Emissions and Fuel Economy Testing of a Naval Academy Heat Balanced Engine (NAHBE)

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Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Environmental Protection Agency

Background

For several years personnel at the Naval Academy have been involved in research efforts directed toward improving the combustion cycle of spark ignition engines. They have developed a technique which is stated to be based on pressure exchange between two zones in the combustion chamber thereby achieving a heat balanced cycle (NAHBE) which combines the best characteristics of the Diesel and Otto cycles. The developers claim that their technique: increases engine efficiency; provides more complete fuel oxidation and therefore lowers HC and CO emissions; reduces peak cylinder pressures; reduces engine temperature; and reduces engine knock tendencies. The hardware utilized by the Naval Academy personnel in implementing this concept consists of a standard Otto cycle engine in which the head of the piston has been modified to establish two distinct combustion volumes and the intake system has been modified through enleanment of the carburetor and the addition of an air bleed with claimed stratification of the intake charge.

In 1977 EPA was requested to test an engine modified to the NAHBE configuration. EPA was furnished two new, military, motor/generator sets (one NAHBE and one stock) for evaluation of the NAHBE concept. The required break-in of the new engines delayed the completion of testing until early 1978.

The primary responsibility of the EPA Motor Vehicle Emission Lab is to test and evaluate vehicles. Therefore, there are only limited facilities and resources available to test a motor-generator set. A comprehensive evaluation of the NAHBE concept was, therefore, neither planned nor conducted. The testing conducted was, however, complete enough to characterize the fuel economy and emissions of the test engines under the operating conditions permitted by the motor-generator configuration.

The conclusions drawn from this EPA evaluation test can be considered to be qualitatively and quantitatively valid only for the specific motor-generator set used; however it is reasonable to extrapolate the results from the EPA test to other types of engine applications in a qualitative manner, i.e., to suggest that similar results are likely to be achieved on other types of engines using similar emission control technology for similar applications.

Summary of Findings*

1. As delivered and operating on gasoline under steady state conditions, the NAHBE engine HC and CO emissions were substantially lower than the stock engine; NOx emissions were substantially higher than the stock engine and the thermal efficiency was significantly higher than the stock engine.

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*All HC, CO, and NOx comparisons are based on grams per kW hr. All thermal efficiency comparisons are based on kW hr per BTU of fuel.

2. Operation of the stock engine with the induction system and carburetor from the NAHBE engine resulted in changes in emissions and thermal efficiency which, within the constraints of experimental error, were identical to those observed with the NAHBE engine.

3. Operation of the NAHBE engine on alcohol caused an incease in HC emissions and a substantial reduction in NOx emissions relative to operation on gasoline. CO emissions and thermal efficiency were unchanged.

4. When operated on gasoline, the NAHBE engine, the stock engine, and the stock engine with the NAHBE induction system and carburetor performed satisfactorily with changes in load and under steady load conditions. Operation of the NAHBE engine on alcohol resulted in unsastifactory operation both under steady state and changing load conditions. When operated on alcohol, carburetor adjustments were required at each load change.

5. Exhaust gas temperatures of the NAHBE engine were, in general, significantly higher than those of the stock engine.

6. Test results from this program were compared to data from an EPA contractor test program on several commercial engines of similar size and type. This comparison showed that:

   a) HC emissions from the stock engine were, on average, higher than those from gasoline fueled commercial engines and much higher than those from diesel engines.

   b) HC emissions from the NAHBE engine were lower than those from gasoline fueled commercial gasoline engines and up to 200 times higher than those from the diesel engines.

   c) CO emissions from the stock engine were on average, twice as high as those from commercial gasoline engines and up to 200 times higher than those from diesel engines.

   d) CO emissions from the NAHBE engine were significantly lower than from the commercial gasoline engines while being up to five to ten times higher than those from diesel engines.

   e) NOx emissions from the stock engine were lower than those from the commercial gasoline engines and substantially lower than those from the diesel engines.

   f) NOx emissions from the NAHBE engine were higher than those from the diesel engines and significantly higher than those from the commercial gasoline engines.

g) The thermal efficiency of the stock engine was between 3% and 39% lower than the worst commercial gasoline engine, between 32% and 57% lower than the best commercial gasoline engine used in the comparison and between 46% and 71% lower than the diesel engines used in the comparison.

h) The thermal efficiency of the NAHBE engine was between 14% higher and 16% lower than the worst commercial gasoline engine used in the comparison, between 20% and 41% lower than the best commercial gasoline engine and between 37% and 60% lower than the diesel engines used in the comparison.

Conclusions*

The stock engine used in the NAHBE engine project is not representative of similar commercial engines and is therefore not a good engine for comparative purposes because it provides misleadingly large improvements for the NAHBE concept. When compared to representative commercial engines, the NAHBE engine is at a significant disadvantage both with respect to thermal efficiency and NOx emissions, while appearing to offer some benefits in HC and CO emissions relative to gasoline engines through enleanment of the air/fuel mixture. The ability to sustain this apparent HC and CO benefit is questionable, however, because many engines of this type depend on charge cooling (operating fuel rich) as a method for attaining acceptable engine life.

All of the emission and fuel consumption characteristics of the NAHBE engine can be reproduced on the stock engine through the substitution of the NAHBE induction system (modified intake manifold and a modified carburetor with a modified metering rod) for the stock components. It appears, therefore, that the modified piston which is used in the NAHBE concept and which is claimed to be its major feature, did not contribute significantly to the observed changes in performance of the test engine.

Performance of the NAHBE engines on alcohol, as built, was unsatisfactory. It is not clear whether this poor performance is inherent with the NAHBE concept or whether it is the result of inadequate development of the test engine.

The results of this test and evaluation project indicate that the NAHBE concept did not offer any benefits in either emissions or fuel economy when compared to similar gasoline and diesel engines.

Test Engine Description

The engines delivered for testing were 10 hp military motor generator sets designed to produce 5 kW of continuous power. The generator is

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*All HC, CO, and NOx comparisons are based on grams per kW hr. All thermal efficiency comparisons are based on kW hr per BTU of fuel.

directly attached to the engine crankshaft and operates at engine rpm. The units are self contained and designed to be operated at all ambient temperatures. They are skid mounted in a tubular frame. The engines and generators are manufactured to military specifications by several manufacturers. Therefore, although the two engines tested were manufactured by Wisconsin and Hercules, they are identical in all respects and have complete parts interchangeability. A complete description of the motor-generator sets is given in Appendix A at the end of this report.

The conversion of a stock engine to NAHBE configuration principally consists of changes to the piston (see Figures 1 & 2) and the fuel/air induction system by using modified metering rods and by introducing small air bleeds (see Figure 3). The piston is modified by the addition of a cap which separates the combustion chamber into two zones (a primary combustion zone and a balancing combustion zone). According to the developers, this design, coupled with the air bleed, stratifies the combustion fuel-air mixture by introducing additional air through the auxilary air inlet at the start of the intake stroke. During compression the leaner mixture is forced into the balancing chamber. This balancing chamber mixture is compressed during ignition and subsequently flows out to the main chamber during the later stages of combustion. The combustion process is thereby prolonged and allowed to achieve a greater degree of completion than the stock engine.

However, the calibrated orifices of the auxilary air bleeds are very small (about 1/8" diameter) and therefore appear to introduce little air when compared to the one inch manifold tube. This air is introduced before the intake valve, thus there is no special means for assuring that this air enters the balancing chamber undiluted as claimed.

The NAHBE is designed for multi-fuel capability. Because the BTU content per unit volume is higher for gasoline than for alcohol, operation of the NAHBE engine with gasoline requires lower volumetric fuel flow than with alcohol. The devolopers furnished metering rods designed to accomplish this. The developers indicated that the stock metering rod was to be used with gasoline and that the modified metering rod was to be used with alcohol. Additional enleanment is also provided on the NAHBE by the carburetor to intake manifold air bleed.

The fuel system components were not modified for sustained operation on alcohol. To prevent deterioration of fuel system components the engine must be switched over to gasoline prior to shutting down.

Test Procedures

Testing procedures for the engines in this project were adapted from the procedures used in the testing of heavy-duty engines by EPA for emissions certification and in the development of engine performance maps by engine manufacturers. Testing was performed at the governed (rated) speed of the engines and represents, therefore, modes 8 through 12 of the heavy-duty diesel procedure. These modes are 100, 75, 50, 25 and 0 percent of rated load at rated (governed) speed.

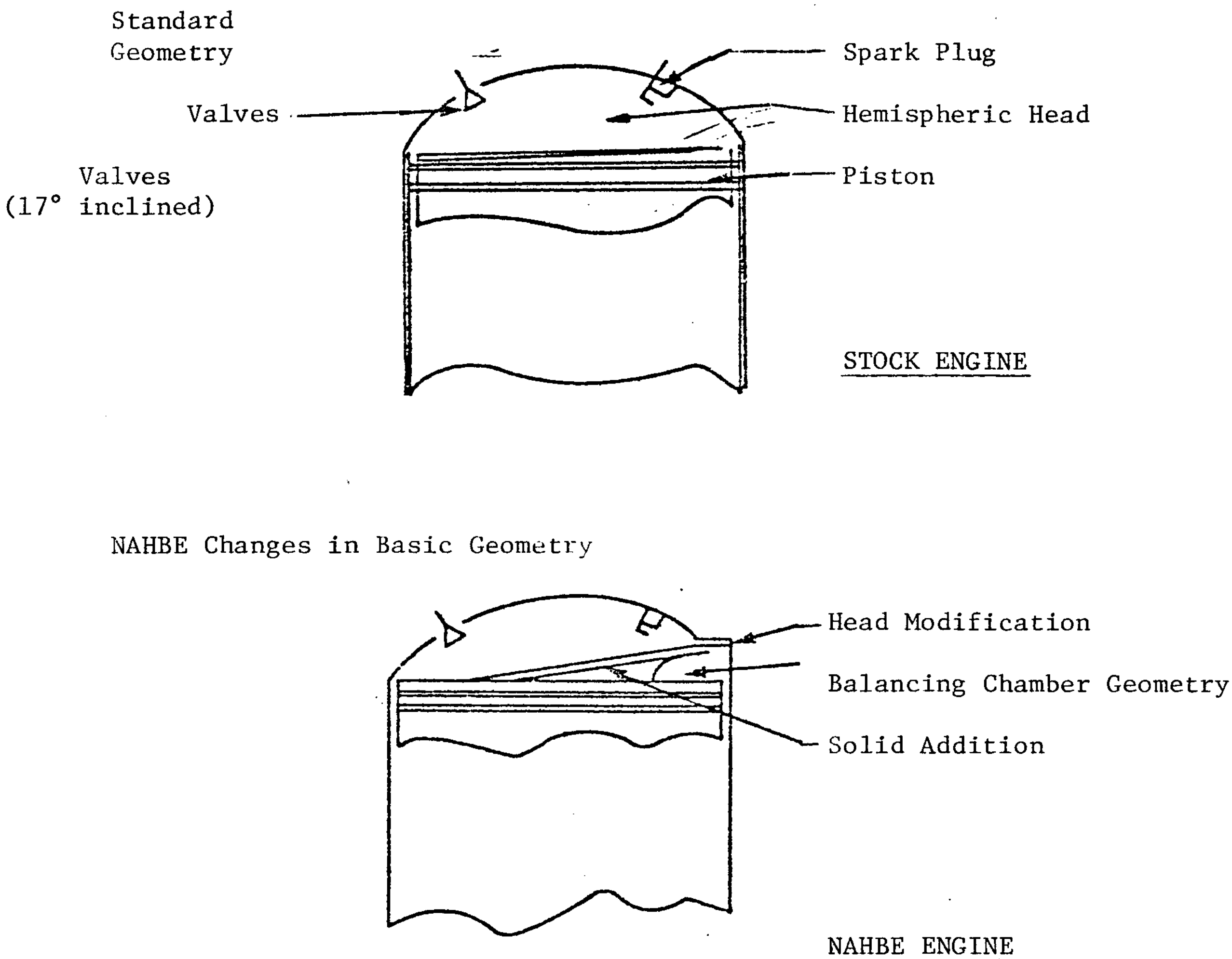

Figure 1 - NAHBE Changes in Basic Combustion Chamber Geometry

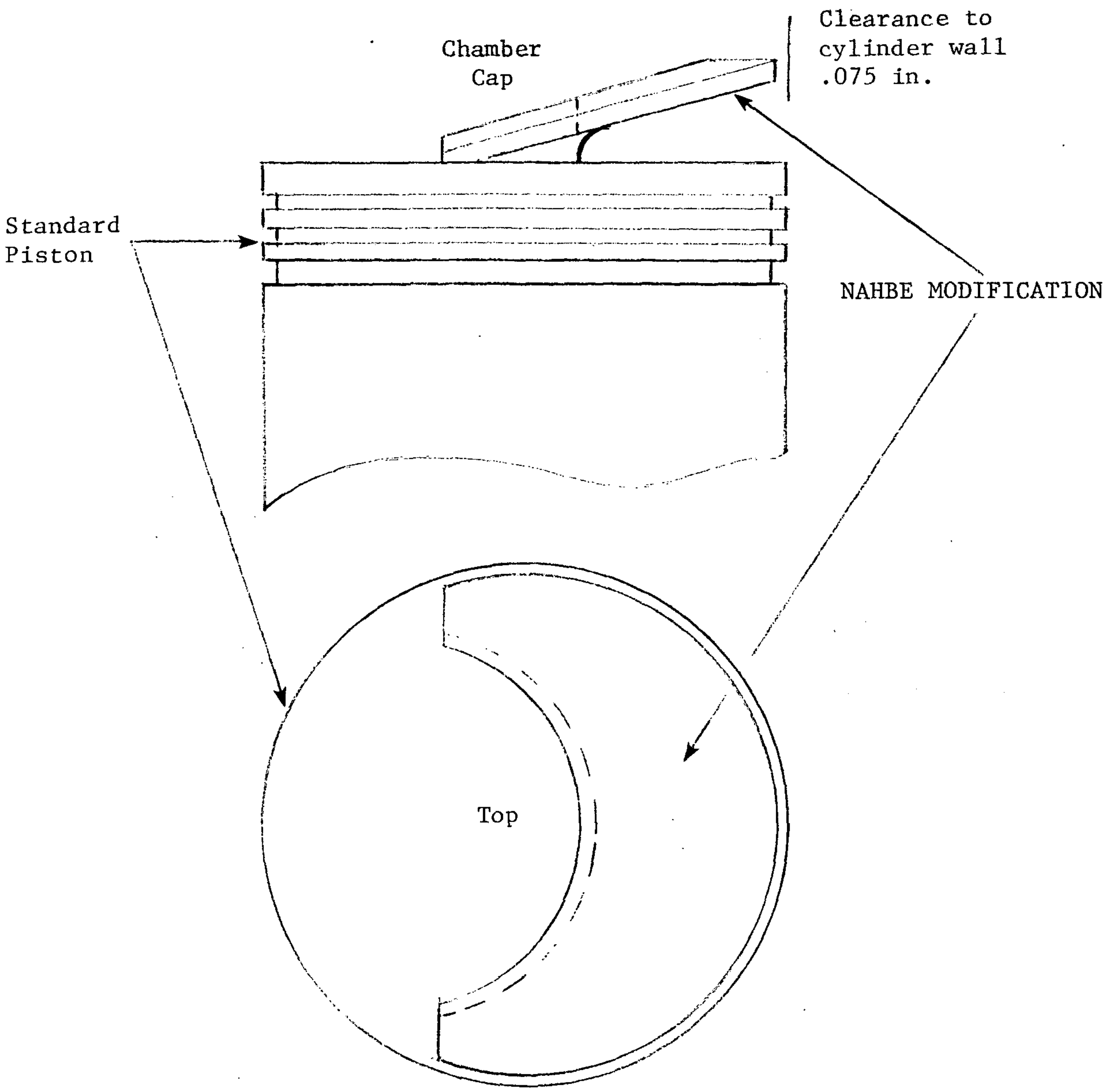

Figure 2
Schematic of NAHBE Piston Modification

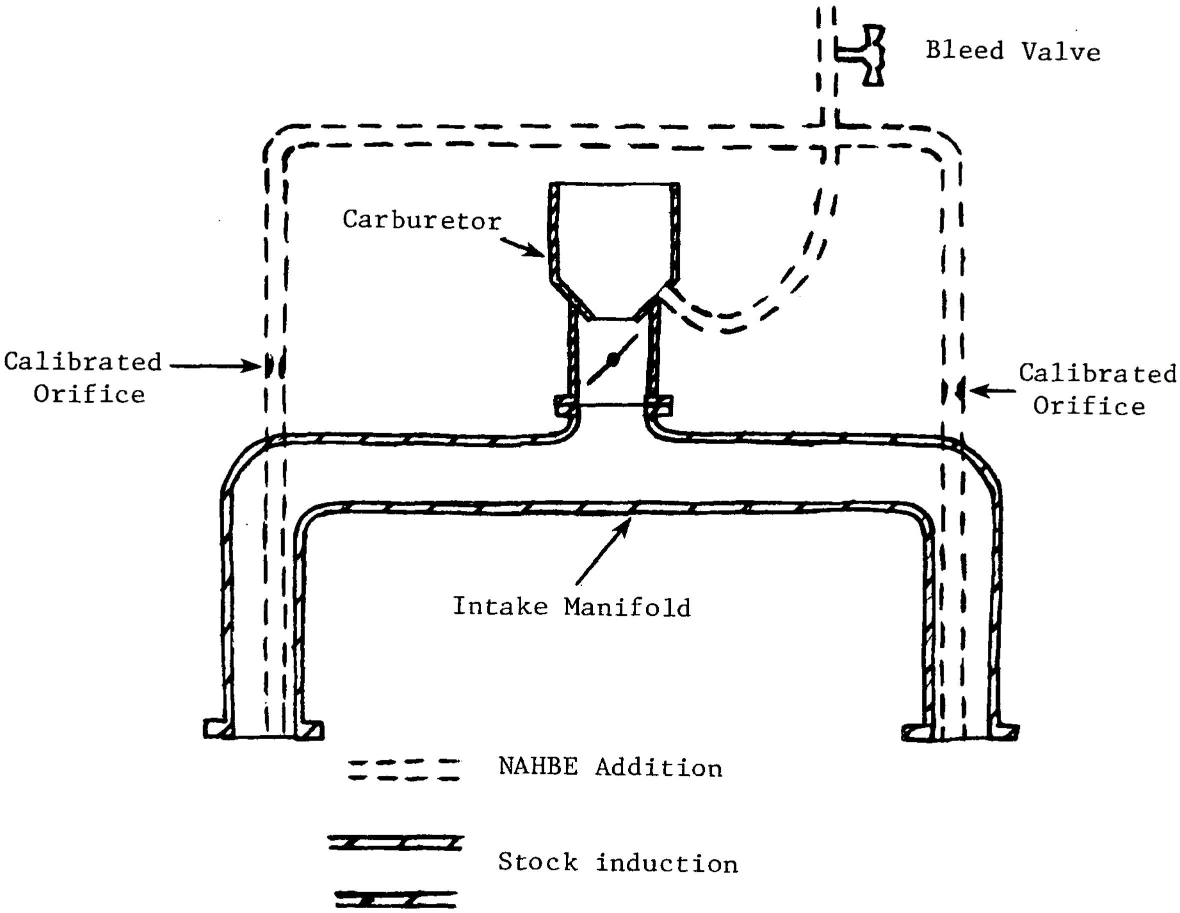

Figure 3 - Fuel Air Induction System

speed of the engines and represents, therefore, modes 8 through 12 of the heavy-duty diesel procedure. These modes are 100, 75, 50, 25 and 0 percent of rated load at rated (governed) speed.

Gaseous exhaust emission tests were run using the analytical equipment and sampling system specified in the 1977 Federal Test Procedure ('77 FTP) described in part 40 of the Combined Federal Register of July 1, 1976 for light-duty vehicles. All tests were steady state and followed the heavy-duty diesel test schedule. A thermocouple was installed in the muffler outlet to monitor exhaust gas temperature (EGT) as an aid in evaluating test results.

The engines/generators were loaded by using a resistive load bank to dissipate the engine/alternator power. Alternator voltage, current, and frequency were controlled and monitored for all testing. The voltage was held at 110V and the frequency at 60 cycles during engine break-in and during all testing. The engine exhaust was collected by the constant volume sampling (CVS) procedure which gives exhaust emissions of HC, CO, CO_2 and NOx in grams per kW hr. Fuel economy was calculated by the carbon balance method. The fuels used were Indolene 30, a leaded 100 RON gasoline, and denatured ethyl alcohol (190 proof, 95% ethyl alcohol). All fuel consumption results for tests using alcohol are given as gallons of denatured alcohol. All tests were conducted at 3600 rpm (governed speed).

Testing

When delivered the engines were "green". The stock engine/alternator had 3.2 total hours and the NAHBE had 6.1 total hours. Apparently both had only been operated during manufacturing inspection check out and following modification to the NAHBE concept. Therefore, before testing, the engines were broken in by operating them to 50 hours total operating time. Break-in consisted of a repetitive cycle of running the engines for two hours at each load (50, 75, and 100 percent of full load). All break-in was done with Indolene 30 fuel.

Exhaust emissions were periodically measured throughout the break-in to establish whether or not emission levels had stabilized prior to official testing. Also during break-in a few tests were performed to determine the potential effects of fuel/air mixture changes on the two engines. These break-in results are tabulated in Tables C-1 and C-2 at the end of this report.

After the engines had accumulated approximately 50 total hours the engines were tested for emissions and fuel consumption. Both engines were extensively baseline tested with their respective standard induction system. The baseline configuration for the NAHBE used the NAHBE induction system consisting of the modified intake manifold and a modified carburetor with a modified metering rod. The baseline configuration of the stock engine used the stock induction system consisting of a stock intake manifold and a stock carburetor with a stock metering rod.

The induction systems of both engines were changed from their baseline configuration to investigate the effects of changes in fuel/air ratio on the engines emissions and fuel consumption performance. The NAHBE was tested with the modified intake manifold, modified carburetor and the stock metering rod. The stock engine was tested with modified intake manifold, modified carburetor, and both the stock and modified metering rods.

According to the engine developers, the NAHBE induction system, as delivered, had a modified fuel metering rod installed which was calibrated for the larger fuel flow required for alcohol. When tested with alcohol, the NAHBE surged badly apparently because of too lean a mixture. The engine developer who was witnessing the tests raised the float level and readjusted the idle mixture to stop the heavy surge. However, after running a few minutes, the engine again surged slightly. Also the engine required additional manual adjustment whenever the load was changed. Therefore, with the necessary warmup, stabilization, the high fuel consumption and the restart, only a few tests were possible with alcohol before the limited supply was used up.

These engine test configurations are summarized below:

Engine	Intake Manifold	Carburetor	Metering Rod
NAHBE (Baseline configuration)	Modified	Modified	Modified (both gasoline and alcohol)
NAHBE (Configuration A)	Modified	Modified	Stock
Stock (baseline configuration)	Stock	Stock	Stock
Stock (Configuration A)	Modified	Modified	Stock
Stock (Configuration B)	Modified	Modified	Modified

The results of the above tests are tabulated in Tables C-1 and C-2 and are summarized in Tables B-1 through B-5 as NAHBE and stock engines.

Discussion of Results

Included in Tables B-1 through B-5 are the results of similar tests on other small utility and small heavy-duty engines. A description of these engines is included in Appendix A. These tests were conducted by Southwest Research Institute under an EPA contract[(1)] and are included here to establish a basis for comparison of the relative merits of the NAHBE concept and the stock engine used as a baseline in this project.

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(1) Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Part 4, Small air cooled spark ignition utility engines, and Part 5, Heavy-Duty Farm, Construction and Industrial Engines. APTD report numbers 1494 and 1495.

Also included in Tables B1 through B5 are the results for the NAHBE and stock engines restated to account for the generator losses. Based on discussions with the army engineering contracts office responsible for the procurement and production testing of these untis, a generator efficiency of 90% was selected as being most representative of the efficiency encountered during EPA testing.

A comparison of the test results (using gasoline) shows little difference in thermal efficiency or HC, CO, or NOx emissions between the NAHBE with the stock metering rod (NAHBE configuration A) and the baseline stock engine. However, a comparison of the tests of the NAHBE with the stock metering rod and the modified metering rod (NAHBE baseline) show a marked difference. With the modified metering rod installed, the NAHBE's HC emissions were reduced by factors of 3 to 15; CO emissions were reduced by factors of 20 to 50; NOx emissions increased by factors of 1 to 5; and thermal efficiency increased by 10 to 20 percent. These results show that the modified metering rod reduces the quantity of fuel supplied to the engine rather than increasing it as planned by the designers. A review of the thermal efficiency and the HC, CO, and NOx emissions of the stock engine shows that it was designed to operate very fuel rich. The HC and CO emissions are the highest of the group of engines listed and, conversely, the thermal efficiency and NOx emissions are the lowest. Therefore, by enleanment alone, the stock engine should show improvements in HC, CO, and efficiency with a possible increase in NOx emissions. These improvements were observed in the test data.

Since the preceding results indicated that a large part of any benefits of the NAHBE concept were due to enleanment, a series of tests was run on the stock engine using the NAHBE induction system (modified carburetor and modified intake tubes) and the two metering rods. When the stock engine (with the NAHBE induction system) was tested with the stock metering rod installed (stock configuration A), the HC, CO, NOx emissions and thermal efficiency were very similar to the baseline tests of the stock engine and the tests of the NAHBE with the stock metering rod (NAHBE configuration A). The only major change was at 100% load where the CO emissions were halved and the NOx emissions doubled. Also, when the stock engine with the NAHBE induction system was tested with the modified metering rod (stock configuration B) the results were very similar to the NAHBE under the same conditions. Therefore from the viewpoint of emissions or thermal efficiency: 1) the benefits of the NAHBE concept, as tested, can be ascribed to fuel enleanment alone, 2) this enleanment can be readily accomplished by modifying the induction system on the stock engine through the use of a leaner metering rod and 3) the NAHBE pressure balance concept requiring piston modification showed no benefit in this series of tests.

Due to the previously reported limited volume of alcohol, only a few tests of the NAHBE were run on alcohol. Compared to the NAHBE with the modified metering rod and running on gasoline, HC emissions were up by a factor of 2 to 4, CO emissions were unchanged, NOx emissions were reduced by a factor of 7 to 10, and thermal efficiency ranged from unchanged to 10% worse.

A comparison of the NAHBE (baseline configuration, using gasoline) test results with those of the other engines in Tables B-1 through B-5 shows few if any benefits. In thermal efficiency the NAHBE at best only equals the poorest of the group. The developers hoped for efficiency of the heat balanced cycle is not evident. Its thermal efficiency is only half that of the diesel under all conditions and several of the gasoline engines better it by more than 30 percent most of the time. The diesels are consistently better than the NAHBE in HC and CO emissions. Although the NAHBE HC and CO emissions are better than some of the gasoline engines, these gasoline engine emisssions could also be reduced by enleanment. In NOx emissions the NAHBE is similar to a few and greater than many by a factor of two. Thus if the other gasoline engine HC and CO emissions were reduced by enleanment, many have a considerable NOx cushion before their NOx emissions would exceed the NAHBE emission levels.

One question left unanswered by the test program is the potential effects on engine durability due to the reduction in charge cooling and increase in exhaust gas temperature (EGT) resulting from the NAHBE conversion. The stock engine was designed for use in a military motor/generator set. The induction system was designed specifically for this military application and was designed to run fuel rich. As shown by the test data in Tables C-1 and C-2, enleanment raised the muffler EGT by 50° to 200°F. The effects of this on piston, valve component, cylinder head, and exhaust system life is unknown. Although both engines experienced similar exhaust gas temperature rises when leaned out, the effect on engine durability may not be identical for both engines. The developers presented only limited durability data on the NAHBE.

Several problems were encountered during testing. On alcohol the NAHBE could not be properly adjusted to a low speed idle since it would surge or stall. At higher power settings the NAHBE surged moderately after a few minutes of steady state testing even after the developer had adjusted the carburetor. In addition it required additional adjustment whenever the load was changed. The NAHBE air injection tube broke during testing and had to be repaired. The modified metering rod was improperly fabricated so that it did not seat exactly in the center of the metering jet.

Appendix A

Heat Balanced Engine

Test System Description

5 kW generator set, military standard DOD model MEP-017A with heat balanced engine

Engine

Nomenclature	Military standard model 2A042 III. Piston, combustion chamber, and induction system were modified by the Naval Academy
Manufacturer, Type	Wisconsin (mfr. of stock engine) 4 stroke, Otto cycle, OHV, 2 cyl. opposed air cooled. Modified by Naval Academy to heat balanced engine concept.
Cooling	Air cooled
Bore and Stroke	76.2 x 76.2 mm/3.00 x 3.00 in.
Displacement	695 cc/42.4 cu. in.
Compression Ratio	8.5 to 1 (modified piston and cylinder head)
Rated HP	7.5 kW/10 hp at 3600 rpm (stock engine rating)
Maximum HP	13.0 kW/17.5 hp at 3600 RPM (stock engine rating)
Speed Range	None. Controlled at 3600 RPM
Governed Speed	3600 RPM
Ignition	Magneto
Fuel Metering	Stock single, side draft, 1 venturi carburetor with air bleed
Fuel Requirement	Regular leaded 91 octane automotive or ethyl alcohol. Tested with Indolene 30, RON 100; and also with ethyl alcohol

Appendix A

Heat Balanced Engine (Continued)

Generator	
Manufacturer	Fermont
Output Power	5 kW AC
Output Voltage	120/240 V single phase, 120/208 V three phase
Frequency	60 hertz
Power Factor	0.8
General	
Frame	Tubular frame, skid mounted
Size	101.0 cm long x 76.2 cm wide x 63.5 cm high; 39 3/4 in long x 30 in wide x 25 in high
Weight	217.3 kg/479 pounds
Mounting	Engine directly coupled to generator
Total System Operating Time	5 hours when received

Appendix A

Stock Test System Description

5 kW Generator Set, Military Standard, DOD Model MEP-017A

Engine

Nomenclature	Military standard model 2A042-III
Manufacturer	Hercules (Identical to engine manufactured by Wisconsin)
Type	4 stroke, Otto cycle, OHV, 2 cyl. opposed
Cooling	Air cooled
Bore and Stroke	76.2 x 76.2 mm/3.00 x 3.00 in.
Displacement	695 cc/42.4 cu. in.
Compression Ratio	6.9:1
Rated hp	7.5 kW/10 hp at 3600 RPM
Maximum hp	13.0 kW/17.5 hp at 3600 RPM
Speed Range	3000 to 4000 RPM
Governed Speed	3600 RPM
Ignition	Magneto
Fuel Metering	Single, side draft, 1 venturi carburetor
Fuel Requirement	Regular leaded, 91 octane automotive gasoline (tested with Indolene 30, RON 100)

Appendix A

Stock Engine (continued)

Generator

Manufacturer	Fermont
Output Power	5 kW AC
Output Voltage	120/240 V single phase; 120/208 V three phase
Frequency	60 hertz
Power Factor	0.8

General

Frame	Tubular frame, skid mounted
Size	101.0 cm long x 76.2 cm wide x 63.5 cm high; 39 3/4in. long x 30 in. wide x 25 in. high
Weight	217.3 kg/479 pounds
Total System Operating Time	3 hours when received

Appendix A (continued)

Specification of Comparison Engines

Manufacturer	Briggs & Stratton	Briggs & Stratton	Wisconsin	Kohler	Mercedes Benz	Onan	Wisconsin
Model	92908	100202	SD 12	K482	OM636	DJBA	VH4D
Cylinders	1	1	1	opposed-2	I-4	I-2	V-4
Bore & Stroke in.	2.56 x 1.75	2.50 x 2.13	3.50 x 3.00	3.25 x 2.88	2.94 x 3.94	3.25 x 3.63	3.25 x 3.25
Displacement, in^3	9.02	10.43	28.86	48.0	108	60	108
Compression Ratio	6.20:1	6.20:1	6.35:1	6.00:1	19.0:1	19.0:1	5.50:1
Rated HP @ RPM	3.5 @ 3600	4 @ 3600	12.5 @ 3600	18 @ 3600	29 @ 2400	14.6 @ 2400	30 @ 2800
Rated Torque (fr lbf) @ RPM	5.2 @ 3100	5.9 @ 3100	21.5 @ 2200	31.7 @ 2400	60 @ 2000	36 @ 1800	66 @ 1700
Cooling	Air	Air	Air	Air	Water	Air	Air
Ignition	mag.	mag.	Batt & mag.	Batt & mag.	CI	CI	Batt
Fuel Metering	1 V	1 V	1 V	1 V	FI	FI	1 V
Fuel Type	gasoline	gasoline	gasoline	gasoline	diesel	diesel	gasoline
Aspiration					natural	natural	
Comb. Chamber					pre-cup	pre-cup	

Table B-1

HC Emissions
gm/kW hr

	% full load @ rated RPM				
	0*	25	50	75	100
ENGINE W/GENERATOR					
NAHBE w/modified MR	13.5	7.2	4.3	2.6	3.9
NAHBE (alcohol)	-	-	-	11.9	5.7
NAHBE w/standard MR	189.4	67.3	30.3	16.3	9.8
Stock	55.8	57.0	31.3	20.4	13.3
Stock w/NAHBE induction & modified MR	-	-	4.4	2.0	1.8
Stock w/NAHBE induction & Standard MR	260.2	90.8	29.3	15.5	9.2
ENGINE					
NAHBE w/modified MR	13.5	6.5	3.9	2.3	3.5
NAHBE (alcohol)	-	-	-	10.9	5.1
NAHBE w/standard MR	189.4	60.6	27.3	14.7	8.8
Stock	55.8	51.3	28.2	18.4	12.0
Stock w/NAHBE induction & modified MR	-	-	4.0	1.8	1.6
Stock w/NAHBE induction & Standard MR	260.2	81.7	26.4	14.0	8.3
B&S 92908	17.7	49.1	31.4	29.8	14.5
B&S 100202	4.18	8.43	6.85	6.05	5.03
Wisconsin SD12	73.3	33.6	23.6	20.5	17.0
Kohler K 482**	120	40.0	22.4	22.2	21.1
Mercedes-Benz OM 636	20.7	5.29	1.93	.78	.36
Onan DJBA	20.2	5.29	2.08	.99	1.18
Wisconsin VH4D	120	24.56	13.07	8.34	8.11

MR - Metering rod
* - grams/hr
** - Emissions from the test engine may be higher than typical due to the carburetor setting

Table B-2

CO Emissions
gm/kW hr

	% full load @ rated RPM				
	0*	25	50	75	100
ENGINE W/GENERATOR					
NAHBE w/modified MR	50	33	19	20	18
NAHBE (Alcohol)	-	-	-	19	12
NAHBE w/standard MR	2813	2151	996	489	394
Stock	2175	2172	1041	687	428
Stock w/NAHBE induction & modified MR	-	-	33	18	14
Stock w/NAHBE induction & standard MR	2582	2269	1008	406	201
ENGINE					
NAHBE w/modified MR	50	30	17	18	16
NAHBE (Alcohol)	-	-	-	17	11
NAHBE w/standard MR	2813	1936	896	440	355
Stock	2175	1955	937	618	385
Stock w/NAHBE induction & modified MR	-	-	30	16	13
Stock w/NAHBE induction & standard MR	2582	2042	907	365	181
B&S 92908	134	619	440	510	199
B&S 100202	20.6	38.0	53.4	80.3	48.9
Wisconsin SD12	1540	838	729	670	636
Kohler K482**	1970	424	419	356	723
Mercedes-Benz OM 636	69.9	7.30	4.81	3.06	11.83
Onan DJBA	70.3	13.69	4.77	2.43	3.37
Wisconsin VH4D	2636	680.5	429.5	318.1	233.6

MR - Metering rod
* - grams/hr
** - Emissions from the test engine may be lower than typical due to the carburetor setting

Table B-3

NOx Emissions
gm/kW hr

	% full load @ rated RPM				
	0*	25	50	75	100
ENGINE W/GENERATOR					
NAHBE w/modified MR	7.11	14.45	14.46	7.33	16.76
NAHBE (Alcohol)	-	-	-	1.04	1.63
NAHBE w/stock MR	2.03	2.91	2.81	6.00	7.84
Stock	3.0	3.24	2.50	3.20	6.35
Stock w/NAHBE induction & modified MR	-	-	18.92	9.75	15.29
Stock w/NAHBE induction & standard MR	5.28	4.26	3.97	5.92	16.00
ENGINE					
NAHBE w/modified MR	7.11	13.01	13.01	6.60	15.08
NAHBE (Alcohol)				.94	1.47
NAHBE w/stock MR	2.03	2.62	2.53	5.40	7.06
Stock	3.0	2.92	2.25	2.88	5.72
Stock w/NAHBE induction & modified MR	-	-	17.03	8.78	13.76
Stock w/NAHBE induction & standard MR	5.28	3.83	3.57	5.33	14.4
B&S 92908	4.30	6.40	4.71	2.66	5.42
B&S 100202	3.14	14.63	18.0	19.2	24.3
Wisconsin SD12	3.21	2.91	2.38	1.66	2.21
Kohler K482**	5.44	3.68	5.23	3.87	3.74
Mercedes-Benz OM 636	19.0	5.91	5.10	4.39	2.97
ONAN DJBA	15.1	13.83	9.44	6.66	4.70
Wisconsin VH4D	6.83	3.69	6.05	10.26	11.60

MR - Metering rod
* - grams/hr
** - Emissions from the test engine may be lower than typical due to carburetor setting

Table B-4

Fuel Economy
kW hr/gal

	% full load @ rated RPM				
	0*	25	50	75	100
ENGINE W/GENERATOR					
NAHBE w/modified MR	1.6	1.9	3.4	4.4	5.1
NAHBE (alcohol)**	-	-	-	2.4	3.1
NAHBE w/stock MR	1.2	1.5	2.7	3.9	4.5
Stock	1.4	1.4	2.7	3.5	4.3
Stock w/NAHBE induction & modified MR	-	-	3.4	4.4	5.2
Stock w/NAHBE induction & standard MR	1.1	1.4	2.7	3.8	4.9
ENGINE					
NAHBE w/modified MR	1.6	1.7	3.1	4.0	4.6
NAHBE (Alcohol)**	-	-	-	2.2	2.8
NAHBE w/stock MR	1.2	1.4	2.4	3.5	4.1
Stock	1.4	1.3	2.4	3.2	3.9
Stock w/NAHBE induction & modified MR	-	-	3.1	4.0	4.7
Stock w/NAHBE induction & standard MR	1.1	1.3	2.4	3.4	4.4
B&S 92908	6.3	2.6	4.3	5.2	7.8
B&S 100202	7.0	3.6	5.1	6.2	7.0
Wisconsin SD 12	1.6	2.5	3.4	4.3	4.9
Kohler K482***	1.1	2.7	4.3	4.8	5.2
Mercedes-Benz OM 636	1.7	5.9	8.5	9.8	10.0
Onan DJBA	3.2	5.2	7.9	9.6	8.8
Wisconsin VH4D	.8	3.5	5.1	6.2	7.1

MR - Metering rod
* - hr/gal.
** - alcohol, gal are gal alcohol (190 proof, 95% ethyl alcohol)
*** - Fuel economy from the test engine may be lower than typical due to the carburetor setting

Table B-5

Thermal Efficiency %

	% of full load @ actual RPM			
	25	50	75	100
ENGINE W/GENERATOR				
NAHBE w/modified MR	5.2	9.3	12.0	13.9
NAHBE (alcohol)	-	-	10.9	14.1
NAHBE w/stock MR	4.0	7.2	10.5	12.3
Stock	3.8	7.4	9.6	11.8
Stock w/NAHBE induction & modified MR	-	9.3	11.9	14.1
Stock w/NAHBE induction & modified MR	3.7	7.3	10.4	13.4
ENGINE				
NAHBE w/modified MR	5.8	10.3	13.3	15.4
NAHBE (Alcohol)	-	-	12.1	15.7
NAHBE w/stock MR	4.4	8.0	11.7	13.7
Stock	4.2	8.2	10.7	13.1
Stock w/NAHBE induction & modified MR	-	10.3	13.2	15.7
Stock w/NAHBE induction & modified MR	4.1	8.1	11.6	14.9
B&S 92908	7.1	11.6	14.2	21.4
B&S 100202	9.8	14.0	16.9	19.0
Wisconsin SD12	6.9	9.4	11.9	13.5
Kohler K 482*	7.2	11.7	13.2	14.1
Mercedes-Benz OM 636	14.4	20.9	24.2	24.4
Onan DJBA	12.8	19.4	23.5	21.6
Wisconsin VH4D	9.4	14.0	16.9	19.3

MR - Metering rod

* - Thermal efficiency from the test engine may be lower than typical due to the carburetor setting

Table C-1

Heat Balanced Engine/Generator

Test No.	Comment	Engine Hours	Power kW	EGT* °F	gm/kW hr HC	CO	CO_2	NOx	Fuel Economy kW hr/gal	Thermal Efficiency %
0% Load										
78-6459	(1)	21.0			11.8	38	5383	6.91	1.6	4.4
78-6632	(1)	51.8		795	13.5	50	5532	7.11	1.6	4.4
78-6808	(1),(3)	58.4		580	223.1	2938	2723	2.05	1.1	3.0
79-0048	(1),(3)	60.7		560	155.6	2688	2697	2.01	1.2	3.3
25% Load										
78-6460		20.2	1.1		6.6	28	5128	12.02	1.7	4.6
78-6467		41.2	1.2	800	5.9	28	4932	14.26	1.8	4.9
78-6631		51.8	1.3	790	7.2	33	4717	14.45	1.9	5.2
78-6809	(3)	58.2	1.3	590	74.9	2344	2542	2.61	1.4	3.8
78-6811	(3)	59.9	1.3	590	59.7	1958	2652	3.20	1.5	4.1
50% Load										
78-6456		13.3	2.3		3.0	17	3043	10.72	2.9	7.9
78-6461		20.1	2.2		2.5	23	2817	11.70	3.1	8.5
78-6468		41.0	2.2	805	3.8	19	2915	15.34	3.0	8.2
78-6475		51.2	2.5	795	4.3	19	2554	14.46	3.4	9.3
78-6815	(3)	57.9	2.5	640	32.2	1079	1611	2.39	2.6	7.1
78-6810	(3)	59.8	2.4	635	28.3	913	1777	3.23	2.7	7.4

(1) Gm/hr, hr/gal
(2) Manifold air bleed closed
(3) Standard (stock) metering rod
(4) Carburetor air bleed blocked off
(5) Alcohol, gal are gal alcohol
* Exhaust gas temperature

Table C-1 (con't)

Heat Balanced Engine/Generator

Test No.	Comment	Engine Hours	Power kW	EGT* °F	gm/kW hr HC	CO	CO_2	NOx	Fuel Economy kW hr/gal	Thermal Efficiency %
75% Load										
78-6457		13.6	3.5		3.4	11	2240	9.64	3.9	10.6
78-6462		19.5	3.5		1.8	14	1885	12.65	4.6	12.6
78-6464	(2)	19.8	3.5		9.1	467	1481	4.22	4.0	10.9
78-6471	(2)	39.7	3.6	685	15.9	486	1480	4.47	3.9	10.6
78-6469		40.9	3.8	825	4.6	17	1980	17.86	4.4	12.0
78-6474		50.9	3.7	815	2.6	20	1956	7.33	4.4	12.0
78-6630	(2)	51.6	3.8	730	15.2	392	1613	7.80	3.9	10.6
78-6816	(5)	56.0	3.8	958	11.9	19	2132	1.04	2.4	10.9
78-6813	(3)	57.7	3.8	705	18.1	564	1428	5.08	3.7	10.1
78-6807	(3)	59.8	3.8	710	14.4	413	1539	6.92	4.0	10.9
100% Load										
78-6458		13.8	4.5		1.9	7	1867	12.60	4.7	12.8
78-6463		19.1	4.6		2.2	9	1766	9.06	5.0	13.7
78-6465	(2)	19.3	4.6		5.9	233	1371	8.48	5.0	13.7
78-6472	(2)	39.4	4.8	765	9.5	203	1393	9.95	5.1	13.9
78-6470		39.9	4.9	920	2.7	13	1730	12.93	5.0	13.7
78-6473		50.7	5.0	895	3.9	18	1696	16.76	5.1	13.9
78-6629	(2)	51.4	5.0	830	8.7	134	1577	17.55	4.9	13.4
78-6791	(2),(4)	52.7	5.0	760	13.4	384	1281	7.10	4.6	12.6
78-6633	(4)	52.8	5.0	840	6.7	89	1588	17.55	3.1	13.9
78-6812	(5)	55.2	5.0	930	5.6	12	1670	1.66	3.1	14.2
78-6817	(5)	55.7	5.0	940	5.8	12	1689	1.60	5.1	13.9
78-6814	(3)	57.5	5.0	780	12.7	381	1318	7.84	4.5	12.3
78-6806	(3)	58.9	5.0	775	13.6	406	1310	7.83	4.5	12.3
78-0049		61.2	5.0	845	5.9	36	1602	19.52	5.3	14.5

(1) Gm/hr, hr/gal
(2) Manifold air bleed closed
(3) Standard (stock) metering rod
(4) Carburetor air bleed blocked off
(5) Alcohol, gal are gal alcohol (190 proof, 95% ethyl alcohol)
* Exhaust gas temperature

Table C-2

Stock Engine/Generator

Test No.	Comment	Engine Hours	Power kW	EGT ** °F	gm/kW hr				Fuel Economy kW hr/gal	Thermal Efficiency %
					HC	CO	CO_2	NOx		
0% Load										
78-6483	(1)	18.9			24.3	1109	3581	4.83	1.6	
78-6488	(1)	40.9		555	35.0	1090	3375	4.95	1.7	
78-6624	(1)	53.4		540	55.8	2175	2781	3.00	1.4	
78-6819	(1),(3)*	57.7		620	249.8	2480	3211	6.34	1.1	
78-6819	(1),(3)*	59.7		635	270.6	2684	3033	4.22	1.1	
25% Load										
78-6484		19.1	1.22		34.4	1811	3149	3.81	1.5	4.1
78-6489		40.7	1.21	630	51.3	1771	2961	4.13	1.5	4.1
78-6625		53.1	1.28	610	57.0	2172	2630	3.24	1.4	3.8
78-6820	(3)*	57.9	1.2	645	90.9	2208	2703	4.57	1.4	3.8
78-6926	(3)*	59.9	1.3	640	90.7	2330	2681	3.95	1.3	3.5
50% Load										
78-6482		9.9	2.4		21.0	1405	1753	2.32	2.2	6.0
78-6482		10.5	2.4		21.0	1407	1727	2.18	2.2	6.0
78-6485		19.3	2.2		22.7	1180	1865	2.66	2.3	6.3
78-6490		40.2	2.5	690	29.4	987	1644	2.58	2.7	7.4
78-6502		48.4	2.5	680	30.1	1009	1541	2.45	2.8	7.6
78-6542		52.5	2.5	680	32.5	1073	1618	2.54	2.6	7.1
78-6821	(2)*	55.1	2.5	730	13.3	326	2034	11.76	3.4	9.3
78-6822	*	56.0	2.5	845	4.0	28	2560	19.23	3.4	9.3
78-6922	*	56.8	2.5	840	4.8	38	2556	18.60	3.4	9.3
78-6923	(3)*	58.0	2.5	695	28.2	980	1686	3.98	2.7	7.4
78-6927	(3)*	56.9	2.5	700	30.4	1035	1693	3.96	2.6	7.1

(1) Gm/hr, hr/gal
(2) Manifold air bleed closed
(3) Standard (stock) metering rod
* Modified Carburetor and modified intake tubes
** Exhaust gas temperature

Table C-2 (con't)

Stock Engine/Generator

Test No.	Comment	Engine Hours	Power kW	EGT ** °F	gm/kW hr HC	CO	CO_2	NOx	Fuel Economy kW hr/gal	Thermal Efficiency %
75% Load										
78-6481		9.5	3.5		13.8	1022	1435	2.30	2.9	7.9
78-6481		10.3	3.5		15.4	1109	1388	2.00	2.8	7.6
78-6486		21.6	3.4		19.0	865	1636	3.65	2.9	7.9
78-6491		39.9	3.8	755	23.1	784	1315	2.40	3.4	9.3
78-6501		48.1	3.7	750	20.1	687	1362	3.22	3.5	9.6
78-6503		52.2	3.7	750	20.7	687	1362	3.17	3.5	9.6
78-6917	(2)*	54.9	3.8	805	8.4	158	1691	13.96	4.5	12.3
78-6918	*	55.8	3.8	935	2.0	18	2052	9.86	4.3	11.7
78-6921	*	56.6	3.8	930	2.0	18	1971	9.64	4.4	12.0
78-6924	(3)*	58.8	3.8	965	15.2	498	1484	7.15	3.8	10.4
78-6929	(3)*	60.3	3.8	780	15.8	314	937	4.69	3.8	10.4
100% Load										
78-6480		9.3	4.5		10.5	798	1296	2.69	3.5	9.6
78-6480		10.1	4.5		12.1	818	1319	2.63	3.4	9.3
78-6487		21.4	4.8		12.8	615	1169	2.62	4.1	11.2
78-6499		39.7	5.0	805	16.5	560	1180	3.07	4.2	11.5
78-6500		47.9	4.6	810	14.0	461	1377	6.15	4.1	11.2
78-6626		52.0	5.0	830	12.5	395	1304	6.54	4.5	12.3
78-6627	*	53.9	5.0	940	1.6	14	1722	15.19	5.1	13.9
78-6629	*	54.1	5.0	920	2.2	16	1692	21.68	5.1	13.9
78-6919	(2)*	54.7	5.0	900	3.6	31	1533	17.44	5.6	15.3
78-6820	*	55.6	5.0	945	1.5	13	1670	12.19	5.2	14.2
78-6818	*	56.4	5.0	945	1.6	13	1640	12.08	5.3	14.5
78-6925	(3)*	59.1	5.0	855	9.0	202	1444	15.09	5.0	13.7
78-6929	(3)*	60.5	5.0	875	9.3	199	1502	16.90	4.8	13.1

(1) GM/hr, hr/gal
(2) Manifold air bleed closed
(3) Standard (stock) metering rod
* Modified Carburetor and modified intake tubes
** Exhaust gas temperature