ATMOSPHERIC POLLUTION*

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ONE might think that the trouble of atmospheric pollution was a result of the industrialization of Great Britain during the past hundred and fifty years. It is therefore interesting to turn to John Evelyn, who wrote of London in 1661 :

"And what is all this, but the Hellish & dismal Cloud of SEA-COALE ? which is not onely perpetually imminent over her head ; but so universally mixed with the otherwise wholesome & excellent aer, that her Inhabitants breathe nothing but an impure & thick mist, accompanied with a fuliginous & filthy vapour, which renders them obnoxious to a thousand inconveniences, corrupting the Lungs, & disordering the entire habits of their bodies ; so that Catarrs, Phthisicks, Coughs & Consumptions, rage more in this one City than in the whole earth besides."

Hence the trouble is no new one. However, no major attempt was made to obtain accurate records of the pollution in towns until about 1912, when a small committee under the chairmanship of Sir Napier Shaw designed suitable instruments and arranged for regular observations to be made which have gone on until the present day. Now it may be asked what good has been done by the very great amount of work which has been put into these observations. The answer is that without them there is no means of knowing whether the trouble is getting better or worse ; whether big changes—for example, construction of the great power stations in London—have appreciably affected conditions, and whether legislation designed to reduce the evil has in fact had any effect. It would have been of great interest if John Evelyn could have made even the simplest observations to show the intensity of pollution in his day.

The pollution usually found in towns can be divided into three distinct classes : (1) 'Smoke', which consists of black carbonaceous matter formed by the imperfect combustion of fuel. This is mainly in the form of very small particles which float for a long time in the air, only settling out very slowly. (2) 'Ash' or grit which is thrown out with the flue gases and comes chiefly from industrial plants where the velocity of the flue gases is high. Such ash consists of much larger particles than 'smoke' and therefore settles relatively quickly out of the air in the immediate neighbourhood of the chimney discharging it. (3) Finally, there are the corrosive sulphurous gases. Of these, sulphur dioxide is generally the most important and comes from the sulphur always present in coal to the extent of 1–4 per cent. These gases are removed by being dissolved by clouds and rain or by reacting with stonework and the like.

The instrument which has been longest in use to measure the amount of pollution is the deposit gauge. This consists of a large glass funnel into which rain and impurities fall, to be collected in a bottle below. The object is to measure the amount of pollution settling out of the atmosphere on to buildings, trees and the like. The deposit is collected once a month and weighed and analysed into its chemical constituents. The gauge is not one of the most useful instruments, since it tends to collect material such as dust which is blown up by the wind.

* Being the substance of a Friday evening discourse entitled "The Air We Breathe in Town and Country" at the Royal Institution on February 12. Acknowledgement is made to the Department of Scientific and Industrial Research for permission to refer to unpublished results of the survey of atmospheric pollution at Leicester.

In order to measure the amount of black polluting matter suspended in the air Dr. J. S. Owens designed the automatic filter ; in this, air is drawn through a filter paper which removes the dirt, the amount of which can be estimated from the blackness of the stain produced. The position of the filter paper is changed automatically once or twice an hour so that variations in pollution throughout the day are recorded. The fact that only black matter is shown on the filter paper is no great disadvantage since most of the dirt usually found in the air is black. It has been shown that the greater part of the dirt caught by the filter consists of carbonaceous matter floating as very small particles in the air and may be described as 'smoke', in contrast to the larger inorganic particles of 'ash' which quickly settle out of the air. A filter can be connected in the pipe supplying air to the apparatus for measuring sulphur dioxide and in this case the filter is changed once a day. A variation of this type of filter has been designed which can be weighed before and after exposure, thus determining directly the weight of suspended matter in a given quantity of air.

Smoke is well known to have the effect of reducing the ultra-violet and visible daylight received in towns, and several instruments have been designed to measure this. Two have been used to enable a count to be made of the number of particles floating in the air. The first, designed by Dr. Owens, drives a jet of damp air at a high speed against a glass plate, when many of the particles are deposited on the glass, though some of the smaller ones may escape. The second instrument, designed by Mr. H. L. Green, uses the principle of thermal precipitation by which dust in warm air is deposited on any cold object. In both instruments the particles are counted with the aid of a microscope, and since the number of small particles that can be seen depends both on the illumination and on the magnification used, standard conditions must be employed if comparable results are to be obtained. If we wish to know the total number of particles present in the air down to the very smallest, we must use the Aitken dust counter, which uses the fact that if damp air is rapidly cooled by expansion, water droplets are condensed on each particle. The water drops fall out on to a polished metal surface and can be counted with the aid of a lens, but since there are so many it is usually necessary to dilute the sample of dirty air with a large volume of clean air to get a reasonable number to count. The number of these particles varies greatly, from some ten million per cubic inch in town air to a thousand or so in the cleanest country air. Some of the particles found in country air are produced naturally and are not due to human activities.

Finally, we come to the gaseous pollutions. The total acidity (mainly due to sulphur dioxide) is measured by passing a known quantity of air through a solution of hydrogen peroxide and titrating the resulting acid after 24 hours. We may determine what may be called activity of the sulphur gases by measuring the rate of sulphation of a standard surface of lead peroxide and in this way obtain a figure which will give an indication of the very much slower rate of attack of stonework, etc., by the sulphur gases. The latter apparatus has been found to be very useful since many sets can easily be exposed in different places—usually for a month—and then analysed.

Turning now to the results that have been obtained with these instruments, we take first the deposit gauge. Of the total catch, part is soluble in water and part insoluble. Some of the insoluble matter is dust blown up by the wind, and is often found to increase in dry weather. Much of the remainder comes from the nearest two or three industrial chimneys. The weight of soluble matter is very closely related to the rainfall, and there is little doubt that the rain removes a considerable amount of the sulphur gases in the air. The sulphur dioxide is mainly caught by cloud droplets as they float in the air rather than by the rain falling through the air. This is indicated by the fact that the amount of sulphates, for example, deposited with the rain falls off much more slowly outside a town than the amount of sulphur dioxide in the surface air. The sulphur dioxide at cloud level will be much more uniformly distributed than that in the lower air.

The results from the automatic filter may be used to show how the amount of smoke varies through the day. As might be expected, the air is cleanest in the early morning just before the first fires are lit for the day. A rapid increase of smoke then occurs, reaching a maximum in the middle of the morning. A shallow minimum during the afternoon is partly due to a reduction in the amount of smoke produced at this time and partly to the increased turbulence of the air in the middle of the day, which removes some of the smoke from street level. A second maximum in the late afternoon, which may or may not exceed the morning maximum, is caused partly by cooking the evening meal and partly by the reduced turbulence at this time of day. A remarkable result that comes out of these observations is that even under conditions of very stagnant air which causes a thick smoke haze during the day, the air in the early morning is comparatively clean. Even a thick fog, which in the evening has become a 'pea-souper' by picking up smoke, is found to be a nearly white fog, resembling a country fog, in the early hours of next morning; in other words, yesterday's fog has been removed or deposited during the night and a new clean fog has taken its place only to become as dirty as its predecessor during the coming day.

Although most measurements of acidity in the air take a single sample running for 24 hours and so cannot show the diurnal variation, yet a few hourly measurements have been made. These show a maximum of acidity during the daytime, but since the lighting of fires produces no extra acidity in the way that it produces extra smoke, we should not expect the morning maximum to be so marked. This is what the observations show to be the fact.

Both smoke and acidity show strong annual variations, with a maximum in winter and minimum in summer. This is natural both because more fuel is burnt in winter than in summer and also because the greater turbulence in summer will carry smoke and acidity more rapidly upwards.

The reduction of daylight—and particularly of ultra-violet light—near the centre of a large town by the smoke may be very great, and the proportional reduction is much greater in winter than in summer, although there is more need for ultra-violet in winter. This is partly due to the greater amount of smoke in winter and partly to the fact that the more oblique rays of the sun must travel a longer path through the smoky air. On a bad day in winter in London, nine tenths of the daylight is probably lost because of smoke alone.

In order to study atmospheric pollution in cities throughout Great Britain, the organization started under Sir Napier Shaw is still in existence; nearly sixty municipal authorities co-operate in making measurements of the pollution of the atmosphere within their respective towns, all the results being co-ordinated by a central committee under the Department of Scientific and Industrial Research, which carries out central services for this co-operative scheme. A large amount of information has been collected in this way during the last twenty-five years about the pollution at selected points in a number of cities. This information is very valuable in showing whether the pollution is getting better or worse, but it is usually not possible for any one city to run more than one or two stations, and we should never in this way have found out much about the distribution of pollution in different parts of a town. Again, since it is probable that the instruments set up in different towns will not be in comparable positions, we could say little about the general cleanness of one town as compared with another. What is perhaps more important still, is that we had little information about the 'life-history' of pollution after it left the chimney, and how it was removed from within the town, and how it was finally removed from the atmosphere. For this reason the Atmospheric Pollution Research Committee of the Department of Scientific and Industrial Research recommended that a thorough investigation should be undertaken into the distribution of pollution within one typical town. The city finally chosen was Leicester, since it is a large industrial city and is fairly well removed from other large towns the pollution from which might complicate the results. The authorities of the City of Leicester gave every possible assistance and two full years observations were made there at a dozen different situations in the centre of the city, in the suburbs and in the country surrounding it. Observations of smoke, sulphur, acidity and daylight were made at all these sites. Later, observations were made for a short time at a few other stations to clear up special points.

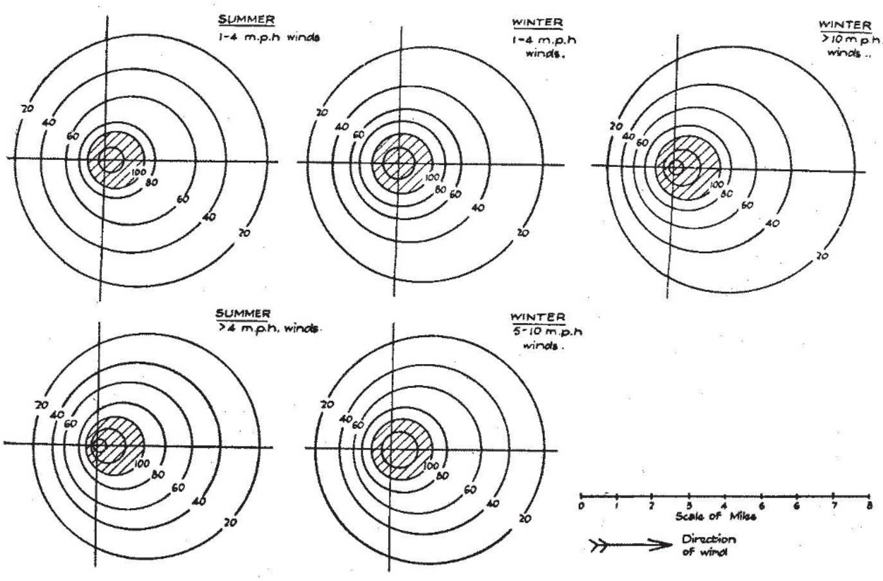
Curves for smoke and sulphur dioxide or acidity show distributions generally similar; the maximum density of pollution coincides closely with the centre of the city.

A point of great interest is the effect of wind on the distribution of pollution. The accompanying illustration shows the distribution of smoke for light and moderate winds in summer and for light, moderate and strong winds in winter; the intersections of the straight lines indicate the centre of the city. At first it is very surprising that in all cases the highest pollution is found close to the centre of the city rather than some distance downwind from the centre; and the general distribution—indicated by the circles—is little distorted by the wind, while the pollution added by the large city of Leicester was under most conditions difficult to detect above the general level of pollution in the surrounding country only a few miles downwind from the centre of the city.

In an earlier research the number of particles found by the Owens dust counter was recorded at various distances downwind from the centre of Norwich. Although this work was less detailed than that at Leicester, it again showed that even in strong winds the maximum number of particles was always found very close to the centre of the city and fell off rapidly downwind. It showed also that an increase of wind, by say three times, only resulted in a decrease of the pollution at the centre by about 30 per cent. At distances of more than five miles downwind the number of particles was nearly constant.

From these diagrams it is quite clear that somehow or other smoke is quickly removed from the surface air where the measurements are made. If there were no removal of smoke, the concentration would steadily increase as the air passed across the city—more rapidly when passing over the centre of the city and more slowly as it passed over the outskirts—so that the densest pollution would be somewhere near the leeward edge of the city. It is possible that the removal of this smoke is affected in three ways: by diffusion sideways across the wind direction, by deposition on to the ground and by spreading upwards. Diffusion sideways could not account for the rapid fall in pollution at a distance downwind from the centre which is small compared with the width of the city. The deposit gauge gives no sign that deposition is sufficiently rapid to give the effect, and we are left to conclude that diffusion upwards into the upper air is the really important factor.

Of course, the smoke is finally carried away from the city area by the wind aloft, but it seems that it is the removal of smoke from street level into the air a few hundred feet up that prevents smoke accumulating to a far greater extent than it usually does. That this is really the case is borne out by observations on days when the meteorological conditions are such that upward diffusion is stopped, for we find on these days that a dense smoke haze is quickly formed. The amount of upward diffusion is determined both by the change of temperature of the air with height and by the wind. When there is a cool layer of air near the ground with a warmer layer above, there is little vertical mixing of the air, and these are the conditions when smoke accumulates excessively near the ground. A strong wind will cause a reduction of smokiness, but this is more because it increases the vertical mixing than because it carries smoke away horizontally. This accounts for the observed fact that the reduction in pollution at street level is much smaller than the relative increase in wind velocity.



Although the smoke produced in towns is removed from the street level mainly by diffusion into the air overhead, it must eventually be removed from the area of the town by being carried away by the wind, and it will go to pollute the air over the surrounding country. Since the pollution from towns is dispersed through a great depth of atmosphere by the time it has drifted many miles away, the actual concentration in surface air will be small and may be difficult to detect in the presence of quite small local sources of pollution. On the other hand, the total mass of pollution through the whole thickness of the atmosphere may be great, so that it greatly affects the visibility and the colour of the sky. This makes the study of the pollution in districts far removed from its source rather difficult, and other methods may have to be used than those employed successfully in towns.

Up to the present time, no thorough study of the spread of the smoke over the country has been made, but it is easy to see its effects at great distances from towns. It has been estimated that, during westerly winds, a point some four miles to the east of Leicester receives about 30 per cent of its pollution from Leicester, about 25 per cent from the Birmingham district which is 30–45 miles away, and 45 per cent from elsewhere. North-easterly winds bring the least pollution to the Leicester district from outside since there are no large towns in that direction for many miles. At Oxford, south-westerly and westerly winds generally give very good visibility, but the smoke from the Midlands some sixty miles away produces much haze when the wind is north-westerly or northerly. With moderate or light northerly winds the visibility may be quite good during the morning, but about noon the Midland smoke can be seen arriving while the visibility decreases and the blue sky becomes whitish.

Turning to the effect of pollution on the light received in different parts of Leicester, we find that in summer, when the amount of smoke is generally low, the reduction even at the centre of the city is small, but in winter the decrease is very appreciable and in December the centre of a city may receive less than half that received outside it. The insidious effect of pollution on public health is partly due to this reduction of ultra-violet light, and may be the greatest evil of all.

It may be well at this point to say a few words about the effect of pollution on town fogs. It is probable that the *number* of fogs in a city is not increased above those in the surrounding country; indeed, as is well known, since there is a small increase in air temperature in towns above that of the country outside and since the rain will run off from roofs and streets much quicker than from open ground, one may expect the air in towns to be slightly drier than that outside them. On the other hand, the *character* of any fog which is formed will be greatly changed. Since there are so many more nuclei on which water droplets can form, the fog is likely to be noticeably more opaque and each droplet will catch some of the dirt floating in the air, so that the fog will lose the white character it would have in the country and tend to become a black fog. The number of 'pea-soup' fogs in London seems to have become definitely smaller in recent years, but it is difficult to say exactly why this is so. Unfortunately, the output of pollution does not seem to have decreased in the same ratio, although there was a substantial decrease in the years 1918–23.

One way in which we can get an estimate of the amount of domestic and industrial smoke is to measure the pollution on the different days of the week. On Saturday afternoon and Sunday, a great proportion of the industrial fires, including office heating, will be out or very low. On the other hand, domestic fires will go on as usual or may be slightly increased. It is found that there is a fall on Saturday afternoons and a marked drop on Sundays except in purely residential districts, the percentage drop varying between the residential and industrial parts of a town. On the average, the Sunday pollution in the centres of towns is about half to three quarters of the weekday pollution, and as a very rough estimate we may take the smoke pollution to be two thirds domestic and one third industrial in origin.

There is a greater reduction of sulphur than of smoke at week-ends. This is because a greater proportion of smoke is produced from open fires in houses. In central Leicester on winter weekdays, two thirds of the sulphur is of domestic origin whereas three quarters of the smoke is of domestic origin. This all shows how much more wasteful of fuel we are in the home than in the office or factory. If domestic heating and cooking were done as economically as industrial heating and steam-raising, we should use less coal in houses than industries, not more. These figures refer to peace-time, of course.

It may not be out of place finally to take a look at the problem with a view to the future and see what could reasonably be done to remove the evil. Of the three evils, 'smoke', 'ash' and 'sulphur', it is reasonably easy to prevent the emission of ash from industrial plants without placing too great a financial burden on industry, and one may hope that this will be made compulsory. The ash from domestic fires is probably too small to cause a serious nuisance.

The removal of 'smoke' depends on burning fuel in a proper manner. There seems no reason why most industrial plants should make any great amount of smoke, and even now the best plants are practically smokeless. Smoke means loss of fuel and it should be in the interest of the industries themselves to burn their fuel efficiently. A reduction in domestic smoke is likely to come about through the ever greater use of gas and electricity for cooking and heating, while smokeless fuel may replace some raw coal. If district heating is widely adopted, it should also help very much. Any method of increasing the efficiency of the open grate would improve matters, but short of abolishing open coal-fires altogether, the most effective reform would be to consume the smoke emitted during kindling and refuelling.

From time to time there have been suggestions that 'smokeless zones' should be established in the centre of cities where no coal could be burnt in such a way as to produce smoke. The results of the detailed work at Leicester allow us to make a rough estimate of the effect. While such efforts are greatly to be encouraged, no striking effect is to be expected unless the smokeless zone is large, owing to the smoke from the surroundings which will be carried into it.

To prevent the emission of sulphur dioxide may prove to be the greatest difficulty. However efficiently coal is burnt, the amount of sulphur dioxide formed depends only on the weight of coal consumed and the sulphur content of the coal. Unless some means is provided for absorbing the sulphur before the gases are discharged into the air, little improvement can be obtained, though washing the coal removes some of the sulphur. Some of the great electric power stations have means of absorbing the sulphur gases, but from by far the greatest amount of coal burnt all the sulphur dioxide formed is discharged into the atmosphere. There is some hope that, in the not too distant future, apparatus for absorbing sulphur gases may be practicable for much smaller plants, but it is perhaps too much to hope that such means could be generally adopted for the domestic fire. If communal or district heating were introduced on a wide scale, the central plants might be fitted with sulphur absorbers. The use of coal gas (where almost all the sulphur is removed) or of electricity (provided sulphur-absorbing plant is installed at the power stations) on a very much greater scale than at present may be the final solution.

It is greatly to be hoped that in planning the new Britain all practicable measures to reduce atmospheric pollution will be adopted.

OBITUARIES

Mr. Rollo Appleyard, O.B.E.

ROLLO APPLEYARD, whose death occurred on March 1, was one of those pioneer engineer-physicists who did so much during the last few decades of the nineteenth century to establish British electrical industry on a scientific basis. Born in 1867 and educated at Dulwich, he was fortunate, as a student at the City and Guilds Institute, to come under the influence of that great coalition Profs. Ayrton and Perry. Bedford College and Coopers Hill College in turn welcomed him afterwards on the physics side.

At the age of twenty-five, Appleyard joined the technical staff of the India Rubber and Gutta Percha Company at Silvertown, where he remained for twenty-two years. Among his colleagues at this time was Rymer-Jones, of world-wide submarine cable reputation, and during this period Appleyard devoted a good deal of time and thought to dielectric and conductor problems in submarine cables. He contributed many papers to the *Proceedings of the Physical Society*, the *Phil. Mag.* and to the engineering institutions, as well as articles to the electrical press. These covered a variety of subjects including electrical alloys, network problems, submarine cable testing and apparatus for this purpose, coherers, surface tension and thermometry. He was mostly interested in dielectric theory, and an outstanding example of his practical application of his knowledge of physics was the production of the submarine cable connecting Honolulu and San Francisco, in which he achieved the lowest dielectric constant obtained on any submarine cable to that date.

In the improvement of the conductor for long-distance submarine cables, Appleyard invented the 'conductometer', an instrument for the measurement of electrical conductivity, and his paper on the subject before the Institution of Civil Engineers gained him the Telford Premium in 1903. As evidence of his versatility and long interest in technical matters, it may be recorded that seventeen years later the award was made to him a second time, for a paper on the mathematics of catenaries. While