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ENGINE TESTS WITH PRODUCER GAS

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ABSTRACT

Bench tests with a four-cylinder stationary engine were made with gasoline and producer gas from charcoal as the fuels. A comparison of their performance revealed that maximum power from producer gas from charcoal is about 55 percent of gasoline power, and that about 11.4 pounds of charcoal is equivalent to 1 gallon of gasoline. When operating an engine on producer gas the spark should be advanced beyond the setting for maximum power with gasoline.

CONTENTS

I. SCOPE AND OBJECTIVE OF INVESTIGATION

The work reported herein is a portion of an extensive investigation [1] [1] of substitute motor fuels, conducted by the National Bureau of Standards for the Foreign Economic Administration. The objective of this phase of the investigation was the evaluation of charcoal as a fuel for automotive purposes and the determination of the performance both of the gas producer and of the engine when operating on producer gas from charcoal.

II. TEST EQUIPMENT

The engine used for this study was a four cylinder International Model U–4 with a displacement of 152.1 cubic inches. It was designed for multifuel uses and was supplied with a combination gas-

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[1] Figures in brackets indicate the literature references at the end of this paper.

gasoline carburetor, a distillate carburetor, a manifold with heat control, and also cylinder head, piston and cylinder sleeve combinations to give compression ratios of 4.75, 5.9, 7.35, and 10.0. The 5.9 compression ratio was used in this work. Ignition was by an impulse-coupled magneto. A spark-advance indicator was added, and the range of adjustment of the ignition timing was increased to 50 degrees. An adjustable carburetor was used so that air-fuel ratios could be changed easily. The temperature of the cooling water was controlled by a regulator, no radiator or fan being used. Gasoline feed to the carburetor was by gravity, and a fuel-measuring device was located in the fuel line. The engine was direct-connected to a Sprague electric dynamometer.

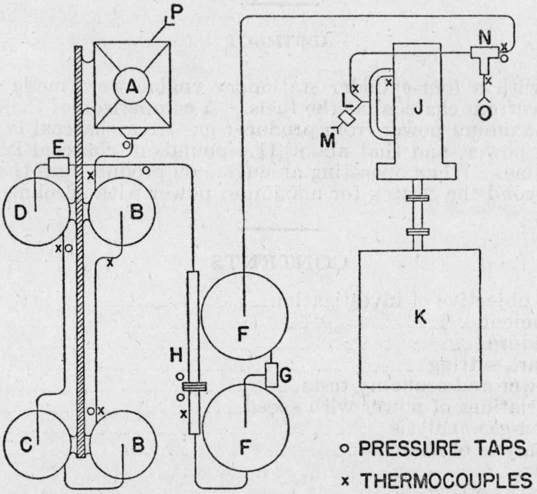

FIGURE 1.—*Schematic layout of test setup.*

A, Gas generator; *B*, cyclone filters; *C*, charcoal filter; *D*, radial-fin filter; *E*, security filter; *F*, buffer drums; *G*, centrifugal blower; *H*, orifice meter; J, engine; K, dynamometer; *L*, change-over valve; *M*, carburetor air intake; N, static mixer; *O*, mixer air intake; *P*, gas-generator air intake.

The gas producer was Gasogene model DR, a model made for export by the M & R Products Co., Inc., Brooklyn, N. Y. Designed for charcoal, it has a cross-draft fire zone, an air-cooled tuyere, and a means for admitting water to the primary air stream (not used in these tests). The gas generator itself is a steel container approximately 6 feet in height, 20 inches wide, and 27 inches deep, with an opening in the top for the admission of fuel, and an ash clean-out door at the bottom. The fire zone is well toward the bottom. The primary air enters from the front (see fig. 1) and passes through the tuyere into the fire zone and across to the take-off point at the back of the generator. From this point the gas passes through a system of filters for cooling and cleaning before entering the engine. The gas first passes through two cyclone filters that remove the entrained heavier fly ash and act as coolers. The gas next passes through a bed of charcoal, where additional filtering takes place as well as the removal of water that may be condensing. The gas is then conducted through a felt cloth filter which removes fine dust that may have passed through the other filters. This is known as the radial-fin filter. It is followed by a security filter, which consists of a wire screen of very fine mesh. The purpose of this filter is to safeguard the engine in case of failure of the other filters. From this point the gas passes through an orifice meter, an electrically driven centrifugal blower, two 35-gallon oil drums (which act as a buffer to eliminate any pulsations that would be transmitted from the engine back to the orifice meter), then through the static mixer to the engine. Butterfly valves are located in the passages for air and for gas. and are interconnected. When the throttle control is operated both valves move together so that the mixture ratio is maintained approximately constant for all throttle settings. Means are provided for changing the air-inlet valve independently of the gas valve so that the air-fuel ratio can be varied. The use of the static mixer constitutes a change from the export design of the gas producer. The export equipment included a carbocharger, which is a centrifugal blower operated by a V-belt from a pulley on the water-pump shaft. This blower mixes the air and producer gas to form a combustible mixture and then forces it into the intake manifold under a slight, positive pressure. For the purposes of this study, it was found that when using a static mixer the gas pressures were easier to control than with the carbocharger. The gas is led from the mixer through a change-over valve to the intake manifold of the engine. One branch of the Y-shaped change-over valve is connected to the static mixer and the other branch to the carburetor. A movable vane at the junction of the two branches opens one passageway or the other to the intake manifold.

The amount of air used by the engine was measured by an air-flow indicator connected to the mixer intake. This air-flow indicator and the orifice meter in the gas line permitted air-fuel ratios to be determined for all operating conditions.

In order to weigh the amount of charcoal consumed during any period of operation, the generator end of the plant was slung between two beam scales. The generator and filters were mounted on a wooden framework so that their relative positions were approximately the same as they are on the truck for which the unit was designed. By weighing the entire generator end of the plant, a close record could be kept of the charcoal consumed.

Temperatures were taken by means of thermocouples located at numerous points around the plant.

It was necessary to know how the resistance to the flow of gas through the plant was changing during operation. By observing manometers connected to pressure taps at a number of points in the gas line, it was possible to tell when the fire bed or a certain filter was clogging sufficiently to require a cleaning. For sampling the producer gas, a take-off cock was located in the line just ahead of the mixer. A Shepherd gas analyzer [10] was used to determine the composition of the gas.

III. TEST PROCEDURE

1. SPARK SETTING

The optimum spark setting for the various engine speeds and load conditions was determined experimentally at speeds of 900, 1,200, 1,500, and 1,800 rpm at full load and at least two part-throttle conditions for both gasoline and producer gas. For both fuels the method was the same—at a given engine speed and throttle setting, and with the air-fuel ratio for maximum power, the spark was advanced a few degrees at a time from an initially retarded position, where the power had fallen off, to an advanced setting, where the power again fell off. Constant engine speed was maintained by varying the electrical load on the dynamometer, and the scale reading at each spark setting was observed. Plotting the horsepower output against spark setting gave a curve for each set of engine conditions. From these curves the optimum spark settings were determined, and a curve was drawn giving the spark setting needed for any condition of load for that particular engine speed.

2. POWER AND ECONOMY TESTS

Tests were made with gasoline and with producer gas at engine speeds of 900 and 1,800 rpm, both at full load and at part-throttle settings giving approximately 75, 50, 25, and 15 percent of the maximum brake power. In the full-load tests, power and fuel-consumption readings were taken at a number of mixture ratios covering the range from lean to rich. As the power was maintained constant in the part-throttle tests, by suitable adjustment of the throttle, readings were taken of intake-manifold depression and fuel consumption at a series of mixture ratios. Power, or intake-manifold depression, and specific fuel consumption were then plotted against measured fuel flow, the latter being an index of mixture ratio.

When the mixture ratio is near that for maximum power, enriching the mixture increases the fuel consumption rapidly without changing the power much, hence it is not possible to determine accurately a "specific fuel consumption at maximum power" because the specific fuel consumption increases rapidly when a mixture near that for maximum power is enriched, although the power changes but little. To obviate these difficulties, it has been customary to use the specific fuel consumption at a lean-mixture ratio giving 99 percent of maximum power, which is in the range of service usage and is capable of rather precise determination. This has been done in the present work.

In the full-load runs, the observed indicated horsepower (sum of brake and friction horsepower) and the fuel consumption were corrected to standard conditions by the formula [2, 3]

$$P_c = P_o \frac{29.53}{B-h}\sqrt{\frac{T}{486.4}},$$

in which

P_o=observed power or fuel consumption
P_c=corrected power or fuel consumption
B=barometric pressure, inches of mercury
h=pressure of water vapor, inches of mercury
T=absolute temperature of air, degrees Fahrenheit.

3. VARIATIONS OF POWER WITH SPEED

The relationship of power to speed was derived from the mixture-ratio runs at constant speeds by plotting the power at optimum spark advance and best mixture ratio against speed.

4. FUEL-GAS ANALYSIS

Samples for analysis were collected in a gas-sampling pipette by mercury displacement. The system was flushed twice, the third filling being retained for analysis. Samples were taken only after the gas generator had been in operation for several hours.

5. ANALYSIS OF CHARCOAL

Samples were collected from a number of bags of each grade of charcoal, and were pulverized and thoroughly mixed. Ash determinations were made on each sample. The heat of combustion of a composite sample was determined in the bomb calorimeter.

IV. TEST RESULTS

1. SPARK SETTING

Upon an inspection of the spark-advance curves, figure 2, two features are at once apparent. The curves for the producer gas indicate the optimum spark advance to be considerably greater than for gasoline. These curves also lack the consistency of the curves for gasoline. The former observation is in general agreement with other studies [4, 5] and is probably due to the slow-burning characteristics of the fuel. The irregularity and lack of consistency in the curves for producer gas is undoubtedly due to the difficulty experienced in maintaining the best mixture ratio during these runs. The significant fact is that an engine operating on producer gas requires a spark advance greater than that for gasoline.

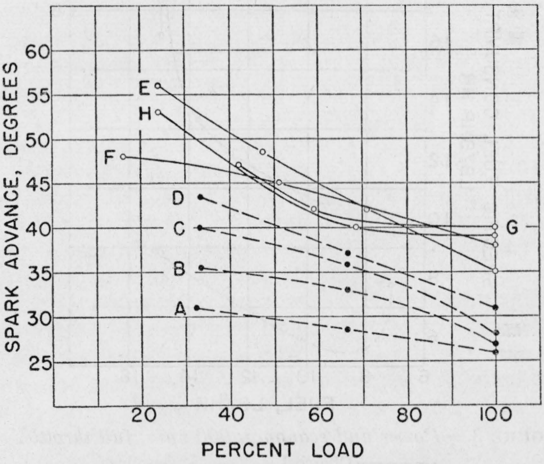

FIGURE 2.—*Spark setting versus load.*

900 rpm, curves A and E; 1,200 rpm, B and F; 1,500 rpm, C and G; 1,800 rpm, D and H; ———— Charcoal. ------------ Gasoline.

2. POWER AND ECONOMY TESTS

The maximum power developed with charcoal as the fuel compared to that with gasoline varies from 59 percent at 900 rpm to 55 percent at 1,800 rpm. This percentage agrees generally with studies made elsewhere [4, 6]. Figures 3 and 4 show power and economy curves for full-throttle conditions at the engine speeds of 900 rpm and 1,800 rpm, respectively, with both fuels. Differences in the peaks of the power curves illustrate the loss of power when operating on charcoal. Figure 5 shows the differences in manifold depressions between the two fuels when the engine is operating at part throttle and constant power output. The peaks of these curves represent a condition of minimum throttle opening or the most powerful mixture of air and fuel. From this type of graph the specific fuel consumption was derived for all the part-throttle conditions.

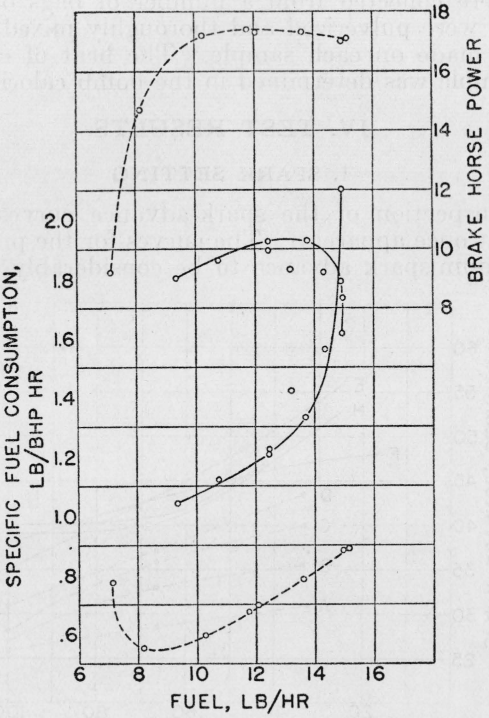

FIGURE 3.—*Power and economy, 900 rpm, full throttle.*

——— Charcoal. - - - - - Gasoline.

The data obtained in tests at engine speeds of 900 rpm and 1,800 rpm are shown in figures 6 and 7, in which specific fuel consumption is plotted against percentage of maximum load. To illustrate the relative performance of gasoline and charcoal more graphically, these data were used to calculate the road performance of a light truck, which might logically be powered by the International U–4 engine used in the tests. The following pertinent truck specifications were assumed: Projected frontal area, 25 ft^2; weight (empty) 3,000 lb, (loaded) 6,000 lb; tires, 6.00×16; rear-axle ratio, 4.16:1. Converting the two engine speeds to road speeds, 1,800 rpm equal 36 mph and 900 rpm equal 18 mph. To compute the horsepower required to propel this truck under the selected conditions of weight and speed, it was reasoned that the load imposed on an automotive engine when propelling a vehicle on a level road at constant speed is composed of frictional resistance in the power-transmission system, including the tires, and of air resistance to the motion of the vehicle and the rotation of its wheels. An unpublished study of car-resistance measurements made here and elsewhere by Donald B. Brooks, of this Bureau shows that the total resistance can be approximated closely by the formula

$$P=0.00000427As^3+0.000000333Ws^2+0.0000333Ws,$$

in which

P=horsepower required to propel vehicle
A=projected frontal area of vehicle, ft^2
W=weight of vehicle, lb
s=vehicle speed, mph.

Although no formula can represent all vehicles accurately, because of the differences in the coefficients of air and frictional resistance this formula is a sufficiently good approximation to forecast maximum road speeds within 2 mph in the majority of cases, when used in conjunction with the engine-power curve. Knowing the power available for these engines speeds, figure 8, the percentages of load were determined. Table 1 is a compilation of this calculated road performance.

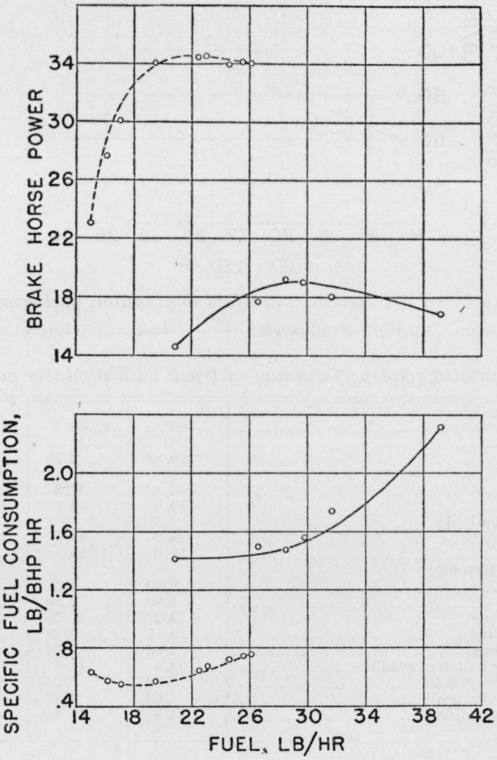

FIGURE 4.—*Power and economy, 1,800 rpm, full throttle.*

——— Charcoal. ---------- Gasoline.

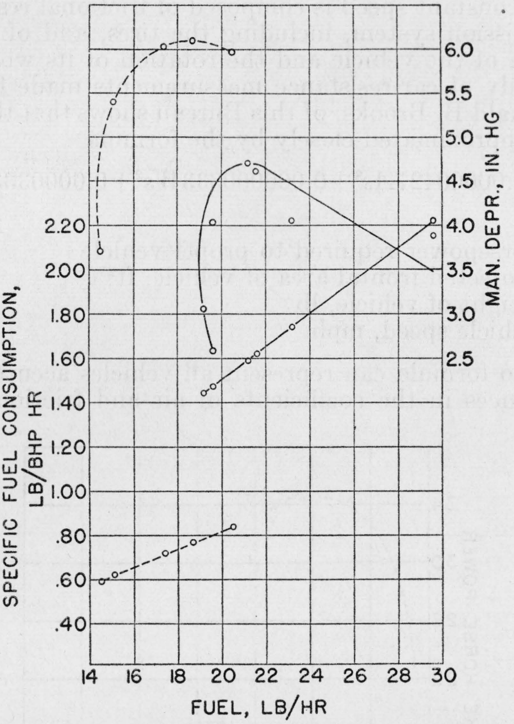

FIGURE 5.—*Part throttle, manifold depression, and economy.*

----------Gasoline, 71 percent of full power; ————charcoal, 70 percent of full power.

TABLE 1.—*Calculated road performance of truck with producer gas and gasoline*

Weight of truck, lb	3,000	3,000	6,000	6,000
Miles per hour	36	18	36	18
Horsepower required	9.88	2.75	14.76	4.87
Horsepower available:				
Gasoline	34.4	17.3	34.4	17.3
Charcoal	19.0	10.2	19.0	10.2
Percentage of power available:				
Gasoline	28.7	15.8	43.0	28.2
Charcoal	52.0	26.9	77.8	47.8
Fuel consumption (lb/bhp hr):				
Gasoline	0.99	1.31	0.80	0.96
Charcoal	1.80	2.36	1.51	1.73
Miles per gallon, gasoline	23.2	31.7	19.3	24.2
Miles per pound, gasoline	3.87	5.28	3.22	4.03
Miles per pound, charcoal	2.03	2.78	1.63	2.13
Pounds of charcoal per gallon of gasoline	11.4	11.4	11.8	11.4
Pounds of charcoal per ton mile	0.330	0.240	0.203	0.156
Ton miles per pound, charcoal	3.03	4.17	4.93	6.41
Ton miles per gallon, gasoline	34.8	45.6	57.9	72.6

Considering the truck performance at 36 mph when loaded to a gross weight of 6,000 lb, it can be seen that 14.76 horsepower is required. This is 43.0 percent of the gasoline power available, but 77.8 percent of the charcoal or producer-gas power available. The respective fuel consumptions are 0.80 lb/bhp hr and 1.51 lb/bhp hr, which is about the best figure for charcoal but considerably poorer than the best for gasoline. The reserve power, needed for acceleration and hill climbing, would be 19.64 hp for gasoline and 4.24 hp for charcoal, which indicates that when operating on charcoal the truck would have very poor performance. This illustrates one of the serious drawbacks to charcoal as a substitute fuel, the loss of about 45 percent of gasoline power, and at the same time suggests a remedy, the use of a larger or supercharged engine. However, where the engine is capable of developing more power with gasoline than is ever likely to be needed, as with most passenger-car engines, the loss of power when operating on charcoal is not as serious. Commerical vehicles, whose power plants are frequently required to perform at or near their rated capacity, would find a proportionate loss of power a serious handicap.

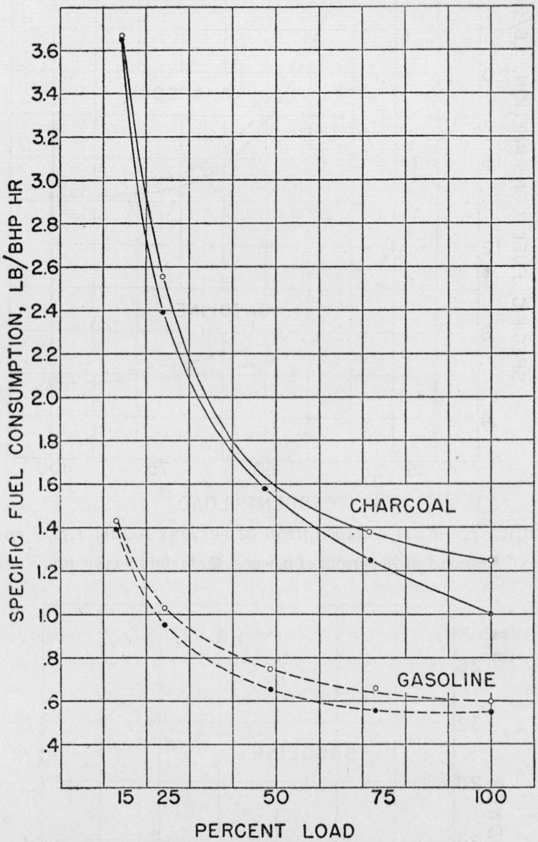

FIGURE 6.—*Fuel consumption at various loads, 900 rpm.*

○Economy at 99 percent of power. ●Maximum economy.

3. VARIATIONS OF POWER WITH SPEED

The curves shown in figure 8 illustrate the differences in the power available with gasoline and with charcoal. The power with charcoal varies from 59 percent of that with gasoline at 900 rpm to 55 percent at 1,800 rpm.

4. FUEL-GAS ANALYSIS

Gas samples were collected under a variety of conditions of engine speed and load. The following shows the principal constituents

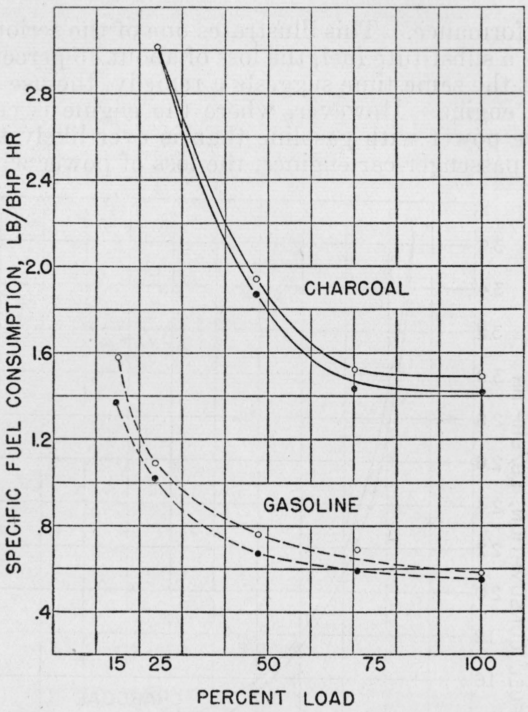

FIGURE 7.—*Fuel consumption at various loads, 1,800 rpm.*

○Economy at 99 percent of power. ●Maximum economy.

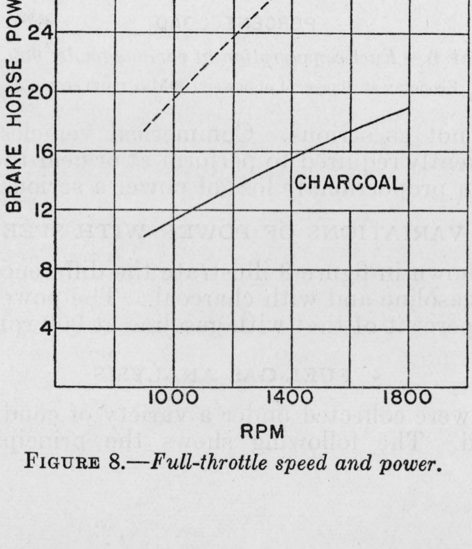

FIGURE 8.—*Full-throttle speed and power.*

found in the producer gas, their average percentage by volume, and the spread, as determined from 12 analyses:

Gas	Average	Spread
CO_2	1.8	0.8 to 4.1
O_2	1.4	.1 to 2.3
H_2	5.2	.3 to 13.0
CH_4	1.8	.0 to 7.0
CO	28.2	21.3 to 30.4
N_2	62.0	52.7 to 67.9

Figures 9 and 10 show the efficiency of the gas generator plotted against pounds of fuel per hour, the efficiency being the ratio of the heating value of the gas divided by the heating value of the charcoal consumed to produce the gas. Examination of these curves indicates that in most cases the efficiency improves as the mixture ratio is made leaner. The reversal of the positions of the part-throttle curves with respect to the full-throttle curves for the two engine speeds may result from the fact that at 1,800 rpm, full throttle, the fire bed was quite extensive with a resulting decrease in the beneficial insulating effects of the surrounding charcoal.

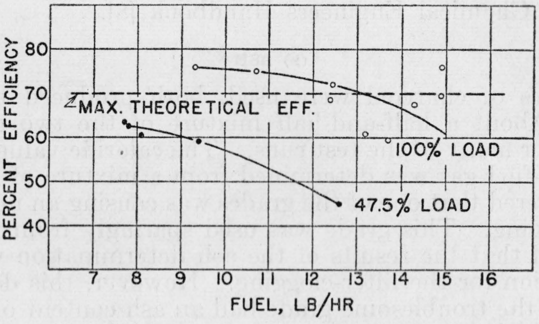

FIGURE 9.—*Gas-generator efficiency, 900 rpm.*

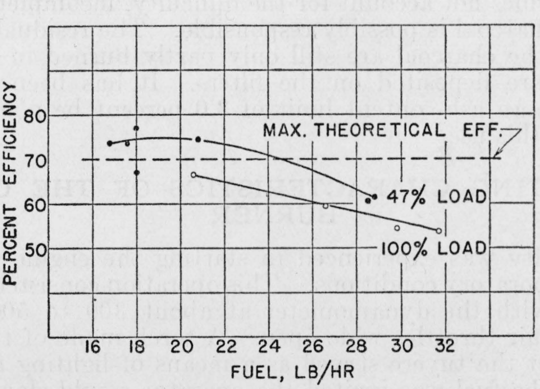

FIGURE 10.—*Gas-generator efficiency, 1,800 rpm.*

In computing the theoretical efficiencies shown in the above figures it was assumed that the carbon burns entirely to carbon monoxide [7]. A ratio between the heats of combustion of CO and C will give this theoretical maximum efficiency value of 70 percent. Efficiencies in excess of this figure may be explained by the presence of other combustibles in the gas, such as H_2 and CH_4.

5. ANALYSIS OF CHARCOAL

(a) CALORIFIC VALUE

From the composite sample the calorific value of the charcoal was established at 13,880 Btu/pound. This value is believed to be correct within 0.5 percent. It is higher than the values 13,325 to 13,487 Btu/pound reported by the National Research Council of Canada. It is also high compared to the values 12,000 to 13,000 Btu/pound given in the Chemical Engineers Handbook [8].

(b) ASH

Two grades of charcoal were used, both produced by the same company. About a half-and-half mixture of the two grades made up the fuel for many of the test runs. The calorific value of the charcoal and the fuel gas was determined from a mixture of the two, but it was discovered that one of the grades was causing an undue amount of filter clogging. This grade was used sparingly from then on. It was expected that the results of the ash determination would reveal the explanation for the filter-clogging. However, this determination showed that the troublesome grade had an ash content of 1.7 percent and that the other grade had an ash content of 7.0 percent. As the ash content does not account for the difficulty, incomplete carbonization of the charcoal is possibly responsible. The residual tarry products left in the charcoal are still only partly burned in the gas producer, and are deposited on the filters. It has been proposed in Canada that an ash-content limit of 3.0 percent be placed on wood charcoal for this use.

V. OPERATING CHARACTERISTICS OF THE CHARCOAL BURNER

No difficulty was experienced in starting the engine on producer gas under laboratory conditions. This operation consisted of cranking the engine with the dynamometer at about 300 to 500 rpm, with the gas and air throttles wide open. A torch made of twisted newspaper held at the tuyere served as a means of lighting the charcoal. As soon as the fuel was ignited the operator would slowly open and close the air butterfly. In less than 2 minutes enough gas was generated and delivered to the engine to make it possible to set the air throttle to give a combustible mixture. From then on a common throttle linkage was used to control the engine, with only slight adjustments of the air valve to maintain a good mixture.

It was found after several experiences that when the radial-fin filter cloth was new or well cleaned its ability to function as a filter was poor, in which case the following security filter would always clog and throttle the engine. After some dirt had collected on the cloth its filtering action would return to normal, and then the security would require very little service.

The nature of the charcoal appeared to be the controlling factor in the clogging of the filters. On one occasion the cyclone filters were operated for more than 50 hours before being cleaned, yet at another time, with a different grade of charcoal, the same filters were completely clogged after only 3 hours and 20 minutes. A different grade of charcoal was used in these two instances. No serious effort was ever made to investigate the causes of this behavior. Apparently the makeup of the charcoal has a great deal to do with the satisfactory operation of the plant. Regardless of the nature of the fuel, however, the filters will become dirty in time and impede the flow of gas sufficiently to cause a serious loss of power. Water manometers across the filters made an excellent means of showing the state of the filters. When the radial-fin filter was not performing as it should and the dirt was being passed on to the security filter, it was impossible to observe the manometer steadily creeping up as the security filter became more and more clogged. At such times another clean security filter was kept nearby and was quickly inserted in the place of the dirty one without stopping the engine. Usually this would not be repeated more than three or four times, by which time the radial fin would be acting satisfactorily. Cleaning the filters is very dirty work but cannot be avoided.

One difficulty that was entirely unforeseen, and which could never be overlooked, was that the metal tuyeres would melt away at their tips when left in the fire overnight. A very simple solution was at once adopted—the tuyere was removed from the generator at the end of the day's run. Most of the trouble was with the 1-inch metal tuyeres; the ¾-inch metal and the silicon carbide tuyeres did not melt so extensively.

VI. CONCLUSIONS

Charcoal may be used as a successfully automotive fuel if its limitations and weaknesses are understood.

A 45-percent loss of power can be expected on an unmodified gasoline engine. This may or may not prove permissible, depending on the amount of excess power available over actual needs.

Spark timing must be advanced beyond the setting for gasoline.

Servicing requirements would make the use of gas producers impractical for the average automobile owner in this country, but for commercial uses where a fleet of vehicles was being operated, trained servicemen could handle this problem satisfactorily.

In general, the gas-generating plant performed satisfactorily. The difficulty experienced with the tuyeres melting at their tips is a subject that should be investigated.

This work shows that although different lots of charcoal vary in their suitability as producer fuel, the ash content is not a satisfactory criterion of performance.

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