EXHAUST EMISSIONS FROM TWO GENERAL MOTORS STEAM CARS

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Introduction

As part of a planned program to develop new techniques and test procedures for measuring exhaust emissions from alternate powerplants for automobiles, tests were conducted on two Rankine cycle powerplants installed in chassis and supplied by the General Motors Corporation.

The development of alternate powerplants to the conventional internal combustion engine is the goal of the Advanced Automotive Power Systems Program of the Environmental Protection Agency. Those alternates which can meet or lower the Federal exhaust emission standards of 1976 will be developed through to demonstration before 1975. The exceedingly low levels of HC, CO, and NOx to be permitted by that date coupled with the unique mass flow characteristics of most alternates under study warrant that considerable research into new measurement methods be undertaken; thus, the testing reported herein.

The two steam cars were made available, at no charge to the Federal Government, by the General Motors Corporation. Delivery of the cars was made to Building 2042 on March 29.

Vehicle Description

The cars had been designated previously as SE 101 and the SE 124 by General Motors. Both cars burn kerosene, use water as the working fluid, use reciprocating expanders, and drive the rear wheels through more or less conventional trnasmissions.

The SE 124 was built by Besler Developments, Inc. of Emeryville, California. This engine uses a double acting, double expansion V-2 expander with a displacement of 124 cubic-inches and is mounted in a 1969 Chevelle sedan. This powerplant is considered to represent a 1930 technology level.

The SE 101 uses a 1969 Pontiac Grand Prix body, with a longer than normal engine compartment to accommodate the powerplant. The expander is an in-line four cylinder, single stage, single acting engine of 101 cubic-inches displacement. The design philosophy employed in the SE 101 was that this powerplant should provide the conveniences of the contemporary automobile including power steering, power brakes, and air conditioning. A detailed description of the vehicle can be found in SAE Paper No. 700163.

Test Procedures

The 1972 Federal Test Procedure was followed as closely as possible, however, certain deviations were made in the test procedure (intended for conventional internal combustion engine powerplants) because of the nature of these unconventional engines.

The high exhaust flow rates of the two test vehicles dictated use of a Constant Volume Sampler (CVS) with a larger capacity than that specified in the 1972 Federal Test Procedure. The CVS capacity was 400 scfm for the SE 124 and approximately 1000 scfm for the SE 101.

During the testing, the combustor exhaust duct was not positively connected to the CVS inlet duct. Instead, a gap of about one inch was left. This was done to avoid a large pressure drop across the combustor, which might have adversely affected combustion. Thus the combustor exhaust and dilution air were pulled through the same duct to the CVS pump. Sample bags of the diluted exhaust were read on two different sets of instruments, which were calibrated to low concentration ranges.

In console #1, NDIR is used for measuring CO, CO_2, and NO, with a FID used for hydrocarbons. The other console (#2) uses a NDIR for CO and CO_2, with a FID for hydrocarbons. The NOx is measured using a chemiluminescent analyzer with the Saltzman technique as a backup.

In addition, undiluted exhaust hydrocarbons were monitored using a Beckman heated FID. Fuel consumption was determined by GM personnel using a GM digital fuel meter.

Because of the relatively long warm-up time required by each of these steam cars to get underway from a cold start, the LA 4 driving schedule was not started until the cars were fully capable of following the schedule. This warm-up procedure, which required between one and two minutes, consisted of getting up a head of steam in the boiler (achieving full pressure), followed by a short expander idle period until full steam pressure again was attained. Only then was the driving schedule started.

Sample bag filling began with initial lighting of the combustor, and continued through the warm-up period as well as the entire driving schedule. On one test of each car a sample bag for the start and warm-up was filled and measured, with a separate bag then being used during the LA 4 driving schedule.

Results and Discussions

The mass emissions data for both cars are presented in grams per vehicle mile in Table I. These are based on bag concentrations as measured on console #2. The NOx data are corrected to 75 grains humidity and are presented as NO_2. The SE 101 data have been corrected according to our latest CVS calibration at the high flow rate. The masses shown are for the total test including the start and warm-up period.

The hydrocarbon data presented in this report are based on readings of a cold bag of a diluted sample on an unheated FID. It is believed that these figures may be significantly less than the actual HC emissions, because of condensation of the heavier HC molecules 1) on the walls of the CVS inlet duct, 2) in the CVS heat exchanger, sample pump and plumbing, and sample bag, and 3) in the console #2 plumbing.

Data from the hot FID were observed on each engine to study combustor transients during the run. It is interesting to note that these traces clearly show large concentration spikes when the combustors go on and off.

On all SE 124 tests the inertia weight was 3500 pounds, while on the SE 101 5500 pounds was used. The final test of the SE 101, test no. 12-1453, was run at 3500 pounds in an attempt to evaluate the two systems on an equal weight basis. This resulted in a ten percent decrease (approximately) in fuel consumption and little else. In that test a smaller-than-normal sample bag was inadvertently used and sampling was halted at 1200 seconds of the LA 4 driving schedule. As a result, the concentrations of pollutants in the bag, and the resultant mass emissions, ignore the final 171 seconds of the driving schedule.

Inspection of Table I shows that neither car meets the 1975 exhaust emission standards. The SE 124 consistently displayed lower emissions than the SE 101 by a factor of two or more for each pollutant.

The hot start emissions from each car are presented in Table II. As expected, emissions of HC and CO are lower, NOx emissions are higher, and fuel consumption is lower than when warm-up is included. Again, 1975 emission standards were not met by either vehicle.

The total mass emissions and fuel consumed during the warm-up period of each vehicle for the tests reported in Table II are presented in Table III.

Fuel consumption data are presented in Table IV. The miles per gallon figures were calculated from the CO_2 emissions data as well as the GM fuel data. It is likely that the fuel consumption of both cars would be considered unacceptable by contemporary standards. The SE 124, a 3500 pound car, delivered an average of about 6.5 miles per gallon of kerosene during the test procedure, including warm-up and LA 4 driving schedule, based on the GM fuel meter data. The SE 101, weighing 5500 pounds, gave 3 miles per gallon over the same conditions. The hot start data show that the fully warmed-up SE 124 delivered 8.6 mpg over the LA 4 driving schedule, and the SE 101 delivered 3.3 gpm.

For comparison, 5000 pound ICE-powered prototype vehicles with advanced emission control systems tested at Bldg. 2042 gave about 8 mpg on the cold start 1972 FTP. These tests were reported in Test & Evaluation Branch Report No. 71-19. Conventional 5000 pound ICE-powered cars give 9 to 11 mpg on the cold start test, and 3500 pound cars give 12 to 16 mpg.

To summarize a comparison of the two cars, the SE 101 emitted more than two times as much HC, CO, and NOx as the SE 124, and consumed over twice as much fuel. When tested at the same inertia weight as the SE 124, the SE 101 still consumed almost twice as much fuel.

Table I

GM Steam Car

Mass Emissions

Modified Cold Start 1972 Federal Test Procedure

Test No.	HC FID gm/mile	CO gm/mile	NO_x C.L. gm/mile	NO_x Saltzman gm/mile	CO_2 gm/mile	CVS Flow Standard cu. ft.	Fuel Flow cc
SE 124							
12-1440	.92	3.80	.87	.87	1148.51	8691	No Data
12-1442	1.19	4.46	1.89	1.44	1313.60	8230	4023
12-1446	.64	7.88	1.03	1.48	1322.74	8560	4360
12-1450	.70	4.49	1.21	1.32	1370.51	8666	4743
SE 101							
12-1444	3.73	14.08	2.00	3.48	2056.18	26085	9418
12-1445	3.47	17.26	2.10	2.56	3059.57	23802	9301
12-1451	2.36	14.10	2.44	3.44	2732.72	25331	9451
12-1453*	3.36	14.48	2.45	1.02	2700.93	25566	8399

* Inertia weight = 3500 pounds. Sample bag pulled at 20 minutes of the LA4 driving schedule.

Table II

GM Steam Cars

Mass Emissions

Hot Start 1972 Federal Test Procedures

Test No.	HC FID gm/mile	CO gm/mile	NO_x C.L. gm/mile	NO_x Saltzman gm/mile	CO_2 gm/mile	CVS Flow, standard cu. ft.	Fuel Flow, cc
SE 124							
12-1442	1.15	2.33	1.76	1.28	1109.3	7641	3298
SE 101							
12-1445	3.29	14.77	2.09	2.55	2853.98	22607	8584

Table III

GM Steam Cars

Mass Emissions During Warm-up

Test No.	HC FID grams	CO grams	NO_x C.L. grams	NO_x Saltzman grams	CO_2 grams	CVS Flow, standard cu. ft.	Fuel Flow, cc
SE 124							
12-1442	.28	15.61	.93	1.21	1532.24	589	725
SE 101							
12-1445	1.30	18.69	No data	No data	1545.67	1199	717

Table IV

GM Steam Cars

Fuel Consumption

Test No.		CO_2 gm/mile	Fuel cc	Miles/gal (CO_2)	Miles/gal (Fuel)
		SE 124			
12-1440		1148.51	No Data	8.3	No Data
12-1442		1313.60	4023	7.3	7.1
12-1442	Hot	1109.3	3298	8.6	8.6
12-1446		1322.74	4360	7.2	6.5
12-1450		1370.51	4743	7.0	6.0
		SE 101			
12-1444		3056.18	9418	3.1	3.0
12-1445		3059.57	9301	3.1	3.1
12-1445	Hot	2853.98	8584	3.3	3.3
12-1451		2732.72	9451	3.5	3.0
12-1453*		2700.93	8399	3.5	3.4

* Inertia weight = 3500 pounds. Sample bag pulled at 20 minutes of LA4 driving schedule.

Appendix

Bag Concentrations
GM Steam Cars

Test No.	HC ppm C	CO ppm	NO_x ppm	CO_2 %
12-1440				
Console 2	48.6	100	16	1.912
Console 1	56	100	104	1.75
12-1442 - Start & warm-up				
Console 2	29.1	800	33	5.02
Console 1	31	740	128	3.70
12-1442 - Hot LA 4				
Console 2	69	70	36	2.10
Console 1	78	80	96	1.82
12-1444				
Console 2	65.7	120	12	1.695
Console 1	93	160	82	1.49
12-1445 - Start & warm-up				
Console 2	66.3	470	no data	2.487
Console 1	67	510	60	2.24
12-1445 - Hot LA 4				
Console 2	66.9	150	14	1.826
Console 1	83	170	80	1.57
12-1446				
Console 2	34.2	210	18	2.235
Console 1	51	240	84	1.82
12-1450				
Console 2	37.2	120	22.40	2.287
Console 1	74	150	no data	2.15
12-1451				
Console 2	41.7	130	15.0	1.56
Console 1	70	150	no data	1.44
12-1453				
Console 2	60.3	130	15.4	1.528
Console 1	80	150	no data	1.47