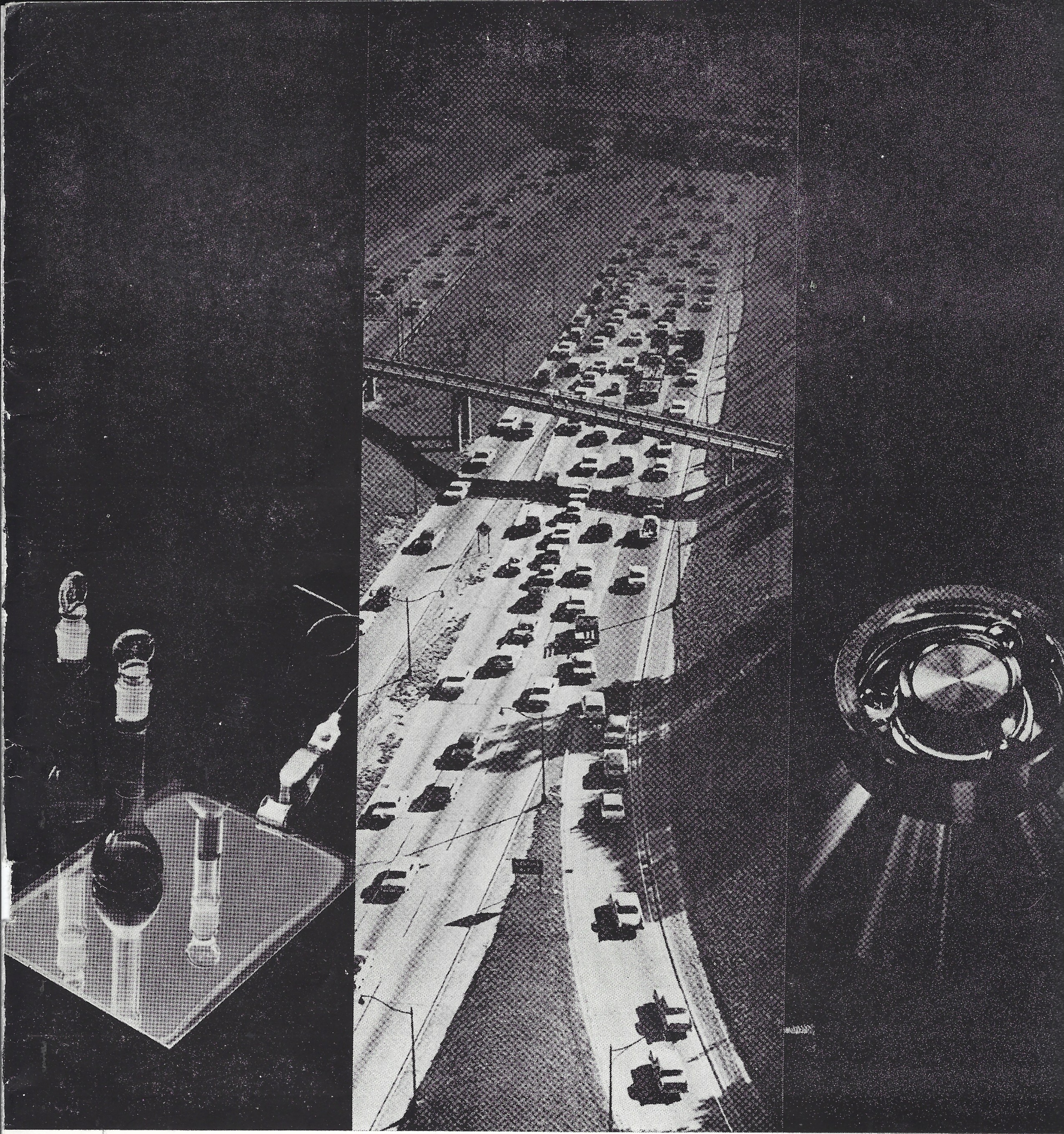

DukEngineer

DECEMBER 1964

Smog: Cause and Control

Part II. Approaching the Problem

By GARY WITZENBURG
Mechanical Engineering 1965

In Part I we looked at the nature and scope of the smog problem. We saw how organic waste materials combine with oxides of nitrogen in sunlight to form smog, and which operating conditions in a gasoline engine produce the incomplete combustion responsible for the emission of large quantities of these harmful substances. We also looked briefly at the geography of the Los Angeles Basin, where contaminants are unable to escape to the upper atmosphere and remain trapped at ground level throughout much of the year. Lastly, we saw the dangers of these contaminants in terms of health, disease, and food damage; considerations serious enough to necessitate a full-scale exhaust emission control program at least in the state of California. Part II will show how the automobile industry is attacking the problem through a concentrated program of research and testing.

TESTING

The California Motor Vehicle Pollution Control Board prescribes in detail a test procedure for exhaust emission control devices. The standard test is performed on a chassis dynamometer (which measures power delivered to the wheels under simulated road conditions) using vehicles of 1500-6000 lb loaded weight. Inertia wheels of 2000-5000 lb are used on the dynamometer to approximate the forward momentum of the vehicle. Continuous sampling of the exhaust gas is accomplished through the analytical train shown schematically in Fig. 1.

The four analyzers shown are most commonly Beckman Infrared Analyzers, each consisting of two sample chambers, a source of infrared light, and two sets of sensitized receiving cells. Exhaust gas is pumped

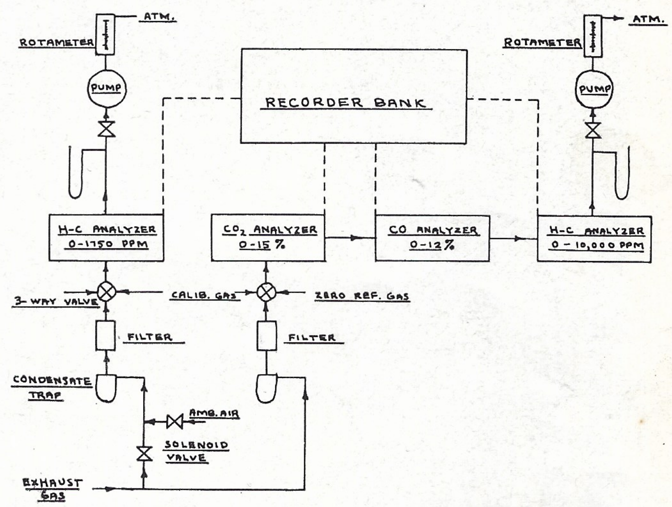

Figure 1.—Schematic of Exhaust Gas Sampling and Analytical System. (1)

through one chamber while a calibrated standard gas is sent through the other. Infrared rays are directed down from the top of each chamber, and that which is not absorbed by the gas in the chamber activates the energy cells at the bottom. The analyzer measures the instantaneous energy difference between the cells of the two chambers and transmits this information to the recorders. Hence a continuous record of the concentration of a substance in the exhaust gas, as compared to a known concentration of the same substance, is graphed by the recorder bank.

A tube is inserted into the exhaust pipe of the test vehicle and is divided into two paths, one to the sensitive low HC (hydrocarbon) analyzer, and one to analy-

(Continued on page 18)

Smog

(Continued from page 16)

zers for CO_2, CO, and high HC concentrations. During modes, of extremely poor combustion, when HC concentration rises far above the range of the low HC analyzer, that path is closed by a solenoid valve and purged by clean air from the atmosphere to avoid damage to the instruments. Flow rate is controlled by pumps and is maintained at a relatively high level. The calibrated gases enter through the three-way valves as shown.

According to the California Board, "the basic test is designed to determine hydrocarbon and carbon monoxide concentrations for an 'average' trip in a metropolitan area of 20 minutes from a cold start." (1) The seven-mode cycle, Fig. 2, is the result of considerable research into the average 20-minute trip in the Los Angeles area. Each cycle takes 137 seconds, and the operator (driving from tape-recorded instructions) must perform every idle, acceleration, deceleration, and cruise sequence in its specified time. The 15-50 acceleration, for instance, (sequences 7 and 8) is accomplished in 29 sec at a rate of 1.2 mph/sec.

Sequence No.	Mode	Acceleration mph/sec.	Time in Mode Seconds	Cumulative Time Seconds	Weighting Factor
1	Idle*		20	20	.042
2	(0-25)	2.2	11.5)	31.5	.244
	( )		)14		
3	(25-30)	2.2	2.5)	34	Data not read
4	30		15	49	.118
5	30-15	—1.4	11	60	.062
6	15		15	75	.050
7	(15-30)	1.2	12.5)	87.5	.455
	( )		)29		
8	(30-50)	1.2	16.5)	104	Data not read
9	50-20	—1.2	25	129	.029
10	20-0	—2.5	8	137	Data not read

*On first cycle only idle engine in neutral at 1,000 to 1,200 rpm for 40 seconds. All subsequent idle periods will be as specified: in gear, at normal speed, and for 20 seconds.

Figure 2.—The seven-mode Cycle.(1)

The test consists of eight consecutive seven-mode cycles: four warm-up cycles, a fifth which is not read, and three hot cycles. Average concentrations for the warm-up and hot cycles are combined to yield the reported values. The performance of a device is judged on the basis of average exhaust emissions of a representative group of vehicles on which it is installed. To meet California requirements, a device must reduce the average emissions of all vehicles of the group to below 275 ppm (parts per million of exhaust) hydrocarbons and 1.5% by weight CO, using fuels representative of the L. A. Basin.

Testing other than the standard California test may be done on engine dynamometers or on the road as well as on chassis dynamometers. Continuous sampling on the road, however, is difficult because of the nature of the instrumentation, which is usually quite bulky and sensitively calibrated. When road sampling is desired, it is generally accomplished by "grab sampling," where a known percentage of the total exhaust is collected in sample bottles or bags for later laboratory analysis. However, since California standards are the ones to be met, most of the testing done by automobile manufacturers at present is done by means of the standard test.

CONTROL

Possible methods of exhaust emission control fall into three classes: (2)

1) Devices that modify engine operating conditions
2) Devices that "treat" exhaust gases
3) Use of modified or alternate fuels

Induction devices. Devices that effect control by modifying engine operating conditions are generally induction devices which operate only during deceleration. These either restrict the amount of fuel entering the cylinders or improve conditions or combustion.

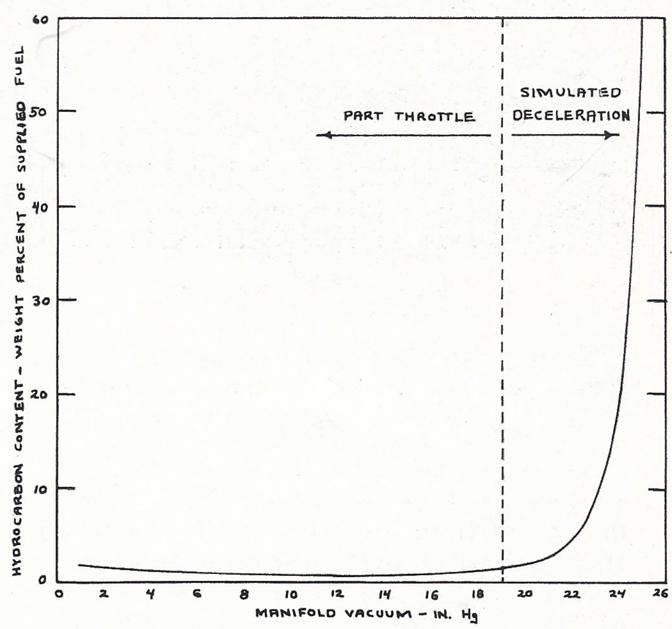

Figure 3.—Influence of manifold vacuum on hydrocarbon content in automotive exhaust.(4)

Fuel restricting devices are either of the air bleed type or cause a complete shutoff of fuel at high manifold vacuum. From Fig. 3 it can be seen that emission of un-

(Continued on page 22)

Smog

(Continued from page 18)

burned hydrocarbons is low for manifold vacuum below 22 in. Hg. Air bleed devices feed air into the carburetor idle circuit when the vacuum exceeds 22 in. Hg, which breaks the suction of the carburetor and stops the flow of fuel to the cylinders. Positive fuel shutoff devices stop fuel flow through the idle circuit by means of a valve actuated either by the closing of the throttle or by the build-up of manifold vacuum under decelerating conditions. Figure 4 shows one type of positive fuel cutoff system.

The large concentration of unburned HC emitted during deceleration is due to the extremely rich air-fuel ratio and poor air-fuel distribution which result when the throttle is suddenly closed and the manifold vacuum rises sharply. Slow, uniform closing of the throttle provides greatly improved air-fuel distribution and a resulting increase in combustion efficiency. Devices that improve conditions for combustion operate on this principle. These are of two classes: throttle retarders, which use a dashpot to slow the rate of throttle closure, and vacuum throttle openers which hold the throttle in a partly open position to keep manifold vacuum below 22 in. Hg.

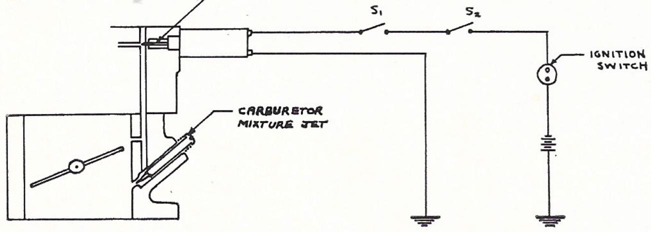

Figure 4.—Positive idle fuel cut off system.(4)

Of the induction devices, the fuel cutoff type is the most effective for long, heavy decelerations, but the throttle retarder works well for quick, sudden stops. For efficient exhaust emission improvement under all conditions, the more complex vacuum throttle openers have proven themselves best (3). Although these devices achieve reductions in HC and CO emission of 50-60%, they are not yet sufficient alone and are usually used in conjunction with some form of exhaust gas treatment.

Devices to treat exhaust gas. Proposed systems which improve exhaust emission by treating the exhaust gases are of five basic types: (2)

1) Afterburners.
2) Catalytic converters.
3) Liquid washing devices (absorbers).
4) Porous solids (absorbers).
5) Miscellaneous filters, condensers, and air dilution devices. Devices considered practical at the present time fall into the first two categories.

Because the quantity and combustible content of exhaust gases vary greatly under differing conditions, the temperature and oxygen requirements for combustion also vary. Space limitations are severe, since the unit must be compact enough to fit under a modern car without reducing road clearance. These design limitations impose the following technical requirements on any exhaust treating device: (3)

1) Extra air must be added under some conditions.
2) Some energy must be added to the incoming exhaust gases under most conditions.
3) Heat must be removed from the combustion chamber rapidly in order to prevent overheating of the materials.

The direct flame afterburner, using a high temperature combustion chamber with spark ignition, provides the most efficient oxidation of unburned fuel for all vehicles under every operating mode. A direct flame afterburner system is shown schematically in Fig. 5. Air

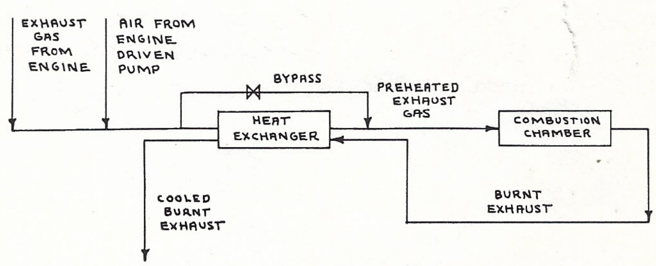

Figure 5.—Schematic diagram of an afterburner system. (3)

is added by a pump or venturi, and energy is supplied in the form of heat, or in some cases, by the addition of extra fuel. Thermal energy is obtained most easily from the burnt gases by sending the incoming exhaust through a heat exchanger as shown. The heat exchanger bypass valve, controlled by a temperature sensitive element, restricts the concentration of combustible materials entering the combustion chamber. Not shown in Fig. 5 is the somewhat complex ignition system necessary to start combustion.

The catalytic converter is essentially an afterburner in which the energy necessary for oxidation is supplied by a chemical catalyst. Air is added as in the direct flame system, but no supplementary fuel or ignition system is required. The principal disadvantage of the catalytic converter lies in the short life expectancy of catalysts. All presently known catalysts applicable to exhaust treatment units are subject to poisoning and extreme fouling by lead salts and other exhaust substances. In addition, they are soon cut down to minute particles by abrasion and carried out in the exhaust flow. A good catalyst must therefore not only be able to oxidize hydrocarbons and CO effectively, but must be light, tough, cheap, and easy to replace as well; and it should not oxidize nitrogen. Although present manufacturers claim life expectancies of 12,000-25,000 miles, the search for suitable catalysts is still very much in progress.

There are long lists of inventions which supposedly "clean" exhaust gases by filtering them through liquid solvents, porous solids, etc. Some are capable of removing a certain amount of the smog-forming substances from exhaust on a small scale, but their inventors usually fail to consider the large volumes of gases involved or the contact time necessary for effective removal. To operate efficiently, most of these systems would have to be larger than the car itself. (2)

Alternate fuels. (2) Suggestions have been made that the use of fuels other than leaded gasoline would alleviate the smog problem. Lead is a notorious catalyst poison, and the use of high-quality non-leaded gasoline would improve the efficiency and greatly lengthen the lives of catalysts in catalytic converter units. The addition of antiknock agents other than tetraethyllead (TEL) to gasoline has also been proposed, but no material is known with the desirable characteristics of TEL, and full-scale use of high-quality gasoline without it is economically unfeasible.

Another idea is the use of liquified petroleum gases (LPG), which is essentially propane and butane. Exhaust emitted from the combustion of LPG supposedly would not contain smog-forming substances. The limited supply and other economic problems, however, make this proposed solution also unfeasible at the present.

* * * * *

Until chemists find better fuels and better exhaust-treating catalysts, therefore, successful exhaust control devices will be for the most part variations of afterburners and engine design modifications. In Part III we will look at the cost of control to the consumer, some approved devices, some "new engine" ideas, and in general what the industry will have to offer in 1966. For the auto makers, the deadline is not far away.

REFERENCES

1. California Motor Vehicle Pollution Control Board. *Exhaust Emission Test Procedure for Gasoline-Powered Vehicles.* California, 1964.
2. Faith, W. L. *Air Pollution Control.* New York, John Wiley and Sons, Inc., 1959.
3. Rose, Andrew H., Jr. "Automotive Exhaust Emissions." From Stern, Authur C. *Air Pollution* (two volumes). New York and London, Academic Press, 1962.
4. U.S. Department of Health, Education, and Welfare. *Motor Vehicles, Air Pollution, and Health.* Washington, 1962.

■ ■ ■