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Formulation and Evaluation of Highway Transportation Fuels From Shale and Coal Oils

Second Annual Report, 20 March 1980 to 19 March 1981, for the Project
Identification and Evaluation of Optimized Alternative Fuels

December 1981

Prepared For

U.S. Department of Energy
Assistant Secretary for Conservation and Renewable Energy
Office of Vehicle and Engine R&D
Under Contract No. AC01-79CS-50017

Alternative Fuels Utilization Program

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Second Annual Report, 20 March 1980 to 19 March 1981, for the Project

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Prepared By

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Under Contract No. AC01-79CS-50017

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Prepared For

U.S. Department of Energy
Assistant Secretary for Conservation and Renewable Energy
Office of Vehicle and Engine R&D
Washington, D.C. 20585

Alternative Fuels Utilization Program

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FOREWORD

The work reported herein was performed under Department of Energy Contract No. DE-AC01-79CS-50017 by Southwest Research Institute, San Antonio, Texas. The contract was administered by the Office of Procurement Operations, Washington, D.C. Project Manager was Dr. Ralph D. Fleming, Alternative Fuels Utilization Program, Office of Vehicle and Engine R & D, at DOE Headquarters. Technical Manager was Mr. George M. Prok, Stirling Engine and Alternative Fuels Project Office at NASA-Lewis Research Center, CLeveland, Ohio.

ABSTRACT

Project work is reported for the formulation and testing of diesel and broadcut fuels containing components from petroleum, shale oil, and coal liquids. Formulation of most of the fuels was based on refinery modeling studies in the first year of the project. Product blends were prepared with a variety of compositions for use in this project and to distribute to other, similar research programs.

Engine testing was conducted in a single-cylinder CLR engine over a range of loads and speeds. Relative performance and emissions were determined in comparison with typical petroleum diesel fuel.

With the eight diesel fuels tested, it was found that well refined shale oil products show only minor differences in engine performance and emissions which are related to differences in boiling range. A less refined coal distillate can be used at low concentrations with normal engine performance and increased emissions of particulates and hydrocarbons. Higher concentrations of coal distillate degrade both performance and emissions.

Broadcut fuels were tested in the same engine with variable results. All fuels showed increased fuel consumption and hydrocarbon emissions. The increase was greater with higher naphtha content or lower cetane number of the blends. Particulates and nitrogen oxides were high for blends with high 90% distillation temperatures. Operation may have been improved by modifying fuel injection. Cetane and distillation specifications may be advisable for future blends.

Additional multi-cylinder and durability testing is planned using diesel fuels and broadcut fuels. Nine gasolines are scheduled for testing in the next phase of the project.

ACKNOWLEDGMENTS

Several organizations supplied fuels and components to the project. Without the cooperation of the very helpful people in these organizations, this portion of the project would have been impossible. They provided not only the fuels and components, but information on their derivation and origin and where necessary, safety precautions in handling and use of the fuels. The fuel suppliers were:

E.I. DuPont de Nemours & Company
Gulf Research & Development Company
Howell Hydrocarbons, Inc.
Koppers Company, Inc.
Mobil Research & Development Corp.
Paraho Development Corp.
Phillips Chemical Company.
Phillips Petroleum Company.
Pittsburg & Midway Coal Mining Company (Gulf)
The Standard Oil Company of Ohio

Thanks are tendered to many SwRI staff members who contributed to the project. John Russell originated the project, provided guidance to keep it on track, and authored sections of the report. Brent Bailey and Jimell Erwin developed the programs for data handling and computer graphics. Julie Madden and Allen Pyle prepared data tabulations and plots. Many technicians participated in blending fuels, doing the multiple laboratory analyses, and running the many engine tests. Angie Gonzales handled typing of the draft and final versions most capably.

The use of facilities and technical support from the U.S. Army Fuels and Lubricants Research Laboratory at Southwest Research Institute is appreciated. Analytical work on numerous samples was done with the concurrence of the U.S. Army Mobility Equipment Research and Development Command (MERADCOM).

Norman R. Sefer
Principal Investigator
Southwest Research Institute

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LIST OF ACRONYMS AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AFUP	Alternative Fuels Utilization Program
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BCF	Broadcut Fuel
BHP	Brake Horsepower
BMEP	Brake Mean Effective Pressure
BSEC	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
BTU	British Thermal Unit
CLR	Coordinating Lubricant Research
CNS	Central Nervous Systems
cSt	Centistokes
DFM	Diesel Fuel, Marine
DOE	Department of Energy
EP	End Point
IBP	Initial Boiling Point
GLC	Gas Liquid Chromatography
MAE	Methyl Aryl Ether
MJ/kg	Millijoules Per Kilogram
MON	Motor Octane Number
MPG	Miles Per Gallon
MSDS	Material Safety Data Sheets
MTBE	Methyl Tertiary Butyl Ether
MTG	Methanol to Gasoline
PEL	Permissible Exposure Limit
RON	Research Octane Number
RPM	Revolutions Per Minute
RVP	Reid Vapor Pressure
SAE	Society of Automotive Engineers
SR	Straight Run
SRC	Solvent Refined Coal
TLV	Threshold Limit Valve

SUMMARY

This report covers activities during the second year of a project whose broad objective is to characterize performance and emissions of future alternative fuels derived from petroleum, shale oils, and coal liquids. The first year effort entailed defining probable compositions and physical properties of liquid hydrocarbon transportation fuels by means of refinery linear programming models and a data base containing petroleum crudes and syncrudes derived from coal and shale oils.

Refinery model cases explored the forecast 1995 baseline fuel demand plus assumed changes in vehicle population. Maximum diesel fuel or broadcut fuel options saved varying amounts of petroleum raw materials. Most of the savings occurred through the reduced volume of higway fuels resulting from better fuel economy of diesel or broadcut fueled vehicles compared to the gasoline powered vehicles they would replace.

The second year activities have included formulation and testing of R&D-scale quantities of prototype synthetic fuels based upon the projected compositions from the refining studies. These blends were tested in a single-cylinder diesel engine and compared to baseline data on typical petroleum diesel fuel. Additionally, quantities of the test fuels were furnished to other laboratories for similar projects or other types of testing.

Diesel fuels and broadcut fuels were tested in a CLR, direct injection diesel engine over a range of speed and load conditions. The engine was used as a screening tool to generate relative performance and emissions on two groups of fuels with a variety of compositions and properties.

Eight diesel fuels were tested, with the following conclusions:

- Straight Paraho shale oil DFM and JP-5 performed well with minor improvement in fuel consumption and differences in emissions related to difference in boiling range.

- Shale oil products that were well refined and blended to 45 cetane number showed no significant differences from base fuel.

- SRC-II middle distillate was used without refining at 13 to 16 volume percent in 41 to 42 cetane blends. A stable operation and normal fuel consumption were obtained, although particulates and hydrocarbon emissions were high. Odor and handling problems would preclude general use of the product at this concentration.

- At higher concentrations of 35 to 50 volume percent SRC-II distillate, engine operation was unstable at some speeds, knock was moderate to severe, and particulates emissions increased.

Seven broadcut fuels were tested in the same engine, with the following findings:

- Properties and composition of the fuel had more effect on performance and emissions than the petroleum or synthetic origins.

- All seven fuel exhibited high relative fuel consumption and high hydrocarbon emissions. These effects appeared to increase with higher percentages of naphtha in the blends.

- Blends with high 90% distillation temperatures produced high particulates and nitrogen oxides emissions.

- Operational problems for certain fuels included knock, unstable operation at low speed, and difficult starting. Performance may have been improved by modification of fuel injection. Specifications may be advisable for minimum cetane and maximum 90% point for future blends.

Future work in the project will include multi-cylinder testing of selected diesel and broadcut fuels and a limited amount of durability testing. Prototype gasolines will be evaluated in a similar program of single-cylinder screening followed by multi-cylinder and durability runs. The distribution of samples to other laboratories will continue as demand and product availability develop.

I. INTRODUCTION

A. Objectives

The project is sponsored by the Department of Energy (DOE) under the Alternative Fuels Utilization Program (AFUP). The objectives of the Project are to:

- Define chemical compositions and physical properties of alternative fuels derived from petroleum, coal, and shale oils.
- Formulate, blend, and produce R&D-scale quantities of prototype synthetic fuels.
- Identify problems associated with the use of these alternative fuels in conventional and advanced engines.
- Characterize promising fuel/engine combinations for minimum energy consumption in highway vehicle systems.

B. Organization and Approach

The four principal project activities (Tasks) into which work has been organized are:

Task 1: Synfuels Optimization-application of linear programming techniques in a variety of scenarios to define chemical and physical characteristics of alternative transportation fuels optimized for minimum costs to satisfy product demands.

Task 2: Synfuels Formulation for Experimental Evaluation-formulation and preparation of experimental batches of prototype synthetic fuels for use in laboratory and internal combustion engine evaluations. These fuel formulations will have been based upon but not limited to results developed in Task 1.

Task 3: Synfuels Formulation for Other Researchers-formulation, blending, and distribution of R&D-scale quantities of prototype synfuels as defined in Task 2 for use in laboratories other than SwRI who have programs and/or facilities in which testing of these synfuels will provide data relevant to the DOE Alternative Fuels Utilization Program.

Task 4: Synfuels Performance Evaluation-bench test and engine evaluations using SwRI facilities to screen and evaluate prototype synfuels to provide feedback information to the database established in Task 1 for further modification and refinement of linear programming modeling criteria.

C. Status

The first year's activities were devoted to Task 1: Synfuels Optimization. Bonner & Moore Associates, Inc. of Houston, Texas, constructed refinery models using their Refinery and Petrochemical Modeling System (RPMS). These linear programming models were designed to represent composite refineries in each of three regions - Rocky Mountains, Mid-Continent, and Great Lakes - where synthetic crudes are expected to have the greatest impact.

Results of the modeling studies were reported in the first annual progress report. (1)* They showed how shale oil and coal oil may be used along with petroleum crudes in the 1995 time frame. Products were made to meet forecast specifications and quantities. In addition, product options were explored for a maximum diesel fuel case replacing a significant quantity of gasoline and a broadcut fuel case also replacing a portion of the gasoline, as potential alternate fuels to conserve petroleum resources. Gasoline supplements were evaluated for 10 volume percent of methanol, ethanol, MTBE and synthetic naphtha from methanol.

This report covers work in the second year of the project on Task 2 and 3: Synfuels Formulation. Fuels were formulated and blended for use in engine evaluation and for distribution to other research laboratories engaged in similar programs and studies. The report also covers a major part of Task 4: Synfuels Performance Evaluation. Engine tests were conducted on 8 diesel fuels and 7 broadcut fuels to evaluate their performance and emissions relative to typical petroleum baseline fuels. Further work is planned in the final year of the project on gasoline engine studies and other fuel evaluation methods.

* Underlined numbers in parentheses designate references listed at the end of the report.

D. Report Contents

The following sections of the report describe various portions of the project work, as follows:

- Section II, Synfuels Formulation, covers the selection of blends from the various computer cases for diesel fuels, broadcut fuels and gasolines. Blending components from petroleum, shale and coal are described along with the blending to prepare products for evaluation. Finally the composition and properties of the diesel fuels and broadcut fuels are reported.

- Section III, Synfuels Evaluation, describes the single-cylinder engine testing equipment and procedures for diesel fuels and broadcut fuels. Both performance and emissions measurements techniques are discussed.

- Section IV, Results and Discussion, summarizes the results and compares performance and emissions from the various fuels.

- Section V, Conclusions, considers the major results from engine testing in relation to the fuels properties.

- Section VI, Future Activities, outlines the project activities scheduled for the final year of the project.

At the end of the report are the list of references and four appendices containing detailed data and supplemental information.

II. SYNFUELS FORMULATION

Results from twenty-seven computer cases presented in the first annual progress report (1) provided the foundation for the synfuels formulation task that was done in this phase of the project.

A. Selection of Blends

The plan was to select a variety of formulations for three major types of fuels - diesel fuels, broadcut fuels and gasolines- from cases in the first annual report. A major factor in the selection was to use a significant percentage of syncrude-derived stocks in the blend. Therefore, most products are from the Rocky Mountain region where syncrudes were a higher proportion of crude charge to the refinery. Also the gasoline supplements were evaluated only in the Rocky Mountain region.

The project plan also provided for synthetic fuels other than from computer cases. Diesel fuels and gasolines are included from other sources where the fuels became available with properties or origins that were applicable to the program. Fuels proposed for evaluation included eight diesel fuels, seven broadcut fuels and nine gasolines.

Diesel fuels selected for evaluation included the following:

1. Shale-derived fuels
   - Case 2A, Rocky Mountains
   - Case 3, Rocky Mountains
   - Paraho DFM
   - Paraho JP-5

2. Coal-derived fuels
   - Case 5A, Rocky Mountains
   - Case 12, Rocky Mountains
   - SRC-II Middle Distillate-Medium Cetane Blend
   - SRC-II Middle Distillate-Low Cetane Blend

The shale oil diesel fractions were provided from a project for the U.S. Navy performed by Paraho Development Company and The Standard Oil Company of Ohio.(2) The Paraho DFM and JP-5 were considered finished products but also were used as synfuel stocks for blending with petroleum components.

The SRC-II middle distillate was provided by the Pittsburg and Midway Coal Mining Company, a Gulf subsidiary. It has a low cetane number because of its high concentration of aromatics, and heterocompounds that contribute to low stability. Therefore, it would not be considered a finished engine fuel. Hydrogenation would normally be used for upgrading for use in transportation fuels. However, it was used in this study without further treatment by blending with other components to acceptable cetane number and other quality levels. Material safety data sheets provided with the product are reproduced in Appendix A along with a set of instructions to laboratory and engine technicians for handling the fuel blends containing SRC-II.

Broadcut fuel is a wide boiling range product without octane or cetane requirement for use in future fuel-tolerant engines. Broadcut fuels were made in seven of the computer cases, with a variety of compositions in petroleum and syncrude components. Blends were made similar to all seven examples, as follows:

Case No.		Region	Type
1.	Case 16	Rocky Mountains	Petroleum
2.	Case 4	Rocky Mountains	Shale-derived
3.	Case 7A	Rocky Mountains	Coal-derived
4.	Case 5	Mid-Continent	Petroleum
5.	Case 4	Mid-Continent	Shale and Coal
6.	Case 5	Great Lakes	Petroleum
7.	Case 4	Great Lakes	Shale and Coal

For simplicity, these products will be referred to as Broadcut Fuels number 1 through 7. A quantity of Paraho shale oil naphtha was provided by SOHIO for use in shale-based blends. Coal-derived naphtha was not available but a reasonable simulation was made as described later in this report. Diesel boiling range fractions from shale, coal and petroleum were also available.

The emphasis on diesel fuels and broadcut fuels in the formulation and testing phase is consistent with the objectives of the study. These two fuel types conserve crude oil and processing energy and would likely be used in engines with higher efficiency than gasoline powered engines. Therefore, they tend toward the objective of optimizing the resource/process/engine system.

It is expected that gasoline will continue as the major transportation fuel for many years because of the large number of gasoline powered vehicles and the continuing improvement being made in fuel economy of new vehicles.

Gasolines are planned for future evaluation in the project and include the following:

1. Gulf Unleaded Regular
2. Gulf Unleaded with 5 Vol% Methyl Aryl Ethers
3. Gulf Unleaded with 7 Vol% Methanol
4. Mobil MTG (Methanol to Gasoline)
5. Simulated Coal-Derived (SCD) Gasoline
6. Modified SCD with 7 Vol% Methanol
7. Modified SCD with 10 Vol% Methanol
8. Modified SCD with 10 Vol% Ethanol
9. Modified SCD with 10 Vol % MTBE

The Gulf Unleaded Regular will be used as the baseline fuel for comparison of results with the other eight gasolines. It was provided by Gulf as the base for 5 volume percent methyl aryl ethers in their evaluation of this product made from phenols present in coal liquids.(3)

Mobil MTG (methanol to gasoline) product is intended to be used as a finished gasoline without further blending. Therefore, the blends of this product in the first annual report are not representative of the most likely application and the product will be tested as a separate fuel.

The simulated coal-derived (SCD) gasoline was made with stocks blended to match hydrocarbon compositions of reformate from coal liquids. The modified SCD blends include a lower octane naphtha, blended to simulate coal naphtha and intended to control octane level of the final gasolines containing oxygenates. It was originally planned to evaluate all oxygenates at 10 volume percent of the blend. Methanol at 7 volume percent was added to obtain comparisons at the same oxygen level by weight as ethanol at 10 volume percent of the blend, consistent with recent trends in use of oxygenates. If gasoline components from shale or coal oils become available, they may be made into blends to add to or substitute in the list above.

B. Blending Components

In addition to the syncrude-derived components mentioned above, several petroleum-based components were needed for preparation of blends similar to the products compositions generated by the computer models. These were obtained in small quantities from several sources, including SOHIO, Howell Hydrocarbons, and Phillips Petroleum Company.

All components were characterized at the Army Fuels and Lubricants Research Laboratory at SwRI. Table 2.1 shows properties of components for diesel fuel and broadcut fuel blending, including 4 petroleum stocks, 3 Paraho shale oil products and SRC-II distillate from coal. Table 2.2 presents properties of eight gasoline boiling range components which could be used in gasolines or broadcut fuels.

Table 2.3 gives laboratory inspections of additional components intended for use in adjusting hydrocarbon type compositions of products, particularly for simulation of coal-derived materials. Decalin and tetralin are minimum 97% purity compounds obtained from DuPont. Tetralin-containing solution and mixed naphthalenes are coal-derived products from Koppers Company and conveniently include a variety of compounds. Composition of the tetralin solution is:

	Percent
Toluene	0.5
Ethylbenzene	9.5
p-Xylene	0.6
m-Xylene	0.6
o-Xylene	1.0
Tetralin	39.6
Naphthalene	18.8
Indene and Tetramethylbenzenes	29.4
Total	100.0

C. Blending of Fuels

The components obtained for blending had origins and properties similar but not identical to the components predicted in the computer models. Therefore, it was necessary to adjust the blend compositions, in volume percent of the various blend stocks, to match the properties of the finished blend to the computer results.

For example, most of the actual diesel fuel components were higher cetane than the computer basis, so a blend of the same volumetric composition would be well above the target 45 cetane number. Calculations were made to adjust cetane number to 45 by adding light cycle oil (26 cetane number) and making minimum change in proportions of other components to match distillation curves.

At the other extreme, SRC-II middle distillate had a low 16.2 cetane number in its untreated state, and an even lower cetane blending number. The computer model used a literature data value of 26.7 cetane blending number. Therefore, the proportion of coal-derived distillate in the blends was reduced to aim for 45 cetane product.

Broadcut fuel blend compositions were also adjusted to accommodate three specifications - Reid vapor pressure, distillation curve and sulfur content. Normal butane was used to control vapor pressure. Light and heavy fractions were shifted slightly to modify distillation curves. Light cycle oil was added in most cases to raise sulfur content; this component also probably lowered the blend cetane number but this quality was not calculated. Table 2.4 summarizes the calculated properties of 8 diesel fuels and 7 broadcut fuels before the actual blends were made.

Blends were made of SRC-II middle distillate with No. 2 diesel baseline fuel to derive cetane blending numbers and to guide the formulation of test fuels. Properties of the two stocks and blends at 25 volume percent increments are listed on Table 2.5. Figure 2.1 shows that cetane number does not vary linearly with composition and, therefore, cetane blending number varies with concentration in the blend.

TABLE 2.1 PROPERTIES OF BLENDING COMPONENTS FOR DIESEL AND BROADCUT FUELS

Component Sample No.	St. Run Kerosene AL-9749-F	Hydrocracker Kerosene AL-9998-F	St. Run Diesel AL-9750-F	Lt. Cycle Oil AL-9751-F	Paraho DFM Al-9090-F	Paraho JP-5 AL-9088-F	Paraho JP-8 AL-9089-F	SRC-II Middle Distillate AL-9251-F
Gravity, °API	38.2	43.6	34.3	19.2	37.9	43.6	44.4	12.3
Specific Gravity, 60°F	0.8338	0.8081	0.8534	0.9390	0.8353	0.8081	0.8044	0.9840
Distillation, D-86,°F								
IBP	378	297	440	266	402	354	352	368
5 vol% Recovered	416	350	479	464	435	370	366	400
10	430	368	495	493	452	373	368	412
20	442	396	511	511	470	378	372	428
50	461	436	545	550	508	396	393	473
90	484	516	651	629	563	442	441	553
95	492	550	686	647	575	458	462	577
EP	539	602	704	665	598	478	494	613
Recovery, %	99.5	99	98.5	97.5	99.0	98.5	98.5	99.0
Residue	0.5	1.0	0.5	1.0	1.0	1.5	1.0	1.0
Loss	0.0	0.0	1.0	1.5	0.0	0.0	0.5	0.0
Viscosity, cSt@40°C	1.86	1.64	3.72	3.27	2.61	1.38	1.30	3.68
Flash Point,°F	150	118	195	85	176	144	135	176
Pour Point,°F	26	-29	32	16	0	-	-	-54
Hydrocarbon Type (FIA) vol%								
Aromatics	24.44	10.89	-	71.70	30	22	21	91.2
Olefins	2.26	1.18	-	2.26	1	2	2	0.7
Saturates	73.30	87.93	-	26.04	69	76	77	8.1
Elemental Analysis, wt%								
Carbon	86.71	85.40	86.44	87.20	86.54	85.92	86.05	86.15
Hydrogen	13.17	14.08	13.01	9.96	13.36	13.68	13.70	8.64
Oxygen	-	-	-	-	0.37	0.38	0.40	3.9
Nitrogen	-	-	-	-	<0.0001	<0.0001	<0.0001	0.82
Sulfur	0.01	<0.01	0.05	2.02	0.004	0.005	0.002	0.26
Hydrogen/Carbon Atom Ratio	1.81	1.96	1.79	1.36	1.84	1.90	1.90	1.19
Heat of Combustion								
Gross, BTU/Lb	19,635	19,845	19,525	18,255	19,540	19,688	19,724	17,200
MJ/Kg	45.67	46.16	45.42	42.46	45.44	45.79	45.88	40.01
Net, BTU/Lb	18,434	18,560	18,338	17,346	18,318	18,440	18,475	16,412
MJ/Kg	42.88	43.17	42.65	40.35	42.62	42.89	42.97	38.17
Accel. Stability, mg/100 ml	0.11	0.14	0.11	12.36	-	-	-	10.5
Existent Gum, mg/100 ml	-	0.85	-	-	-	-	0.4	-
Cetane Number	48.8	49.6	57.2	26.0	49	44	45	16.2
0.10% DII*	-	-	-	-	55	50	50	-
0.25% DII*	-	-	-	-	59	53	55	-
0.50% DII*	-	-	-	-	64	56	59	-

* Diesel Cetane Improver Additive

TABLE 2.2 PROPERTIES OF BLENDING COMPONENTS FOR GASOLINES AND BROADCUT FUELS

Component	Catalytic Gasoline	Alkylate	Reformate 90 RON	Reformate 100 RON	Lt. St. Run Naphtha	Hvy. St. Run Naphtha	Paraho Naphtha	Normal Butane
Sample NO.	AL-9914-G	AL-9748-G	AL-9833-G	AL-9980-G	AL-9746-G	AL-9747-F	AL-9087-F	AL-9698-G
Gravity, °API	56.6	70.8	46.9	30.9	78.6	54.9	54.9	110.8
Specific Gravity, 60'F	0.7523	0.6995	0.7932	0.8713	0.6735	0.7591	0.7591	0.584
Distillation, D86, °F								
IBP	101	87	125	298	79	157	213	-
5 vol% Recovered	121	120	174	308	89	191	240	-
10	133	144	188	309	100	201	253	-
20	153	181	205	312	108	212	262	-
50	232	221	240	323	136	237	284	31
90	384	325	305	355	186	295	321	-
95	418	385	324	369	197	313	328	-
EP	446	436	390	404	282	363	353	-
Recovery,%	99.0	97.0	99.5	99.5	97.5	99.0	99.0	-
Residue	1.0	1.5	0.5	0.1	0.0	0.6	0.5	-
Loss	0.0	1.5	0.0	0.4	2.5	0.4	0.5	-
Reid Vapor Pressure, psi	6.90	9.4	3.83	0.62	15.5	2.4	4.5	51.6(65*)
Oxid. Stability, min.	>1440	>1440	>1440	>1440	>1440	1440	-	-
Existent Gum, mg/100 ml.								
Unwashed	1.4	1.6	9.7	1.1	0.8	0.8	4.2	-
Washed	0.7	0.4	4.6	0.1	0.6	0.3	-	-
Hydrocarbon Types, vol%								
Aromatics	27.6	2.15	50.71	95.5	3.66	17.49	12.48	0.0
Olefins	16.4	1.20	1.63	1.1	0.40	0.64	1.62	0.0
Saturates	56.0	96.65	47.66	3.4	95.94	81.87	85.90	100.0
Elemental Analysis, wt%								
Carbon	86.15	83.98	87.84	89.71	84.28	85.92	84.36	82.66
Hydrogen	13.29	15.68	11.79	10.16	15.45	13.92	14.17	17.34
Oxygen	-	-	-	-	-	-	0.93	-
Nitrogen	-	-	-	-	-	-	0.11	-
Sulfur	0.06	0.02	<0.005	<0.01	<0.01	<0.01	<0.005	-
Hydrogen/Carbon Atom Ratio								
Heat of Combustion								
Gross, BTU/Lb	19,430	20,030	19,125	18,295	19,390	19,680	19,890	21,136
MJ/Kg	45.19	46.59	44.49	42.55	45.10	45.78	46.26	49.16
Net, BTU/Lb	18,218	18,600	18,049	17,368	17,980	18,410	18,600	19,493
MJ/Kg	42.37	43.26	41.93	40.40	41.82	42.82	43.26	45.34
Cetane Number	-	-	-	-	-	-	31.1	-
Octane Number								
Research	89.0	90.7	92.3	102.6	78.8	63.5	-	-(96.5*)
Motor	79.4	87.7	81.7	96.2	76.0	61.9	-	-(99.9*)

(*Blending Value)

TABLE 2.3 BLENDING COMPONENTS FOR GASOLINES AND BROADCUT FUELS

	Decalin AL-9761-A	Tetralin AL-9762-A	Tetralin Solution AL-9996-A
Gravity, °API	30.0	14.4	15.8
Specific Gravity, 60'F	0.876	0.970	0.9606
Distillation, D86 °F			
IBP	-	-	316
5 vol% Recovered	-	-	348
10	-	-	357
20	-	-	366
50	367 (est)	405 (est)	391
90	-	-	402
95	-	-	404
EP	-	-	437
Recovery,%	-	-	99.5
Residue	-	-	0.5
Loss	-	-	0.0
Reid Vapor Pressure, psi	0.1(est)	0.1(est)	-
Oxid. Stability, min.	-	-	-
Existent Gum, mg 100 ml.			
Unwashed	-	-	-
Washed	-	-	-
Hydrocarbon Types, vol%			
Aromatics	3.0	98.0	100.0
Olefins	0.0	0.0	0.0
Saturates	97.0	2.0	0.0
Elemental Analysis, wt%			
Carbon	86.88	90.84	-
Hydrogen	13.12	9.16	-
Oxygen	-	-	-
Nitrogen	-	-	-
Sulfur	-	-	-
Hydrogen/Carbon Atom Ratio			
Heat of Combustion			
Gross, BTU/Lb	19,550	18,414	-
MJ/Kg	45.47	42.83	-
Net, BTU/Lb	18,307	17,578	-
MJ/Kg	42.58	40.89	-

TABLE 2.4 CALCULATED PROPERTIES OF DIESEL AND BROADCUT FUEL BLENDS

Diesel Fuel Sample No. AL-	Shale Case 2A 10253-F	Shale Case 3 10256-F	Coal Case 5A 10287-F	Coal Case 12 10288-F	SRC-II Med. Cetane 10289-F	SCR-II Low Cetane 10290-F
Gravity, °API	33.5	33.1	31.0	32.7	26.8	23.2
Specific Gravity, 60°F	0.8575	0.8597	0.8709	0.8618	0.8938	0.9147
Distillation, Vol%						
at 400 °F	10.6	7.2	1.0	1.7	1.4	2.0
460 °F	22.6	25.2	-	-	-	-
500 °F	-	-	32.0	53.5	52.4	55.5
540 °F	64.6	68.3	62.9	74.2	76.6	78.5
600 °F	89.9	90.1	85.0	89.7	94.8	95.8
Sulfur, Wt%	0.53	0.54	0.08	0.06	0.26	0.28
Cetane No.	45.0	45.0	45.0	45.0	32.5	24.5

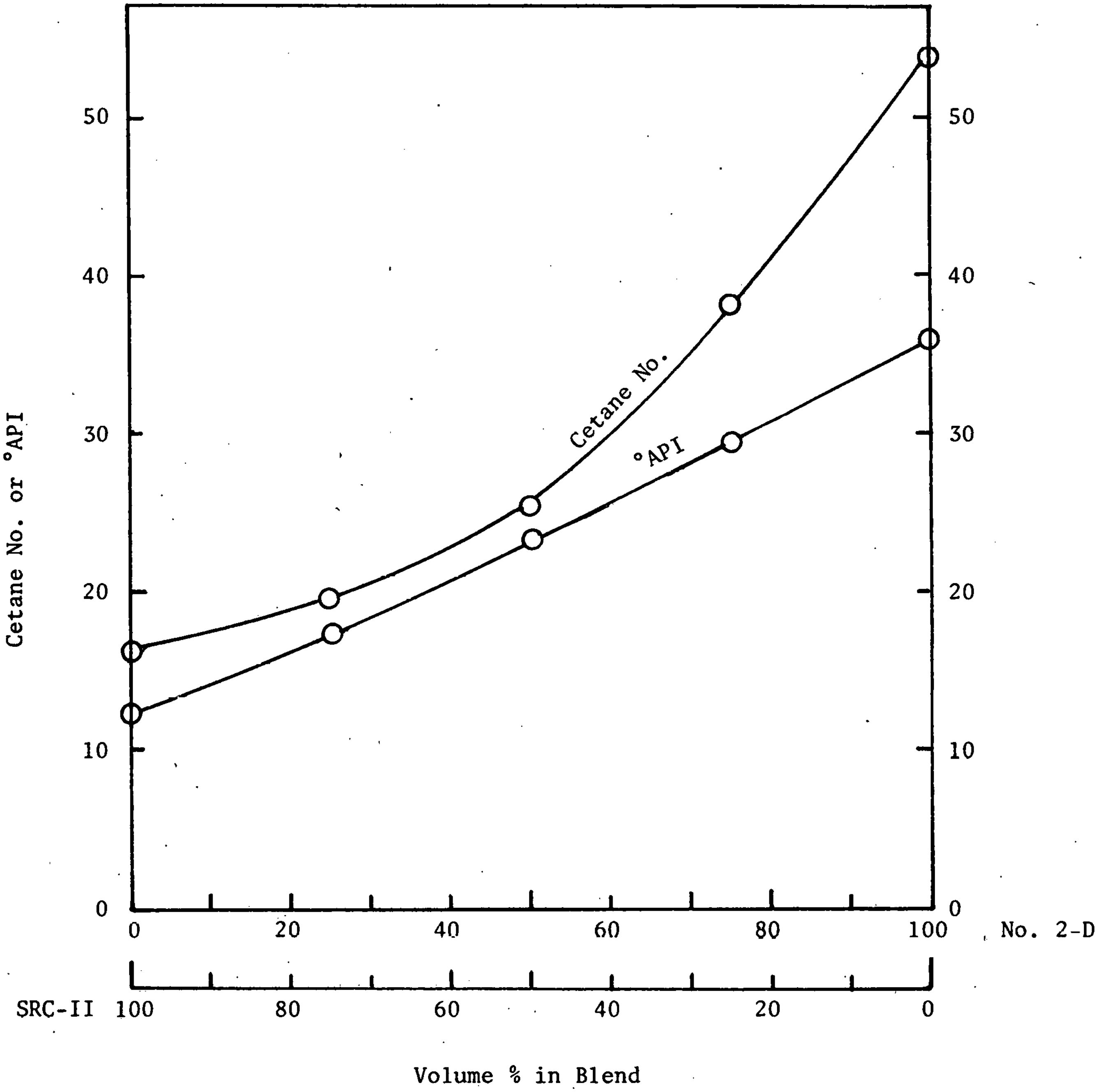
Broadcut Fuel Sample No. AL-	1 10286-F	2 10305-F	3 10306-F	4 10307-F	5 10308-F	6 10309-F	7 10310-F
Gravity, °API	54.2	55.3	57.1	50.1	46.9	57.1	50.3
Specific Gravity, 60°F	0.7619	0.7576	0.7504	0.7790	0.7931	0.7502	0.7783
Distillation, Vol%							
at 200 °F	42.7	35.2	45.1	27.8	19.1	31.5	29.3
300 °F	66.5	61.1	78.6	55.4	37.5	74.1	69.2
400 °F	68.7	77.0	88.4	58.1	44.3	77.9	77.1
540 °F	82.2	86.4	92.7	76.7	80.7	88.5	94.9
600 °F	93.1	95.8	97.5	90.7	92.4	95.1	98.7
Sulfur, Wt%	0.25	0.24	0.24	0.25	0.25	0.02	0.06
Reid Vapor Pressure, Lb	7.9	9.0	9.0	9.0	9.0	9.0	9.0

TABLE 2.5 LABORATORY INSPECTIONS OF BLENDS OF SRC-II MIDDLE DISTILLATE WITH NO. 2 DIESEL

Composition, VOL%					
NO. 2 Diesel	100	75	50	25	0
SRC-II Middle Distillate	0	25	50	75	100
Sample No.	AL-9649-F	AL-9757-F	AL-9758-F	AL-9759-F	AL-9251-F
PROPERTIES					
Gravity, °API	35.9	29.4	23.2	17.5	12.3
Specific Gravity	0.8453	0.8794	0.9147	0.9497	0.9840
Distillation, D-86, °F					
IBP	410	386	364	375	368
5 vol% Recovered	446	417	409	405	400
10	458	432	422	417	412
20	472	452	440	432	428
50	508	496	485	476	473
90	589	583	570	563	553
95	617	612	596	587	577
EP	648	645	635	625	613
Recovery, %	98.5	98.8	99.0	99.2	99.0
Residue	1.5	1.2	1.0	0.8	1.0
Loss	0.0	0.0	0.0	0.0	0.0
Viscosity, cSt@ 40°C	2.74	-	-	-	3.68
Flash Point, °F	175	-	-	-	176
Pour Point, °F	-	-	-	-	-54
Hydrocarbon Type (FIA) vol.%					
Aromatics	28.3	-	-	-	91.2
Olefins	1.3	-	-	-	0.7
Saturates	70.4	-	-	-	8.1
Elemental Analysis, wt%					
Carbon	86.39	-	-	-	86.15
Hydrogen	13.15	-	-	-	8.64
Oxygen	-	-	-	-	3.9
Nitrogen	-	-	-	-	0.82
Sulfur	0.31	-	-	-	0.26
Hydrogen/Carbon Atom Ratio	1.81	-	-	-	1.19
Heat of Combustion					
Gross, BTU/Lb	19,410	-	-	-	17,990
MJ/Kg	45.14	-	-	-	41.84
Net, Btu/Lb	18,210	-	-	-	17,200
MJ/Kg	42.36	-	-	-	40.01
Cetane Number	53.7	38.2	25.2	19.7	16.2
0.10% DII*	-	-	26.0	20.7	-
0.25% DII*	-	-	28.0	21.2	-
0.50% DII*	-	-	29.3	21.7	-
1.00% DII*	-	-	32.1	-	-

* Diesel Cetane Improver Additive

FIGURE 2.1 CETANE NUMBER AND GRAVITY OF BLENDS OF SRC-II MID-DIST AND BASE NO. 2-D



Since coal-derived naphtha and reformate were not available, an effort was made to simulate these materials. Detailed analyses of these products from pilot scale processing of H-coal liquids were given in a UOP report. (5) The main characteristic to distinguish coal-derived stocks from petroleum of the same boiling range was the number of double ring compounds, both cycloparaffins and aromatics. It was concluded that adding compounds of those types would be a reasonable simulation, especially if the added compounds were derived from coal.

Simulated coal-derived naphtha was blended by adding appropriate volumes of Koppers tetralin solution and DuPont pure tetralin and decalin to heavy straight run naphtha from petroleum. The calculations involved only hydrocarbon types to match that analysis as closely as possible. The inspections of the final blend are given on Table 2.6 and are compared with the UOP pilot plant product. The resulting physical properties such as gravity and distillation are also remarkably similar. The simulated coal naphtha was used in Broadcut Fuel 3.

Coal-derived reformate was simulated by blending tetralin solution and tetralin and decalin components into 90 RON reformate to match hydrocarbon type analyses. The results are shown on Table 2.7 compared with UOP product analyses. Again, the physical properties are similar although they were not included in the calculations. The mass spectrometer hydrocarbon type analyses found somewhat lower concentrations of double ring compounds than expected from the known amounts that were added. The simulated coal reformate was used at 57.5% concentration with petroleum components to make a simulated coal-derived gasoline which will be used in the following phase of the project.

With product formulations defined, the next step was blending. Although composition was defined in volume percent of each component, this was converted to weight percent with specific gravity. All blending was done by weight of each component into the blend drum or out of the component container (drum or cylinder). Blends were mixed with propeller mixer. All blends were made in new, clean 55-gallon drums except the simulated coal gasoline where 300 gallons were blended in a 500-gallon tank.

D. Fuels for Engine Evaluation

Two baseline diesel fuels were used for reference with properties as shown on Table 2.8. Howell No. 2-D was used at the start of the engine testing in June 1980.

The second baseline fuel, Phillips D-2 Diesel Control Fuel, became available later. Its 48 cetane number was a good basis for comparison with the 45 cetane number test fuels to be evaluated. Also, the testing was switched to another engine so a change in base fuel did not lose any comparable data.

TABLE 2.6 COMPARISON OF PROPERTIES
COAL-DERIVED NAPHTHA

	UOP Product	Simulated Blend
Sample No.	-	AL-10304-F
Gravity, °API	46.8	49.6
Specific Gravity	0.7936	0.7813
Distillation, °F		
IBP	153	163
5 vol% Recovered	185	195
10	199	205
20	217	217
50	263	253
90	352	350
95	367	366
EP	393	412
Recovery, %	99.0	99.0
Residue		1.0
Loss		0.0
Octane RON Clear	66.8	-*
Elemental Analysis, Wt%		
Carbon	86.45	86.27
Hydrogen	13.59	13.51
Nitrogen	<.0001	-
Sulfur	.0004	<.005
Hydrocarbon Types, Vol% (MS)		
Paraffins	15.96	37.3
Naphthenes		
Monocycloparaffins	55.02	32.5
Bi, Dicycloparaffins	9.49	6.5
Tricycloparaffins	0.09	-
Aromatics		
Alkylbenzenes	16.54	19.3
Indans, Tetralins	2.83	4.4
Naphthalenes	0.07	0.0
Total	100.0	100.0
Hydrocarbon Types, Vol % (FIA)		
Saturates	81.1	79.9
Olefins	0.0	0.9
Aromatics	18.9	19.2

* Not determined because octane low (probably less than 70 RON) and product intended for use in broadcut fuel blend.

TABLE 2.7 COMPARISON OF PROPERTIES
COAL-DERIVED REFORMATE

	UOP Product	Simulated Blend
Sample No.	-	AL-10117-G
Gravity, °API	38.2	40.7
Specific Gravity	0.8338	0.8217
Distillation, °F		
IBP	169	129
5 vol% Recovered	194	177
10	206	191
30	239	227
50	275	259
70	317	302
90	366	378
95	384	392
EP	418	418
Recovery, %		99
Residue		1.0
Loss		0.0
Octane, Clear		
Research	94.2	94.5
Motor	-	81.7
Elemental Analysis, Wt%		
Carbon	88.20	88.68
Hydrogen	11.76	11.34
Hydrocarbon Types, Vol% (MS)		
Paraffins	17.84	31.44
Naphthenes		
Monocycloparaffins	14.90	8.55
Bi, Dicycloparaffins	1.45	1.38
Aromatics		
Alkylbenzenes	55.78	53.01
Indans, Tetralins	8.41	5.16
Naphthalenes	1.62	0.46
Hydrocarbon Types, Vol % (FIA)		
Saturates		40.4
Olefins		2.4
Aromatics		57.2

TABLE 2.8 LABORATORY INSPECTIONS OF BASELINE DIESEL FUELS

Baseline Fuel Sample No.	Howell No. 2-D AL-9649-F	Phillips D-2 AL-9993-F
Gravity, °API	35.9	34.8
Specific Gravity	0.8453	0.8509
Distillation, D-86, °F		
IBP	410	384
5 vol% Recovered	446	414
10	458	432
20	472	454
50	508	510
90	589	574
95	617	588
EP	648	608
Recovery, %	98.5	98.5
Residue	1.5	1.5
Loss	0	0
Viscosity, cSt@ 40°C	2.74	2.48
Flash Point, °F	175	161
Pour Point, °F	-	-7
Hydrocarbon Type (FIA) vol %		
Aromatics	28.3	29.6
Olefins	1.3	1.6
Saturates	70.4	68.8
Elemental Analysis, wt%		
Carbon	86.39	86.63
Hydrogen	13.15	12.85
Oxygen	-	-
Nitrogen	-	-
Sulfur	0.31	0.34
Hydrogen/Carbon Atom Ratio	1.81	1.78
Heat of Combustion		
Gross, BTU/lb	19,410	19,265
MG/kg	45.14	44.81
Net, BTU/lb	18,210	18,093
MJ/kg	42.36	42.08
Accelerated Stability, Mg/100ml	-	0.3
Existent Gum, Mg/100ml	-	3.9
Cetane Number	53.7	48.0

Eight diesel fuels for testing are listed on Table 2.9. Composition of each fuel is shown in the upper portion of the tabulation. Laboratory inspections are shown in the lower portion.

Seven broadcut fuels for evaluation are listed on Table 2.10 with compositions at the top and properties below. These fuels were compared with Phillips D-2 baseline fuel in CLR engine tests since a broadcut reference fuel was not available.

Properties of the diesel and broadcut fuel blends reported in Tables 2.9 and 2.10 may be compared with their calculated properties in Table 2.4. Good agreement between actual and calculated properties was obtained in most cases.

Reid vapor pressure (RVP) of the broadcut fuels was higher than the 9 pound target value. A check of the technical grade normal butane composition by gas liquid chromatography showed it to contain 9.5% isobutane and 90.5% butane. The product was specified to be 95% minimum normal butane. This difference would raise the butane blending RVP from 65 pounds to 67.5 pounds and account in part for the RVP of the finished blends being higher than planned.

E. Formulation for Other Laboratories

A blend of 53 gallons was made of each formulated fuel in Tables 2.9 and 2.10. About 15 gallons of fuel was scheduled for single-cylinder engine testing, and an additional 10 gallons would be used if a limited amount of multi-cylinder engine evaluation was to be performed with certain fuels.

Therefore, the remaining 28 to 38 gallons of each fuel was made available for shipment to other laboratories. Larger volumes were available of Paraho DFM and SRC-II middle distillate. These quantities were offered through the Project Technical Manager who sent the information to all known interested parties. Products were made available at no cost except for shipping charges and in exchange for data from the evaluation studies.

F. Supplemental Fuels Data

Hydrocarbon type analyses were determined by mass spectrometer (MS) analyses on selected samples where it was desired to know the proportions of naphthenes and aromatics with mutiple rings. Results from the SOHIO laboratory are given in Table 2.11 along with their determination by fluorescent indicator adsorption (FIA). Hydrocracker kerosene contains less aromatics and more single ring naphthenes than straight run kerosene. The simulated coal-derived naphtha made up 45.8 volume percent of Broadcut Fuel 3.

Boiling range distributions by gas chromatography, ASTM Method D 2887, are given in Appendix B for selected blend components and all blends of diesel and broadcut fuels.

TABLE 2.9 DIESEL FUELS FOR EVALUATION

Fuel	Paraho DFM	Paraho JP-5	Shale Case 2A	Shale Case 3	Coal Case 5A	Coal Case 12	SRC-II Med. Cetane	SRC-II Low Cetane
Sample No. AL-	9090-F	9088-F	10255-F	10256-F	10287-F	10288-F	10289-F	10290-F
Composition, Volume %								
Kerosene								
Petroleum	0	0	1.3	21.7	17.3	39.3	0	0
Shale JP-5/JP-8	0	100.0	17.1	10.6	0	0	0	0
Diesel								
Petroleum	0	0	23.0	21.4	66.7	45.7	65.0	50.0
Shale DFM	100.0	0	36.2	23.2	0	0	0	0
Coal SRC-II	0	0	0	0	16.0	13.0	35.0	50.0
Light Cycle Oil	0	0	22.4	23.1	0	0	0	0
HC Kerosene	0	0	0	0	0	2.0	0	0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Properties								
Gravity, °API	37.9	43.6	33.0	32.9	31.1	32.8	26.8	23.3
Specific Gravity, 60°F	0.8353	0.8081	0.8602	0.8607	0.8702	0.8612	0.8939	0.9141
Distillation, D-86, °F								
IBP/5 % Recovered	402/435	354/370	369/409	373/417	378/432	326/416	346/409	329/387
10/20	452/470	373/378	427/450	432/452	453/472	434/455	424/446	420/438
30/40	482/497	384/389	472/491	467/481	487/499	468/480	464/476	455/470
50/60	508/521	396/403	508/525	497/513	512/528	491/504	489/502	485/500
70/80	533/547	412/424	543/565	531/565	546/576	521/547	522/543	517/538
90/95	563/575	442/458	599/627	595/631	626/667	603/652	577/610	570/600
EP	593	478	664	661	690	683	638	626
Recovery, %	99.0	98.5	99.0	98.0	98.5	98.5	98.5	99.0
Residue	1.0	1.5	1.0	2.0	1.5	1.5	1.2	1.0
Loss	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Viscosity, cSt at 40°C	2.61(38°C)	1.38(38°C)	2.53	2.48	3.08	2.61	2.83	2.95
Pour Point °F (°C)	0(-18)		9(-13)	-2(-19)	21(-6)	10(-12)	0(-18)	-6(-21)
Flash Point, °F	176	144	142	140	176	166	176	176
Hydrocarbon Type, Vol%								
Aromatics	30	22	36.9	36.1	34.9	34.3	49.5	57.8
Olefins	1	2	1.3	1.3	1.4	1.3	1.8	1.4
Saturates	69	76	61.8	62.6	63.7	64.4	48.7	40.7
Elemental Analysis, Wt%								
Carbon	86.54	85.92	86.69	86.25	86.47	86.60	86.03	86.02
Hydrogen	13.36	13.68	12.38	12.32	12.38	12.55	11.47	10.86
Oxygen	.33	.41	-	-	-	-	-	-
Nitrogen	.022	.015	-	-	0.15Est	0.12Est	0.39Est	0.44Est
Sulfur	0.004	0.005	0.55	0.52	0.10	0.08	0.33	0.34
Hydrogen/Carbon Atom Ratio	1.84	1.90	1.70	1.70	1.71	1.73	1.59	1.50
Heat of Combustion								
Gross, BTU/LB	19,537	19,688	19,470	19,520	19,485	19,585	18,950	18,430
MJ/kg	45.44	45.79	45.29	45.40	45.32	45.56	44.08	42.87
Net, BTU/LB	18,318	18,440	18,341	18,396	18,391	18,440	17,904	17,439
MJ/kg	42.6	42.89	42.66	42.79	42.73	42.89	41.64	40.56
Accel. Stability, MG/100ml	0.20	0.14	3.3	2.3	(Filter plugged on all SRC-II samples)			
Steam Jet Gum, MG/100ml	0.0	0.0	15.3	16.5	42.4	31.9	100.9	134.1
Cetane Number	48.9	44.9	45.4	45.0	42.0	41.1	31.4	25.4

TABLE 2.10 BROADCUT FUELS FOR EVALUATION

	ROCKY MOUNTAINS			MID-CONTINENT		GREAT LAKES	
Case No.	16	4	7A	5	4	5	4
Sample No. AL-	10286	10305	10306	10307	10308	10309	10310
Fuel Identification	BCF-1	BCF-2	BCF-3	BCF-4	BCF-5	BCF-6	BCF-7
Composition, Volume%							
LSR Naphtha	40.0	32.0	39.9	17.3	7.4	20.3	19.7
HSR Petroleum	26.9	0	0	32.1	4.8	50.5	34.0
Shale	0	35.0	0	0	20.9	0	15.8
Coal (Simulated)	0	0	45.8	0	0	0	0
Kero Petroleum	0	0	0	0	22.0	0	0
Shale JP-8	0	10.0	0	0	0	0	0
Diesel Petroleum	19.7	7.7	0	30.6	23.0	22.1	4.1
Shale DFM	0	0	0	0	0	0	0
Coal SRC-II	0	0	0	0	6.2	0	19.6
Light Cycle Oil	11.8	11.5	11.4	11.5	5.2	0	0
N-Butane	1.6	3.8	2.9	8.5	10.5	7.1	6.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Properties							
Gravity, °API	51.4	53.2	55.4	47.9	44.1	55.6	48.0
Specific Gravity, 60°F	0.7736	0.7661	0.7571	0.7887	0.8058	0.7563	0.7883
Distillation, D-86, °F							
IBP/5 vol% Recovered	89/121	81/92	81/97	73/100	69/127	81/105	81/109
10/20	133/157	117/157	117/143	127/175	199/279	130/168	133/181
30/40	181/207	200/242	167/188	211/246	319/387	195/217	213/237
50/60	237/291	280/318	210/235	305/460	446/482	238/265	261/291
70/80	484/534	355/438	268/325	512/547	504/539	295/450	333/412
90/95	590/644	542/600	435/570	600/637	620/-	562/612	506/556
EP	662	634	615	679	670	669	600
Recovery, %	96.0	96.5	96.0	98.0	94.0	97.5	98.0
Residue	1.5	1.5	1.5	1.0	1.0	1.5	1.0
Loss	2.5	2.5	2.5	1.0	5.0	1.0	1.0
Reid Vapor Pressure, LB	9.2	9.8	9.9	10.9	10.6	9.9	9.8
Viscosity, cSt at 40 °C	0.79	0.72	0.59	0.98	1.53	0.75	0.73
Pour Point, °F (°C)	-22(-30)	-52(-47)	-76(-60)	-15(-26)	-22(-30)	-31(-35)	-76(-60)
Hydrocarbon Type, Vol %							
Aromatics	16.4	14.8	15.3	18.2	16.2	12.5	18.4
Olefins	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Saturates	83.6	84.9	84.7	81.8	83.8	87.5	81.6
Elemental Analysis, Wt%							
Carbon	85.89	85.65	85.96	86.03	86.05	85.45	85.73
Hydrogen	13.71	13.91	13.76	13.46	13.22	14.09	13.03
Sulfur	0.31	0.31	0.30	0.31	0.17	0.015	0.1
Hydrogen/Carbon Atom Ratio	1.90	1.94	1.91	1.86	1.83	1.96	1.81
Heat of Combustion							
Gross, BTU/lb	20,445	20,345	19,990	20,140	20,035	20,385	19,835
MJ/kg	47.56	47.32	46.50	46.85	46.60	47.42	46.14
Net, BTU/lb	19,194	19,076	18,735	18,912	18,829	19,100	18,649
MJ/kg	44.65	44.37	43.58	43.99	43.80	44.43	43.38
Cetane Number	31.1	30.9	25.0	33.8	35.2	33.4	22.7

TABLE 2.11 HYDROCARBON TYPE ANALYSES, VOL %

Sample Sample No.	Straight Run Kerosene AL-9749-F	Hydrocracker Kerosene AL-9998-F	Sim. Coal Naphtha AL-10304-F	Broadcut Fuel-3 AL-10306-F
1. Mass Spectrometer				
Paraffins	42.88	45.39	37.30	48.00
Naphthenes*				
Monocycloparaffins	16.51	26.99	32.50	24.90
Dicycloparaffins	16.41	16.61	6.50	9.90
Aromatics*				
Alkylbenzenes	14.75	6.22	19.30	13.70
Indans & Tetralins	5.11	4.00	4.40	3.50
Naphthalenes	4.15	0.53	0.00	0.00
Benzothiophenes	0.19	0.26		
Total	100.00	100.00	100.00	100.00
Carbon No.				
Paraffins			8.32	9.45
Alkylbenzenes			7.59	7.72
2. Fluorescent Indicator Adsorption				
Saturates	72.6	86.5	79.30	82.70
Olefins	3.1	2.8	1.10	1.20
Aromatics	24.3	10.7	19.60	16.10

*Note: Mass spec determines olefins as naphthenes, cyclic olefins as aromatics.

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III. SYNFUELS EVALUATION - ENGINE TESTING

The fifteen fuels were evaluated initially in single-cylinder CLR engines and results are presented in this report. Further multi-cylinder testing on selected fuel is planned to be done later.

A. Description of Test Equipment

The fuels were tested in a CLR direct-injection diesel engine. This type of single-cylinder, four-stroke engine was originally developed for lubricant evaluations. It has also been used for fuel testing because of its adaptability to other cylinder head configurations and for installing instrumentation. The engine specifications for this series of tests were:

Compression Ratio	14:1
Bore	3.80 inch (9.65 cm)
Stroke	3.75 inch (9.53 cm)
Displacement	42.5 cubic inches (696.6 cm^3)

The engine was coupled to an eddy current dynamometer. The load was measured by torque reaction on a strain gauge type electronic load cell.

Two fuels were tested on the first CLR engine. This engine was being shared with another project which involved frequent modification of the fuel system. Since it would not be possible to get consistent comparisons with changing equipment, the testing was switched to a second CRL engine at the Army Fuels and Lubricants Research Laboratory. The second engine was identical to the first in all major factors.

Emissions analyzers for the two systems were as follows:

Compound	CLR# 1	CLR# 2
Carbon Monoxide	Beckman Model 315B NDIR	Beckman Model 865 NDIR
Carbon Dioxide	Beckman Model 315B NDIR	Beckman Model 865 NDIR
Hydrocarbons	Beckman Model 402 FID	Beckman 402 FID
Nitric Oxide	Thermo-Electron 10A Chemiluminescence Analyzer	Beckman Model 995
Total Oxides of Nitrogen	Thermo-Electron 10A Chemiluminescence Analyzer with NOx Converter	Beckman Model 955
Oxygen	Beckman Fieldlab Oxygen Analyzer	Beckman Model DM-11A

With the CLR# 1 system, all instruments were on-line with continous flow of sampled exhaust gas. With the CLR# 2 system, an evacuated plastic bag was filled with exhaust gas at a controlled rate and then taken directly to a bank of analyzers for simultaneous measurements. The comparative particulates samples were collected on filter paper with the system shown in Appendix C.

A closed fuel system was devised for minimizing vapors from coal-derived fuels in the engine test cell. All necessary vents were connected by tubing to the exhaust fan. Details are shown in Appendix C.

B. Description of Test Procedure

Since the objective of the engine testing was to compare the test fuel performance with a baseline diesel fuel, the comparison should be made with a minimum of other changes. The following chart shows the combinations of CLR engine with base fuel and test fuels. In the discussion of results in the following section, Paraho DFM is compared with Howell No. 2-D and all other fuels are compared with Phillips D-2 baseline fuel.

Baseline Fuels	CLR# 1	CLR# 2
Howell No. 2-D	X	
Phillips D-2		X
Test Fuels		
Paraho DFM	X	
All Other Diesel Fuels		X
All Broadcut Fuels		X

The test matrix for CLR# 1 was set up to measure performance (P) and emissions (E) at various loads and 3 speeds, as follows:

Torque, ft-lb	4	8	12	16	20	24
1,000 RPM	P,E		P,E		P,E	
1,500 RPM	P,E	P,E	P,E	P,E	P,E	P,E
2,000 RPM	P,E		P,E		P,E	

When the testing moved to CLR# 2, the test matrix was modified to obtain more data points on performance. Also the engine operation was unsteady at 4 ft-lb torque and smoky at 24 ft-lb. Therefore, the matrix was shifted for better coverage, to the following:

Torque, ft-lb	6	10	14	18	22
1,000 RPM	P,E	P	P,E	P	P,E
1,500 RPM	P,E	P	P,E	P	P,E
2,000 RPM	P,E	P	P,E	P	P,E

Results of engine tests are summarized and discussed in Section IV.

IV. RESULTS AND DISCUSSION

Performance and emissions data were obtained in two single-cylinder CLR engines as described in the preceding section. Complete data are given in Apppendix D for two baseline fuels, eight diesel fuels, and seven broadcut fuels with a variety of physical and chemical properties. The results discussed in this section include the significant variations in peformance or emissions for the test fuels. Comparisons are made with a baseline fuel at a common brake horsepower output. Possible reasons are offered for the differences, based on a recent study of fuel-related causes of emissions. (6)

Because of the relatively small number of tests on each fuel, the results indicate trends for the type of engine used for testing. Comparisons among the various fuels should be made on a qualitative basis rather than apply precise quantitative differences.

A. Definitions and Data

Performance data are reported and discussed in various units for power and fuel consumption as usually applied in engine testing. (7) Power was calculated as Brake Horsepower (BHP) and Brake Mean Effective Pressure (BMEP) for data tabulations in Appendix D, but only BHP is used in the discussion. The Air to Fuel Weight Ratio (AFR) was also tabulated.

Fuel consumption was measured in pounds per unit of time and converted to three forms tabulated in Appendix D, as follows:

Brake specific fuel consumption (BSFC)	$\frac{\text{Pounds}}{\text{BHP-Hour}}$
Brake specific energy consumption (BSEC)	$\frac{\text{BTU}}{\text{BHP-Hour}}$
Specific Range	$\frac{\text{BHP-Hour}}{\text{Gallon}}$

Only BSFC and BSEC are used in the discussion. Specific Range is a volumetric measure of fuel economy, similar to miles per gallon, and is an inverse function of BSFC incorporating fuel density; it was calculated when data were stored on computer tapes.

Emissions data are reported for four exhaust components as percentages of exhaust gas as follows:

Particulates	Weight%
Nitrogen Oxides (NO_x)	Volume%
Hydrocarbons (HC)	Volume%
Carbon Monoxide (CO)	Volume%

Fuel consumption data in BSFC and BSEC versus BHP for each fuel are presented in graphic form in Appendix D. Curves for all three speeds were generated with a least squares polynomial equation curve fitting program. Second order equations of the form $y = A+Bx+Cx^2$ were used in all cases. Similar plots are not presented for emissions data versus BHP because the smaller number of emissions measurements and an unusual amount of scatter in the data produces less reliable curves.

Fuel comparisons in this section of the report are based on relative performance and emissions at 75 percent of maximum load, or 18 ft-lb torque. For example:

$$\text{Relative BSEC at 18 ft-lb} = \frac{\text{BSEC for Test Fuel}}{\text{BSEC for Base Fuel}}$$

This load is close to minimum fuel consumption on the BSFC curves for most fuels and corresponds to the following horsepower at the three speeds:

Speed,RPM	BHP
1000	3.43
1500	5.14
2000	6.85

Comparisons on this basis avoid problems of slope or curvature of the least squares line. Scatter is not eliminated but variations may be less in the area of higher engine efficiency.

B. Diesel Fuels

Two shale-derived fuels were used as received. Two shale-derived blends and two coal-derived blends were prepared using patterns from the refinery modeling studies to make 41 to 45 cetane number product meeting No. 2-D specifications. In addition, two lower cetane diesel fuels were blended with SRC-II distillate to explore the maximum proportion of this component that could be used. The blends met the properties selected as targets. Their compositions and properties are reported in Table 2.9 for reference in the discussion of performance.

Relative performance of the four shale-derived diesel fuels in the CLR engine at 75 percent load and three speeds is presented in four figures, as follows:

Figure 4.1A	Relative BSEC
Figure 4.1B	Relative Particulates
Figure 4.1C	Relative NO_x
Figure 4.1D	Relative Hydrocarbons

FIG.4.1A RELATIVE BSEC

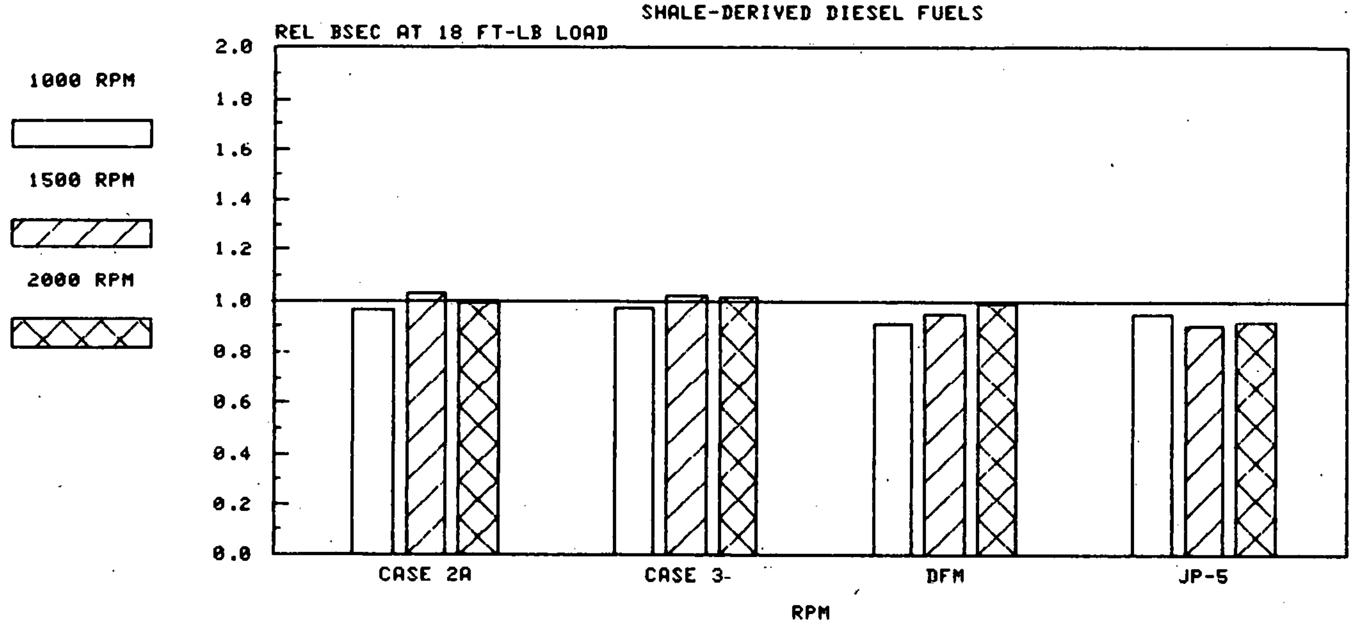


FIG.4.1B RELATIVE PARTICULATES

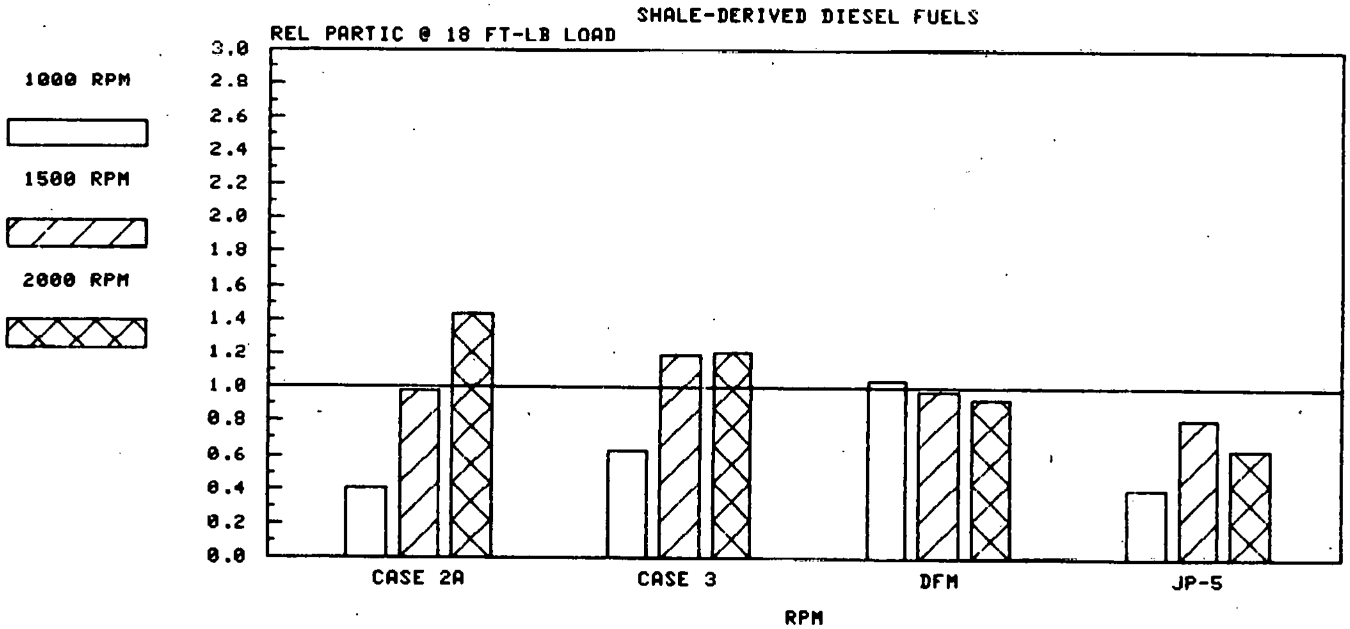


FIG.4.1C RELATIVE NOx

SHALE-DERIVED DIESEL FUELS

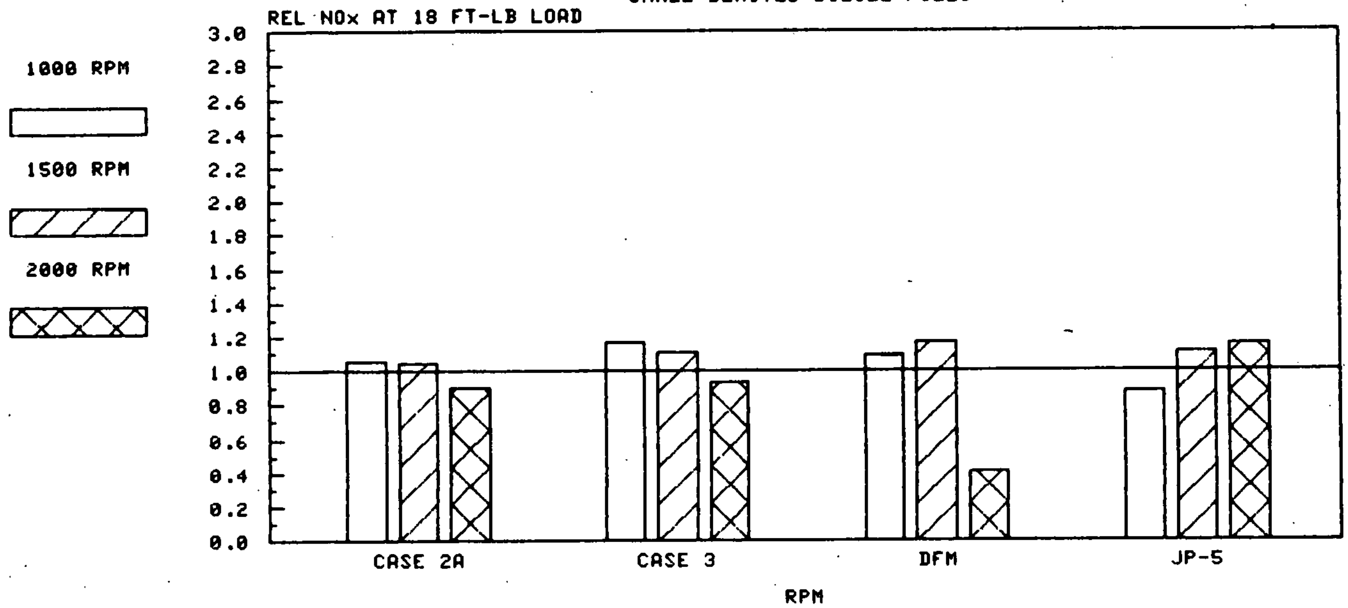


FIG.4.1D RELATIVE HYDROCARBONS

SHALE-DERIVED DIESEL FUELS

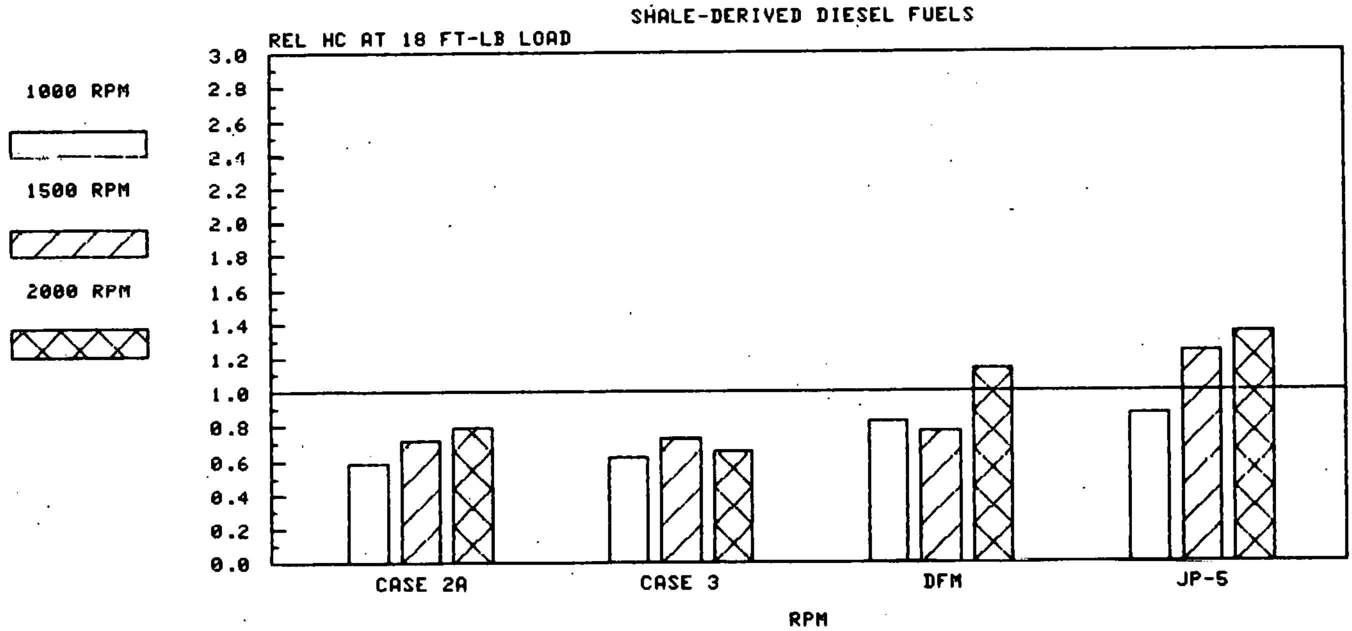


Figure 4.1A shows that Paraho DFM and JP-5 have slightly lower BSEC at most speed conditions. The BSEC function includes the adjustment for BTU content of the fuels. Therefore, it appears that these two fuels were used more efficiently by the engine. Both fuels have a narrower boiling range than the base fuel, considering the 10% and 90% temperatures, which could lead to more complete combustion. The other two fuels show no significant differences in fuel consumption.

Figure 4.1B indicates that JP-5 produced lower particulates emissions which would be expected from its lower boiling point. This property also produced the higher hydrocarbons emissions shown on Figure 4.1D, since these may increase with fuel that is more easily vaporized in the injector.

Shale Case 2A and Case 3 fuels exhibit only minor differences from baseline fuel. Lower hydrocarbon emissions for both of these fuels on Figure 4.1D appear to be related to their narrower boiling range and lower end point than the baseline fuel.

A similar set of plots is provided for the four coal-derived fuels on Figures 4.2A through 4.2D. Relative fuel consumption on Figure 4.2A shows very small differences from base fuel. The SRC-II low cetane blend is lower at 1000 RPM, but this is probably a result of normal data variation at low fuel usage rate.

All four coal fuels produced more particulates emissions, as indicated on Figure 4.2B. Higher aromatics and lower hydrogen contents are the probable reason for this result in SRC-II medium and low cetane blends. However, the Case 5A and Case 12 blends had aromatics and hydrogen contents similar to the Shale Case 2A and Case 3 blends. Higher particulates emissions than the shale fuels (see figure 4.1B) are probably related to the higher 90% points for the coal fuels. Higher viscosity may also have been a contributing cause; three of the fuels ranged from 2.83 to 3.08 centistokes (cSt) at 40°C compared with 2.48 cSt for the base fuel. Coal Case 12 with lower 90% point and lower viscosity at 2.61 cSt showed slightly lower particulates than the other coal-derived fuels.

Hydrocarbon emissions for Coal Case 5A on Figure 4.2D were higher than base fuel which may be related to viscosity and 90% point. Other emissions from coal-derived fuels appear to be equivalent to base fuel.

All shale-derived fuels ran well in the CLR engine at all speeds. So did the two coal-derived blends containing 13 and 16 volume percent SRC-II distillate with 41 and 42 cetane numbers.

When coal distillate was increased to 35 volume percent, the 31.4 cetane number blend caused moderate to severe knock at all speeds. The fuel ran erratically at 2000 RPM, and some speed and load conditions could not be run. With 50 volume percent coal-based distillate and 25.4 cetane number, severe knock occurred at all

FIG.4.2A RELATIVE BSEC

COAL-DERIVED DIESEL FUELS

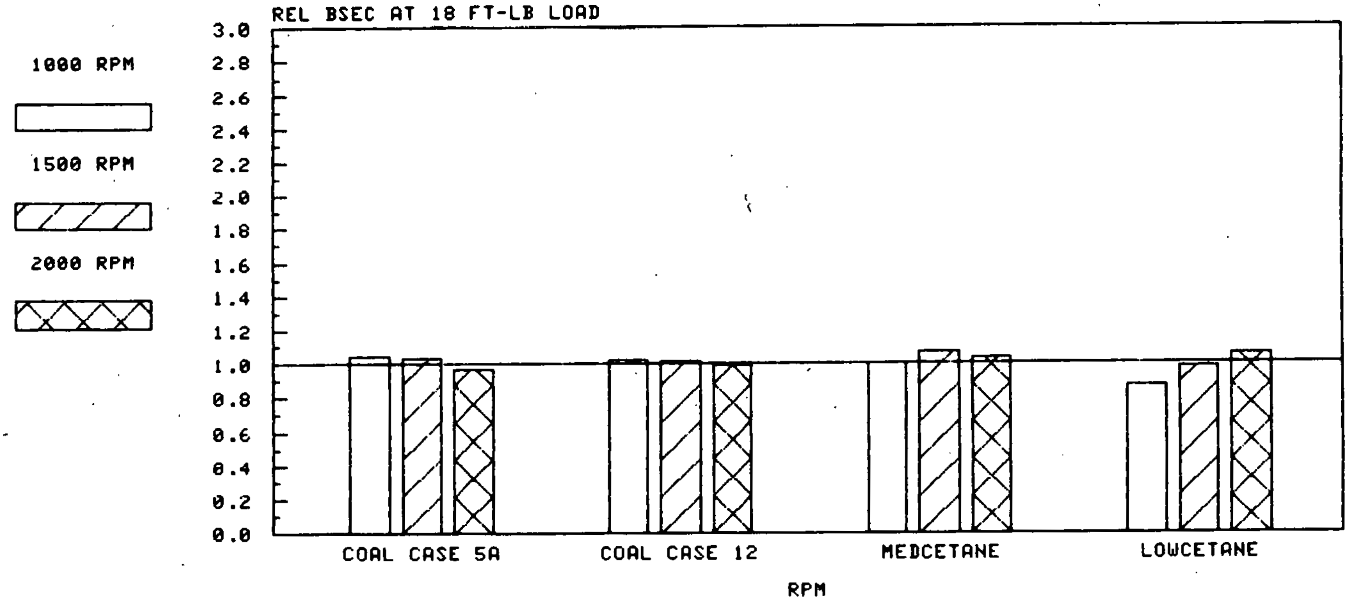


FIG.4.2B RELATIVE PARTICULATES

COAL-DERIVED DIESEL FUELS

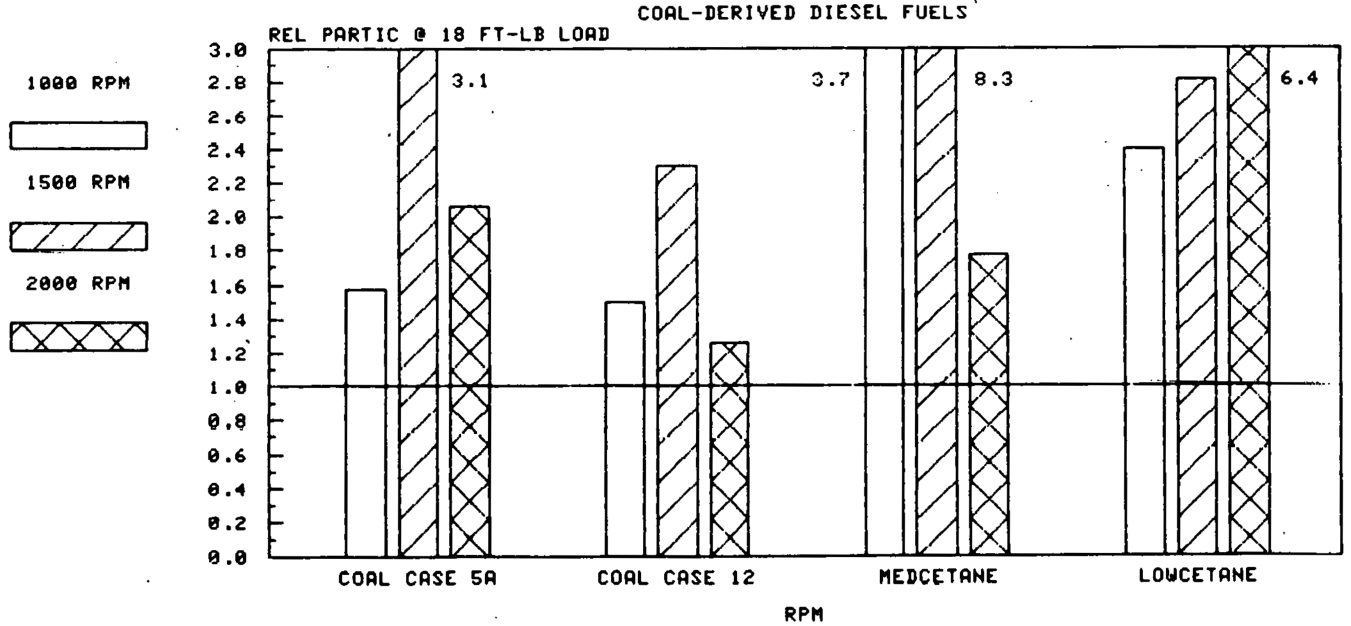


FIG.4.2C RELATIVE NOx

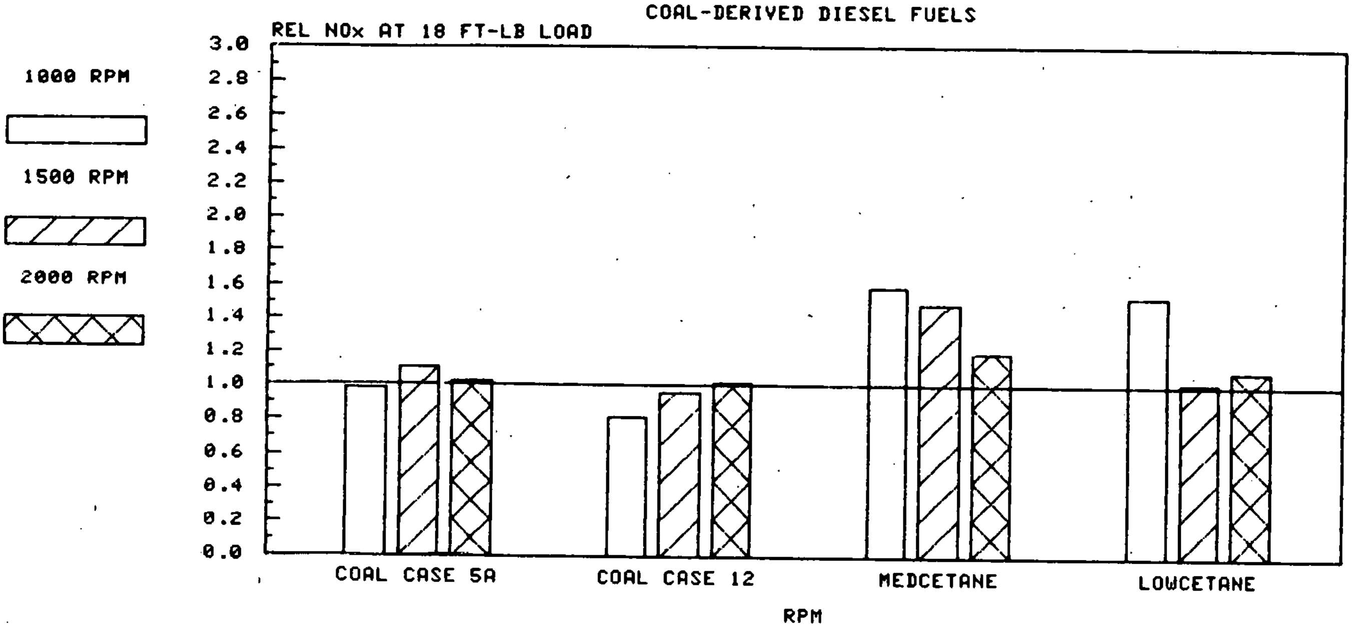
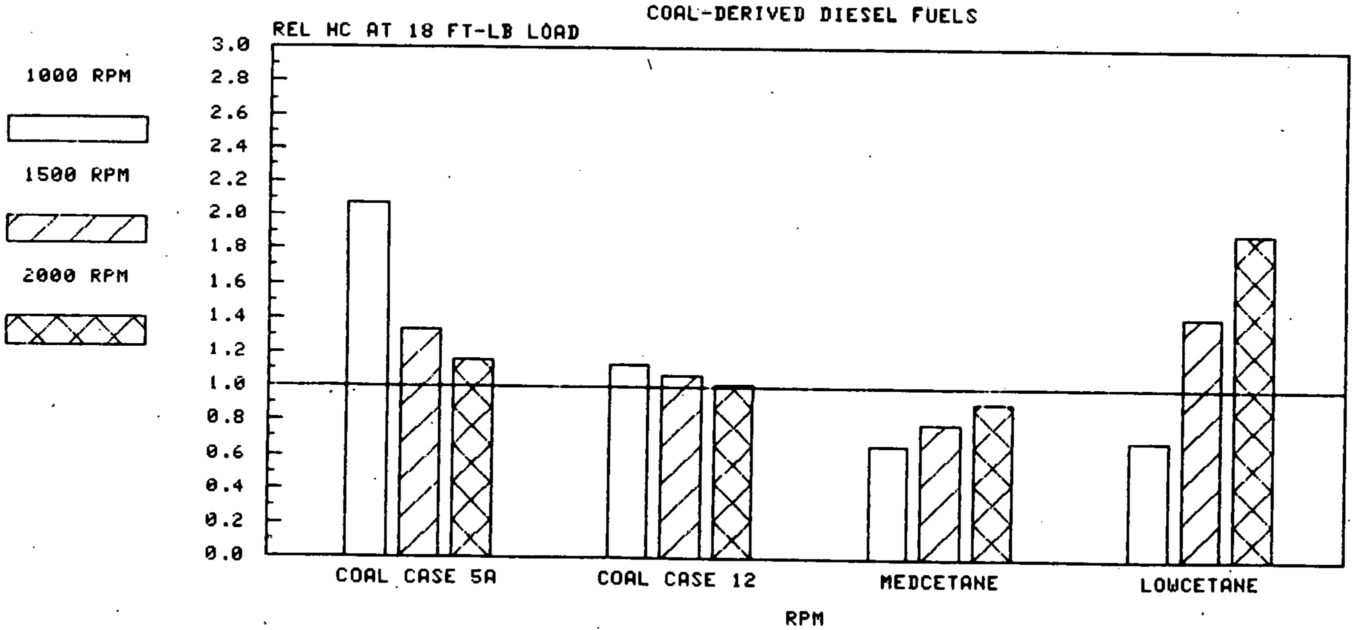


FIG.4.2D RELATIVE HYDROCARBONS



speeds. Misfiring with the latter two fuels also caused erratic emissions results. Cold starting with the lowest cetane fuel was not possible.

It appears that SRC-II middle distillate can be used at concentrations under 20 volume percent, if an increase in particulates and perhaps hydrocarbon emissions can be tolerated. However, even at low concentrations, the fuel blend has low stability and strong and persistent odor. Hazards of vapor inhalation and skin contact require special handling procedures. It was recognized that the SRC-II material was not a finished product. Upgrading by hydrogenation or other treating would alter its properties and composition and make a much better diesel fuel. It was felt worthwhile to evaluate its performance in blends, to indicate the degree of upgrading that might be required.

C. Broadcut Fuels

The seven broadcut fuel blends met the properties used as blending criteria as discussed in Section II. The resulting family of fuels has a diverse array of compositions and properties reported in Table 2.10. Cetane number, which was not a target, varied from 22.7 to 35.2. The total of light and heavy naphtha fractions varied from 33.1 to 85.7 volume percent. Aromatics content stayed in a fairly limited range of 12.5 to 18.4 volume percent, and hydrogen from 13.03 to 14.07 weight percent.

A few composition and property factors that affect performance and emissions are given on Table 4.1 for ready access in the discussion of test results. The seven fuels will be referred to as BCF-1, BCF-2, etc., instead of the longer case number identifiers.

TABLE 4.1 SELECTED BROADCUT FUEL DATA

Fuel	Base Diesel	BCF-1	BCF-2	BCF-3	BCF-4	BCF-5	BCF-6	BCF-7
Stocks	Petr.	Petr.	Shale	Coal	Petr.	Shale & Coal	Petr.	Shale & Coal
Composition, Vol%								
Naphthas	-	66.9	67.0	85.7	49.4	33.1	70.8	69.5
SRC-II Mid. Dist.	-	-	-	-	-	6.2	-	19.6
Lt. Cycle Oil	-	11.8	11.5	11.4	11.5	5.2	-	-
Distillation, °F								
10%	432	133	117	127	127	199	130	133
90%	574	590	542	435	600	620	562	506
End Point	608	662	634	615	679	670	669	600
Cetane No.	48.0	31.1	30.9	25.0	33.8	35.2	33.4	22.7

Relative performance and emissions data at 75 percent load and three speeds are presented in four bar charts, as was done for the diesel fuels earlier. Data are missing at 1000 RPM for some of the fuels which would not support stable operation at that speed, especially at low loads. The three all-petroleum fuels - BCF-1, BCF-4 and BCF-6 - are in Figures 4.3A through D. The remaining fuels containing synthetic components are on Figures 4.4A through D. Performance and emissions appear to be affected more by properties or composition than by origin of the stocks, so all seven fuels will be discussed as a group.

Fuel consumption as BSEC was consistently high for all seven fuels. Although the amount of increase varied from about 2 to 20 percent, an overall average could be about 10 percent increase. Since energy content of each fuel is included in the relative BSEC, it appears that the CLR engine used the broadcut fuels less efficiently. The fuel-related reason for the lower efficiency is probably the large proportion of naphtha boiling under 400°F,and particularly the amount of light straight run naphtha as indicated in fuel compositions on Table 2.10. Partial support for this opinion is that two fuels with the lowest percentage naphtha - BCF-4 and BCF-5 have close to 1.0 relative BSEC. BCF-3, one of the fuels with the high light naphtha and total naphtha content has the highest relative fuel consumption.

Cetane number correlates inversely with naphtha content and could be involved with fuel consumption, with two exceptions. BCF-6 has one of the higher cetane numbers, due to the absence of light cycle oil, but second highest BSEC. BCF-7 has the lowest cetane number, with the most SRC-II used in any blend, but shows relatively low BSEC. Comparing BCF-6 with SRC-II medium cetane diesel fuel at about the same cetane number, the broadcut fuel with its wider boiling range had higher fuel consumption.

Particulates emissions were high with three fuels - BCF-1, BCF-4, and BCF-5. Nitrogen oxides were relatively high with BCF-2, BCF-4, and BCF-5. These two emissions generally increase with higher 90% distillation temperatures or with wider boiling range which applies with three of the four fuels. Particulates were low with the other fuels, as would be expected with lighter fuels.

A common factor for all seven broadcut fuels was their high relative hydrocarbon emissions, at all speeds or at the highest speed. This effect occurs often with light fuels, of which these are extreme examples. Causes of incomplete combustion may be related to injection timing, injection duration and injector tip design. The fuels caused misfiring at various load and speed conditions which may have been improved by injector adjustments.

FIG.4.3A RELATIVE BSEC

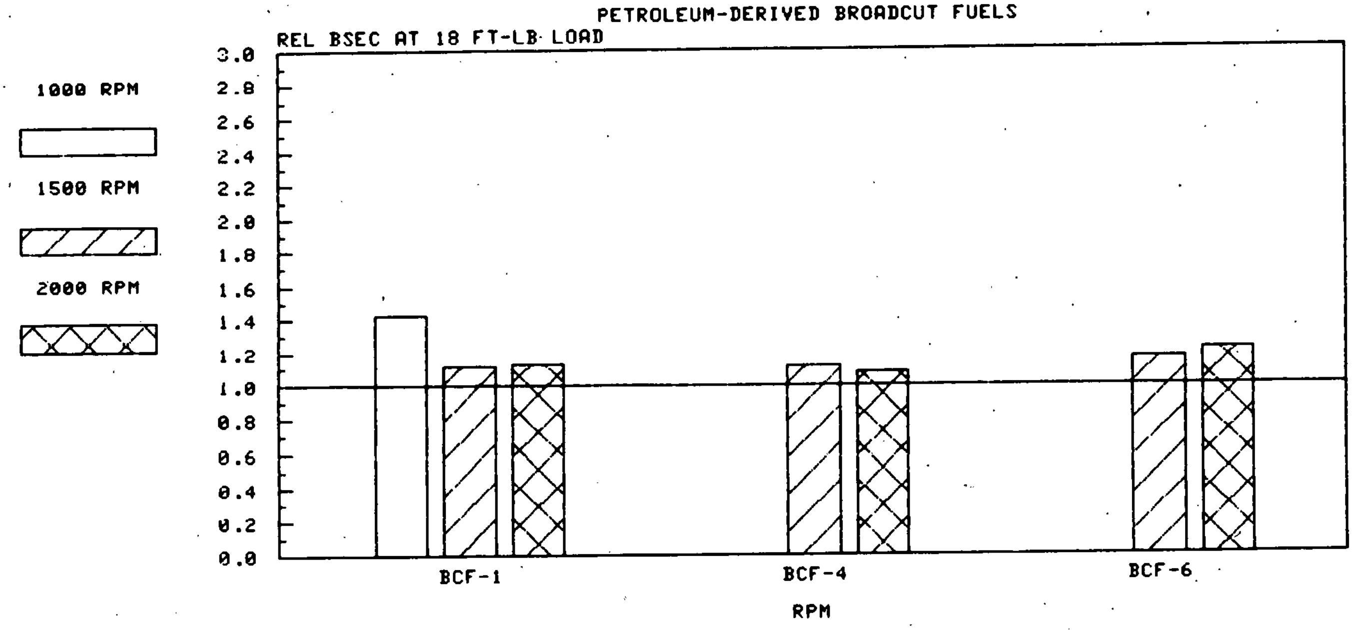


FIG.4.3B RELATIVE PARTICULATES

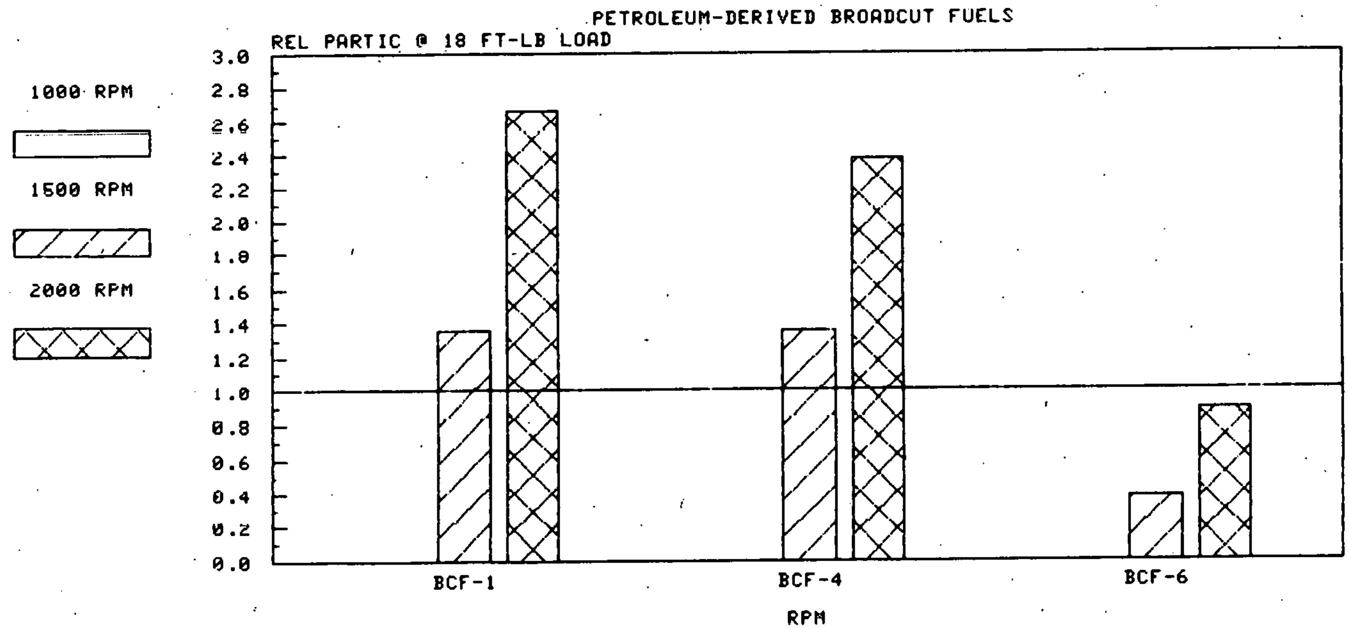


FIG.4.3C RELATIVE NOx

PETROLEUM-DERIVED BROADCUT FUELS

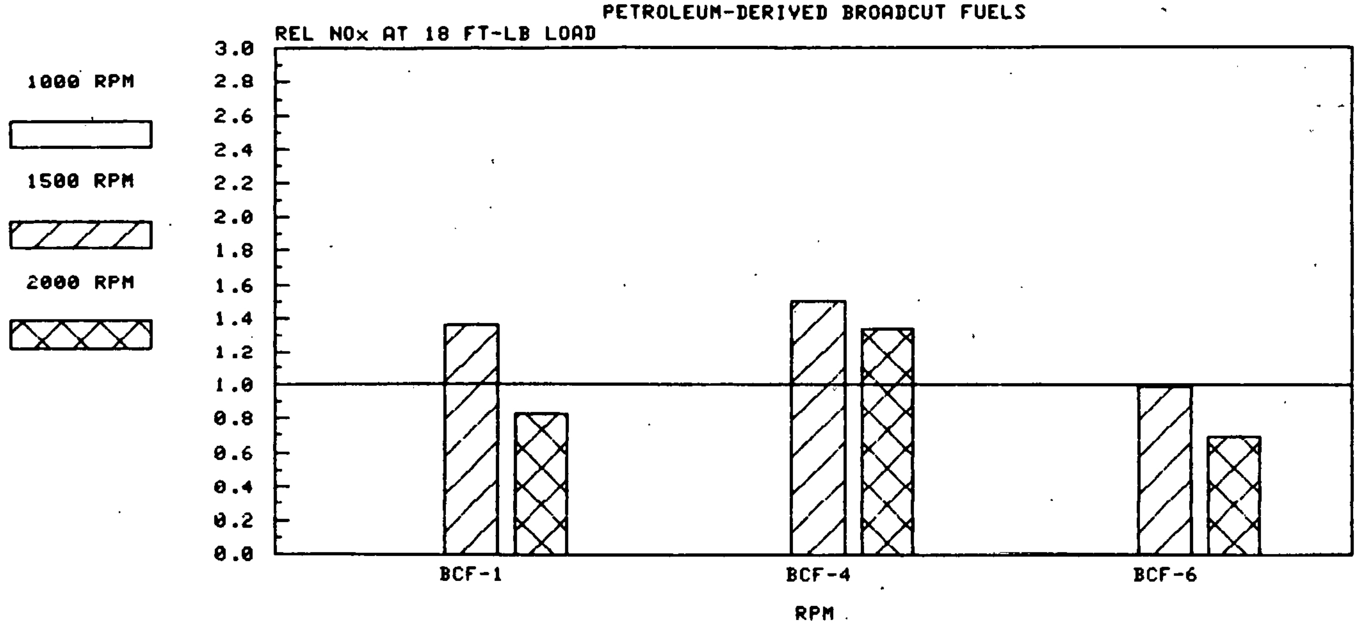


FIG.4.3D RELATIVE HYDROCARBONS

PETROLEUM-DERIVED BROADCUT FUELS

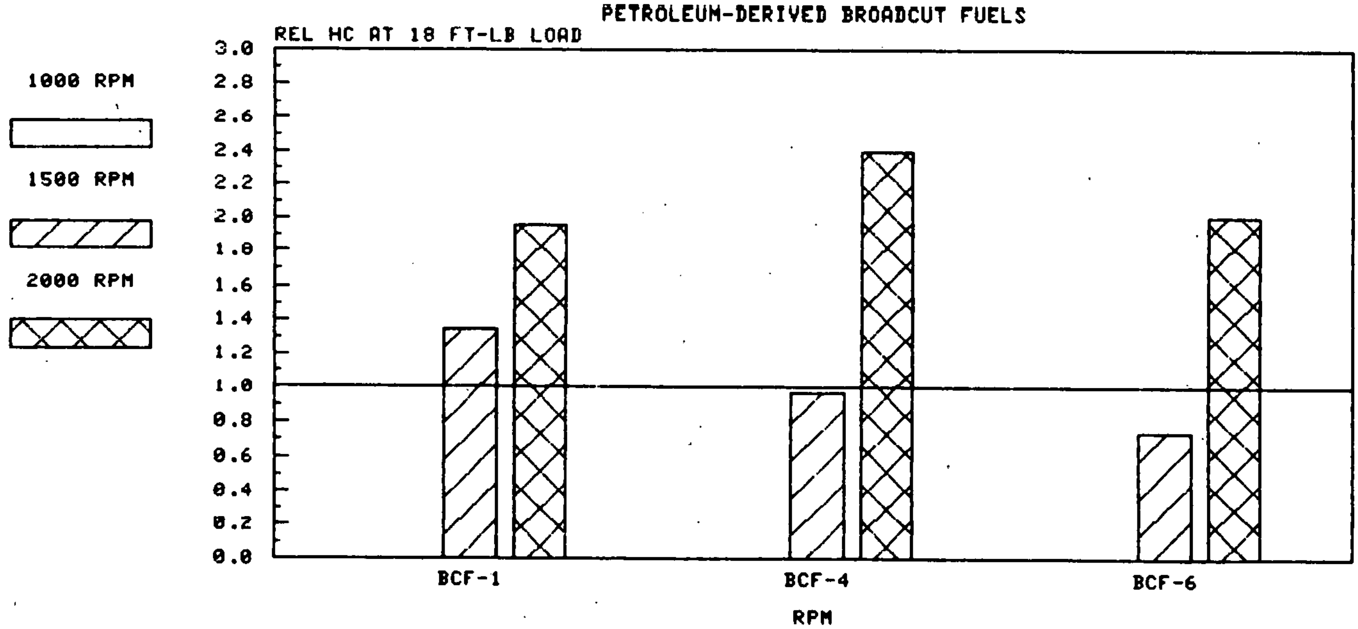


FIG.4.4A RELATIVE BSEC

SYNTHETIC-DERIVED BROADCUT FUELS

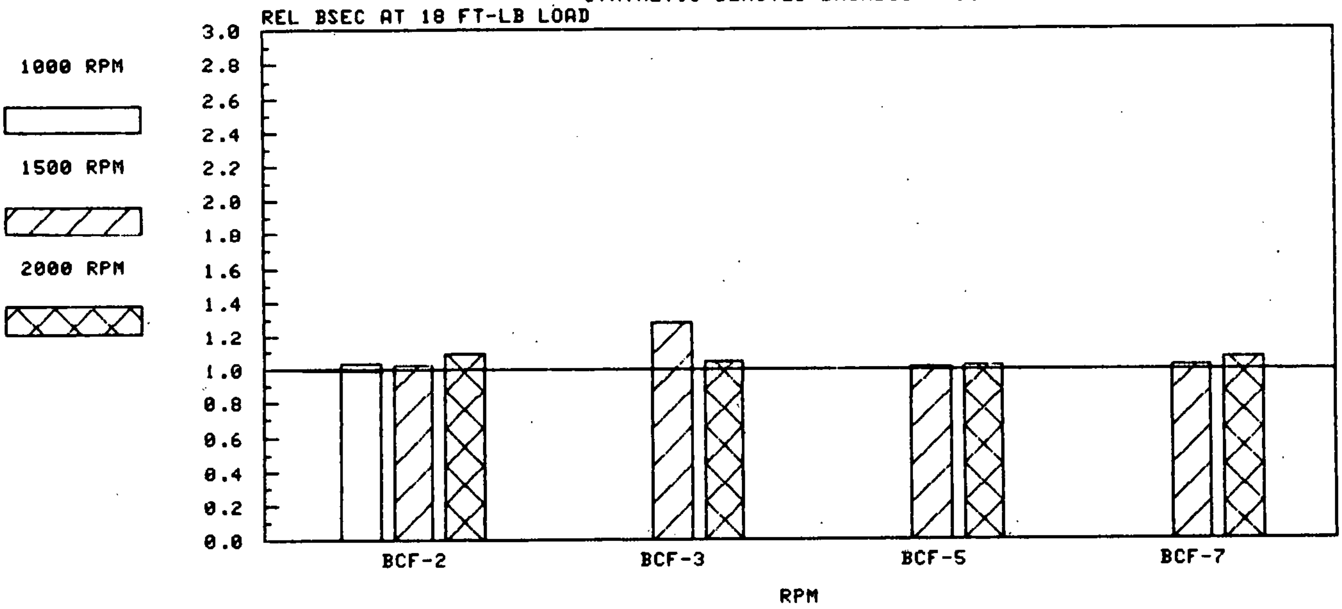
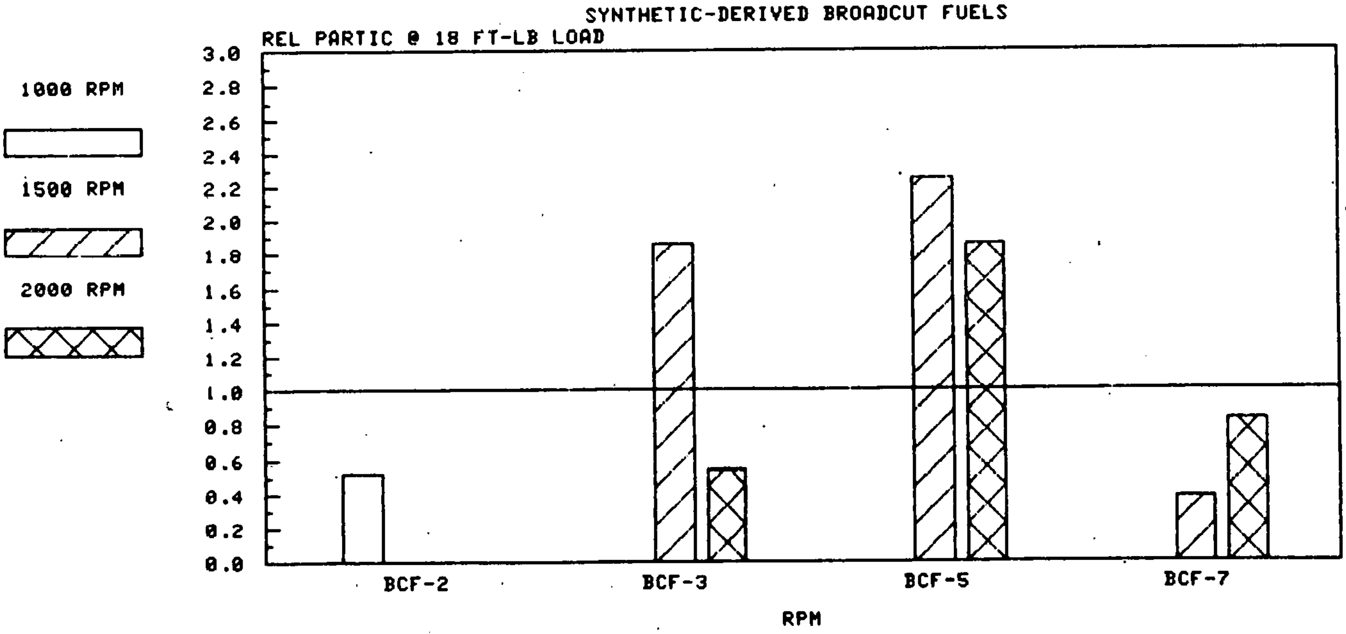


FIG.4.4B RELATIVE PARTICULATES

SYNTHETIC-DERIVED BROADCUT FUELS



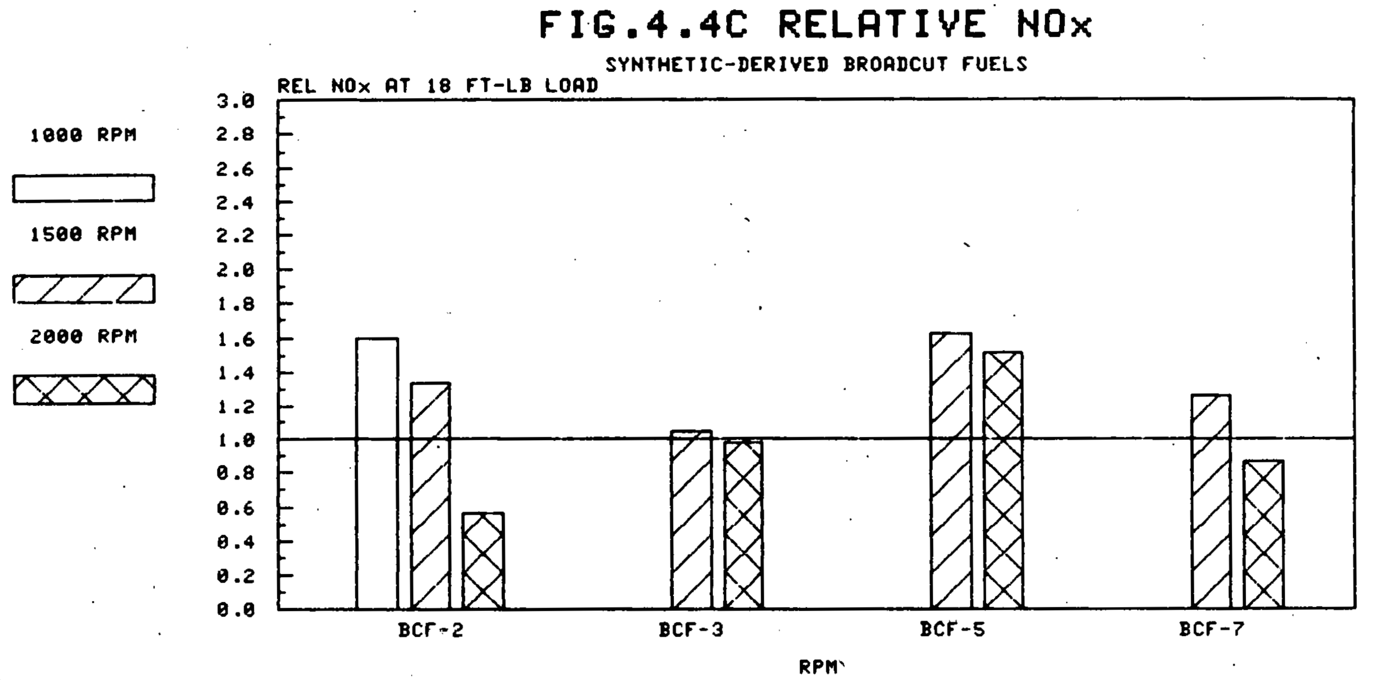


FIG.4.4C RELATIVE NOx
SYNTHETIC-DERIVED BROADCUT FUELS
REL NOx AT 18 FT-LB LOAD
1000 RPM
1500 RPM
2000 RPM
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
BCF-2
BCF-3
BCF-5
BCF-7
RPM

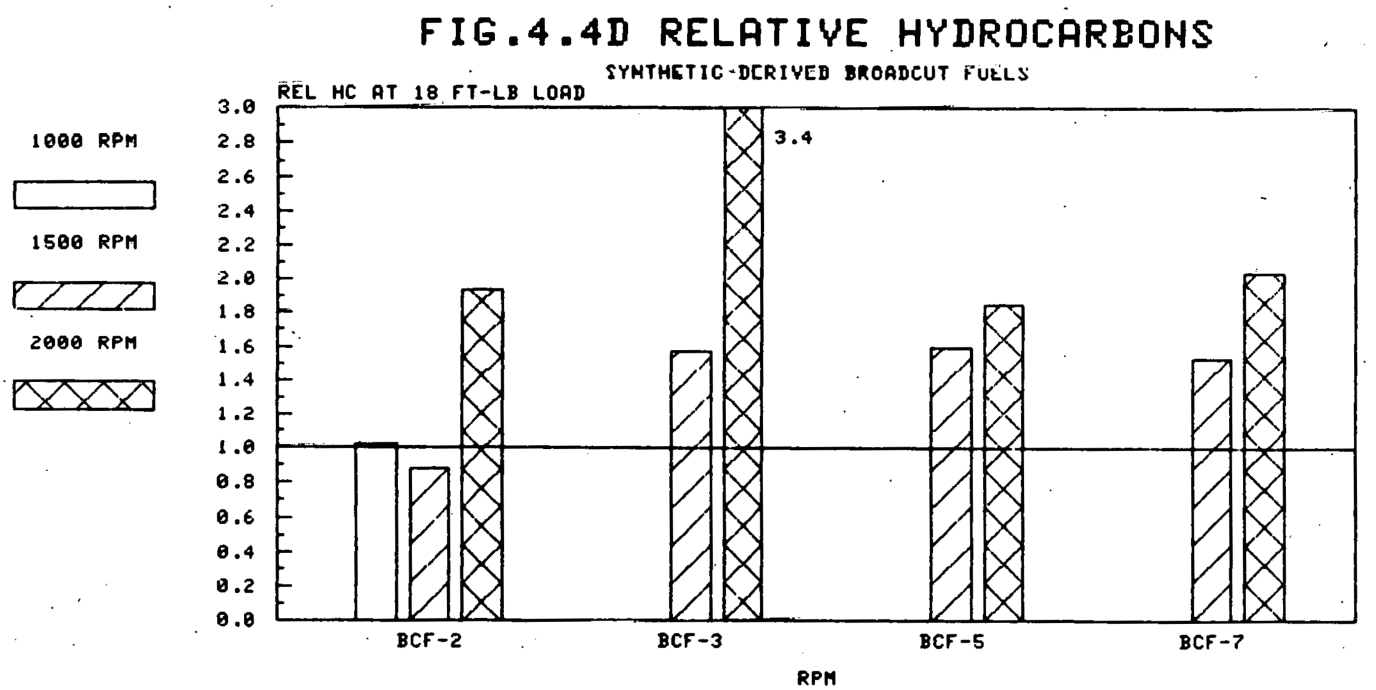


FIG.4.4D RELATIVE HYDROCARBONS
SYNTHETIC-DERIVED BROADCUT FUELS
REL HC AT 18 FT-LB LOAD
1000 RPM
1500 RPM
2000 RPM
3.4
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
BCF-2
BCF-3
BCF-5
BCF-7
RPM

Qualitative aspects of broadcut fuel performance included audible knock from all fuels. Probable cause was ignition delay followed by abnormally rapid pressure rise after ignition. A technique was devised for the operators to calculate rate of pressure rise from the oscilloscope trace, with an arbitrary limit of 100 psi per degree of crank angle. If a run condition exceeded that limit, it was abandoned.

The rate of pressure rise was highest at low speeds. Therefore, only partial data were available at 1000 RPM on some fuels. Unstable operation at 1000 RPM (misfiring on every other cycle) eliminated other data.

The CLR engine started on most of the fuels tested, with occasional help from ether starting fluid. The two lowest cetane fuels - BCF-3, and BCF-7 - required that the engine be started and warmed up on diesel fuel.

The broadcut fuels were tested on the CLR engine with no modifications. The objective was screening tests on the fuels, within the normal fuel tolerance of the engine, to demonstrate relative performance and emissions for an unconventional type of fuel. No attempt was made to optimize the engine operation by advancing or retarding the injection timing. Other options might have included modifying the injector, or revising the compression ratio.

V. CONCLUSIONS

A. Fuel Formulation

A variety of diesel fuels and broadcut fuels containing components derived from shale oil and coal were blended for the engine testing phase of the project. The principal objectives met in this phase of the project were:

- Formulations for most of the fuels were derived from refinery modeling studies in the initial phase of the project.

- Fuel blends were prepared and met selected properties with variations in components used.

- Communications were established through the Project Technical Manager to provide research quantities of test fuel to other laboratories.

B. Diesel Engine Testing

Eight diesel fuels were tested in a one-cylinder, direct injection CLR diesel engine. Based on test results in comparison with the baseline fuels, the following conclusions are drawn:

1. Shale-derived DFM and JP-5, which were refined to meet Navy specifications, showed minor differences from typical petroleum baseline fuel. Fuel consumption was slightly less for both shale fuels. JP-5 emissions included lower particulates and higher hydrocarbons, probably because of differences from base fuel in boiling range.

2. The Paraho products blended with petroleum fractions to 45 cetane diesel fuel showed no significant differences in fuel consumption or emissions. Stable operation of the engine was obtained at all speed and load conditions.

3. SRC-II middle distillate at 13 and 16 volume percent in blends with petroleum fractions (to 41 and 42 cetane) showed normal fuel consumption and stable operation. Both fuels showed higher particulates emissions, and one fuel produced more unburned hydrocarbons.

4. At 35 and 50 volume percent SRC-II distillate in diesel fuel, particulates emissions were substantially higher. Engine knock was moderate to severe on the 31 and 25 cetane number fuels and operation was unstable at 2000 RPM.

5. Although SRC-II middle distillate could be used in diesel fuel at concentrations under 20 volume percent, odor and contact hazards would preclude its general use. Treating to overcome these problems would also improve the performance and emissions characteristics.

C. Broadcut Fuels

Seven broadcut fuels were tested in the same CLR engine as the diesel fuels, to demonstrate performance and emissions relative to the same baseline diesel fuel. The main findings were as follows:

1. Broadcut fuels can be run in a single-cylinder CLR engine using the normal fuel tolerance of the engine.

2. Performance and emissions were affected more by the properties and composition of the fuels than by differences in origins from petroleum or synthetic sources.

3. All fuels had high relative fuel consumption, averaging about 10 percent more than base fuel BSEC. The presence of naphtha in the fuels is the probable cause. Fuel consumption increased with higher percentages of naphtha in the blends, particularly the amount of light naphtha.

4. All seven fuels exhibited high relative hydrocarbon emissions which would be expected with the amount of low boiling material but may also be related to the fuel injection system with lower viscosity fuels.

5. Three fuels showed high particulates and/or nitrogen oxides because of wider boiling range and high 90% distillation temperatures.

6. All fuels caused knock which was more severe for the fuels with higher naphtha content. Cold starting was not possible on the two lowest cetane fuels.

7. The fuels were run at the same conditions as diesel fuel for comparative data. Operation and performance may have been improved by adjustment or modification of fuel injection. Control of blend properties to provide a minimum cetane number and maximum 90% point may be advisable on future blends.

VI. FUTURE WORK

Work to be done in the final phases of the project will be centered in the following areas:

1. Engine testing will be continued on selected diesel and broadcut fuels. Chassis dynamometer studies will be made with four fuels in comparison with the baseline fuel, including two diesel fuels:

- Coal Case 5A
- SRC-II Medium Cetane

Two broadcut fuels chosen for chassis dynamometer testing are:

- Rocky Mountain Case 4 (Shale Base)
- Mid-Continent Case 5 (Petroleum Base)

2. A durability test run will be made with Coal Case 5A diesel fuel.

3. At least nine gasolines will be evaluted in engines for performance and emissions, similar to work described for diesel and broadcut fuels. CLR screening tests on all fuels will be followed by chassis dynamometer and durability evaluations on selected fuels.

4. Distribution of samples to other laboratories has started and will continue to the extent of sample availabilty. Data or references from these other evaluations will be collected for inclusion in the final report.

REFERENCES

1. N.R. Sefer, and J.A. Russell, "Regional Refining Models for Alternative Fuels Using Shale and Coal Synthetic Crudes," Report No. DOE/CS/50017-1, November 1980.

2. E.T. Robinson, "Refining of Paraho Shale Oil Into Military Specification Fuels," Twelfth Oil Shale Symposium, Colorado School of Mines, April 1979.

3. G.M. Singerman, "Methyl Aryl Ethers from Coal Liquids as Gasoline Extenders and Octane Improvers," SAE Paper 810443, SAE Special Publication SP-480, Alternate Fuels, February 1981.

4. D.M. Jackson, and B.K. Schmid, "Production of Distillate Fuels by SRC-II," Coal Dilemma II, ACS Symposium, Colorado Springs, Colorado, February 1979.

5. G. Tan, and A.J. deRosset, "Hydrotreating and Reforming H-Coal Process Derived Naphthas," UOP, Inc., DOE Report No. FE-2566-12, March 1978.

6. T.W. Ryan, J.O. Storment, B.R. Wright, and R. Waytulonis, "The Effects of Fuel Properties and Composition on Diesel Engine Exhaust Emissions - A Review," SAE Paper 810953, September 1981. SAE Special Publication SP-495, Diesel Combustion and Emissions, Part III.

7. E.F. Obert, Internal Combustion Engines and Air Pollution, Harper & Row, 1973.

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APPENDIX A

SAFETY PRECAUTIONS IN FUEL HANDLING

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Gulf Oil Corporation

MATERIAL SAFETY DATA SHEET

MEDICAL & HEALTH RESOURCES DIVISION, TOXICOLOGY DEPARTMENT
P. O BOX 3240, PITTSBURGH, PA 15230

Middle Distillate — SRC II MATERIAL

SECTION I

CODE NUMBER: 10SRCII3APR810		PREPARED BY: C.R.Hopper
MANUFACTURER'S NAME: The Pittsburg & Midway Coal Mining Co.	EMERGENCY TELEPHONE NO.: (713) 651-0693	NEW / REVISED 4/81 / REPLACES 8/79 / EXPIRES 4/82
ADDRESS (NUMBER, STREET, CITY, STATE & ZIP CODE): North Fort Lewis, WA 98433		
CHEMICAL NAME & SYNONYMS: NA	TRADE NAMES & SYNONYMS: Middle Distillate	
CHEMICAL FAMILY: Coal-derived middle distillate	FORMULA: NA	
CAS NUMBER: 68911-57-9	UN Number 1137	

SECTION II – HAZARDOUS INGREDIENTS

MATERIALS	%	TLV (Units)	MATERIALS	%	TLV (Units)
Middle Distillate	99+	*	Benzene	< 1	10 ppm
Phenolics, wt. %	(10-25)	5ppm			

*The health hazards, particularly skin lesions associated with coal liquefaction processes, are recognized as potential health problems. Therefore, it is strongly recommended that inhalation and skin exposure be kept to a minimum and that all recommended precautions be observed when handling this material. See Sections V and IX.

DOT HAZARD CLASS: Combustible liquid

SECTION III – PHYSICAL DATA

BOILING POINT °C (°F)	177-288°C (350-550°F)	SPECIFIC GRAVITY (H_2O=1) 15.6 / 15.6 C	0.97
VAPOR PRESSURE (mm Hg.)	ND	PERCENT, VOLATILE BY VOLUME (%)	97
VAPOR DENSITY (Air = 1)	ND	EVAPORATION RATE	ND
SOLUBILITY IN WATER	Slightly soluble		
APPEARANCE AND ODOR	Amber to black oil, strong creosote-like odor.		

SECTION IV – FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	> 71°C (160°F) closed cup	FLAMMABLE LIMITS: ND	LEL	UEL

EXTINGUISHING MEDIA

- ☐ ALCOHOL FOAM
- ■ CARBON DIOXIDE
- ■ DRY CHEMICAL
- ■ FOAM
- ■ WATER SPRAY (FOG)
- ☐ OTHER

SPECIAL FIRE FIGHTING PROCEDURES Use water spray to keep fire-exposed containers cool, flush spills away from fire exposures and to disperse vapors. Use air-supplied rescue equipment for enclosed areas. This material floats and emulsifies with water.

FIRE AND EXPLOSION HAZARDS Combustible. Flammability similar to diesel fuel or kerosene. Either misting of the material through handling or heating to its flash point is likely to give sufficient vapors for ignition upon exposure to flame or incendiary sparks.

NA = Not Applicable   ND = No Data Available   Gulf Modified Form OSHA-20

SECTION V – HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE Suggested guideline for airborne exposure to coal-derived materials: 0.2 mg/m3 as benzene solubles. See Section II.

EFFECTS OF OVEREXPOSURE **Severely irritating to the eyes; strongly irritating to the skin. Systemic toxicity, particularly CNS and respiratory effects, can occur from the possible skin absorption, inhalation, and ingestion of this material due to the presence of phenolic compounds. Prolonged and repeated exposures may lead to dermatitis and possibly to skin tumor formation. CAUTION: High press. skin injection may occur when working with fuel injectors. Injury will not appear serious at first; within a few hours tissue will become swollen, discolored, and extremely painful.**

EMERGENCY AND FIRST AID PROCEDURES SKIN CONTACT: Immediately water deluge shower. Follow by rinsing with castor or olive oil for large skin surface exposures. EYE CONTACT: Flush immediately with water for 15 min. INHALATION: Remove from exposure. Give artificial respiration if necessary. INGESTION: DO NOT INDUCE VOMITING. (aspiration hazard). Give 1-2 oz. activated charcoal followed by 1-2 glasses of milk or 2-4 oz. of vegetable or olive oil. Obtain immediate medical aid for all cases of contact. HIGH PRESS. SKIN INJECTION: Emergency medical treatment must be obtained immediately after accidental injection. Physician must be familiar with local procedures for treatment of this type of wound (i.e., incision, saline irrigation, removal of necrotic tissue and wound dressing).

SECTION VI – REACTIVITY DATA

STABILITY:	UNSTABLE		STABLE	X	CONDITIONS TO AVOID

INCOMPATABILITY (Materials to avoid)
Reacts with strong oxidizing materials.

HAZARDOUS DECOMPOSITION PRODUCTS
When heated to decomposition, it will emit irritating and toxic fumes.

HAZARDOUS POLYMERIZATION:	MAY OCCUR		WILL NOT OCCUR	X	CONDITIONS TO AVOID

SECTION VII – SPILL OR LEAK PROCEDURES

- ☐ EVACUATE AREA
- ■ STOP FLOW
- ■ ELIMINATE ALL SOURCES OF IGNITION, FLAMMABLES
- ■ AVOID INHALATION
- ■ AVOID DERMAL CONTACT
- ■ RESPIRATORY PROTECTION (AS PER SECTION VIII)
- ■ SKIN PROTECTION (AS PER SECTION VIII)
- ■ ABSORB OR SCRAPE UP
- ■ VACUUM UP
- ☐ OTHER
- ☐ EVAPORATE SMALL AMOUNTS IN HOOD
- ■ INCINERATE UNDER CONTROLLED CONDITIONS
- ☐ INCINERATE USING AFTER BURNER & SCRUBBER
- ☐ LANDFILL OR LANDFARM
- ☐ SECURE CHEMICAL LANDFILL
- ☐ NEUTRALIZE AND WASH AWAY WITH WATER
- ■ OBSERVE GOVERNMENTAL SPILL & WATER QUALITY REGULATIONS
- ■ REMOVE SOILED CLOTHING
- ☐ KEEP UPWIND AND ISOLATE EXPOSURE AREA

SECTION VIII – SPECIAL PROTECTION INFORMATION

	DURING NORMAL USE EXPOSURE LESS THAN TLV	FOR GASES, VAPORS, DUSTS, FUMES, MISTS EXCEEDING TLV	SPECIAL (E.G. THERMAL PROCESSING, SPRAY APPLICATIONS)
GENERAL VENTILATION	Yes	Yes	
LOCAL EXHAUST	Yes	Yes	
NIOSH - CERTIFIED RESPIRATORY PROTECTION (1-3)	NA	2, if needed	3, for large spills

1. Particle Removing Air Purifying Air Respirator (Mechanical Filter) *2. Gas and Vapor Removing Air Purifying Respirator (Canister)* *3. Full Face Mask Positive Pressure-Demand Type Supplied Air*

EYE PROTECTION	SAFETY GLASSES		CHEMICAL GOGGLES	X	FACE SHIELD	X	*(E) EXCELLENT*
PROTECTIVE GLOVES	NEOPRENE	G	POLYVINYL ALCOHOL	NR	POLYETHYLENE	NR	*(G) GOOD* *(F) FAIR*
	NATURAL RUBBER	P	BUTYL RUBBER	NR	POLYVINYL CHLORIDE	NR	*(P) POOR* *(NR) NOT RECOMMENDED*

OTHER PROTECTIVE EQUIPMENT The application of a skin barrier cream before work and several times during work is recommended.

SECTION IX – SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING Avoid skin and eye contact. Avoid the inhalation of mists, fumes, or vapors. Maintain good ventilation. Fresh change of work clothes daily Showering and clothes change recommended at the end of each shift. Combustible hydrocarbons empty drums may contain combustible vapors. Wash out drums with water before discarding.

OTHER PRECAUTIONS
Animal data suggest that SRC materials have the potential of producing fetotoxic effects. Therefore, it is prudent to prevent fertile females from receiving significant exposure to this material.

FOR TRANSPORTATION SPILLS OR LEAK EMERGENCIES, CALL: CHEMTREC - 800 424 9300 (CHEMICAL TRANSPORTATION EMERGENCY CENTER).

SRC II - MSDS ADDENDUM

DIESEL EXHAUST POTENTIAL HAZARDS - PROTECTIVE MEASURES

1. COMBUSTION PRODUCTS WILL CONTAIN IRRITATING AND TOXIC FUMES AND SMOKE. IRRITATION TO THE EYES AND UPPER RESPIRATORY TRACT WILL OCCUR WITH OVER-EXPOSURE.
2. DIZZINESS, NAUSEA, AND OTHER CNS EFFECTS WILL ALSO OCCUR WITH OVEREXPOSURE. OBSERVE THE VARIOUS REQUIRED PELS (OSHA) AND RECOMMENDED TLVS (ACGIH) FOR COMBUSTION MATERIALS.
3. OBSERVE THE SUGGESTED GUIDELINES FOR AIRBORNE EXPOSURE TO COAL DERIVED MATERIAL: 0.2 MG/M^3 AS BENZENE SOLUBLES.
4. VENT THE OPERATING ENGINE WITH LOCAL EXHAUST. IF LEAKAGE OF SEALS, GASKETS, AND/OR VALVES ARE OCCURRING, THE USE OF GENERAL FLOW-THROUGH VENTILATION IS ALSO RECOMMENDED.
5. FOR PREPARATION OF THE FUEL, WEAR PROTECTIVE GLOVES[a] AND A LONG-SLEEVE SHIRT WHERE POSSIBLE SPILLAGE OR SPLASHING MAY OCCUR.
6. THE USE OF PROTECTIVE EYE GOGGLES AND/OR FACE SHIELD IS RECOMMENDED WHERE THERE IS A POSSIBILITY OF SPLASHING INTO THE EYES.
7. ALL CONTAMINATED CLOTHING SHOULD BE REMOVED AT THE END OF THE WORK SHIFT. SPECIAL CLOTHES CLEANING PROCEDURES SHOULD BE ESTABLISHED.
8. INDIVIDUALS EXPOSED TO SRC MATERIALS SHOULD SHOWER AND CHANGE CLOTHES AT THE END OF EACH SHIFT.

(a) BESIDES NEOPRENE GLOVES, DISPOSABLE VINYL OR LATEX GLOVES MAY BE USED ONCE AND THEN DISCARDED WHERE NO SIGNIFICANT EXPOSURE RISK EXISTS.

THE PITTSBURGH & MIDWAY COAL MINING CO.
NORTH FORT LEWIS, WA 98433

PROCEDURES FOR COAL-DERIVED FUELS

General

1. Avoid inhaling vapors.

2. Avoid skin and eye contact.

3. Avoid engine exhaust gas.

ENGINE TEST CELL AREA

1. Use closed fuel system with vapor vents to exhaust fan.

2. Run exhaust fans in test cell.

3. Stay in test cell only when necessary.

4. Use vapor barrier cream on exposed skin (optional).

5. When working with fuel or fuel system, wear the following:
   a. Safety glasses
   b. Face shield or goggles
   c. Gloves (neoprene preferred).
   d. Long sleeve shirt or coat.

6. Avoid liquid drips or spills. Wipe up any liquid immediately and discard rags.

7. If skin contact occurs, wash affected area promptly or use safety shower. Change contaminated clothing.

FUEL HANDLING

1. Wear the following gear:
   a. Safety glasses
   b. Face shield or goggles
   c. Gloves (neoprene preferred)
   d. Long sleeve shirt or coal

2. Make transfers in fume hood if possible.

3. Keep containers closed. Wipe up any drips or spills.

4. Use funnel or tubing exclusively for this fuel. Wash with solvent and then detergent-water mix at end of project, even if plan to discard.

5. If get skin contact, wash affected area promptly or use safety shower. Change contaminated clothing.

APPENDIX B

BOILING RANGE BY GAS CHROMATOGRAPHY, ASTM D 2887

B. 1 DIESEL AND BROADCUT FUEL COMPONENTS

Component	St. Run Kerosene	Hydrocracker Kerosene	St. Run Diesel	Lt. Cycle Oil	Paraho DFM	Paraho JP-5	SRC-II Middle Distillate
Sample No.	AL-9749-F	AL-9998-F	AL-9750-F	AL-9751-F	AL-9090-F	AL-9089-F	AL-9251-F
Distillation, D2887,°F							
IBP	238	194	304	289	281	317	304
5 Wt%	365	287	443	451	388	339	368
10	408	331	477	469	424	347	387
20	438	386	501	499	461	360	420
30	454	409	520	521	489	379	450
40	461	428	539	541	509	389	471
50	474	443	559	563	525	404	497
60	486	456	581	587	547	419	514
70	493	473	607	611	566	428	536
80	501	501	644	637	582	448	563
90	517	548	690	666	603	465	592
95	524	579	725	686	615	488	615
EP	617	714	816	737	645	545	710

B.2 DIESEL FUELS

Fuel Sample No.	Howell No.2-D AL-9649-F	Shale Case 2A AL-10255-F	Shale Case 3 AL-10256-F	Coal Case 5A AL-10287-F	Coal Case 12 AL-10288-F	SRC-II Med. Cetane AL-10289-F	SRC-II Low Cetane AL-10290-F
Distillation, D2887, °F							
IBP	282	283	261	291	256	290	294
5 Wt%	395	359	367	393	378	371	370
10	426	393	405	427	418	404	399
20	458	446	450	463	458	443	434
30	485	481	474	489	478	467	462
40	499	502	493	506	497	493	488
50	521	524	513	523	511	511	505
60	542	549	535	547	528	532	527
70	568	575	563	576	554	557	553
80	593	600	593	610	589	584	579
90	628	639	635	670	650	618	610
95	664	674	673	714	695	654	643
EP	789	796	792	810	795	763	759

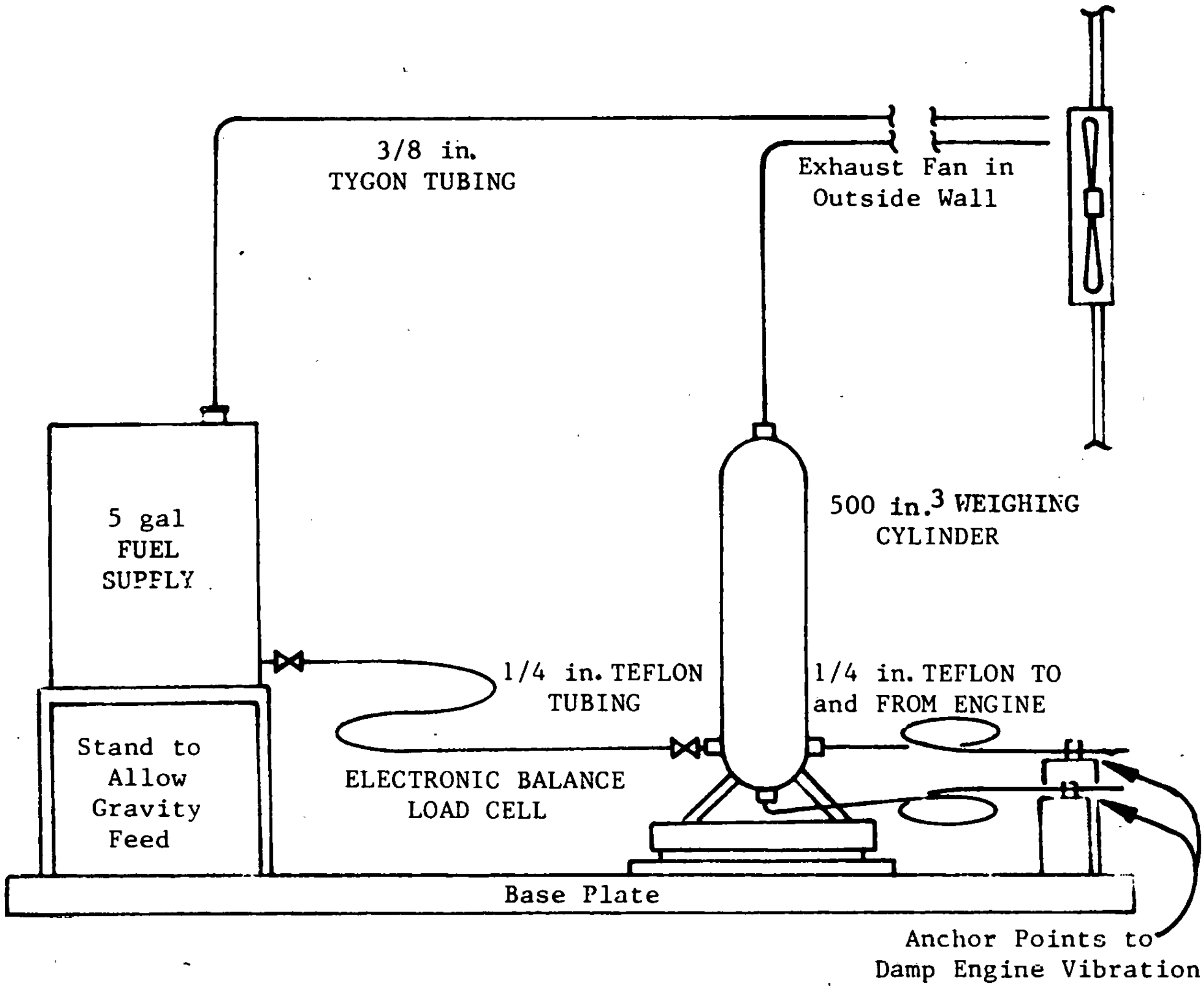
B.3 BROADCUT FUELS

Region	Rocky Mountain		Mid-Continent			Great Lakes	
Case No.	16	4	7A	5	4	5	4
Sample No.	AL-10286	AL-10305	AL-10306	AL-10307	AL-10308	AL-10309	AL-10310
Fuel Identification	BCF-1	BCF-2	BCF-3	BCF-4	BCF-5	BCF-6	BCF-7
Distillation, D2887, °F							
IBP	29	12	29	29	29	29	29
5 Wt%	77	35	75	35	33	33	35
10	95	86	84	99	84	79	84
20	146	157	141	181	242	156	166
30	179	209	170	222	304	186	207
40	217	259	197	274	365	219	236
50	247	303	223	344	453	239	264
60	323	337	259	496	487	276	303
70	496	386	304	536	505	311	343
80	550	491	375	580	538	491	442
90	618	579	522	638	600	576	521
95	661	633	600	678	652	634	566
RP	756	737	700	779	757	753	683

APPENDIX C

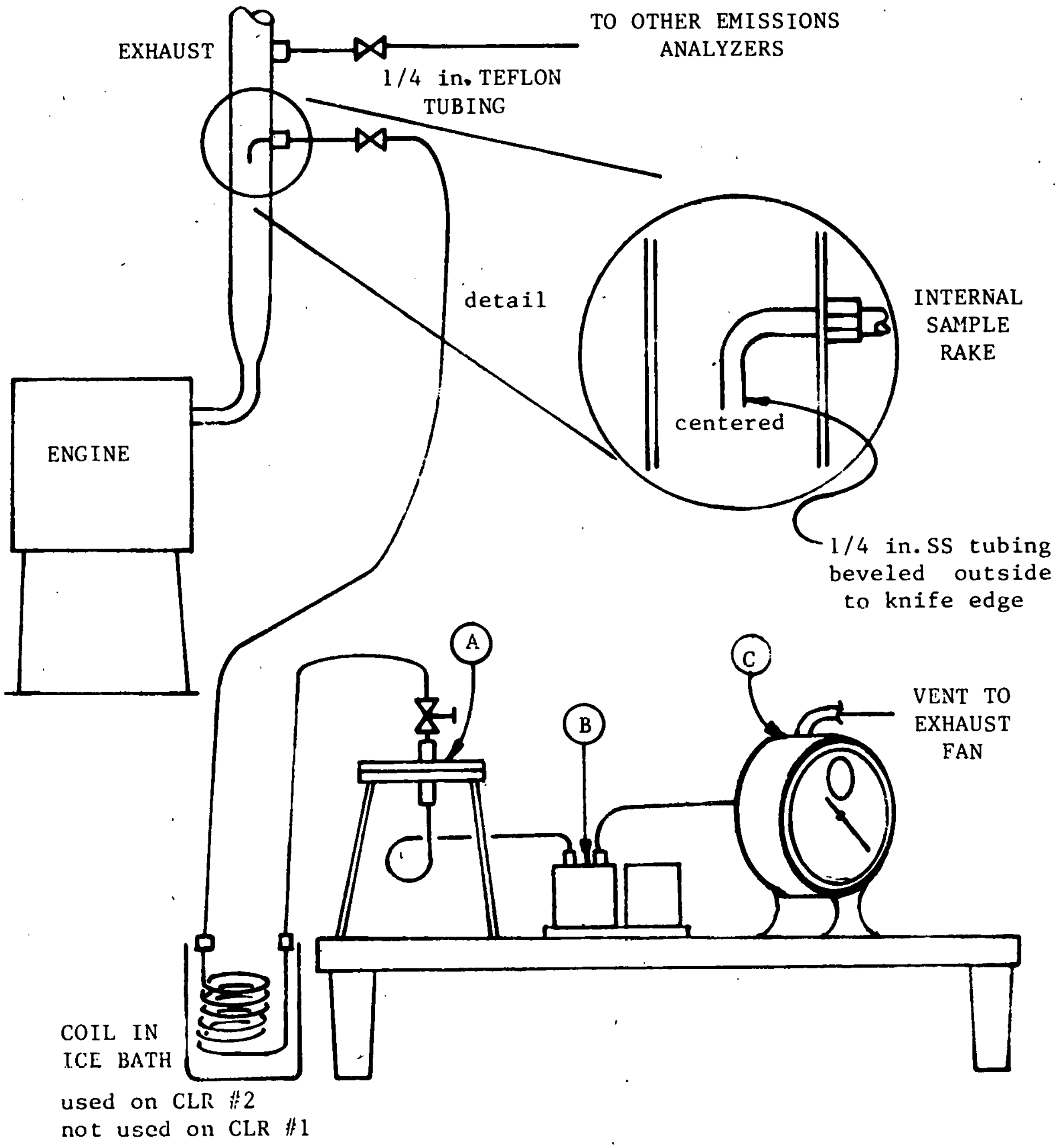
FUEL AND EMISSIONS SYSTEMS

FIGURE C.1 CLOSED FUEL SYSTEM FOR CLR ENGINE



TUBING: Metal tubing or Teflon, heavy wall, for liquid lines.
Tygon tubing for vapor lines.
Tubing loops to minimize vertical thrust on fuel weighing cylinder.

FIGURE C.2 PARTICULATE SAMPLE SYSTEM FOR CLR DIESEL



(A) Millipore filter holder, 142 mm size
(max 200 PSI inlet, 100 PSI differential)
Used Pallflex filters T60A20 (fiberglass) 125 mm size

(B) Air pump, bellows type Robbins & Meyers, Model No. KS-M330-Bowl
Part No. D-28817

(C) Wet test meter (CLR #1) 3 ℓ/rev (0.1 SCF). Sample 30-60 ℓ/test.
OR
Test meter (CLR #2) American Meter Division Type AL-120, 100 CFH.

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APPENDIX D CONTENTS

TABLES - PERFORMANCE AND EMISSIONS DATA

FIGURES - PERFORMANCE DATA FOR ALL FUELS

TABLE D.1 HOWELL NO.2-D BASELINE FUEL

PERFORMANCE

HOWELL NO. 2-D AL-9649-F 1000 rpm 10 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
1472	4.38	81.61	0.569	10354	12.38	17.17
1473	4.21	78.42	0.573	10429	12.29	17.71
1474	4.00	74.51	0.570	10384	12.35	18.76
1475	3.81	70.96	0.562	10233	12.53	20.05
1476	4.02	74.87	0.538	9791	13.09	20.36
1477	3.08	57.48	0.580	10568	12.13	24.96
1478	2.28	42.58	0.630	11477	11.17	31.59
1479	1.49	27.68	0.761	13855	9.25	40.43
1496	3.85	71.67	0.559	10179	12.59	20.21
1495	4.57	85.16	0.569	10361	12.37	16.51

HOWELL NO. 2-D AL-9649-F 1500 rpm 7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
1481	6.31	78.42	0.555	10098	12.70	19.95
1482	7.54	93.67	0.534	9733	13.17	17.25
1483	6.28	78.06	0.532	9680	13.24	20.86
1484	5.03	62.45	0.521	9491	13.51	26.85
1485	3.77	46.84	0.560	10192	12.58	33.72
1486	2.51	31.22	0.660	12027	10.66	43.09
1487	1.26	15.61	0.923	16809	7.63	62.26

HOWELL NO. 2-D AL-9649-F 2000 rpm 7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
1488	8.30	77.35	0.564	10266	12.49	18.76
1489	7.62	70.96	0.545	9923	12.92	21.21
1490	7.92	73.80	0.561	10208	12.56	19.71
1491	6.40	59.61	0.564	10275	12.48	24.42
1492	4.57	42.58	0.606	11038	11.61	31.92
1493	2.93	27.32	0.733	13352	9.60	41.07
1494	1.60	14.90	0.963	17534	7.31	56.82

EMISSIONS

HOWELL NO 2-D AL-9649-F 1000 rpm 11 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
1472	4.38	0.1690	0.0913	0.1852	0.7000	17.17
1473	4.21	$$$$$$	0.0905	0.1642	0.6000	17.71
1474	4.00	$$$$$$	0.0900	0.1782	0.5000	$$$$$
1475	3.81	0.1250	0.0845	0.1582	0.4000	20.05
1476	4.02	$$$$$$	0.0945	0.0990	0.3000	20.36
1477	3.08	0.0950	0.0725	0.1802	0.4000	24.96
1478	2.28	$$$$$$	0.0875	0.1420	0.2000	31.59
1479	1.49	$$$$$$	0.0763	0.1290	0.1000	40.43
1480	0.63	0.0700	0.0475	0.1000	0.1000	56.37
1495	4.57	$$$$$$	0.0850	0.2000	1.0000	16.51
1496	3.85	0.2030	0.0750	0.1600	0.4000	20.21

HOWELL NO 2-D AL-9649-F 1500 rpm 7 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
1481	6.31	$$$$$$	0.0913	0.1480	0.6000	19.95
1482	7.54	0.2310	0.0943	0.0890	1.2000	17.25
1483	6.28	0.1470	0.0950	0.1200	0.4000	20.86
1484	5.03	$$$$$$	0.0925	0.1080	0.1000	26.85
1485	3.80	0.0630	0.0750	0.0990	0.1000	33.72
1486	2.51	$$$$$$	0.0005	0.0910	0.0000	43.09
1487	1.00	0.0200	0.0383	0.0880	0.0000	62.26

HOWELL NO 2-D AL-9649-F 2000 rpm 7 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
1488	8.30	$$$$$$	0.1400	0.1000	0.8000	18.76
1489	7.62	$$$$$$	0.1400	0.1000	0.4000	21.21
1490	7.92	$$$$$$	0.0800	0.0900	0.6000	19.71
1491	6.44	$$$$$$	0.0750	0.0900	0.2000	24.42
1492	4.57	0.1070	0.0575	0.0800	0.1000	31.92
1493	2.93	$$$$$$	0.0425	0.0700	0.1000	41.07
1494	1.22	0.0310	0.0300	0.0700	0.0000	56.82

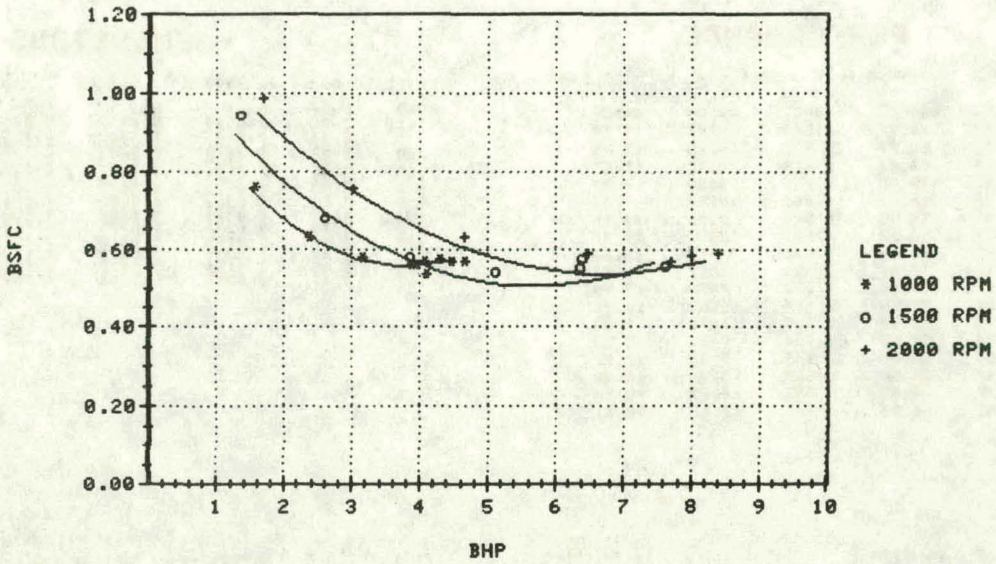

FIG. D.1A HOWELL N0. 2-D BSFC VS BHP
CLR#1

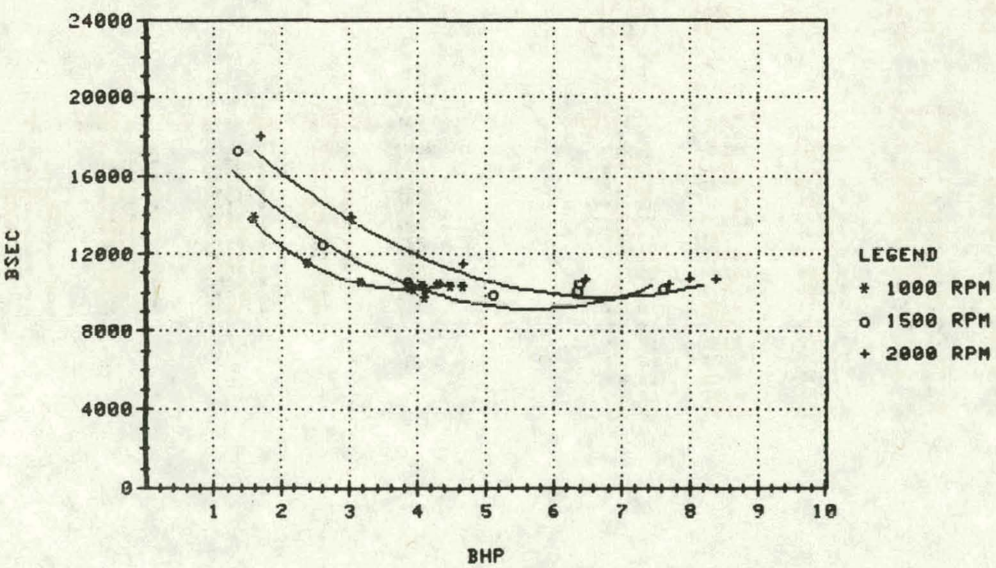

FIG. D.1B HOWELL N0. 2-D BSEC VS BHP
CLR#1

TABLE D.2 PHILLIPS D-2 BASELINE FUEL

PERFORMANCE

PHILLIPS D-2 AL-9993-F 1000 rpm 17 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE
367	3.47	64.72	0.541	9794	13.09
3	3.05	56.77	0.565	10215	12.55
4	2.33	43.43	0.614	11102	11.55
5	1.55	28.88	0.755	13658	9.39
6	0.86	16.07	1.009	18250	7.03
122	3.89	72.45	0.504	9121	14.06
142	2.29	42.69	0.681	12322	10.40
358	3.47	64.65	0.530	9596	13.36
179	2.02	37.61	0.600	10847	11.82
181	4.19	78.10	0.523	9455	13.56
231	4.29	79.98	0.650	11762	10.90
271	1.95	36.40	0.599	10836	11.83
272	2.73	50.85	0.524	9483	13.52
273	3.56	66.28	0.548	9920	12.92
307	3.47	64.58	0.568	10286	12.46
321	3.47	64.65	0.565	10222	12.54
333	3.45	64.33	0.562	10168	12.61

PHILLIPS D-2 AL-9993-F 1500 rpm 19 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE
368	5.26	65.39	0.545	9865	13.00
8	4.57	56.77	0.551	9978	12.85
9	3.43	42.58	0.581	10505	12.20
10	2.30	28.53	0.710	12843	9.98
11	1.29	16.07	0.858	15523	8.26
123	5.77	71.75	0.504	9117	14.06
124	3.62	45.03	0.582	10533	12.17
125	1.20	14.90	1.034	18703	6.85
359	5.33	66.25	0.549	9942	12.90
334	5.16	64.12	0.533	9641	13.30
180	3.02	37.47	0.660	11938	10.74
182	6.34	78.77	0.516	9331	13.74
232	1.22	15.12	1.134	20522	6.25
233	1.83	22.78	0.829	14999	8.55
274	2.97	36.87	0.691	12499	10.26
275	5.36	66.60	0.550	9956	12.88
276	6.46	80.23	0.551	9975	12.85
308	5.21	64.68	0.584	10564	12.14
322	5.33	66.25	0.536	9704	13.21

PHILLIPS D-2 AL-9993-F 2000 rpm 15 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE
12	7.66	71.39	0.549	9942	12.90
13	6.21	57.87	0.538	9730	13.18
14	4.65	43.29	0.598	10827	11.84
15	3.10	28.92	0.709	12825	10.00
369	7.11	66.25	0.537	9721	13.19
360	7.05	65.71	0.556	10057	12.75
183	8.43	78.59	0.564	10210	12.56
234	2.33	21.75	0.900	16277	7.88
277	2.33	21.72	0.811	14673	8.74
278	3.93	36.58	0.695	12581	10.19
279	5.54	51.63	0.579	10482	12.23
280	7.17	66.78	0.537	9720	13.19
309	7.09	66.10	0.550	9946	12.89
323	6.97	64.97	0.531	9601	13.35
335	7.06	65.82	0.552	9989	12.83

EMISSIONS

PHILLIPS D-2 AL-9993-F 1000 rpm 13 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
1	3.82	0.0617	0.0767	0.3450	0.5300	27.81
4	2.33	0.0145	0.0362	0.1250	0.2200	42.89
6	0.86	0.0216	0.0245	0.0701	0.1000	71.79
122	3.89	0.0195	0.0768	0.1258	0.2700	31.29
142	2.29	0.0362	0.0568	0.1079	0.1680	40.22
144	4.58	0.0522	0.0607	0.4823	2.9500	19.66
179	2.02	0.0323	0.0672	0.0815	0.0830	51.80
181	4.19	0.0419	0.1080	0.2587	0.5200	27.43
272	2.73	0.0230	0.0727	0.1104	0.1425	42.93
307	3.47	0.0158	0.0618	0.1763	0.2465	30.21
321	3.47	0.0235	0.0678	0.1481	0.2960	30.65
333	3.45	0.0156	0.0922	0.1335	0.1610	30.68
367	3.47	0.0253	0.0563	0.1505	0.3420	31.76

PHILLIPS D-2 AL-9993-F 1500 rpm 16 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
7	5.71	0.0676	0.0705	0.1139	0.2000	25.91
9	3.43	0.0107	0.0556	0.0636	0.0950	40.64
11	1.29	0.0155	0.0395	0.0560	0.0780	72.73
123	5.77	0.0082	0.0895	0.0493	0.0890	28.09
124	3.62	0.0063	0.0603	0.0431	0.0590	39.27
125	1.20	0.0054	0.0428	0.0381	0.0640	66.62
143	3.65	0.0301	0.0510	0.0619	0.1410	36.91
145	6.86	0.0235	0.0789	0.1207	1.0800	17.64
180	3.02	0.0234	0.0613	0.0582	0.0710	41.38
182	6.34	0.0217	0.0949	0.1120	0.4000	24.69
276	6.46	0.0150	0.0771	0.0924	0.3755	22.68
308	5.21	0.0117	0.0543	0.1278	0.2070	25.77
322	5.33	0.0114	0.0632	0.0815	0.1050	28.23
334	5.16	0.0052	0.0778	0.0651	0.0650	29.06
359	5.33	0.0072	0.0670	0.0946	0.0905	27.55
368	5.26	0.0068	0.0577	0.0649	0.1000	28.03

PHILLIPS D-2 AL-9993-F 2000 rpm 12 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
12	7.66	0.0236	0.0738	0.0676	0.1470	23.95
14	4.65	0.0068	0.0530	0.0612	0.0670	36.59
126	7.77	0.0147	0.0610	0.0503	0.4500	20.06
146	8.10	0.0123	0.0528	0.0406	0.5200	20.54
183	8.43	0.0096	0.0919	0.0439	0.2300	21.19
234	2.33	0.0040	0.0367	0.0451	0.0685	47.77
277	2.33	0.0114	0.0398	0.0465	0.0775	54.21
279	5.54	0.0143	0.0658	0.0493	0.0585	31.55
309	7.09	0.0056	0.0709	0.0896	0.1250	25.49
323	6.97	0.0087	0.0751	0.0777	0.0845	27.11
335	7.06	0.0037	0.0853	0.0552	0.0540	25.83
369	7.11	0.0043	0.0592	0.0557	0.0820	26.40

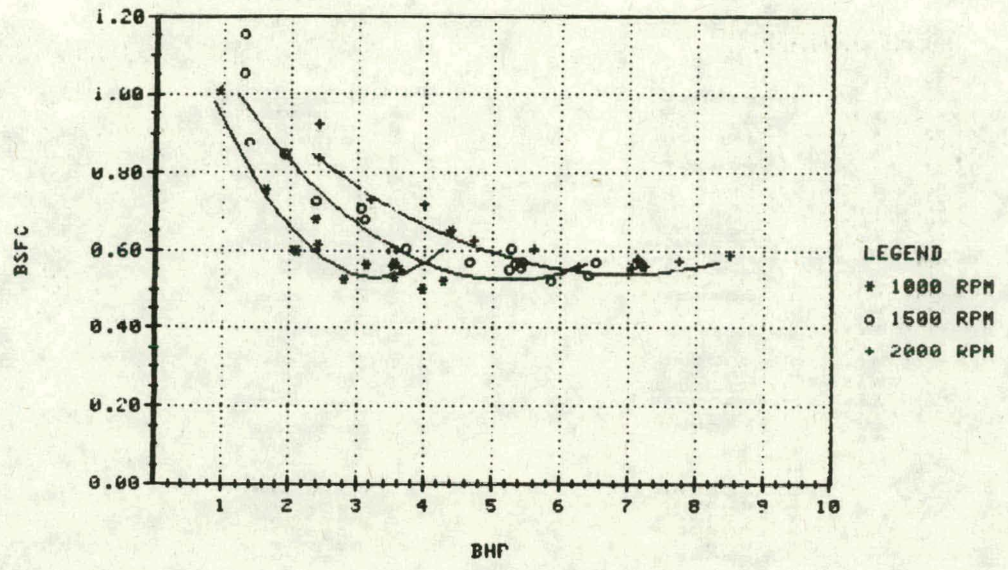

FIG.D.2A PHILLIPS D-2 BSFC VS BHP
CLR #2

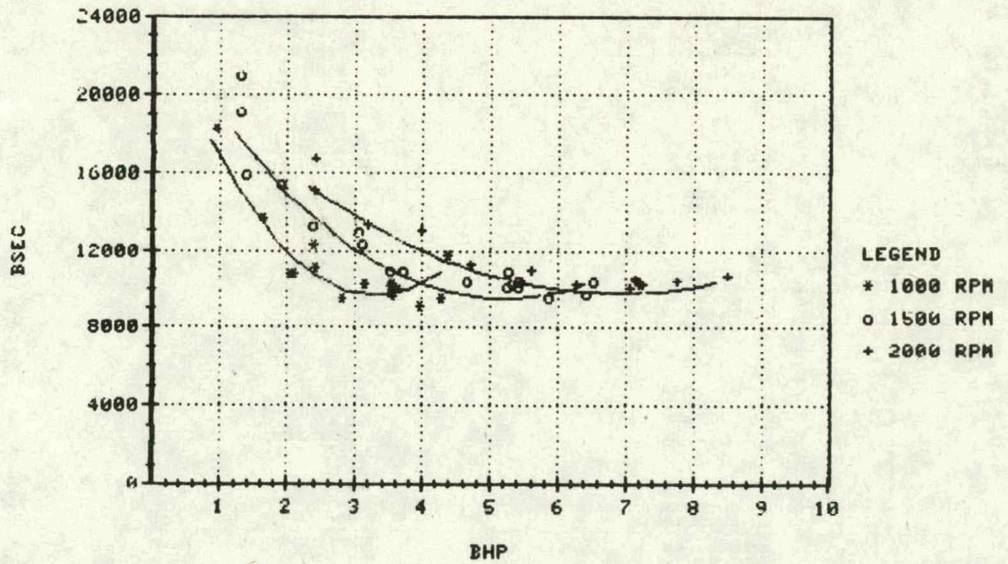

FIG.D.2B PHILLIPS D-2 BSEC VS BHP
CLR #2

TABLE D.3 PARAHO DFM

PERFORMANCE

PARAHO DFM AL-9090-F 1000 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
1497	4.76	88.71	0.544	9967	12.78	16.72
1498	4.06	75.58	0.515	9440	13.50	21.11
1499	2.51	46.84	0.549	10058	12.67	32.19
1500	2.51	46.84	0.549	10058	12.67	32.19
1501	1.68	31.22	0.639	11698	10.89	41.67
1502	0.76	14.19	0.985	18039	7.06	60.03

PARAHO DFM AL-9090-F 1500 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
1503	7.54	93.67	0.525	9621	13.24	17.54
1504	6.77	84.09	0.504	9228	13.81	20.48
1505	5.46	67.77	0.511	9369	13.60	25.29
1508	1.26	15.61	0.963	17638	7.22	58.91
1506	4.03	50.03	0.536	9825	12.97	32.60
1507	2.83	35.13	0.626	11467	11.11	40.16

PARAHO DFM AL-9090-F 2000 rpm 3 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
1509	7.88	73.45	0.566	10364	12.29	19.45
1510	4.61	42.93	0.608	11131	11.45	31.49
1511	1.52	14.19	1.083	19843	6.42	53.46

EMISSIONS

PARAHO DFM AL-9090-F 1000 rpm 6 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
1497	4.76	$$$$$$	0.0950	0.1500	1.0000	16.72
1498	4.06	0.2050	0.0870	0.1300	0.3000	21.11
1499	3.47	$$$$$$	0.0875	0.1300	0.2000	23.37
1500	2.51	0.0540	0.1020	0.1200	0.1000	32.19
1501	1.68	$$$$$$	0.0875	0.1100	0.0000	41.67
1502	0.76	0.0070	0.0650	0.0790	0.0000	60.03

PARAHO DFM AL-9090-F 1500 rpm 6 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
1503	7.54	$$$$$$	0.1050	0.0900	1.0000	17.54
1504	6.77	0.1480	0.1090	0.0990	0.4000	20.48
1505	5.45	$$$$$$	0.0950	0.0780	0.2000	25.29
1506	4.03	0.1290	0.0825	0.0880	0.1000	32.60
1507	2.83	$$$$$$	0.0675	0.0800	0.1000	40.16
1508	1.26	0.0420	0.0453	0.0500	0.0000	58.91

PARAHO DFM AL-9090-F 2000 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
1509	7.88	0.1840	0.0808	0.1220	0.6000	19.45
1510	4.61	0.0750	0.0650	0.0660	0.1000	31.49
1511	1.52	0.0470	0.0313	0.0580	0.1000	53.46

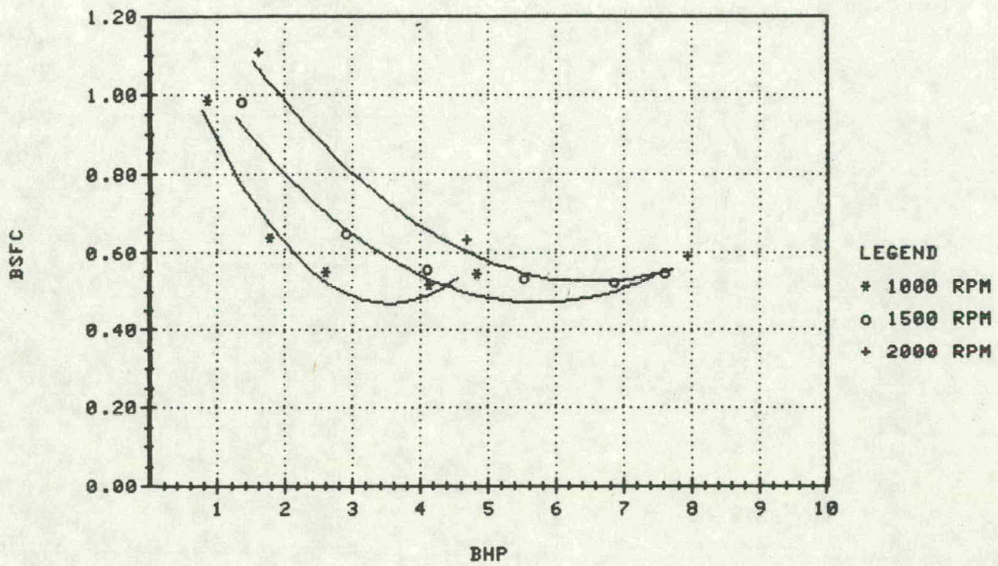

FIG. D.3A PARAHO DFM BSFC VS BHP
CLR#1

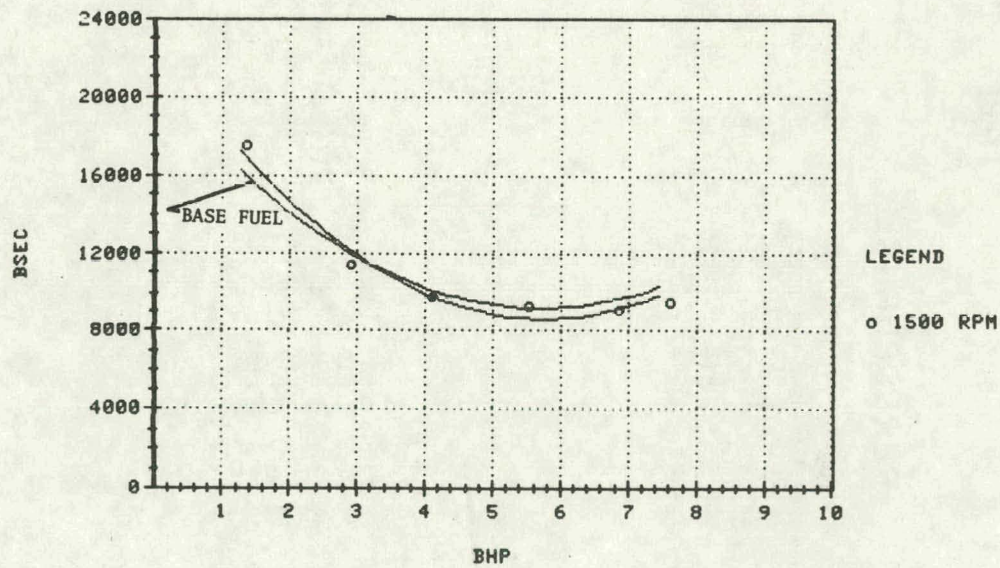

FIG. D.3B PARAHO DFM BSEC VS BHP
CLR#1

TABLE D.4 PARAHO JP-5

PERFORMANCE

PARAHO JP-5 AL-9088-F 1000 rpm 7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
17	3.82	71.21	0.502	9265	13.39	31.48
18	3.09	57.66	0.533	9834	12.62	36.63
19	2.37	44.25	0.733	13514	9.18	34.73
20	1.56	29.06	0.744	13717	9.05	53.[illegible]2
21	0.91	16.89	1.042	19207	6.46	66.46
235	1.93	36.05	0.631	11629	10.67	49.38
236	3.84	71.50	0.506	9324	13.31	30.49

PARAHO JP-5 AL-9088-F 1500 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
22	5.85	72.74	0.516	9511	13.05	27.31
23	4.60	57.09	0.527	9711	12.78	34.24
24	3.44	42.72	0.611	11261	11.02	39.84
25	2.31	28.71	0.679	12530	9.90	52.87
26	1.29	15.97	1.019	18795	6.60	63.26
237	1.96	24.34	0.791	14588	8.51	52.70
238	3.04	37.79	0.602	11094	11.19	44.63
239	6.40	79.48	0.547	10088	12.30	23.22

PARAHO JP-5 AL-9088-F 2000 rpm 7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
27	7.84	73.09	0.532	9802	12.66	24.62
28	6.17	57.45	0.530	9780	12.69	31.46
29	4.58	42.65	0.590	10877	11.41	38.26
30	3.35	31.22	0.668	12326	10.07	46.59
31	1.56	14.55	0.922	17007	7.30	72.19
240	2.43	22.67	0.822	15156	8.19	51.12
241	8.56	79.76	0.515	9499	13.06	22.99

EMISSIONS

PARAHO JP-5 AL-9088-F 1000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
19	2.37	0.0068	0.0445	0.0677	0.1130	34.73
21	0.91	0.0020	0.0332	0.0844	0.0585	66.46
17	3.82	0.0132	0.0608	0.1577	0.2340	31.48
236	3.84	0.0062	0.0729	0.1457	0.2330	30.49

PARAHO JP-5 AL-9088-F 1500 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
22	5.85	0.0071	0.0751	0.1200	0.1320	27.31
24	3.54	0.0072	0.0595	0.0951	0.0600	39.84
26	1.29	0.0073	0.0369	0.0810	0.0760	63.26
238	3.04	0.0060	0.0556	0.0631	0.0545	44.63

PARAHO JP-5 AL-9088-F 2000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
27	7.84	0.0043	0.0920	0.0995	0.1140	24.62
29	4.58	0.0020	0.0680	0.0805	0.0450	38.26
31	1.56	0.0027	0.0323	0.0634	0.0800	72.19
240	2.43	0.0032	0.0330	0.0616	0.0730	51.12

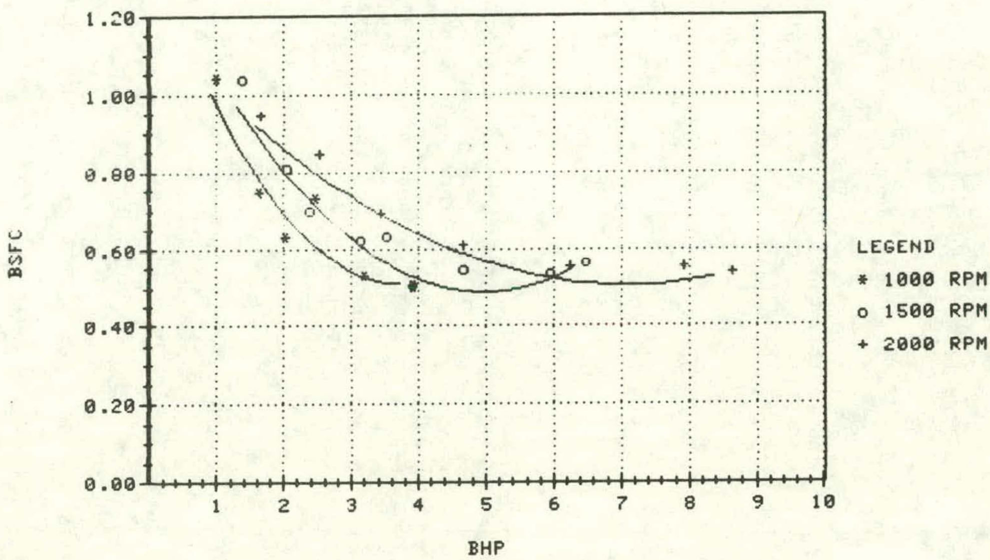

FIG.D.4A PARAHO JP-5 BSFC VS BHP

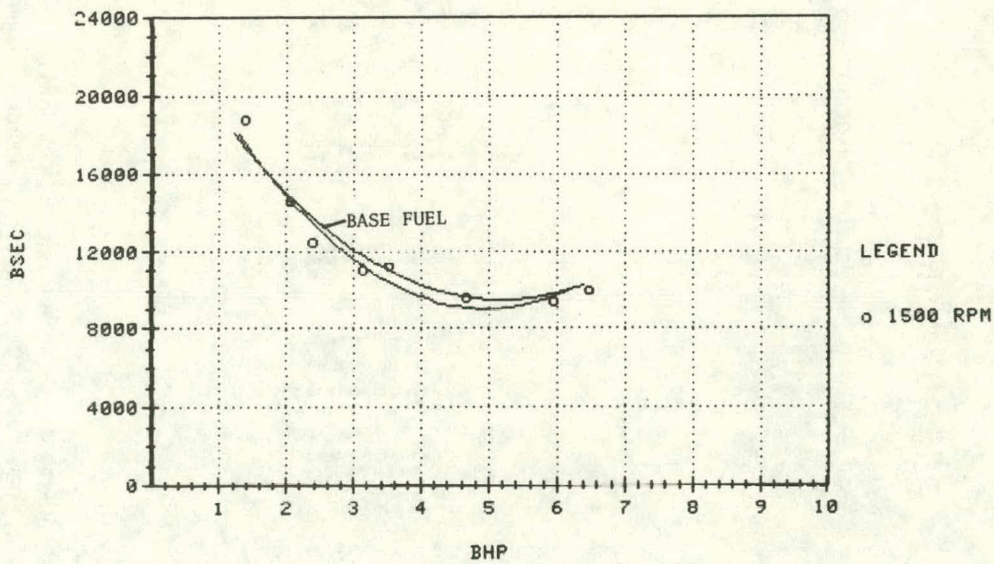

FIG.D.4B PARAHO JP-5 BSEC VS BHP

TABLE D.5 SHALE CASE 2A

PERFORMANCE

SHALE CASE 2A AL-10255-F 1000 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
32	3.83	71.46	0.522	9566	13.74	30.93
33	3.07	57.23	0.573	10511	12.50	35.45
34	2.30	42.79	0.496	9106	14.43	54.27
35	1.57	29.34	0.635	11648	11.28	58.31
36	0.87	16.18	1.024	18780	7.00	70.57
352	3.53	65.78	0.524	9612	13.67	32.67

SHALE CASE 2A AL-10255-F 1500 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
37	5.73	71.21	0.539	9887	13.29	26.56
38	4.60	57.09	0.537	9858	13.33	33.34
39	3.48	43.29	0.631	11580	11.35	37.61
40	2.47	30.66	0.705	12933	10.16	47.63
41	1.27	15.72	1.059	19425	6.76	61.94
242	1.82	22.57	0.804	14742	8.91	56.76
243	6.31	78.38	0.526	9652	13.61	24.56
353	5.21	64.72	0.562	10316	12.74	27.51

SHALE CASE 2A AL-10255-F 2000 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
42	7.86	73.24	0.548	10057	13.06	23.64
43	6.24	58.12	0.556	10203	12.88	29.37
44	4.81	44.81	0.609	11173	11.76	35.08
45	3.09	28.81	0.724	13286	9.89	45.84
46	1.89	17.63	1.009	18509	7.10	54.48
244	2.49	23.21	0.855	15686	8.38	48.30
245	8.50	79.23	0.533	9771	13.45	22.57
354	7.09	66.10	0.553	10134	12.97	25.81

EMISSIONS

SHALE CASE 2A AL-10255-F 1000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
32	3.83	0.0066	0.0848	0.2554	0.3850	30.93
34	2.30	0.0052	0.0421	0.1651	0.1640	54.27
36	0.87	0.0026	0.0209	0.1191	0.1130	70.57
352	3.53	0.0081	0.0732	0.1037	0.1860	32.67

SHALE CASE 2A AL-10255-F 1500 rpm 5 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
37	5.73	0.0122	0.1010	0.1585	0.2460	26.56
39	3.48	0.0144	0.0785	0.0993	0.0780	37.61
41	1.27	0.0118	0.0380	0.0837	0.1060	61.94
353	5.21	0.0083	0.0667	0.0619	0.0870	27.51
243	6.31	0.0156	0.0825	0.0911	0.2330	24.56

SHALE CASE 2A AL-10255-F 2000 rpm 5 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
42	7.86	0.0275	0.1047	0.1011	0.1690	23.64
44	4.81	0.0368	0.0843	0.0912	0.0690	35.08
46	1.89	0.0174	0.0398	0.0574	0.0975	54.48
354	7.09	0.0080	0.0652	0.0550	0.0780	25.81
245	8.50	0.0070	0.0809	0.0658	0.2340	22.57

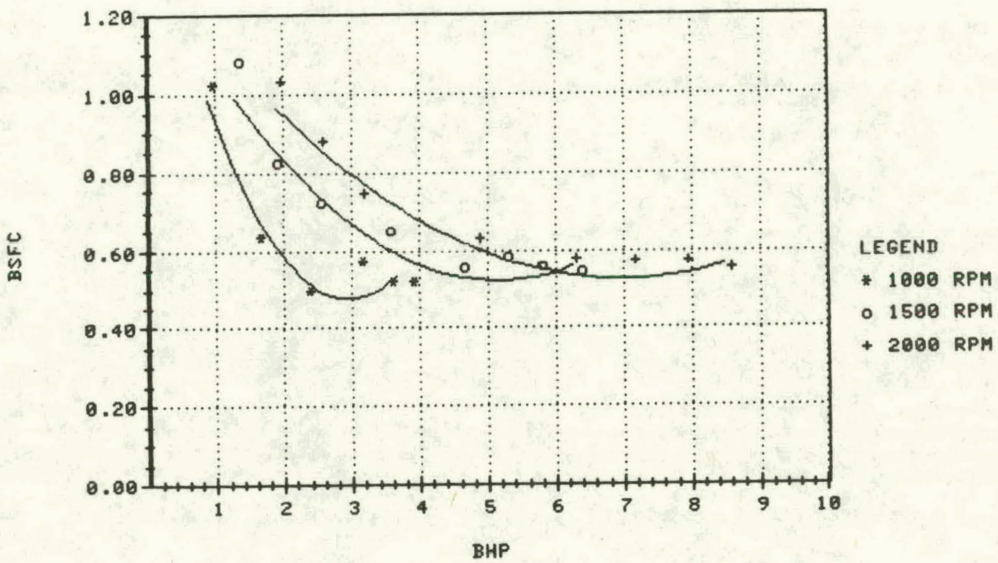

FIG.D.5A SHALE CASE 2A BSFC VS BHP

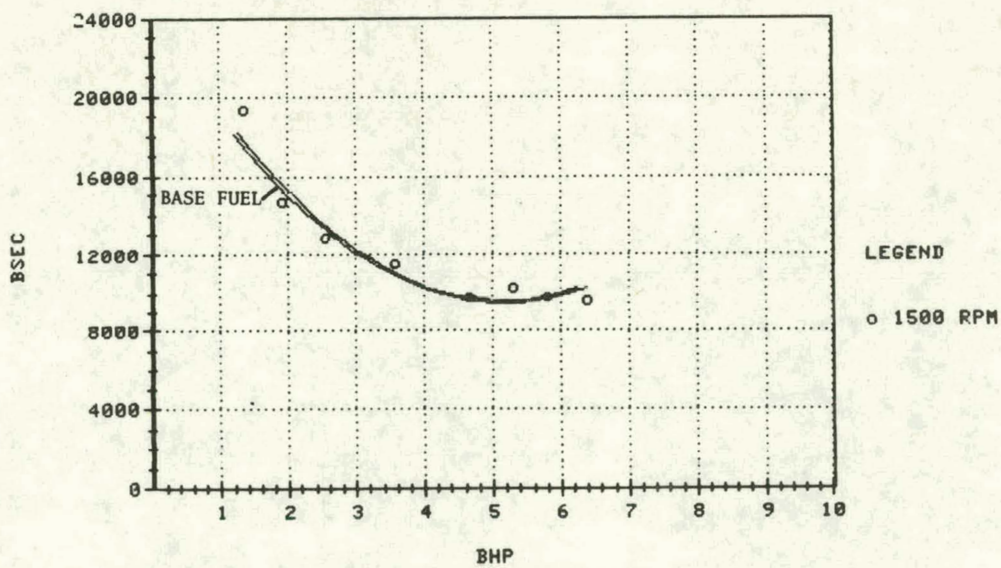

FIG.D.5B SHALE CASE 2A BSEC VS BHP

TABLE D.6 SHALE CASE 3

PERFORMANCE

SHALE CASE 3 AL-10256-F 1000 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
47	3.89	72.49	0.599	11019	11.97	26.24
48	3.07	57.23	0.606	11141	11.84	32.69
49	2.39	44.46	0.654	12029	10.96	39.66
50	1.59	29.59	0.699	12859	10.25	54.94
51	0.93	17.24	1.091	20079	6.57	61.95
246	1.22	22.74	0.869	15977	8.25	58.37
247	4.29	79.98	0.557	10245	12.87	25.21
355	3.52	65.64	0.525	9662	13.65	32.57

SHALE CASE 3 AL-10256-F 1500 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
52	5.94	73.80	0.515	9476	13.92	26.42
53	4.58	56.91	0.561	10320	12.78	31.78
54	3.55	44.10	0.625	11504	11.46	37.09
55	2.41	29.91	0.752	13830	9.53	45.49
56	1.30	16.11	1.033	19011	6.94	61.25
248	1.85	22.99	0.773	14214	9.28	57.86
249	6.42	79.76	0.528	9713	13.58	24.01
356	5.34	66.32	0.555	10201	12.93	27.18

SHALE CASE 3 AL-10256-F 2000 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
57	7.64	71.18	0.555	10211	12.91	23.91
58	6.23	58.08	0.577	10624	12.41	28.31
59	4.62	43.08	0.649	11938	11.05	34.15
60	3.21	29.91	0.819	15071	8.75	39.16
61	1.54	14.33	1.398	25708	5.13	48.00
250	3.87	36.05	0.667	12267	10.75	39.84
251	8.62	80.30	0.512	9414	14.01	23.18
357	7.08	66.00	0.565	10389	12.69	25.21

EMISSIONS

SHALE CASE 3 AL-10256-F 1000 rpm 5 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
47	3.89	0.0829	0.1193	0.3796	0.6300	26.24
49	2.39	0.0292	0.0578	0.1964	0.1500	39.66
51	0.93	0.0220	0.0291	0.1052	0.1520	61.95
247	4.29	0.0202	0.0747	0.2439	0.4900	25.21
355	3.52	0.0127	0.0814	0.0946	0.2200	32.57

SHALE CASE 3 AL-10256-F 1500 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
356	5.33	0.0101	0.0710	0.0634	0.1510	27.18
54	3.55	0.0245	0.0990	0.0948	0.0710	37.09
56	1.30	0.0174	0.0357	0.0713	0.1310	61.25
249	6.42	0.0103	0.0704	0.0951	0.1900	24.01

SHALE CASE 3 AL-10256-F 2000 rpm 5 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
57	7.64	0.0324	0.1153	0.1198	0.1500	23.91
59	4.62	0.0233	0.0970	0.0924	0.0720	34.15
61	1.54	0.0173	0.0598	0.0842	0.0825	48.00
251	8.62	0.0080	0.0824	0.0654	0.2070	23.18
357	7.08	0.0068	0.0683	0.0455	0.0670	25.21

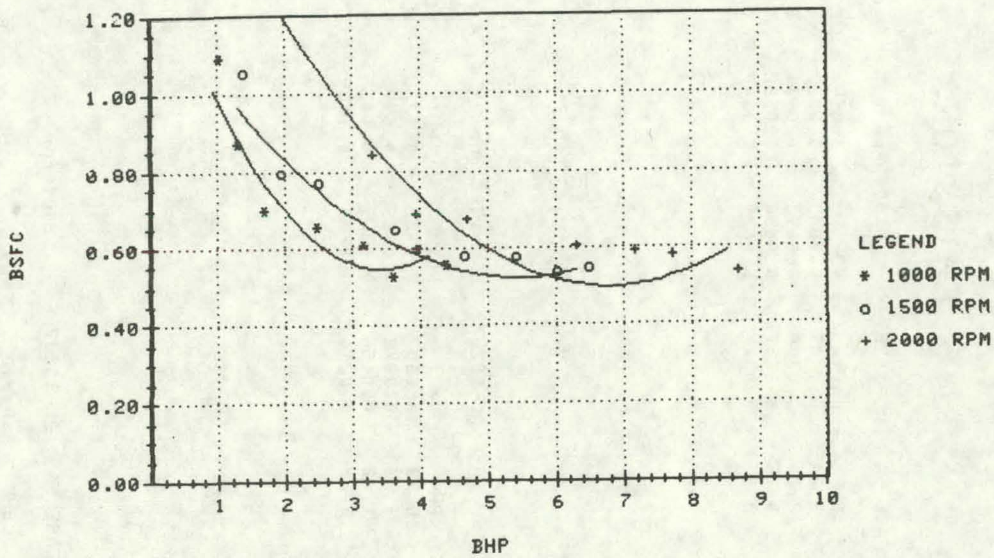

FIG.D.6A SHALE CASE 3 BSFC VS BHP

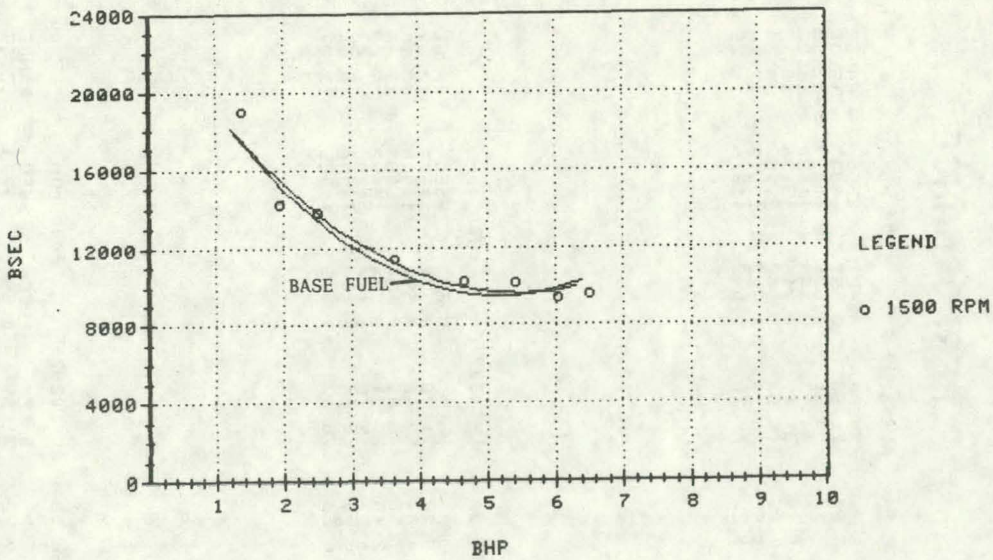

FIG.D.6B SHALE CASE 3 BSEC VS BHP

TABLE D.7 COAL CASE 5A

PERFORMANCE

COAL CASE 5A   AL-10287-F   1000 rpm   7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
77	3.84	71.50	0.589	10833	12.30	26.09
78	3.13	58.26	0.601	11059	12.05	31.66
79	2.36	44.03	0.643	11830	11.27	39.76
80	1.69	31.47	0.716	13176	10.12	49.95
81	0.85	15.83	1.142	21007	6.34	63.14
324	3.55	66.17	0.572	10513	12.68	29.68
325	4.28	79.76	0.642	11816	11.28	21.51

COAL CASE 5A   AL-10287-F   1500 rpm   7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
82	5.78	71.78	0.571	10504	12.69	24.34
83	4.64	57.66	0.599	11016	12.10	29.62
84	3.53	43.89	0.634	11660	11.43	36.82
85	2.40	29.81	0.734	13492	9.88	46.78
86	1.22	15.12	1.110	20406	6.53	61.38
326	5.29	65.75	0.559	10286	12.96	27.14
327	6.33	78.63	0.545	10025	13.29	23.24

COAL CASE 5A   AL-10287-F   2000 rpm   7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
87	7.72	71.89	0.582	10703	12.45	22.65
88	6.17	57.48	0.579	10643	12.52	28.70
89	4.62	43.08	0.632	11616	11.47	35.20
90	3.15	29.31	0.773	14208	9.38	42.47
91	1.61	15.01	1.223	22492	5.93	52.40
328	7.06	65.82	0.534	9815	13.58	26.75
329	8.46	78.81	0.539	9916	13.44	22.00

EMISSIONS

COAL CASE 5A   AL-10287-F   1000 rpm   4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
77	3.84	0.0409	0.0845	0.2387	0.5500	26.09
79	2.36	0.0304	0.0693	0.0931	0.1340	39.76
81	0.85	0.0227	0.0450	0.0552	0.1250	63.14
324	3.55	0.0317	0.0679	0.3149	0.4800	29.68

COAL CASE 5A   AL-10287-F   1500 rpm   4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
82	5.78	0.0607	0.0702	0.1238	0.2780	24.34
84	3.53	0.0272	0.0685	0.0591	0.0750	36.82
86	1.22	0.0158	0.0389	0.0455	0.0900	61.38
326	5.29	0.0266	0.0706	0.1159	0.1545	27.14

COAL CASE 5A   AL-10287-F   2000 rpm   4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
87	7.72	0.0386	0.0873	0.0869	0.2700	22.65
89	4.62	0.0083	0.0612	0.0559	0.0695	35.20
91	1.61	0.0184	0.0419	0.0498	0.0960	52.40
328	7.06	0.0115	0.0743	0.0807	0.0770	26.75

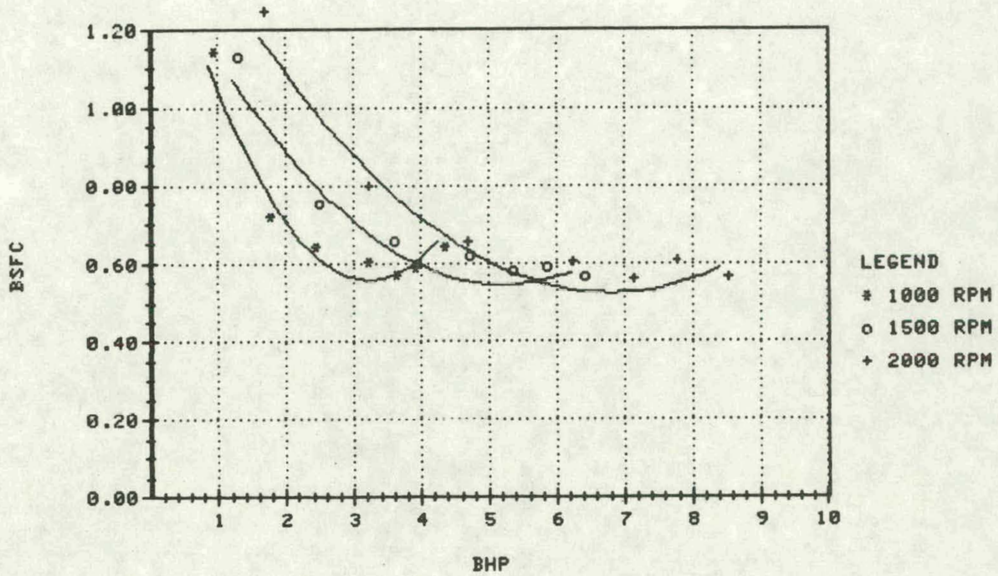

FIG.D.7A COAL CASE 5A BSFC VS BHP

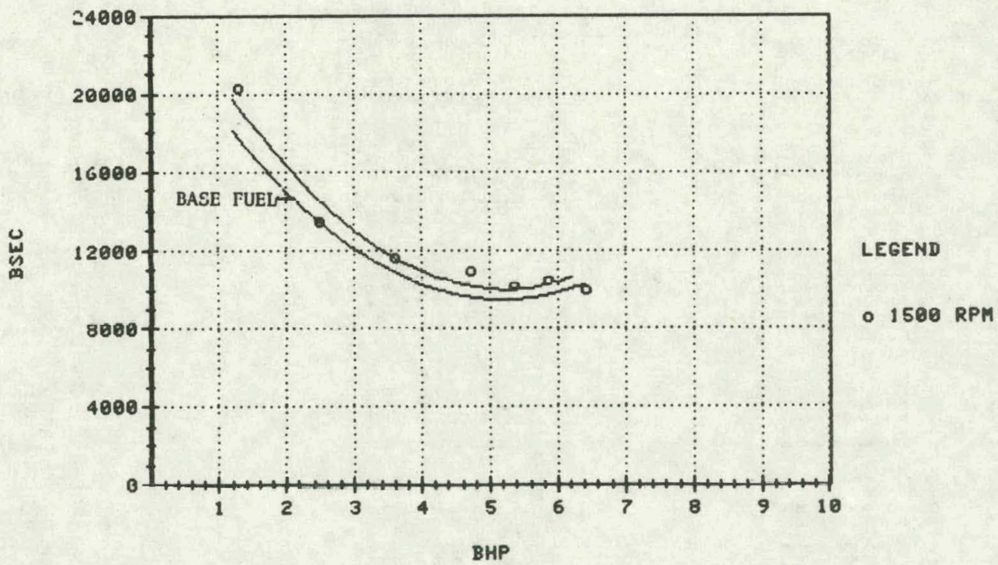

FIG.D.7B COAL CASE 5A BSEC VS BHP

TABLE D.8 COAL CASE 12

PERFORMANCE

COAL CASE 12 AL-10288-F 1000 rpm 7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
92	3.87	72.10	0.574	10581	12.50	27.54
93	3.08	57.30	0.589	10854	12.18	33.69
94	2.34	43.54	0.604	11129	11.88	42.71
95	1.58	29.41	0.741	13668	9.68	52.86
96	0.89	16.50	1.079	19890	6.65	65.33
314	3.48	64.83	0.555	10231	12.93	31.32
315	4.31	80.30	0.550	10143	13.04	25.11

COAL CASE 12 AL-10288-F 1500 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
97	5.78	71.85	0.590	10872	12.16	23.95
98	4.60	57.09	0.579	10674	12.39	30.30
99	3.54	44.00	0.630	11611	11.39	36.63
100	2.46	30.51	0.729	13438	9.84	45.63
101	1.19	14.80	1.159	21367	6.19	60.62
316	5.26	65.29	0.559	10316	12.82	27.32
317	6.47	80.33	0.534	9839	13.44	23.32
318	5.18	64.36	0.540	9966	13.27	28.78

COAL CASE 12 AL-10288-F 2000 rpm 7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
102	7.80	72.67	0.571	10522	12.57	23.02
103	6.28	58.47	0.577	10637	12.43	28.18
104	4.66	43.43	0.629	11592	11.41	35.08
105	3.29	30.69	0.732	13491	9.80	42.74
106	1.56	14.55	1.178	21731	6.09	56.26
319	7.18	66.92	0.543	10013	13.21	26.00
320	8.43	78.56	0.538	9930	13.32	22.09

EMISSIONS

COAL CASE 12 AL-10288-F 1000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
92	3.87	0.0397	0.0745	0.2117	0.5700	27.54
94	2.34	0.0183	0.0623	0.0921	0.1350	42.71
96	0.89	0.0090	0.0423	0.0540	0.1110	65.33
314	3.48	0.0300	0.0569	0.1726	0.3800	31.32

COAL CASE 12 AL-10288-F 1500 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
97	5.78	0.0450	0.0871	0.1297	0.3820	23.95
99	3.54	0.0171	0.0663	0.0681	0.0710	36.63
101	1.19	0.0094	0.0389	0.0495	0.0920	60.62
316	5.26	0.0195	0.0615	0.0931	0.1570	27.32

COAL CASE 12 AL-10288-F 2000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
102	7.80	0.0176	0.0872	0.0864	0.2690	23.02
104	4.66	0.0153	0.0620	0.0569	0.0590	35.08
106	1.56	0.0136	0.0357	0.0475	0.0900	56.26
319	7.18	0.0070	0.0732	0.0706	0.0760	26.00

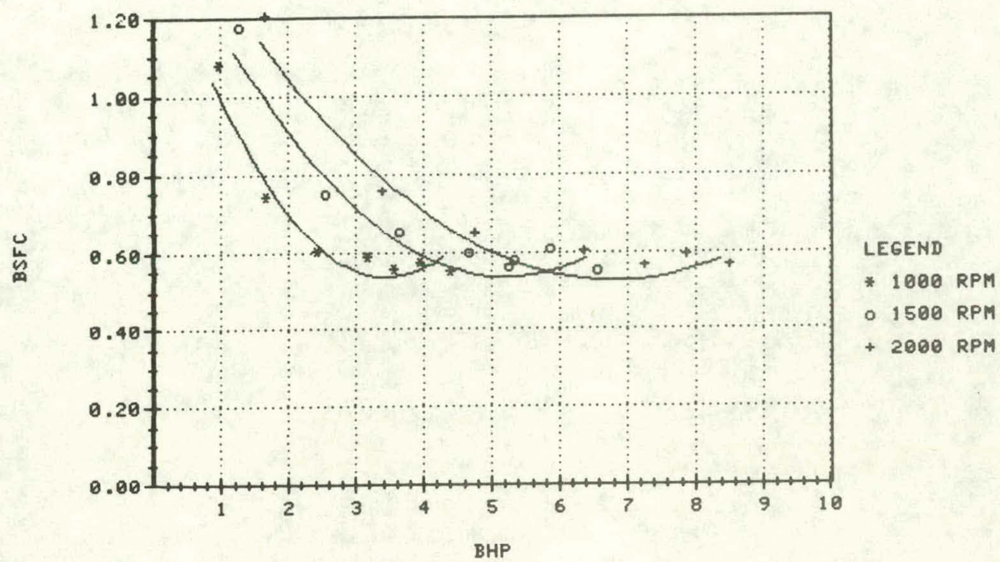

FIG.D.8A COAL CASE 12 BSFC VS BHP

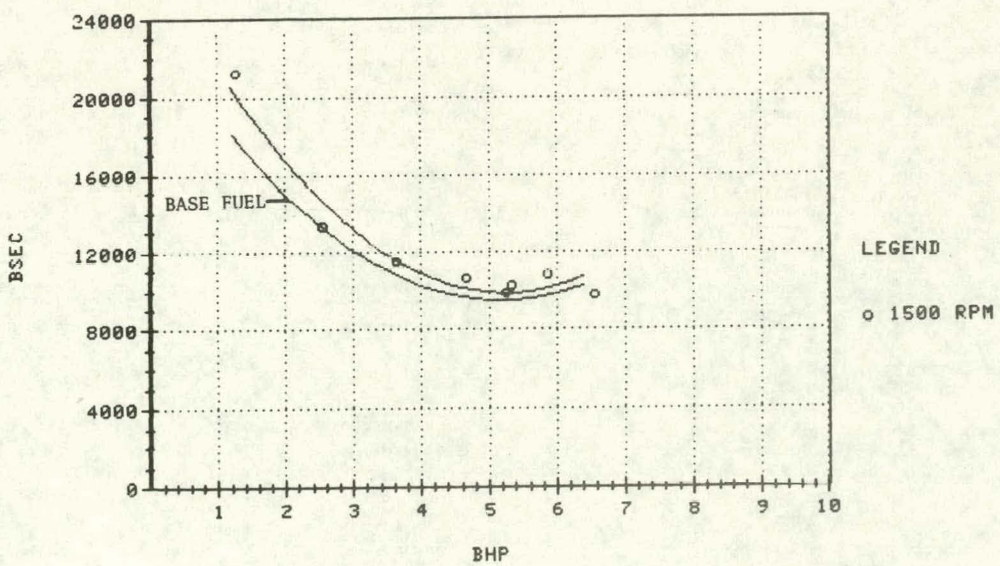

FIG.D.8B COAL CASE 12 BSEC VS BHP

TABLE D.9 SRC-II MEDIUM CETANE

PERFORMANCE

SRC II MED CETANE AL-10289-F 1000 rpm 5 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
107	3.88	72.38	0.543	9726	13.70	29.73
108	3.19	59.36	0.568	10173	13.10	34.47
109	2.32	43.18	0.634	11358	11.73	42.92
110	1.54	28.67	0.774	13849	9.62	53.16
111	0.84	15.65	1.104	19766	6.74	68.62

SRC II MED CETANE AL-10289-F 1500 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
112	5.90	73.31	0.544	9740	13.68	25.86
113	4.68	58.19	0.570	10206	13.06	31.09
114	3.46	42.93	0.654	11709	11.38	36.90
115	2.40	29.77	0.764	13673	9.75	46.14
116	1.35	16.75	1.098	19656	6.78	56.53
331	5.24	65.04	0.590	10568	12.61	26.04

SRC II MED CETANE AL-10289-F 2000 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
117	7.83	72.92	0.564	10090	13.21	23.23
118	6.21	57.84	0.593	10615	12.56	28.13
119	4.76	44.35	0.632	11321	11.77	34.22
120	3.06	28.53	1.182	21169	6.30	28.66
121	1.70	15.83	1.189	21294	6.26	51.61
332	6.88	64.15	0.588	10532	12.65	24.90

EMISSIONS

SRC-II MED CETANE AL-10289-F 1000 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
107	3.88	0.0913	0.1245	0.1196	0.3200	29.73
109	2.32	0.0405	0.0847	0.0733	0.1250	42.92
111	0.84	0.0229	0.0378	0.0604	0.1690	68.62

SRC-II MED CETANE AL-10289-F 1500 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
112	5.90	0.0963	0.1037	0.0757	0.1200	25.86
114	3.46	0.0244	0.0740	0.0530	0.0668	36.90
116	1.35	0.0357	0.0355	0.0441	0.1890	56.53

SRC-II MED CETANE AL-10289-F 2000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
117	7.83	0.0219	0.0944	0.0579	0.1480	23.23
119	4.76	0.0216	0.0620	0.0453	0.0780	34.22
121	1.70	0.0269	0.0355	0.0483	0.1720	51.61
332	6.88	0.0099	0.0872	0.0636	0.0740	24.90

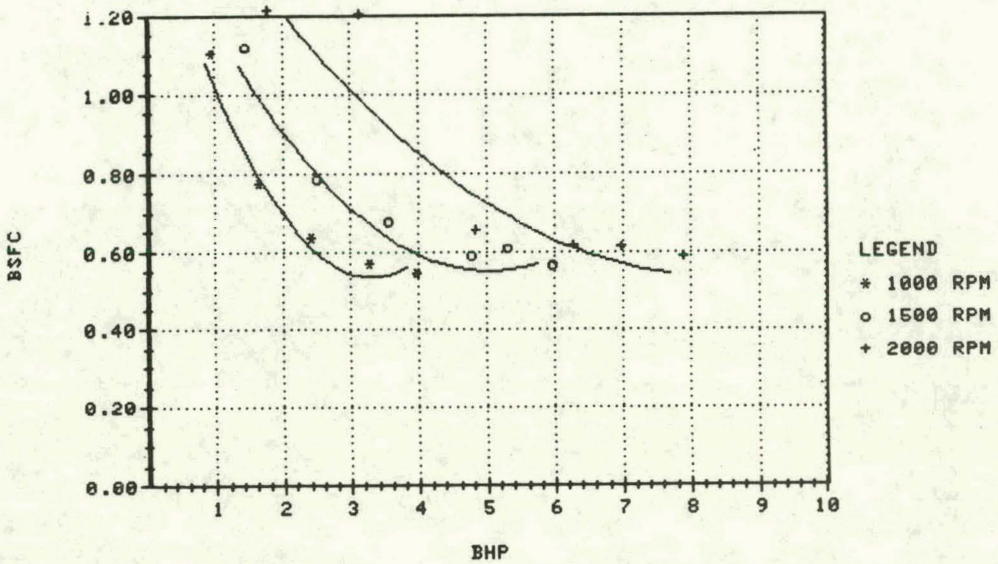

FIG.D.9A SRC II MED CETANE BSFC VS BHP

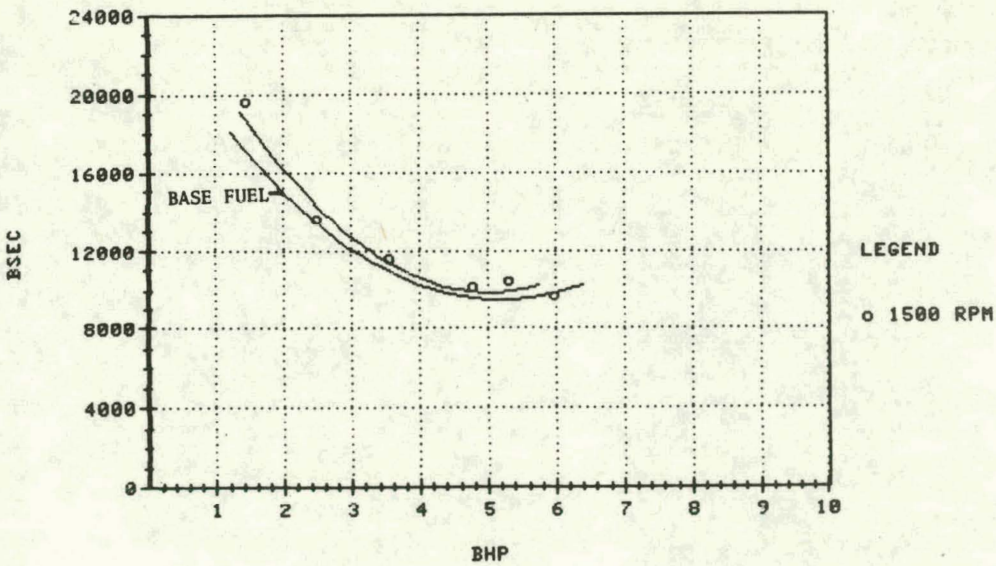

FIG.D.9B SRC II MED CETANE BSEC VS BHP

TABLE D.10 SRC-II LOW CETANE

PERFORMANCE

SRC II LOW CETANE AL-10290-F 1000 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
127	3.84	71.57	0.495	8628	15.39	32.09
128	3.14	58.58	0.528	9209	14.42	36.73
129	2.34	43.61	0.624	10880	12.20	42.73
130	1.60	29.81	0.725	12648	10.50	53.64
131	0.88	16.43	1.248	21760	6.10	57.04
310	3.47	64.72	0.492	8587	15.46	35.66

SRC II LOW CETANE AL-10290-F 1500 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
132	5.85	72.74	0.557	9710	13.67	28.62
133	4.70	58.40	0.545	9497	13.98	31.90
134	3.44	42.76	0.648	11300	11.75	36.86
135	2.39	29.70	0.816	14225	9.33	42.09
136	1.38	17.17	1.201	20942	6.34	48.96
311	5.38	66.81	0.560	9760	13.60	26.96

SRC II LOW CETANE AL-10290-F 2000 rpm 5 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
137	7.86	73.27	0.615	10734	12.37	21.67
138	6.10	56.84	0.674	11749	11.30	25.32
139	6.15	57.27	0.731	12740	10.42	22.94
313	8.47	78.91	0.554	9657	13.75	21.46
312	7.07	65.89	0.605	10555	12.58	23.66

EMISSIONS

SRC-II LOW CETANE AL-10290-F 1000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
127	3.84	0.0130	0.1145	0.0656	0.1500	32.09
129	2.34	0.0200	0.0671	0.0607	0.1570	42.73
131	0.88	0.0808	0.0362	0.1005	0.2520	57.04
310	3.47	0.0481	0.1065	0.1278	0.1800	35.66

SRC-II LOW CETANE AL-10290-F 1500 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
132	5.85	0.0262	0.1020	0.0654	0.1520	28.62
134	3.44	0.0196	0.0566	0.0708	0.1870	36.86
136	1.38	0.0392	0.0287	0.1052	0.2755	48.96

SRC-II LOW CETANE AL-10290-F 2000 rpm 2 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
137	7.86	0.0357	0.0592	0.0497	0.4100	21.67
312	7.07	0.0356	0.0788	0.0876	0.1655	23.66

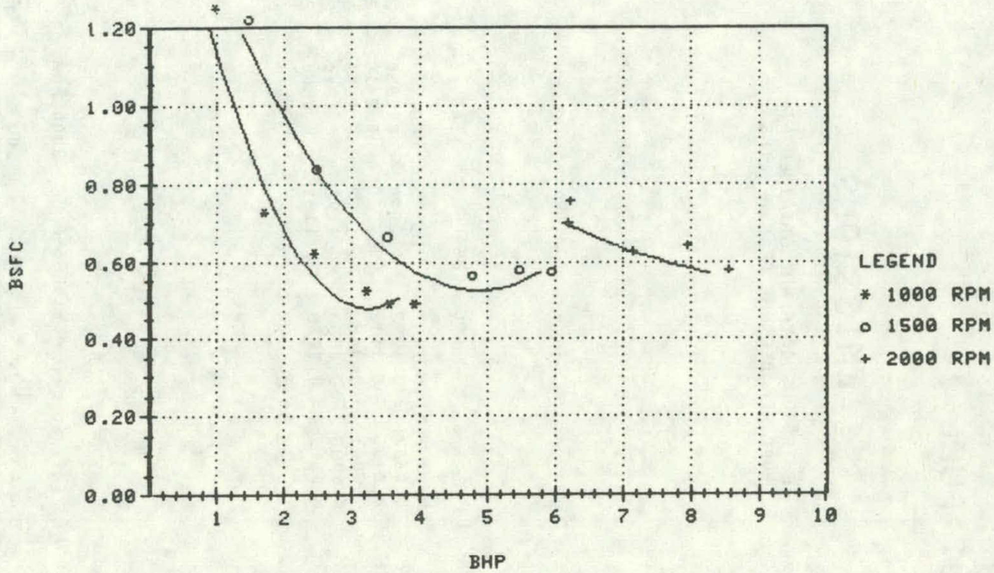

FIG.D.10A SRC II LOW CETANE BSFC VS BHP

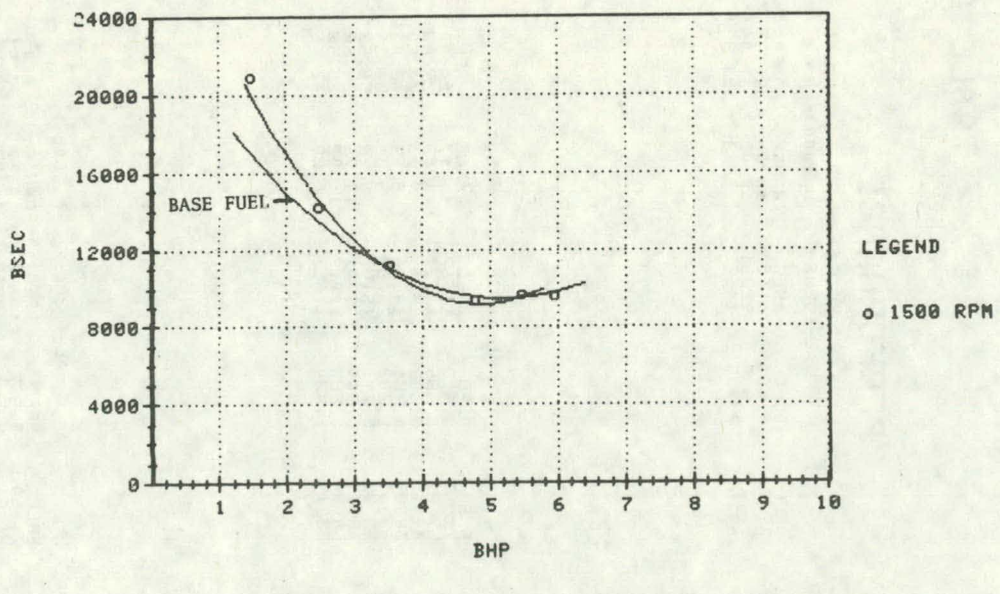

FIG.D.10B SRC II LOW CETANE BSEC VS BHP

TABLE D.11 BROADCUT FUEL 1

PERFORMANCE

BROADCUT FUEL 1 AL-10286-F 1000 rpm 3 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
62	3.82	71.21	0.604	11603	10.66	26.55
63	3.08	57.37	0.640	12281	10.07	31.04
339	3.47	64.61	0.738	14172	8.73	23.82

BROADCUT FUEL 1 AL-10286-F 1500 rpm 9 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
67	5.76	71.53	0.577	11067	11.17	24.40
68	4.65	57.80	0.585	11221	11.02	29.88
69	3.56	44.18	0.669	12847	9.63	34.20
70	2.42	30.05	0.781	14996	8.25	43.00
71	1.26	15.61	1.202	23063	5.36	54.36
252	1.85	22.92	0.791	1518[illegible]	8.14	56.58
253	6.29	78.17	0.505	9701	12.75	25.68
336	5.37	66.74	0.584	11219	11.02	25.58
337	1.87	23.17	1.024	19657	6.29	42.41

BROADCUT FUEL 1 AL-10286-F 2000 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
72	7.68	71.60	0.557	10690	11.57	23.54
73	6.11	56.91	0.571	10967	11.28	28.86
74	4.74	44.21	0.672	12904	9.58	31.71
75	3.20	29.81	0.797	15301	8.08	39.85
76	1.54	14.37	1.251	24019	5.15	52.87
254	2.32	21.57	0.967	18570	6.66	46.12
255	8.41	78.35	0.524	10067	12.28	23.11
338	6.98	65.07	0.603	11570	10.69	23.95

EMISSIONS

EMISSIONS DATA NOT OBTAINED AT 1000 RPM BECAUSE OF MISFIRING.

BROADCUT FUEL 1 AL-10286-F 1500 rpm 5 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
67	5.76	0.0367	0.1392	0.2040	0.0850	24.40
69	3.56	0.0105	0.1112	0.1760	0.0410	34.20
71	1.26	0.0063	0.0467	0.1612	0.1130	54.36
253	6.29	0.0088	0.0888	0.1476	0.1810	25.68
336	5.37	0.0115	0.0938	0.1161	0.0800	25.58

BROADCUT FUEL 1 AL-10286-F 2000 rpm 5 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
72	7.68	0.0807	0.1385	0.1344	0.0740	23.54
74	4.74	0.0173	0.1010	0.1555	0.0375	31.71
76	1.54	0.0107	0.0496	0.0629	0.1230	52.87
255	8.41	0.0080	0.1020	0.1850	0.0735	23.11
338	6.98	0.0149	0.0601	0.1358	0.1565	23.95

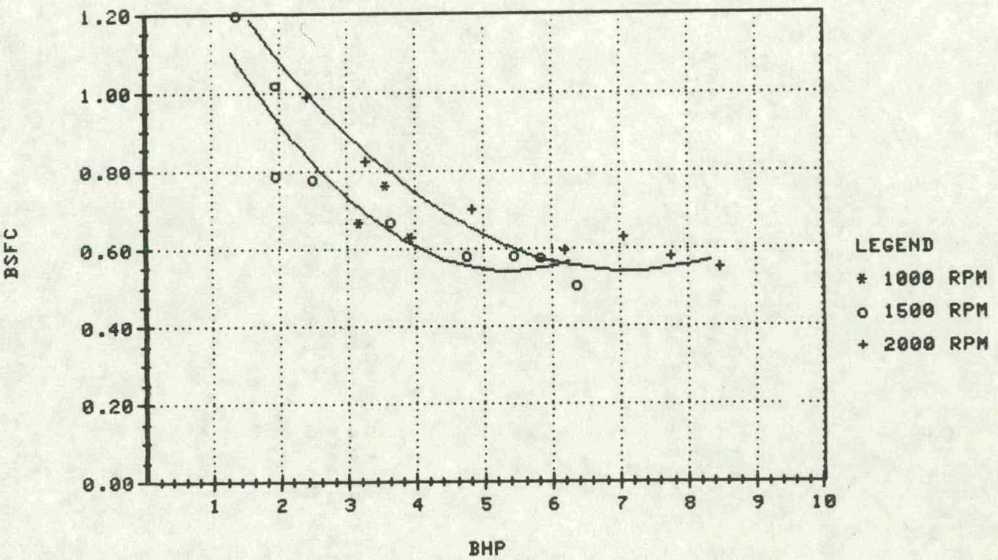

FIG.D.11A BROADCUT FUEL 1 BSFC VS BHP

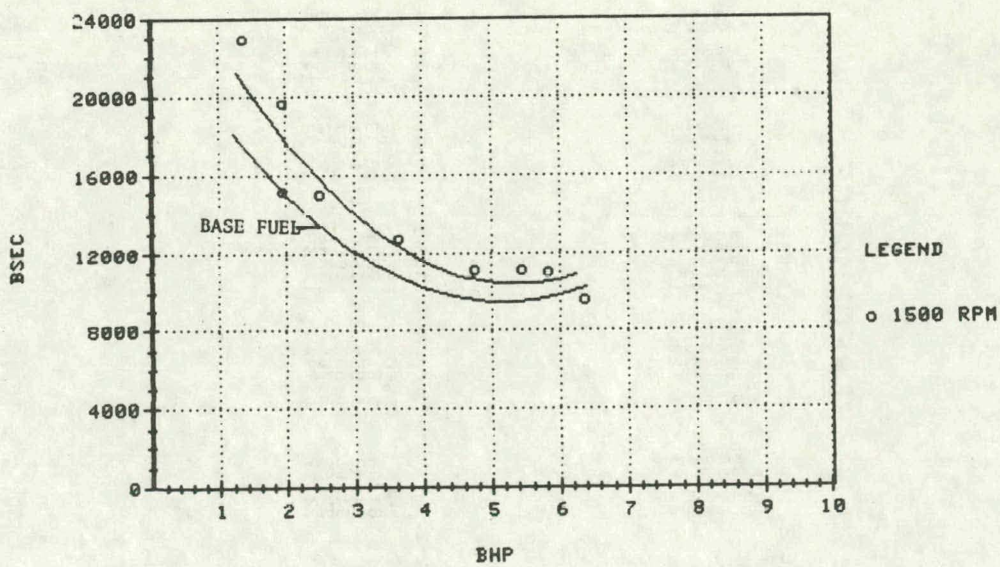

FIG.D.11B BROADCUT FUEL 1 BSEC VS BHP

TABLE D.12 BROADCUT FUEL 2

PERFORMANCE

BROADCUT FUEL-2 AL-10305-F 1000 rpm 5 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
199	4.32	80.58	0.502	9573	12.71	27.52
200	3.44	64.08	0.576	10984	11.08	30.34
201	2.82	52.58	0.613	11695	10.40	34.83
202	1.96	36.51	0.720	13728	8.86	42.73
203	1.18	21.93	1.020	19454	6.25	50.81

BROADCUT FUEL-2 AL-10305-F 1500 rpm 5 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
204	6.52	81.04	0.517	9855	12.35	23.63
205	5.19	64.47	0.559	10660	11.41	27.79
206	4.11	51.06	0.603	11511	10.57	32.39
207	3.03	37.65	0.700	13346	9.12	38.33
208	1.85	22.99	0.940	17935	6.78	46.17

BROADCUT FUEL-2 AL-10305-F 2000 rpm 5 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
209	8.43	78.52	0.564	10752	11.32	18.80
210	6.90	64.26	0.574	10954	11.11	25.60
211	5.46	50.88	0.624	11912	10.21	29.80
212	3.92	36.55	0.742	14153	8.60	34.91
213	2.55	23.74	0.848	16174	7.52	47.58

EMISSIONS

BROADCUT FUEL 2 AL-10305-F 1000 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
199	4.32	0.0107	0.1380	0.1765	0.0850	27.52
201	2.82	0.0118	0.1088	0.1322	0.0670	34.83
203	1.18	0.0058	0.0515	0.1188	0.0975	50.81

BROADCUT FUEL 2 AL-10305-F 1500 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
204	6.52	$$$$$$	0.0989	0.0559	0.2260	23.63
206	4.11	$$$$$$	0.0756	0.1015	0.0710	32.39
208	1.85	$$$$$$	0.0490	0.1010	0.0840	46.17

BROADCUT FUEL 2 AL-10305-F 2000 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
209	8.43	$$$$$$	0.0458	0.1319	0.7800	18.80
211	5.46	$$$$$$	0.0298	0.1379	0.0520	29.80
213	2.55	$$$$$$	0.0436	0.1428	0.0960	47.58

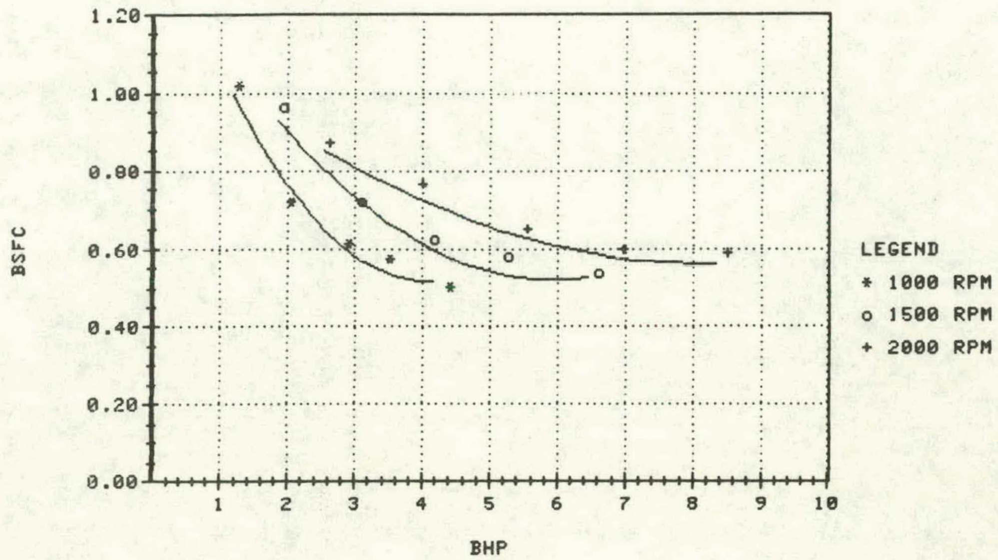

FIG.D.12A BROADCUT FUEL-2 BSFC VS BHP

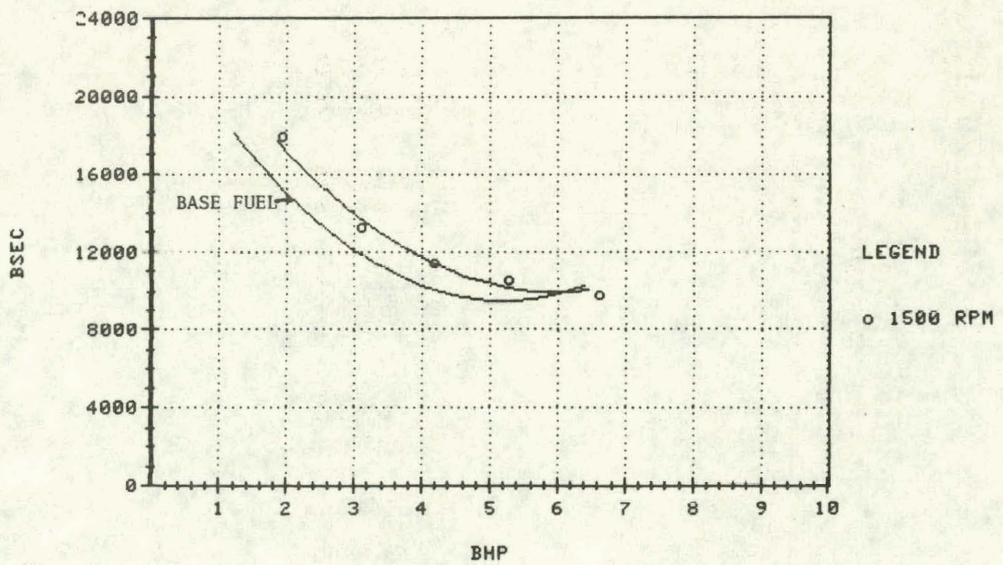

FIG.D.12B BROADCUT FUEL-2 BSEC VS BHP

TABLE D.13 BROADCUT FUEL 3

PERFORMANCE

BROADCUT FUEL-3 AL-10306-F 1000 rpm 2 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
224	1.16	21.64	1.171	21938	5.38	45.88
225	1.99	37.08	0.789	14783	7.99	39.06

BROADCUT FUEL-3 AL-10306-F 1500 rpm 8 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
219	6.37	79.13	0.548	10266	11.51	23.01
220	2.90	35.98	0.763	14297	8.26	37.00
221	4.00	49.68	0.640	11995	9.85	31.91
222	1.71	21.29	1.319	24708	4.78	36.44
340	5.26	65.29	0.679	12727	9.28	22.58
341	4.13	51.27	0.766	14345	8.23	25.51
342	3.06	37.97	0.884	16553	7.14	30.05
343	1.95	24.27	1.172	21962	5.38	35.49

BROADCUT FUEL-3 AL-10306-F 2000 rpm 4 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
226	2.41	22.50	1.098	20564	5.74	38.77
227	3.92	36.55	0.798	14950	7.90	32.67
228	5.33	49.68	0.660	12370	9.55	28.87
229	6.85	63.87	0.570	10687	11.05	25.65

EMISSIONS

BROADCUT FUEL 3 AL-10306-F 1000 rpm 1 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
224	1.16	0.0035	0.0277	0.2357	0.2180	45.88

BROADCUT FUEL 3 AL-10306-F 1500 rpm 5 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
219	6.37	0.0038	0.1430	0.2221	0.0700	23.01
221	4.00	0.0045	0.0854	0.1785	0.0630	31.91
222	1.71	0.0022	0.0352	0.1916	0.2030	72.87
340	5.26	0.0158	0.0668	0.1362	0.2800	22.58
342	3.06	0.0048	0.0405	0.1352	0.0860	30.05

BROADCUT FUEL 3 AL-10306-F 2000 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
226	2.41	0.0032	0.0219	0.2594	0.2650	38.77
228	5.33	0.0030	0.0604	0.2036	0.0800	28.87
229	6.85	0.0031	0.0675	0.2634	0.0670	25.65

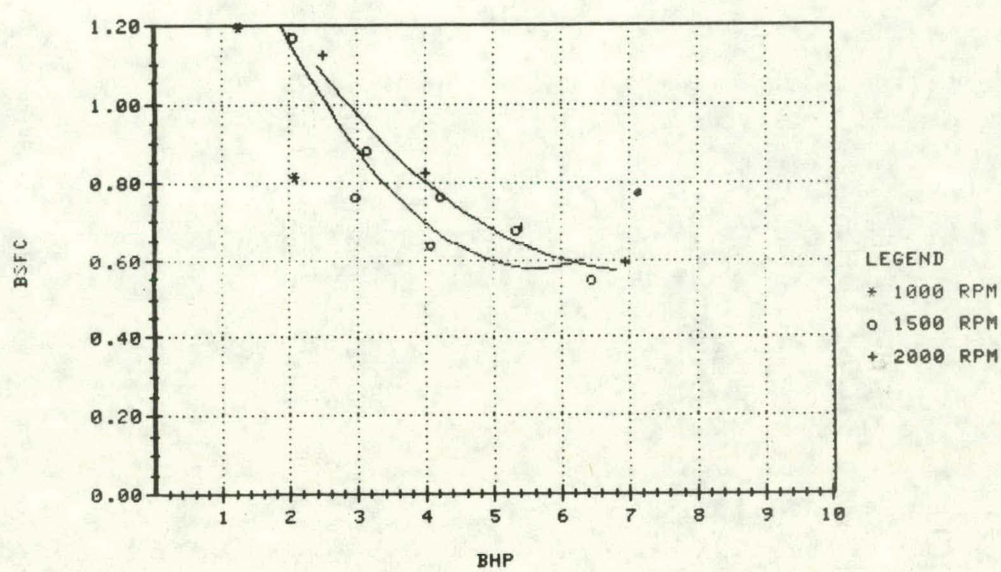

FIG.D.13A BROADCUT FUEL-3 BSFC VS BHP

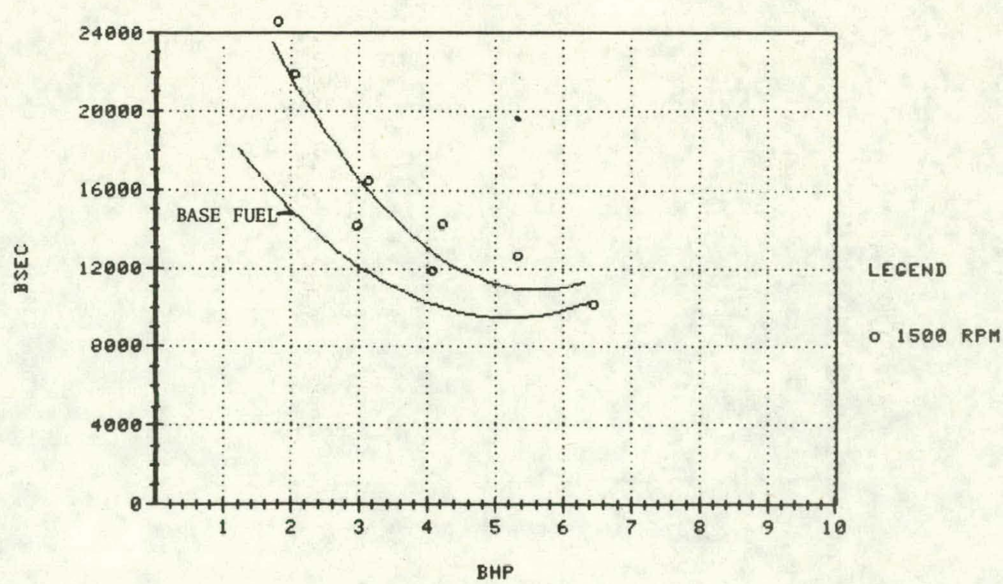

FIG.D.13B BROADCUT FUEL-3 BSEC VS BHP

TABLE D.14 BROADCUT FUEL 4

PERFORMANCE

BROADCUT FUEL-4 AL-10307-F 1000 rpm 5 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
184	4.24	79.02	0.519	9812	12.66	27.47
185	3.51	65.46	0.552	10444	11.89	31.15
186	2.69	50.17	0.620	11731	10.59	36.51
187	1.98	36.90	0.712	13466	9.22	43.75
188	1.25	23.35	0.910	17208	7.22	54.27

BROADCUT FUEL-4 AL-10307-F 1500 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
189	6.31	78.42	0.499	9438	13.16	25.80
190	5.18	64.40	0.554	10471	11.86	28.36
191	4.06	50.38	0.575	10865	11.43	34.94
192	3.09	38.39	0.647	12240	10.15	40.97
193	1.81	22.53	0.855	16163	7.68	52.52
347	5.21	64.68	0.588	11115	11.17	26.03

BROADCUT FUEL-4 AL-10307-F 2000 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
194	8.55	79.66	0.504	9534	13.03	23.52
195	6.93	64.58	0.556	10506	11.82	26.47
196	5.40	50.28	0.582	11005	11.29	32.53
197	3.84	35.80	0.726	13732	9.04	36.61
198	2.36	22.00	0.936	17702	7.02	46.56
348	7.08	65.96	0.572	10820	11.48	24.90

EMISSIONS

BROADCUT FUEL 4 AL-10307-F 1000 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
184	4.24	0.0297	0.1380	0.2211	0.1600	27.47
186	2.69	0.0311	0.1185	0.1421	0.0760	36.51
188	1.25	0.0190	0.0594	0.1275	0.0900	54.27

BROADCUT FUEL 4 AL-10307-F 1500 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
189	6.31	0.0104	0.0923	0.0512	0.1300	25.80
191	4.06	0.0143	0.0323	0.1250	0.0615	34.94
191	1.81	0.0156	0.0498	0.1158	0.0945	52.52
347	5.21	0.0115	0.0955	0.1815	0.0900	36.03

BROADCUT FUEL 4 AL-10307-F 2000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
194	8.55	0.0153	0.0890	0.0361	0.1340	23.52
196	5.40	0.0077	0.0789	0.1035	0.0565	32.53
198	2.36	0.0089	0.0492	0.0837	0.0850	46.56
384	7.08	0.0133	0.0966	0.1666	0.0760	24.90

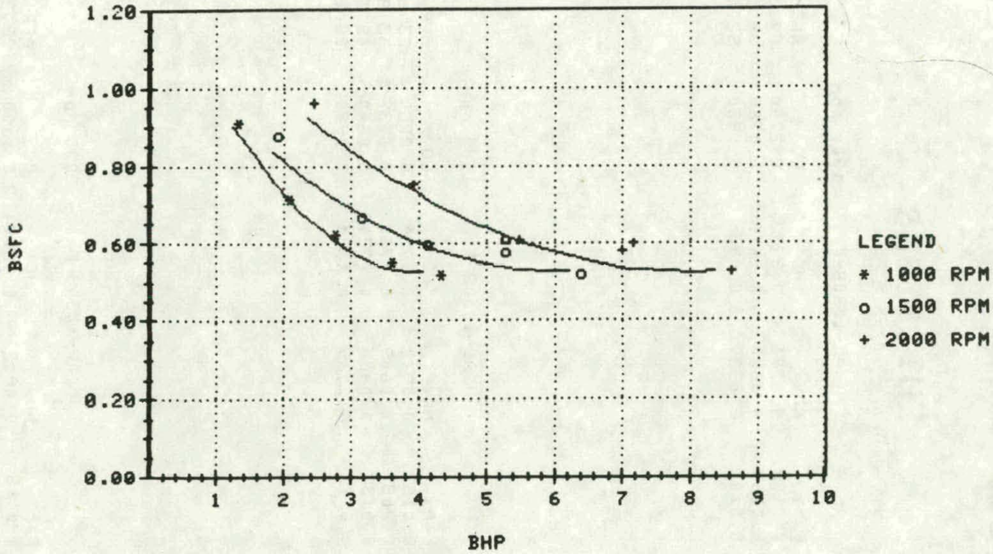

FIG.D.14A BROADCUT FUEL-4 BSFC VS BHP

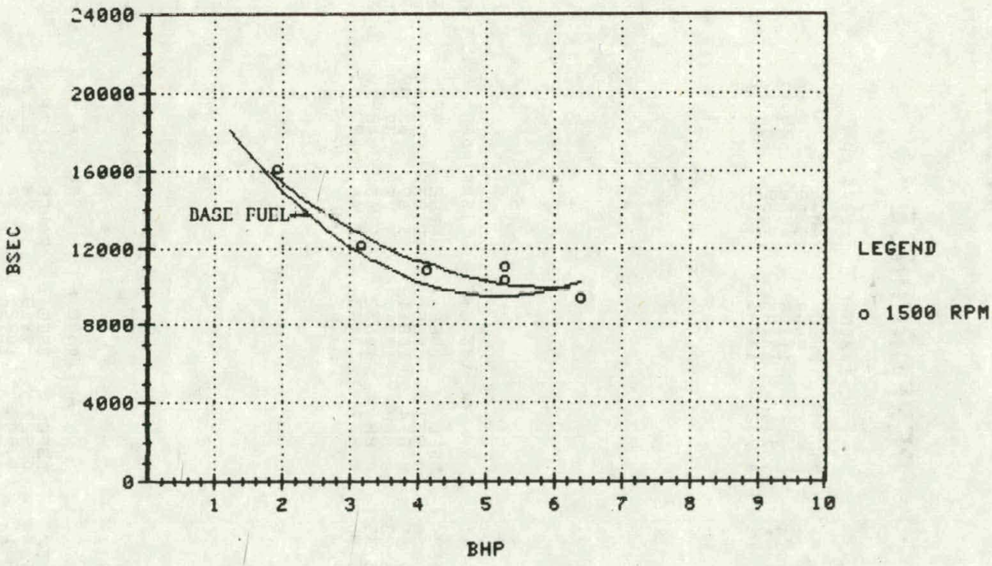

FIG.D.14B BROADCUT FUEL-4 BSEC VS BHP

TABLE D.15 BROADCUT FUEL 5

PERFORMANCE

BROADCUT FUEL 5 AL-10308-F 1000 rpm 4 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
256	4.25	79.20	0.513	9659	13.08	27.64
258	2.69	50.14	0.595	11198	11.28	38.11
259	2.00	37.26	0.700	13185	9.58	43.17
260	1.24	23.13	0.942	17746	7.12	52.12

BROADCUT FUEL 5 AL-10308-F 1500 rpm 5 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
261	6.46	80.26	0.523	9851	12.83	23.64
263	4.09	50.85	0.574	10811	11.69	33.89
264	2.96	36.83	0.688	12957	9.75	39.38
265	1.88	23.35	0.883	16632	7.60	48.79
350	5.31	65.96	0.539	10143	12.46	28.23

BROADCUT FUEL 5 AL-10308-F 2000 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
266	8.53	79.44	0.527	9915	12.74	22.34
267	6.99	65.11	0.548	10320	12.24	25.30
268	5.41	50.38	0.590	11108	11.38	31.71
269	4.06	37.82	0.685	12895	9.80	36.47
270	2.44	22.71	0.940	17692	7.14	44.51
351	7.01	65.29	0.557	10480	12.06	25.87

EMISSIONS

BROADCUT FUEL 5 AL-10308-F 1000 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
256	4.25	0.0178	0.0776	0.2273	0.2750	27.64
258	2.69	0.0067	0.0680	0.1176	0.0760	38.11
260	1.24	0.0109	0.0380	0.0938	0.0980	52.12

BROADCUT FUEL 5 AL-10308-F 1500 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
261	6.46	0.0152	0.0742	0.0926	0.2750	23.64
263	4.09	0.0087	0.0605	0.0931	0.0535	33.89
265	1.88	0.0133	0.0422	0.0921	0.0840	48.79
350	5.31	0.0192	0.1035	0.1384	0.0990	28.23

BROADCUT FUEL 5 AL-10308-F 2000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
266	8.53	0.0116	0.0812	0.0899	0.1100	22.34
268	5.41	0.0061	0.0623	0.0956	0.0500	31.71
270	2.44	0.0071	0.0337	0.0812	0.0840	44.51
351	7.01	0.0104	0.1050	0.1285	0.0685	25.87

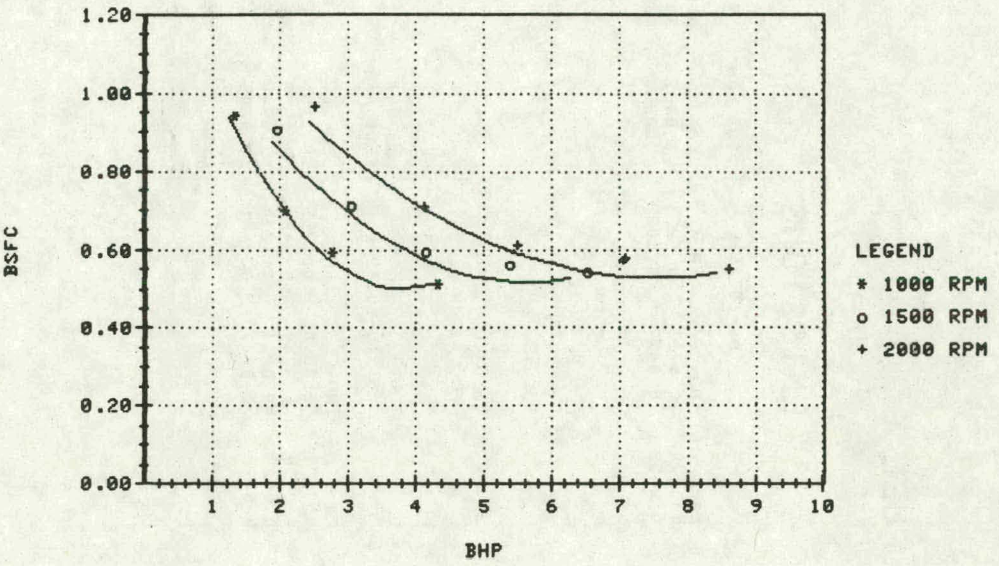

FIG.D.15A BROADCUT FUEL 5 BSFC VS BHP

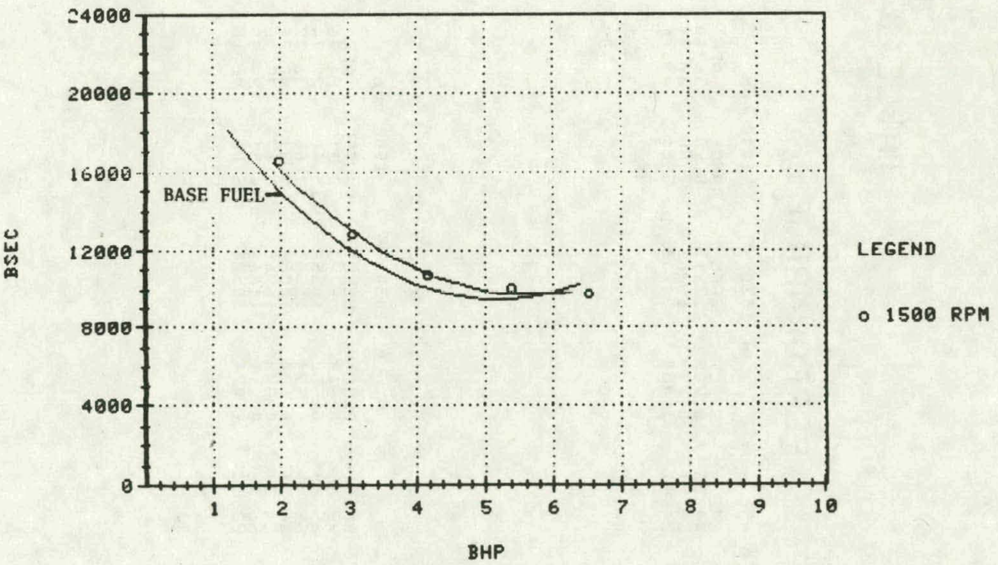

FIG.D.15B BROADCUT FUEL 5 BSEC VS BHP

TABLE D.16 BROADCUT FUEL 6

PERFORMANCE

BROADCUT FUEL 6 AL-10309-F 1000 rpm 3 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
284	2.37	44.25	0.708	13515	8.90	36.40
285	1.93	35.91	0.799	15265	7.88	39.94
286	1.31	24.41	1.084	20704	5.81	43.94

BROADCUT FUEL 6 AL-10309-F 1500 rpm 7 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
287	6.33	78.66	0.512	9773	12.31	24.96
288	5.29	65.68	0.552	10550	11.40	27.74
289	4.16	51.66	0.594	11345	10.60	33.07
290	2.92	36.33	0.684	13062	9.21	40.84
291	1.95	24.20	0.878	16768	7.17	47.92
362	5.39	66.92	0.611	11666	10.31	24.50
363	1.80	22.32	1.074	20520	5.86	42.18

BROADCUT FUEL 6 AL-10309-F 2000 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
292	8.71	81.11	0.508	9698	12.40	22.59
293	7.09	66.03	0.553	10565	11.39	25.72
294	5.58	52.02	0.611	11667	10.31	29.83
295	4.13	38.46	0.739	14112	8.52	33.31
296	2.45	22.85	1.007	19237	6.25	41.29
361	6.87	64.05	0.653	12477	9.64	22.58

EMISSIONS

BROADCUT FUEL 6 AL-10309-F 1000 rpm 2 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
284	2.37	0.0070	0.0923	0.1283	0.0485	36.40
286	1.31	0.0052	0.0477	0.1282	0.0850	43.94

BROADCUT FUEL 6 AL-10309-F 1500 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
287	6.33	0.0079	0.0890	0.1755	0.1135	24.96
289	4.16	0.0050	0.0749	0.1429	0.0525	33.07
291	1.95	0.0028	0.0414	0.1243	0.0940	47.92
362	5.39	0.0032	0.0717	0.0641	0.0605	24.50

BROADCUT FUEL 6 AL-10309-F 2000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
292	8.71	0.0047	0.0957	0.2379	0.0800	22.59
294	5.58	0.0057	0.0578	0.1733	0.0600	29.83
296	2.45	0.0050	0.0329	0.1463	0.1275	41.29
361	6.87	0.0049	0.0447	0.1401	0.1300	22.58

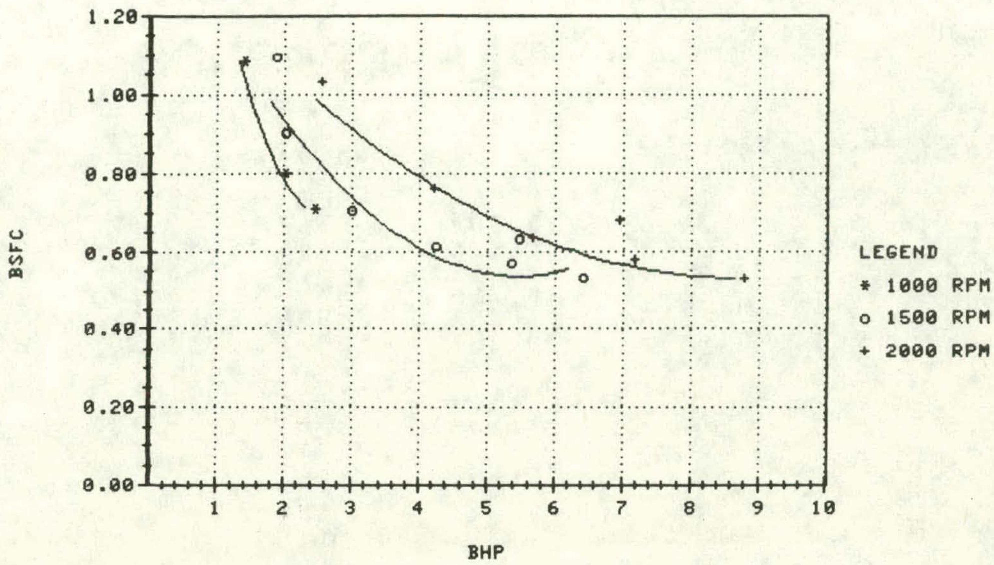

FIG.D.16A BROADCUT FUEL 6 BSFC VS BHP

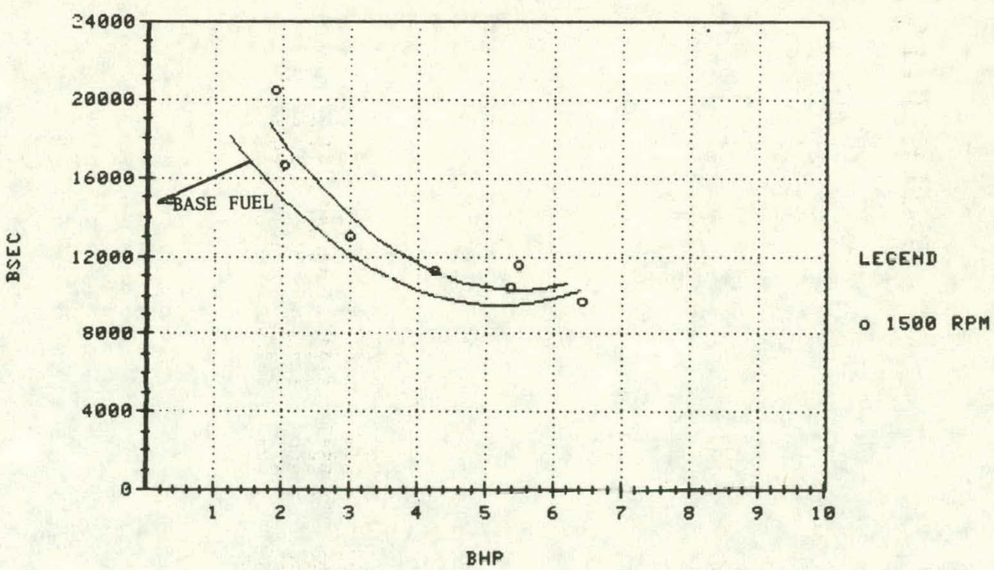

FIG.D.16B BROADCUT FUEL 6 BSEC VS BHP

TABLE D.17 BROADCUT FUEL 7

PERFORMANCE

BROADCUT FUEL 7 AL-10310-F 2000 rpm 6 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
302	7.94	74.02	0.502	9367	13.07	24.86
303	7.12	66.35	0.536	10004	12.24	26.31
304	5.35	49.85	0.611	11398	10.74	30.84
305	3.96	36.90	0.715	13326	9.19	35.64
306	2.41	22.50	1.073	20006	6.12	38.81
366	7.10	66.14	0.583	10877	11.26	24.49

ROADCUT FUEL 7 AL-10310-F 1500 rpm 5 runs

RUN#	BHP	BMEP	BSFC	BSEC	RANGE	AFR
298	4.97	61.74	0.569	10620	11.53	28.14
299	4.25	52.80	0.536	10005	12.24	35.35
300	3.06	37.97	0.651	12144	10.08	40.84
364	5.37	66.71	0.551	10281	11.91	27.41
365	2.93	36.37	0.820	15289	8.01	33.92

EMISSIONS

BROADCUT FUEL 7 AL-10310-F 1500 rpm 3 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
298	4.97	0.0114	0.1220	0.1775	0.0385	28.14
299	4.25	0.0039	0.0907	0.1728	0.0455	35.35
364	5.37	0.0032	0.0800	0.1325	0.1350	27.41

BROADCUT FUEL 7 AL-10310-F 2000 rpm 4 runs

RUN#	BHP	Part	NOx	'HC'	CO	AFR
302	7.94	0.0067	0.1020	0.2174	0.0590	24.86
304	5.35	0.0057	0.0539	0.2053	0.1410	30.84
306	2.41	0.0050	0.0300	0.2294	0.2470	38.81
366	7.10	0.0046	0.0623	0.1416	0.2300	24.49

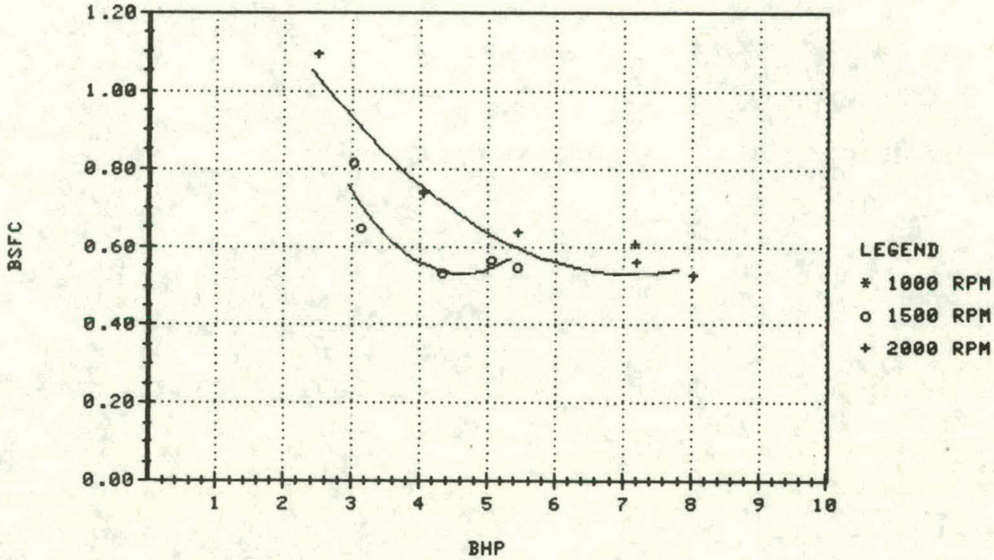

FIG.D.17A BROADCUT FUEL 7 BSFC VS BHP

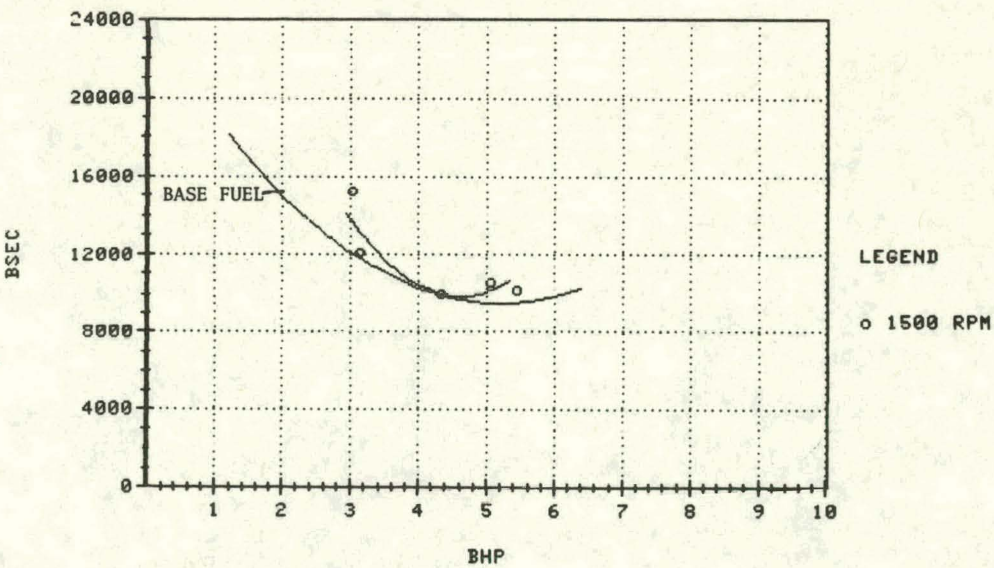

FIG.D.17B BROADCUT FUEL 7 BSEC VS BHP