Exhaust Emissions from a 53-Passenger Lear Rankine Cycle Steam Bus

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Test and Evaluation Branch
Emission Control Technology Division
Environmental Protection Agency

Background

A steam Rankine cycle power system, designed and built by Lear Motors Corporation, was installed in a 40-foot urban transit coach, in a Department of Transportation sponsored program to demonstrate the potential of external combustion power systems in city bus service.

After the installation of the steam power system and a period of shakedown, development, and optimization, the bus was sent from Lear Motors in Reno, Nevada to California. There it was tested by the California Air Resources Board and easily met the California clean air standards. The bus was then used by the San Francisco Municipal Railway, the transit system of that city, in revenue service for limited service testing and to determine passenger acceptance. The bus performed well over even the steepest routes and received good public acceptance. (Reference 1)

Arrangements were made with Lear Motors for exhaust emissions tests at the Office of Mobile Source Air Pollution Control (OMSAPC), Ann Arbor laboratory. The tests of the steam bus reported herein were conducted over a two week period in October 1973.

The emissions tests were conducted by the Test and Evaluation Branch of the Emission Control Technology Division as part of a continuing effort to stay abreast of alternative power systems development and assess the emission control potential of such systems. OMSAPC provided transportation of the bus from Reno, Nevada to the Ann Arbor laboratory. Lear Motors Corp. provided personnel to operate the bus and interpret engine parameter data.

Vehicle Description

The bus chosen for this project was a GMC model T6H 5305A built by General Motors Coach Division. The engine usually installed in this 53-passenger bus is a 426 cubic inch displacement (CID) Detroit Diesel supercharged Diesel V-6 internal combustion engine. For heavy duty service such as in San Francisco a 567 CID V-8 would usually be used.

The Lear Motors steam rankine cycle power system installed in the bus is described in References 1 and 2 at the end of this report. Briefly, the power system includes a monotube vapor generator that provides superheated steam for a turbine expander. Turbine power output goes through a reducing gearbox to the four-speed automatic transmission originally installed in the bus. Diesel number 1 is the fuel. The engine, including condensers, was installed in the rear of the bus in the normal engine compartment. Test instrumentation was neatly packaged and occupied only two seats at the rear of the bus. Only a few additional gauges and switches were required by the vehicle operator.

The curb weight of the stock bus is about 20700 pounds. The bus as tested with the steam power system and instrumentation installed weighed about 22775 pounds. All testing was done with an inertia weight of 28500 pounds to simulate the weight of the standard bus fully loaded. This also duplicated the test weights of the bus during its California tests.

Test Program

The Lear bus arrived at the Ann Arbor laboratory on Monday evening, October 15, 1973, and was used for demonstration through Wednesday. Vehicle preparation and facility checkout took several days. Testing started on October 23 and continued through October 29. However, due to several vehicle problems, only a small number of tests were completed. These were principally a modified version of the Federal 13-mode heavy duty Diesel engine test procedure. This modified procedure is similar to the heavy duty Diesel engine test procedure developed by the California Air Resources Board (CARB) and the Engine Manufacturers Association. This procedure, which will be referred to as the Federal 13-mode procedure, is described in SAE paper number 700671, and the Federal Register of November 15, 1972, Vol. 37, Number 221, Part II.

For these tests a heavy duty electric chassis dynamometer was used which had motoring capability and permitted both speed and torque control. The dynamometer is equipped with large diameter (40") rolls to minimize slippage and tire loss problems. Rear wheel horsepower was measured and engine brake horsepower was then calculated to provide the basis for determining brake specific emissions.

The heavy duty Diesel procedure is a steady state procedure for testing a Diesel engine on an engine dynamometer with engine load as the operating variable at each of two engine speeds, "rated" and "intermediate". The load is varied from zero to maximum torque available at each of these two engine speeds, in steps of 25% of maximum torque. Three idle periods are interspersed among these load points, for a total of 13 operating modes. Rated speed is self-explanatory: the maximum allowable continuous engine speed. Intermediate speed is defined in the procedure as "...peak torque speed or 60% of rated speed, whichever is higher". For the steam power system, 57,000 and 62,000 rpm were selected as the intermediate and rates speeds, respectively, since these were the turbine speeds used when the bus was tested in California. These were chosen since they would give road speeds of 30 mph (3rd gear) and 50 mph (4th gear) respectively, these speeds corresponding to city and inter-city cruise speeds.

The 13-mode procedure calls for continuous analysis of exhaust pollutant concentrations and measurements of engine fuel and air consumption rates for calculation of exhaust pollutant mass emissions. However, for simplicity and ease of calculation in our tests of the steam bus, the Constant Volume Sampling technique (CVS) was also employed. In the CVS method a positive displacement air pump pulls a constant volume stream consisting of all the engine exhaust plus dilution air. From this mixture a small sample is pumped into an impermeable Tedlar plastic bag for analysis at the end of the test period. The product of pollutant mole concentration times pollutant density times constant volume flow rate, in appropriate units, gives pollutant mass emissions.

The sample bags and raw exhaust were analyzed using the usual array of instruments: unburned hydrocarbons (HC) were measured with a flame ionization detector (FID), CO and CO_2 with non-dispersive infrared (NDIR) analyzers, and nitrogen oxides (NO_x) with a chemiluminescence (CL) device. Fuel flow was measured with a Flotron mass flow meter.

The raw exhaust sample probes were located in each exhaust duct. Suitable plumbing was installed to permit sampling from either duct. Manometer taps were also located in each exhaust duct to monitor backpressure. Throughout the testing exhaust backpressure was held to less than plus or minus 5 mm of water ($\pm$.2 in.).

Since the expected large exhaust mass flow rates, 1500 SCFM, were well beyond the capabilities of the laboratory CVS unit, it was connected to only one side of the vehicle.

New procedures were developed to calculate total mass emissions. By a carbon balance method, the CVS mass emissions can be used to calculate the amount of fuel they represent. Therefore, the remainder of the fuel and its combustion products go out the opposite exhaust. Thus by a procedure similar to the heavy duty gasoline procedure the exhaust mass flow rate can be calculated and since the emission concentrations are measured in each exhaust duct, the mass emissions going out the non-CVS side can be calculated.

Early in the testing of the steam bus it became evident that it would be impossible to obtain stable emission levels at stable preselected power settings due to the nature of the engine design and its controls. Fuel is supplies proportionally to air flow to maintain steam pressure between selected limits. However, apparently slightly too much fuel was supplied; thus raising the temperature and pressure to their operating limits. This caused a fuel/air cutback and, when the pressure dropped sufficiently, a fuel/air increase. This was seen as an 80 second cycling in the emission concentrations and cycling in the fuel flow rates during all tests. Thus neither the emission mass flow rates, emission concentrations, nor fuel flow rates were at the required constant levels.

The Flotron as instrumented gives errors in total fuel consumed during cyclic operation. By comparing the ratio of fuel measured by CVS carbon balance to total fuel measured by the Flotron, an estimate of the fuel error introduced and fuel split versus horsepower was made. The right exhaust sometimes showed a slightly higher (no greater than 15%) emission concentration than the left side, particularly at higher power settings.

Therefore the procedure for calculation of emissions was altered. Emissions were assumed to be directly proportional to fuel flow rate; thus emissions on the non CVS side were equal to emissions on the side connected to the CVS times the ratio of fuel used on each side.

Major mechanical problems were encountered which interrupted testing and limited the total number of tests. The feedwater pump was changed once in testing. The water turbine* failed on October 23 during a bus route test. During this test there was a higher than desired load of the dynamometer. A second water turbine failure on October 26 necessitated using an organic* turbine wheel for the final tests. Surprisingly, it gave greater power.

Desired load and engine speed settings were calculated prior to each test. However, these were not always readily attained and when these values were adjusted for dynamometer friction losses, rear wheel motoring losses, transmission efficiency, and converter efficiency, they differed from the 25, 50 and 75% hp values. These corrections were nearly the same for all tests as were the observed maximum horsepowers.

The corrected horsepower values were used to interpolate between the fuel-adjusted CVS emission numbers to find the desired 2, 25, 50 and 75% hp values. These values were weighted together to obtain overall brake specific emissions.

Tests of a "Baseline Bus"

The Test and Evaluation Branch tested a Diesel bus prior to the steam bus in order to check out instrumentation and establish baseline emissions with which emissions from the steam bus could be compared. Only a few tests were completed due to equipment problems which delayed testing.

The baseline bus was a GMC T6H 4523A 45-passenger city bus powered by a Detroit Diesel 426 CID supercharged V-6 Diesel engine. This vehicle is identical to the T6H 5305A except that it is 5' shorter and weighs less, at 19500 pounds. The bus was manufactured in May 1973 and arrived with only 670 miles on the odometer. This vehicle was obtained through the courtesy of Mr. John Hubbard of GM Truck and Coach Division where it is to be an engineering vehicle. Mr. Richard Schultz of GM Truck and Coach provided technical assistance. Since the engine was new, additional mileage was accumulated during instrumentation setup and checkout. About 200 additional miles were accumulated prior to testing. The dynamometer inertia weight setting was the same as for the steam bus, 28500 pounds. For the 13-mode test the converter was locked up through the use of a bypass line on the torque converter, thus eliminating converter slip. The Lear bus was not locked up during testing, therefore, the test results were adjusted to include the converter losses.

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* See Notes 1 and 2 on page 10.

Operating conditions included a simulation of the Federal 13-mode heavy duty procedure, and the Ann Arbor-1 (AA-1) Urban Bus Cycle.

The AA-1 cycle is a speed versus time trace generated in the summer of 1971 by attaching a fifth wheel to one of the buses of the Ann Arbor Transportation Authority. The cycle is not an official test cycle, but rather is used as an experimental tool for comparing buses. The cycle consists of 26 start/stop modes, and the 5.4-mile route requires 29.5 minutes to complete, for an average speed of about 11 mph. The maximum speed on the cycle is 38 mph.

The procedure for the 13-mode test was to establish the desired engine speed by using the dynamometer to control vehicle speed. At this speed the load is controlled by the vehicle throttle setting. Bag samples of the diluted exhaust gas were taken at 0%, 25%, 50%, 75% and 100% of the maximum power at the chosen engine speed. The idle modes were run with the transmission in Neutral. Each mode was maintained for three minutes to allow time for an adequate sample to be taken. It had previously been determined that 1200 rpm and 2000 rpm were the desired intermediate and rated speeds, respectively, for the Detroit Diesel 426 engine in the bus. These corresponded to speeds of 27 mph and 45.5 mph with the converter in lockup. The raw exhaust concentration, air flow, and fuel flow rates were constant for each test.

To develop a valid dynamometer road load for the AA-1 bus route, and steady state tests, the GMC calculated road load data for the T6H 5305A was used to obtain steady state road load data. These conditions were duplicated on the chassis dynamometer and a road load curve, Table VIII, was developed.

Results and Discussion

Results of the emissions tests on the steam bus are presented in the Appendix in Tables I through V, and on the baseline Diesel-engined bus in Tables V and VII. Emissions of CO_2 are included to indicate fuel consumption. The fuel economy figures in the tables were calculated by a carbon balance equation from the mass emissions of HC, CO and CO_2. Rolling resistance data on the buses are presented in Table VIII. A schematic of the test setup is shown in Figure 10.

Mass emissions from the 13-mode tests on the steam bus are presented as grams per hour in Tables I, II, and III. Between the tests on October 25 and October 29, the turbine wheel type was changed and the air-fuel ratio was adjusted to a more optimum value. Brake specific emissions were calculated using the equation in Table I.

Using the brake specific emissions from Tables I, II, III and VI the following composite brake specific emissions were calculated:

Grams Per Brake Horsepower Hour

	HC	CO	NOx	HC+NOx
Steam Bus (10-25)	.5*	2.7	2.9	
Steam Bus (10-25)	.3*	2.3	3.2	
Steam Bus (10-29)**	.4*	2.0	1.9	
Diesel Bus (10-15)	1.2	7.4	11.8 8.4 (CVS)	
'77 Cal. Std.		25		

* Not heated FID
** Organic turbine wheel

Since the heated FID used on the CVS-diluted exhaust was not operational during all tests on the steam bus, the CVS bag hydrocarbon concentrations were used. When the FID was used, it read hydrocarbon values approximately thirty percent greater than were measured in CVS bag sample. The steam bus control system shuts off the burner during idle and thus there is no fuel consumption during stops. This does not sacrifice vehicle acceleration performance since the boiler pressure is maintained at idle and the recovery is instantaneous. The burner relights as required to maintain pressure. The pressure can be held up to 10 minutes without relighting. During the five minute idle modes the burner relighted about half the time. This was evidenced by the continuous emissions traces and the higher fuel consumption in modes 1, 7 and 13 (Tables I, II, III).

The steam bus emissions tabulated in Tables I, II and III are plotted in Figures 4,5,6 and 7. The trends were as expected - CO, CO_2 and NOx increased with horsepower, HC levels did not change. Usually the organic turbine wheel test showed better performance. Also, this wheel produced more horespower.

During identical tests at the GM Technical Center the following week, similar results were obtained (Ref.3). The engine, however, operated differently, producing little or no cycling during the 13-mode tests. Maximum measured rear wheel horsepower was the same. This difference was probably due in large part to additional adjustments to the air-fuel ratio.

Although the Diesel bus emissions were considerably higher than the steam bus emissions, the CO emissions are misleading. The Diesel bus had been used less than 15 hours when tested. These emissions were nearly identical to those from the durability engine (used in the Federal Heavy Duty certification procedure) at 0 hours as shown in Table VII. Under continued use this engine gave 30% lower CO emissions at 125 hours. This downward trend continued with further usage.

The vehicle fuel consumption plotted in Figure 8 shows that fuel consumption was appreciably less with the organic fluid turbine wheel than with the steam turbine wheel. Figure 9 shows that fuel consumption on the Diesel bus was about 1/3 as much as on the steam bus.

Steady state fuel economy in miles per gallon and emissions are given in Table IV. These results were similar to those achieved in testing the bus at the GM Proving Ground and Technical Center (Ref.3). GM tests for fuel economy at both the test track and Technical Center were within .25 mpg of the EPA results at all speeds. These fuel economy results are about 20% better than the results achieved during tests in California a year ago (Ref.1). Also, the steam bus achieved an average emission improvement of 5.7% for HC, 70% to 40% for CO_2 and 78% for NOx. This is a considerable improvement over a vehicle whose engine easily met 1974 standards. In addition, the steam bus meets the 1977 California HC, CO and NOx standards. Some important cautions must be observed however: 1) although it has considerable mileage the steam bus is a first generation demonstration model; considerable improvements in relaibility and fuel economy are necessar-, 2) the certification results for the Diesel engine show that CO emissions were appreciably lower after additional use, and 3) 60% of the Diesel CO emissions came at intermediate speed and full power, and therefore might not be representative of typical engine performance.

Emissions from the steady state cruise modes on the steam bus are listed in Table IV as grams per hour and grams per mile at horsepowers selected to duplicate the vehicle road load. Fuel economy ranged from 1.3 to 3.2 miles per gallon and was fairly constant from 30 to 50 mph. Fuel economy was calculated by the carbon balance method.

The Ann Arbor-1 bus route was run as a hot start only. The road load curve as listed in Table VIII, is based on GM computations derived from actual testing of similar vehicles. The values in columns 1 and 3 are the horsepower required at the engine to drive the vehicle at the steady state speeds. The values in columns 2 and 4 are horsepower measured at the rear wheels with corrections for driveline, tire and dynamometer losses. Results for both buses are given in Table V and summarized below:

	HC gm/mi	CO gm/mi	NOx gm/mi	MPG
Steam bus*	3.3	7.0	8.9	1
Diesel bus avg.	6.2	14	31.5	4.6

*Incomplete test

Conclusions

These tests of the Lear steam and a GM Diesel bus on a chassis dynamometer correlated well with previous tests on each. For the steam bus the results compared well with testing by the California Air Resources Board and GM/ The Diesel bus test results were comparable to the engine certification data. Both vehicles were clean, easily meeting current standards. The steam bus was appreciably cleaner and met 1977 California standards, however, the Diesel bus fuel economy was approximately three times better than the steam bus.

REFERENCES

1. "California Steam Bus Project Final Report," January 1973, Assembly Office of Research, California Legislature.

2. "Exhaust Emission Tests for the California Steam Bus Development and Demonstration Project CAL MTD-13," October 1972, California Air Resources Board, Air Resources Laboratory.

3. GM Research Laboratories letter dated November 15, 1973, to Lear Motors Corporation.

NOTES

1. Water Turbine Wheel - Lear Motors Corporation Supersonic turbine wheel designed for steam service.

2. Organic Turbine Wheel - Lear Motors Corporation Subsonic organic fluid turbine wheel. This wheel was utilized to complete the test program after the water wheels failed. The organic wheel operates off design due to the nozzle and working fluid mismatch.

REFERENCES

1. "California Steam Bus Project Final Report," January 1973, Assembly Office of Research, California Legislature

2. "Exhaust Emission Tests for the California Steam Bus Development and Demonstration Project CAL MTD-13," October 1972, California Air Resources Board, Air Resources Laboratory

3. GM Research Laboratories letter dated November 15, 1973, to Lear Motors Corporation.

APPENDIX

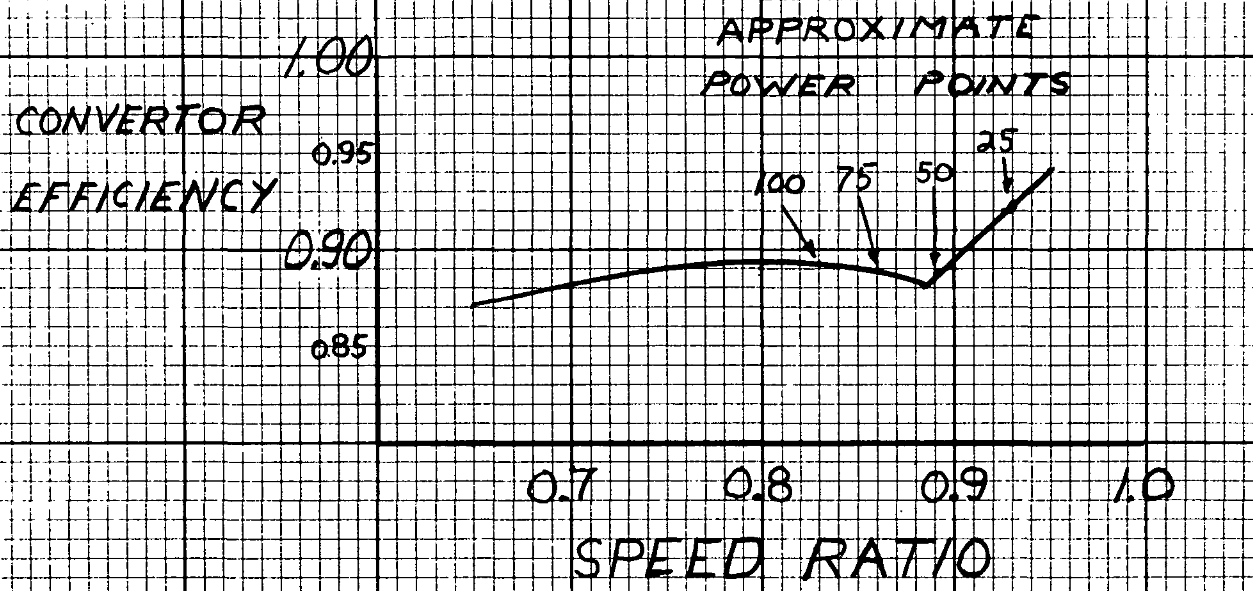

FIG 1 TRANSMISSION EFFICIENCY
STEAM BUS

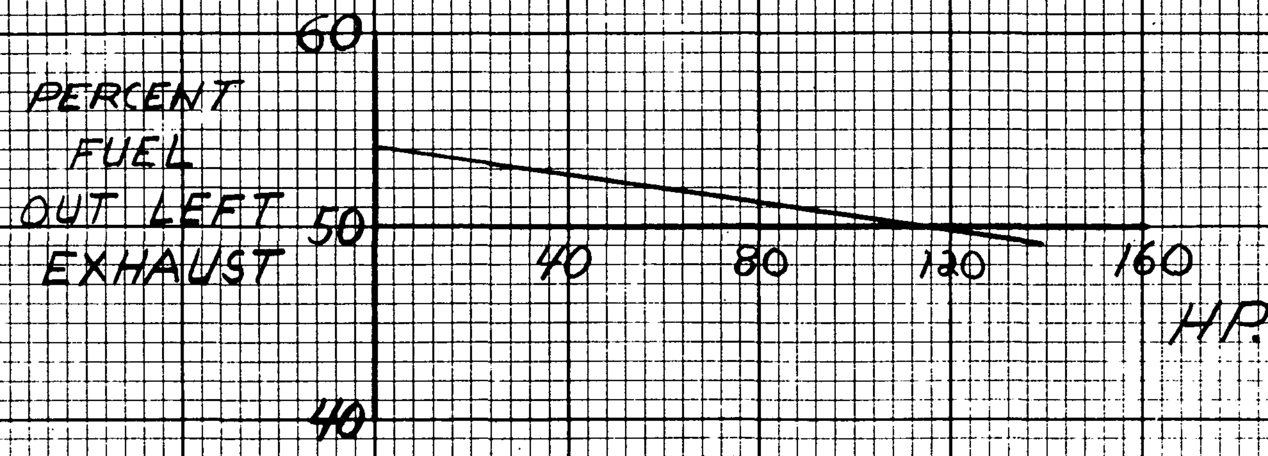

FIG 2 PERCENT FUEL OUT LEFT
EXHAUST

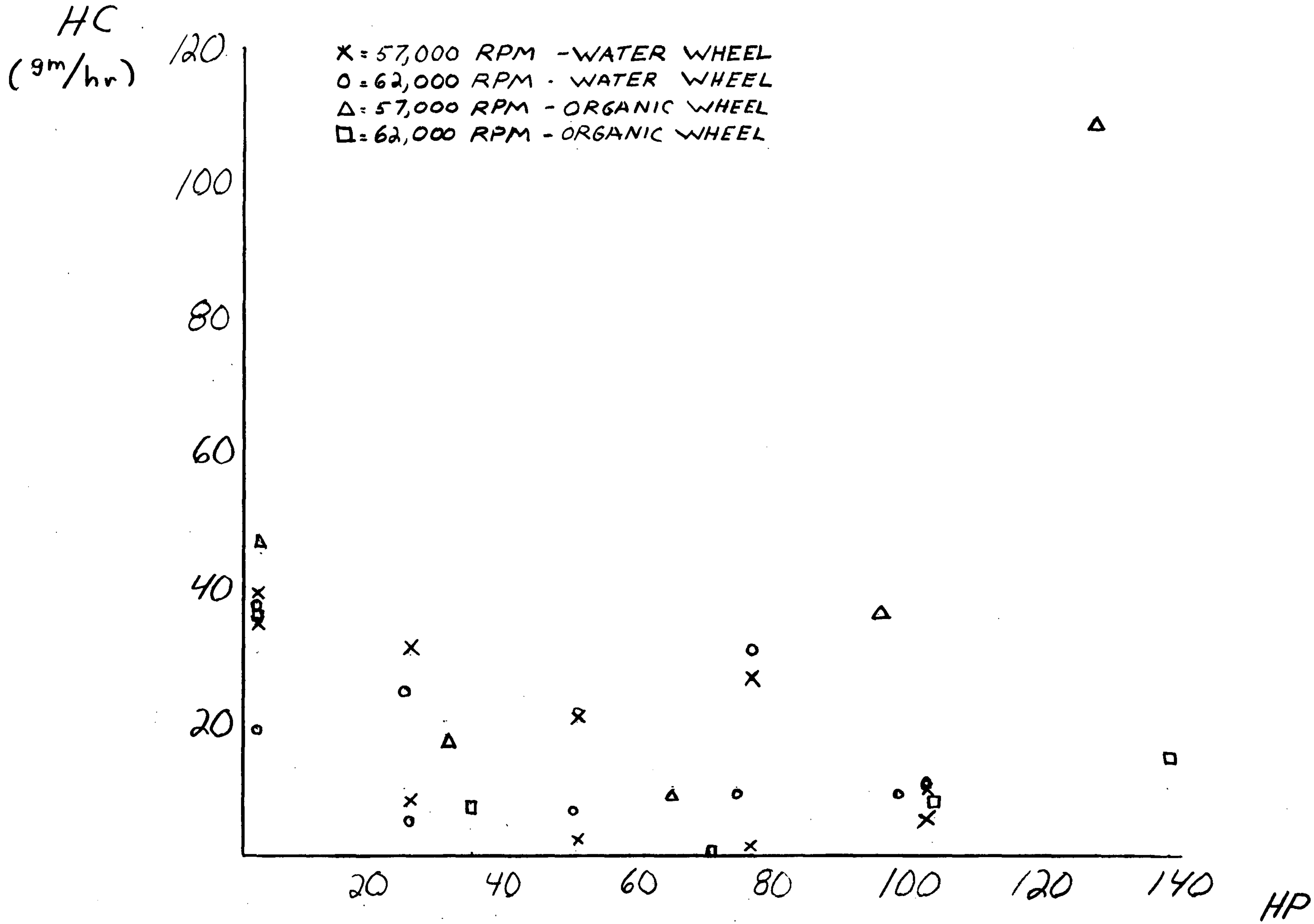

FIGURE 4 - HC vs HP

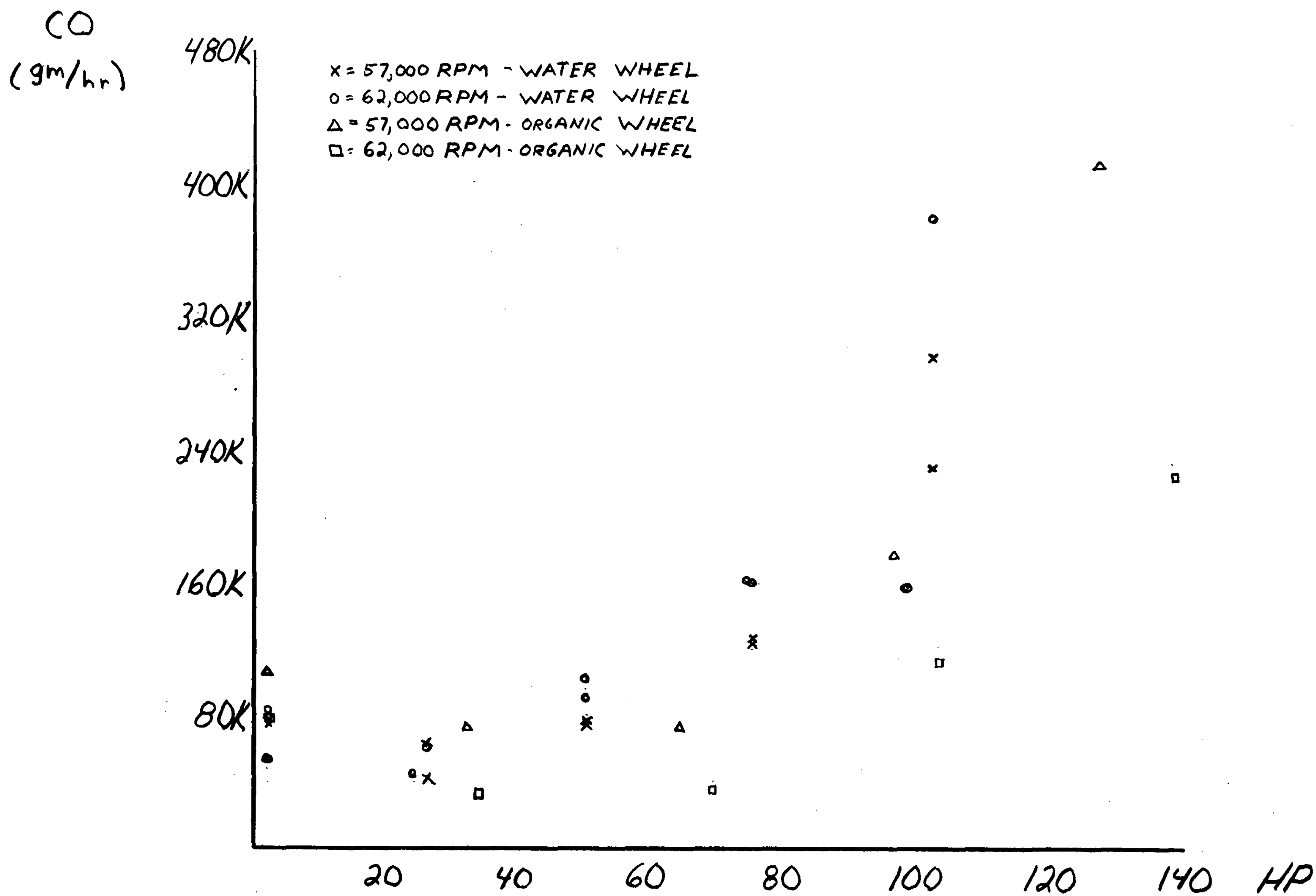

FIGURE 5 - CO vs. HP

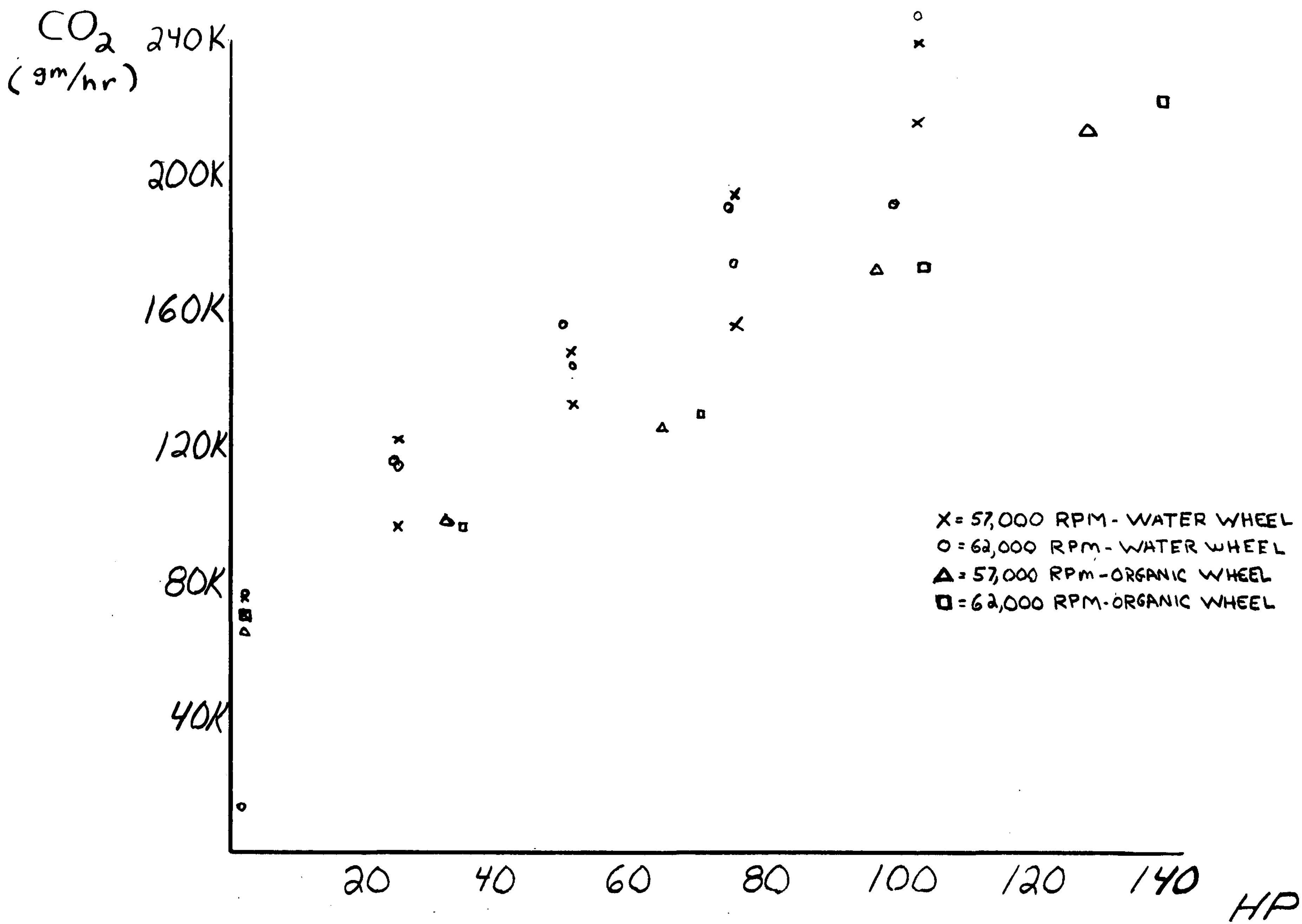

FIGURE 6 - CO_2 vs. HP

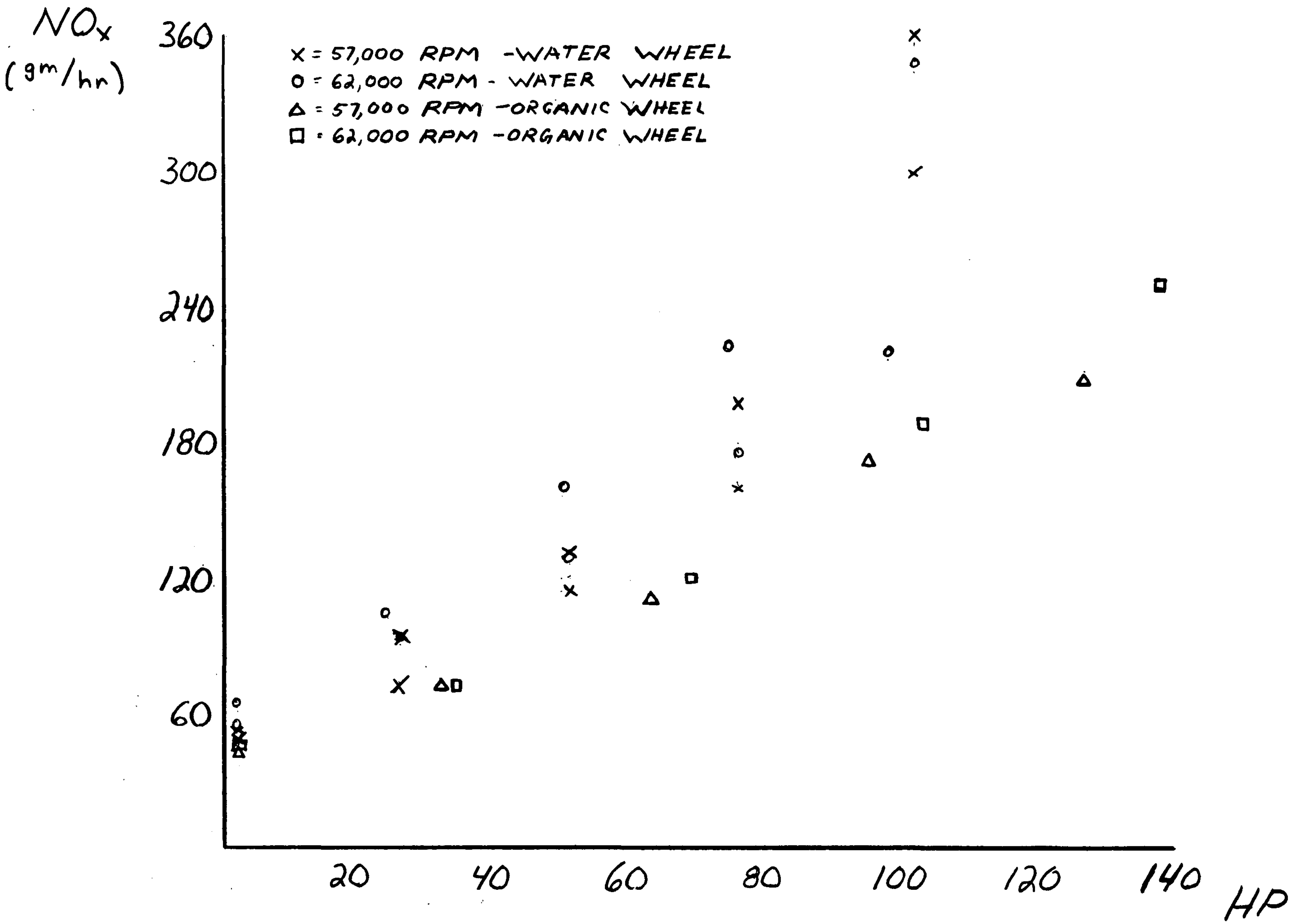

FIGURE 7 - NO_x vs HP

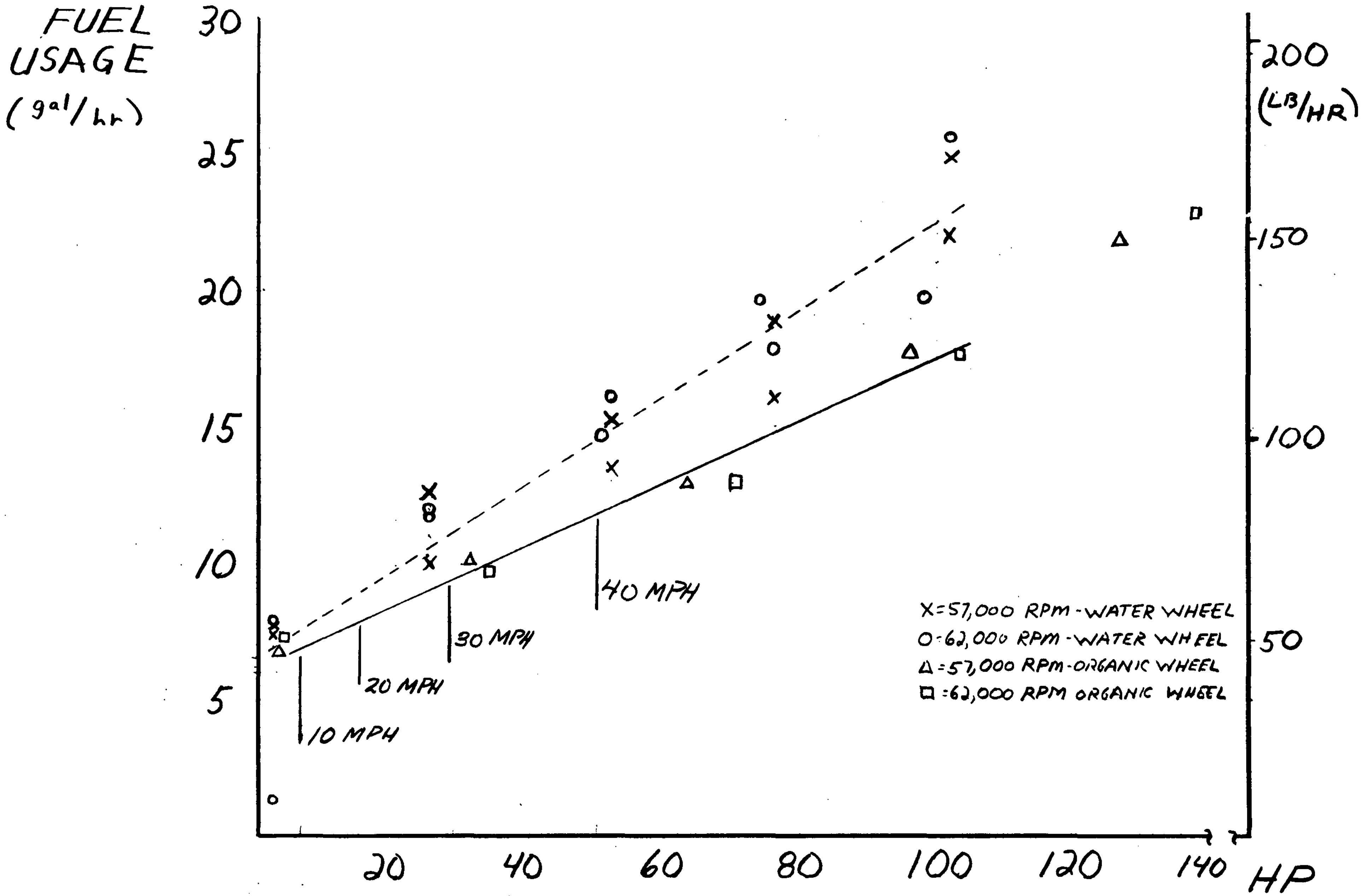

FIGURE 8 - FUEL USAGE vs HP

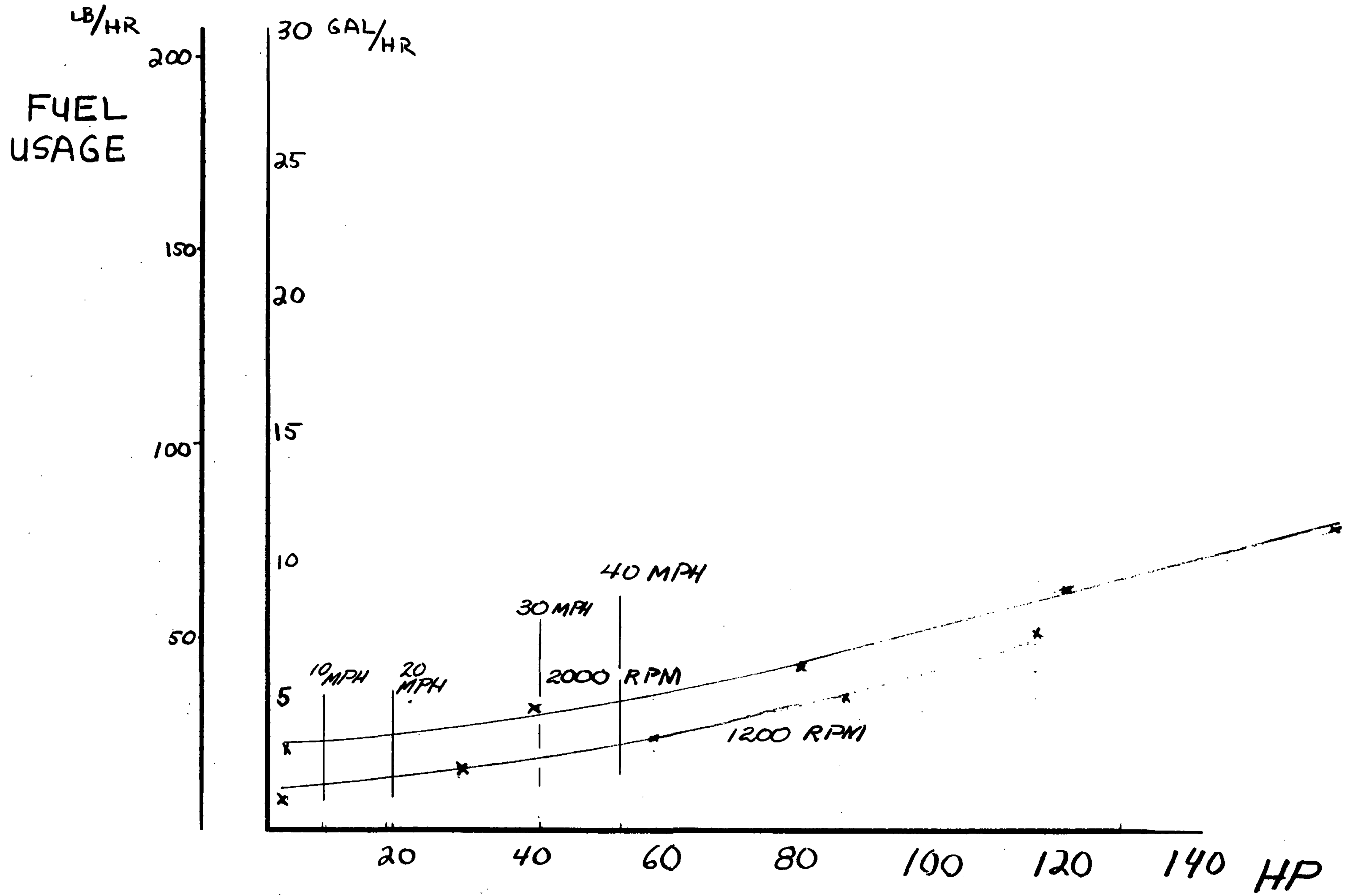

FIGURE 9 - FUEL USAGE vs HP

TABLE I

53-Passenger Steam Rankine Cycle Bus Mass Emissions
Federal Experimental 13-Mode Procedure

MODE	% POWER	HORSEPOWER	TURBINE RPM	HC gm/hr*	CO gm/hr	CO_2 gm/hr	NOx gm/hr	Lbs/hr	gal/hr
1	Idle	0	0	14.3	12.0	3,050	2.8	2.2	.3
2	2%	2.0	57,000	39.5	73.0	70,400	48.0	49.4	7.3
3	25%	25.6	57,000	31.5	67.7	96.700	73.0	67.8	10.0
4	50%	51.2	57,000	21.6	76.4	132,300	113.4	92.7	13.6
5	75%	76.8	57,000	26.3	129.1	155,000	160.6	108.6	16.0
6	100%	102.4	57,000	10.8	228.5	215,500	298.1	151.0	22.2
7	Idle	0	0	8.5	6.3	330	0	.3	.0
8	2%	2.0	62,000	37.0	82.6	76,400	53.8	53.6	7.9
9	25%	25.6	62,000	15.6	63.7	114,400	94.3	80.1	11.8
10	50%	51.2	62,000	21.8	92.3	143,600	129.6	100.6	14.8
11	75%	76.8	62,000	30.3	160.9	173,600	175.7	121.7	17.9
12	100%	102.4	62,000	11.4	379.1	246,700	346.0	173.0	25.5
13	Idle	0	0	20.0	17.6	5,780	3.7	4.1	.6

$$\text{Brake specific emissions} = \frac{\Sigma\ (\text{pollutant} \times \text{weighting factor})}{\Sigma\ (\text{measured BHP} \times \text{weighting factor})}$$

w.f. = .2 x avg. idle for idle mode
w.f. = .08 power modes

HC	.5	gm/Bhp-hr*
CO	2.7	gm/Bhp-hr
NOx	2.9	gm/Bhp-hr

*HC data based on CVS bag sample. A heated FID sample would give higher values.

TABLE II

53-Passenger Steam Rankine Cycle Bus Mass Emissions
Federal Experimental 13-Mode Procedure

MODE	% POWER	HORSEPOWER	TURBINE RPM	HC gm/hr*	CO gm/hr	CO_2 gm/hr	NOx gm/hr	Lbs/hr	gal/hr
1	Idle	0	0	16.9	17.7	5,280	3.8	3.8	.6
2	2%	2.0	57,000	34.9	77.6	75,900	52.7	53.3	7.8
3	25%	25.6	57,000	8.0	44.9	121,900	94.9	85.4	12.6
4	50%	51.2	57,000	2.1	76.7	147,400	131.8	103.2	15.2
5	75%	76.8	57,000	1.5	124.8	183,700	197.9	128.7	18.9
6	100%	102.4	57,000	5.9	296.0	238,000	359.5	166.8	24.6
7	Idle	0	0	2.2	8.4	540	0	.4	.1
8	2%	2.0	62,000	18.6	54.5	13,500	65.6	9.5	1.4
9	25%	24.6	62,000	5.5	47.3	116,600	103.8	81.6	12.0
10	50%	49.3	62,000	6.6	101.1	155,900	160.7	109.2	16.1
11	75%	74.0	62,000	9.2	162.7	189,600	221.0	132.8	19.6
12	100%	98.6	62,000	9.1	157.0	191,000	219.0	133.8	19.7
13	Idle	0	0	12	17.1	6,070	5.1	4.3	.6

Brake Specific Emissions

HC	.3	gm/Bhp-hr*
CO	2.3	gm/Bhp-hr
NOx	3.2	gm/Bhp-hr

*HC data based on CVS bag sample, a heated FID would give higher values.

TABLE III

53-Passenger Steam Rankine Cycle Bus Mass Emissions
Federal Experimental 13-Mode Procedure

MODE	% POWER	HORSEPOWER*	TURBINE RPM	HC gm/hr**	CO gm/hr	CO_2 gm/hr	NOx gm/hr	Lbs/hr***	gal/hr***
1	0	0	0	0	0	0	0	0	0
2	2%	2.6	57,000	46.6	107.8	65,400	42.9	45.0	6.8
3	25%	31.9	58,000	17.2	73.4	98,600	72.3	69.1	10.2
4	50%	63.9	58,000	9.2	74.3	125,600	108.7	88.0	13.0
5	75%	95.8	58,000	36.0	176.1	172,200	170.4	120.7	17.8
6	100%	127.7	60,000	108.4	411.3	211,700	205.2	148.8	21.9
7	0	0	0	5.7	5.2	126	0	.1	.0
8	2%	2.8	62,000	35.9	79.7	69,500	47.6	48.8	7.2
9	25%	34.5	62,000	7.6	31.6	96,400	71.6	67.5	9.9
10	50%	69.0	62,000	0.0	35.9	129,300	121.9	90.5	13.3
11	75%	103.6	62,000	4.4	112.1	172,100	188.7	120.5	17.8
12	100%	138:1	62,000	14.6	223.2	220,600	247.6	154.6	22.8
13	0	0	0	8.3	7.3	0	.9	.0	0

Brake Specif Emissions

HC	.4	gm/Bhp-hr*
CO	2.0	gm/Bhp-hr
NOx	1.9	gm/Bhp-hr

*Organic turbine wheel
**HC data based on CVS bag sample, a heated FID sample would give higher values.
***Diesel no. 1 6.79 lbs/gal

TABLE IV

53-Passenger Steam Rankine Cycle Bus Mass Emissions
Steady State Modes*
grams/hr

MPH	HORSEPOWER	TURBINE RPM	GEAR	HC gm/hr	CO gm/hr	CO_2 gm/hr	NOx gm/hr
10	6.3	46,000	1	29.1	81.6	75,100	55.1
20	17.2	54,000	2	29.7	61.7	87,400	40.0
30	32.5	54,000	3	32.9	86.9	92,900	79.5
40	63.7	54,000	4	10.7	59.1	122,500	115.4
48	87.7	64,000	4	15.0	101.0	153,400	158.4

grams/mile

MPH	HORSEPOWER	MILES/GAL	HC gm/mi	CO gm/mi	CO_2 gm/mi	NOx gm/mi
10	6.3	1.3	2.9	8.1	7,510	5.5
20	17.2	2.2	1.5	3.1	4,370	3.3
30	32.5	3.1	1.1	2.9	3,000	2.6
40	63.7	3.2	.3	1.5	3,060	2.9
48	87.7	3.0	.3	2.2	3,200	3.3

*Organic turbine wheel

TABLE V

Ann Arbor Bus Route Mass Emissions
grams/mile

DIESEL BUS	DATE	HC**	CO	CO_2	NOx	MPG***
	10-16	5.1	14.9	2,004	30.1	4.8
	10-16	5.2	14.3	1,996	30.4	4.8
	10-16	11.5	14.5	2,194	27.0	4.3
	10-17	4.9	11.5	2,044	33.1	4.7
	10-17	4.3	14.6	2,156	37.0	4.4
Diesel Bus	Average	6.2	14.0	2,079	31.5	4.6
Steam Bus	10-23*	3.3	7.0	9,060	8.9	1.0

*Steam bus turbine wheel failed, test stopped at 4.95 miles.

**For Diesel bus this is heated continuous sampling line data. For steam bus it is CVS result - heated continuous sample estimated to be 30% higher

***Diesel no. 1

TABLE VI

45-Passenger Diesel Bus Mass Emissions
Federal Experimental 13-Mode Procedure

MODE	% POWER	HORSEPOWER	TURBINE RPM	HC gm/hr	CO gm/hr	CO_2 gm/hr	NOx gm/hr	Lbs/hr*	gal/hr*
1	0	0	550	20.0	35.7	4,950	45.0	3.5	.5
2	2%	2.3	1,200	57.0	122.6	12,240	81.9	8.8	1.2
3	25%	28.9	1,200	47.9	59.5	21,540	180.8	15.2	2.2
4	50%	57.8	1,200	46.7	42.6	33,500	497.8	23.6	3.5
5	75%	86.8	1,200	46.9	79.1	48,280	972.0	34.0	5.0
6	100%	115.7	1,200	61.9	3396.0	65,790	1007.6	49.9	7.4
7	0	0	550	21.1	39.9	4,550	46.9	3.3	.5
8	2%	3.2	2,000	95.7	123.2	28,820	185.7	20.5	3.0
9	25%	40.1	2,000	89.4	82.5	45,070	444.0	31.8	4.7
10	50%	80.3	2,000	92.4	75.0	59,510	787.0	41.9	6.2
11	75%	120.4	2,000	87.5	53.3	88,400	1797.0	62.1	9.1
12	100%	160.6	2,000	128.1	988.0	108,930	2058.0	77.6	11.4
13	0	0	0	20.6	37.8	4,750	46.2	3.4	.5

Brake Specific Emissions

HC	1.2	gm/Bhp-hr
CO	7.4	gm/Bhp-hr
NOx	11.8	gm/Bhp-hr - Diesel procedure
	8.4	gm/Bhp-hr - CVS results

*Diesel no. 1 6.79 lbs/gal

TABLE VII

Heavy Duty Emissions

Standards		HC	CO	NOx	HC + NOx
1974 Federal & California				40	16
1975-76 California				30	10
1977 California				25	5
Steam Bus	10-25	.5*	2.7	2.9	3.4
	10-25	.3*	2.3	3.2	3.5
	10-29**	.4*	2.0	1.9	2.4
Diesel Bus 6V71N(2V)C60	10-15	1.2	7.4	11.8	13.0
Diesel Engine (Durability test) 1974 Certification Data					
6V71N92V)C60	0 hours		7.3		14.3
	125 hours		4.1		13.6
	1000 hours		2.7		14.9
Certification Engine	125 hours		5.2		12.6
	125 hours		4.5		11.2

*not heated FID
**organic turbine wheel

TABLE VIII

Bus Horsepower Requirements*

	Steam Bus 28,500 lb.		Diesel Bus 26,750 lb.	
MPH	Road HP (cal)	Dyno HP	Road HP (cal)	Dyno HP
10	5.7	5.0	9.2	9.1
20	14.6	13.6	19.2	18.2
30	28.8	28.5	41.0	38.8
40	50.3	53.6	53.2	52.9

*Driveline and rear wheel hp losses are included in dyno hp and are determined by motoring vehicle. This dyno hp is also corrected for transmission losses. The steam bus had radial tires, the Diesel bus had bias tires. When the steam bus is equipped with bias tires, its hp requirements are almost identical to the Diesel bus.