**L-STAR PULSED COAL COMBUSTOR FOR
RESIDENTIAL SPACE HEATING**

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**QUARTERLY PROGRESS REPORT
FOR THE PERIOD
NOVEMBER 1988 - JANUARY 1989**

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prepared for

U.S. DEPARTMENT OF ENERGY

**WORK PERFORMED UNDER
CONTRACT DE-AC22-87PC79652**

prepared by

**AVCO RESEARCH LABORATORY, INC.
a subsidiary of Textron Inc.
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1.0 CONTRACT OBJECTIVE

The objective of this contract is the design, fabrication, and testing of a residential size pulsed combustion system based on the L-star concept. Phase I of the program consists of the bulk of the development and optimization of the combustor, while Phase II is to be centered around complete system development. The scope of work in Phase I is as follows:

- Task 1 - Experimental System Design
- Task 2 - Reactor Fabrication/Facility Modification
- Task 3 - Combustion Characterization

2.0 SUMMARY OF PROGRESS

During this quarter, substantial improvement in the coal carbon conversion was achieved. Specifically, for a scaled-down version of the residential combustor, coal carbon conversions exceeding 97 percent were realized, when utilizing methane as carrier gas for the coal. (Although technically not within the November-January period, it should be mentioned here that in March a few design changes have resulted in > 99 percent coal carbon conversion, with no electric spark and complete elimination of methane during coal combustion and in a residential scale unit.)

Design changes made during this quarter include insulation of the combustor, introduction of a flame holder, combustion air preheat and presence of an obstructing plate at the combustor exhaust port. Only the first two changes contributed towards substantial improvement in coal conversion. In addition, monitoring of CH_4 concentration in the exhaust gases gave a real time indication of the combustor performance.

Finally, the results of experiments performed in this quarter contributed to design changes that have led to a combustor that has achieved the program goal of > 99 percent conversion of coal carbon. These changes and the results will be described in the final report.

3.0 TECHNICAL STATUS

During this quarter, several avenues were investigated to optimize coal carbon conversion. Two basic combustor configurations were tested, the second resulting in a > 97 percent coal carbon conversion.

First an induced recharging configuration was set up as shown in Figure 1. In this configuration, combustion of the fuel/air mixture drives gas out of the combustor, with the majority of the flow going toward the exhaust because of the combined effects of the exhaust fan and the diode flow resistance. The water-cooled combustor walls induce densification of the combustion gases, drawing in fresh air to repeat the cycle again.

This was indeed the case, as several runs of a few minutes duration were carried out. However, the amount of fresh air drawn in was insufficient to operate at an acceptable heat release rate. Also, there was some unburned coal remaining in the combustor after each run.

It was therefore decided to modify the combustor such that it features forced airflow of sufficient quantity and hot combustor walls. As shown in Figure 2, this was accomplished by reconnecting the small blower used in the past and lining the inside of the combustor with a flexible ceramic fiber blanket approximately 2 inches thick, which considerably decreased the effective volume of the combustor. It should be noted that unlike all of the experiments performed on this program to date, in this case the air flow was from bottom to top. In this configuration, good retention and hot walls are achieved.

After fine tuning during several short runs, an extended duration test was conducted. To preheat the system, methane without coal was combusted for 37 minutes in a pulsed manner. Immediately afterwards, coal with methane as a

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Figure 1: Induced Recharging Combustor Configuration

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Figure 2: Bottom to Top Forced Airflow Configuration

carrier gas was combusted for 38 minutes. This run yielded 97.9 percent coal conversion. No unburned coal, or even char, was found in the combustor. A mere 2 g was recovered from the downstream filter assembly (analysis not performed) out of 96.5 g fed to the combustor. A summary of the variation with time of the combustion products and combustor temperature is presented in Table 1.

After this initial run, several runs were performed with this new configuration of up to three hours duration. Minor changes were made from run-to-run to optimize performance. Specifically, the effect of variations of the following parameters were studied: run duration, flow resistance, combustion air preheat, presence of the aerodynamic diode, and presence of an obstructing plate at the combustor exhaust port to retain solids. The results of these tests are presented in Table 2. Because chemical analysis of collected solids are not performed in all cases, two estimates of coal carbon conversion which should bracket the actual value are provided. The constant carbon method assumes that the collected coal is identical in composition to the input coal. The ash allowance method assumes that all the ash present in the input coal is recovered, and that any excess collected material is pure carbon. Because multiple variables are involved, neither method can be expected to always yield a higher value than the other.

While it is difficult to draw statistically significant conclusions from the data at this point, certain points are evident. Most obvious is the unexpectedly negative influence of preheating the combustion air. A comparison of the data from runs 4 and 5 shows that conversion was 6 percent lower when the combustion air was preheated under otherwise identical conditions. It is conceivable that the increased velocity of the heated, less dense air under essentially constant mass flow conditions results in more coal being carried away unburned. In any case, this approach has not been pursued further.

TABLE 1

Time	Temp _{Top}	Temp _{Bottom}	% O ₂	% CO ₂	% CO	% CH ₄
<u>Methane Only for Warmup</u>						
7 min	1123°F	143°F	13.63	4.03	-	.115
12	1150	175	13.30	4.17	-	.115
17	1152	202	12.85	4.38	-	.115
22	1151	218	12.42	4.60	-	.110
27	1150	239	11.91	4.90	-	.110
32	1136	259	11.37	5.16	-	.110
37	1116	271	11.22	5.27	-	.100
<u>Methane and Beulah Zap</u>						
3	1005	348	7.65	8.59	.01	.170
8	1015	490	5.92	9.72	.017	.155
13	1020	570	5.49	9.99	.018	.135
18	1020	605	5.21	10.22	.022	.135
23	1030	630	5.07	10.26	.026	.135
28	1022	650	4.82	10.46	.032	.145
33	1025	650	4.62	10.70	.022	.105
38	1010	670	4.60	10.64	.026	.115

TABLE 2

<u>Run Number</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>
Duration (minutes)	180	30	180	100	100	60	180
Diode in Place	Y	Y	Y	N	N	Y	Y
Heat Exchanger in Place	Y	Y	Y	N	N	N	N
Preheated Air (600°F)	N	N	N	Y	N	N	N
Obstructing Plate	N	N	N	N	N	N	Y
Typical Exhaust Gas Composition							
CH ₄ (ppm)	620	3770	560	540	280	3680	410
CO (ppm)	1400	720	-	-	-	-	-
CO ₂ (%)	11.6	13.0	10.3	8.0	6.8	4.5	5.6
O ₂ (%)	3.2	1.8	5.4	11.9	10.3	13.8	11.9
Temperature-Upper Thermocouple (°F)	1140	1334	1190	1227	1260	1170	1130
Temperature-Lower Thermocouple (°F)	800	746	650	612	420	178	260
Coal Carbon Conversion (%)							
Constant Carbon Method	97.6	90.2	95.7	88.4	94.0	91.8	95.2
Ash Allowance Method	98.9	85.0	95.3	81.9	92.2	88.1	94.4

All tests were performed at a pulse repetition rate of .875 HZ and a heat release rate of 6700 BTU/HR.

The remaining runs all exhibited worst case conversion in excess of 85 percent, with a maximum of 97.6-98.9 percent being achieved for run #1 featuring the diode, the increased flow resistance of the heat exchanger, no preheated air, and no exhaust obstruction plate for a run duration of three hours.

Other conclusions can be drawn from the available data. In all cases, residual solids are collected only from the ash collector; the combustor itself is always free of coal. Consequently, one must assume that the solids collected for each run are being carried out of the combustor at least partially unburned and that the problem is primarily one of residence time. Attempts to reduce the air flow enough to preclude this problem resulted only in a too-rich condition (carbon monoxide present). A 1 inch diameter obstruction placed in the 2 inch diameter exhaust orifice failed to retain the particles. Run duration does not appear to be a critical factor.

Subsequent experiments were conducted to fine tune both the combustor geometry and the test procedure in order to achieve as high as possible coal carbon conversion. During the tests, the following parameters were kept constant.

- 1) The combustion air was not preheated.
- 2) The aerodynamic diode was always in place.
- 3) The heat exchanger was removed.
- 4) An obstruction plate was kept in place since its presence did not affect the coal conversion levels.

Two changes were, however, made. First, a flameholder (see Figure 3) was designed and installed, in order to introduce recirculatory zones in the combustor and hence increase residence time at the coal particles. The

M9760

Figure 3: Flame Holder Plate

flameholder was placed in the primary combustion zone approximately 3" over the electrodes. Figure 4 shows the combustor arrangement used for this series of tests (notice the flameholder location). A relatively good coal carbon conversion of 96.7 percent was observed as a result of this change. Second, a thermo-anemometer was installed in the air flow line to measure the air mass flow at the exit of the fan.

This was a considerable improvement over the previous procedure where the air mass flow was not recorded during the test, but rather before and after it, giving only continuous flow measurements. In addition, this gave the ability to introduce the air mass flow as a new well controlled parameter. A bleed-off valve in the line gave good control of the air flow between 2.2 and 3.5 ft³/min (typical air flow approximately 2.9 ft³/min).

An important experimental observation was also made from these runs. The time averaged (over the test time 1-3 hrs) CH₄ volumetric concentration at the combustor outlet, as measured by the gas analyzer, was found to correlate with the coal carbon conversion. This can be seen in Figure 5 where the results of a series of tests under various conditions are plotted. According to this figure, the coal carbon conversion increases as the volumetric concentration of CH₄ in the outlet gases decreases. The CH₄ concentration in the outlet gases can be kept low during the tests by adjusting the air mass flow. Therefore the volumetric concentration of CH₄ can be used as a "real-time," on-line indicator of coal carbon conversion.

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Figure 4: Bottom to Top Forced Airflow Configuration with Flame Holder

Figure 5: Correlation between Coal Carbon Conversion and Average CH₄ Concentration in the Outlet Gases

4.0 FUTURE PLANS

Since > 97 percent coal carbon conversion was achieved in this quarter with a scaled-down version of the combustor, it is planned to first scale the combustor back to residential scale. Initial effort would be directed to obtaining the same high conversions in the residential scale combustor, with methane assist. The combustor will be fitted to allow introduction of secondary air downstream of the flame holder, so as to provide better mixing of partially combusted products with fresh air.

Once high conversions are achieved, the next goal is to reduce the amount of methane assist with the ultimate aim of complete elimination of methane. Finally, the performance combustor will be tested when running without an electric spark. Tests up to three hours duration will be performed.

(In March 1989 all the above goals were achieved.)