AIR POLLUTION DYNAMICS AND MODELING

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Summary

Air pollution dynamics has a nature of complexity. Firstly, it is influenced by the characteristics of the emission source, especially the elevation where a pollutant is discharged. Then the meteorological conditions are discussed since they are determinant for the dispersal of the air pollutant. Some important meteorological factors are described in detail in this chapter.

The air pollutant can be removed by dry and wet deposition processes in the atmosphere, and this has an important impact on the fate of the pollutant. Although a

dynamic process can be described using a physical theory, it is not always possible to solve such mathematical equations. A general Eulerian and Lagrangian approach is introduced in this regard and the Gaussian plume equation is extensively illustrated, as it is the most commonly used one.

A simple description is then given for constructing the necessary components for a comprehensive air quality model, and a brief concept of an air pollution episode complemented with meteorological control is also presented. Finally, the authors give their comments on future developments in air pollution dynamics and modeling.

1. Introduction

Personal experience tells humans that air pollution constantly changes with meteorological conditions. Air laden with visible pollution can be transformed to clear, blue skies within hours by a sudden change in the weather, such as the passage of a weather front. It is obvious, therefore, that air pollution is a dynamic problem.

In practice, how air pollutants are transported to a specific location is always important. Most industrial effluents are discharged vertically into the air through a stack or duct. After leaving the discharge point, the contaminated gas stream (the plume) expands and gradually mixes with the ambient air.

Horizontal air flow tends to bend the discharge plume downwind. At some point, the effluent plume levels off. While the effluent plume is rising, bending, and moving horizontally, the gaseous effluents are being diluted by the surrounding ambient air. As the contaminated gases are diluted by ever larger volumes of ambient air, they eventually reach the ground through dispersion.

The mere presence of sources of emissions does not necessarily constitute air pollution. Every air pollution problem has three requisites:

- There must be an emission of the pollutant or its precursor into the free atmosphere.
- The emitted pollutant must be confined to a restricted volume of air.
- The polluted air must interfere with the physical, mental, or social well being of people.

Very often urban air pollution problems are aggravated by meteorological and topographical factors that concentrate pollutants in the city and inhibit quick dispersion and dilution processes. As complex as the phenomenon may be, it can be easily depicted by means of a simplified systems analysis diagram.

Figure 1 represents such a system approach. Air pollution dynamics refers to the various processes operating during a pollutant's lifetime in the atmosphere, from the emission source to a receptor.

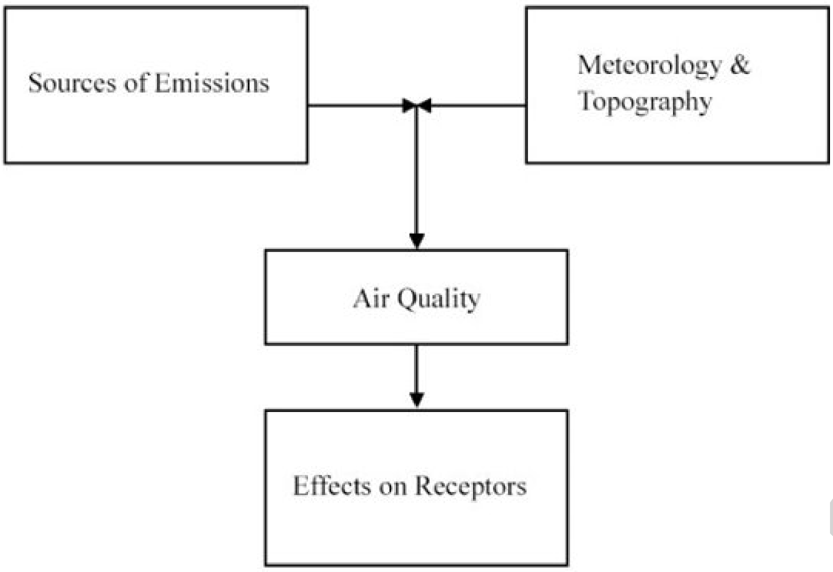

Figure 1. Air pollution system

2. Source characteristics

An important factor affecting ground level concentrations is the rise of the plume above the discharge point, and its subsequent transport. The higher the plume rises initially, the greater distance there is for diluting the contaminated gases as they expand and mix downward to the ground.

The plume rise is determined by both the upward inertia of the discharge gas stream and by its buoyancy. The vertical inertia is related to the exit gas velocity and mass, whilst the plume's buoyancy is related to the exit gas density relative to the surrounding air density. Increasing the exit velocity or the exit gas temperature will generally increase the plume rise, resulting in lower ground level concentrations.

The physical stack height plus the plume rise, is called the effective stack height. When the pollutant plume rises significantly before leveling out, the calculation of ground level plume concentrations should use the effective stack height instead of physical stack height.

The effective stack height can be estimated using a number of equations such as the Holland equation and the Davidson-Bryant equation. No allowance is made in these equations for conditions of atmospheric stability. Modifications are needed since the rise of the plume above the stack under unstable conditions is about 10% higher than calculated and under stable conditions about 10% lower. Also, the effect of water droplets cools the plume and causes it to lose buoyancy.

Given a specific discharge height and a specific set of plume dilution conditions, the ground level concentration is proportional to the amount of contaminant materials discharged from the stack outlet for a specific period of time. Thus, when all other conditions are constant, an increase in the pollutant discharge rate will cause a proportional increase in the ground level concentrations. This is the basic principle of reducing pollutant emissions in order to achieve air quality improvement.

3. Air Pollution Meteorology

While pollutant stack emission parameters such as gas velocity, temperature and molecular weight are important, atmospheric dispersion of a pollutant is primarily dependent on meteorological conditions. Therefore, the air quality of a region is greatly influenced by the local meteorology.

Weather parameters such as ambient temperature, wind speed, cloud cover, solar radiation, and inclement conditions (rain, snow, hail, etc.) can determine the atmospheric dynamics and therefore impact the severity of air pollution problems.

Meteorology is the study of the various dynamic processes of the atmosphere. Meteorological scales of motion can be divided into three categories as follows:

- Macroscale. Phenomena occurring on scales of thousands of kilometers, such as semi-permanent high and low pressure areas that reside over the oceans and continent. (The term synoptic is commonly used to denote macroscale.)
- Mesoscale. Atmospheric motions occurring on scales of hundreds of kilometers, such as land-sea breezes, mountain-valley winds, and migratory high and low pressure fronts.
- Microscale. Phenomena occurring on scales of the order of 1 km, such as the meandering and dispersion of a chimney plume and the complicated flow regime in the wake of a large building.

Meteorological phenomena are important for the study of air pollution. Each of these scales of motion plays a role in air pollution, although over different periods of time. For example, micrometeorological effects take place over scales of the order of minutes to hours, whereas mesoscale phenomena influence transport and dispersal of pollutants over hours to days.

Finally, synoptic scales of motion have characteristic times of days to weeks. The term "long-range transport" commonly refers to transport on the synoptic scale, which is important for global and regional issues such as the greenhouse effect and acid rain.

The importance of wind direction and speed on the dispersal of pollutants is always important, and the variation of these two parameters with time of day and season of the year is an even greater factor.

This variation is relatively constant at a given location and is to be carefully considered when a plant is located and the degree of control necessary for emissions of air pollutants is determined. The pressure differences and the rotation of the earth combine to produce a localized wind rose.

The wind rose of a region refers to its characteristic wind patterns with respect to wind speed and wind direction on an annual base.

The wind speed also changes with height and it increases with increased elevation; this is called the wind shear. Wind speed is also a function of topography and urbanization.

Mountains, hills, trees, buildings and other obstructions can divert wind patterns, increase atmospheric turbulence, influence general atmospheric stability, and, thereby, affect air pollution dispersion.

Regarding urban air pollution, the region of the atmosphere governing transport and dispersion is the so-called planetary boundary layer, roughly the lowest 500m. The planetary boundary layer represents the extent of influence of the earth's surface on the wind field in the atmosphere. Within the planetary boundary layer, winds are determined by the prevailing high-level air flows and the roughness of the surface.

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