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A HISTORICAL REVIEW OF ATMOSPHERIC POLLUTION

Introduction

Man cannot live without breathing oxygen diluted with some inert gas and in the atmosphere there is a suitable mixture of oxygen and nitrogen. But in addition there is a variety of gases, vapours and aerosols, varying in content and concentration at different places over the surface of the earth, and these he needs must breathe in too. Some of the materials in question are physiologically inert, but others produce reactions which range from mild inconvenience to severe toxicity.

A simple consideration indicates that there has never been a truly unpolluted atmosphere, for decaying vegetable matter, decaying dead animals and the products of forest fires have emitted gaseous and particulate matter since the world began. However, atmospheric pollution, as a subject for concern on the part of the general public, has come into existence only as the result of technology. The first technical development of man was the use of fire, which produced carbon dioxide, smoke and ash; and the atmosphere of all towns, even in early civilizations, must have contained a considerable amount of pollution. Accounts of mediaeval towns in Europe indicate that the air was fouled not only by wood smoke but also by the odours of many domestic activities, of noxious trades such as tanning, and of the decaying rubbish in the streets caused by a most primitive sanitation system. Nevertheless, the citizens of the towns do not seem to have been unduly concerned by the quality of the atmosphere which they breathed.

With the introduction of coal as a source of heat, signs of the rise of public dissatisfaction are noted by historians, and one might say that atmospheric pollution as a social problem dates from the beginning of the 14th century. But a scientific and technical review of the history of air pollution cannot commence much before the year 1850, for before that

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time, though there was much talk about the obnoxiousness of smoke, little knowledge was available and so no progress was made in the control of pollutants.

An over-all view of the hundred years since the first steps were taken in understanding the nature of air pollution indicates that two processes have been in operation. On the one hand, developing techniques have introduced new forms of pollution into the atmosphere and, on the other, town populations have become more intolerant of the types of pollution which they were having to breathe. With this growing dislike of pollutants, interest has spread to the effects of these materials not only upon man himself but also on vegetation and animals, upon buildings, clothing, works of art and other articles of property. This latter development is hardly within the immediate scope of public health, and yet the study of atmospheric pollution can scarcely fail to take notice of it, since it indirectly affects man's mental, if not physiological, well-being.

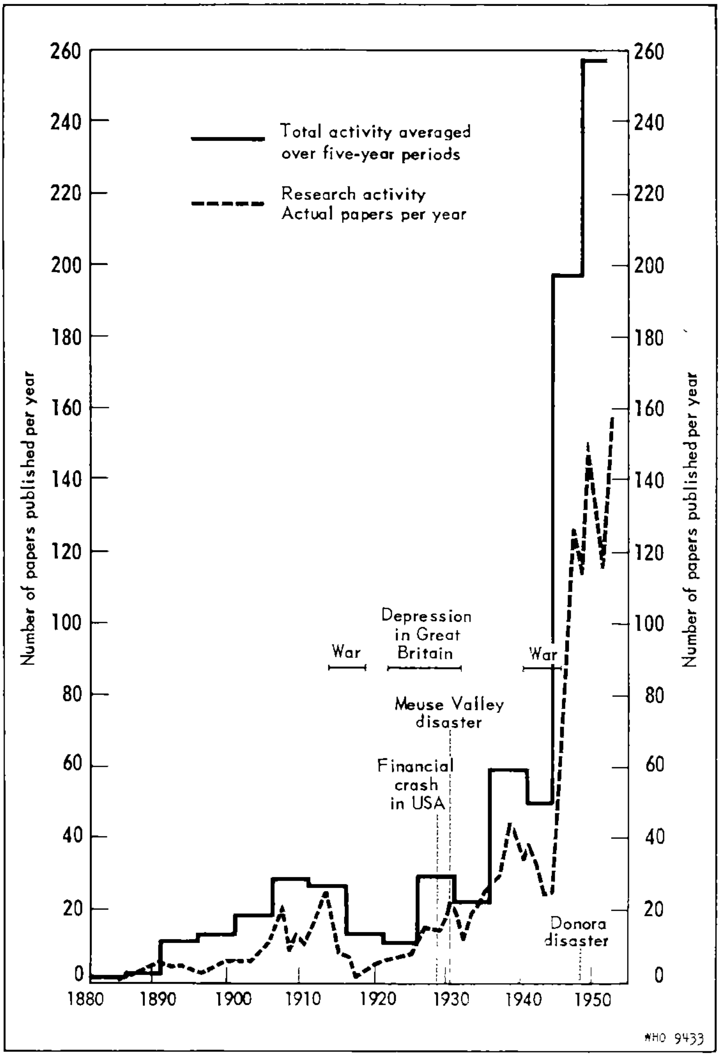
It therefore appears that atmospheric pollution consists of that material, gaseous or particulate, which is commonly found associated with the oxygen and nitrogen of the atmosphere and which is (*a*) toxic, (*b*) irritant, and (*c*) in the nature of a hardship to man, either directly or because of its toxic or harmful effects upon animals, vegetation or human property.

In the time available for the preparation of this historical survey it has not been possible to make a very full study of the many scientific and technical publications which have marked the progress in the study and control of pollutants in the air. Considerable use has been made of (1) a bibliography prepared by the US Bureau of Mines (Davenport & Morgis, 1954); (2) a bibliography attached to an article by Schwartz et al. (1955); (3) a bibliography drawn up by the Fuel Research Station of the Department of Scientific and Industrial Research (Great Britain, Department of Scientific and Industrial Research, 1956); (4) a monograph on air pollution (Meetham, 1952) and a book on smoke (Marsh, 1947), a compilation of papers on air pollution (Mallette, 1955) and a number of reports which have been sent by public health departments or prominent research workers in France, the Netherlands, Austria, Italy and Australia.

It was thought that graphic demonstrations of the growth of activity in the field of air pollution might help in an appreciation of the subject, and for this purpose the US Bureau of Mines bibliography was made use of, although it was clear that in this volume the information about work in Germany and France was very inadequate, and that quite a number of articles published in England had escaped attention. In addition, the bibliography lists some papers more than once if they happen to deal with several of the subjects in the classification adopted by the compilers. Nevertheless, it was thought that in general the bibliography was a complete enough collection of data on which to construct graphs that would give a revealing picture of historical development.

The first graph (Fig. 1) shows the development of total world activity in the form of a histogram based on five-year averages. Superimposed on

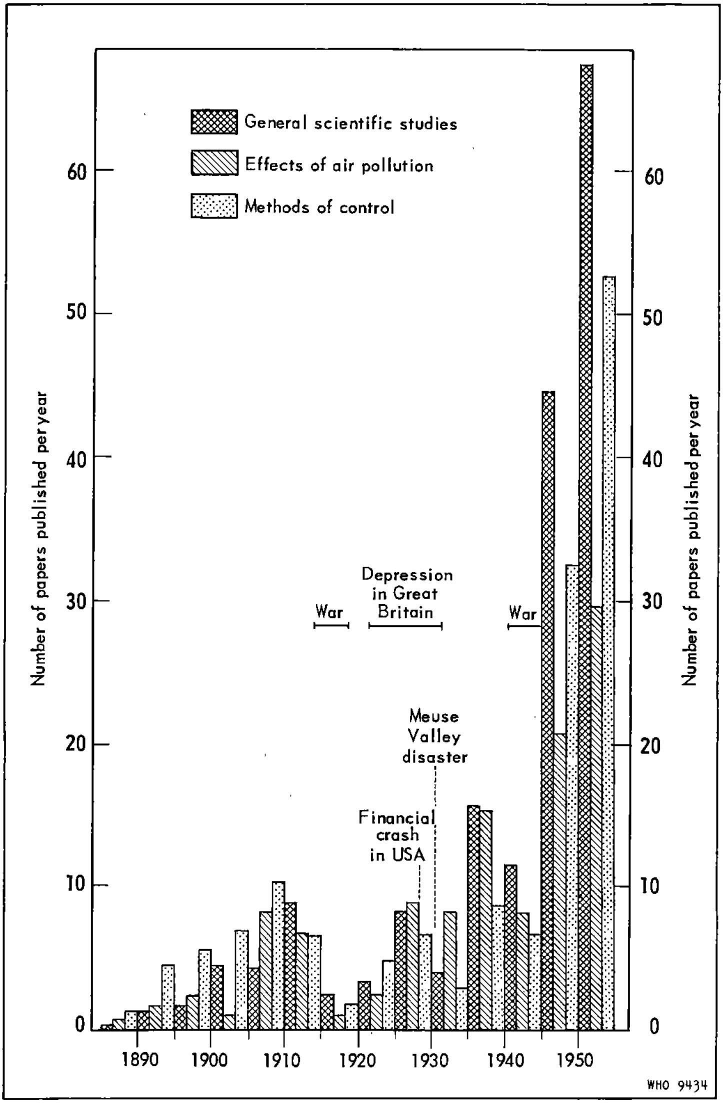
FIG. 1
PROGRESS OF TOTAL TECHNICAL ACTIVITY AND OF RESEARCH ACTIVITY IN THE FIELD OF ATMOSPHERIC POLLUTION



the histogram is a graph of the actual number of research papers published every year for the same period. The second graph (Fig. 2) shows the development of world activity under three headings—the nature and origin of pollution, effects of air pollution (medical and other), and the methods of control. These graphs show that (*a*) there has been a steady development in

FIG. 2

DEVELOPMENT OF THREE DIFFERENT LINES OF INVESTIGATION IN THE FIELD OF ATMOSPHERIC POLLUTION



The three histograms give average figures for five-year periods.

Though each column covers a space of about one year on the time axis, it actually applies to the whole of the five-year period in which it stands.

scientific and technical activity in the field of air pollution for over sixty years; (*b*) though medical and technical activity led the way prior to 1900, physical and chemical research is now playing a leading part in the studies; (*c*) activity in the study of air pollution has been adversely affected both by wars and by economic depressions, probably more than other forms of scientific investigation. This indicates that air pollution research has been a marginal activity, a sort of " extra " to the normal community interests, and has not achieved the status attained by other branches of public hygiene (such as food pollution and epidemic control); and (*d*) activity in air pollution studies has increased during the last ten years at a very much faster rate than during the previous fifty years, the slope of the graphs indicating that at least one strong new influence must have made itself felt about 1945. It is not possible to continue the graphs beyond 1952 because knowledge of the papers that have been published during the years 1953-55 is incomplete. The card index which the US Library of Congress is compiling is by no means complete, so that is would not be a true indication of the present state of affairs to make use of the information at present available, but the general impression gained from a study of the various journals is that the rate of publication and the amount of study being carried out are still increasing.

The Different Pollutants and their Place in History

Smoke is the first pollutant to have attracted community attention, and its history goes back to the 13th century. The immediate cause of the production of smoke in such quantities as to constitute a nuisance was the exhaustion of the supplies of wood fuel in Europe and the introduction of coal as a substitute. The growth of populations and the development of manufacturing methods produced an increased demand for fuel, rapidly depleting the reserves of wood in the afforested areas. In very many articles which have been written on the subject (Davenport & Morgis, 1954) reference is made to the conditions in London as early as 1300, when a royal proclamation prohibited the use of coal in London, and from that time onwards communities have suffered from smoke and soot, until comparatively recently without relief.

Sulfur dioxide is the second pollutant to cause community discomfort, for it is produced at the same time as smoke, from the burning of coal; but for quite three hundred years the sulfur dioxide was not recognized as a separate pollutant because of the inadequate chemical knowledge available. All that was known was that smoke was accompanied by an unpleasant smell and an irritation to the throat and nose. By 1600, however, it was well known that the sulfur in the coal was responsible for the annoyance, and methods of coking coal to remove some of the sulfur and volatile components were already being developed.

Sulfur dioxide in much higher concentrations than are met with as a result of the combustion of coal has become a pollutant wherever the metallurgical industry has developed, for so many metallic ores are sulfides that a very high percentage of processes for producing pure metals also produce tremendous quantities of sulfur dioxide.

Hydrochloric acid first became a recognized atmospheric pollutant some time after 1800, with the development of the chemical industry. In the production of sodium carbonate from common salt a strong emission of hydrochloric acid was produced which did great damage to property and vegetation.

The chemical industry also introduced such pollutants as hydrogen sulfide from tar distillation, nitrogen dioxide from the chamber process for sulfuric acid, hydrogen fluoride from the production of super phosphate fertilizer (and later from the manufacture of aluminium), while the metallurgical industry introduced the community to a variety of poisonous or noxious fumes from such metals as lead, arsenic, zinc and copper. In very recent times the use of beryllium for a number of industrial purposes has created a fresh hazard in the form of finely divided beryllium, and there is a likelihood that in the future new industrial techniques will bring with them their own types of pollutant, which will first be experienced by the industrial worker and may later become part of the pollution of city air unless steps are taken to control the processes.

From what has been said above one fact emerges which must always be remembered—that pollution of the air of the city is an extension of the pollution of the air of the factory, so that the science of air pollution control is an extension of the science of industrial hygiene. The methods of measurement are similar in principle but not in practice, for the industrial hygienist is working in a semi-closed atmosphere where concentrations are higher than they are in the street, and his conditions are slightly simpler, so that sampling processes which last for only a few minutes are usually sufficient to give him a picture of what is taking place in the factory, while sampling procedures in the street must usually continue for months and often for years before an understanding is obtained of the processes concerned in the production of the pollution. Thus the new forms of pollution which have been encountered in Los Angeles since 1945 are still not well understood, although measurements have been proceeding for nearly ten years, virtually without interruption. These pollutants cannot be named in this outline because their nature is not yet properly understood, but it is quite clear that they are a type of pollutant which can be expected to play an increasingly important part in the atmospheres of cities in the near future.

The History of Smoke and Sulfur Dioxide

Until perhaps 1940 or thereabouts the words " air pollution " meant for most people smoke and sulfur dioxide. A study of the bibliographies which have been prepared on the general subject of atmospheric pollution (Davenport & Morgis, 1954; Great Britain, Department of Scientific and Industrial Research, 1956; Schwartz et al., 1955) indicates that almost all the scientific and technical papers which were written before that date deal with smoke, its manner of production, its effect, methods of determining the emission rate from stacks, and technical methods of reducing the emission of smoke from industrial furnaces and of lowering the concentration of sulfur dioxide in the neighbourhood of refineries and smelters. So the problem of smoke and sulfur dioxide far outweighed in interest the problems produced by any other form of pollution.

The Bureau of Mines bibliography lists only thirty articles, on the nature, composition and effects of air pollution, published in the thirty years before 1890, and all of them are concerned with the effects of combustion. Not a single paper was written upon the technique of determining the nature and concentration of this pollution. On the other hand, nearly eighty articles are listed on the subject of the control of air pollution by means of stoking techniques and the use of smokeless fuels. This shows the small part that scientific methods and the scientific mind were taking in the handling of this problem.

For the following ten years the bibliography lists thirty-three articles on the composition and effects of pollution and eighty-eight on methods of control, but still nothing had been written on the technique of the determination of concentrations of pollutants. Practically all of this literature was concerned with smoke and sulfur dioxide, although, as has been noted earlier, the production of hydrochloric acid and hydrogen sulfide pollutants had already developed considerably as a result of the growth of the chemical industry. However, the fact that smoke was an almost universal blight upon the city populations of the United States of America, Great Britain and other countries of Europe caused it to claim almost all technical interest. As early as 1880 an article in the *Journal of the Royal Society of Arts* (Carpenter, 1880) stressed that coal combustion in low-temperature domestic and semi-domestic furnaces was a major cause of smoke, while in 1897 the *Journal of the Franklin Institute* analysed very concisely the mechanism of coal combustion and indicated that low-temperature combustion is a prolific source of smoke; and in 1899 a lecturer in London (Beilby, 1899) commented on the same factors, condemned over-stoking, inadequate air supply and low-temperature combustion, discussed the need for mechanical stokers and smokeless fuels, and showed that smoke is the result of abuse of combustion equipment. Thus by the turn of the century almost everything that is known today about the causes of smoke and their elimination had already been said, but hardly anything had been done to reduce the smokiness of cities.

The reason for this inability to take advantage of knowledge had been stated very clearly by a writer in a British building journal (*Builder (Lond.)*, 1899). He had pointed out that (*a*) smoke was a by-product of an activity which commanded the attention and the support of all financial interests in the country because it produced goods and profits, and therefore the willingness to give thought to the smoke aspect of the activity was very limited; (*b*) the damage done by smoke, though very considerable throughout the country, was not very clearly visible to the individual smoke producer, because it was very widely spread, so that interest in the reduction of smoke was lacking; and (*c*) since the damage done by smoke was due to a very large number of small producers of smoke, a clear relationship between cause and effect was difficult to establish.

This analysis of the situation remains true to this day. The control of smokiness depends upon the control of the production of smoke, and the control of a very large number of sources is very inadequate when the owners of the sources do not see any clear need for such control in their particular case, even though they may be quite convinced of the undesirability of the smokiness as a whole.

The history of smoke control in American cities, such as St Louis, Pittsburgh, and Cincinnati, shows that even when a very large volume of public opinion was convinced of the need for smoke reduction, that same public was militantly unwilling to take the technical steps necessary for the reduction, the mental attitude always being that the responsibility for cure must surely lie at someone else's door. The following quotation comes from a historical article by R. R. Tucker (1945), one-time Smoke Commissioner to the City of St Louis:

> In 1925 a fresh start was initiated . . . the attempt was to be one wherein the general public would be educated to the advantages of the elimination of smoke. A competent staff was employed . . . A firing school was started in the center of the city and instructions were given to individuals in the proper method of firing typical equipment used in St Louis. While in progress a survey showed that there was a material reduction in the quantity of smoke discharged into the atmosphere. *This was not however readily apparent to the average citizen.* As the campaign tapered off interest waned and St Louisians returned to their slovenly habits of firing.

With reference to the 1939 smoke regulations, he writes, " Enforcement of the ordinance was resisted by some, and brochures were even distributed within a radius of two miles of the Commissioner's house insinuating that the Commissioner was dishonest and was showing favouritism for monetary considerations. "

During the period 1890-1914 quite a number of studies were made of the smoke situation in various cities. A very intense investigation was conducted in Chicago in about 1910, resulting in the publication of a printed report of some five hundred pages in which almost everything that is studied nowadays regarding smoke, soot and ash was examined and reported upon. Other cities investigated were St Louis, in 1907 (*League Amer. Munic. Bull.*, 1907), and Pittsburgh, in 1912 (Pittsburgh University, 1912). A large scale measurement of smoke, sulfur dioxide and soot-and-ash fall was started in Great Britain in 1912 (*Sci. Amer.* 1914a), and has continued for over forty years, with a steady increase in the number of measuring stations. (In passing it is interesting to note that the possible origin of the British " lead peroxide method " of estimating sulfur dioxide lies in a paper by Witz in 1885 on the smoke of Paris, in which it is suggested that the attack of sulfur dioxide on the lead peroxide in paint might be made a method of studying the pollution of the atmosphere.)

In spite of these studies and even in spite of the passage of a number of ordinances in Cincinnati, Montreal, Chicago, St Louis, Pittsburgh and other cities, and of laws in Germany (Schwartz et al., 1955, p. 542) and Italy (Mallette, 1955, p. 253), the smoke position apparently did not improve, for in 1930 city agitation on the matter of smoke was still an issue. By this time it was becoming apparent not only that the remarks made in the *Builder* (1899) and on various subsequent occasions were true, but that as the small consumers of coal had no really effective method of preventing the production of smoke from their small and inefficient appliances, legislation and penalties were of almost no effect, so that the only way of stopping smoke at the source was to supply a fuel which was very nearly incapable of producing smoke. As a result cities such as St Louis and Pittsburgh prohibited the sale of bituminous coal with a volatile content of more than 20 % and provided alternative smokeless fuels such as anthracite, or processed smokeless fuels such as Pittsburgh's " Disco ". At the same time the increasing supply of oil or of natural gas as a heating fuel in many American cities, at a price comparable with that of coal, caused a widespread switch to these fuels and in this way dramatically changed the pollution situation in many of the great cities of the USA.

Great Britain was in a vastly different situation, for natural gas was unobtainable, and oil had to be imported and paid for with foreign exchange, so that coal gas, coke and smokeless solid fuel were the only substitutes available. At this point, economic depression and then war intervened to prevent action in Great Britain. It is fairly certain that the programme of pollution measurement which was started in 1912 was intended to be a preliminary to a programme of smoke abatement. However, the 1914-18 war held up the measurement programme, and by 1925 the economic situation was such that no one had the heart to urge any action that did not have the promise of increased earnings as its immediate goal. Then came rumours of war and finally war itself, and it was not until 1946 that the country was once again in a position to consider the situation. By that time it had become clear that with the high price of coal and the reduced coal reserves of Great Britain, even that saving in coal which would be obtained by a smoke elimination campaign would be extremely valuable, apart from the other advantages to be expected from smoke reduction. With the country in this frame of mind it was possible for national action to be considered, and this led to the Clean Air Act, which is now in its early stages of application. The Act is based upon the same realization that motivated the anti-smoke administrators in the American cities—that only a rationalized use of fuel would lead to the elimination of smoke. The Act therefore involves considerable national planning (*a*) to equip all new houses, and by degrees all old houses, with equipment which will burn smokeless fuel—either gas, coke or low volatile carbonized coal; and (*b*) to develop throughout the country an efficient use of the country's coal for the purpose of supplying gas, coke, smokeless solid fuel (by several different methods suitable for different raw supplies) and such by-products as benzol, pharmaceutical and other chemical raw materials, road tar and fuel tar for large boilers. This process has only recently been started and it will be intensely interesting to watch its development.

It is probably worth while to consider briefly the factors which have caused the Americans to apply city control and the British to apply national control. In both cases the clue to the solution is rationalized fuel supply. In the USA unorganized processes, such as the development of waste natural gas supplies and of oil burners for house heating, at a price competitive with coal, caused householders and others to turn to the right sort of fuel for the purpose of reducing smoke emission. In addition, the USA being a federation and extremely large in area, with an expanding economy and fiscal funds in plenty, the conditions were right for city control of smoke emission, aided by state legislation to give the cities the necessary powers. In Great Britain the question of fuel supply was difficult to solve and, in addition, by the time that public opposition to air pollution had grown strong, the economic situation had become stationary, leaving very few surplus funds to allow for independent ventures by cities. Thus, although under the terms of the Clean Air Act the cities and local authorities are entrusted with the carrying out of many provisions of the Act, the drive for the elimination of smoke has come from the central government, which alone can sponsor a study of the fuel situation and its rational development in the direction of the most economic supply of smokeless fuel.

In all this one must not lose sight of the part played by the smoke abatement societies in both countries, for the problem being faced was that of changing the habits of a nation, and only considerable and capable propaganda activity could develop the thinking of citizens sufficiently to make it possible for these administrative programmes to receive satisfactory support. There is no great value in tracing the rise and fall of various smoke abatement associations in the USA and Great Britain, but reference should be made to the two main associations, the Air Pollution Control Association in the USA, which not long ago celebrated its fiftieth anniversary, and the National Smoke Abatement Association in Great Britain, whose journal *Smokeless Air* has recently published its hundredth issue. These associations, by public meetings, propaganda literature, appeals to the public, the industrialists and the government, and by other activities, have continually stressed the need to take atmospheric pollution seriously and not to allow it to become a chronic condition of city life.

Up to this point nothing has been said about sulfur dioxide in association with smoke because, while the emission of smoke is difficult to prevent, the emission of sulfur dioxide when coal is burnt is almost impossible to prevent. Some of the 1%-4% of sulfur which is present in coal can be removed by washing the heavy pyrites from the lighter coal, but some sulfur is always left and the result is the production of sulfur dioxide when the coal is burned. If the concentration of sulfur dioxide in the flue gases were high the chemical extraction of the sulfur might be possible, but the very large volumes of gas which have to be treated make the processes very intractable. Two large electricity plants in London have installed flue-gas scrubbing equipment in spite of the very high costs involved (Meetham, 1952, p. 239; Pearson, Nonhebel & Ulander, 1936), but nowhere else in the world have industries using large quantities of coal been able to face the problem of sulfur recovery. Large industries produce little smoke but large quantities of sulfur dioxide, so this is their main problem and it is far from easy to solve. Small consumers of coal make much more smoke and much less sulfur dioxide, so that their problem is efficient combustion, which is capable of solution.

Smoke and Sulfur Dioxide in Europe

Pollution by smoke and soot in the continent of Europe has had a history somewhat similar to that in Great Britain and the USA, but with variations due to local conditions. In Germany, the Netherlands and Austria the domestic pattern of fuel usage in many cities is the use of gas for cooking and for water heating and the use of coke for space heating, in box-type stoves. This domestic pattern produces hardly any pollution, so that industrial sources begin to be of predominant interest. Nevertheless, measurement in Berlin in 1954 (Heller, 1954) showed quite a high proportion of smoke of domestic origin. Towards the end of the 19th century there is evidence of extensive damage being done to forests in Germany by the sulfur dioxide from smelters, and even to this day the heavily industrialized Ruhr Valley is an area of intense smoke pollution, from both industrial and domestic sources. But in general it may be said that the conditions in Germany, the Netherlands and Austria were better than they were in Great Britain and the USA. One writer has said that this is not so much due to a consideration of the need for the reduction of air pollution as to a need to conserve every ton of fuel available. Nevertheless, in 1928 a writer claims that the public health authorities should give more consideration to the control of smoke and fumes (Hahr, 1928), and in 1943 another writer speaks of the necessity for investigations on the nature of damage to plant life due to waste gases (Koritnig, 1943).

The legal situation is that in Germany and Austria laws were passed, in 1820 and 1909 in the former country and in 1811 in the latter, with the object of enabling any person who suffered damage through the action of waste gases upon himself, his livestock or his property to claim compensation. The result of this has been that industries have had to watch their effluents because of the possibility of large claims for damages, and as a result associations of industrialists, such as the Vereinigung der Grosskesselbesitzer, discuss at their conferences technical papers on the prevention of smoke emission; in addition the literature includes a large number of articles on methods of assessing damage to plants and property. The laws, however, make no provision for damage caused by the effluents from domestic chimneys, and there is at present a move in Germany to bring about the adoption of legislation which will control the emission of smoke and fumes from domestic buildings and from vehicles. The situation in France seems to be somewhat similar. Legislation was passed in 1932 (Schwartz et al., 1955, p. 540) defining what shall be tolerated in the way of smoke and fume production, and the implementation of this legislation has been left in the hands of the local authorities. Such pollution as is caused by domestic combustion is uncontrolled, but the use of coal in France is not as extensive as it is in Great Britain, so that conditions on the whole are not severe. However, measurements of smokiness and of sulfur dioxide concentration in Paris during 1950-56 show that the smokiness of Paris is comparable with that of London on certain occasions, and a government commission was appointed in 1954 to consider the dangers which are caused in the country be the emission of pollutants to the air (Raymond, 1956).

Italy has become a city-dwelling industrial country only comparatively recently, and even now almost all its southern portions are largely farming lands. A technical article (Mallette, 1955, p. 252) states that, owing to the meteorological conditions of Italy, the accumulation of pollutants is less than it is in other parts of the world, but gives quite a number of cases of physiological upset due to pollutants, indicating that there must often be conditions in which dangerous concentrations of pollutants are present.

Italian law on air pollution, dating from 1912, seems to be concerned only with the control of effluents from industries, so that one is inclined to say that public opinion in Italy, of a nature unfavourable to pollutants in the air, has grown rather slowly.

General Review of the More Specific Pollutants

The sources of air pollution from the products of combustion are almost always very numerous and widespread. This type of pollution is therefore diffuse, the concentration levels usually varying only slightly from place to place in a city. The air pollution caused by the emission of specific pollutants, such as SO_2 from smelters, HCl and NO_2 from chemical industry, HF from aluminium plants and fertilizer factories and some foundries, H_2S from gas retorts, and arsenic, lead and zinc fumes from some metallurgical processes, has this characteristic that the number of such sources in or near a city will usually be limited and the affected area around each source is usually small. Thus the offensiveness or the toxicity of the effluent is found in a confined area, and the complaint rate is consequently lower, while the source of the effluent, once it has been identified by techniques (which have been developed in the practice of industrial hygiene and are now used in the control of city air pollution) is fairly easily discovered. The result is that the problem of these pollutants is actually not as difficult as that of the products of combustion, and less has been written on the subject.

In the Bureau of Mines bibliography up to the year 1930 nearly 90 per cent of the articles listed were concerned with the products of combustion and only 10 per cent dealt with specific pollutants. After 1945 only 45 per cent of articles were concerned with products of combustion, 20 per cent discussed aerosols, and 22 per cent dealt with the toxic and noxious chemical gases. The cause of the heightened scientific and technical interest must to some degree be due to the increasing activities of city pollution-control organizations, which had been covering the chemical industries as part and parcel of their normal activities throughout the USA. These control organizations were in all cases originally established to handle the products of combustion, but as soon as their activities had become streamlined they became conscious of the localized pollution situations caused by the chemical and metallurgical industry and included them in the control scheme.

The administrative pattern for the control of such pollutants in the USA has been for each city to draw up its own regulations and specifications for the concentrations of pollutant (varying from type to type) which might be allowed to escape from a stack. Some of the states have passed basic legislation giving the cities a set of principles on which to work, while other states have taken each application made by each city for powers to control pollution on its own merits and approved or modified the terms of the application as the situation seemed to require (Smoke Prevention Association of America, 1922).

In the continent of Europe the pattern of action has on the whole been to pass national legislation specifying what concentrations of different pollutants would be tolerated, and to leave the application of the law to local authorities. One interesting development was the early action of Italy—in 1912—in classifying a group of industries as dangerous and prohibiting their operation at less than a stated distance from a town or city. This of course left the country folk to bear the uncontrolled effluents; and, moreover, as time has passed, some of these industries have been enveloped by the towns, so that the legal provisions have become inoperative.

In Great Britain a rather different approach was adopted when the chemical industry began to develop in the second half of the 19th century. The emissions of strong acid fumes from the new factories were very offensive and dangerous for quite a distance round each factory, and the first reaction of government authorities was to forbid the operation of the factories altogether. However, the commercial importance of the activities concerned to the country's economy was realized, and so under the terms of the " Alkali, etc. Works Regulation Act ", first passed in 1863 and amended in 1878, in 1881 and in subsequent years, all these factories were placed under the care of a specially created government-controlled inspectorate.

The object of the inspectorate was to ensure that all these factory processes were operated at the highest level of efficiency known to the chemical industry. With two exceptions, no statutory specifications were written for the maximum amount of effluent which would be allowed from any given stack. Instead, the inspectors acted as advisers and consultants to the industries under their care, and saw to it that any discovery of a method of reducing effluent in one factory was immediately communicated to all similar factories and put into operation there. This method of control is not directly based upon a health criterion, but upon a " chemical efficiency " conception, so that the " Alkali Inspectors " as they are called are all men of considerable experience in chemical industry rather than in industrial hygiene or sanitary engineering, but the effect of the control method has been to produce steady reductions in effluent levels in chemical factory stacks. In addition, this line of action has fostered the development of quite a number of new uses for pollutants scrubbed from industrial effluents, so that waste has been turned into a marketable by-product.

It should be noted that although the organization of the prevention of chemical effluent emission in the USA had its origins in public hygiene, the actual basis of operation of the control authorities in many American towns is almost identical with that of the British Alkali Inspectorate. It has been found that the inspector who considers a factory merely from the hygiene aspect can only attempt to control the effluent escaping from the factory; but since he is not an industrial chemist he cannot enter into a consideration of the processes in the factory which produce the effluent, and so cannot be of any assistance to the industrialist in advising him as to the technique to be employed in reducing the effluent, or, on occasions, the method to be used for turning mere waste into an income-producing by-product.

" Los Angeles " Pollution: a New Type

In 1943 Los Angeles began to experience a new type of pollution which has caused the city to become known throughout the world for its smog. It is now thought that similar pollutants are to be found in almost all large cities, but Los Angeles was the first area to experience high concentrations of this new pollutant, because of two circumstances more marked there than in most other cities of the world. Los Angeles has a poor natural ventilation (on a meteorological scale) and it also uses no coal but has a very high consumption of petrol. The result is that the atmospheric concentration of sulfur dioxide is very low, but because of the stagnation of the air over the city, other pollutants, which are now thought to be of a petroleum origin, are held in the air-volume above the city until quite high concentrations result.

Los Angeles became a very highly industrialized area during the recent world war, and its population increased very rapidly. By 1944 the inhabitants became aware of an atmospheric condition which appeared and disappeared, but sometimes remained for days at a time, in which visibility was reduced markedly by a light blue haze, and many persons suffered from sore throat, running nose and eyes, and varying degrees of headache. Air pollution officials from the eastern towns of the USA came to study the situation and decided that the cause was sulfur dioxide, which can produce some of the above symptoms, though usually not all of them. A programme for the reduction of sulfur dioxide emission by various industries, including the oil refineries, did not produce the expected reduction in the smog, as it was called, so further investigation was made and it was discovered that petrol vapour (hydrocarbons) in combination with perhaps nitrogen dioxide or some other reagent present in the air, and under the influence of the energy of sunlight, produced some organic compound which has still not been defined with certainty but which is thought to be a strong oxidizer. A substance which was made from hydrocarbons and nitrogen dioxide, irradiated by ultraviolet light under experimental conditions, was shown to possess the lachrymatory properties of Los Angeles smog, and so the smog control agency set out to prevent the escape of petrol vapours from the storage tanks of the oil refineries. This activity still did not have the required effect, so further thought was given to the subject and it was realized that the very high number of two and a half million motor cars in Los Angeles used five million gallons of petrol a day and, because of the inefficiency of the automobile carburetter, emitted over a thousand tons of hydrocarbons to the atmosphere daily. This means that in a new situation the old problem has again arisen—namely, that the major source of the pollution comes from a very large number of domestic consumers of fuel, this time petrol. As in the case of domestic coal combustion in St Louis and Pittsburgh, the cure cannot be found in terms of legislation forbidding motorists to produce hydrocarbon effluent. It must consist in technical advances which will enable the automobile engine to burn its fuel with an efficiency approaching 100 per cent. This is the present situation in Los Angeles, whose short history of ten years of air pollution research has made air pollution officials in all the large cities of the world reconsider their position for the future. If hydrocarbons from automobile exhausts are the cause of a major problem in Los Angeles, then the problem can appear in other cities as soon as the number of automobiles becomes large enough, and in all cities the number is steadily rising. Scientific articles on Los Angeles smog are very numerous, but luckily a good many of them are gathered together in the proceedings of conferences which have been held on the Los Angeles situation (California State Department of Public Health, 1955; *National air pollution symposia*, 1949, 1952, 1955; Stanford Research Institute, 1954).

History of the Scientific Analysis of Air Pollution

The following is a short review of the scientific aspect of the study of air pollution, leaving out almost entirely the technical and engineering advances which have been made in the control of the emission of effluents by means of filters and precipitators of a variety of types. Though this work is interesting and very important it has to do with the control of known entities, whereas the vital issue in air pollution has been the discovery of the nature of what was in the atmosphere, so that in turn the source of such entities could be found. The story is intimately bound up with the history of the development of industrial hygiene, for very often the discoveries made in industrial hygiene laboratories, in which the health of the workers was the question at issue, were applicable to the work being done in air pollution research, in which the amenities of the city dweller were the basis of action.

1890-1905

In the graphs shown in Fig. 1 and 2 it will be noticed that in the period 1890-1905 there was a steady rise in the number of papers on air pollution produced each year. As Fig. 2 shows, most of the papers were devoted to methods for controlling the emission of smoke. When these contributions are examined it is found that a great many of them were of the nature of " common-sense " attempts to remove smoke, for 1890 was still the era of " common-sense " engineering, during which, in Great Britain, truly amazing achievements in the textile industry, in railroad engineering and in general mechanization had been accomplished by men with no scientific training but abundant mother wit and tremendous perseverance. This was the period in which the phrase " consume its own smoke " was largely used by engineers, administrators and the public, without many of the users really knowing what the term implied. It can be seen that a good many of the control systems which were developed depended on a belief that if smoke were to be heated to a sufficiently high temperature it would be " consumed ". This belief was adhered to in spite of the fact that the chemical section of the report of the London Smoke Prevention Exhibition of 1883

(Frankland, 1883) had made a most exhaustive analysis of the nature of combustion and shown that not only a high temperature was needed but also a sufficient supply of oxygen. However, engineers in general were not in close contact with chemists, and there is an obvious time-lag between the thorough analysis of the chemistry of combustion and the beginnings of a sound application of this knowledge to designs for almost complete combustion.

In the period before 1900, however, there were several noteworthy publications. Among these were five papers on damage to plants from sulfur dioxide, in one of which (Watson, 1899) workers in Kew (near London) remarked that damage can be prevented by deliberately retarding plant growth (causing the plant to rest) during a fumigation period—a fact which has recently been rediscovered in California. In another article (Ost & Wehmer, 1899) it is shown that the brown or red spots on the leaves of plants consist of air-filled collapsed cells—a finding which has been recently demonstrated in the case of Los Angeles smog by Bobrov (1952).

At this time also the original article in which Ringelmann (1898) described his chart for estimating smoke blackness was published, and the first paper appeared describing a light-absorption method for estimating quantities of pollutant in fine particulate form (Fritzsche, 1898). Witz, writing in 1885, suggested that the increased sulfur dioxide in the air over Paris was responsible for a reduction of the ozone content of that air during a period of ten years (a theory which has again been advanced in Los Angeles, where the lack of sulfur dioxide has been thought to allow the building up of a high concentration of ozone and other oxidants). In addition, two papers described techniques for obtaining deposits of smoke on a revolving paper, in which it looks as if the principle of the thermal precipitator were being invoked (*Stationary Engr*, 1892; Thomson, 1892).

Thus in this period, although there was a great deal of activity of a non-scientific type, including a proposal to suck fog through pipes laid in the streets and discharge it through large chimneys—strongly resembling a similarly foolish proposal made in Los Angeles in 1945—a great many fundamental principles concerning the origin, nature and dispersal of air pollutants had been stated with a certain amount of precision.

1905-1915

During this period interest in the effects of air pollution greatly increased and the graphs show that research activity caught up considerably on technical activity. A good deal of the medical interest was of a clinical and epidemiological nature, and, as can be expected, there were papers which contradicted one another, for opinions based on clinical impressions cannot be very reliable. The general level of the medical discussion was that there were undesirable clinical effects from smoke, sulfur dioxide and other pollutants, but there was no consensus of opinion that general city pollution was fatally toxic. However, there was one paper (*Sci. Amer.*, 1914 b) which claimed that cancer had a higher incidence in places where coal is used. During this period also a good many of the city surveys were undertaken in the USA in an attempt to find a basis on which to plan a smoke control system, and a general survey of smokiness was begun in British cities.

Activities in Germany were mostly in the direction of (*a*) assessing the damage done to vegetation by sulfur dioxide, for the purpose of establishing the compensation which was to be paid under the German laws governing damage done by effluents; and (*b*) studying the dispersal of gases from factory stacks, though it would seem from a review of the titles of the papers that much of the work was done at the level of industrial investigation and was not carried to the stage of fundamental research. Consideration of possible harm to health through air pollution was apparently not given much attention in Europe.

1915-1925

During this period war, and the readjustment after it, caused a marked drop in the level of activity connected with air pollution. Almost nothing was written on the subject of the effects of air pollution, and the few papers on methods of determination of pollution are all of American origin and mostly of a review nature.

In the section on control methods there is not much of interest, but three points may be noted: (*a*) it is clear that engineering thinking had realized that the prevention of smoke emission from boilers is very largely a matter of correct design of the furnace and not of adding " smoke consumers " to badly functioning furnaces (Buell, 1923); (*b*) references to the use of powdered fuel and to the fly ash which it produces began to accumulate; and (*c*) in 1915 the report of the Selby Smelter Commission was published (Holmes, Franklin & Gould, 1915), and this is important because it is one of the earlier instances in which scientific assistance to a company whose effluent was a serious danger to the surrounding country resulted in the recovery of sulfur as a by-product and in the installation of continuous recording instruments to keep a constant check upon the sulfur dioxide concentration in the air round the smelter. Selby is also the owner of the highest stack in the world (650 feet, or about 200 m), as the result of an appreciation of the effect of high stacks in reducing the concentration of pollution.

1926-1935

In this period the most dramatic event was the Meuse Valley disaster, in which over sixty persons were killed by polluted air (Firket, 1931; Haldane, 1931; van Leeuwen, 1931), and this triggered off activity throughout the world. French works begin to appear in the bibliographies, and the dangers of air pollution were discussed in the French Chamber of Deputies. In the French papers published at that time there was considerable interest in the work being done in Great Britain and also in the USA, but there were almost no references to French writers in the past (with the exception of Bordas (Bordas, 1926; de Boissezon, 1927), who had worked in Great Britain, the USA and Germany), so that it appears that very little work had been done in France before that time.

The German bibliography (Schwartz et al., 1955) lists for this period ten articles on the effects of air pollution of which five are on damage to human health, whereas in the period before 1925 almost all the papers listed deal with the effects of air pollution on vegetation.

Thus the medical scientists, who had been to the fore in the years before 1890, but whose speculations at that time were based more on conjecture than on factual knowledge as to the specific damage done by air pollution, were once again able to take a lead in directing interest to a subject worthy of very active physiological and clinical study.

Work on methods of measurement of pollutants is represented by the statement of the British Department of Scientific and Industrial Research that a close relationship had been established between the solid content of a smoke-stack plume and the optical density of that plume, as measured by the Ringelmann chart or other instrument. This was a considerable advance, for it gave the chart measurements an additional authority which was much needed. In the USA, a paper by Drinker & Hazard (1934) described an apparatus for the measurement of dust, consisting of a travelling transparent tape on to which the dust was blown through a nozzle, thus giving a permanent record. It is probable that the immense labour involved in examining such a tape is the main reason why this instrument has not been more used. Both in the USA and in Great Britain instruments were being developed for the measurement of smoke inside boiler flues, as a means of assisting in the control of stoking. In these two countries and in Germany attention began to be drawn to the dangers of the exhaust from internal combustion engines (Florentin, 1928; Sayers et al., 1929). At that time the emphasis was on carbon monoxide, for it was shown that concentrations of this gas in the streets of the larger cities often came close to the threshold of tolerance. In addition, a couple of papers appeared pointing out that air pollution contributed considerably to the hazard of flying (Aldworth, 1930; Connolly, 1934). This is an important point and it is surprising that so little has been done by the aeronautical technicians of the world to draw more attention to this aspect of air pollution.

This ten-year period started well with research work in the USA, but activity in Great Britain and other countries of Europe was reduced by unemployment conditions. An economic crash in the USA in 1928 had an adverse effect on research, and it is likely that the Meuse Valley incident would have produced a much greater development of interest if economic conditions had been more favourable.

1936-1945

At the beginning of the period 1936-45 there was a noticeable increase in research and technical activity. Interest grew in the nuisance value of fly ash from boilers, and the " dust bowl " dust storms of central USA aroused considerable interest in silicious and other dusts as a public health hazard. The US Public Health Service undertook to make a nation-wide survey of the extent of city air pollution and started a survey of the smoke, soot and sulfur dioxide concentrations in the air of fourteen American cities (Ives et al., 1936). The aftermath of the Meuse Valley disaster (six years before) produced at least four papers discussing the possible causes of the deaths which occurred, and the blame was laid on sulfur dioxide by some authorities and on fluorides by others.

A monograph appeared on fluorine intoxication (Roholm, 1937), indicating the industrial activities which produced fluoride effluents and describing the hazards to vegetation, animals and man. In 1937, two articles appeared, one emanating from France, on the production of aldehydes by internal combustion engines (Maillard, 1937; Pardoe, 1937), in which it was shown that the aldehyde concentration in the exhaust was forty times greater during the deceleration period (with throttle closed) than it was during acceleration or normal running. In the following year four more articles were published on the same subject (Grunder & Rich, 1938; Maurin & Kling, 1938; Pardoe, 1938; Roberts, 1938), and one of them indicated that similar effluents could be expected from oil-burning furnaces if the air supply was too great and incomplete combustion took place. Thus at this early date information was being collected which should have been of considerable value to the investigators in Los Angeles ten years later. At this time (1937) the Department of Scientific and Industrial Research reported that the smokiness of many cities in Great Britain had been markedly reduced by the depression, but the war which followed made conditions very much worse than they had been before. A Japanese paper described a photo-cell method of measuring the optical density of filter papers containing particulate air pollutants (Kashiwai, 1938). This of course was not a new process except for the use of the comparatively new photo-cell, and it is doubtful if the Japanese publication advanced scientific methods appreciably. The investigation of the massive sulfur dioxide emissions from the stacks of the Trail smelters in Canada (which produced considerable damage across the border in the USA) had begun in 1929, but a preliminary report was presented by the international commission only in 1937, and it was not until 1941 that a final decision was arrived at (Dean & Swain, 1944). This scientific study of industrial pollution is historically important because it was the first case in which meteorological control methods were specifically applied to industrial pollutants, the industry undertaking to shut down certain processes whenever the meteorological observations taken in the neighbourhood of the smelters showed that conditions were right for the production of atmospheric stratification and a resultant fumigation in the valley running south from the smelter stacks.

The year 1942 is interesting for the appearance of a paper on the toxic effects of pollutants (Easton, 1942), in which it was suggested that the presence of two pollutants, both in concentrations below the accepted tolerance threshold (or M.A.C.), could produce toxic effects because the effects were additive. This is not the first reference to synergistic effects with regard to air pollutants but it is certainly an early one.

In 1943, Great Britain, in the midst of a total war, was still able to hold a conference to consider the claims of clean air in the reconstruction of British cities when the war should come to an end (National Smoke Abatement Society, 1943). In 1944 came increased interest in meteorological factors affecting pollution concentration (Fletcher & Smith, 1944), and the suggestion that the US Weather Bureau statistics would be of assistance to control authorities in the cities of the USA (Fletcher, 1945). In 1945 the Los Angeles Air Pollution Control Office, which had been working on smog control since 1942, issued a paper on the various sources of sulfur dioxide, which was then thought to be the main cause of eye irritation (Swartout & Deutch, 1945). At the same time the report on the Leicester Survey in Great Britain, whose publication had been delayed during the war, appeared, drawing attention to the important part played by turbulence in the dispersion of pollutants from the air above a city (Great Britain, Department of Scientific and Industrial Research, 1945).

In this period, according to the information available, German interest grew considerably, and twenty-eight papers are known of which contributed to knowledge of such matters as dispersion of dust from stacks (Löbner, 1937a), meteorological factors affecting dispersal of pollutants (Lettau & Schwerdtfeger, 1937; Roetschke, 1937), the measurement of sulfur dioxide (Müller, 1941; Schepp & Frömme, 1938), carbon monoxide (Bayer, 1938; Wirth & Muntsch, 1940), and dust concentrations (Löbner, 1937b).

There is not much information on French activity except for a couple of papers on aldehydes from internal combustion engine exhausts, an article on smoke in Paris stating that 90 % of coal burned in Paris is used in domestic grates (Kling, 1938), and some medical discussions of the Meuse Valley disaster.

1946-1957

In this period research developed very rapidly, as is evidenced by the number of papers published and the variety of subjects studied. There was a sudden development of activity immediately the war ended, but it looks as if for some years the output of scientific and technical articles remained steady at about 150 per year. The number of papers is far too great for it to be possible to review all of them, but mention will be made of a few of the most interesting examples.

The 1948 Donora disaster was a historic event and stimulated even more research than did the Meuse Valley disaster, but in addition it caused scientific interest in air pollution to develop in South Africa and Australia and in other young countries that were just arriving at the point where city populations had reached the level at which danger from pollution arises. The Donora disaster also stimulated a considerable amount of physiological and epidemiological research into the nature of the reaction of the human system to air pollutants, and work on this subject is progressing in many American universities and research institutes, and in a number of laboratories in Canada, Great Britain and the continent of Europe. The past ten years has seen the development of several instruments for the measurement of pollutants, such as the American Iron and Steel Institute smoke sampler, the Gast air sampler, the Hi-vol air sampler, the Thomas autometer for gaseous pollutants, the titrilog, the Salzman reagent in a modified recording colorimeter for nitrogen dioxide, the infra-red carbon monoxide recorder, the mass spectrometer for the analysis of hydrocarbons, the rubber-cracking technique for the estimation of ozone, and the colorimeter for oxidant determination. The work of this last period, however, deserves a section to itself.

The Modern Era in Air Pollution Study and Control

The year 1945 can be taken as the start of the modern era in the study of air pollution. First, it is the year in which general activity increased so rapidly that the number of publications appearing in 1947 was four times greater than in 1944. Secondly, by 1945 the Los Angeles smog, which first attracted attention about 1940, had developed to serious proportions and the Control Office, which had been established in 1945, was reorganized as a County Control in an endeavour to meet the crisis. Thirdly, in 1948 the Donora disaster roused the US Public Health Service into intensive activity and convinced a very large percentage of the scientists in the USA that even if clear evidence could not be presented that pollutants such as sulfur dioxide in low concentrations produced physical damage to the human body, there was at last proof that under some circumstances air pollution in the streets of a town could be accompanied by a death rate high enough to frighten public health officials. The London disaster of 1952 confirmed this fact, but even before that date the whole tenor of air pollution research in the USA, Great Britain and on the continent of Europe had changed. Research activity was heightened, money grants for study and city control schemes were enormously increased, and a conviction grew that the pollutants of the air in the modern era were not only smoke, sulfur dioxide, ash and the chemically known gases which are effluents from industries, but a number of substances which had never before been suspected to exist in the normal city atmosphere (and which possibly had not existed there before the year 1900). These substances, whose presence was first detected in Los Angeles, were thought to exist at low concentration in all modern cities, and the characteristic of air pollution study in the present era is a concerted effort to discover what the substances are, for until they are identified it will be difficult, even impossible, to remove them. In addition, in about 1946 the realization had come that air pollution is an area problem, not a city problem. The control techniques therefore began to change from city units to county units in the USA, and the planners in Great Britain turned to national legislation as the only way of dealing with the situation.

Thus it may be said that the years 1945 to perhaps 1953 were a time of mental reassessment of the whole problem of air pollution, while the years since then have been a period during which a move has been made to marshal the forces of all the branches of science into a concerted attack upon what is now realized to be a problem concerned with highly complex organic chemical reactions and a multiplicity of physiological reactions produced by the chemical by-products.

It has been realized that there are a number of fields which need to be explored, and work has been developing very intensively under the following headings:

(1) The development of instrumentation for the continuous recording of the many parameters (ozone, aldehydes, oxides of nitrogen, oxides of sulfur, oxides of carbon, hydrocarbons, etc.) which need to be studied.

(2) Studies of the chemical composition of the atmospheres of large cities with a view to finding out which gaseous compounds are common to all cities, or at least to many cities, and which are peculiar to some cities. In this work the mass spectrometer and the infra-red spectrometer have been the most valuable tools, the one assisting the other.

(3) Attempts to unravel the complex chemical reactions which apparently give rise to the type of pollutant that causes the eye-irritating smog in Los Angeles. This problem is being approached both by the synthetic method, in which compounds are produced and their biological effects are tested, and by the analytical method, in which attempts are made to separate out of normal air some component which will produce specific biological effects.

(4) Toxicological studies of the effects of various materials, particularly ozone, on animals, and population studies in which attempts are made to correlate general population symptoms with the rise and fall of various factors in city air. Here of course the industrial hygiene experts are coming

into even closer contact and co-operation with the workers on air pollution than they did before, and it is only too obvious that air pollution studies are an extension of industrial hygiene.

(5) Meteorological studies to develop a sound knowledge of the nature of air movement in the first few hundred feet above a city, the mechanism by which pollutants are dispersed above a city and the sort of measurement which will most reliably indicate what degree of dispersal rate is in process at the time of the measurement.

(6) Study of damage to vegetation as a means both of learning how the damage takes place and of being able to use specific plants as a form of instrument to indicate the degree of pollution which is present at any time.

(7) Development of methods for the control of effluent from all types of industry and all processes which may produce effluent, including domestic burning of coal, and burning of petrol in private automobiles.

The first attempt to marshal scientific manpower in the USA was the government-sponsored technical conference on air pollution which was held in Washington in 1950 (McCabe, 1952). Another is represented by the national air pollution conferences which were sponsored in California by the Stanford Research Institute in co-operation with the California Institute of Technology, the University of California, the University of Southern California, the Air Pollution Control Association and the Air Pollution Foundation (*National air pollution symposia*, 1949, 1952, 1955).

The most important move was the decision by the US Federal Government in 1955 to vote five million dollars annually for the promotion of research on air pollution, and its administrative action in establishing a research division on air pollution at the Robert Taft Sanitary Engineering Center, Cincinnati. This move has produced a marked increase in research activity throughout the USA and has enabled the Robert Taft Center to act as a clearing-house for ideas about research projects and for the pooling of the results of research. The British authorities have been strong in urging that there should be a pooling of effort and of results, for they have realized, as have all workers in this field, that the development and the discovery of the complexities of air pollution are just an indication of a new factor in society which has developed as a result of the technical advance of mankind. In Great Britain, because of its small size and high population density, research has been fairly well co-ordinated for some considerable time, so that the move to establish close relations with the American workers is a natural development.

Another subject of study which has been considered in this reassessment of the problem is that of the spread of radioactivity as a result of the explosion of nuclear weapons. This is a specialist department of air pollution research which is at present being handled by departments of the atomic energy organizations of the various countries, but it is very apparent that with the development of nuclear energy for industrial purposes the whole subject of the dispersal, monitoring and control of radioactive effluents will have to become the province of scientists concerned with air pollution in general. It is not surprising, therefore, that more and more papers concerned with this aspect of air pollution are being published, and that in the co-ordination of research on air pollution, radioactive pollutants are being given serious thought.

The following references are indicative of the type of work which is being done in these different directions: Beckman & Co., 1955; Billings, Small & Silverman, 1955; Bobrov, 1955; Cadle & Magill, 1951; Cleeves, 1953; Eichfelder, 1955; Eisenbud et al., 1949; Gucker, Pickard & O'Konski, 1947; Haagen-Smit, 1952; Hewson, 1951; Hueper, 1954; LaBelle et al., 1955; Littman, 1956; McCabe, 1956; Magill et al., 1950; Noble, 1955; Patton & Lewis, 1955; Shepherd et al., 1951; Sherlock & Stalker, 1941; Sinclair & LaMer, 1949; Sutton, 1949; Sutton, 1950; Tebbens, Thomas & Mukai, 1956; Thomas & Ivie, 1946.

Comments on the History of Air Pollution

At the end of this review of the history of air pollution it might be of value to comment on the factors of importance which seem to emerge from the study.

(1) The first comment is that air pollution is a subject which seemed to be rather simple at first sight, but which has been found to be more and more complex as it has been explored. Not only is it now known that the oxidant type of pollutant which is associated with what might be called a " hydrocarbon economy " is extremely complex in nature, but it is beginning to be suspected that the reducing type of pollution—referred to in general as sulfur dioxide—is also very complex, a supposition which could account for the fact that concentrations which used to be thought of as quite harmless have been shown to cause considerable injury to health.

(2) The result of this complexity is that though it is fairly easy to obtain generalized information about air pollution (the British investigators gained extremely valuable information with apparatus costing not more than £40, or US $112.00) the cost involved in taking the next step inwards towards the heart of the problem rises out of all proportion to the amount of information obtained.

(3) The preceding two statements lead naturally to the observation that a great many of the research projects which have been instituted during the last sixty years have produced inconclusive results (*a*) because the design of the experiments was inadequate for the problem, or (*b*) because the experimental and organizational structure was deficient, owing to the fact that the funds available were quite insufficient for the task in hand.

(4) It is noticeable in studying the history of air pollution that there has been a tremendous amount of repetition of experiments, discoveries and observations. This means that the waste of effort on the research side has been enormous, but it is not at all certain that effort has been wasted on the social side. It is quite evident that the implications of air pollution to society in the spheres of health, amenity, comfort, and straight cost have never been clear to the community in the past sixty years, in spite of the efforts of control associations. Thus the continual production of scientific review articles giving a general idea of the issues involved in air pollution has rendered a very valuable service in forming in the public mind a desire to deal with the problem, a realization that it can be dealt with, and a willingness to supply the funds which are necessary to deal with it. Notwithstanding this consoling thought, however, in many cases the pooling of money and of workers could have produced experimental projects which would have reached a conclusive end-point; instead one is left with tantalizing suggestions of what might have been found if only something had been done better.

(5) The next comment is that it is very necessary for workers on the same subject in different cities, let alone in different countries, to have a common basis of understanding. In the past, varying tests for the same factor have been used, and it has been impossible to compare the work of one research group with that of another because the units were not the same, the techniques were different and conversion factors could not be applied. Thus the result obtained in one area could not help to achieve an advance in another area. This has been appreciated by most students of the subject, and there is no lack of willingness to pool results and make the pooling as simple as possible.

In this connexion the report of the Air Pollution Planning Seminar which was held in Cincinnati in December 1956 should be cited. A great many of the issues which have been raised above were considered in that seminar and the 176 pages of the report are full of quite fascinating and most encouraging reading (US Department of Health, Education, and Welfare, 1956).

(6) It is no longer possible to think that any country, which is not still to be described as having a purely agricultural economy, can afford to be ignorant about air pollution. Such pollution as is observable in the cities of the world may be slight where populations are small and techniques are not highly developed, but there is no hope that the concentration levels will remain low. As industrial development takes place, pollution will have to be controlled, and a country can ill afford to be without the services of men trained in the investigation and the control of pollution in the air.

(7) Finally, it has been amply proved that air pollution cannot effectively be controlled by placing the control in the hands of the public health organizations of a city, a state or a country. The requirements are diverse

and complex and a team of trained minds is necessary. Medical, physical, chemical and engineering abilities are needed and must be supplied if the job is to be done effectively.

Thus well planned effort is required in every country of the world (the level of the effort adjusted to the level of social development), and there is a great need for these national efforts to have a considerable measure of coherence, so that advance on one front can immediately be used to make easier the work on all other fronts. The beginnings of such an approach are very evident, and it is worthy of much time and thought to make this approach world wide.

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