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## METEOROLOGY and AIR POLLUTION

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An Address Given to the Royal Meteorological Society, Canadian
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# METEOROLOGY AND AIR POLLUTION

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Although air pollution is very much in the news, it is neither new nor entirely man made. First, it must be appreciated that nature is a prolific source of pollution. High winds pick up dust and sea spray to give dust and salt pollution. Forest fires, earthquakes, volcanoes, meteorites and even the pollen of plants all give rise to pollutants which are not without their effect. It is recorded that the eruption of Krakatoa in 1883 caused red sunsets for more than two years, until the dust had been removed by natural processes.

Historically, primitive man added his quota from his fires, and, by the twelfth century, smelting and the use of coal had already created pollution problems. Queen Eleanor is recorded as having moved the court out of London to avoid the smoke of coal; a few years later the use of coal was outlawed while Parliament was in session. By 1666, John Evelyn could write a whole book (Fumifugium - Escape from the Fumes) dealing with the smoke problems of London and, about the same time, German villagers banished a copper smelter out of the village because of the fumes he produced.

So much for the background. To-day, we know that excessive pollution results from atmospheric conditions reducing the rate of dispersion below the rate of production, thus causing a build up of pollutants. There is also the opposite effect - the influence of pollution on the weather. While it is not claimed that fog or rain would be drastically reduced, there is overwhelming evidence that increasing pollution, especially combustion products, leads to an increase in fog and rainfall in the heavily industrialized areas. Prague averaged 20 more foggy days per year during the period 1880-1950 compared with 1800-1880. Similar results have been obtained for rainfall in the industrial areas of England, where it has also been shown that, in areas working a six-day week, the rainfall on Sundays was significantly less than on week days. This is not surprising in view of our recent discoveries concerning the role of particles as condensation nuclei and the recent vogue of "seeding" rain clouds with nuclei to promote precipitation. It is, of course, the formation of rain drops on the dust particles which accomplished the major part of the cleaning of the atmosphere. Smaller quantities of dust (excluding the particles which are large enough to settle out under gravity) are removed by impingement on the earth or vegetation.

From the air pollution point of view, the effect of meteorology on the concentration of pollutants is of paramount importance. The reduction in the production of pollution is naturally the primary aim, but industrial production is an economic process and numerous processes cannot reduce effluents to a negligible level without considerable increase in cost. The alternative is to arrange the release of the effluents to give the minimum nuisance; that is, by utilizing to the best advantage the turbulence of the atmosphere.

If a given mass of air is taken from a point $h_1$ to a higher point $h_2$ under adiabatic conditions, its temperature falls due to the work done in expanding from $V_1$ to $V_2$ against the decreasing pressure. This temperature change is approximate - $5^{\circ}$ F. per 1000 ft. Under such conditions the atmosphere is in neutral equilibrium and there is no tendency for parcels of air to move from their positions, or if moved by an external agency, for them to return. The temperature gradient so defined is known as the <u>Adiabatic Lapse Rate</u>.

In practice, due to the ebb and flow of warm and cold air masses plus the exchange of heat with the earth's surface, such a temperature gradient seldom exists. If, as happens on most sunny days, the lower layers of air become heated from contact with the earth, the temperature gradient becomes greater than for the adiabatic condition, and a parcel of air brought down from a height would be cooler and denser than the air which has been heated at the earth's surface. There exists, therefore, an instability giving rise to strong vertical convection currents, which is a characteristic of a <u>Super Adiabatic Lapse Rate</u>. Under these conditions, pollutants put into the air near the earth's surface are quickly carried aloft where they are diluted by mixing and diffusion and are eventually precipitated in rain or snow. This effect is often enhanced by turbulence and eddies arising from the velocity of the wind giving rise to viscosity turbulence.

When the converse applies and the temperature gradient is less than for the adiabatic state, the atmosphere becomes stable. That is to say, the denser air is at the bottom and, if any influence tends to lift these lower strata, they quickly subside again due to their greater density. If the stability increases sufficiently, the temperature gradient becomes zero (isothermal - no change of temperature with height) and may even become positive. There then exists a condition known as an "inversion" and it is the prolonged existence of an inversion that gives rise to smog and the London "pea soup" fogs. Such a condition is by no means rare. Over most of the world, a short period of stability exists for a few hours about three days in five, with the development of hazy conditions. After 24 hours, thick fog tends to develop in industrial areas and after 70 to 100 hours (as far as we can tell from our meagre data) sickness and death rates begin to climb. There are very few data available on the actual temperature gradient or lapse rates except for specialized areas such as Los Angeles, and air pollution studies will need much help from the meteorological services in collecting these data. In general, air pollution study requires data on the lower 500-1000 ft. of the atmosphere only and the Radiosonde data are of little value in this range. In many areas, radio and television masts have been used to carry temperature-sensitive elements and, where the cost has been justified, captive balloons have been employed. It is possible, however, to guess the category of lapse rate from observation of smoke plumes and hence estimate the turbulence coefficients in which we are interested. Thermal turbulence, which is caused by vertical air currents give rise to a condition known as "looping". The smoke plume, caught alternately in up draughts and down draughts trace a vertical wave form which is easily recognized. Similarly, mechanical or viscosity turbulence gives rise to changes in wind direction and the plume traces a horizontal wave form. Under cloudy skies with a low wind velocity or on clear starry nights, stability is to be expected and the plume rises vertically with very little dilution, losing heat until it is at the same density as the surrounding air. The plume then levels off and drifts with the atmosphere. Dilution is very slow, being by diffusion only, and it is sometimes possible to trace the plume, substantially unchanged, for twenty or more miles. Observations such as these are purely qualitative and give no indication of the strength or intensity of the inversion and thus they allow only the crudest possible correlation with air pollution measurements.

The thickness of the inversion layer is also important in assessing the pollution hazard of an area. With a thick inversion layer, the smoke, while trapped and prevented from soaring to a great height, can rise high enough to cause little inconvenience at ground level. If, however, the inversion layer extends only 200-300 feet, substantially all the pollution is trapped in this layer so that not only does the concentration rise rapidly, but the pollutants quickly get down to ground level, reducing visibility and interfering with respiration.

Usually inversions are broken by the sun's heat warming the earth's surface and thus heating the lower cold air layers. The presence of trapped smoke, however, reduces the heat arriving at the ground and increases the radiation absorbed at higher levels. Thus the presence of smoke not only prevents the sun from breaking the inversion, but can, in bad cases, actually strengthen it. Under such conditions, inversions can last for several days and can only be broken by the mechanical turbulence resulting from high wind velocity.

Inversions can develop from three main causes: (1) A warm air mass climbing over a cold air mass. (2) A warm air mass blowing over cold land and thus being cooled from the bottom. (In this connection, in Ontario, southwest winds from the Caribbean, that is maritime tropical air, is usually stable and polluted while continental polar air in the northeast winds are exceptionally clean.) (3) By radiation cooling of the earth's surface during cloudless nights, irrespective of the air mass. Although inversions occur frequently all over the world, they are only of vital importance in relatively few areas where either there is an abnormally heavy pollution load or where topographical features aid the formation and hinder the break up of inversion conditions. This is demonstrated by the situation at Los Angeles, where in spite of sustained efforts which have resulted in an abnormally low per capita production of pollutants, objectionable pollution of the atmosphere still exists. A continuous high pressure area far out in the Pacific Ocean supplies the upper air over California with a constant supply of hot air at a high level, while the ocean and land at night give rise to a cooler layer below. Even if the sun is unable to overcome the stability, the sea breeze would normally carry the pollution well inland but the Los Angeles county is surrounded by a horseshoe of the Sierra mountains which traps the pollutants and prevents their removal in an easterly direction. Later the land breeze carries them back over the populated area and out to sea, whence they return the next day to become even more concentrated. This mechanism, which is even now imperfectly understood, has been discovered only by years of painstaking measurement of the air currents within an area of a few hundred square miles. In mountainous districts, the effect of hills and valleys, and even large buildings has been found to be of paramount importance so that micro-meteorology is becoming an indispensable adjunct to air pollution studies.

Under some conditions, especially in valleys, control of pollution is best effected by meteorological control - that is, the evolution of pollutants is only permitted when atmospheric dispersion is good. This is not a happy solution, but it is the only remedy so far for long periods of very stable atmosphere.

At other times, use is made of the existing turbulence to disperse pollution. At one time, all combustion processes needed high stacks to give sufficient draught. The use of induced and exhaust fans made high stacks an unnecessary expense and in time the boiler house had no more than a token stack. Recent work by Bosanquet et al. and Sutton in England has produced empirical formulae by means of which the exact role of turbulence is defined and we can calculate the maximum ground concentration of pollutant from a given stack. These two workers, starting from different premises, developed their equations independently. It is not necessary to go into the mathematics here; it is sufficient to say that, if due consideration is given to the assumptions made, the two results show remarkable agreement even though they use different parameters. From these expressions, it is possible to calculate the stack height necessary to keep the maximum ground concentration below a predetermined limit and hence to calculate the best economic compromise between the costs of increased stack height, of low-sulphur fuel, of pollution damage and of pollution removal equipment. This gives industry a very great advantage in the design of new plants and we hope this type of planning will increase rapidly. However, to arrive at the solution of these equations, it is necessary to assign numerical values to certain parameters which express the meteorological variables, notably wind speed and turbulence. The former is, of course, easily estimated from climatological records but very few data are available concerning turbulence.

Both Sutton and Bosanquet have suggested average values for certain types of air mass, but little confidence can be placed in the computations until such data have been checked. We have, at present, three methods of assessing the turbulence parameters, all of them long and costly. First, we can study the ground level pollution concentrations of existing stacks in the area, and calculate back to our parameters. This is extremely difficult since the mathematical expression gives magnitude and location of maximum ground concentration but it is extremely rare that a pre-selected recorder will be at the point of maximum concentration and calculations based on intensities at other than the points of maximum concentration are very difficult. Secondly, we can estimate the turbulence parameters from the gustiness (velocity profile) or from the rate of change in direction (direction profile) of the wind. This requires either a bivane recorder, a light double wind vane to record changes in direction in the horizontal and vertical planes (bearing and inclination of wind direction) or a sensitive velocity recorder such as the Bendix-Frieze anemovane which follows the wind direction in the horizontal plane if the instrument is at least 80 ft. high. Above 80 ft., the horizontal and vertical turbulence components are substantially the same and only one needs to be determined.

Lastly, we can use scale models in a wind tunnel. This is also an expensive method but one which has been used to advantage in hilly or built-up areas where mathematical delineation of the down-wind area is impossible.

To sum up, it must be admitted that pollution can affect the weather. Basically, the pollutants do what the rain makers of this century try to do - provide condensation nuclei for supersaturated clouds. On the other hand, given ideal weather, pollution problems would be non-existent. Since, however, we cannot yet ask the meteorologist to control the weather, we must engineer our plants to use what favourable meteorological conditions are available to arrive at the most economical procedure to give production of goods without the evils of excessive pollution. To do this we need masses of data to give statistically reliable pictures of the temperature profile (lapse rate) and the turbulence coefficients applicable to industrial areas, and thus to refine to empirical relationships so far developed. Since these data change unpredictably in short intervals of time and over short distances of the order of fractions of a mile, we need to expand considerably our understanding of the influence of hills and even buildings on the meteorological conditions around our factories. Only then shall we be able to exercise the control which we think will be necessary within a few years to implement man's objective of "clean air for all".