AIR POLLUTION DISPERSION TERMINOLOGY

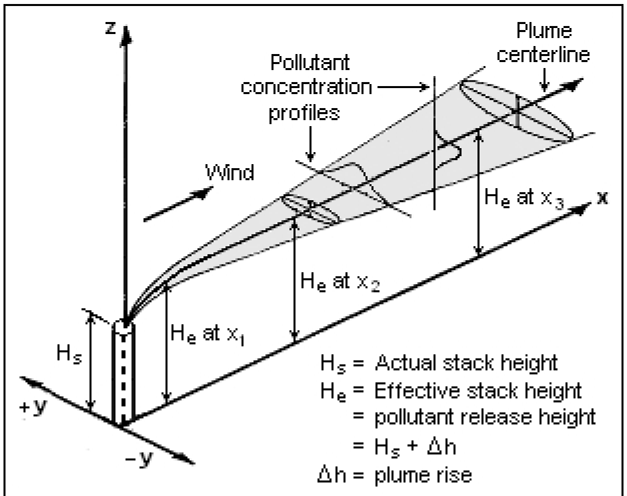
PD (Photo) U.S. EPA
Industrial emissions plume

Air pollution dispersion terminology describes the words and technical terms that have a special meaning to those who work in the field of air pollution dispersion modeling.

Governmental environmental protection agencies (local, state, province and national) of many countries have adopted and used much of the terminology (described herein) in their laws and regulations regarding air pollution control.

It should be noted that some of the words and technical terms in air pollution dispersion terminology quite often have other special meanings when used in fields of activity other than air pollution dispersion modeling.

Air pollution emission plumes



Visualization of a Buoyant Gaussian Air Pollutant Dispersion Plume

There are three primary types of air pollution emission plumes:

Buoyant plumes **—** Plumes which are lighter than air because they are at a higher temperature and lower density than the ambient air which surrounds them, or because they are at about the same temperature as the ambient air but have a lower molecular weight and hence lower density than the ambient air. For example, the emissions from the flue gas stacks of industrial furnaces are buoyant because they are considerably warmer and less dense than the ambient air. As another example, an emission plume of methane gas at ambient air temperatures is buoyant because methane has a lower molecular weight than the ambient air.

Dense gas plumes **—** Plumes which are heavier than air because they have a higher density than the surrounding ambient air. A plume may have a higher density than air because it has a higher molecular weight than air (for example, a plume of carbon dioxide). A plume may also have a higher density than air if the plume is at a much lower temperature than the air. For example, a plume of evaporated gaseous methane from an accidental release of liquefied natural gas (LNG) may be as cold as -161 °C.

Passive or neutral plumes **—** Plumes which are neither lighter or heavier than air.

Air pollution dispersion models

There are five types of air pollution dispersion models, as well as some hybrids of the five types:

- ***Box model* —** The box model is the simplest of the model types. It assumes the airshed (i.e., a given volume of atmospheric air in a geographical region) is in the shape of a box. It also assumes that the air pollutants inside the box are homogeneously distributed and uses that assumption to estimate the average pollutant concentrations anywhere within the airshed. Although useful, this model is very limited in its ability to accurately predict dispersion of air pollutants over an airshed because the assumption of homogeneous pollutant distribution is much too simple.
- ***Gaussian model* —** The Gaussian model is perhaps the oldest model (circa 1936) and perhaps the most commonly used model type. It assumes that the air pollutant dispersion has a Gaussian distribution, meaning that the pollutant distribution has a normal probability distribution. Gaussian models are most often used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources. Gaussian models may also be used for predicting the dispersion of non-continuous air pollution plumes (called *puff models*). The primary algorithm used in Gaussian modeling is the ***Generalized Dispersion Equation For A Continuous Point-Source Plume***.
- ***Lagrangian model* —** A Lagrangian dispersion model mathematically follows pollution plume parcels (also called particles) as the parcels move in the atmosphere and they model the motion of the parcels as a "random walk" process. The Lagrangian model then calculates the air pollution dispersion by computing the statistics of the trajectories of a large number of the pollution plume parcels. A Lagrangian model uses a moving frame of reference as the parcels move from their initial location. It is said that an observer of a Lagrangian model follows along with the plume.
- ***Eulerian model* —** A Eulerian dispersions model is similar to a Lagrangian model in that it also tracks the movement of a large number of pollution plume parcels as they move from their initial location. The most important difference between the two models is that the Eulerian model uses a fixed three-dimensional Cartesian grid as a frame of reference rather than a moving frame of reference. It is said that an observer of a Eulerian model watches the plume go by.
- ***Dense gas model* —** Dense gas models are models that simulate the dispersion of dense gas pollution plumes (i.e., pollution plumes that are heavier than air). The three most commonly used dense gas models are:
- The ***DEGADIS*** model developed by Dr. Jerry Havens and Dr. Tom Spicer at the University of Arkansas under commission by the United States Coast Guard and United States Environmental Protection Agency (EPA).
- The ***SLAB*** model developed by the Lawrence Livermore National Laboratory funded by the United States Department of Energy, the United States Air Force and the American Petroleum Institute.

- The***HEGADIS*** model developed Shell Oil Research

  Currently, the AERMOD air pollution dispersion model is the preferred regulatory model of the U.S. Environmental Protection Agency.

Air pollutant emission sources

The types of air pollutant emission sources are commonly characterized as either point, line, area or volume sources:

- **Point source** — A point source is a single, identifiable source of air pollutant emissions (for example, the emissions from a combustion furnace flue gas stack). Point sources are also characterized as being either elevated or at ground-level. A point source has no geometric dimensions.
- **Line sources** — A line source is one-dimensional source of air pollutant emissions (for example, the emissions from the vehicular traffic on a roadway).
- **Area source** — An area source is a two-dimensional source of diffuse air pollutant emissions (for example, the emissions from a forest fire, a landfill or the evaporated vapors from a large spill of volatile liquid).
- **Volume source** — A volume source is a three-dimensional source of diffuse air pollutant emissions. Essentially, it is an area source with a third (height) dimension (for example, the fugitive gaseous emissions from piping flanges, valves and other equipment at various heights within industrial facilities such as petroleum refineries and petrochemical plants. Another example would be the emissions from an automobile paint shop with multiple roof vents or multiple open windows.

  Other air pollutant emission source characterizations are:

- Sources may be characterized as either **stationary** or **mobile**. Flue gas stacks are examples of stationary sources and automobiles are examples of mobile sources.
- Sources may be characterized as either **urban** or **rural** because urban areas constitute a so-called "heat island" and the heat rising from an urban area causes the atmosphere above an urban area to be more turbulent than the atmosphere above a rural area.
- Sources may be characterized by their elevation relative to the ground as either **surface** or **ground-level**, **near surface** or **elevated** sources.
- Sources may also be characterized by their time duration:
- **puff** or **intermittent:** short term sources (for example, many accidental emission releases are short term puffs)

- **continuous:** a long term source (for example, most flue gas stack emissions are continuous)

Characterization of atmospheric turbulence

The amount of turbulence in the ambient atmosphere has a major effect on the dispersion of air pollution plumes because turbulence increases the entrainment and mixing of unpolluted air into the plume and thereby acts to reduce the concentration of pollutants in the plume (i.e, enhances the plume dispersion). It is therefore important to categorize the amount of atmospheric turbulence present at any given time.

The Pasquill stability classes

The oldest and, for a great many years, the most commonly used method of categorizing the amount of atmospheric turbulence present was the method developed by Pasquill in 1961. He categorized the atmospheric turbulence into six stability classes named A, B, C, D, E and F with class A being the most unstable or most turbulent class, and class F the most stable or least turbulent class. Table 1 lists the six classes and Table 2 provides the meteorological conditionsthat define each class.

Table 1: The Pasquill stability classes

Stability class	Definition	Stability class	Definition
A	very unstable	D	neutral
B	unstable	E	slightly stable
C	slightly unstable	F	stable

Table 2: Meteorological conditions that define the Pasquill stability classes

Surface windspeed		Daytime incoming solar radiation			Nighttime cloud cover	
m/s	mi/h	Strong	Moderate	Slight	> 50%	< 50%
< 2	< 5	A	A – B	B	E	F
2 – 3	5 – 7	A – B	B	C	E	F
3 – 5	7 – 11	B	B – C	C	D	E
5 – 6	11 – 13	C	C – D	D	D	D
> 6	> 13	C	D	D	D	D

Note: Class D applies to heavily overcast skies, at any windspeed day or night

For air dispersion modeling exercises, the conditions of dual stability classes like A – B, B – C and C – D can be considered as B, C and D respectively. Historical stability class data, known as the Stability Array (STAR) data, for sites within the United States can be purchased from the National Climatic Data Center (NCDC) which is part of the National Oceanic and Atmospheric Administration.

Advanced methods of categorizing atmospheric turbulence

Many of the more advanced air pollution dispersion models do not categorize atmospheric turbulence by using the simple meteorological parameters commonly used in defining the six Pasquill classes as shown in Table 2. The more advanced models use some form of Monin-Obukhov similarity theory.

For example, the United States Environmental Protection Agency's most advanced model, AERMOD, no longer uses the Pasquill stability classes to categorize atmospheric turbulence. Instead, it uses the surface roughness length and the Monin-Obukhov length.

As another example, the United Kingdom's most advanced model, ADMS, uses the Monin-Obukhov length, the boundary layer height and the windspeed to categorize the atmospheric turbulence.

The detailed explanation of the mathematical formulation for the turbulence categorization methods used in AERMOD, ADMS and other advanced air pollution dispersion models is very complex and beyond the scope of this article. More detailed explanations are available on the Internet.

Miscellaneous other terminology

Building effects or downwash: When an air pollution plume flows over nearby buildings or other structures, turbulent eddies are formed in the downwind side of the building. Those eddies cause a plume from a stack source located within about five times the height of a nearby building or structure to be forced down to the ground much sooner than it would if a building or structure were not present. The effect can greatly increase the resulting near-by ground-level pollutant concentrations downstream of the building or structure. If the pollutants in the plume are subject to depletion by contact with the ground (particulates, for example), the concentration increase just downstream of the building or structure will decrease the concentrations further downstream.
Deposition: Deposition of the pollution plume components to the underlying surface can be defined as either dry or wet deposition:

- ***Dry deposition:*** The removal of gaseous or particulate material from the pollution plume by contact with the ground surface or vegetation (or even water surfaces) through transfer processes such as absorption and gravitational sedimentation. This may be calculated by means of a *deposition velocity*, which is related to the resistance of the underlying surface to the transfer.

- ***Wet deposition:*** The removal of pollution plume components by the action of rain. The wet deposition of radionuclides in a pollution plume by a burst of rain often forms so called "hot spots" of radioactivity on the underlying surface.

Inversion layers: Normally, the air near the Earth's surface is warmer than the air above it because the atmosphere is heated from below as solar radiation warms the earth's surface, which in turn then warms the layer of the atmosphere directly above it. Thus, the atmospheric temperature normally decreases with increasing altitude. However, under certain meteorological conditions, atmospheric layers may form in which the temperature increases with increasing altitude. Such layers are called inversion layers. When such a layer forms at the earth's surface, it is called a ***surface inversion***. When an inversion layer forms at some distance above the earth, it is called an ***inversion aloft*** (sometimes referred to as a ***capping inversion)***. The air within an inversion aloft is very stable with very little vertical motion. Any rising parcel of air within the inversion soon expands, thereby adiabatically cooling to a lower temperature than the surrounding air and the parcel stops rising. Any sinking parcel soon compresses adiabatically to a higher temperature than the surrounding air and the parcel stops sinking. Thus, any air pollution plume that enters an inversion aloft will undergo very little vertical mixing unless it has sufficient momentum to completely pass through the inversion aloft. That is one reason why an inversion aloft is sometimes called a capping inversion.

Mixing height: When an inversion aloft is formed, the atmospheric layer between the earth's surface and the bottom of the inversion aloft is known as the ***mixing layer*** and the distance between the earth's surface and the bottom of inversion aloft is known as the ***mixing height***. Any air pollution plume dispersing beneath an inversion aloft will be limited in vertical mixing to that which occurs beneath the bottom of the inversion aloft (sometimes called the *lid*). Even if the pollution plume penetrates the inversion, it will not undergo any further significant vertical mixing. As for a pollution plume passing completely through an inversion layer aloft, that rarely occurs unless the pollution plume's source stack is very tall and the inversion lid is fairly low.

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