74-13 DWP

An Evaluation of a 350 CID Compound Vortex Controlled Combustion (CVCC) Powered Chevrolet Impala

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Emission Control Technology Division
Office of Air and Water Programs
Environmental Protection Agency

NOTE REGARDING HONDA ACTION FOLLOWING CVCC IMPALA TEST

Honda R&D Co. Ltd. has informed EPA that the hot start emission problem encountered in the EPA test program has been investigated with the following results.

1. The hot start (Bag 3) tests were influenced by flooding of the auxiliary pre-chamber carburetor. The flooding was caused by a sticking float valve.

2. Honda has taken corrective action by redesigning the float valve system to prevent side forces on the valve body and changing the tip material to provide a more positive seal.

Although no further tests have been made by EPA on the redesigned system, it is acknowledged that the corrective action described by Honda reflects the type of "further engineering effort" anticipated in the attached EPA report in paragraph 2 of the Test Results section.

Background

In the fall of 1971 Honda Motor Company of Japan announced publicly that they had developed an engine featuring Compound Vortex Controlled Combustion (CVCC) which would meet the Federal emission requirements for model year 1975 without after-treatment devices such as thermal reactors or catalysts. To confirm what appeared to be a substantial breakthrough in emission control technology, EPA conducted confirmatory tests during December of 1972 on three Civic vehicles powered by 119 CID versions of this concept. The following 1975 FTP emissions values are the overall average values for the tests performed on those cars at the EPA laboratory:

Hydrocarbons (HC) 0.21 gm/mi
Carbon Monoxide (CO) 1.96 gm/mi
Oxides of Nitrogen (NOx) 0.81 gm/mi

After their earlier work on four cylinder engines and sub-compact cars Honda adapted the CVCC process to a larger engine and vehicle combination to demonstrate that the CVCC concept would successfully reduce emissions on full-size American cars. A 350 CID Chevrolet V-8 engine was modified and installed in a Chevrolet Impala. After Honda reported achievement of the 1976 Interim Standards, a confirmatory test program was scheduled by EPA.

Vehicle Tested

A 1973 Chevrolet Impala powered by a Honda Compound Vortex Controlled Combustion (CVCC) engine was tested by EPA. This CVCC engine was a modification of a stock 350 CID Chevrolet engine. The heads and intake manifold were replaced with the prechamber and dual carburetion systems which form the CVCC concept. Rated maximum horsepower was 160 hp at 4000 rpm for the CVCC engine as opposed to 160 hp at 3700 rpm for the stock 350 CID engine as measured by Honda.

The CVCC engine burns a heterogeneous air-fuel mixture. In concept it is similar in some respects to the stratified charge engines of Ford (PROCO) and Texaco (TCCS). While the Ford and Texaco engines use direct cylinder fuel injection to obtain charge stratification, the Honda CVCC engine obtains stratification with the use of a separately carbureted prechamber.

Two separate intake valves are used on each cylinder of the CVCC engine. One valve is located in the prechamber and the other in the main chamber. A small one-barrel carburetor is used on the 350 CID engine to supply a rich mixture to each prechamber. A four-barrel carburetor is used to supply the engine's main chamber with a very lean mixture. Combustion is initiated in the prechamber with a conventional ignition system and spark plugs (one plug per prechamber). As the burning gases expand from the prechamber, they ignite and burn the lean mixture present in the main chamber. A schematic of the combustion system appears in Figure 1.

The overall air-fuel ratio of the CVCC engine is significantly leaner than stoichiometric. Conventional engines cannot be operated as lean because of the difficulty in igniting homogeneous mixtures leaner than about 18:1 A/F. Ignition is easily achieved in the CVCC engine by locating the spark plug in the fuel rich prechamber. This very lean overall operation is conducive to low CO emissions because the high availability of oxygen facilitates the conversion of CO to CO_2. The combination of adequate oxygen and temperature in the main chamber is the essential factor in controlling HC emissions.

NOx formation is a function of air (N_2+O_2) availability and temperature. A significant portion of the combustion in the engine occurs in the very rich region of the prechamber where the air availability is low. By the time the combustion has progressed to the main chamber, where there is high air availability, the temperature has dropped because of expansion.

The Impala had accumulated 3000 miles with the CVCC engine at the time of the EPA testing. The vehicle was equipped with a three-speed automatic transmission, air conditioning, power steering and power brakes. No "add-on" type emission control systems such as catalysts, thermal reactors, air injection, or exhaust gas recirculation (EGR) were used.

Test Program

The following test work was conducted on the subject vehicle:

1. Four cold start 1975 Federal Test Procedures at 5000 pounds simulated vehicle inertia.

2. Steady state gaseous emission testing at idle, 15 mph, 30 mph, 45 mph, 60 mph.

3. One hot start split bag 1972 Federal Test Procedure at 5000 pounds simulated vehicle inertia and light duty rear wheel power setting.

4. One hot start split bag 1972 Federal Test Procedure at 5500 pounds simulated vehicle inertia and medium duty rear wheel power setting.

5. One Clayton Key-Mode test.

In addition to analysis for typical gaseous emissions the samples were analyzed for aldehydes using an MBTH (3-methyl, 2-benzothiazolinone hydrozone) method. Fuel consumptions were also calculated using a carbon balance technique. Because of Honda's scheduling commitments for the test car, there was not sufficient time to obtain particulate or sulfate emissions data.

Test Results

Test results are summarized in Tables I, II, III, IV, V and VI attached.

Table I presents the results of the 1975 Federal Test Procedure emission measurements. Tests 1 and 4 demonstrate that levels of CO and HC below the statutory 1975/76 levels can be achieved with this vehicle, and that oxides of nitrogen levels are consistantly below the 1976 interim standard of 2.0 grams per mile. During tests 2 and 3, problems associated with the hot soak period resulted in high levels of CO and HC during the bag 3 portion of the tests. The high CO level in bag 3 of test 2 appeared to be associated with flooding of the prechamber carburetor. This was corrected by Honda technicians prior to test 3. The high hydrocarbon level in bag 3 of test 3 was apparently caused by a false hot start which resulted in excessive cranking by the EPA driver. Another false start occurred on test 4, but the more experienced Honda driver was able to recover with less hydrocarbon penalty. It is believed that the hot start problems experienced on the prototype vehicle can be corrected with further engineering effort.

The consistently low cold start (bag 1) hydrocarbon and CO levels during all of the tests should be emphasized. An average value for bag 1 of 0.38 gm/mi HC and 3.51 gm/mi CO was observed. Good control of oxides of nitrogen was also demonstrated with this vehicle. An average value equal to 1.72 gm/mi was obtained for the 1975 FTP testing.

Table II gives 1972 FTP hot start results for both a light duty loading and a medium duty loading. This testing was conducted by running bag 1 and bag 2 sections of the 1975 FTP from a hot start (1972 FTP hot start split bag). The bag 1 and 2 data was then combined to give a 1972 FTP hot start result. Some problem relative to hot starting may be reflected in the medium duty results. Test number 2-H was run after readjusting the dynamometer load for a medium duty horsepower with the subject vehicle. Thus, prior to the hot soak the vehicle was subject to higher than normal loads. However, the bag 2 results show promise for the CVCC approach in medium duty vehicle application.

Table III gives steady state emissions and fuel economy test results. Table V gives results of Clayton Key-Mode testing.

Aldehyde levels as measured by the EPA MBTH method are given in Table IV. An average level of approximately .03 gm/mi was observed during this testing. In comparison with other late model cars, the CVCC engine appears to yield low aldehyde emissions.

Comparison of the subject vehicle's fuel economy with certification results for 1973 vehicles of similar weight and engine displacement is given in Table VI. It is apparent that the CVCC-powered Impala had comparable or slightly better fuel economy than these vehicles.

Conclusions

1. Although the results of this testing were not consistent as a result of hot starting problems, the ability of the CVCC engine concept to meet statutory 1975/76 hydrocarbon and carbon monoxide standards when applied to a full-sized vehicle application was confirmed.

2. Low cold start hydrocarbon and carbon monoxide levels were repeatedly demonstrated during this testing.

3. Although the statutory 1976 NOx standard was not achieved, good NOx control was demonstrated even without the use of EGR.

4. Fuel economy of this vehicle was comparable or slightly better than 1973 vehicles having similar weight and engine displacement.

5. Aldehyde emissions from the CVCC engine were found to be lower than from present production cars.

6. The CVCC engine achieved low emission levels without the use of "add-on" type devices or exhaust after-treatment.

HONDA CVCC ENGINE

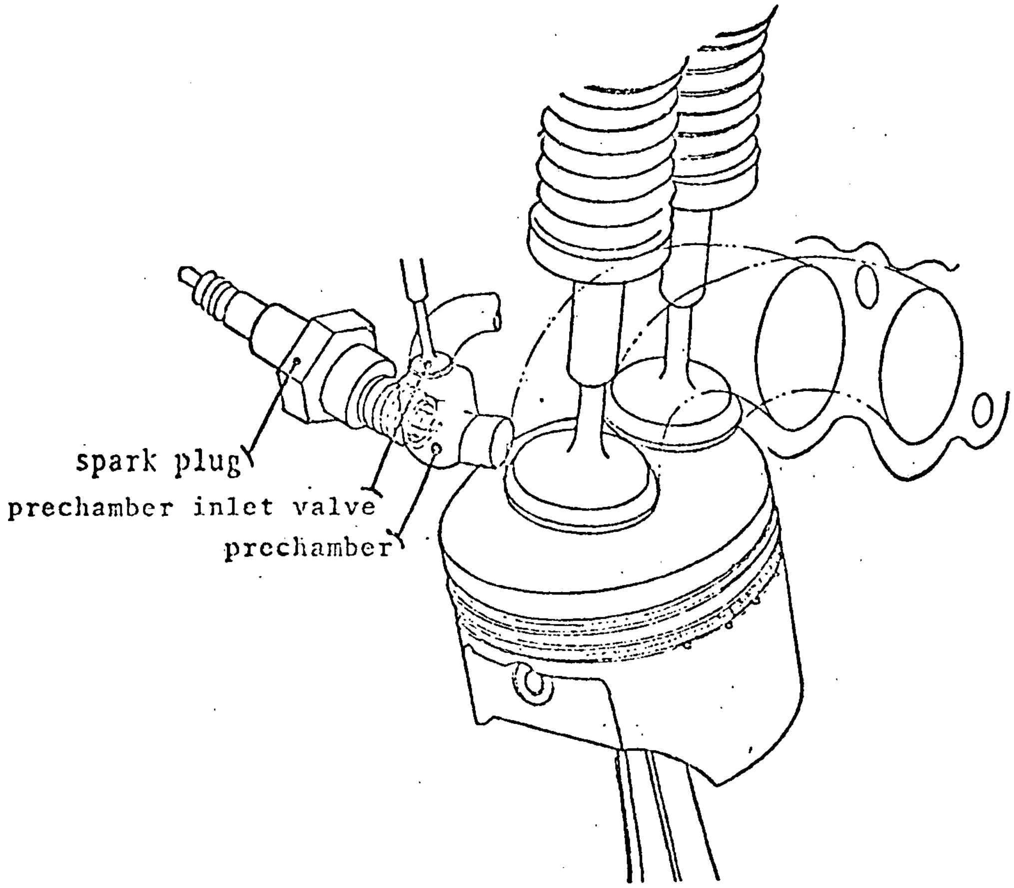

Figure 1

Table I
1975 FTP Results on 350 CID CVCC Powered
Chevrolet Impala

Test#	Hydrocarbon(gm/mi)				Carbon Monoxide (gm/mi)				Oxides of Nitrogen (gm/mi)				Carbon Dioxide (gm/mi)				Cal. Fuel Consumption
	Bag 1	Bag 2	Bag 3	Composite	Bag1	Bag 2	Bag 3	Composite	Bag 1	Bag 2	Bag 3	Composite	Bag 1	Bag 2	Bag 3	Composite	MPG
1	0.45	0.14	0.39	0.27	4.62	2.53	2.22	2.88	2.57	1.17	2.14	1.72	864.97	876.26	770.13	844.98	10.5
2	0.35	0.05	0.50	0.23	1.77	2.45	12.35	5.01	2.58	1.42	2.47	1.95	789.60	787.56	765.76	787.05	11.2
3	0.40	0.13	2.38	0.80	4.34	1.96	2.67	2.64	2.11	1.00	2.02	1.51	849.57	858.94	738.10	824.04	10.8
4	0.33	0.12	0.71	0.32	3.32	2.71	2.54	2.79	2.30	1.29	1.97	1.68	892.07	9.2.17	796.68	876.52	10.2

Note: Above tests run at 5000 lbs. inertia
and 14.7 rear wheel hp at 50 mph
(hp includes 10% for air conditioning)

TABLE II

Comparison of Light Duty vs. Medium Duty
Loading on 350 CID CVCC Impala
1972 FTP (Hot Start, Split Bag) Results

Test #	Hydrocarbon (gm/mi)			Carbon Monoxide (gm/mi)			Oxides of Nitrogen (gm/mi)			Carbon Dioxide (gm/mi)			Cal. Fuel Consump.	Comment
	Bag 1	Bag 2	Composite	Bag 1	Bag 2	Composite	Bag 1	Bag 2	Composite	Bag 1	Bag 2	Composite	MPG	
1 H	0.34	0.04	0.18	2.46	2.19	2.34	2.23	1.54	1.87	737.23	790.70	765.11	11.5	Inertia=5000 lbs hp=14.7 @ 50 mph
2 H	2.83	0.05	1.38	2.91	2.23	2.56	2.77	1.55	2.13	834.85	853.55	844.45	10.4	Inertia=5500 lbs hp=22.7 @ 50 mph (Med. Duty LD.)

NOTE: Because of an apparent hot start problem on test 2H, the bag 1 data are questionable. However, the bag 2 data illustrate that there was very little increase in emissions when the vehicle was tested using medium duty loading.

TABLE III

Comparison Steady State Emissions
350 CID CVCC Impala vs. A Stock 1973 350 CID Impala

	HC		CO		NOx		CO_2		Fuel Economy (mpg)	
	350 CVCC	Stock 350	350 CVCC	Stock 350	350 CVCC	Stock 350	350 CVCC	Stock 350	350 CVCC	Stock 350
Idle (gm/5 min)	0.50	N/A	2.04	N/A	0.21	N/A	424.32	N/A	*	N/A
15 mph (gm/mi)	0.16	0.60	3.30	7.26	0.37	0.52	662.68	620.32	13.3	14.0
30 mph (gm/mi)	0.00	1.22	0.65	9.98	0.53	0.37	542.49	443.44	16.3	19.2
45 mph (gm/mi)	0.00	0.51	0.19	4.71	1.00	0.93	604.73	451.89	14.7	19.3
60 mph (gm/mi)	0.01	0.32	0.53	2.48	3.00	1.78	557.75	487.24	15.9	18.0

NOTE: a) CVCC data - - rear axle ratio: 3.08
- - loading characteristic is per belt-driven Clayton Dynamometer set at 14.7 rear wheel Hp at 50 mph

b) Stock data - - rear axle ratio: 2.73
- - loading characteristic is per belt-driven Clayton Dynamometer set at 14.0 rear wheel Hp at 50 mph

* 350 CID CVCC Idle Fuel Consumption: 0.58 gal/hr

Table IV

MBTH Aldehyde Results for
350 CID CVCC Powered
Chevrolet Impala

Test #	Comment	Composite Bag HC gm/mile	Ald'y gm/mi	% Ald'y
2	Cold Start 75 FTP	0.23	0.0286	12.4
3	Cold Start 75 FTP	0.80	0.0355	4.4
4	Cold Start 75 FTP	0.32	0.0195	6.1
2 H	Hot Start 72 FTP Split Bag	1.38	.0338	2.4
	350 CVCC---Average		0.0294	6.3
'73 Duster (225 CID eng.) Avg. 3 tests		1.80	0.116	6.5
'73 Maverick (302 CID eng.) Avg. 3 tests		2.25	0.104	4.6

TABLE V

Clayton Key-Mode Results
and Comparison for 350 CID
CVCC-Powered Chevrolet Impala

	HC ppm-c	CO ppm	NOx ppm
High Speed			
Avg. 15 1970-71 vehicle	136	4000	3151
Catalyst-equipped Prototype Ford Galaxie (351 CID)	29.9	181	286
350 CID CVCC Impala	2.01	91.7	563
Low Speed			
Avg. 15 1970-71 vehicle	158	5000	2013
Catalyst-equipped Prototype Ford Galaxie (351 CID)	47.5	52.4	390
350 CID CVCC Impala	5.68	206	236
Idle			
Avg. 15 1970-71 vehicle	192	22000	164
Catalyst-equipped Prototype Ford Galaxie (351 CID)	170	81.5	54.2
350 CID CVCC Impala	292	1010	97.9

Table VI

Comparison of 350 CID CVCC Impala
Fuel Economy with Similar Homogenous
Charge Gasoline Powered 1973 Vehicles

Vehicle	Eng. Displacement - CID	Test Inertia Lbs.	Axle Ratio	Economy MPG
Pontiac Catalina	350	5000	3.23	8.1
Olds Delta 88	350	5000	3.08	9.9
Olds Cutlass Supreme Vista Cruiser	350	5000	3.23	9.4
Buick LaSabre	350	5000	3.08	10.5
			Average	9.5
CVCC Impala	350	5000	3.08	Avg. '72: 10.4

Note: 1) Comparative Data taken from 1973 Certification results

2) Avg. '72 FTP Fuel Economy Results for CVCC Impala Calculated from Bag 1 and 2 results from '75 FTP Results.

3) Data from 1973 Chevrolet Impala certification not used because the car was certified at a lighter weight (4500 lbs.).