April 9, 1956

Mr. C. A. Harrell
City Manager
City of Cincinnati
Cincinnati, Ohio

Dear Mr. Harrell:

Transmitted herewith are copies of a report prepared by the Committee on Air Pollution from Automotive Exhaust. The report and recommendations contained therein, were unanimously approved by the Committee members.

Certain summary documents by individual committeemen are attached as Appendices I-V. All correspondence, minutes of committee meetings, and other matter accumulated during development of the report are held by Mr. Charles Gruber, Secretary of the committee, and are therefore available for review by City officials if required.

All the members of the committee have worked faithfully and effectively, and have exhibited sincere interest in recommending actions commensurate with the actual magnitude of the problem. It has been an unusual pleasure, and a profitable experience to act as Chairman of the group.

As you are perhaps aware, my transfer to the position of Director of Research, Los Angeles County Air Pollution Control District, effective April 15, 1956, makes it necessary to tender my resignation from the committee. It has been an honor to be a member.

Sincerely yours,

Leslie A. Chambers

Leslie A. Chambers, Chairman
Committee on Air Pollution from
Automotive Exhaust

Attachments

Report to the City Manager,
City of Cincinnati
by
Committee on Air Pollution
from Automotive Exhausts

I. The Composition of Automotive Engine Exhausts.

Extensive review of studies on engine exhausts leads to the following conclusions:

A. The exhausts are composed principally of water vapor, carbon monoxide, oxides of sulfur, oxides of nitrogen, aldehydes, acetylenic compounds, incompletely burned hydrocarbons, carbon (soot), and small amounts of inorganic fuel additives such as lead or boron.

B. Of these components, the visible exhaust (smoke) is largely made up of carbon and unburned fuel. The irritating quality of the exhaust is chiefly attributable to lower aldehydes (e.g. formaldehyde) and oxides of nitrogen. Oxides of sulfur and nitrogen, carbon monoxide, lead, and possibly some of the organic compounds are toxic when present in relatively high concentration.

C. While the relative amounts of these various substances emitted during engine operation vary with type of fuel, state of engine maintenance, and skill of operation, there is generally a greater output of all except oxides of nitrogen during acceleration and deceleration phases of vehicle operation. Relatively smaller amounts of other troublesome exhaust components are produced during the crusing phase.

D. While there appears to be no exact relationship between visible smoke, and emissions of irritants such as aldehydes, it is believed that excessive smoking constitutes a satisfactory index of poor combustion performance and the probable discharge of large quantities of irritating and potentially harmful substances. There is no practicable means for on-the-spot estimation of lower aldehydes, or other invisible noxious gases.

II. Health Aspects of Automotive Exhausts.

Numerous components of automotive exhausts (gasoline, diesel, propane) are known to be toxic for man. Concentrations of carbon monoxide, oxides of nitrogen, aldehydes, and other gases capable of affecting human life can unquestionably be developed by operation of motor vehicles within closed spaces for considerable periods of time.

On the other hand, there appears to be no evidence that exhausts from motor vehicles operating on open streets and highways in Cincinnati are capable of producing toxic substances fast enough to produce health effects on the community as a whole. Obviously exhaust gases can produce illness or death if breathed undiluted, but admixture with the general air supply is so rapid and complete under most conditions that toxic concentrations are unlikely to be attained except immediately adjacent to the exhaust vent. It is possible that concentrations of exhaust components much less than those required to produce illness, may some day be demonstrated to act cumulatively and to have subtle physiological effects long after the exposure. However, the present lack of evidence supporting such a possibility does not constitute a basis for municipal control.

III. Nuisance Aspects of Automotive Exhausts.

In a limited area adjacent to the exhaust vent of any automotive vehicle, and especially one in a poor state of maintenance, operated improperly, or burning improper fuel, there is likely to be created a nuisance to exposed persons. Noxious fumes (nitrogen oxides, sulfur compounds, aldehydes) often prove irritating to the eyes, nose and throat, may cause nausea, and are generally objectionable. Within reasonable limits this cannot presently be avoided if we are to depend on internal combustion engines for transport. Nevertheless, the magnitude of such nuisances and the frequency of their occurrence can be reduced by appropriate action to insure good mechanical maintenance of the engine and use of appropriate fuel.

IV. Magnitude of the Problem in Cincinnati.

Analysis of the available data on registration of automotive vehicles in Cincinnati and Hamilton County, and on automotive fuel consumption, indicates that approximately 185,000 vehicles burn about 370,000 gallons of gasoline and 46,000 gallons of diesel fuel daily in the city. Registrations in the county total 266,255. Passenger vehicles account for about 87% of the gasoline use, the balance of 13% being consumed by trucks and buses. About 87% of the daily diesel fuel use is by trucks, with buses accounting for the remainder.

Data developed by the Los Angeles County Air Pollution Control District indicate approximately 1100 tons of unburned hydrocarbons are released into the atmosphere of that area from the operation of about 2,500,000 motor vehicles. On the assumption of similar operational characteristics it would appear that the present release of exhausts to the atmosphere per square mile of area in Cincinnati approximates that in metropolitan Los Angeles, since Cincinnati uses about one-tenth as much fuel in about one-tenth of the area of Los Angeles. Apparently the relatively more fortunate situation of Cincinnati with respect to natural ventilation permits exhaust release at this rate (110 tons of unburned fuel daily) without the undesirable consequences which might otherwise ensue.

It is recommended that responsible agencies of the City be cognizant of the potential air pollution problem inherent in future increased use of automotive transport, and be prepared to adopt such control measures as may appear necessary and feasible should they be indicated by future changes in quantity or objectionable quality of exhaust gases and fumes. Such cognizance could be assured by periodic review of the situation by a committee of experts designated for the purpose.

V. Inspection Lane Experience.

The magnitude of the immediate problem - control of individual offending vehicles - is indicated by experience gained at the Cincinnati Inspection Lane during 1954 and 1955. Warnings or rejections on the basis of defective exhaust systems (noisy or smoking excessively) were issued to about 0.75% of all inspected vehicles. This means that less than seven vehicles in each thousand inspected were judged by the Inspection Lane Supervisor to be smoking excessively. On the basis of this experience, it appears that less than 1300 of the 185,000 vehicles registered in Cincinnati constitute the obvious sources of the present complaints. Immediate attention to the elimination of these nuisance sources is desirable and possible.

VI. Mechanical Maintenance and Proper Fuel in Relation to Excessive Exhaust.

It is the judgment of competent representatives of the automotive, public transport, and trucking industries that an automotive vehicle in proper maintenance, properly operated, and using fuel appropriate for the particular engine, will not give rise to excessive exhaust fumes and smoke. Furthermore, occurrence of excessive smoking during operation of the vehicle indicates an economic loss to the owner, since it evidences failure to burn fuel completely. Mechanical maintenance, procurement of appropriate fuels, and skill in highway operation, receive attention among the companies operating large fleets of trucks and buses. Owners of smaller fleets, or of individual vehicles, are not subjected to the same economic motivation; other means will be required to encourage them in the maintenance of engines and use of proper fuels.

VII. Experience of Other Cities.

The nuisance effects of excessive automotive exhaust emissions have concerned many cities in the United States. Questionnaires submitted to responsible officials in 26 municipalities as to their past experience and actions in relation to the problem, elicited responses from 19. (See Appendix V.)

While research has been conducted in most of them and consideration given to specific regulatory measures, very few have attempted any form of legally defined control. New York City has recently prohibited "emission of visible smoke or visible fumes from a standing vehicle or from one moving for a distance of more than 100 yards." The same city

also prohibits the operation of a bus engine at a terminal longer than three minutes, and has proposed a rule requiring "the use of a device for limiting vacuum in the manifold of a gasoline bus to 21 inches of mercury."

Some cities have used or experimented with propane, butane, or other liquified petroleum gas as a substitute for gasoline or diesel fuels in the operation of transport buses, and in Washington, D.C., a fleet of taxis is reported to be using LPG. In the light of recent research, it appears impracticable to adopt LPG generally in place of other fuels. Furthermore, there is no substantial evidence that significant air pollution from exhausts would be minimized through use of LPG.

VIII. The Unique Possibility for Control of Excessive Exhaust Emissions in Cincinnati.

The City of Cincinnati appears to be unique among major American municipalities in the possession of a ready-made mechanism for spotting excessively smoking vehicles and effectively denying them access to city streets until defects have been corrected. The Cincinnati Safety Inspection Lane is operated by, and under direct control of, the City government and is already empowered to reject vehicles on the basis of defective exhaust systems (excessive noise or excessive smoke). Since but one lane is operated by the city all vehicles are, in principle, subject to the judgment of the Supervisor of Inspection Lane; thus all are liable to the same person's subjective determination of what constitutes "excessive smoke."

Semiannual spotting and elimination of excessive smokers could be supplemented by empowering the Police Department to cancel current inspection stickers when, in the judgment of an officer, a vehicle is smoking excessively. The owner would then be required to have his vehicle reinspected within a limited period. Upon reinspection the judgment of the police officer could be affirmed or overruled by the Supervisor of Inspection Lane. No citation would be involved, and no punitive measures other than the usual requirement to correct defects within 10 days or be subject to citation for operation of the vehicle without a current inspection sticker.

IX. Recommendations.

The Committee recommends that official consideration be given to the following actions aimed at elimination of the more obvious automotive exhaust nuisances:

1. Use of the Safety Inspection Lane for determination of excessively smoking vehicles and their temporary (10 day) or permanent exclusion from city streets. It is assumed that suitable extension of reciprocity agreements with the City of Norwood can be negotiated if needed.

2. Empowering of the Police Department to require reinspection, within 10 days, of vehicles registered within the city and judged to be smoking excessively in operation.

3. Empowering of the Police Department to issue citations or warning notices for excessive exhaust smoking during operation to drivers or owners of vehicles not subject to Safety Lane inspection.

4. Prohibition of the practice of idling engines of buses at terminals for more than three minutes.

In addition, it is suggested that the City:

5. Consider appropriate action to require use by diesel powered automotive vehicles within the city, of diesel fuels meeting reasonable minimal quality specifications.

6. Provide for review of the local problems of air pollution, presented by automotive vehicles, every two years, in the interest of timely action to protect the health and comfort of the citizens of Cincinnati.

APPENDIX I

Report on the Hygienic Aspects of Atmospheric Pollution from Automobile Engine Exhausts

The significance of any specific problem of general air pollution, which occurs not as the result of an unusual incident or accident, but in consequence of activities which are part of the normal life of a community, must be considered on the background of our knowledge of the general problem. In fulfilling a public responsibility by the exercise of balanced judgment in a situation involving human safety and comfort and tinged thereby with some public apprehension or annoyance, it may be helpful to refer to certain basic facts and to views arrived at by the examination of the available evidence in a period of freedom from stress. With these considerations in mind, an article by the author of this statement, reprinted from the Proceedings of The First National Air Pollution Symposium (Pasadena, California, November 10-11, 1949) is attached. Since it was written, additional information has been made available by the increasing scope and ingenuity of present-day research. Some of the more recent facts which are pertinent to this report are referred to below. As a general and considered statement of the matters at issue, however, this article gives the position of the writer of the following paragraphs.

In proceeding from general considerations of air pollution to the particulars of the contamination of the air with components of the exhaust of automobile engines, it is necessary to recognize that one is concerned with the constituents of the original fuels which escape combustion altogether, and with the products of partial as well as complete combustion of the petroleum hydrocarbons and of certain other substances added to these hydrocarbons to impart certain desired properties to them as fuels for various types of internal combustion engine. The number and variety of the chemical compounds that are released into the atmosphere in this manner are very large, and since the actual components of specific fuels are not capable of detailed description as specific chemical compounds, so the multitude of the products of their partial thermal decomposition cannot be described except in the general terms of classes of compounds. Of the degradation products that have received the greatest attention in the past at the hands of investigators, much the greatest importance has been ascribed to carbon monoxide. Next in importance, no doubt, has been sulfur dioxide, and next the oxides of nitrogen. These may be dealt with at this point with a few simple statements.

1. Carbon monoxide from the exhaust gas of internal combustion engines has caused, and will continue to cause, many deaths under circumstances involving the exposure of persons to automotive exhausts in unventilated or ill ventilated places. Moreover, many persons, by virtue of their employment in spaces sufficiently contaminated with exhaust gases, suffer from varying mild degrees of carbon monoxide intoxication. City streets and

highways generally, however, are not sufficiently contaminated in this manner to give rise to symptomatic evidences of carbon monoxide intoxication among persons whose occupations require them to spend many or all of their working hours in these locations. Moreover, the results of analytical surveys of urban atmosphere have demonstrated that the prevailing levels of concentration of carbon monoxide are within safe limits, i.e., well under 100 parts per million parts of air by volume (1). Under highly unusual circumstances, an occasional individual, such as a traffic officer at a specific location, has been found to have absorbed a significant amount of carbon monoxide within his period of duty. Also, occasionally, persons in motor cars have been exposed to dangerous quantities of carbon monoxide while their cars were idling in a traffic jam at a time when the air-intake ports in the hood were open. It is of some importance to recognize that cars or trucks or buses equipped with diesel engines constitute a much less important source of this hazard than do those equipped with gasoline engines, the ratio of the concentration of carbon monoxide in the exhausts in the two instances being, on the average, somewhat more than 1 (diesel) to 10 (gasoline) (2).

2. The concentration of sulfur dioxide derived from the combustion of sulfur-containing petroleum hydrocarbons is small and, from the aspect of the public health, can only be regarded, at present, as insignificant (3). (Certain other sources of atmospheric pollution with sulfur dioxide, including the combustion of coal, are not always insignificant. It is highly probable, for example, that sulfur dioxide is an important factor in the effects sustained by many people in a "pea-soup" London fog of the persistent type that occurred in December of 1952 and again in December of 1955.)

3. The oxides of nitrogen, in and of themselves, have not been found to reach significant proportions, in consequence of the combustion of automotive fuels of ordinary composition, or of those containing nitrogenous addition products. This is not to say that some of the latter may not be found to have significance, but there is no present evidence that they do (3). On the other hand, a postulated interaction of oxides of nitrogen and other oxidants, such as ozone, in the atmosphere, with petroleum hydrocarbons, whereby in some manner, highly irritant substances are produced, may be an indirect effect of the occurrence of even low concentrations of such oxides in the atmosphere (4). Reference will be made later to this phenomenon.

Of the hydrocarbons and their incomplete combustion products, the following classes of constituents may be singled out for brief comment.

1. Certain mercaptans (organic sulfur compounds) may be implicated in the evil-smelling exhausts of engines operating on certain (sulfur containing) fuels.

2. Aldehydes (analogous to and including formaldehyde) are certainly involved in the irritant effects of exhaust gases on the upper respiratory and occular mucous membranes.

3. Polycyclic aromatic hydrocarbons give rise to the presence in the atmosphere of minute concentrations of compounds which under controlled conditions in the experimental laboratory, have been found to be capable of inducing cancer of the skin of susceptible animals (5). One must hasten to point out that any relationship between the latter type of contamination of urban atmosphere and the production of human cancer of the lung is purely conjectural. No experimental evidence has been found to substantiate such a relationship.

4. Lacrymators. In the Los Angeles area, an unusual and perhaps unique phenomenon, that of severe occular irritation from a contaminant (or contaminants) of the atmosphere, tends more and more, on the basis of current investigations, to be attributed to some reaction product (or products) of petroleum hydrocarbons with other atmospheric constituents. This up to the present time is the only observed and authenticated clinical response of any significant proportion of the population of any American city to any widely distributed atmospheric pollutant which may reasonably (not certainly) be charged to petroleum hydrocarbons or their combustion (incomplete) products.

The significance of the experience of the citizens of Los Angeles, in relation to the occurrence or development of the same or a similar situation in other American cities, is not altogether clear. It is possible that the same situation exists in many other cities in such minor degree as to be recognized only rarely and fleetingly or not at all. It is more likely, in the opinion of this writer, that certain peculiarities in the atmospheric and solar environment of Los Angeles are responsible for the occurrence of an organic synthesis (with the formation of a chemical compound that induces occular irritation and lacrymation) which does not occur or occurs only theoretically in other urban atmospheres. In the present atate of our information, no useful purpose would be served here by balancing the inconclusive evidence on the two sides of this question. One thing appears to be reasonably certain - namely, that if the situation in Los Angeles is to be regarded as a warning of what may develop later in other American cities, including Cincinnati, the warning is well in advance of the event, if for no other reason than that provided by topographical and meteorological factors in the Los Angeles area which would seem to put that city at a great disadvantage, as compared with most, if not all, other large American cities.

The question may be raised as to whether there may not be injurious effects, associated with the contamination of the atmosphere of our cities with automotive engine exhausts, of which we are not aware. This question has validity now only in terms of its worthiness as a subject for investigation. Such investigations are in progress. Those concerned with the possibly harmful effects of pollutants derived from petroleum hydrocarbons are being carried out most extensively (and are being reported fully) in Los Angeles, where the problem exists now in a troublesome form. Other extensive investigations are under way elsewhere, and it may be pertinent to refer to attempts which are being made in the Sub-Department of Preventive Medicine in the College of Medicine of the University of Cincinnati, under a grant of funds from the United States Public Health Service, to develop methods of investigation whereby specific physiological or abnormal human responses to atmospheric pollutants can be discovered and subjected to further study. Still other investigations of the potentially injurious components of the atmosphere in Cincinnati have been under way during the past ten years in The Kettering Laboratory of the University, and these have been augmented recently and extended to other areas of the country, by the work of the Robert A. Taft Sanitary Engineering Center of the U. S. Public Health Service. In view of these efforts, and of the acquaintance with the work of other investigators elsewhere in this country and abroad which has been engendered thereby, it would seem that any significant danger to the health of the citizens of Cincinnati from this source would be made known here as promptly as evidence could be developed here or elsewhere.

Something should be added to these paragraphs on the subject of the hygienic significance of the elements of nuisance associated with the pollution of the atmosphere of the City of Cincinnati by the products of the exhausts of automotive engine exhausts. There is no doubt that the mal-odorous and irritating materials released from motor vehicles are objectionable. The willingness of many, if not most, people to disregard the nuisance, thereby accepting it as a necessary concomitant of modern life and modern transportation, is not shared by all. Some, who have chronic respiratory diseases, and who believe, whether correctly or not, that they suffer increased distress because of this type of air pollution, find themselves greatly discommoded in their daily lives. Others, afflicted or not with present disabilities, live in a poorly founded but growing apprehension at the prospect of serious ultimate damage to their health. These inconveniences and anxiety, regardless of our judgments concerning their significance and validity, are matters of concern in the field of public health, if for no other reason than the surrounding air is so directly a part of human life, - is so obviously the very breath of life, - that any air-borne threat tends to be inescapable and hence a constant source of concern. There seems to be no means of dealing with this hygienic problem in modern life except through an educational process whereby those responsible for the protection of the health of the public come to be regarded with the respect and confidence which they deserve on the basis

of past experience. This fact suggests that the matters dealt with in these paragraphs, especially those which relate to the difficulties of finding any evidence of injury or ill health among our people from this source, and to the efforts being made to find even minor sources of injury to human health, need to be disseminated more widely than they have been by the responsible health agencies of the community.

Prepared by:
Dr. Robert A. Kehoe
University of Cincinnati
Department of Preventive Medicine
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Cincinnati, Ohio
January 15, 1956

APPENDIX II

Magnitude of the Problem:

The magnitude of the problem of air pollution of Cincinnati from automotive engine exhaust is rather difficult to assess in relation to other sources of air pollution. Setting down the daily consumption of gasoline and diesel fuel will bring out that a rather startling quantity of these fuels is burned daily in Cincinnati. For example, it is estimated by the Traffic Engineer(1) that 370,000 gallons of gasoline and 46,000 gallons of diesel fuel oil are consumed daily in the travel of 3,600,000 miles by passenger cars, trucks and buses on city streets. Table 1 breaks this down by type of vehicle and fuel consumed.

Table 1

Type Vehicles	Daily Mileage	Daily fuel cons. - Gal. Gasoline	Diesel
Passenger	3,200,000	320,000	
Trucks - Gasoline	200,000	50,000	
Buses - Gasoline	3,000	500	
Trucks - Diesel	200,000		40,000
Buses - Diesel	36,000		6,000
	3,639,000	370,500	46,000

Table 2 is the motor vehicle registration for Hamilton County for 1954 with the estimate for the City of Cincinnati.

Table 2

	Hamilton Co.	Cincinnati (Est.)
Passenger Cars	228,477	160,000
Trucks	23,448	17,275
Buses	496	400
Church buses	40	30
Farm trucks	1,345	345
Trailers	8,246	4,000
House trailers	295	200
Motorcycles	1,280	1,000
Dealers	381	300
Public owned	2,247	1,450
	266,255	185,000

EXHAUST FROM GASOLINE ENGINE. The spotlight of the contribution to air pollution from the exhaust products of gasoline engines comes from Los Angeles County, California. One of the effects of the now famous Los Angeles smog is the widespread eye irritation on days of severe smog. Extensive research has implicated the products of combustion from the gasoline engine as the source of one of the major contaminants responsible for the eye irritation effects. Research further implicates the strong California sunlight as being a factor in the chemical reaction producing the eye irritating compounds.

(1) Special Report to Committee on A.P. from Automotive Engine Exhaust, October 19, 1955.

In Cincinnati there is no widespread eye irritation complaint. In the long history of the Bureau of Air Pollution Control and Heating Inspection there has been only one incident of a multiplicity of eye irritation. This situation occurred on September 1, 1953 for about a period of one hour and involved some 30 persons. There has been no reoccurrence of such an incident since that time.

This evidence or lack of obvious evidence raises a question as to the extent of the contribution of exhaust from gasoline engines to the overall air pollution of Cincinnati and where it fits in importance to other sources of pollution.

If one sets out to observe, he can find a bad smoker here and there that contributes a heavy visible discharge to the atmosphere. These should be dealt with but beyond this point it is questionable whether the city should concern itself with the exhaust from gasoline engines. However, the time may come when this point of view will be no longer valid. This may come about by the continued increase of the use of automobiles dumping waste products into the air beyond the ability of our atmosphere to drain them off - or new scientific findings implicating exhausts as a health problem, that we at present are not aware of. Thus, except for the obvious smoker, future developments will set the course of dealing with gasoline engine exhaust in Cincinnati.

FUMES FROM DIESEL BUSES AND TRUCKS. The discharge of fumes from diesel buses and trucks is a more real problem in Cincinnati than the gasoline engine exhaust. The importance of the matter lies in the large number of localized situations of complaint, that is the diesel fumes causing discomfort and disturbances to pedestrians or to individuals riding in automobiles following a smoking bus, or the effect of the fumes on the shop keeper on heavily traveled streets during the summer months when doors and windows are open.

Prepared by:
Chas. W. Gruber
Air Pollution Control
and Heating Engineer
Cincinnati, Ohio
December 25, 1955

APPENDIX III

Subject: Conference with Mr. Jos. Maurer, Supt. of Municipal Equipment, and Mr. Tom Frey, Supervisor of Inspection Lane. Practices of the Inspection Lane dealing with exhaust systems. October 31, 1955.

The Cincinnati Safety Inspection Lane has maintained an inspection of the exhaust systems of cars going through the Lane for the past several years. Effective June 1955, Item 24 Exhaust System -- Too noisy or Emitting Excessive Smoke or Fumes -- was made an item of rejection. Prior to this time it was an item of warning.

The record of cars inspected and warnings or rejections issued are as follows:

Time Period	Cars 1st Insp.	Warnings or Rejections for Exhaust System	% Rejections
Year 1954	220,000	1069	.49%
1st 6 months 1955	118,000	1008	.85%
July, August and Sept. 1955	61,000	468	.77%
October 1955	21,000	146	.7%

The criteria for rejection is the judgment on the part of the inspector, which must be confirmed by the Supervisor, Mr. Frey, or a foreman on the Lane. In other words, a noisy or excessively smoking exhaust is first noted by the line inspector, who calls the supervisor for a final decision.

Rejections from all causes on the Inspection Lane run about 23% of the first inspections.

Regarding buses and trucks, all buses and trucks with PUCO or ICC licenses are not required to go through the Lane. All City Transit buses are required to go through the Lane, as well as local trucks. There have been very few, if any, rejections from buses and trucks due to exhaust system defects.

If the committee wishes, Mr. Maurer or Mr. Frey would be glad to come to the committee and answer any questions regarding the Inspection Lane procedures.

A copy of the Motor Vehicle Inspection Ordinance and points of inspection is attached for each of the committee members.

Prepared by Chas. W. Gruber
Air Pollution Control
and Heating Engineer

November 1, 1955

APPENDIX IV

I. OBJECTIVE

To determine practical and economical measures to be considered so as to minimize visible smoke from diesel engine exhaust.

II. THE CAUSE OF DIESEL ENGINE EXHAUST SMOKE

A. Two Types of Smoke

There are two types of diesel exhaust smoke which can occur together or separately. The first type is that which is composed primarily of fuel soot, is black in color, and occurs primarily on acceleration even though the engine has reached heat equilibrium. The second type of visible smoke undoubtedly contains some fuel soot but is primarily the light gray-colored smoke which leaves a long plume behind the tailpipe. It is believed that this type of smoke is composed of vapors of the fuel from the combustion chamber which have not burned and are not visible at engine and exhaust pipe temperatures, but which become visible upon expulsion to the temperature of the atmosphere air.

B. Air Fuel Ratios

Any type of fuel requires sufficient air to burn completely. If complete combustion is obtained, there should be little, if any, exhaust smoke. When complete combustion is obtained, the fuel is being utilized to the maximum and will give the most economical operation with regard to horsepower and miles per gallon. However, theoretically complete combustion of the fuel is practically impossible to obtain due to various factors which will be discussed later. When there is insufficient air to completely burn the fuel the black sooty-type of smoke will generally result, and the lower the air fuel ratio the more of this type of smoke is produced.

C. Combustion Temperature

The diesel engine is a compression ignition engine wherein the fuel is injected into the air compressed in the cylinder. Therefore combustion in the diesel engine is more sensitive to the temperature of the air in the cylinder than in the gasoline engine which, of course, is a spark ignition engine. When the ambient air temperature is too low the temperature of the compressed air in the cylinder is also too low to obtain (1) rapid ignition of

the injected fuel, and (2) complete combustion of the injected fuel. Therefore, it is believed that in extremely cold weather the air temperature in the combustion chamber, even after the engine has reached heat equilibrium, will permit the vapor-type of smoke referred to before, which condenses upon reaching atmosphere air. In stop-and-go operation this type of smoke will occur much more frequently than an over-the-road operation.

III. FACTORS CONTRIBUTING TO DIESEL EXHAUST SMOKE

A. The Operating Conditions

1. Stop-and-Go Driving

2. Highway Operation

3. The Driving Habits of the Vehicle Operator

B. The Weather

C. The Type of Equipment

1. The Engine

2. The Transmission

D. Maintenance of the Equipment

E. Diesel Fuel

F. Special Equipment

IV. DISCUSSION OF FACTORS CONTRIBUTING TO DIESEL EXHAUST SMOKE

In paragraph III above, a number of factors are listed as contributing to diesel exhaust smoke. In many cases more than one of these factors are involved in incomplete combustion, but each will be discussed as to how it contributes to objectionable smoke.

A. The Operating Conditions

1. Stop-and-Go Driving

In stop-and-go driving, generally speaking, engine temperatures are not as high as in highway operation. This is due to frequent stopping for traffic lights, stop signs, dense traffic, and other factors which permit many cooling periods of varying duration. When the air for combustion is taken from the engine compartment, its temperature is also lower than in highway operation for the same reason. In city coach operation the engine frequently is at full throttle for half a block and at no throttle for the remainder of the block to the next coach stop. This also

contributes to lower air and engine temperatures.

Stop-and-go driving involves considerable full throttle operation where the air fuel ratio is apt to be richer than highway operation, thus producing a much larger quantity of fuel soot, most of which appears in the exhaust from the engine.

2. Highway Operation

In general, highway operation of diesel engines should not produce objectionable exhaust smoke. Loads are relatively constant and throttle setting is constant with less frequent demands for acceleration. Engine temperatures and air temperatures in the engine compartment are generally higher. However, almost all diesel trucks and coaches must frequently pass through large population centers and revert to a stop-and-go type of operation while passing through these centers.

3. The Driving Habits of the Vehicle Operator

The vehicle operator can assist materially in reducing diesel engine exhaust smoke. This depends somewhat on the type of engine used; i.e., naturally aspirated or artificially aspirated. However, if the operator of the vehicle will ease his coach or truck away from a stop light or from a curb, not using full throttle, he can avoid obtaining too rich an air fuel ratio which contributes to the black type of smoke. This is most important in city stop-and-go driving. The delay in the use of full throttle need only be a few seconds until the rich fuel mixtures obtained at idle are scavenged from the engine and there is sufficient air, particularly in artificially aspirated engines, to provide for more complete combustion. If, after coasting down a hill, the operator of the vehicle will give part throttle upon reaching the bottom of the hill, rather than full throttle to climb the next hill as rapidly as possible, the rich air fuel mixtures which have been accumulating going downhill will be given time to be scavenged, minimizing the black smoke which generally occurs at quick full throttle acceleration. The engine going downhill, having no load imposed upon it, will tend to cool down as will the temperature of the air in the combustion chamber, and gradual acceleration going up the next hill will tend also to reduce the visible vapor type of smoke.

When shifting gears manually, or when automatic transmissions shift to a higher gear, the driver should avoid immediate full throttle operation. Engine RPM drop rapidly upon shifting, permitting lugging which can result in smoke. The vehicle or engine should be brought up to higher speeds by gradual use of the throttle.

B. The Weather

The contribution of ambient temperature to exhaust smoke has been discussed briefly, but it is believed that somewhat more tolerance towards diesel exhaust smoke should be allowed in cold weather operation than during periods when ambient temperatures are higher. It would appear that during cold weather, since the air is more dense and the combustion process is based on the weight of air rather than the volume, exhaust smoke should be less. However, it has been mentioned that one of the factors for good combustion in a diesel engine is adequate combustion chamber temperatures and the colder air reduces the temperature of the air in the combustion chamber. During rainy weather the moisture in the air delivered to the cylinder will tend to cool the temperature in the cylinder as well as displace some of the air, making the air fuel ratio richer, thus contributing to the formation of black sooty smoke as well as the light gray vapor-type of smoke. In rainy weather and dense atmosphere exhaust smoke will tend to hug the ground and disperse less rapidly.

C. The Type of Equipment

The type of equipment can affect diesel engine exhaust smoke. This is not to imply that one engine will necessarily give more smoke than another but that the smoke may occur under different conditions of speed and load. The type of transmission, i.e., a manual gear shift or an automatic transmission, can in some cases affect the quantity of diesel engine exhaust smoke.

Some automotive diesel engines have a type of governor, the purpose of which is to correlate the fuel supply to the engine to engine RPM, particularly when starting, thus maintaining a better air fuel ratio. Another automotive diesel engine has fuel injection advance timing so as to inject sooner as engine speed increases. This tends to eliminate smoke as it gives a longer period of crankshaft degrees during which the fuel may burn more completely.

1. The Engine

Naturally aspirated diesel engines, i.e., engines which do not depend on turbochargers, superchargers, or blowers to supply the air for combustion tend to smoke less under conditions of low engine speed. Engines with turbochargers, superchargers, or blowers tend to smoke more at low engine speed due to the fact that the lower the engine RPM the less air is delivered for combustion.

With those diesel engines which depend on mechanical means for air supply, it is impossible not to have a "first puff" of smoke

when the throttle is first opened. This is quite natural since as the engine operates the mechanical means for supplying air, additional engine RPM must be obtained before more air is supplied and, therefore, at the initial opening of the throttle a very rich air fuel ratio exists. The conditions described herein apply to both two-cycle and four-cycle engines.

2. Automatic Transmissions

There are several types of automatic transmissions used in diesel trucks and diesel coaches. One of the purposes of the automatic transmission is to give quick acceleration or to produce high engine speed rapidly upon acceleration, and in this manner, particularly in those engines where air for combustion is dependent upon high engine speed, the automatic transmissions can assist materially in reducing diesel exhaust smoke. Also, the use of the automatic transmission in many cases minimizes lugging which also can produce excessive diesel exhaust smoke.

D. Maintenance of the Equipment

Maintenance of the equipment and particularly maintenance of the fuel system and air supply system are probably the most important factors in minimizing diesel engine exhaust smoke.

1. Fuel System

a. Injector Condition

If any one injector tip in a multi-cylinder engine is in poor condition, it may cause heavy exhaust smoke to such a degree that fuel quality characteristics, such as volatility and cetane index, are completely nullified. If an injector tip has a hole which is enlarged, this condition can occur, or if one or more injector tip holes are plugged the pattern of swirl designed in the original injector tip to mix the incoming air with the fuel in the combustion chamber may be disturbed so as to provide poor mixing and resultant poor combustion.

b. The Amount of Fuel Delivered by the Injectors

The amount of fuel delivered to accommodate road-load conditions will affect the exhaust smoke intensity. With the same amount of air available the larger the quantity of fuel injected the greater the smoke intensity and, of course, the opposite is true - the less the amount of fuel injected for the same quantity of air, the lesser the smoke intensity.

c. Fuel Injection Timing

Late injection timing can increase the intensity of the diesel exhaust smoke. Only a few crankshaft degrees retardation in timing can affect exhaust smoke intensity more so than a difference of 75°F. to 100°F. in the end point of the diesel fuel used.

d. Dribbling Injectors

Injectors which dribble or permit some fuel to leak into the combustion chamber during cycle periods when the fuel supply is supposed to be shut off can produce exhaust smoke.

2. Air Supply

a. Amount of Air Delivered

As has been mentioned, the air fuel ratio, or the amount of air delivered to burn the fuel injected, is the most critical feature in exhaust smoke intensity. A relatively small difference in the amount of air delivered can affect exhaust smoke intensity more so than 100 degrees difference in the end point of the fuel. In one make of engine which has an air chamber surrounding the cylinders and admits air from this chamber to the cylinders by means of ports in the cylinder liner, a difference of less than 1/2 pound pressure in the air chamber increases the smoke intensity as much as 100 degrees difference in the end point of the fuel.

b. Increased Scavenging of Burnt Gases

Any method which will increase the scavenging of the burnt gases remaining in the cylinder can improve diesel exhaust smoke tendencies to a high degree. In one diesel engine, increased scavenging so improved exhaust smoke tendencies that a fuel with an end point of 625°F. produced the same or less exhaust smoke as a 550°F. end point fuel without this improved scavenging.

E. The Diesel Fuel

The characteristics of the diesel fuel used can affect the intensity of the diesel exhaust smoke. Generally speaking, there are three quality factors which should be considered in selecting the proper diesel fuel.

1. Volatility - (End Point)

As the end point or final boiling point of the fuel increases, the tendency to produce exhaust smoke is also increased. However,

the degree of this exhaust smoke increase with increase in end point, varies with different engines and appears to be much more sensitive to engine condition than to the volatility characteristics of the fuel.

2. Cetane Index

As cetane index increases, the tendency to produce exhaust smoke is reduced. Here again, as with volatility, the effect of cetane index on exhaust smoke varies with different types of engines. Some diesel engines are relatively insensitive to cetane index while other engines are very critical with regards to the cetane index of the fuel and the intensity of the exhaust smoke.

3. The Chemical Composition of the Fuel

It is generally advisable to use a straight run diesel fuel, i.e., one that is not cracked nor contains cracked fuel stock. With regard to the black sooty smoke, within limits, the cracked fuels do not give materially more of this type of smoke than straight run fuels of the same volatility range. However, visual observation has shown that cracked fuels produce smoke of the vapor type previously referred to which produces a plume or cloud for some considerable distance behind the tailpipe of the vehicle upon reaching the ambient atmosphere temperatures.

F. Special Equipment to Minimize Diesel Exhaust Smoke

There have been several devices which are not standard equipment on the vehicle or engine but which have been offered to eliminate, minimize, or divert diesel exhaust smoke.

1. Catalytic Element for the Tailpipe

There have been developed catalytic elements for the tailpipe which have been reported to be effective in eliminating exhaust smoke in 4-stroke cycle diesel engines. There is also reported to be a similar element which is effective in 2-stroke cycle diesel engines. These catalytic elements are quite expensive, relatively speaking, on initial cost and apparently will require frequent recharging or replacement at some mileage interval which experience to date has not indicated due to lack of adequate use of such elements in actual service. However, the catalytic type exhaust controls for diesel engines have not been used for a sufficient length of time so as to determine their effectiveness for the various operating conditions encountered.

2. After Burner

There also appears to be a device utilizing a burner which burns the uncombusted products from the combustion chamber prior to their omission from the tailpipe. Not too much is known about this particular device at this time.

3. Special Tailpipe

There has been devised at least one special tailpipe which mixes air with the exhaust smoke prior to omission from the tailpipe and which has the effect of diluting the exhaust smoke with air, making for greater initial dispersion. After all, the principal problem with any offensive gas is dispersion of the gas to avoid large concentrations which may be objectionable. Reducing the concentration of the gas renders it less offensive and the more rapidly this is done the fewer the complaints on diesel exhaust smoke.

V. RECOMMENDATIONS

Of the various factors described above which can contribute to diesel exhaust smoke, some may be considered controllable and other uncontrollable.

A. Controllable Factors

1. Driving Habits

It is recommended that the proper steps be taken by every organization operating diesel engines in the City of Cincinnati to promote good driving habits on the part of the operators of the vehicles so as to reduce smoke resulting from lack of such habits.

2. Type of Equipment

There are approximately four makes of diesel engines used in bus operations and considerably more used in over-the-road trucking operations. Any operator of diesel-powered equipment must be free to choose the type of engine he feels is best suited for his operation based on practical and economical factors. It is recommended, however, that each operator become sufficiently familiar with the equipment he operates so as to know its characteristics towards producing smoke and how to operate his equipment with a minimum of exhaust smoke.

3. Maintenance

Maintenance of equipment appears to be one of the primary factors in exhaust smoke and it is recommended that every operator maintain strict vigilance over engine maintenance with particular attention to the fuel system and the air supply system.

4. Fuel

There are a large number of diesel engine manufacturers and almost every manufacturer has his own fuel specification for his engine. Each of these specifications differ one from the other in one or more respects or requirements. As a practical matter, refineries cannot be expected to supply a fuel tailored especially for each diesel engine. Such items as refinery equipment, distribution, and bulk storage restrict the number of fuels available to a relatively few. Therefore, the operator of diesel engine equipment must choose an available fuel which is best suited for his equipment and operating conditions. There are approximately three main types of diesel fuels available with regards to volatility range. One is a kerosene-type with an end point ranging from 510°F. to 570°F. The second is a fuel generally meeting the requirements of the American Society of Testing Materials 1-D Specification which has a maximum 625°F. end point and a minimum 40 cetane number; and third, is a fuel with an end point of between 625°F. and 700°F., one which is very frequently used as a furnace oil. Generally speaking, the first two of these three fuels are straight run products with a chemical composition highly paraffinic in nature and containing no cracked stocks. The third type of fuel is very frequently a furnace oil and may contain, and generally does contain a large percentage of cracked stock which combined with its relatively high end point makes it unsuitable for use as an automotive diesel fuel. Although not necessarily true of every diesel engine, generally speaking the higher the end point of the fuel the more horsepower is realized from the engine. For this reason, some engine manufacturers prefer heavier fuels so that their engine may perform better from the standpoint of horsepower and mileage.

Therefore, based on engine manufacturers specifications and based on the available fuel supply, it is recommended that no attempt be made to define a fuel suitable for use in diesel engines operating in Cincinnati or through Cincinnati, but that common sense and a sense of public responsibility on the part of the operator and his fuel supplier dictate the type of fuel used. An attempt to use special fuels may be not only impractical but may raise the fuel cost. Fuel cost is the largest single cost item used in diesel engine operation and should not be increased to the point where it is uneconomical for the operator to continue in business.

5. Special Equipment

It is recommended that the various types of special equipment mentioned previously be investigated and tested to determine their effectiveness and practical economy in reducing diesel engine exhaust smoke.

B. Uncontrollable Factors

1. Type of Operation

By the very nature of the operation and equipment assembly, such as transmissions and axles, it is to be expected that over-the-road vehicles operating through cities will perhaps give more smoke when in the cities than when on the road. The stop-and-go driving experienced in city operation, for reasons mentioned previously, may tend to give more smoke in the winter, and as traffic increases city operation may be increasingly subjected to more stopping and less going which, of course, will accentuate the tendency to produce diesel exhaust smoke. Therefore, it is recommended that due allowance be given to the type of operation in judging objectionable exhaust smoke.

2. Weather

It is recommended that the weather at the time of observing diesel exhaust smoke be taken into consideration as adverse weather can be a factor in producing more diesel exhaust smoke from a given engine than would be expected if the weather were more favorable.

3. Unexpected Failures

With any mechanical device, in this case a diesel engine, failures may occur unexpectedly during operation. Such failures with diesel engines which would produce more exhaust smoke would be an injector suddenly developing a hole or the air system developing a leak. These failures and others could not be repaired until the vehicle reached the garage.

VI. ENFORCEMENT

In the policing of objectionable diesel exhaust smoke, the controllable factors and the uncontrollable factors should be taken into consideration. It would definitely be unfair to condemn an operator if objectionable diesel smoke is occurring because of uncontrollable factors.

With regard to the controllable factors, it takes time to determine whether one or more are contributing to objectionable exhaust smoke and additional time is required to establish control over such

factors. It should be mentioned here that engine manufacturers, fuel suppliers, and operators are intensively investigating, and have been for some time, methods of decreasing diesel exhaust smoke and eventual solution of this problem will have to be as a result of these combined efforts.

It is recommended that we do not attempt to legislate type of equipment, maintenance practices, or the type fuel used, and that no punitive penalties be invoked against the operator or the owner of the individual vehicles deemed to be producing excessive and objectionable smoke. As a matter of fact, determination of objectionable exhaust smoke is extremely difficult to judge visibly. There have been many juries of engineers, laymen, and combinations of laymen and technical personnel who have as groups observed exhaust smoke on vehicles being tested on dynamometers and operating on the road. The findings of these various panels or juries have been very confusing as in many cases there have been almost as many opinions as there have been individuals on rating objectionable and non-objectionable smoke observing the same smoke.

With regard to mechanical, chemical, or other devices to be used to detect smoke and/or degree of smoke, there are such smokemeters available. However, they are designed to be used on the equipment either in the shop or in test vehicles on the road. Their use requires considerable labor and equipment to install and a considerable amount of time to complete tests. There is no such device available for spot checks on vehicles in operation or during ordinary standing periods.

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January 19, 1956

APPENDIX V

ANALYSIS OF REPLIES TO QUESTIONNAIRE SURVEY

Twenty-six Questionnaires sent out.

Nineteen replies received. (Listed below in order in which they were received.)

1.	Indianapolis, Indiana	- Mr. R. E. Wetzel
2.	Providence, Rhode Island	- Mr. Austin C. Daley
3.	Baltimore, Maryland	- Mr. Milton Reizenstein
4.	St. Louis, Missouri	- Mr. J. H. Carter
5.	Minneapolis, Minnesota	- Mr. George R. Bean
6.	Akron, Ohio	- Mr. L. E. Bunts
7.	Omaha, Nebraska	- Mr. Herbert H. Ulrich
8.	Commonwealth of Pennsylvania	- Mr. J. S. Sharrah
9.	Boston, Massachusetts	- Mr. G. C. Doyle
10.	Cleveland, Ohio	- Mr. Howard J. Scott
11.	Columbus, Ohio	- Mr. H. C. Johnson
12.	Milwaukee County, Wisconsin	- Mr. J. E. Brown
13.	Pittsburgh, Pennsylvania	- Mr. Sumner B. Ely
14.	Washington, D.C.	- Mr. H. K. Kugel
15.	New York City, New York	- Dr. L. Greenburg
16.	Los Angeles County, California	- Dr. R. L. Chass
17.	Atlanta, Georgia	- Mr. W. E. Tidmore
18.	Allegheny County, Pa.	- Mr. T. C. Wurts
19.	Detroit, Michigan	- Mr. B. J. Linsky

3. STANDARDS OF PERFORMANCE: Do you have Standards of Performance different from those applying to chimneys and stacks, apply specifically to the discharge of smoke or fumes?

All replied in the negative except New York City and Allegheny County, Pennsylvania. Several pointed out that standards of discharge of smoke applying to steam locomotives also applies to diesel locomotives, internal combustion engines and vehicles. Also in several replies the nuisance sections dealing with discharge of dusts, fumes, etc., specifically applies to vehicles. New York City has proposed standards for all trucks and buses based on "prohibiting emission of visible smoke or visible fumes from a standing vehicle or from one moving for a distance of more than 100 yards." New York City now prohibits the operation of a bus engine at a terminal longer than three minutes. Allegheny County, Pennsylvania has special provisions for diesel locomotive performance.

5. SPECIAL REQUIREMENT FOR FUME REDUCING APPLIANCES: Do you have any specific requirement established by ordinance or rules and regulations requiring the installation of special fume reducing appliances or equipment (for example, the after-burning type muffler)?

All replied in the negative except New York City. New York City has a proposed rule requiring "the use of a device for limiting vacuum in the manifold of a gasoline bus to 21" of mercury." New York City has

watched experimentations with catalytic mufflers, but are not yet satisfied, either as to their effectiveness, or their practicability. Minneapolis entered this note: "A short time ago, an ordinance was proposed to require bus exhausts to be above six (6) feet off the ground. It was recommended that this be defeated as increasing nuisance."

8. Have you conducted research investigations or other studies as to the nature of exhausts?

All negative except the following:

Indianapolis, Indiana - Yes on all equipment. Study made by visual observation of engine performance of vehicles in service. Motivation; complaints and observations.

Providence, R.I. - Yes on all equipment. Worked with manufacturers of diesel locomotives to get better smoke performance on start. Bus studies uncovered no solution of the fumes problem. Motivation; smoke and fumes from these vehicles.

State of Pennsylvania - Research on diesel and gasoline power buses and trucks. Results not available. Individual studies were made of individual garages which were made to ascertain ventilation efficiencies of certain installations and one overall study was made of City CO concentrations in one of our large cities which indicated after hundreds of samples that during periods of heavy traffic, pedestrians are subjected to measurable but varying amounts of carbon monoxide, the average of which was under 25 parts per million for these peak periods. It is our opinion that much work should be done on these exhaust devices before recommendation for them is indirectly given by requiring their use.

Cleveland, Ohio - Studies were made on noise. Noise limitation set at 95 decibels at 5'-0". Motivation; noise complaints, hollywood mufflers.

Milwaukee County, Wisconsin - On 2-cycle diesel power buses only. Local study on feasibility of catalytic afterburner not published. Found exhaust temperatures of idling or waiting bus engines too low for effective use of catalytic afterburner. Investigated scrubbing devices. Motivation; diesel bus and locomotive exhaust odors.

Pittsburgh, Pennsylvania - Have made some traffic tests on CO. No tests for hydrocarbons, oxides, etc.

New York City, New York - Paying particular attention to feasibility of using LPG or Propane as a fuel. Many obstacles to having this fuel adopted, particularly reluctance of the fire department authorities in modifying their regulations for storage and dispensing of LPG. The use of LPG in warehouse trucks seems to indicate that its exhaust is much less objectionable than gasoline. Its widespread use by Chicago Transit Authority and its growing use by taxicab fleets in various cities indicates that it is economically advantageous also.

Los Angeles County, California - Research investigations on diesel and gasoline power buses and trucks. Results published in numerous reports and technical papers. Motivation; In our research and engineering investigations to determine the total quantities of air contaminants released into the Los Angeles atmosphere the path led to the automobile exhaust as a possible contribution to smog in this area.

11. Information on the subject and comments.

Pittsburgh, Pennsylvania - Observations on a Diesel Locomotive through a Railway Tunnel. U.S. Bureau of Mines RI 3887, June 1948 R.R. Sayers Division. Use of Diesel Engines in Tunnels, October 1942. U.S. Bureau of Mines IC-7222 Sayers Division.

Milwaukee County, Wisconsin - Oxy-Catalyst, Inc., Research & Development Report #5314A. SAE Report "The Composition of Diesel Exhaust Gases," November 1949. Bureau of Mines RI-4531 "Sampling and Determination of Aldehydes in Diesel Engine Exhaust Gas."

Columbus, Ohio - The Removal of Aldehydes from Diesel Exhaust Gas. U.S. Bureau of Mines. ASME Transactions, 1948.

Baltimore, Maryland - Papers 55-18 thru 55-21 presented at 1955 Detroit APCA Convention.

Omaha, Nebraska - Leland Stanford University, Los Angeles.

Providence, Rhode Island - Have obtained nothing concrete from the manufacturers. Recommend funds to U.S. Bureau of Mines for independent research.

Minneapolis, Minnesota - General Motors has an excellent film on this subject.

New York City, New York - Papers by Soc. of Auto Engineers.

Los Angeles County, California - Suggests papers at APCA, Detroit Meeting.

The results of this survey are not for publication without specific authorization from those contributing to the survey.

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