 1977 Chevrolet Impala with a 305 CID engine and 2V carburetor; vehicle B was a 1977 Buick Skylark with a 231 CID engine and 2V carburetor. Both vehicles had activated carbon canisters for vapors from fuel tank only.

3. TEST SITE

Bartlesville Test Center, Bartlesville, Oklahoma.

4. TEST OBJECTIVE

- To determine the influence of the addition of methanol to gasoline on evaporative emissions from light-duty vehicles.

5. SPONSORING AGENCY

U.S. Department of Energy
Bartlesville Energy Technology Center
Bartlesville, Oklahoma

Project Manager: Ken R. Stamper
Telephone No: 918-336-2400

6. CONTRACTOR

None

7. TEST CONDITIONS

Tests were performed using EPA's Sealed Housing for Evaporative Determina-

*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

tions (SHED) test procedure which focuses on the measurement of evaporative losses generated in two operations: diurnal and hot soak. The diurnal portion of the test simulates a condition in which the temperature of the fuel is raised from 60°F to 84°F (16°C to 29°C), due to the daily temperature cycle. The hot-sock portion of the test is designed to simulate evaporative emissions resulting from the rise in temperature of the fuel in the carburetor bowl, typical of the temperature rise which occurs after a fully warmed engine is turned off.

8. ENVIRONMENTAL MONITORING

Hydrocarbons (corrected for methanol) and methanol.

9. PROJECT STATUS

Tests completed, and paper presented October 20-23, 1980.

10. RESULTS

Results from these tests show that using a 10 percent methanol/90 percent gasoline blend increases evaporative emissions by 130 percent for short-term use and 220 percent for long-term use, relative to the evaporative emissions produced using a reference gasoline. The evaporative hydrocarbon emissions produced when the vehicles were operating on the methanol blend had a slightly higher photochemical reactivity than those produced from the reference gasoline.

11. REFERENCE

Stamper, K.R. Evaporative Emissions from Vehicles Operating on Methanol/Gasoline Blends. SAE Technical Paper 801360, Presented to Society of Automotive Engineers, Fuels and Lubricants Division, Baltimore, Maryland, October 20-23, 1980. 12 pp.

TEST 31

EXPERIMENTAL RESULTS USING METHANOL AND METHANOL/GASOLINE BLENDS AS AUTOMOTIVE ENGINE FUEL

1. FUELS TESTED*

Non-synfuels: two unleaded gasolines (Indolene and a commercial fuel) were used as base fuels. Test data were obtained for each base fuel used alone and in a blend with 5, 10, and 15 percent methanol and for pure methanol.

2. TEST EQUIPMENT

The test equipment included a fleet of 10 cars of varying size (Table A-50) and a stand-mounted 1975 350-CID engine.

TABLE A-50. TEST VEHICLES OPERATED ON METHANOL/GASOLINE FUEL BLENDS

Vehicle Designation	Year and Make	Engine Size, CID	Transmission	Carburetor
A	1974 Chevelle	350	Automatic	2 bbl
B	1974 Ford Torino	351	"	2 bbl
C	1975 Maverick (non catalyst)	250	"	1 bbl
D	1975 Vega	140	"	1 bbl
E	1975 Chevelle	350	"	2 bbl
F	1975 Granada (non catalyst)	351	"	2 bbl
G	1975 Dodge Dart (non catalyst)	318	"	2 bbl
H	1975 Impala	454	"	4 bbl
I	1975 Monza	262	"	2 bbl
J	1975 Plymouth (non catalyst)	318	"	2 bbl
K	1972 Buick	350	"	4 bbl

*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

3. TEST SITE

Bartlesville Energy Research Center, Bartlesville, Oklahoma.

4. TEST OBJECTIVE

- To determine the emission and fuel-economy characteristics of methanol and methanol/gasoline blends as automotive fuels.

5. SPONSORING AGENCY

Energy Research and Development Administration
Bartlesville Energy Research Center
Bartlesville, Oklahoma

The work was done, in part, in cooperation with the EPA.

Project Leader: J. R. Allsup
Telephone No: 918-336-2400

6. CONTRACTOR

None.

7. TEST CONDITIONS

On the stand-mounted engine, test variables and engine parametric adjustments included engine speed, exhaust gas recirculation rate, air-fuel ratio, ignition timing, and compression ratio for 5, 10, 15, and 100 percent methanol/gasoline blend fuels. The test vehicles were tested on a chassis dynamometer to determine the influence of ambient temperature (20°, 75°, and 100°F) using 5 and 10 percent methanol fuels. Five of the test vehicles were also tested to determine the effects of sustained use (5000-7500 miles) of gasoline/methanol blends (10 percent methanol). These vehicles were repetitively driven over a controlled test route during both summer and winter seasonal periods.

8. ENVIRONMENTAL MONITORING

Steady-state engine emissions of the following compounds were measured: hydrocarbons, methanol, aldehyde, nitrogen oxides, and carbon monoxide.

9. PROJECT STATUS

Tests are completed, and report is dated January 1977. A companion study involving the physical properties of the methanol/gasoline mixtures was conducted concurrently and will be made available as a Report of Investigations entitled "Physical Properties of Gasoline/Methanol Mixtures" by B.H. Eccleston and F.W. Cox.

10. RESULTS

Emissions data are summarized in Tables A-51 and A-52.

- The data indicate that for both base fuels, at normal ambient temperature, the average HC emissions were increased by addition of methanol and were further increased (up to 30 percent) at higher temperatures; the change in HC emissions due to methanol may be the result of methanol in leaning the air/fuel ratio or to its effect in increasing fuel vapor pressure.
- In general, aldehyde emissions increased with higher concentration of methanol in the fuel. Levels of NO_x emissions were unaffected by the amount of methanol in the fuel but were slightly reduced as the ambient test temperature was increased and slightly increased at cold ambient temperature.
- CO was substantially reduced by the addition of methanol to the base fuel at cold and median ambient temperatures. At high ambient temperature, CO emission levels varied erratically. In general, the fuels containing methanol produced higher CO levels than the base fuels.
- Results from the dynamometer tests suggest that emissions are generally affected to the extent that methanol addition affects air-fuel stoichiometry, fuel heat content, and fuel vapor pressure.
- Results from the road tests indicate that vehicle emissions and fuel economy were essentially unchanged during approximately 7,500 miles of road testing; no engine or fuel system component failures were encountered during that testing.
- Results from the bench-mounted engine suggest that operation with pure methanol may allow use of high-compression engines to realize improved fuel energy economy with relatively low oxides of nitrogen emission.

11. REFERENCE

Allsup, J.R. Experimental Results Using Methanol and Methanol/Gasoline Blends as Automotive Engine Fuel. BERC/RI-76/15, Bartlesville Energy Research Center, Energy Research and Development Administration, Bartlesville, Oklahoma, January 1977. 81 pp.

TABLE A-51. EXHAUST EMISSIONS AND FUEL RATE - VEHICLES A-E

	Ambient temperature, °F								
	20			75			100		
	Base fuel	5% MeOH	10% MeOH	Base fuel	5% MeOH	10% MeOH	Base fuel	5% MeOH	10% MeOH
	BASE FUEL -- INDOLENE								
Emissions, g/mile:									
CO.................	48.8	39.1	35.0	17.7	14.2	10.9	25.8	44.0	34.2
HC.................	2.7	2.6	2.3	1.4	1.6	1.8	1.6	2.0	2.1
NO_x................	2.1	2.1	2.0	2.0	1.9	1.9	1.8	1.6	1.7
Aldehydes..........	.09	.11	.13	.10	.12	.13	.09	.10	.09
Methanol...........	.01	.08	.13	.01	.08	.15	.02	.10	.17
Fuel economy, mi/10^6 btu:									
Emission cycle.....	8.7	8.6	8.7	10.0	9.8	9.7	10.2	9.6	9.8
Highway cycle......	15.4	15.4	15.1	15.9	15.9	15.6	16.4	15.8	15.9
	BASE FUEL -- COMMERCIAL GASOLINE								
Emissions, g/mile:									
CO.................	48.2	42.3	32.1	18.7	13.2	9.6	19.7	28.3	19.6
HC.................	2.5	2.5	2.6	1.3	1.6	1.7	1.6	2.1	2.3
NO_x................	1.9	1.9	2.0	1.8	1.8	1.7	1.7	1.6	1.7
Aldehydes..........	.10	.11	.16	.10	.10	.12	.10	.11	.13
Methanol...........	.02	.08	.14	.02	.08	.15	.02	.10	.17
Fuel economy, mi/10^6 btu:									
Emission cycle.....	9.5	9.0	8.7	10.1	9.8	9.6	10.3	10.0	9.8
Highway cycle......	16.8	15.9	15.2	15.9	15.2	14.9	16.5	16.3	15.8

TABLE A-52. EXHAUST EMISSIONS AND FUEL RATE - VEHICLES A-J - COMMERCIAL GASOLINE BASE FUEL/METHANOL BLENDS

	Ambient temperature, °F								
	20			75			100		
	Clear fuel	5% MeOH	10% MeOH	Clear fuel	5% MeOH	10% MeOH	Clear fuel	5% MeOH	10% MeOH
Emissions, g/mile:									
CO	40.3	35.7	29.2	13.5	10.1	8.2	13.2	18.3	13.2
HC	2.5	2.6	2.8	1.1	1.3	1.5	1.2	1.6	1.8
NO_x	1.9	2.1	2.0	2.1	2.0	1.9	2.0	1.8	1.8
Aldehydes	.11	.13	.16	.10	.11	.12	.09	.10	.12
Methanol	.01	.08	.15	.02	.07	.13	.02	.08	.14
Fuel economy, mi/10^5 btu:									
Emission cycle	9.3	9.1	8.9	10.0	9.7	9.7	10.4	10.0	10.0
Highway cycle	15.8	15.3	14.8	15.9	15.2	14.8	16.0	15.9	15.7

TEST 32

FLEET TRIALS USING METHANOL/GASOLINE BLENDS

1. FUELS TESTED*

Non-synfuels: 10 percent methanol/90 percent gasoline blends.

2. TEST EQUIPMENT

The seven automobiles used in this study are described below in Table A-53. The fuel metering hardware of the vehicles was not changed.

TABLE A-53. FLEET DESCRIPTION

Vehicle No.	Vehicle Description	Engine Disp., CID	Carb.	Test I.W., lb.
161	1977 Chevrolet Impala	305	2V	4,000
162	1977 Buick Skylark	231	2V	3,500
163	1977 Ford LTD II	302	2V	4,500
164	1977 Plymouth Fury	225	2V	4,000
176	1978 Volvo 242 DL*	130	FI	3,000
175	1978 Ford Pinto*	140	2V	2,750
190	1978 Ford Fairmont	200	1V	3,000

*Vehicles are equipped with 3-way catalytic converters and closed-loop A/F control.

3. TEST SITE

Bartlesville Energy Technology Center, Bartlesville, Oklahoma.

*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

4. TEST OBJECTIVE

- To provide information on the fuel economy, driveability, emissions, and the engine and fuel-handling component deterioration associated with extended use of methanol/gasoline blends in current-production automobiles.

5. SPONSORING AGENCY

U.S. Department of Energy
Bartlesville Energy Technology Center
Bartlesville, Oklahoma

Telephone No: 918 - 326-2400

6. CONTRACTOR

Same as sponsoring agency.

7. TEST CONDITIONS

The vehicles were operated over a course designed to accumulate mileage at a rate and duty cycle similar to automobiles used by the private sector. Vehicle tests were run at each 5,000-mile accumulation interval to determine the fuel economy and the mass of pollutant emissions generated.

8. ENVIRONMENTAL MONITORING

CO, NO_x, unburned fuel, evaporative emissions of hydrocarbons and methanol.

9. PROJECT STATUS

The tests described in this report have been completed, although further tests were recommended.

10. RESULTS

- The data show consistent reduction in CO emissions associated with the use of the 10 percent methanol blend (see Figure A-18).
- The influence of the methanol blend on NO_x emissions did not show a consistent effect on the individual test vehicles. However, the 1977 model-year fleet showed slightly increased NO_x emissions relative to the emissions generated while operating on indolene, and the 1978 model-year fleet showed slightly decreased NO_x emissions compared to those from indolene-operating engines (see Figure A-19).

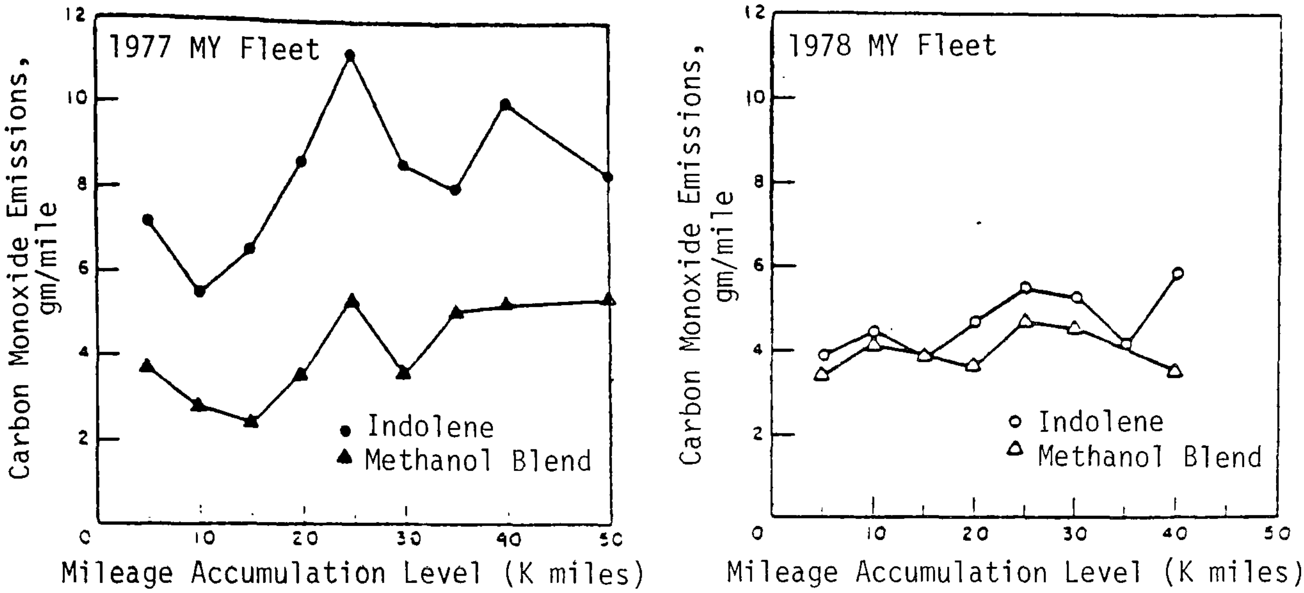

Figure A-18. CO Emission Rates From 1977-MY and 1978-MY Vehicles Operated Over the FTP Urban Cycle on Indolene and Methanol/Gasoline Blends

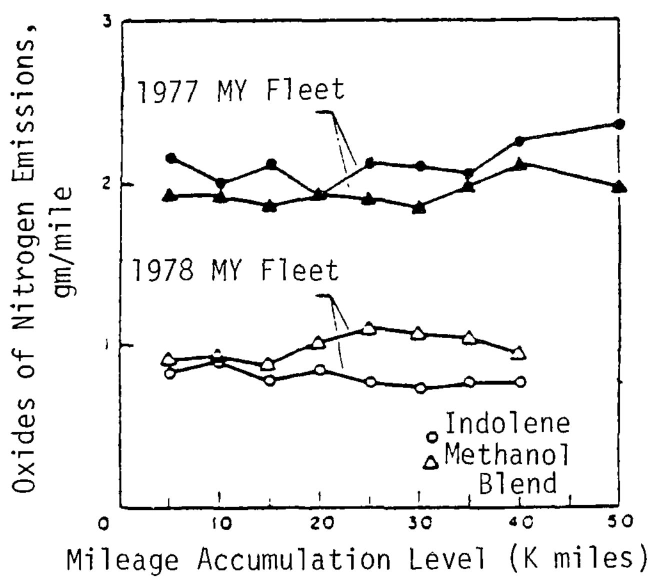

Figure A-19. NO_x Emission Rates From Vehicles Operated Over the FTP Urban Cycle on Indolene and Methanol/Gasoline Blends

- The emission rates of unburned fuel from the test fleet show slight increases associated with the use of 10 percent methanol blend over test results from the fleet operating on indolene (see Figure A-20).

- The data showed a significant increase in evaporative emissions associated with short-term use of the methanol blends and an even greater increase when the methanol blend is used for extended periods.

11. REFERENCE

Stamper, K.R. Fleet Trials Using Methanol/Gasoline Blends. In: Proceedings of the IV International Symposium on Alcohol Fuels Technology, Sao Paulo, Brazil, October 5-8, 1980. Vol. II. pp. 563-571.

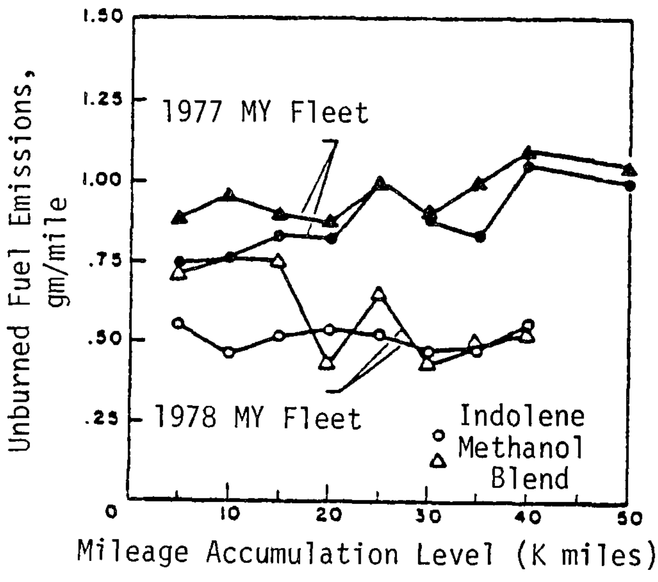

Figure A-20. UBF Emission Rates From Vehicles Operated Over the FTP Urban Cycle on Indolene and Methanol/Gasoline Blends

TEST 33
GASOHOL FLEET OPERATIONS

1. FUELS TESTED*

Non-synfuel: gasohol and gasoline.

2. TEST EQUIPMENT

110 Southwestern Bell Telephone fleet vehicles.

3. TEST SITE

Bartlesville Energy Technology Center, Bartlesville, Oklahoma.

4. TEST OBJECTIVES

- To obtain comparative field experience and laboratory emission data with gasohol and gasoline in controlled tests with units of a commercial service fleet.

5. SPONSORING AGENCY

U.S. Department of Energy
Bartlesville Energy Technology Center
P. O. Box 1398
Bartlesville, Oklahoma 74003

Project Manager: Jerry Allsup
Telephone No: 918 - 336-2400

6. CONTRACTOR

Same as sponsoring agency.

7. TEST CONDITIONS

Operators of SWBT vehicles observed and recorded information from vehicles during use in normal field service. Service records provided information

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

on fuel economy and fuel system problems. Emissions and fuel economy data were obtained from tests of the vehicles at BETC using a chassis dynamometer to run EPA-prescribed test routines.

8. ENVIRONMENTAL MONITORING

Regulated pollutants.

9. PROJECT STATUS

Project complete.

10. RESULTS

- On the average, emissions were lower for vehicles fueled with gasohol, but data is inadequate to conclude real differences.
- Fuel economy was found to be unchanged between fuels, while driveability was somewhat poorer with gasohol.

11. REFERENCE

Allsup, J. The BETC Fleet Test Program. In: Proceedings of Conference on Fleet Use of Unique Automotive Fuels; Report No. MED117, August 13-14, 1980.

TEST 34

EVAPORATIVE EMISSIONS FROM METHANOL/GASOLINE BLENDS

1. FUEL TESTED*

Non-synfuel: unleaded low-octane indolene and a 10 percent methanol/90 percent indonene blend.

2. TEST EQUIPMENT

Two automotive vehicles.

3. TEST SITE

Bartlesville Energy Technology Center, Bartlesville, Oklahoma.

4. TEST OBJECTIVE

- To determine the effect of short-term and long-term canister service on evaporative emissions from vehicles using the above indicated fuels.

5. SPONSORING AGENCY

U.S. Department of Energy
Bartlesville Energy Technology Center
P. O. Box 1398
Bartlesville, Oklahoma 74003

Project Manager: Jerry Allsup
Telephone No: 918 - 336-2400

6. CONTRACTOR

Same as sponsoring agency.

7. TEST CONDITIONS

The original canisters were aged by operating the vehicles on 10 percent methanol blends over routine duty for an extended period. Additional

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

tests were run on both test fuels using fresh canisters to determine effects of short-term service with methanol blends.

8. ENVIRONMENTAL MONITORING

Evaporative emissions (hydrocarbons).

9. PROJECT STATUS

Project complete.

10. RESULTS

- Aged canisters resulted in a 90 percent increase in evaporative losses over fresh canisters with the vehicle operating on the methanol blend.
- Data from the short-term use of methanol blends indicated that a 75 percent increase in evaporative emissions would result with the blend over a straight gasoline.
- Effect of long-term canister service on evaporative emissions operating on methanol blends indicated that either fuel modifications or emission control design modification must be made before emissions standards can be met with this type of fuel.
- There are indications that the "Sealed Housing for Evaporative Determination" test procedure employed was not completely adequate to simulate in-use evaporative losses from light-duty vehicles.

11. REFERENCE

Allsup, J. The BETC Fleet Test Program. In: Proceedings of Conference on Fleet Use of Unique Automotive Fuels Report No. MED117, August 13-14, 1980.

TEST 35

PERFORMANCE EVALUATION OF ALCOHOL-GASOLINE BLENDS IN LATE MODEL AUTOMOBILES

1. FUELS TESTED*

Non-synfuels: ethanol/gasoline fuel blends, and methanol/gasoline fuel blends.

2. TEST EQUIPMENT

Fourteen test vehicles as indicated in Table A-54.

3. TEST SITE

Anaheim, California.

4. TEST OBJECTIVES

- Performance evaluation of alcohol-gasoline blends in late-model automobiles.
- Experimental evaluation of the effect of ethanol and methanol in gasoline on: 1) exhaust emissions; 2) evaporative emissions; and 3) vehicle driveability.

5. SPONSORING AGENCIES

U.S. Department of Energy and
Coordinating Research Council (CRC)
Atlanta, Georgia
CRC Contract No. CM-125-1-79

Project Officer: Al Zingle
Telephone No: 404 - 396-3400

6. CONTRACTOR

Systems Control, Inc.
Environmental Engineering Division
421 E. Cerritos Avenue
Anaheim, California 92805

*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

TABLE A-54. TEST VEHICLE DESCRIPTION

VEHICLE NUMBER	MAKE	MODEL	VEHICLE ID. NUMBER	ENGINE SIZE	INERTIA WEIGHT	ACTUAL HORSEPOWER	CONTROL SYSTEM
G-1	Plymouth	Horizon	ML24AAD102722	105	2,625	6.8	Open
G-2	Plymouth	Horizon	ML24AAD186522	105	2,625	6.8	Open
G-3	Dodge	Omni	ZL24AAD230651	105	2,625	6.8	Closed
G-4	Dodge	Omni	ZL24AAD230652	105	2,625	6.8	Closed
G-5	Volvo	DL	VC24245A1166691	2.3L	3,000	12.5	Closed
G-6	Dodge	Aspen	NE41CAF150663	225	4,000	11.6	Open
G-7	Buick	Century	4L69AAZ116617	231	3,500	11.3	Closed
G-8	Buick	Century	4L69AAZ116703	231	3,500	11.3	Open
G-9	Chevrolet	Impala	1L69HAC114146	305	4,000	10.3	Open
G-10	Ford	Pinto	0T10A149924	2.3L	3,000	9.7	Open
G-11	Ford	Pinto	0T10A142387	2.3L	3,000	9.7	Open
G-12	Ford	Pinto	0T10A152199	2.3L	3,000	9.7	Closed
G-13	Ford	Pinto	0T10A152198	2.3L	3,000	9.7	Closed
G-14	Cadillac	Eldorado	6L57AE617086	350	4,250	11.8	Closed

Program Manager: Richard Carlson
Telephone No: 714 - 956-5450

7. TEST CONDITIONS

This program is divided into a program start-up phase and two testing phases (Phase I for ethanol/gasoline fuel blends and Phase II for methanol/gasoline fuel blends).

8. ENVIRONMENTAL MONITORING

Ethanol, aldehyde, methanol, hydrocarbon, carbon monoxide, and nitrogen oxides.

9. PROJECT STATUS

Work performed to date includes the following: 1) fuel and vehicle acquisition; 2) vehicle preparation including 4,000 mile break-in; 3) demonstration testing; and 4) Phase I emissions, fuel economy, and driveability testing was completed in April 1981. Phase II of the program is to be completed in 1982.

10. RESULTS

None reported to date. A draft final report is currently being prepared for Phase I results and should be available by the end of 1981. A draft final report for Phase II will be prepared in 1982.

11. REFERENCE

Carlson, R.R. "Performance Evaluation of Alcohol-Gasoline Blends in Late Model Automobiles". In: Proceedings of Conference on Fleet Use of Unique Automotive Fuels Report No. MED117, August 13-14, 1980.

TEST 36

DETERMINATION OF INDIVIDUAL ALDEHYDE CONCENTRATIONS IN THE EXHAUST OF A SPARK IGNITED ENGINE FUELED BY ALCOHOL/GASOLINE BLENDS

1. FUEL TESTED*

Non-synfuels: 100 percent Indolene; 20 percent ethanol/80 percent Indolene (20E); 20 percent methanol/80 percent Indolene (20M); and 30 percent methanol/70 percent Indolene (30M).

2. TEST EQUIPMENT

A 1963 four-cylinder Pontiac engine modified with a 1974 cylinder head and camshaft. The compression ratio was 8.1:1.

3. TEST SITE

Department of Mechanical Engineering, University of Miami, Coral Gables, Florida.

4. TEST OBJECTIVE

- To measure and compare individual aldehyde emissions from an alcohol/gasoline blend fueled engine operated at various fuel-air equivalence ratios.

5. SPONSORING AGENCY

U.S. Department of Energy
Heavy Duty Transport and Fuels Utilization
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Project Officer: Eugene Ecklund
Telephone No: 202 - 252-8055

*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

6. CONTRACTOR

Department of Mechanical Engineering
University of Miami

Project Manager: Robert R. Adt, Jr.
Telephone No: 305-284-2571

7. TEST CONDITIONS

Engine was operated at steady-state conditions, 2000 rpm and minimum spark advance for maximum torque with fuel-air equivalence ratios of 0.96, 0.90, and 0.82. During operation at 0.82, the engine experienced lean-limit misfiring.

8. ENVIRONMENTAL MONITORING

Total aldehydes, formaldehyde, acetaldehyde, acetone, propionaldehyde, and acrolein.

9. PROJECT STATUS

Project complete; final report presented in October 1979.

10. RESULTS

- Total aldehydes (including acetone) increase 25 percent in going from Indolene to 20E, 10 percent to 20M, and 30 percent to 30M.
- Aldehyde concentrations in the engine exhaust are generally a stronger function of fuel blend than equivalence ratio.
- Formaldehyde is the largest component of the total aldehydes; up to 70-90 mole percent of the total.
- The emissions of formaldehyde and acetaldehyde are strongly controlled by the content of methanol and ethanol in the fuel, respectively.
- Acetone concentration increases as the lean misfire limit is approached ($\Phi = 0.82$).
- Acrolein concentration decreases slightly with increasing alcohol blend level.
- Aldehydes are partially destroyed in the exhaust system and virtually completely destroyed in the catalyst.

11. REFERENCE

Harrenstien, M.S., K.T. Rhee, and R.R. Adt. Determination of Individual Aldehyde Concentrations in the Exhaust of a Spark Ignited Engine Fueled by Alcohol/Gasoline Blends. SAE Paper No. 790 952. 1-4 October 1979.

TEST 37

METHANOL AS A BOILER FUEL

1. FUELS TESTED*

   Reference fuels: methanol, natural gas, and residual oil No. 6.

2. TEST EQUIPMENT

   A small scale boiler test stand and a Babcock & Wilcox R-B95 utility boiler with a rated capacity of 425,000 lb/hr steam and a net capability of 49 MW.

3. TEST SITE

   Boiler test stand: Coen Co., Burligame, California.

   Utility boiler: A.B. Patterson steam generating station, New Orleans, Louisiana.

4. TEST OBJECTIVES

   - Demonstrate the use of methanol in external combustion boiler systems.
   - Compare boiler performance and emissions of methanol and conventional fuel combustion.

5. SPONSORING AGENCY

   Vulcan Cincinnati, Inc.
   Cincinnati, Ohio

   Program Manager: R.W. Duhl
   Telephone No: 513-281-2800

6. CONTRACTOR

   None.

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

7. TEST CONDITIONS

All fuels were tested at two excess air levels and at load levels of 100, 75, and 50 percent. Methanol firing required a centrifugal pump and Babcock & Wilcox 85° "Y" type burner tips; no other changes were made.

8. ENVIRONMENTAL MONITORING

NO_x, CO, and aldehydes.

9. PROJECT STATUS

Testing was conducted in 1972. Final report dated December 1972.

10. RESULTS

In the boiler stand test, combustion of methanol produced NO_x emissions one-fourth and one-tenth of those produced by natural gas and No. 6 residual oil, respectively.

The results of the utility boiler test program are highlighted below and in Figure A-21.

- No particulate or sulfur compounds were emitted during methanol combustion.
- NO_x emission levels of methanol were 7-14 percent of those measured during residual oil combustion.
- CO emission levels of methanol were less than 100 ppm and generally less than those observed for the residual oil.
- Organic acids and aldehydes were generally less than 10 and 1 ppm, respectively. These emissions, as well as hydrocarbon emissions, were considered negligible.

11. REFERENCES

- Hagen, D.L. "Methanol as a Fuel: A Review With Bibliography". Paper No. 770792, In: Passenger Car Meeting, Detroit, Michigan, September 1977.
- Vulcan Cincinnati, Inc. "Methyl Fuel Combustion Test, Vol. I and II". Report of Test at A.B. Paterson Plant, Restricted to the Sponsors. December 15, 1972, 1000 pp.
- Duhl, R.W. and T.O. Wentworth (Vulcan Cincinnati, Inc.). "Methyl Fuel From Remote Gas Sources". Am. Instit. Chem. Eng. Soc. Calif. Section 11th Annual Mtg., April 16, 1974, Los Angeles, CA.

• Duhl, R.W. (Vulcan Cincinnati, Inc.). "Methanol, A Boiler Fuel Alternative". Am. Inst. Chem. Eng., 8th Annual Mtg., Boston, Mass., Sept. 7-10, 1975.

• Duhl, R.W. "Methanol as a Boiler Fuel". Submitted for Publication, Chem. Eng. Prog., February 1976.

• Duhl, R.W. (Vulcan Cincinnati, Inc.) and J.W. Boylan (A.M. Kinney, Inc.). "Use of Methanol as a Boiler Fuel". IV A - Symposium Swedish Academy of Engineering Sciences, Stockholm, Sweden, March 23, 1976.

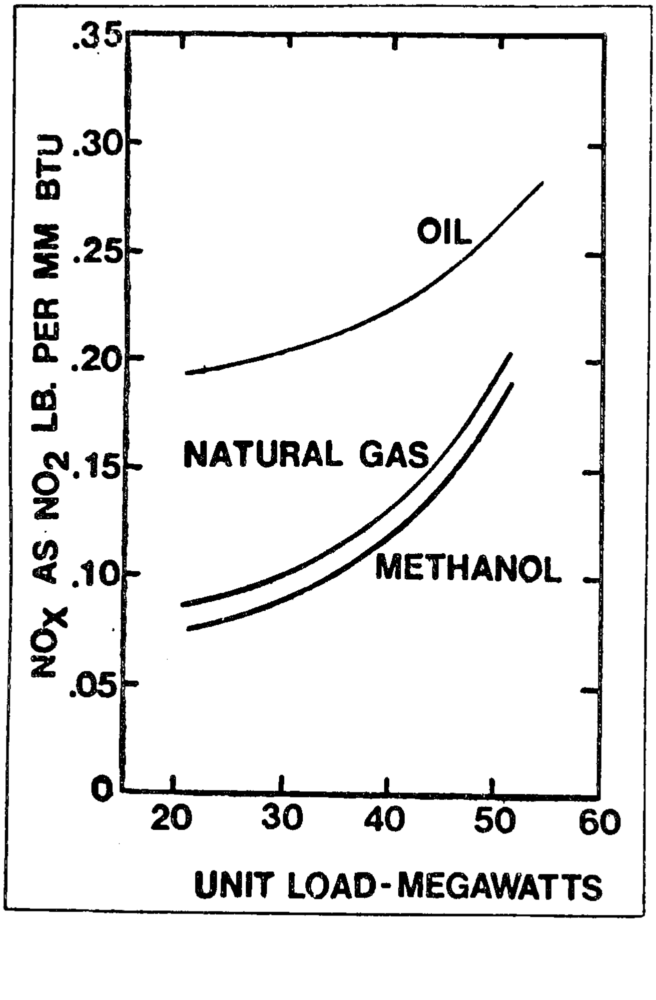

Figure A-21.
NO_X Emission Levels of Methanol, Natural Gas, and Oil

TEST 38

CHARACTERIZATION OF EMISSIONS FROM METHANOL AND METHANOL/GASOLINE BLENDED FUELS

1. FUELS TESTED*

   Non-synfuels: M-20 fuel (methanol/Indolene clear fuel - 20/80 volume percent); pure methanol, and Indolene clear fuel.

2. TEST EQUIPMENT

   Vehicle test: 1975 Ford LTD with 400 CID engine; automatic transmission and air conditioning operating during test.

   Engine test: a 1975 Ford, 400 CID engine without EGR.

3. TEST SITE

   Scientific Research Laboratory, Dearborn, Michigan.

4. TEST OBJECTIVES

   - To develop techniques for the quantitative analysis of methanol in vehicle exhaust.
   - To compare the influence of fuel composition on the aliphatic, aromatic, and oxygenated hydrocarbon emissions.

5. SPONSORING AGENCY

   Ford Motor Company
   Scientific Research Laboratory
   Dearborn, Michigan

   Telephone No: 313 - 322-3494

6. CONTRACTOR

   None.

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

7. TEST CONDITIONS

The vehicle was operated at steady state and over a Federal test procedure CVS-C/H certification cycle on a chassis dynamometer. The engine was run at steady-state conditions using the following speed/load map:

Point 1:	Speed = 1000 rpm Load = WOT Ø FA = 1.1 Spark = MBT
Point 2:	Speed = 1000 rpm Load = 25 percent of WOT Ø FA = 0.95 Spark = MBT
Point 3:	Speed = 3000 rpm Load = WOT Ø FA = 1.1 Spark = MBT
Point 4:	Speed = 3000 rpm Load = 25 percent of WOT Ø FA = 0.95 Spark = MBT

8. ENVIRONMENTAL MONITORING

Total hydrocarbons (as propane) and specific organics.

9. PROJECT STATUS

Project completed and presented in February 1981.

10. RESULTS

A summary of the results are presented in Figures A-22 to A-24; general findings are listed below:

Vehicle Chassis Dynamometer Test

- M-20 fuel gave significantly higher hydrocarbon and aromatic emissions than Indolene fuel without a catalyst. M-20 fuel gave only slightly higher aliphatic hydrocarbon, aldehyde, and aromatic emissions than Indolene in the presence of a catalyst.

Engine Dynamometer Test

- Methanol and aldehyde emissions from 100 percent methanol fuel comprised more than 98 mole percent of total measured hydrocarbons.
- Methanol comprised about 50 percent of the hydrocarbon emissions at lower operating speeds of engine with M-20 fuel.

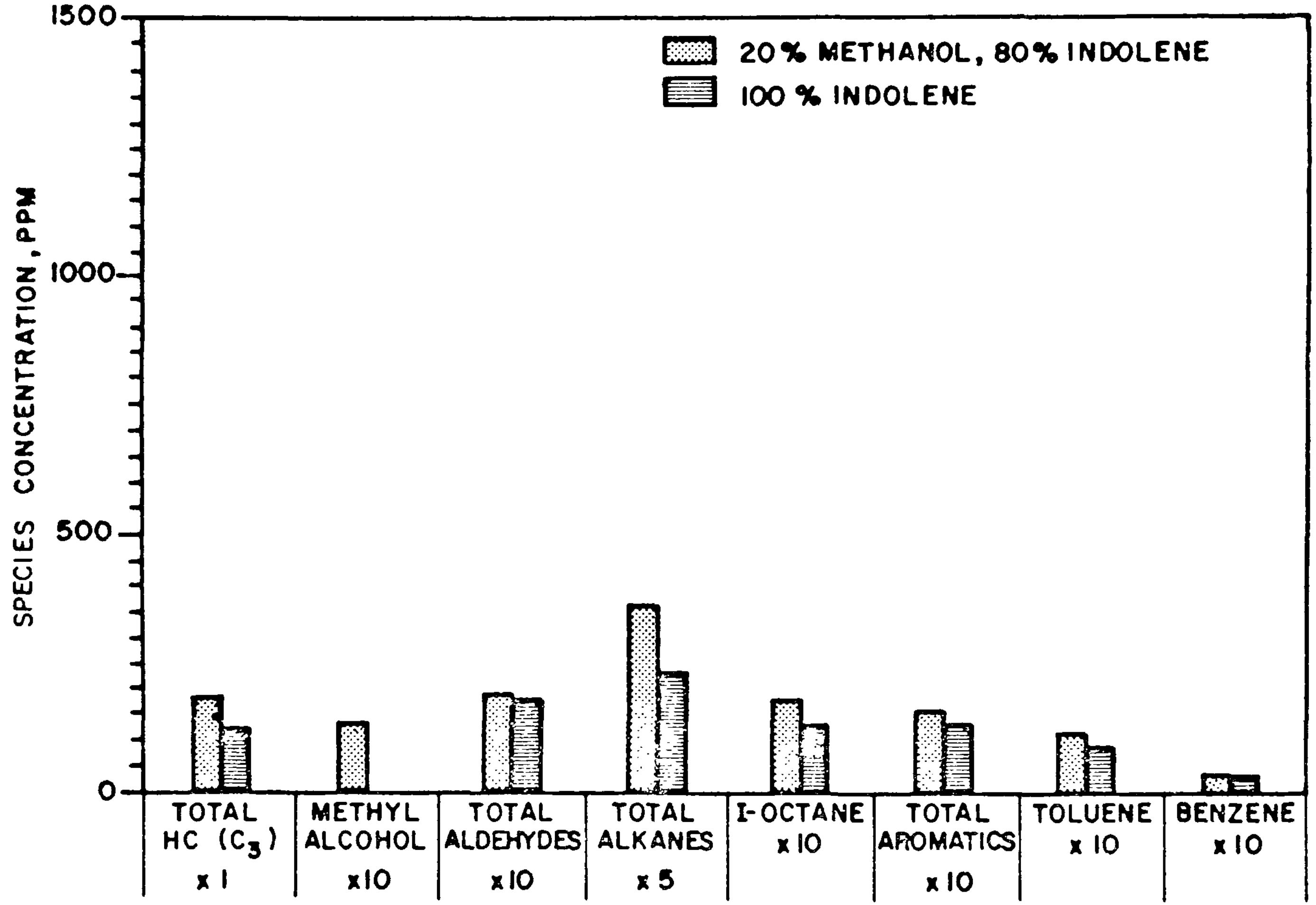

Figure A-22. A Comparison of Tailpipe Emissions (Post-catalyst) From a Vehicle Burning 20% Methanol/80% Indolene and 100% Indolene (CVS C/H - Cycle #1)

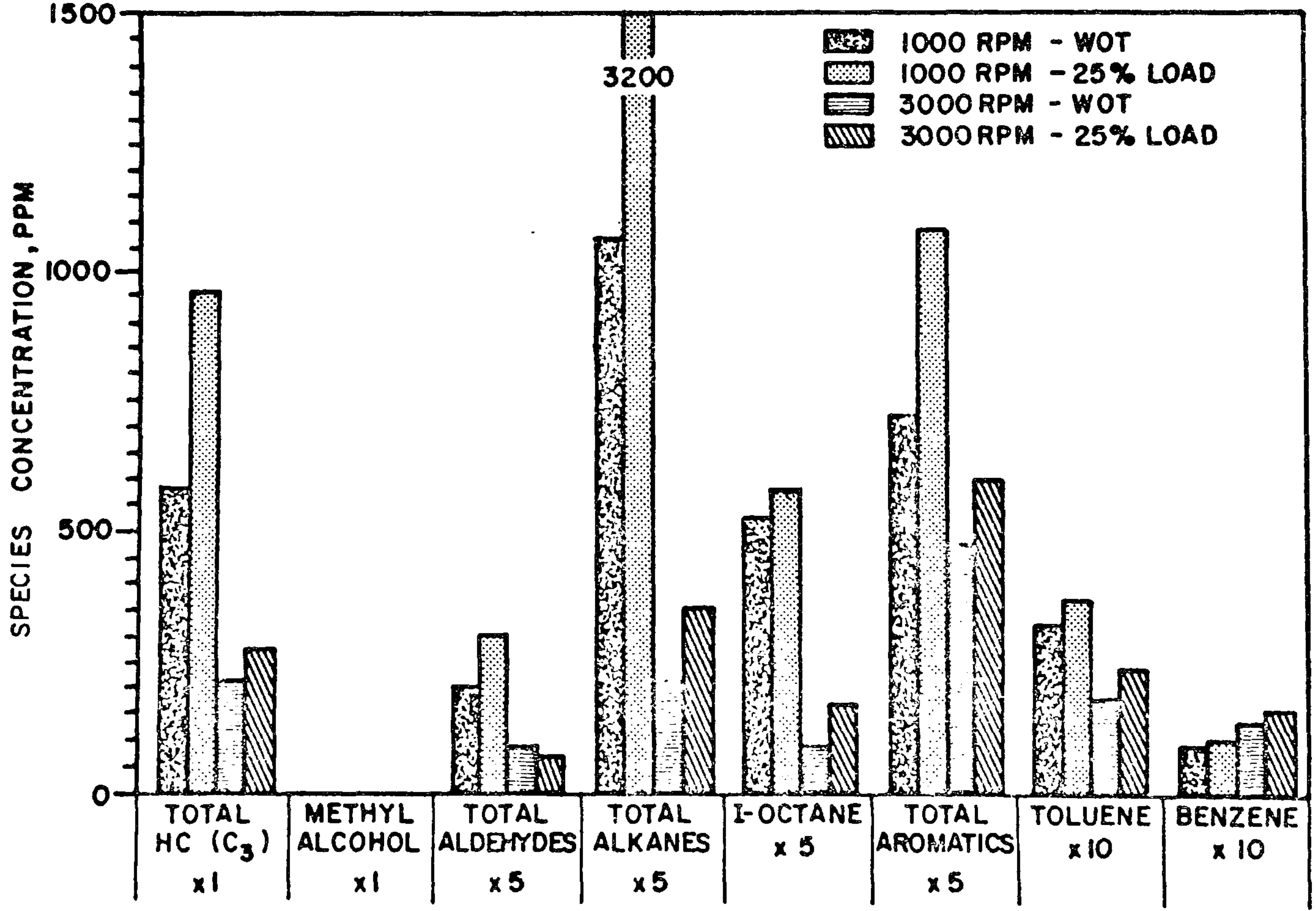

Figure A-23. The Effect of Engine Parameters on Emissions Using 100% Indolene Fuel

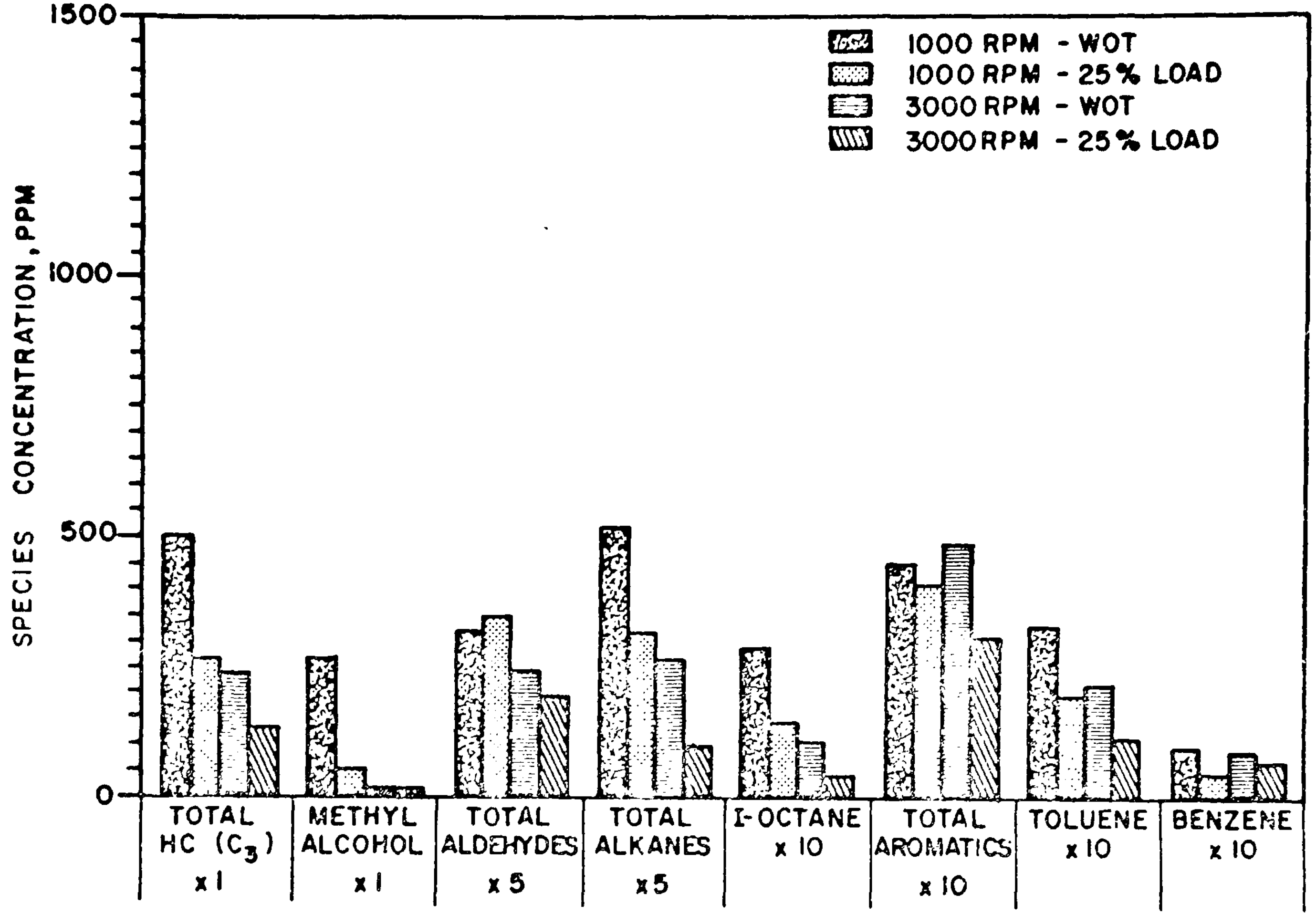

Figure A-24. The Effect of Engine Parameters on Emissions Using 20% Methanol/80% Indolene Fuel

- Total aldehyde emissions from pure methanol fueled engine were 2-3 times higher under most operating conditions than those emitted from Indolene clear and M-20 fueled engines.
- In general, all hydrocarbon species decrease in concentration with increasing exhaust temperatures (higher rpm).

11. REFERENCE

Schuetzle, D., T.J. Prater, and R.D. Anderson. "Characterization of Emissions From Methanol/Gasoline Blended Fuels". SAE Technical Paper No. 810 430. 23-27 February 1981.

TEST 39

COMPARATIVE MUTAGENICITY OF COMBUSTION EMISSIONS OF A HIGH QUALITY NO. 2 DIESEL FUEL DERIVED FROM SHALE OIL AND A PETROLEUM-DERIVED NO. 2 DIESEL FUEL

1. FUELS TESTED

Synfuel: diesel fuel marine (refined from Paraho crude by SOHIO).

Reference fuel: petroleum-derived No. 2 diesel fuel (see Table A-55)

TABLE A-55. FUELS ANALYSIS

Analysis	Shale*	Petroleum #1†
API Gravity	38.8	35.5
Density @ 15°C Kg/liter	0.8359	0.8469
% Sulfur	0.024	0.16
Cetane Index	57.0	48.0
% Carbon	84.08	84.59
% Hydrogen	14.96	14.81
% Nitrogen	<0.01	<0.01
Distillation Range		
IBP	395°F	380°F
10%	450°F	427°F
50%	503°F	504°F
90%	553°F	600°F
EP	574°F	642°F
FIA		
% Saturates	61.6	66.2
% Olefins	4.1	1.3
% Aromatics	34.3	32.5

*Hydrotreated Diesel Fuel Marine courtesy of Navy Shale Oil refining run.

†Local #2 diesel fuel from Phillips Petroleum, Couch V.

2. TEST EQUIPMENT

Test vehicle was a prototype turbocharged diesel Volkswagen Rabbit (European Golf). The vehicle was equipped with a 1.5 liter prototype injection engine with a rated 70 hp at 4,800 rpm.

3. TEST SITE

U.S. Department of Transportation, Cambridge, Massachusetts.

4. TEST OBJECTIVE

- To determine the relative quantity of mutagenic materials contained in diesel fuels from synfuels as compared to those prepared from petroleum.

5. SPONSORING AGENCIES

U.S. Environmental Protection Agency
Environmental Research Center
Research Triangle Park, North Carolina

U.S. Department of Transportation
Transportation Systems Center
Cambridge, Massachusetts

Project Officer: J. Sturm
Telephone No: 617-494-2716

6. CONTRACTOR

None

7. TEST CONDITIONS

The vehicle was repetitively operated on a chassis dynamometer to simulate an actual driving pattern; the highway fuel economy test cycle (HWFET). This cycle is 12.75 minutes long over 10.24 miles at an average speed of 48 miles per hour.

8. ENVIRONMENTAL MONITORING

HC, NO_x, CO, particulates, particulate matter composition, and mutagenicity of particulates (Ames test).

9. PROJECT STATUS

Project is completed. Paper presented June 23-24, 1980.

10. RESULTS

Generally, the HC and CO emissions were found to be lower and NO_x levels higher for the shale-derived fuel as compared to the petroleum-derived fuel. The particle emission rate and fuel economy values were similar with both fuels. The emissions from the shale-derived fuel were somewhat higher in extractable organics.

The emissions were measured by DOT as 0.14/0.89/1.07 grams per mile of HC/CO/NO_x, respectively. Using the Federal Test Procedure driving cycle, this vehicle emitted 0.17 grams of particles per mile, which would meet the newly proposed EPA standard of 0.2 g/mile (the fuel used in these tests was not specified).

The mutagenic activity of the organics from the particle emissions was similar for the two fuels, but because the shale-fuel sample was somewhat higher both in mutagenic activity and extractable organics, the revertants/mile was greater for the shale-derived fuel (see Table A-56).

11. REFERENCE

Huisingh, J.L., et al. Comparative Mutagenicity of Combustion Emissions of a High Quality No. 2 Diesel Fuel Derived From Shale Oil and a Petroleum Derived No. 2 Diesel Fuel. In: Proceedings of the Symposium on Health Effects Investigation of Oil Shale Development, Sponsored by the U.S. Environmental Protection Agency, Gatlinburgh, Tennessee, June 23-24, 1980. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1981. 255 pp.

TABLE A-56. COMPARISON OF THE MUTAGENIC EMISSION RATE* BETWEEN A PETROLEUM AND SHALE DERIVED FUEL IN *SALMONELLA TYPHIMURIUM* TA98 WITHOUT ACTIVATION

	Rev/ µg Org.	% Ext	Rev x 10^5/ gm Part.	Per gm/mi	Revertants/ Mile
Petroleum	5.10	17.8	9.08	0.18	163,000
Shale	7.68	21.4	16.43	0.17	279,000

*Turbocharged VW Rabbit diesel vehicle (56.4 mi/gal).

TEST 40

REPORT ON THE METHANOL-POWERED BANK OF AMERICA VEHICLE FLEET IN SAN FRANCISCO AND LOS ANGELES

1. FUELS TESTED*

Reference fuels: simple blends of methanol and gasoline ranging between 2 and 18 percent by volume.

2. TEST EQUIPMENT

93 vehicles from the Bank of America fleet. 44 were control vehicles, 49 were run on the blends.

3. TEST SITE

San Francisco and Los Angeles areas.

4. TEST OBJECTIVES

- To demonstrate the practicality of using the various kinds of blends.

5. SPONSORING AGENCY

Bank of America
San Francisco, CA (Headquarters)

6. CONTRACTOR

Carson Associates
4117 Robertson Boulevard
Alexandria, VA 22309

Project Manager: Mr. Gavin McGurdy
Telephone No: 703-780-8284

7. TEST CONDITIONS

Fleet tested in California from February 1980 to present.

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

8. ENVIRONMENTAL MONITORING

CO, NO, and unburned hydrocarbons.

9. PROJECT STATUS

Intensive data gathering in November, December, and January (80-81). Bank now expanding use of blends at 2 and 4 percent levels. The contractor is continuing to supply support.

10. RESULTS

- Use of 2 and 4 percent blends recommended.
- Blends are practical and economical, result in improved mileage in new cars and decrease emissions of CO and unburned hydrocarbons.
- An operating cost decrease of 1¢ per mile noted with use of certain blends.

TEST 41

ADVANCED COMBUSTION SYSTEMS FOR STATIONARY GAS TURBINE ENGINES

1. FUELS TESTED

   Synfuel: shale-derived diesel fuel marine (DFM).

   Reference fuels: No. 2 fuel, No. 2 fuel with 0.5 percent nitrogen.

2. TEST EQUIPMENT (See Figures A-25 and A-26)

   Utilizing a Rich Burn/Quick Quench concept from bench scale model evaluations, two configurations of a full-scale prototype (25 megawatt engine size) gas turbine combustor were constructed and tested.

3. TEST SITE

   Pratt and Whitney Aircraft, West Palm Beach, Florida.

4. TEST OBJECTIVES

   - Identify, evaluate, and demonstrate alternative combustor design concepts for significantly reducing the production of NO_x in stationary gas turbine engines.
   - Program goals were 50 ppmv NO_x (at 15 percent O_2) for non-nitrogenous fuels, and 100 ppmv NO_x (at 15 percent O_2) for oil or gas containing 0.5 percent nitrogen by weight. The goal for CO was 100 ppmv (at 15 percent O_2).

5. SPONSORING AGENCY

   U.S. Environmental Protection Agency
   Industrial Environmental Research Laboratory
   Office of Environmental Engineering and Technology
   Research Triangle Park, NC

   Project Officer: W. S. Lanier
   Telephone No: 919-541-2432

6. CONTRACTOR

   United Technologies Corporation
   Pratt and Whitney Aircraft Group
   Government Products Division
   West Palm Beach, Florida

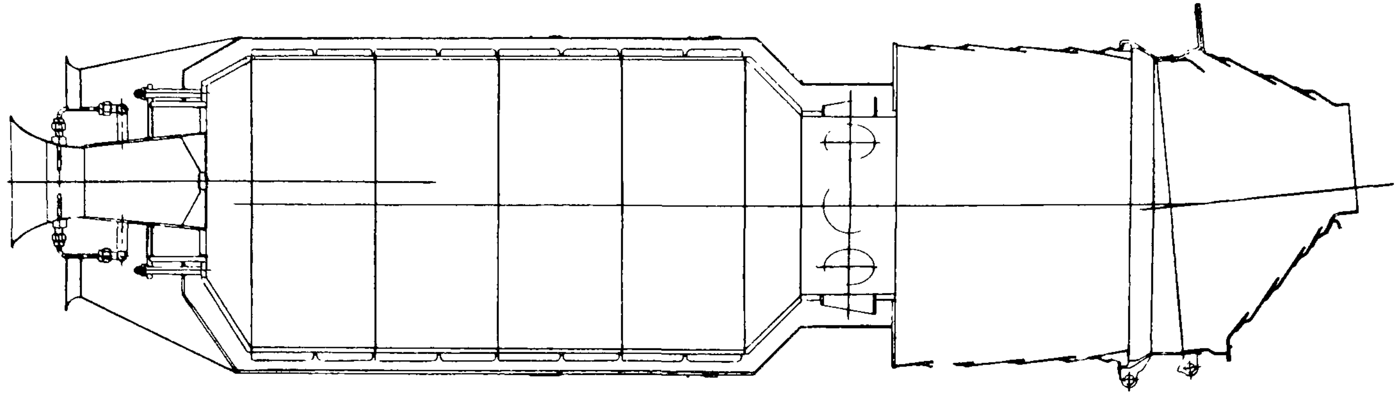

Figure A-25. Full-Scale Combustor Scheme FS-03A

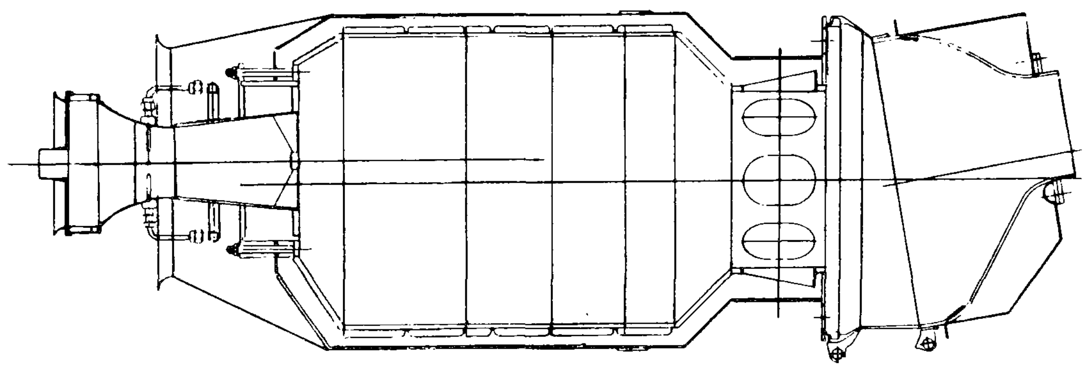

Figure A-26. Full-Scale Combustor Scheme FS-04

Program Manager: Robert M. Pierce
Telephone No: 305-840-2239

7. TEST CONDITIONS

Test conditions are summarized in Table A-57 below. (For a complete list of test parameters, see referenced document.)

TABLE A-57. TEST CONDITIONS

Combustor Configuration	Fuel Type	Power Level	Inlet Air Temp., °F	Rig Pressure psia
FS-03A	No. 2 fuel with 0.5% N	100%	400	50
FS-03A	No. 2 fuel, No. 2 fuel with 0.5% N	100%	450	50
FS-03A	No. 2 fuel, No. 2 fuel with 0.5% N	100%	575	100
FS-03A	Shale DFM	100%	475	50
FS-03A	Shale DFM	100%	570	100
FS-03A	No. 2 fuel	100%	570	100
FS-04B	Shale DFM	Idle	320	40
FS-04B	Shale DFM	50%	550	96
FS-04B	No. 2 fuel	Idle	320	40
FS-04B	No. 2 fuel	50%	550	96

8. ENVIRONMENTAL MONITORING

NO_x, CO, and unburned hydrocarbons.

9. PROJECT STATUS

Research was conducted from 1 January 1978 through 12 April 1979. Final report is dated January 1980.

10. RESULTS

The results of the Rich Burn/Quick Quench combustor emission tests are summarized in Figures A-27 through A-34, and highlighted below.

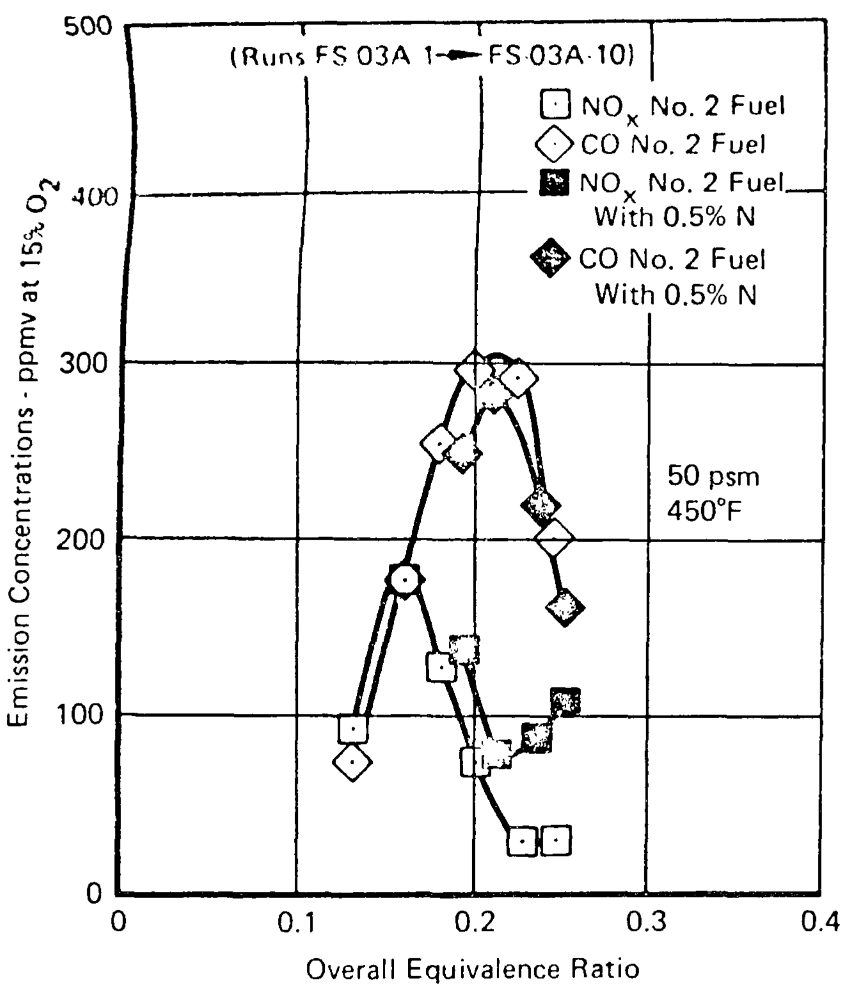

Figure A-27.
Variation in Emission Concentrations with Overall Equivalence Ratio for Scheme PS-03A, First Test Series

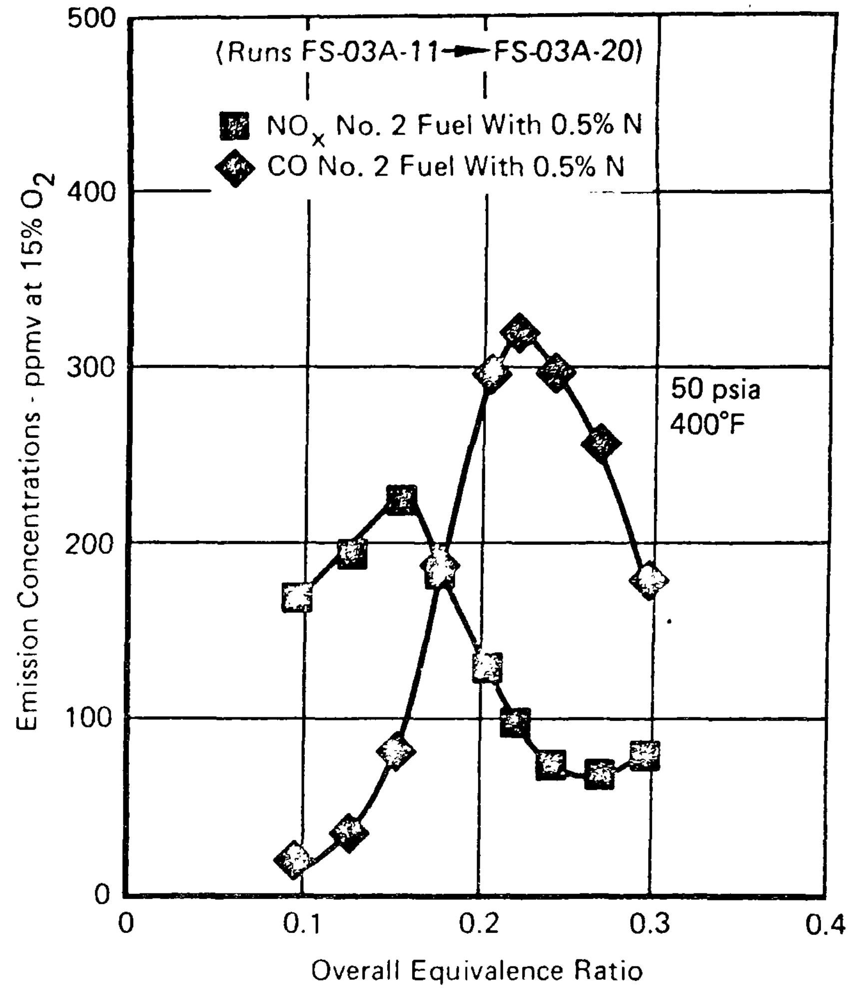

Figure A-28.
Variation in Emission Concentrations with Overall Equivalence Ratio for Scheme PS-03A, Second Test Series

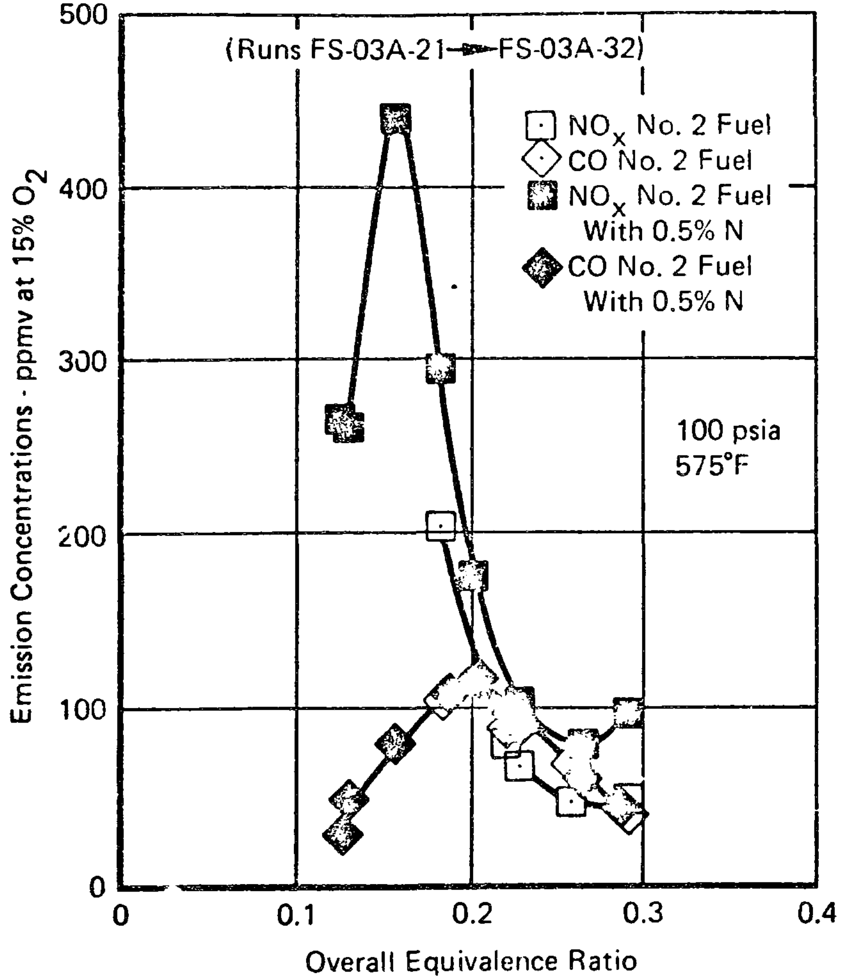

Figure A-29.
Variation in Emission Concentrations with Overall Equivalence Ratio for Scheme PS-03A, Third Test Series

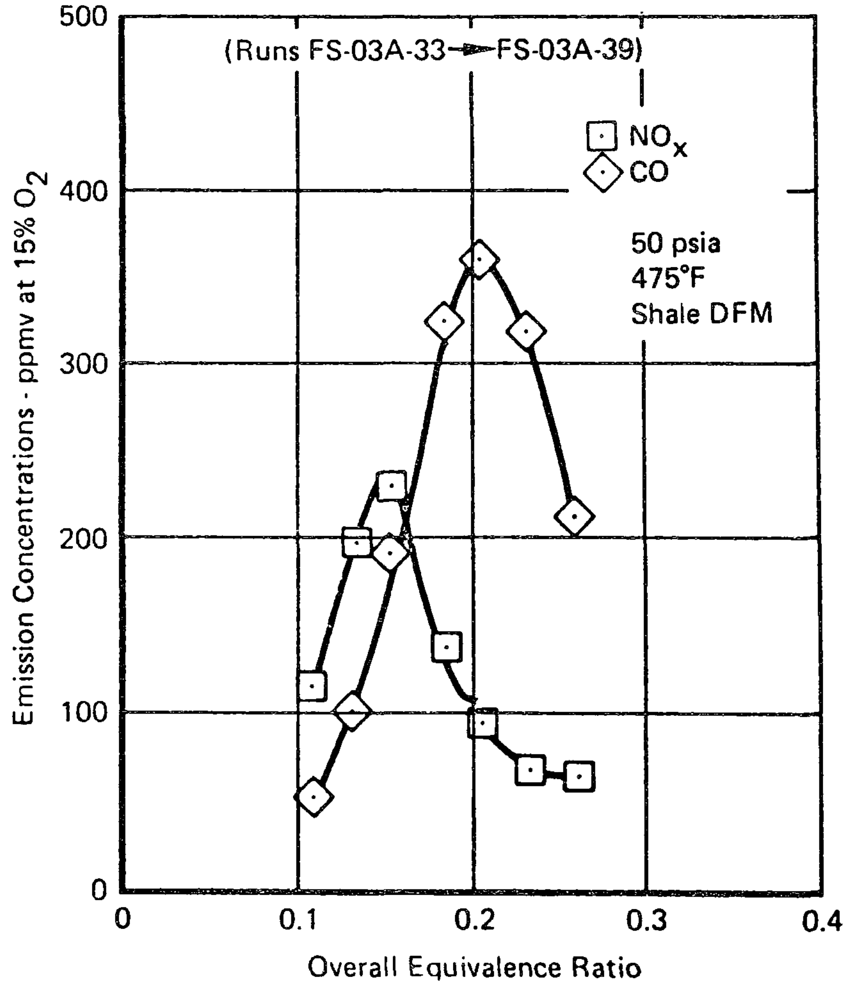

Figure A-30.
Variation in Emission Concentrations with Overall Equivalence Ratio for Scheme PS-03A, Fourth Test Series

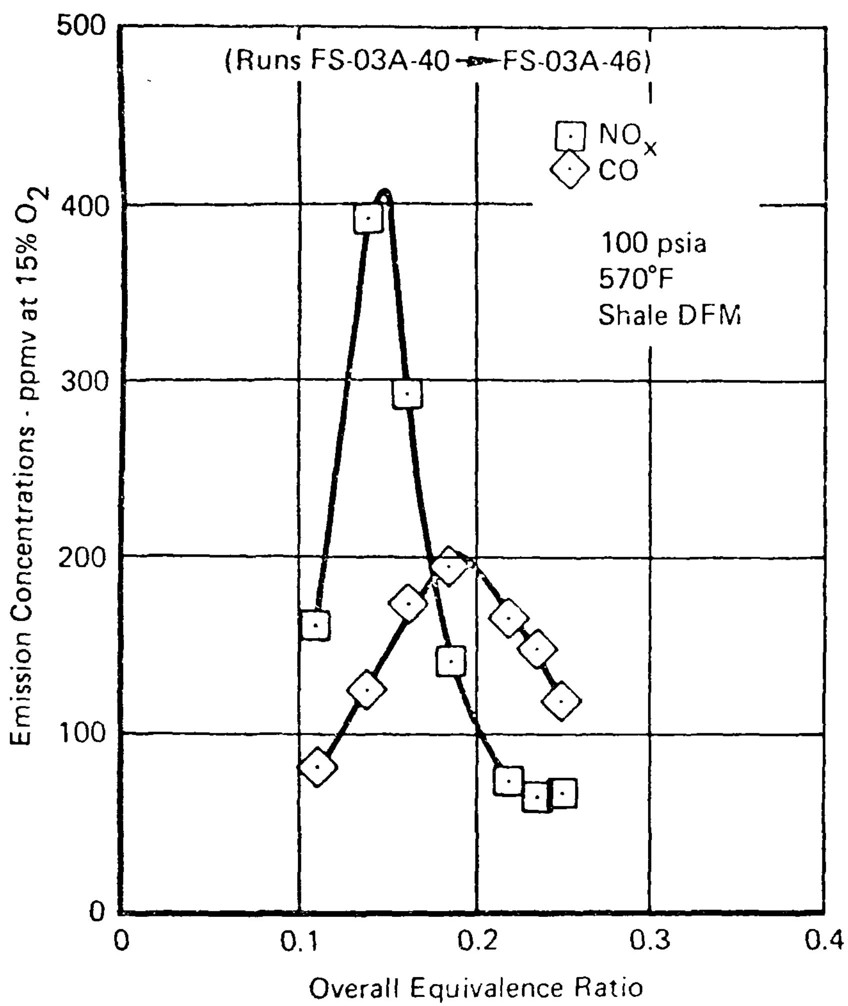

Figure A-31.
Variation in Emission Concentrations with Overall Equivalence Ratio for Scheme PS-03A, Fifth Test Series

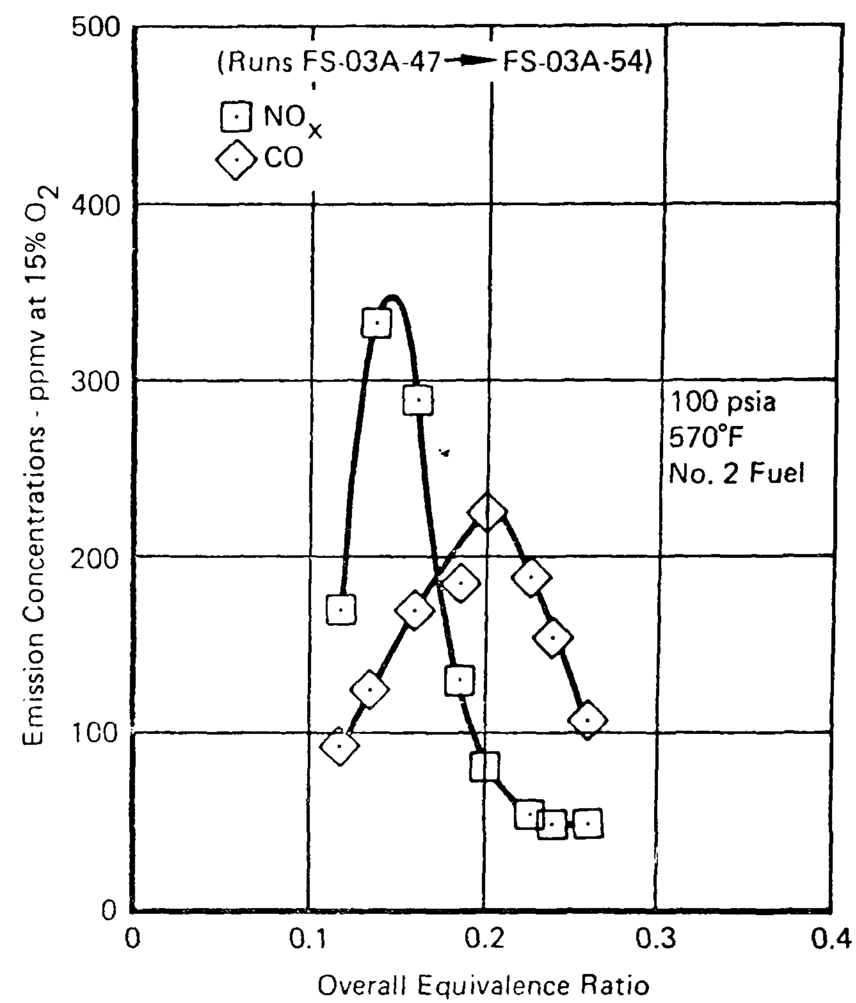

Figure A-32.
Variation in Emission Concentrations with Overall Equivalence Ratio for Scheme PS-03A, Sixth Test Series

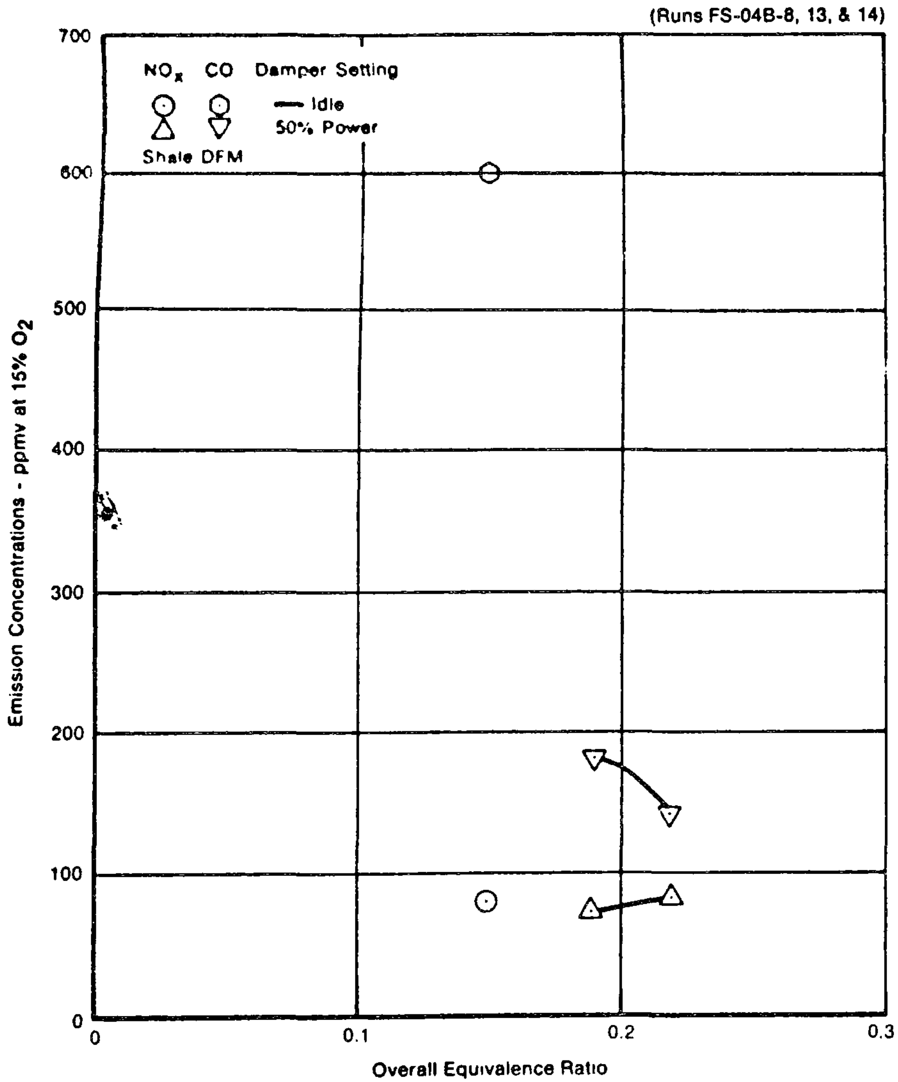

Figure A-33.
Variation in Emission Concentrations with Overall Equivalence Ratio for Scheme FS-04B Firing Shale DFM

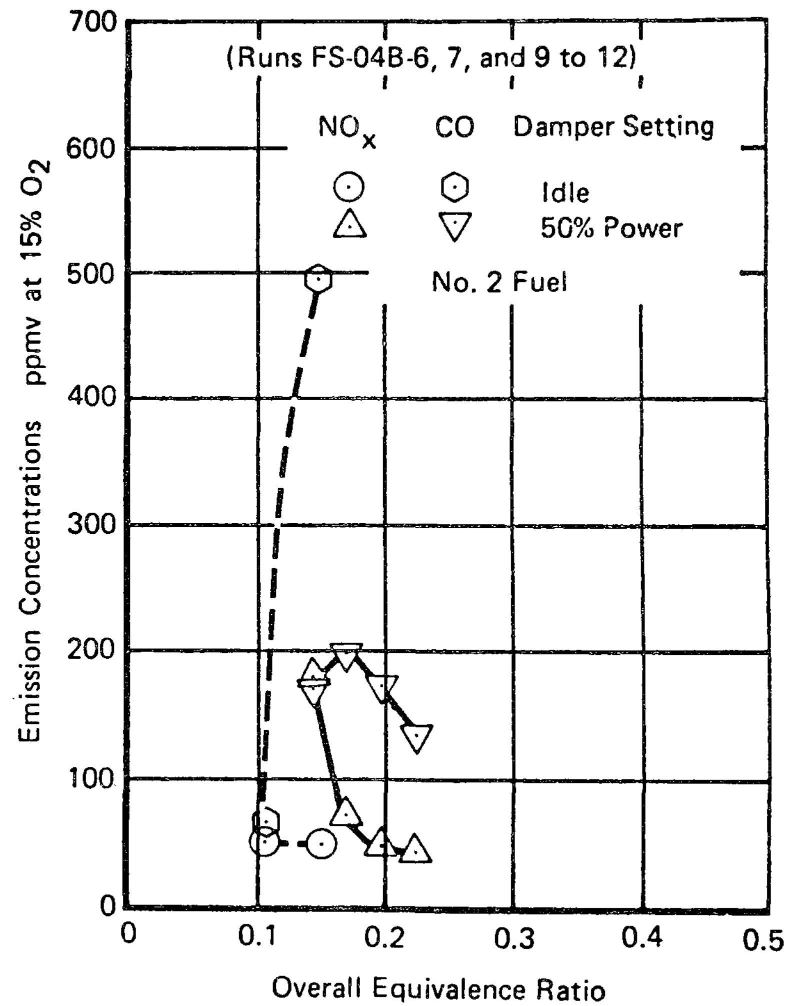

Figure A-34.
Variation in Emission Concentrations with Overall Equivalence Ratio for Scheme FS-04B Firing No. 2 Fuel

- Both combustor configurations (longer and shorter primary zone residence lengths) met emission goals of the program on both non-nitrogenous and nitrogen-bearing fuels.
- The Rich Burn/Quick Quench combustor also met the program emission goal while operating on a shale-derived diesel fuel marine. This indicates the potential for handling other alternative fuels (both shale oil and coal derived) by this combustion concept.
- Variable geometry was successfully employed to vary the airflow admitted into the primary combustion volume. This demonstrated the ability to meet the program emission goals over the range of operating conditions experienced in a typical 25-Mw GTE.
- Unburned hydrocarbon emissions from combustor FS-03A ranged from 0.9-7.3 ppmw for No. 2 fuel; 1.1-21.8 ppmv for No. 2 fuel with 0.5 percent N; and 1.3-15.3 ppmv for shale DFM at 15 percent O_2.

11. REFERENCE

Pierce, R.M., C.E. Smith, and B.S. Hintan. Advanced Combustion Systems for Stationary Gas Turbine Engines: Volume III. Combustor Verification Testing. Prepared by United Technologies Corp. for U.S. Environmental Protection Agency. EPA-600/7-80-017c. January 1980.

TEST 42

ADVANCED COMBUSTION SYSTEMS FOR STATIONARY GAS TURBINE ENGINES

1. FUELS TESTED (See Table A-58)

   Synfuels: SRC-II middle distillate fuel oil and shale-derived residual oil.

   Reference fuels: No. 2 fuel and an Indonesian/Malaysian residual oil.

2. TEST EQUIPMENT (See Table A-59)

   A prototype full-scale (25 megawatt engine size) Rich Burn/Quick Quench gas turbine with two combustor configurations.

3. TEST SITE

   Pratt and Whitney Aircraft, West Palm Beach, Florida.

4. TEST OBJECTIVES

   - Identify, evaluate, and demonstrate the effects of a Rich Burn/Quick Quench combustor on NO_x formation while burning synthetic liquid and residual fuel oils.
   - Program goals were 50 ppmv NO_x (at 15 percent O_2) for non-nitrogenous fuels, and 100 ppmv NO_x (at 15 percent O_2) for oil or gas containing 0.5 percent nitrogen by weight. The goal for CO was 100 ppmv (at 15 percent O_2).

5. SPONSORING AGENCY

   U.S. Environmental Protection Agency
   Industrial Environmental Research Laboratory
   Office of Environmental Engineering and Technology
   Research Triangle Park, NC

   Project Officer: W.S. Lanier
   Telephone No: 919-541-2432

6. CONTRACTOR

   United Technologies Corporation
   Pratt and Whitney Aircraft Group
   Government Products Division
   West Palm Beach, Florida

TABLE A-58. COMPARISON OF FUEL PROPERTIES FOR TEST FUELS*

	No. 2 (Typical)	SRC-II Middle Distillate	Indonesian/ Malaysian Resid	Shale Resid
Specific Gravity	0.84 (60°F)	0.97 (60°F)	0.87 (210°F)	0.82 (210°F)
Viscosity, centistokes	5.0 (60°F)	6.3 (60°F)	11.6 (210°F)	3.3 (210°F)
Surface Tension dynes/cm	25.7 (60°F)	33.3 (60°F)	22.6† (210°F)	20.6† (210°F)
Heat of Combustion (net) Btu/lbm	18,700	17,235	17,980	18,190
Pour Point, °F	<5	<-45	61	90 (remains waxy)
Flash Point, °F	>130	>160	210	235
Ultimate Analysis				
Carbon%	87.0	85.77	86.53	86.71
Hydrogen %	12.8	9.20	11.93	12.76
Nitrogen %	<0.02	0.95	0.24	0.46
Sulfur %	0.04-0.48	0.19	0.22	0.03
Ash %	<0.003	0.001	0.036	0.009
Oxygen %	<0.09	3.89	---	0.03
Conradson Carbon, Residue %	<0.30	0.03	3.98	0.19
End Point, °F Atmos. Distillation	640	541	NA	700
Carbon/Hydrogen Ratio (by wt)	6.537	9.323	7.253	6.795
Hydrogen/Carbon Molar Ratio	1.823	1.278	1.643	1.754

*Fuel properties are given at stand delivery temperatures to be maintained in test program.

†Estimate on basis of fuel specific gravity.

TABLE A-59. SUMMARY OF COMBUSTOR DESIGN FEATURES

	Premixed Configuration (Scheme FS-05A/B)	*Nonpremixed Configuration (Scheme FS-07A)*	*High Temperature Rise Configuration (Scheme FS-08A)*
Type Combustor	Combustor Can. Convective Primary Zone Cooling. Finned Secondary Zone	Combustor Can. Convective Primary Zone Cooling. Finned Secondary Zone	Combustor Can. Convective Primary Zone Cooling. Finned Secondary Zone
Length (Primary)	19.0 in.	19.0 in.	19.0 in.
Length (Dilution)	8.0 in.	8.0 in.	8.0 in.
Length (Overall)	48.0 in. (including transition section to turbine inlet)	43.2 in. (including transition section to turbine inlet)	43.2 in. (including transition section to turbine inlet)
Outer Diameter	11.25 in.	11.25 in.	11.25 in.
Inner Diameter	9.8 in.	9.8 in.	9.8 in.
Combustor Reference Area (Primary)	75.4 in. sq	75.4 in. sq	75.4 in. sq
Type Nozzle (Initial Configuration)	Single-zone low-pressure spraybars (12 with a total of 36 holes at 0.031 dia)	Sonicore Model 281T boost-air nozzle, compressed nitrogen boost supply	Sonicore Model 281T boost-air nozzle, compressed nitrogen boost supply
Swirler (Initial Configuration)	3.20 in. O.D., 0.56 in. I.D., 15 constant solidity vanes with vented, flat centerbody (26 deg swirl angle)	4.03 in. O.D., 1.75 in. I.D., 20 vane recessed swirler (45 deg swirl angle)	4.03 in. O.D., 1.75 in. I.D., 20 vane recessed swirler (45 deg swirl angle)
Combustor Material			
Outer Liner	Type 347 SST	Type 347 SST	Type 347 SST
Inner Liner	Stellite 31 (X40)	Stellite 31 (X40)	Stellite 31 (X40)
Combustor Wall Thickness			
Outer Liner	0.0625 in.	0.0625 in.	0.0625 in.
Inner Liner	0.125 in. on diameter with 0.125 high fins	0.125 in. on diameter with 0.125 high fins	0.125 in. on diameter with 0.125 high fins
Design Point Conditions			
Fuel-Air Ratio	0.0189	0.0189	0.0292
Volumetric Heat Release	2.05×10^6 Btu/(ft^3-hr-Atm)	2.05×10^6 Btu/ft^3-hr-Atm)	2.05×10^6 Btu/ft^3-hr-Atm)
Rate Based on:			
Inlet Pressure	188 psia	188 psia	188 psia
Combustor Airflow	31.5 lb/s	31.5 lb/s	20.4 lb/s
Combustor Reference Velocity (Primary)	29.0 f/s	29.0 f/s	29.0 f/s
Combustor Total Pressure Loss	5.5%	5.5%	5.5%

Program Manager: Robert M. Pierce
Telephone No: 305-840-2239

7. TEST CONDITIONS

Inlet air temperatures (in °F), inlet total pressures (in psia), and exit equivalence ratios are given in Figures A-35 through A-42 of the results section.

8. ENVIRONMENTAL MONITORING

NO_x, CO, unburned hydrocarbons, and smoke.

9. PROJECT STATUS

Research was conducted from 1 July 1979 through 12 October 1979. Final report is dated January 1980.

10. RESULTS

The results are summarized in Figures A-35 through A-42, Tables A-60 and A-61, and highlighted below.

- All exhaust emission goals of the program were met while burning the test synfuels and Malaysian residual oil.
- Sufficient residence time - A trade-off was shown to exist between primary zone residence time and attainable NO_x emission concentrations. This trade-off, however, appears to be asymptotic with increasing residence time. It is thought that the level of the asymptote (NO_x) is a function of the degree to which each of the critical features of the concept were executed.
- It was also shown in this program that the Rich Burn/Quick Quench concept essentially eliminates the adverse effect that increased pressure can have on NO_x formation (this effect is very evident in lean combustion and is ordinarily found to be proportional to the square root of the pressure ratio).

11. REFERENCE

Pierce, R.M., C.E. Smith, and B.S. Hintan. Advanced Combustion Systems For Stationary Gas Turbine Engines: Vol. IV. Combustor Verification Testing (Addendum). Prepared by United Technologies Corp. for U.S. Environmental Protection Agency, EPA-600/7-80-017d. January 1980.

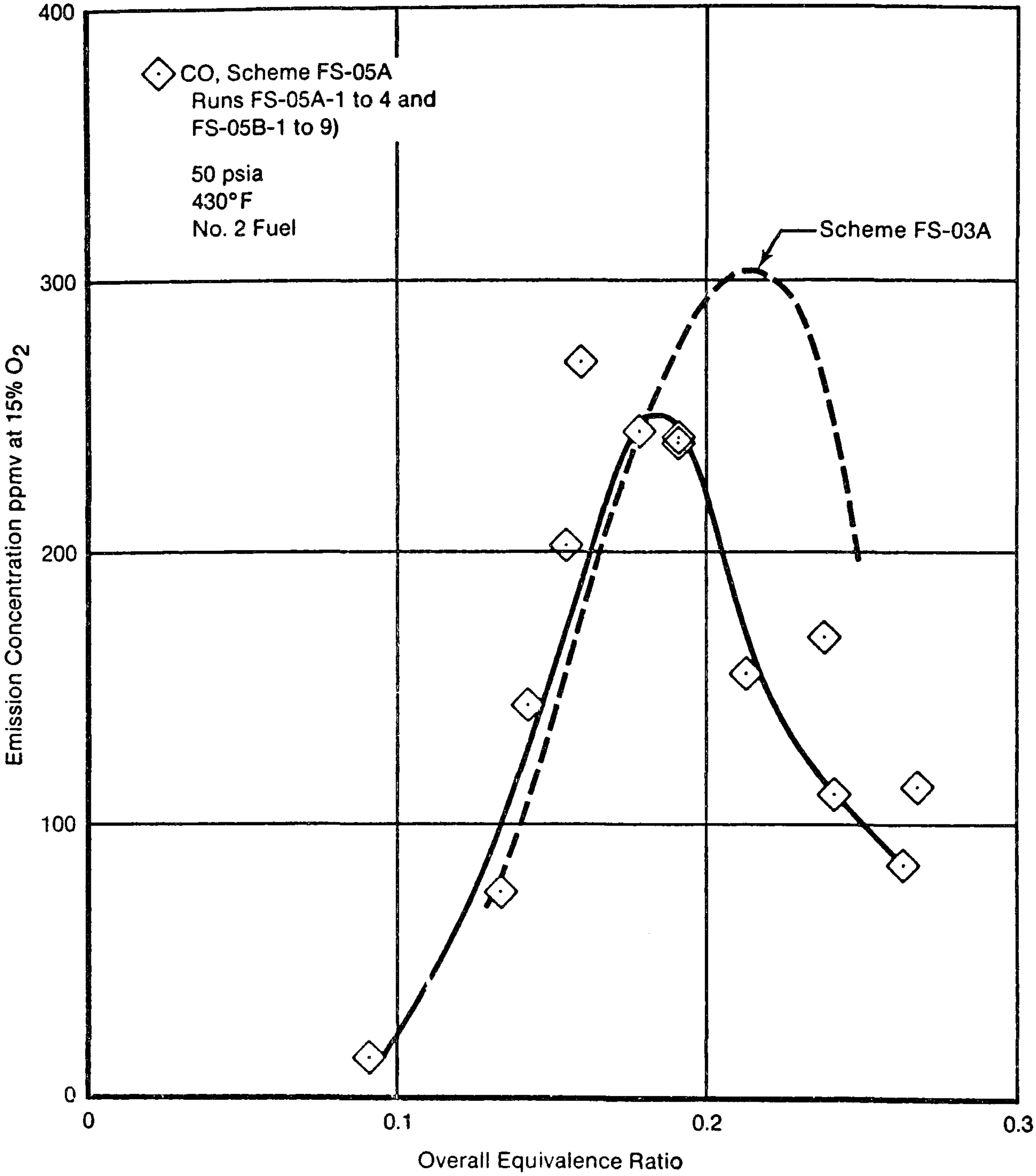

Figure A-35. Comparison of Variation in CO Concentration With Overall Equivalence Ratio for Schemes FS-05A, FS-05B, and FS-03A

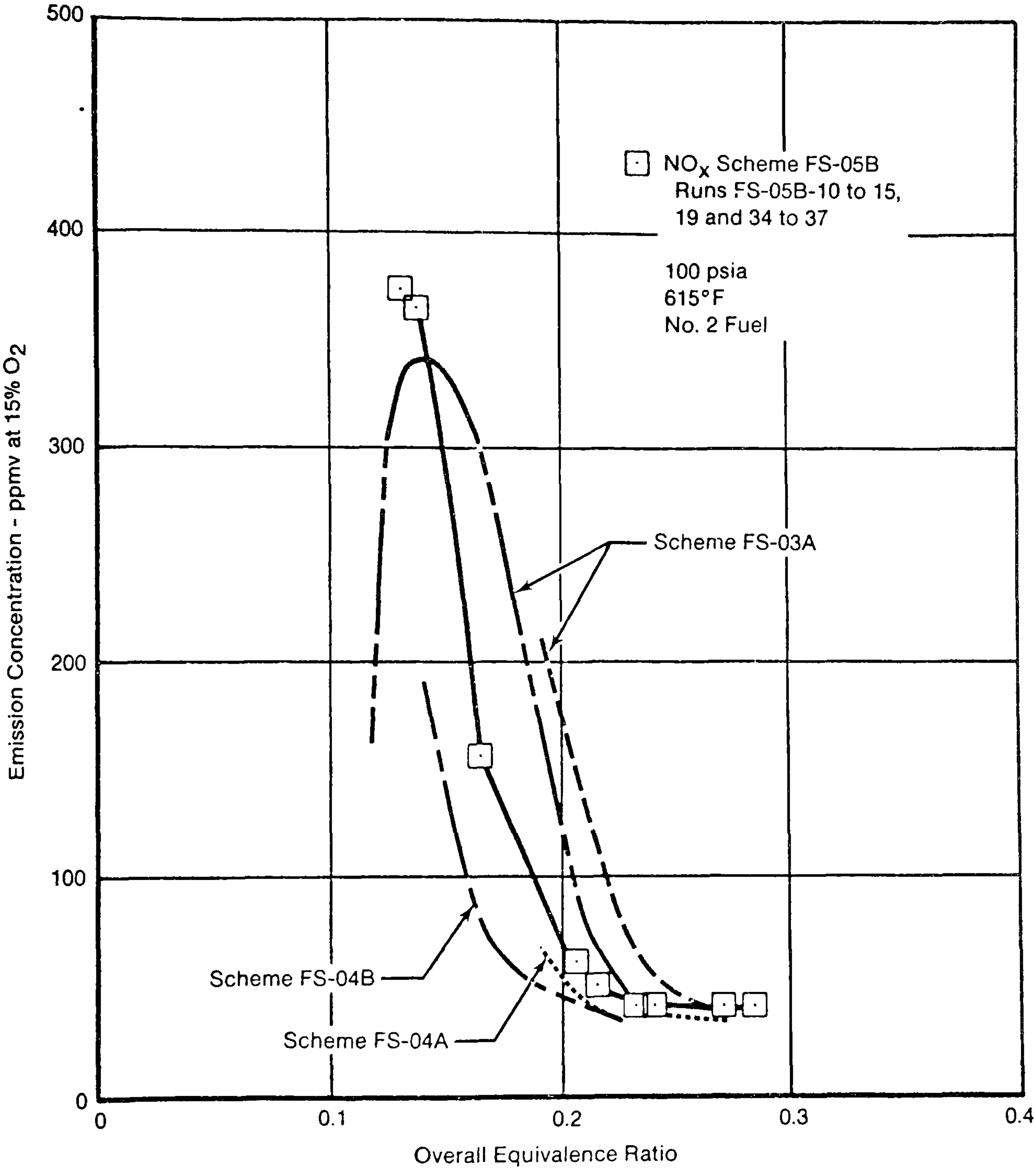

Figure A-36. Comparison of Variation in NO_X Concentration With Overall Equivalence Ratio for Schemes FS-05B, FS-03A, FS-04A, and FS-04B

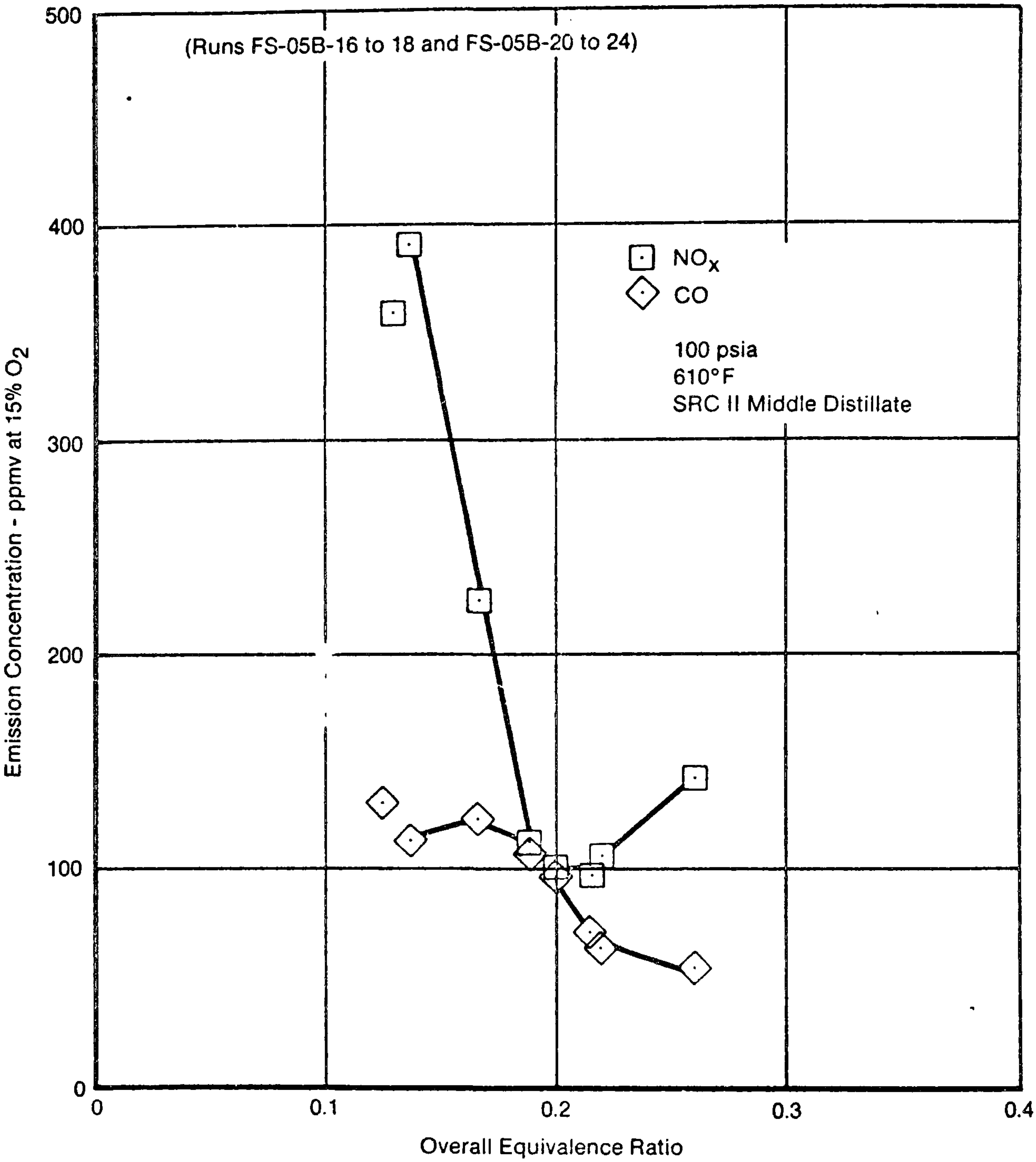

Figure A-37. Variation in Emission Concentrations With Overall Equivalence Ratio for Scheme FS-05B Using SRC-II Middle Distillate Fuel

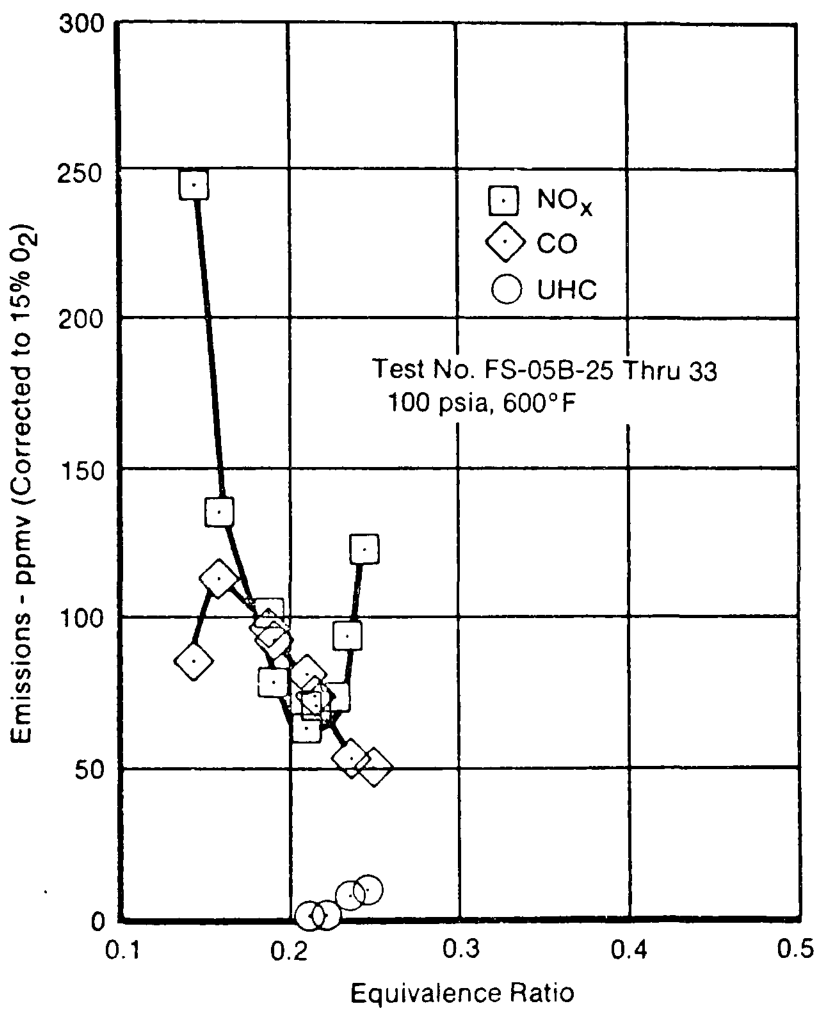

Figure A-38. Emission Signature of Scheme FS-05B Firing Shale Residual

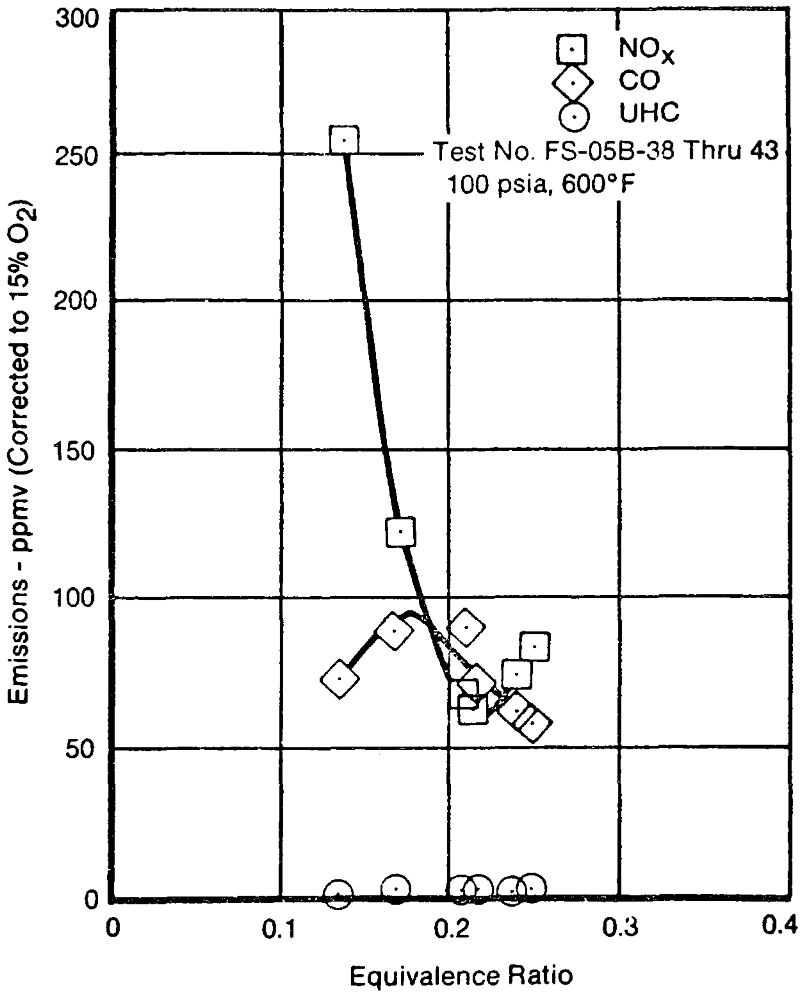

Figure A-39. Emission Signature of Scheme FS-05B Firing Indonesian/Malaysian Residual

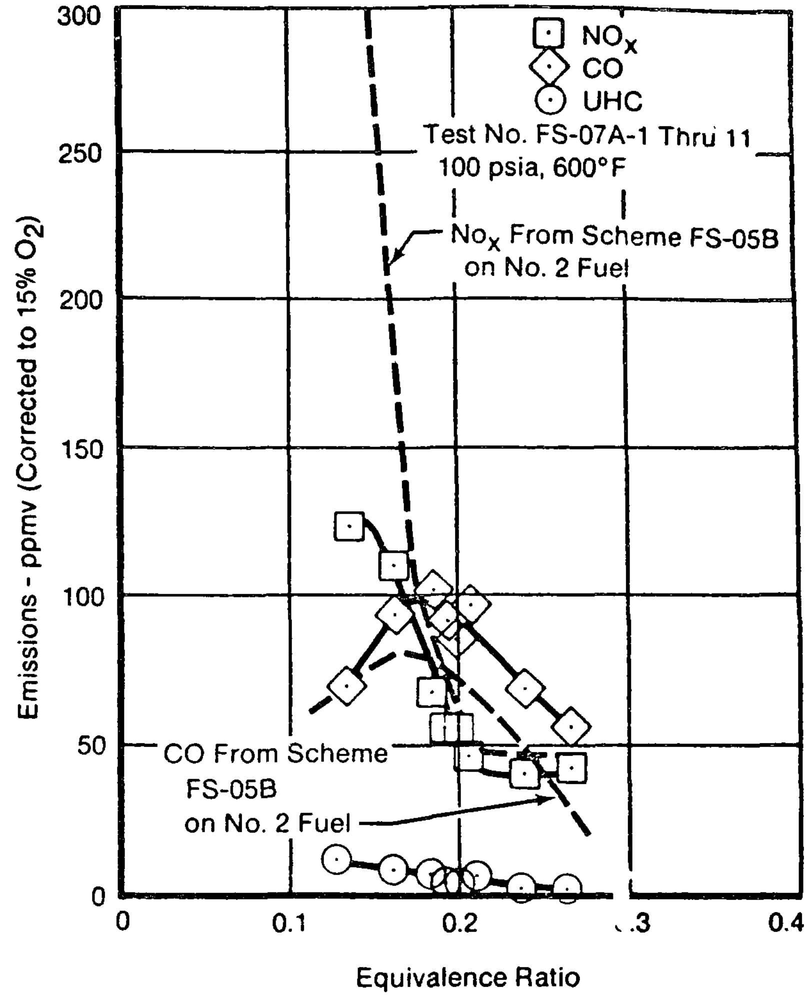

Figure A-40. Emission Signature of Scheme FS-07A Firing No. 2 Fuel

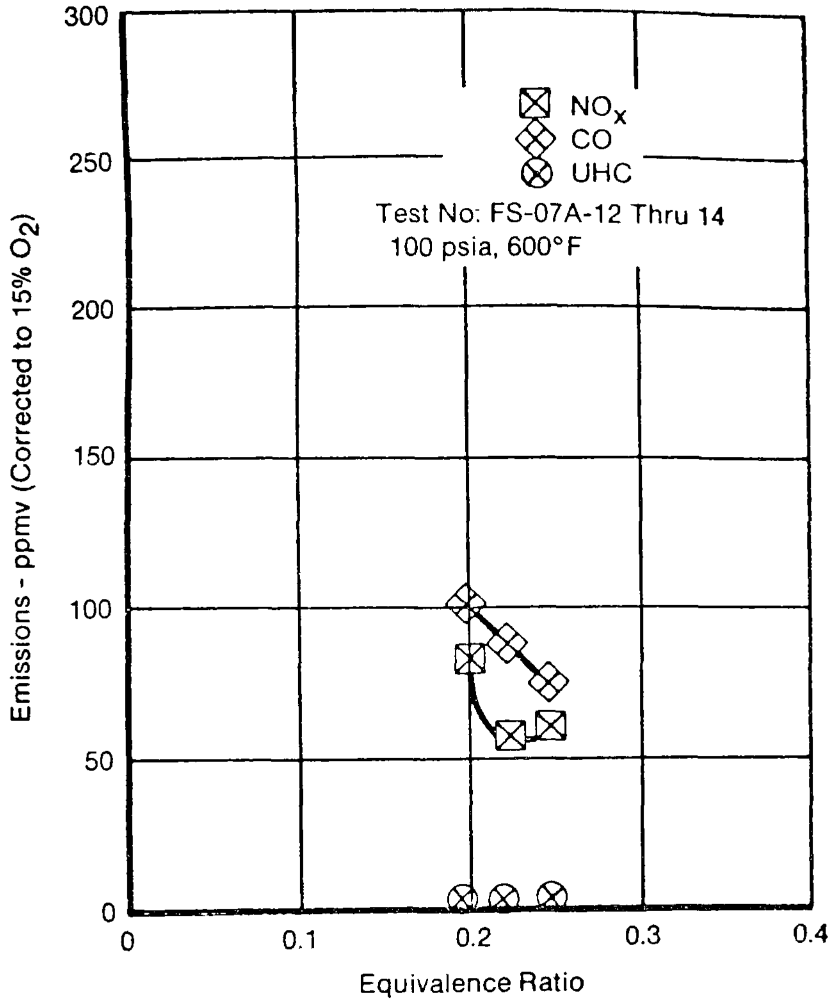

Figure A-41. Emission Signature of Scheme FS-07A Firing Indonesian/Malaysian Residual

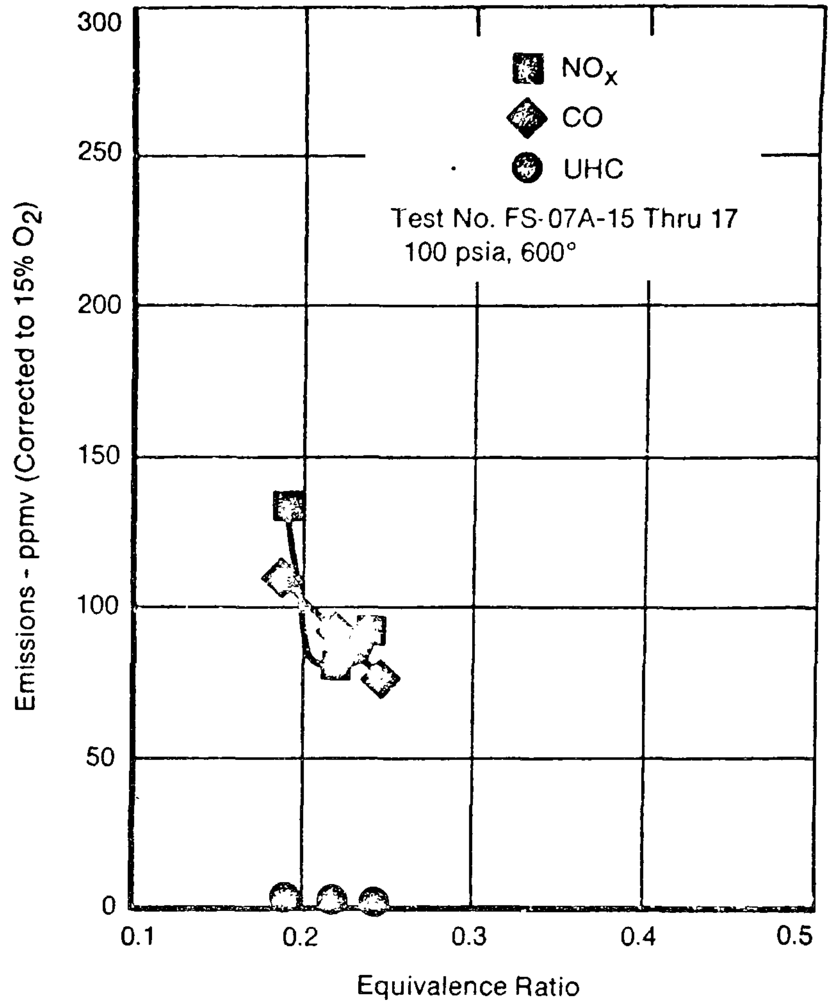

Figure A-42. Emission Signature of Scheme FS-07A Firing SRC-II Middle Distillate

TABLE A-60. SUMMARY OF SAE SMOKE NUMBERS

Fuel	*Combustor Configuration*	*Test No.*	*Equivalence Ratio*	*Approximate Primary Zone Condition**	*SAE Smoke No. (ARP 1179)*
No. 2 Fuel	Premixed	FS-05B-36	0.1265	3	1.8
	Nonpremixed	FS-07A-1	0.1354	3	0.7
		FS-07A-6	0.2629	2	43.5
		FS-07A-11	0.1988	1	13.9
SRC II Middle Distillate	Premixed	FS-05B-22	0.2134	1	9.9
		FS-05B-23	0.2590	2	44.9
		FS-05B-24	0.1269	3	1.6
	Nonpremixed	FS-07A-16	0.2190	1	31.0
Shale Resid.	Premixed	FS-05B-32	0.1818	1	14.0
		FS-05B-33	0.2490	2	42.6
	Nonpremixed	—	—	—	Not tested
Indo/Malaysian Resid.	Premixed	FS-05B-42	0.2370	2	51.2
		FS-05B-43	0.2047	1	46.3
	Nonpremixed	FS-07A-14	0.1949	1	23.2

* 1 — primary equivalence ratio near the bottom of the NO_x bucket
2 — primary equivalence ratio overly fuel rich
3 — lean primary equivalence ratio

TABLE A-61. SUMMARY OF APPROXIMATE NITROGEN CONVERSION RATES

Fuel	*Scheme FS-05B*	*Scheme FS-07A*	*Complete Conversion of Fuel N to NO_x (15% O_2)*
SRC II (0.95% N)	12%	9%	424 ppmv
Shale Resid (0.46% N)	12%	Not Tested	185 ppmv
Indo/Malay. Resid (0.24% N)	24%	15%	102 ppmv

TEST 43

EVALUATION OF NO_x EMISSION CHARACTERISTICS OF ALCOHOL FUELS FOR USE IN STATIONARY COMBUSTION SYSTEMS

1. FUELS TESTED* (See Table A-62)

   Reference fuels: residual oil, distillate oil, natural gas, propane, isopropanol, methanol, and 50 percent methanol and isopropanol.

2. TEST EQUIPMENT

   An experimental refractory wall furnace designed and constructed by Aerotherm/Acurex to maintain a nominal 87,864 watts and a Dowtherm-cooled furnace designed and constructed by Ultrasystems, Inc., to incorporate the significant features of a firetube package boiler (1 MW).

3. TEST SITE

   Refractory wall furnace test: EPA (in house), IERL/RTP.
   Package boiler test: Ultrasystems, Inc., Irvine, California.

4. TEST OBJECTIVE

   - Evaluate combustion data on alcohol fuels in smaller stationary boilers and furnaces and compare the emission characteristics to those generated from conventional fuels.

5. SPONSORING AGENCY

   U.S. Environmental Protection Agency
   Combustion Research Branch
   Industrial Environmental Research Laboratory
   Research Triangle Park, N.C.

   Project Officer: G. Blair Martin
   Telephone No: 919-541-7504

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

TABLE A-62. FUEL PROPERTIES

Fuel	Chemical Formula	Fuel Type	Higher Heating Value 10^7 J/Kg
Refractory Wall Furnace Test			
Distillate oil	CH 1.78 0.025% N 0.035% S	Commercial	4.58
Propane	C_3H_8 90%	LPG	5.303
Methanol	CH_3OH	Chemical grade	2.27
Isopropanol	C_3H_7OH	Chemical grade	3.314
50% Methanol and isopropanol	Mixture	Blend of chemical grade	2.79
Package Boiler Test			
Residual oil	C/H = 0.633 0.36% N	Commercial	---
Distillate oil	C/H = 0.565 0.05% N	Commercial	---
Natural gas	CH_4+	Commercial	---
Methanol	CH_3OH	Commercial grade	---

6. CONTRACTOR

Ultrasystems, Inc.
Irvine, California

7. TEST CONDITIONS

The refractory wall furnace tests were conducted under the following conditions: (1) nominal nozzle flow and water content of selected fuels as shown in Table A-63; (2) 115 percent theoretical air for all runs; (3) all fuels were run at swirl block positions 2, 4, 6, and 8 (increasing tangential air); and (4) flue gas recirculation run at swirl block position 4 with distillate oil, propane, methanol, and isopropanol.

The package boiler simulator tests were conducted under the following conditions: (1) a baseline burner air distribution of 50 percent primary

TABLE A-63. LIQUID FUEL NOZZLE SELECTION

Fuel	Water Content Mass % of Total Flow	Nominal Nozzle Flow Rate x 10^{-6} cu.m./sec.
Distillate oil	0	2.103
	21	2.629
	32	3.15
	42	3.68
	54	4.206
Isopropanol	0	3.15
	29	5.258
50% Isopropanol and 50% Methanol	0	4.206
Methanol	0	5.25

and 50 percent secondary air; (2) baseline excess air was chosen to be 17 percent with variations up to 90 percent; and (3) full load heat release of 1 MW.

8. ENVIRONMENTAL MONITORING

NO_x, NO, CO, hydrocarbons, aldehydes.

9. PROJECT STATUS

Project complete. Final report dated 1977.

10. RESULTS

The results of the refractory wall furnace tests are highlighted below and in Figures A-43 through A-45.

- NO emission levels for the five fuels were as follows: distillate oil > propane > isopropanol > alcohol mixture > methanol.
- NO emissions decreased with increasing tangential air swirl for the alcohol fuels.
- NO trend for alcohol fuels is more similar to that for propane than that for distillate oil.

- NO emissions for all fuels decreased with increasing fraction of flue gas recirculation.
- Theoretical flame temperature is an important factor in explaining reduced NO phenomenon.
- CO and hydrocarbon emissions were always below 50 ppm and smoke was not observed for any fuel.

The results of the package boiler simulator tests are highlighted below and in Figures A-46 and A-47.

- NO emissions for methanol were virtually constant at about 50 ppm for all primary air levels, which are lower than those for residual oil, distillate oil, or natural gas.
- Residual oil NO emissions increased rapidly as excess O_2 increased to 4 percent, then leveled off, while methanol NO emissions increased linearly with increasing excess O_2.
- Methanol transferred only 23.6 percent of the heat in the combustion zone, while the residual oil transferred 36.4 percent in the same zone.
- Although there was considerable scatter in the data, aldehyde concentrations were around 10 ppm for methanol and there was no detectable difference between methanol and natural gas aldehyde concentrations.

11. REFERENCE

Martin, G.B. and M.P. Heap. Evaluation of NO_x Emission Characteristics of Alcohol Fuels for Use in Stationary Combustion Systems. In: American Institute of Chemical Engineers Symposium No. 165, Volume 73, 1977.

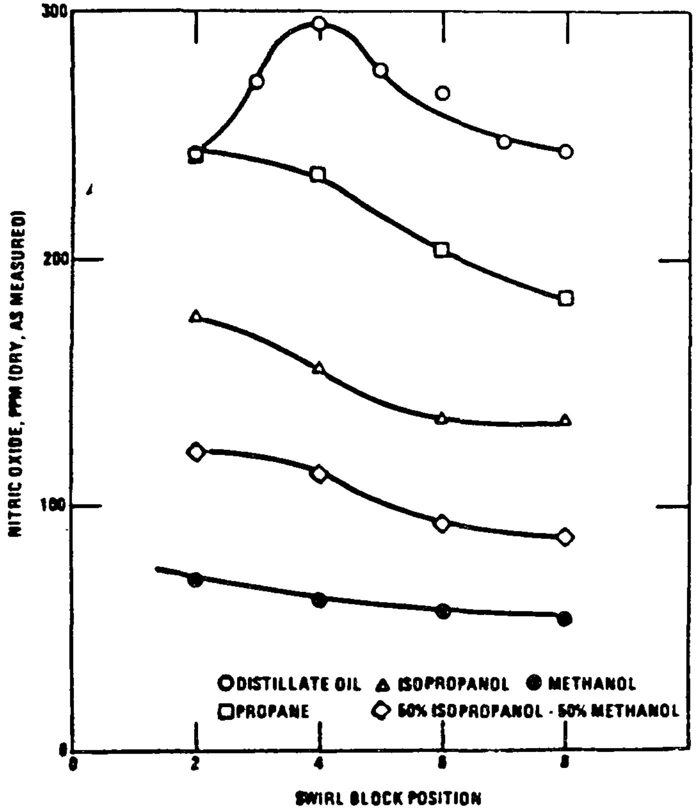

Figure A-43.

Comparison of Baseline Nitric Oxide Emissions for Various Fuels as a Function of Swirl Parameter.

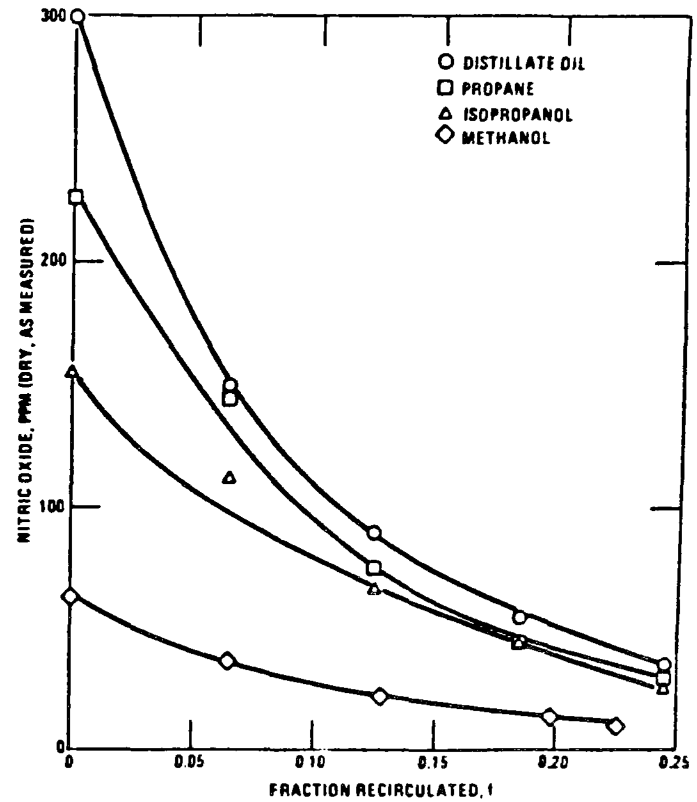

Figure A-44.

Effect of Flue Gas Recirculation on Nitric Oxide Emissions for Various Fuels.

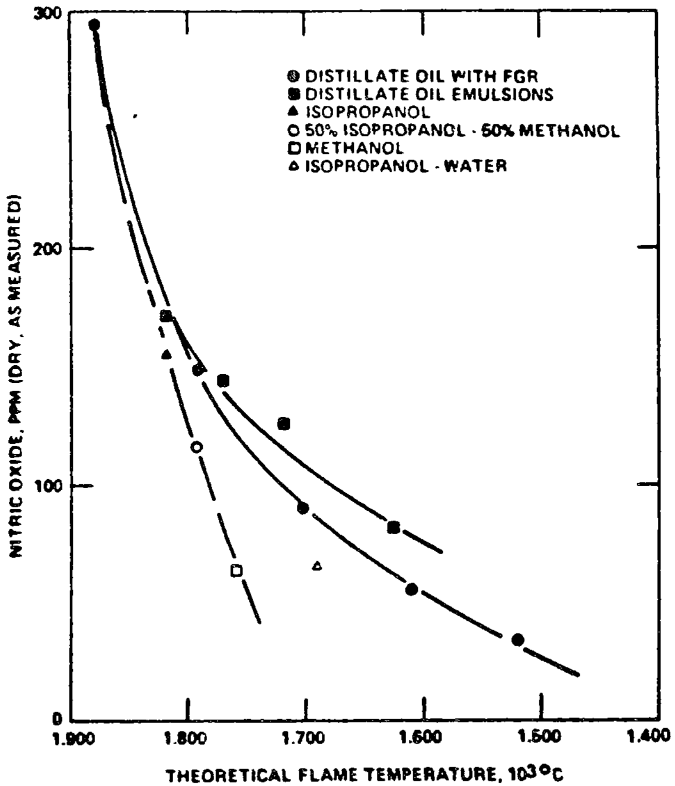

Figure A-45.

Comparison of Nitrix Oxide Emission Reduction as a Function of Theoretical Flame Temperature for Various Diluent Addition Techniques.

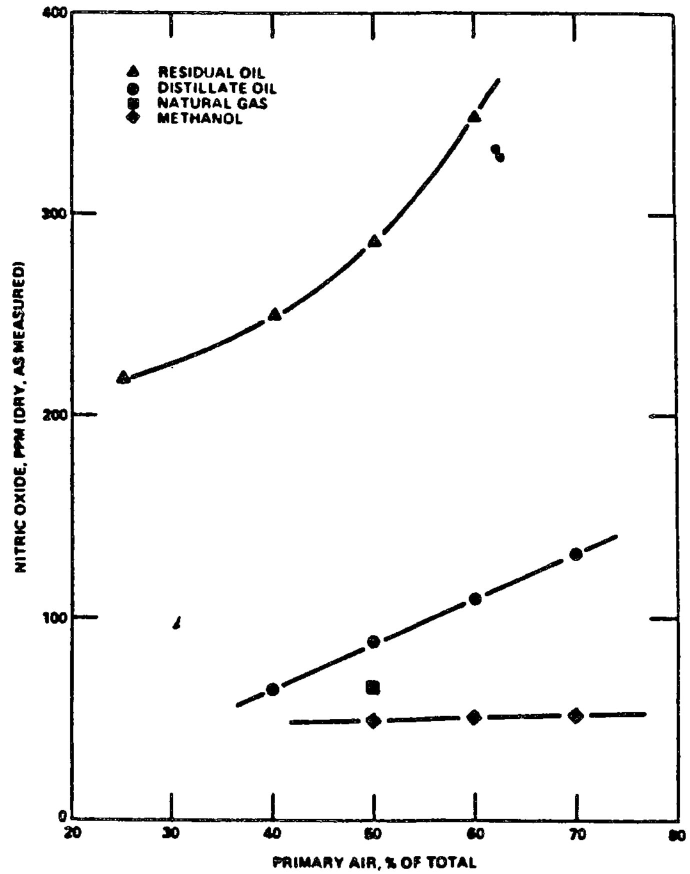

Figure A-46.

Comparison of Baseline Nitric Oxide Emissions for Various Fuels as a Function of Burner Primary Air.

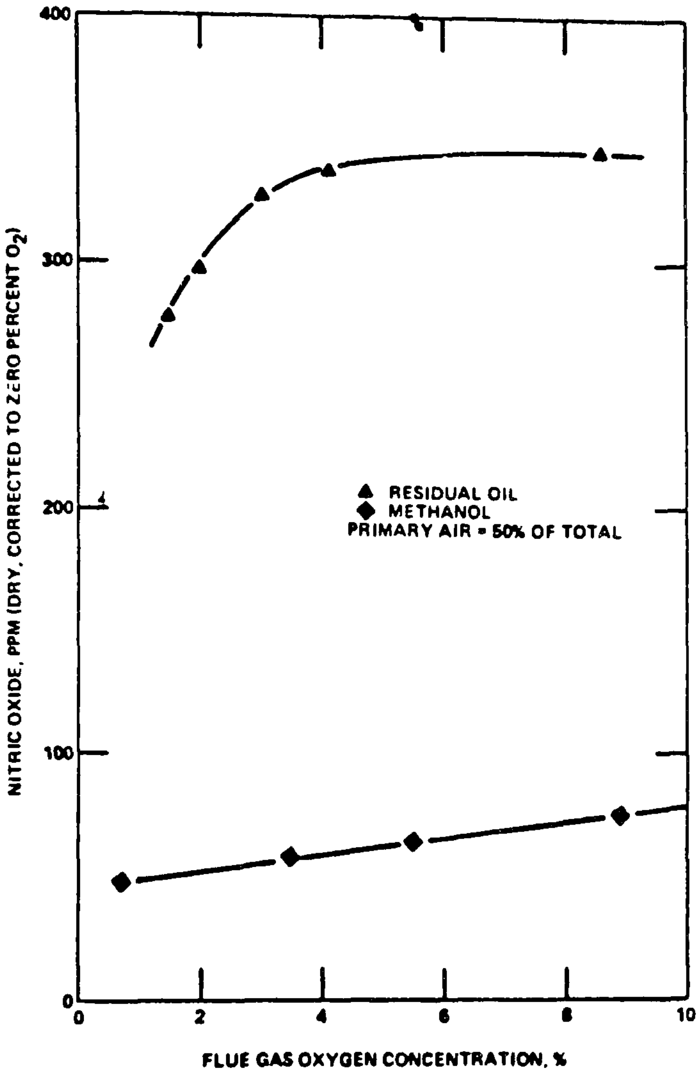

Figure A-47.

Effect of Excess Air on Nitric Oxide Emissions for Methanol and Residual Oil.

TEST 44
THE CONTROL OF NITROGEN OXIDE EMISSIONS FROM PACKAGE BOILERS

1. FUELS TESTED*

Reference fuels: methanol, natural gas, and No. 5 residual oil.

2. TEST EQUIPMENT

An industrial watertube boiler and an industrial firetube boiler.

3. TEST SITE

Essex County Correctional Center, New Jersey.

4. TEST OBJECTIVE

- Evaluate NO_X emission characteristics of alcohol and conventional fuels in industrial boilers.

5. SPONSORING AGENCY

U.S. Environmental Protection Agency
Combustion Research Branch
Industrial Environmental Research Laboratory
Research Triangle Park, N.C.

Project Officer: G. Blair Martin
Telephone No: 919-541-7504

6. CONTRACTOR

Energy and Environmental Research Corporation
2400 Michelson Drive
Irvine, California

Principal Investigator: M. P. Heap

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

7. TEST CONDITIONS

Excess air and load levels are reported in Figures A-48 through A-51 of the results. Influence of flue gas recirculation was also tested.

8. ENVIRONMENTAL MONITORING

NO_x

9. PROJECT STATUS

Project complete, report dated February 1977.

10. RESULTS

The effect of fuel type and excess air on NO_x emissions from these two boilers is shown in Figures A-48 and A-49. The No. 5 fuel oil contained approximately 0.1 percent nitrogen, which accounts for the higher emissions of that fuel. The lower emissions of the watertube boiler can be attributed to the lower volumetric heat release rate. The influence of flue gas recirculation (FGR) for both boilers at constant excess air on NO_x emissions is shown in Figures A-50 and A-51. As seen here, FGR was capable of reducing methanol NO_x emissions. The effect of excess air level on thermal efficiency is shown in Figures A-52 and A-53.

11. REFERENCE

Cichanowicz, J.E., M.P. Heap, C. McComis, R.E. McMillan, and R.D. Zoldak "The Control of Nitrogen Oxide Emissions From Package Boilers", February 1977. EPA Contract 68-02-1498.

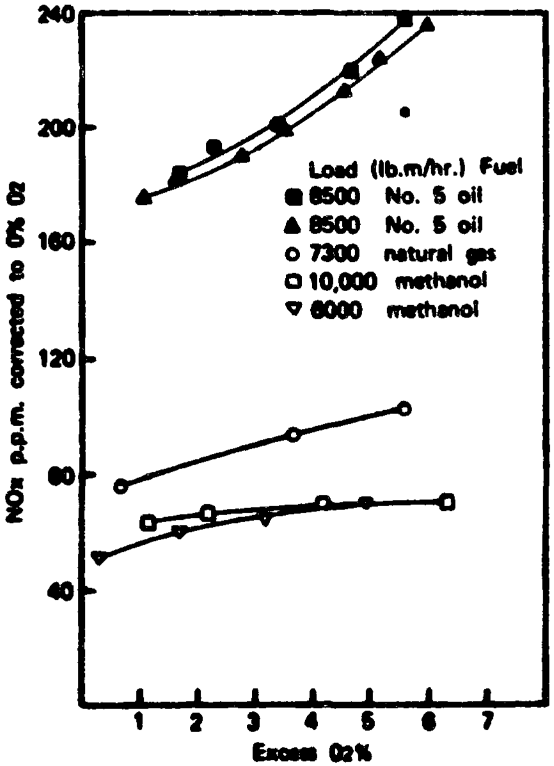

Figure A-48.
NO_x Emissions From a Firetube Boiler As a Function of Fuel Type and Excess Oxygen.

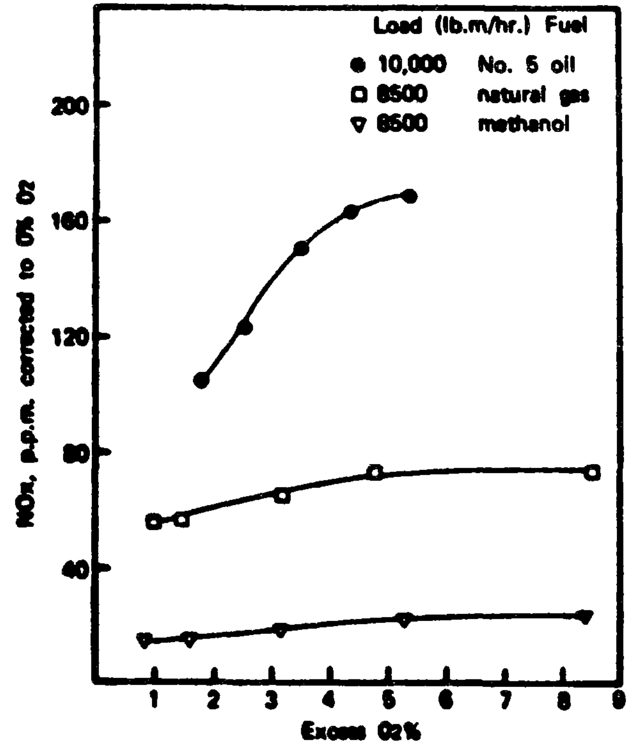

Figure A-49.
NO_x Emissions From a Watertube Boiler As a Function of Fuel Type and Excess Oxygen.

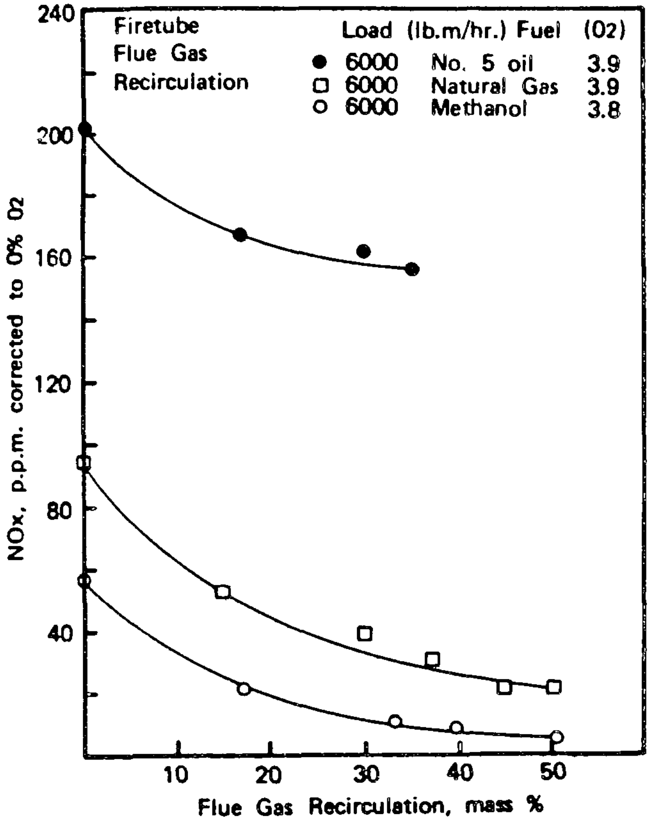

Figure A-50.
The Influence of Flue Gas Recirculation on NO_x Emissions From a Firetube Boiler

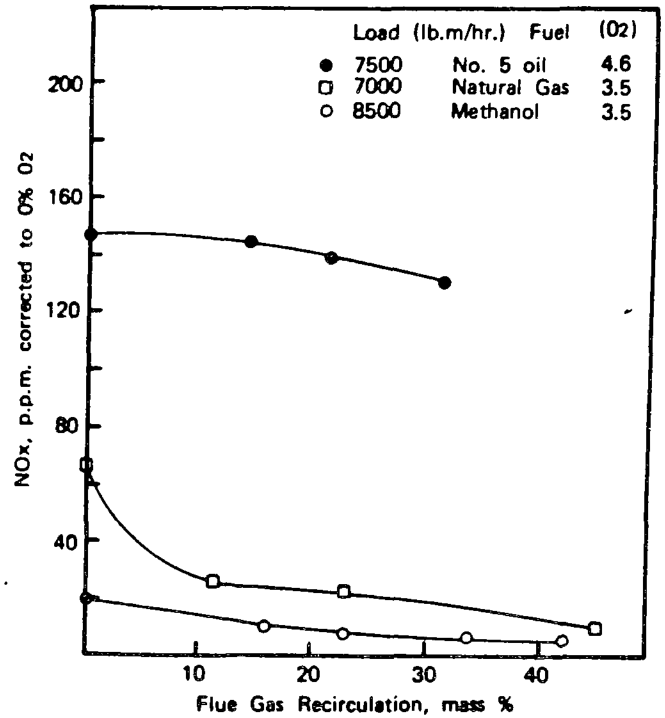

Figure A-51.
The Influence of Flue Gas Recirculation on NO_x Emissions From a Watertube Boiler

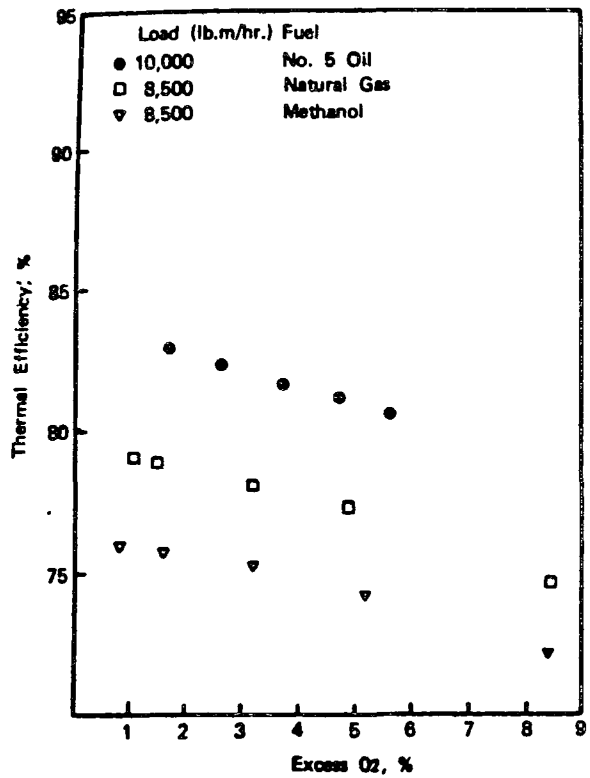

Figure A-52.
The Effect of Excess Air Level and Fuel Type on the Thermal Efficiency of a Watertube Boiler

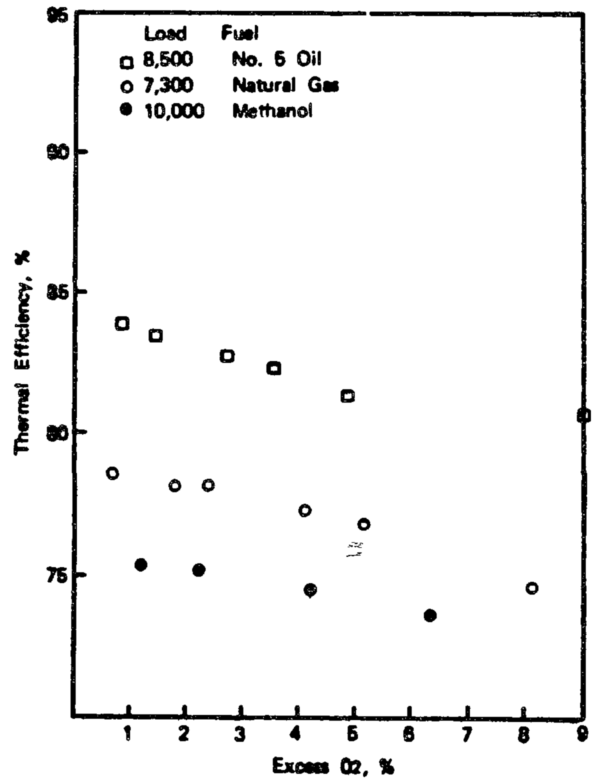

Figure A-53.
The Effect of Excess Air Level and Fuel Type on the Thermal Efficiency of a Firetube Boiler

TEST 45

IMPACT OF GASOHOL ON AUTOMOBILE EVAPORATIVE AND TAILPIPE EMISSIONS

1. FUELS TESTED* (see Table A-64)

   Non-synfuels: Indolene clear (Fuel 1); Indolene with added ethanol (Fuel 2); summer-grade unleaded regular octane fuel with and without added ethanol (Fuels 3 and 4); and blended gasohol with added ethanol (Fuel 5).

2. TEST EQUIPMENT

   Descriptions of the two light duty vehicles tested are provided in Table A-65.

3. TEST SITE

   "Raleigh Road Route", North Carolina. EPA Environmental Research Center, RTP, North Carolina.

4. TEST OBJECTIVE

   - To examine the impact of gasohol on vehicle evaporative and tailpipe emissions.

5. SPONSORING AGENCY

   U.S. Environmental Protection Agency
   Mobile Sources Laboratory
   Research Triangle Park, North Carolina

   Project Officer: Frank M. Black
   Telephone No: 919 - 541-3037

6. CONTRACTOR

   Northrop Services, Inc.
   Research Triangle Park, North Carolina

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*Because of the unavailability of synfuels, the fuels used in some of these programs were not "true" synfuels (e.g., methanol-derived from natural gas was used instead of coal-derived methanol). These studies, however, are included in this report because they were conducted to show what might be expected from the combustion of actual synfuels in the indicated combustion systems.

TABLE A-64. TEST FUEL SPECIFICATIONS

Specification	1	2	3	4	5
RVP	9.15	9.10	9.85	9.65	9.40
IBP, °F	91	101	89	95	94
10	138	129	124	121	124
50	238	212	231	213	242
90	322	320	361	356	362
EP	341	359	405	413	408
Ethanol (% vol)	1.4	6.2	0.86	8.1	10.1
API gravity	59.8	58.7	57.5	56.5	52.6
FIA (% paraffin)	69.7	67.5	52.1	46.4	37.7
FIA (% olefin)	0.4	0.6	17.2	16.6	17.6
FIA (% aromatic)	28.5	25.7	29.8	28.9	34.6

TABLE A-65. VEHICLE SPECIFICATIONS

Specification	Vehicle 1	Vehicle 2
Make	Mustang II	LTD II
Manufacturer	Ford	Ford
Engine Family	302 CID	351 CID
Emissions Control	EGR, CAT, PCV, single canister (fuel tank)	EGR, AIR, CAT, PCV, dual canister (carb. & fuel tank)
Mileage	10,000	400
Inertial weight (pounds)	3,000	4,500
Fuel tank capacity (gallons)	16	21

7. TEST CONDITIONS

Each car was tested with Fuels 1-5 in sequential order. The vehicles were driven on a standard road course 44 miles long involving 13 stops and an average speed of 45 mph. One complete test included: a diurnal evaporative test; an urban dynamometer driving test; and a hot-soak evaporative test. For complete details, see referenced report.

8. ENVIRONMENTAL MONITORING

Tailpipe exhaust samples: THC, CO, CO_2, NO_x, and ethanol.

Evaporative samples: THC and ethanol.

9. PROJECT STATUS

Project complete; report is dated February 1981.

10. RESULTS

Exhaust and evaporative emission results are summarized in Tables A-66 through A-69.

- With both vehicles, the addition of ethanol to gasoline resulted in a decrease in THC and CO emissions, and an increase in NO_x emissions (lean shift in combustion due to oxygen content of ethanol).
- Use of gasohol in both cars substantially increased evaporative emissions. The aggragate change, tailpipe plus evaporative, in hydrocarbon emissions with gasohol varied from no significant change with Mustang II to a maximum increase of about 50 percent with the LTD II.

11. REFERENCE

Lang, J.M. and F.M. Black. "Impact of Gasohol on Automobile Evaporative and Tailpipe Emissions". SAE Paper No. 810 438. 23-27 February 1981.

TABLE A-66. EXHAUST EMISSION RATES FOR 1977 MUSTANG II

Fuel	Gram/mile				
	THC*	CO	NO_x	Ethanol	Fuel Economy
1	3.83	26.7	NA	0	15.5
2	2.82	19.8	1.53	0.026	14.7
3	3.15	27.0	1.27	0.002	14.3
4	1.72	17.2	1.72	0.024	17.1
5	2.66	25.5	1.48	0.044	12.8

*Sum of hydrocarbons and ethanol.

TABLE A-67. EVAPORATIVE EMISSIONS FOR 1977 MUSTANG II

Fuel	Grams				
	HCD	HCHS	Total	Ethanol	HC + Ethanol
1	0.42	10.60	11.02	0.05	11.07
2	0.32	22.10	22.40	5.59	27.99
3	0.42	18.80	19.22	0.29	19.51
4	0.34	36.10	36.44	7.80	44.24
5	0.51	22.90	23.41	6.51	29.92

TABLE A-68. EXHAUST EMISSION RATES FOR 1979 LTD II

Fuel	Gram/mile				
	THC*	CO	NO_x	Ethanol	Fuel Economy
1	0.50	12.7	1.36	0	11.3
2	0.37	9.2	1.83	0.002	11.4
3	0.60	10.3	1.85	0	11.0
4	0.46	5.7	2.20	0.012	10.9
5	0.55	7.8	2.10	0.023	11.4

*Sum of hydrocarbons and ethanol.

TABLE A-69. EVAPORATIVE EMISSIONS FOR 1979 LTD II

Fuel	Grams				
	HCD	HCHS	Total	Ethanol	HC + Ethanol
1	0.47	1.07	1.54	0.03	1.57
2	0.86	3.53	4.39	0.55	4.94
3	0.86	1.65	2.51	0.07	2.58
4	0.74	6.49	7.23	0.94	8.17
5	1.22	4.86	6.08	0.91	6.99

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

1. REPORT NO. EPA-600/7-82-015	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE A Compendium of Synfuel End-Use Testing Programs		5. REPORT DATE April 1982
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Masood Ghassemi, Sandra Quinlivan, and Michael Haro		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS TRW, Inc. One Space Park Redondo Beach, California 90278		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3174, Task 18
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 3-9/81
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Joseph A. McSorley, Mail Drop 61, 919/541-2827.

16. ABSTRACT The report gives information on major, recently completed, current, and planned synfuel end-use testing projects. It is intended to promote the flow of information between synfuel testing programs, thereby reducing the duplication of effort and enabling design and implementation of cost-effective and systematic approaches to the collection of appropriate environmental data in conjunction with on-going and planned performance testing projects. EPA plans to update this compendium to include results from current and future testing programs. Projects described in the compendium include testing of shale-derived fuels, SRC-II middle distillates, EDS fuel oils, H-coal liquids, and methanol/indolene mixtures in such equipment as utility boilers, steam generators, diesel engines (laboratory and full scale), auto engines, and other combustors. Published reports on testing and discussions with test sponsors/contractors are the sources of data for the compendium. Agencies/organizations providing input include DOD, DOE, NASA, EPRI, private synfuel developers, and engine manufacturers.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Tests	Stationary Sources	14B
Fossil Fuels	Synthetic Fuels	21D,08G
Synthetic Oils	Indolene	11H
Carbinols		07C
Combustion		21B

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