Meteorological conditions make the air pollution problem particularly acute in the Los Angeles area.

The Control of Air Pollution

A progress report on smog control in Los Angeles County

by Robert L. Daugherty

Air pollution is becoming a worldwide problem, but it is particularly acute in the Los Angeles area because of the meteorological conditions that cause a temperature inversion more than 50 percent of the time. A layer of air aloft may have a temperature 20 degrees or more higher than the air at ground level and so it acts as a "ceiling" to prevent convection currents from dissipating contaminants into space. When this ceiling is several thousand feet above the ground there is no particular trouble, but when it drops down to 1,000 feet, or 500 feet, or even lower, the contaminants arising from the activities of something over 6,000,000 people are confined in too small a space.

Other places have legislation to cope with air pollution, but no place has a code for control that is as comprehensive and as strict as that of Los Angeles County. The word "smog" is coined from "smoke" and "fog" and is applicable to conditions in areas where coal is burned, but it is not an appropriate term here. Air pollution is the result of chemical reactions between many contaminants, and the products may be very different from the original constituents. Sunlight is an important factor in producing photochemical reactions. As an illustration, nitrogen dioxide (NO_2) is decomposed into NO and O and the free atom of oxygen then combines with O_2 in the air to produce ozone (O_3).

Air contaminants consist of: (1) invisible gases, (2) minute liquid droplets suspended in the air which produce haze and decrease visibility (3) particulate matter such as dusts and carbon particles which also decrease visibility. These air contaminants come from many different sources, but practically all of them may be put into one of 3 groups. In order of importance these are:

(1) Motor vehicle exhaust gases.

(2) Emissions from industry of all types, including steam power plants; heating plants for schools, hospitals, hotels, office buildings and others where residuum oil fuel is burned; oil refineries; storage and marketing of petroleum products; steel mills; iron foundries; chemical plants; and many others.

(3) And, formerly, emissions from open fires and single-chamber incinerators ranging from the silo-type in lumber yards, through the chute-fed type in apartment houses in which garbage and all other combustible refuse was burned, to the small backyard type in which theoretically only clean dry paper was burned — but in reality garbage, fresh grass cuttings, old rubber hose, greasy papers, oily rags, and other objectionable matter was consumed.

A reason for this grouping into three sources is the difference in the control problem for each.

(1) For the motor vehicle exhaust gases there is, up to the present time, no feasible commercial device for control for general use, but there may be in the near future. Until there is a practicable method of control there can be no enforcement of any law. The nuisance of smoking Diesel trucks and smoky emissions from worn "jalopies" is not included here because there is a law covering such emissions, which can be and is enforced by enforcement officers in patrol cars of the Air Pollution Control District. The main concern here is with the much greater quantity of invisible gases emitted from cars with engines in good condition.

(2) For industry there is a variety of control equipment — electrostatic precipitators, bag houses, water scrubbers, cyclone or centrifugal separators, gas-fired after-burners, catalytic chambers, sulfur recovery plants, and vapor recovery systems at gasoline loading-racks. And there are laws which are applied to industry which necessitate the employment of some means of control.

(3) The control for open fires and single-chamber incinerators was to prohibit their use. Open fires were forbidden in 1956. The use of 17,000 commercial incinerators was prohibited after July 1, 1957, and the 1,600,000 "backyard" incinerators for family use were banned after October 1, 1957. Multiple-chamber incinerators, which can be so designed as to comply with the rules and regulations, are permitted, but these are too large and too costly for family use.

Before there was any prohibition of such burning, it was estimated that about 2,000 tons of rubbish per day were burned in open fires and about 9,000 tons per day in single-chamber incinerators. To burn any substance completely it is necessary that four fundamental conditions be fulfilled:

1. There must be a proper amount of air supplied, usually from 10 to 50 percent more than the theoretical amount.
2. There must be a thorough mixing of air and combustible gases in the proper zone so that each particle of combustible matter may be in contact with the necessary oxygen at the proper time and place.
3. There must be a sufficiently high temperature for the reaction to take place. This temperature is about 2000°F to 3000°F.
4. There must be sufficient time for the chemical reaction to be completed before the temperature drops to too low a value for combustion to continue. This may be of the order of something below 1800°F.

THE AIR POLLUTION CONTROL DISTRICT

Los Angeles County's code for the control of air pollution is one of the most comprehensive — and one of the strictest — in existence. Violations of the air pollution control laws are criminal offenses. They are tried in regular courts, which may (and do) impose fines and even jail sentences.

The Air Pollution Control District of Los Angeles County is made up of three branches:

1. The Board of County Supervisors is the Legislative Branch.
2. The Air Pollution Control Officer — with a staff of engineers, inspectors, and enforcement officers — is the Executive Branch.
3. The Hearing Board is the Judicial Branch.

By State law the Hearing Board must consist of two attorneys and one chemical or mechanical engineer. It has a court room in the Hall of Records. It has three functions. It is a court of appeal for anyone denied a permit by the Control Officer. It can revoke permits when requested to do so by the Control Officer. But the greatest part of its duties consists in deciding cases of variances. A variance permits a plant to operate in violation and may be granted for a short time only if the petitioner can convince the Board that it is proceeding to remedy the situation and is diligent in so doing.

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With 6,000,000 people here now, and more arriving every day — what chance have we got of returning to a pure atmosphere?

These four conditions can be fulfilled in the furnace of a steam boiler. They cannot be fulfilled in a single-chamber incinerator or in the cylinder of an automobile engine. In the incinerator the combustion conditions are very bad, especially when wet rubbish or other unsuitable material is burned. Even with the best of care in operation the single-chamber incinerator will periodically emit smoke with an opacity in excess of that permitted by the Health and Safety Code of the State of California, and it will also emit ash in excess of that permitted. Some of the ash emitted may be easily seen, but much of it may be so fine as to be practically invisible to the naked eye, and it would add to the dust in the air and decrease visibility.

Emissions from single-chamber incinerators vary greatly in amount and in character, depending upon the material burned and the conditions of operation. The Air Pollution Control District estimated that prior to their banning these incinerators emitted 130 tons per day of organic gases and 222 tons per day of inorganic gases – or a total of 352 tons of contaminant gases, and from 45,000 to 225,000 pounds of particulate matter per day. The organic gases are hydrocarbons (CH compounds), phenols such as carbolic acid (C_6H_5OH), aldehydes such as formaldehyde ($HCHO$), and ketones such as acetone ($CH_3-CO-CH_3$). The inorganic gases are carbon monoxide (CO), sulfur dioxide (SO_2), sulfur trioxide (SO_3), oxides of nitrogen as (NO_2 and NO), and ammonia (NH_3) All of these are contaminants. Non-contaminants, which form the bulk of the emissions, are carbon dioxide (CO_2), nitrogen (N_2), and water vapor (H_2O).

The contribution of incinerators

No informed person ever contended that incinerators were the principal source of "smog," or that their abolishment would eliminate it. But their contribution, though minor in amount, consisted of very objectionable material, and they were responsible for odors, for which there is no numerical scale. It is my opinion that they were the chief source of just plain smoke.

This is borne out by a movie film taken one clear Sunday morning by a camera set up overlooking all of Pasadena, in which one frame was exposed every few minutes, so that in a few minutes one can see on the screen what took place over several hours. Shortly after daybreak it is possible to see all of Pasadena and even the Montebello Hills in the distance. Then one incinerator is lit and a plume of white smoke rises from it. Then smoke can be seen from a second incinerator, and a third, and many others. Soon all these plumes of smoke merge and blanket the entire city from view. The film is entitled *The City That Disappeared.*

The cost of control equipment

Industry has spent in excess of $79,000,000 for control equipment, practically none of which pays any dividends to stockholders. It is not at all uncommon for the control equipment to cost from 10 to 20 percent of the cost of the entire plant. For instance, a plant costing $40,000 required $10,000 more for control equipment, and another plant costing $1,300,000 needed $320,000 for control equipment. Industry has been very cooperative. In a number of instances, when the Air Pollution Control Hearing Board of Los Angeles, which controls smog violations, has been told of plans to spend several hundred thousand dollars for control, and the question is asked, "Is your company willing to spend this amount?", the answer has been, "Absolutely yes! Our board of directors has told us we must solve this problem regardless of how much it costs."

This amount is only the capital cost. The cost of operation is unknown, but covers such items as the electric power, water, gas, replacement of parts, repairs, and maintenance.

Some problems in industry are readily solved, but others involve much time and expense with many trials. An electrostatic precipitator, for example, may be entirely satisfactory in one plant and not in another similar plant.

Of the many types of industry only two, oil refineries and steam power plants, will be discussed here. The oil refineries have spent $42,000,000 for control equipment and, as a result, their emission of hydrocarbons has been reduced from 800 tons per day to 103 tons per day, and sulfur dioxide has been reduced from 900 tons per day to 115 tons per day.

Sulfur dioxide in the atmosphere

Steam power plants and other installations must use residuum oil fuel at times because there is not enough natural gas to meet all of our needs all of the time. All fuel oil in this area contains sulfur in an amount ranging from a minimum of about 1.2 percent up to 3 or 4 percent, the average being around 1.6 percent. Thus, for every 100 pounds of oil burned there will be emitted an average of 3.2 pounds of sulfur dioxide. The total amount of sulfur dioxide emitted to our atmosphere is now as much as 400 tons per day at times, and will tend to increase in the future. Hence a recent rule prohibits the use of fuel oil which contains more than 0.5 percent sulfur during the "smoggy" season from May 1 to September 30.

There is no known method of removing sulfur from fuel oil except at a prohibitive price and the product will then be a refined oil of some type. And there is no feasible way of removing the sulfur from flue gas, so far as is now known. For example, at a certain power plant the volume of flue gas at stack temperature of 745°F is 775,000 cubic feet per minute, and the percent of sulfur dioxide in it is only about 0.07 percent. To treat such a large volume of gas for such a small amount of sulfur dioxide is impractical.

The Air Pollution Control District reports these emissions from industry (in tons per day) as of July 1, 1959.

Contaminant	*Total Possible Emission*	*Actual Emission*
Hydrocarbons and other organic gases	1,705	580
Oxides of sulfur	1,325	330
Aerosols (smoke, dust, fumes, mists)	455	65
Carbon monoxide	1,680	890
Oxides of nitrogen	350	280
	5,515	2,145

In 1940 there were 6,000 industrial plants in Los Angeles County. In 1957 there were 18,000. In 1940 the population was 2,800,000. In 1959 it was 5,830,000. In the face of these increases the APCD has done well to keep the air pollution from becoming worse.

The gains that have been made by the elimination of single-chamber incinerators and by the control in industry have been nearly offset by the increase in automobiles and gasoline consumption. In Los Angeles County as of July 1, 1959, we have the following:

Population	5,830,000
Automobiles	2,634,000
Gasoline buses & trucks	286,000
Diesel powered vehicles	9,000
Gasoline, gallons per day	5,820,000
Diesel fuel, gallons per day	100,000

The population has been increasing at an average rate of about 200,000 a year and the gasoline consumption has been increasing at the rate of about 200,000 gallons a day per year. It was recently reported that as of January 1, 1960, the population of the county was slightly in excess of 6,000,000. There is approximately 1 automobile for every 2 persons, and the average consumption of gasoline is 2 gallons per car per day or 1 gallon per day per person. Hence the gallons of gasoline per day is equal to the population. The volume of exhaust gas each day would cover one square mile to a depth of 250 feet.

The air theoretically required to burn 1 lb. of gasoline is about 15 lb. It is necessary to have a high velocity of flame propagation in order that the flame may travel from the spark plug to the most remote part of the combustion chamber while the piston is on or near dead center. The flame velocity will be a maximum when there is a deficiency of air of from 10 to 40 percent. Another consideration is that maximum power will be attained when all of the oxygen in the cylinder is used up, and this requires an air/fuel ratio of around 12:1. Thus, both these factors lead to the same conclusion, which is that for good power at or near full throttle, the mixture must be on the rich side.

Incomplete combustion products

For other reasons, the mixture at or near idling must be even richer. For cruising at steady speed on part throttle the carburetor may provide a mixture with a ratio near to 15:1 or even up to 16:1 in some cases. But even this is not lean enough to ensure complete combustion. To have complete combustion, the mixture would be so lean that the engine would lack power, it would overheat, and combustion would be so slow that exhaust valves would be burned, and there might even be flame coming out of the tail pipe. Hence it is inevitable that there will be incomplete combustion products in the exhaust. This is not the fault of the fuel, the carburetor, or the engine. It is inherent in the combustion process.

The percentage of unburned or partially burned fuel is very high during deceleration, but the amount of fuel used during that operation is relatively small. The rate of fuel use is greatest at full throttle and so any incomplete combustion, even though small in percentage, will provide a substantial amount of incomplete combustion products in the exhaust. So, to estimate the amount of unburned fuel in the exhaust during a normal car operation it is necessary to know, not only what percentages of incomplete products are found in each cycle of operation, but also the total gasoline use in such cycles. In other words one must know the driving cycle of the car. And to estimate the total amount of air contaminants during the day from all cars, it is necessary to determine an average driving pattern for all cars as to the duration of time in idling, decelerating, accelerating, cruising, and full throttle steady speed.

As a result of such studies of driving patterns, the Air Pollution Control District has given the following estimates of automobile exhaust gases as of July 1, 1959, from gasoline powered vehicles only.

	Tons/day	*% of Fuel*	*% of Exhaust Gas*
Hydrocarbons, aldehydes, ketones and other organic gases	947	5.26	0.368
Oxides of nitrogen	430	2.39	0.167
Oxides of sulfur	48	0.268	0.019
Carbon monoxide (CO)	4,200	23.33	1.63
	5,625	31.248	2.184

In addition to the above, some very recent measurements have revealed that the "blowby" (or leakage) past the piston rings and emerging from the crankcase ventilator may be from 10 to 50 percent or more of the hydrocarbons in the exhaust. These emissions are mostly unburned gasoline with only a trace of exhaust gas. Thus the total hydrocarbons from motor vehicle operation may be from 1,000 to 1,500 tons per day. (Compare this with the 103 tons per day from the refineries).

Carbon monoxide—no hazard

Carbon monoxide is deadly in closed spaces, but it is not considered a hazard outdoors because its concentration there is too low. It is colorless, odorless, and tasteless, and is not a contribution to "smog" as we know it.

Oxides of nitrogen are formed by a union of the oxygen and nitrogen in the air when it is at high temperature in a furnace, in an engine cylinder, or in an electric arc. This is a contaminant which has not received much attention up to now.

It has recently been proposed that the crankcase emissions from blowby be returned to the intake manifold to prevent their emission into the air. It has also been found that recycling a small fraction of the exhaust gas into the cylinder will decrease the amount of oxides of nitrogen in the exhaust gases, but more study of this seems to be needed to determine its practicability.

A complete solution of the motor vehicle problem will require an afterburner of some type to complete the combustion of the gases after they have left the cylinder. The afterburner problem is a difficult one. The exhaust gases are hot, but the temperature is not high enough for spontaneous combustion and the addition of the necessary air will further reduce the temperature. Thus it is necessary to initiate combustion by a direct flame or by a catalyst. The problem is also difficult because the percent of combustible gases in the mixture is low. It is necessary to maintain a high temperature to ensure combustion, and this is hard on the material of the afterburner. The catalytic device has many merits, chief of which is that oxidation takes place at a lower temperature than with the direct flame type. But the catalyst has a short life, as it is "poisoned" by the tetraethyl lead used in all grades of gasoline.

A number of afterburners have been used on test cars and have given promising results. But a commercially successful one must not be too expensive; it must have a long life without any maintenance; replacement of parts should be easy and inexpensive; and an official inspection should not be required too frequently.

So far as the fuel is concerned, it is well known that a petroleum product is "cracked"— that is, its molecular composition is altered by being subjected to high pressure and high temperature simultaneously. But that is the condition in the cylinder of the internal combustion engine. In other words the engine is a good cracking device. It has been determined that hydrocarbons in the exhaust may be very different from those in the gasoline. Thus the U.S. Bureau of Mines found that when pure butane, a paraffin (C_4H_{10}), was used as fuel, the olefins (C_nH_{2n}) in the exhaust were 42.1 percent.

It has been determined by Dr. A. J. Haagen-Smit, professor of bio-organic chemistry at Caltech, that the olefins are more reactive than the paraffins, and there would be some advantage in reducing the percentage of the olefins in the exhaust. With the gasolines used in this area, there seems to be a relation between the proportion of olefins in gasoline and those in the exhaust, and hence there is to be a restriction in the percent of olefins permitted in the gasoline sold in the county.

A look ahead

The abolition of single-chamber incinerators and the use of various control means by industry has resulted in a material reduction of air contaminants from those sources. However, this has been nearly offset by the continual increase in the number of automobiles, with a resulting steady increase in gasoline consumption, until now the motor vehicle is responsible for about 70 percent of the air pollution. There is hope, though, that in the near future satisfactory control devices for automobiles will be available and, in that event, there should be a material reduction in the "smog" nuisance. But with over 6,000,000 people here now, and more coming every day, we cannot expect to return to the atmosphere of 50 years ago. We can, however, look forward to better conditions than we now have.