EVALUATION OF COAL DERIVED LIQUIDS AS UTILITY BOILER FUELS EASTERN TEST

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INTRODUCTION

The synthetic fuels evaluation at Mississippi Power Company's Plant Sweatt is just one of a number of tests, sponsored by the Electric Power Research Institute (EPRI) under project RP 2112, to assess the potential of coal derived, liquid synthetic fuels as an alternative or substitute for liquid petroleum fuels. Specifically, the work done at Plant Sweatt examined the applicability of six liquid synthetic fuels to a full scale, wall fired utility boiler. EPRI sponsored testing with synthetic fuels at other sites included small scale combustors, a Combustion Engineering wall-fired utility boiler, a Combustion Engineering tangentially-fired utility boiler, a combustion turbine and diesel piston engines with generally favorable results.

The testing at Plant Sweatt was sponsored by EPRI, Mississippi Power Company (MPC) and Southern Company Services, Inc.(SCS). EPRI also contributed the 27,700 barrels of synthetic fuel to the test effort.

OBJECTIVES

The objectives of the test were to:

- o Demonstrate the use of coal derived liquids as potential substitutes for petroleum fuel oil in a full scale, wall fired utility boiler.
- o Assess the potential for minimizing nitrogen oxide (NO_x) emissions from the six, high fuel-bound nitrogen liquids.
- o Obtain data on the quantity and composition of other emissions from the combustion of the synthetic fuels such as particulate loading, particulate morphology, hydrocarbons, chlorides and flue gas acid dew point temperature.
- o Assess the future utilization of coal derived liquids as a possible replacement fuel for other existing boilers or as a design basis for new boilers.
- o Compare and contrast the combustion characteristics of the two baseline fuels and the six synthetic fuels in terms of combustion efficiency, regulated emissions and fuel handling.

At the original writing of this paper, a large portion of the data require additional reduction and analysis. Therefore, the results and conclusions that follow have not yet been subject to the thorough investigation that remains to be done as part of the EPRI contract.

FACILITIES

Mississippi Power Company's Plant Sweatt is located on Valley Road, approximately five miles south of Meridian, Mississippi, in Lauderdale County. This station has two identical steam units labeled 1 and 2 which were placed in service in 1951 and 1953, respectively. Although rated at 40 MW, each unit is capable of generating 49 MW and with the onsite 39.4 MW combustion turbine, represent 4.5% of Mississippi Power's generating capacity. The boilers are Babcock & Wilcox (B&W), balanced draft, front wall fired (2 vertical x 3 horizontal burner matrix) units with welded cases. Each is designed to produce 425,000 pounds of steam per hour at 850 psig and 900°F. Both are currently fired on either natural gas or No. 6 oil and have no environmental controls of any type. While this plant is normally restricted to providing peaking capability during the summer, arrangements were made to isolate Unit 1, the test unit, from economic dispatch and to set load based on testing requirements from September 1983 through December 1983 to accommodate the project schedule.

PROJECT ORGANIZATION

The project at Plant Sweatt was organized with Southern Company Services as EPRI's prime contractor responsible for project management, project direction and subcontractor performance. Subcontracted to Southern Company Services were Babcock & Wilcox(B&W) and KVB. B&W provided technical consultation and boiler performance evaluations, KVB provided combustion gas emission characterizations and supplementary technical consultation. Although not directly subcontracted to SCS, Radian, Inc. provided fuel logistics support and Control Data Health Care Services assisted with the industrial hygiene program as part of the multi-site EPRI work with synthetic fuels, RP 2112.

PLANT MODIFICATIONS

Before testing could begin in September of 1983, minor modifications to Plant Sweatt were required to accommodate the objectives of the work. Five areas were addressed:

(1) Fuel forwarding system
(2) Rail transloading site
(3) Burner air registers
(4) Exterior ductwork
(5) Industrial hygiene program

The well documented aggressiveness of the synthetic fuels toward rubber-based gasketing material dictated the design of a redundant fuel forwarding system of predominantly welded joints. The few joints that were gasketed were done so with Flexitalic gaskets(asbestos/metal) which are resistant to deterioration from synthetic fuels. This redundant fuel system allowed Unit 1 to operate concurrently on natural gas and a liquid fuel in any configuration. It also provided the flexibility to transition online from liquid synthetic fuel to either baseline fuel at the burner front should Plant Sweatt have been needed for a production type emergency. This redundant fuel system was designed to provide the same liquid pressures and flow rates to the existing Racer burner components at the boiler front as in normal No. 6 fuel oil operation.

The onsite surge capacity for storing synthetic fuels was accomplished through the use of four, 7800 gallon commercial fuel hauling trailers which were manifolded into the synthetic fuel forwarding system. When emptied, each trailer was pulled out for refilling at the rail transloading site.

The six synthetic fuels were delivered to Plant Sweatt in 23,500 gallon "jumbo" railcars from their various origins. These cars were temporarily sited on Illinois Central & Gulf Railways Okatibbee siding approximately 1/4 mile from the plant. This railsiding was the location for the second set of modifications. An area approximately 200'x20' was graded and paved to support the transloading operation from railcar to mobile trailer. Curbing and a drainage sump were included to prevent any ground water contamination. The transloading was done with the fuel transporter's tractor power-take-off pump, gravity fed from the railcar's bottom discharge. Fuel transloading was a continuous process during any testing over 25 MW due to synthetic fuel consumption rates.

The third area of modification was in the boiler windbox. Although B&W had reworked the burners on Unit 1 in 1974, moderate to severe warpage and misalignment were noted during the B&W Field Service Engineer's inspection in November of 1982. Consequently, the air register vanes in all six burners were replaced and individually aligned for reliable air flow control. Partial shrouds were also added around each burner to augment the control of combustion airflow.

Corrosion penetrations in the flue gas ductwork downstream of the air preheater caused the replacement of some ductwork to be the fourth modification. Although air inleakage on the suction side of the ID fan was not operationally troublesome, any dilution of the flue gas upstream of the proposed emission extraction grid would discredit the analytical procedures for measuring combustion emissions. When this ductwork was replaced, an access platform for the sampling crews was added around the flue gas extraction ports.

The last area of modification actually took place in several locations around the plant to support the industrial hygiene program. First, the plant employee locker room area was subdivided into a clean side/dirty side concept similar to that found at nuclear installations. All equipment or personnel involved in synthetic fuel handling were segregated on the dirty side. In order to pass to the clean side where street clothing was stored, personnel were required to take a shower at the end of their shift. A daily change of coveralls and laundry service were also mandatory for synthetic fuel handlers. Personnel not involved in handling the synthetic fuels were denied access to those areas where spills and contamination were most probable; the redundant fuel system/trailer pad, the boiler front, the rail transloading area and the dirty side locker room. Barricade tape and signs were appropriately placed as a reminder. In order to contain any large spillage, the stationary trailer pad and the rail transloading area were paved and curbed. Fuel handling personnel were equipped with hard hats, eye protection, face masks with organic vapor filters, coveralls, a bib rainsuit, and elbow-length gloves. They were reimbursed for their work boots if contaminated at the project end. Personnel involved in the testing were given baseline medical examinations and classes on personal hygiene as a part of the industrial hygiene philosophy of "no contact" with the synthetic fuels. Fortunately, no spills or gross contamination occurred during the four months of testing.

TEST PLAN

Six synthetic fuels from three major research firms were provided by EPRI for testing at Plant Sweatt:

- Gulf Research/Tacoma, Washington
  - Solvent Refined Coal-II (Full Range Mixture)
  - Solvent Refined Coal-II (Middle Distillate Fraction)
- Ashland Oil/Catlettsburg, Kentucky

H-Coal (Light Fraction)
H-Coal (Heavy Fraction)
H-Coal (Blended Mixture)
Exxon Research/Baytown, Texas
Exxon Donor Solvent

Mississippi Power Company provided the baseline fuels:
Natural Gas
No. 6 Fuel Oil

In satisfying the test objectives, it was necessary to "test" the single gaseous fuel and seven liquid fuels on as common a basis as possible for a meaningful comparison. Generally, the areas of investigation were:

(1) Limits of operability,
(2) operability at repeatable conditions, and
(3) adaptability for combustion optimization.

The test points contemplated were based on each fuel's "smoke point" as the boundary between complete and incomplete combustion. Smoke point was operationally defined as the flue gas excess oxygen level measurement at which drastic upswings in carbon monoxide and opacity occurred on B&W and KVBs instantaneous monitors. This level is a function of each fuel's molecular composition and is somewhat dependent on a boiler's particular combustion dynamics. This level may be influenced by burner type, tip placement, combustion air distribution, fuel atomization and other physical factors. By operating just above the smoke point, the combustion loss due to excess air is minimized, which results in higher boiler efficiencies. Three test points for each liquid fuel were originally established based on a fuel's smoke point:

(1) <u>Low Excess Air - "LEA"</u>
Smoke point plus 0.5% excess oxygen in the flue gas

(2) <u>Normal Excess Air - "NEA"</u>
Smoke point plus 1.0% excess oxygen in the flue gas

(3) <u>High Excess Air - "HEA"</u>
Smoke point plus 2.0% excess oxygen in the flue gas

A fifth test point was also established later to give the test results commonality at one excess oxygen level. This test point was to be at a comparable excess oxygen level found for the baseline liquid fuel (No. 6 fuel oil) known as the Oil Comparable (OC) test point. These five points were established with normal burners in service at three loads; 40 megawatts, 25 megawatts and 15 megawatts and again with burners out of service. This satisfied the three areas of investigation outlined earlier. In some cases, however, testing was limited by unstable combustion or combustion air availability (fan limited). This caused the early termination of some tests.

Coal liquefaction processes are designed to chemically clean coal by removing ash, sulfur and to a lesser extent, nitrogen from the feed coal. The principal differences between the fuels tested at Plant Sweatt and their petroleum counterparts are that synthetic fuels have a higher carbon/hydrogen ratio and higher fuel-bound nitrogen content. A high C/H ratio is sometimes an indication of increased soot formation. This, however, was not found in the Plant Sweatt testing. Increased fuel-bound nitrogen in coal derived fuels can serve as the precursor for another currently regulated emission, nitrogen oxides (NO_x). One of the objectives of the Plant Sweatt testing was to measure and reduce NO_x emissions through combustion modifications. These modifications were limited to changes in the combustion process within the boiler. No equipment such as selective catalytic reduction devices was added. This was done to demonstrate the feasibility of "no cost" options for NO_x reduction in existing liquid fueled boilers.

The conversion of nitrogen to NO_x is predominantly a conversion of fuel nitrogen as opposed to the conversion of combustion air nitrogen. This conversion (combustion) is stoichiometrically limited by the presence of available oxygen. The work at Plant Sweatt relied mainly on "burners out of service" (BOOS) as the combustion modification to reduce NO_x emissions. This was done, of course, in combination with operation at minimum excess oxygen levels. The BOOS configuration that gave the least NO_x emission on each fuel and each load was subjected to the full testing matrix of excess oxygen levels.

BOOS owes its success to the resulting segregation of the boiler into two zones: oxygen rich and oxygen lean. The BOOS concept objective is to force the combustion reaction to occur in the oxygen lean zone. By optimizing each burner flame with air register adjustments and then simply closing the fuel valve on selected burners, the BOOS technique is accomplished. Burners without fuel (the BOOS) are producing fuel lean/oxygen rich zones by still contributing combustion air. The burners remaining in service become fuel rich/oxygen lean in two ways:

(1) The aggregate fuel flow to maintain load remains constant but increases proportionately to those burners remaining in service with no increase in available combustion air. This causes the burners remaining in service to be less stoichiometrically excessive in oxygen.

(2) It is also theorized that air flow increases slightly in the BOOS as there is no flame back pressure at these burners. This makes the burners still in service even less stoichiometrically excessive in oxygen.

Of course, it is still necessary to maintain an excess oxygen level sufficient to complete combustion by maintaining air vane settings in the BOOS. It is also desirable that particulate emissions (measured as opacity) and carbon monoxide levels be held within acceptable limits rather than optimizing the NO_x reduction at the expense of other considerations.

DATA ACQUISITION

The data acquisition role at Plant Sweatt was performed by Babcock & Wilcox and KVB. B&W used their Computerized Boiler Diagnostic System (CBDS) programmed into a Hewlett-Packard portable computer in gathering and calculating boiler operating data. This automated system was complemented by the traditional checklist approach for non-automated control room information. The CBDS recorded approximately 200 data points every sixty seconds for refinement into ten minute averages for each test. Data measurement devices included extensive thermocouple grids, differential pressure transmitters and extractive flue gas analysis both before and after the air preheater. Instantaneous scan values could be read on a CRT screen while data values and averages were stored on a non-volatile, magnetic disk. These averages were combined later to provide a single, boiler efficiency value for each test. B&W also calibrated the plant's combustion air flow orifice readings with their Velocity/Pressure Averaging System (VPAS) prior to testing.

KVB acquired real time data on several emissions and gathered many samples for later analysis. Included in their matrix were the continuous monitoring of carbon monoxide, carbon dioxide, excess oxygen, nitrogen oxides and sulfur dioxide. Gas sampling for sulfur trioxides and chlorides was done intermittently as was measurement of acid dew point, particulate loading, particulate morphology and particulate size distributions.

At the original writing of this paper, a large portion of both B&W and KVBs data require additional reduction and analysis. Therefore, the results and conclusions that follow have not yet been subject to the thorough investigation that remains to be done as part of the EPRI contract.

RESULTS AND CONCLUSIONS

The testing of the six synthetic fuels at Plant Sweatt was very successful. Results on the first three synthetic fuels(SRC-II(Full range mixture), H-Coal(Heavy fraction) and H-Coal(Blended mixture)) indicate that all three have higher boiler efficiencies and produced fewer emissions than the baseline No. 6 fuel oil. Results of testing on the last three synthetic fuels(SRC-II(Middle distillate fraction), H-Coal(Light fraction) and Exxon Donor Solvent) indicate comparable findings but lack the depth of data taken on the first three fuels. The burners out of service technique in combination with reduced excess combustion oxygen was also very successful, providing as much as a 50% reduction in NO_x levels. These coal derived liquid fuels appear to be quite adequate for petroleum liquid replacement in existing units and should certainly be considered in the design basis for liquid fuel boilers of the future. The only drawbacks to the use of these fuels are in their material aggressiveness toward standard gasketing materials and their implied human toxicity. Both problems should be surmountable through simple design accommodations.

Combustion efficiency for the fuels ranged from a low of 83.6% for natural gas at 15 MW to a high of 91.2% for SRC-II at 25 MW (Figures 2 and 3). The efficiencies calculated for SRC-II, H-Coal(Heavy) and H-Coal(Blend) are on the order of one to two percentage points higher than No. 6 fuel oil and five to seven percentage points higher than natural gas. This is strongly associated with the higher amount of excess combustion oxygen required for natural gas and No. 6 fuel oil to operate above their smoke points. Table I illustrates this point.

Table I
Ranking Of Low Excess Air (LEA) Levels (40 MW, 6 burners)

(1) 2.7% H-Coal(Heavy)	(5) 3.0% H-Coal(Blend)
(2) 2.7% H-Coal(Light)	(6) 3.5% SRC-II(Middle Distillate)
(3) 2.7% EDS	(7) 4.0% Natural Gas
(4) 2.9% SRC-II(Full Range)	(8) 5.8% No. 6 Fuel Oil

As anticipated, the nitrogen oxide emissions from the coal derived liquids were higher than that of No. 6 fuel oil or natural gas (Figure 1). However, the combination of BOOS and LEA reduced NO_x emissions as much as 50% in some cases (Figures 4 and 5). Table II lists some typical results.

TABLE II
Selected NO_x Reduction Results

Fuel	Load	Burners	Excess O_2 Level	NO_x	% Reduction
SRC-II(Full Range)	25MW	no BOOS	HEA	403ppm	
					25%
		no BOOS	LEA	301ppm	53%
					37%
		2 BOOS	LEA	191ppm	
H-Coal(Blend)	40MW	no BOOS	HEA	398ppm	
					21%
		no BOOS	LEA	316ppm	51%
					30%
		1 BOOS	LEA	195ppm	
No. 6 Fuel Oil	40MW	no BOOS	HEA	275ppm	
					21%
		no BOOS	LEA	217ppm	33%
					15%
		1 BOOS	LEA	185ppm	

It is interesting to note that NO_x emissions from the synthetic fuels could be lowered to a level approximating the NO_x emission from optimized No. 6 fuel oil combustion. From another perspective, optimized synthetic fuel combustion resulted in considerably less NO_x than unoptimized No. 6 fuel oil operation (HEA, no BOOS).

Particulate emissions from the synthetic fuels were very low, on the order of 0.01 lb per million Btu. This is approximately one order of magnitude less than particulate emissions from No. 6 fuel oil. Also, LEA and BOOS operation did not significantly contribute added particulate emissions. Data on particulate morphology and submicron particle size distributions are still undergoing analysis.

The difficulty in fuel handling was somewhat self-imposed by the project philosophy of, "no human contact" with the synthetic fuels. The personal hygiene requirements (clothing changes, mandatory raingear/facemask/gloves, and restricted areas) were more burdensome than problematic. At a plant designed specifically to use synthetic fuels, the potential for contact with the fuel could be minimized through bulk liquid storage, welded pipe joints, dry disconnect couplings and backflushing filters. This would limit potential spillage (and human contact) to infrequent fuel transfer operations and emergencies.

Overall, the consensus of the participants is that any of the six coal derived liquids could be used as a replacement for liquid petroleum fuel in this utility boiler with no equipment modifications, equipment additions or environmental variances. The relatively small modifications required at Plant Sweatt indicate that few design criteria would be affected if these synthetic fuels were to be included in the fuel specifications of future design criteria.

When all the data have been reduced and analyzed, a final EPRI report on the work at Plant Sweatt(RP 2112-02) will be published. Further specific inquiries will be welcomed pending the distribution of this final report.

LIQUID SYNTHETIC FUEL COMBUSTION TEST

NITROGEN OXIDES VS. EXCESS OXYGEN

40MW BASELINE

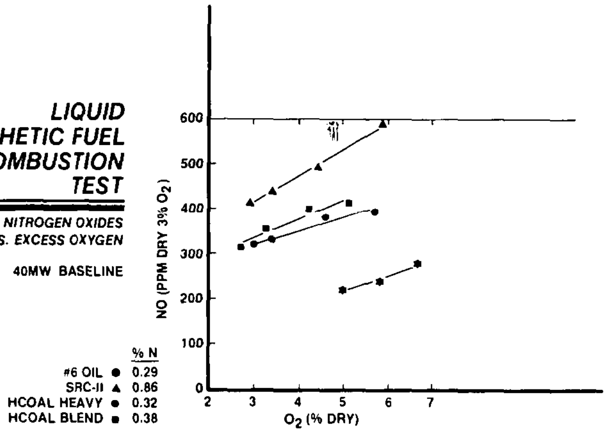


FIGURE 1

LIQUID SYNTHETIC FUEL COMBUSTION TEST

COMBUSTION EFFICIENCY VS. EXCESS OXYGEN

40 MW
6 BURNERS
IN SERVICE

OIL ●
SRCII ●
H-COAL (HEAVY) ▲
H-COAL (BLEND) ●
H-COAL (LIGHT) ●

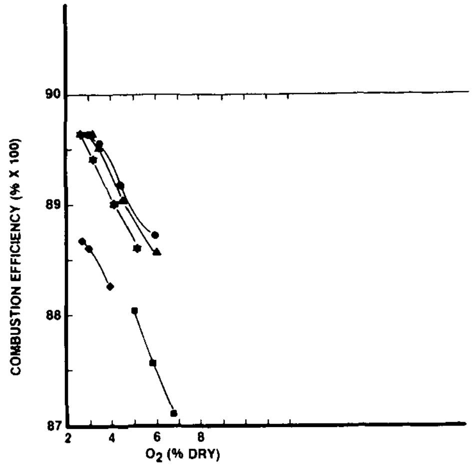


FIGURE 2

LIQUID SYNTHETIC FUEL COMBUSTION TEST

COMBUSTION EFFICIENCY VS. EXCESS OXYGEN

SRC II LOW NO_x
AT 25 MW

BASELINE ■
1 BOOS ▲
2 BOOS ●

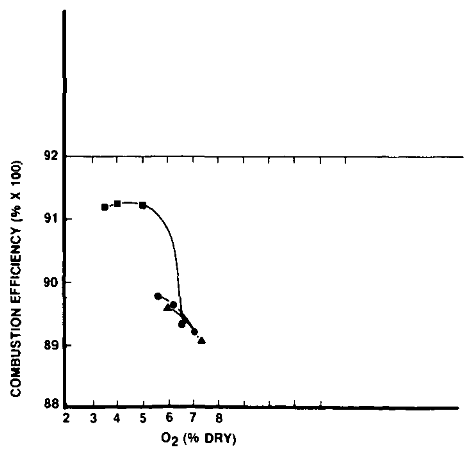
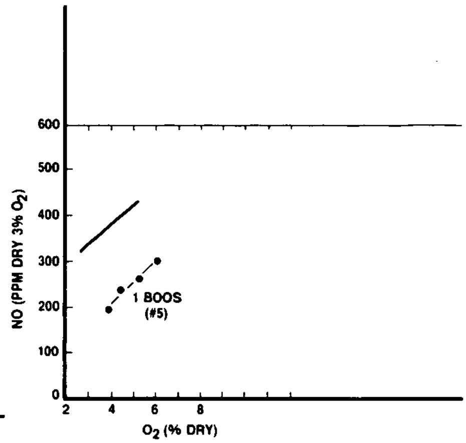


FIGURE 3

LIQUID SYNTHETIC FUEL COMBUSTION TEST

NITROGEN OXIDES VS. EXCESS OXYGEN

H-COAL (BLEND) LOW NO_x AT 40 MW



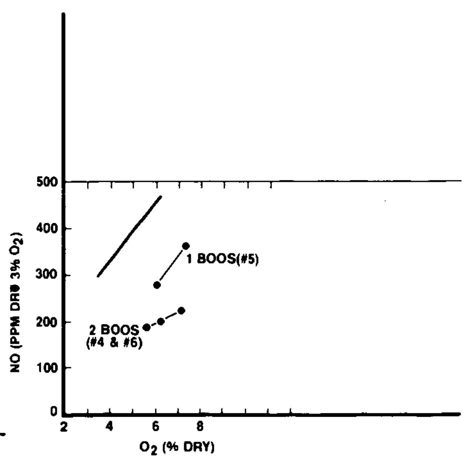
BASELINE ——
BURNER OUT OF SERVICE •

FIGURE 4

LIQUID SYNTHETIC FUEL COMBUSTION TEST

NITROGEN OXIDES VS. EXCESS OXYGEN

SRC-II LOW NO_x AT 25 MW



BASELINE ——
BURNERS OUT OF SERVICE •

FIGURE 5