Air Quality Fundamentals

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AIR QUALITY FUNDAMENTALS

NATURE AND CLASSES OF DIFFERENT AIR POLLUTANTS

What is an air pollutant? According to the USEPA, it is “unwanted chemicals or other materials found in the air that can harm health, the environment and property. Many air pollutants occur as gases or vapors, but some are very tiny solid particles: dust, smoke or soot.”

It seems that all chemicals in the air may fit this category. Are all chemicals air pollutants? It appears that the only compounds that do not have an adverse effect on animals and plants are H_2O, N_2, O_2, and CO_2. Even these cannot be excluded as dangerous compounds. An atmosphere of only N_2 would lead to asphyxiation. A world of high O_2 would result in many fires. People can drown in too much water. Given the world’s attention on climate change, CO_2 is considered a villain. Therefore, we are really concerned with compounds that have a known effect on the public or animals or flora when the concentration builds up to a range shown to have an adverse effect.

We think of pollutants as unnatural compounds. Are there pollutants that are “natural” or emitted from natural sources? Yes, there are. Pollutants are emitted from natural processes such as fire, vegetative decay, wind erosion, oxidation, and volcanoes. There is a natural ambient concentration of critical compounds (indicated herein) that we all are exposed to. Measurements in areas without significant human activity (i.e., Antarctica) demonstrate this. However, through millions of years of evolution, fauna and flora have adapted to exposure to air pollutants from these sources and can tolerate a certain concentration of these compounds in the ambient air (or else the species would have died).

Therefore, what we are concerned with is manmade activities, mainly in the last roughly 140 years (the industrial revolution), a blip of time relatively speaking, that cause the ambient concentration of these compounds to exceed the levels that our bodies have taken millions of years to adapt to.

AMBIENT AIR QUALITY STANDARDS

The USEPA determined a list of such compounds that occur naturally in the ambient air, but may cause adverse public health problems if their concentration exceeds a certain “criteria” threshold. These criteria pollutants are:

- nitrogen dioxide (NO_2)
- sulfur dioxide (SO_2)
- carbon monoxide (CO)
- particulate matter (PM)
- ozone (O_3)
- lead (Pb)

Ozone is a special case. Few industrial processes emit ozone (some water and food purification processes), and ozone is an unstable compound. Ozone is a “secondary” pollutant, formed as a result of chemical reactions in the ambient air of other compounds. Ozone is an indicator of smog, a cacophony of probably thousands of compounds in the ambient atmosphere. Smog has adverse public health effects and causes haze restricting visibility. Smog also causes damage to trees and other vegetative growth and even to manmade structures.

The main conventional pollutants that are the precursors of ozone and smog formation are nitrogen oxide and nitrogen dioxide (NO and NO_2, commonly called “NO_x”) and volatile organic compounds (VOCs). VOCs are defined as carbon-containing compounds capable of volatilizing into the air and react to form ozone. The USEPA has defined certain compounds called “exempt” VOCs that do not participate or participate mildly in these reactions. In order to combat high concentrations of ozone in the ambient air in non-attainment areas, states are mandated to develop rules that minimize VOC and NO_x emissions. These long lasting reactions have another effect. Research has shown that many areas with high smog and ozone levels are not necessarily characterized by large sources of VOCs and NO_x. Instead, these areas are often hundreds of miles downwind from such sources of emissions; which in many cases may be located in other states. Therefore, states with areas designated as non-attainment for ozone cannot improve their status unless other states upwind reduce emissions of precursors. However, those states may not be willing to promulgate and enforce such rules if they do not feel the effects of ozone and smog.

Another special case is particulate matter. Initially, in the 1970’s, the ambient air quality standard for particulate matter covered total suspended particulates. It became evident as studies progressed that not all solid particulate matter had equal public health effects. Over millions of years, humans developed defenses, such as nasal hair and mucous to prevent the infiltration of particulates into our lungs. However, the particles that animals were exposed to were mainly larger diameter particulate matter from blowing soil. With the rise of combustion processes as part of the industrial revolution, we became exposed to solid particles of combustion, which are mainly much smaller sized particles. These particles are capable of reaching our lungs and avoiding the defenses much more effectively than the larger diameter particulates we had adapted to. Therefore, the USEPA added an ambient air quality standard for “respirable” particulates or “PM-10”; particulate matter with an aerodynamic diameter of 10 microns (µms) or less. Later, the USEPA removed the standard for total suspended particulates. Over time, it was recognized that even this standard was insufficient to protect public health. Another standard was developed for “fine” particulate matter, or “PM-2.5”, particulate matter with an aerodynamic diameter of 2.5 µms or less, to protect the public health. PM-2.5 can even more readily penetrate deep into the lungs than PM-10. Fine particulate also contributes to haze. PM-2.5 is also considered, at least partially, a secondary pollutant. In many cases, aerosols that coalesce and condense, are considered as a fraction of PM-2.5.

The USEPA has reviewed hundreds of health studies on humans and animals to determine an acceptable national ambient air quality standard (NAAQS) to protect public health for each criteria pollutant. By law, the USEPA must review each criteria standard and review new studies on a regular basis and update the previous findings and standards. The USEPA must recommend changes to the ambient air quality standards when new studies indicate that they should change to protect public health.

The USEPA requires the states to set up and operate monitors throughout the country to continually measure ambient concentrations of criteria pollutants. These hundreds of monitors inform the public of the ambient air quality measurements of the criteria pollutants in all parts of the country and near where they live. These monitors alert the authorities whether the area is in attainment or out of attainment of each federal ambient air quality standard.

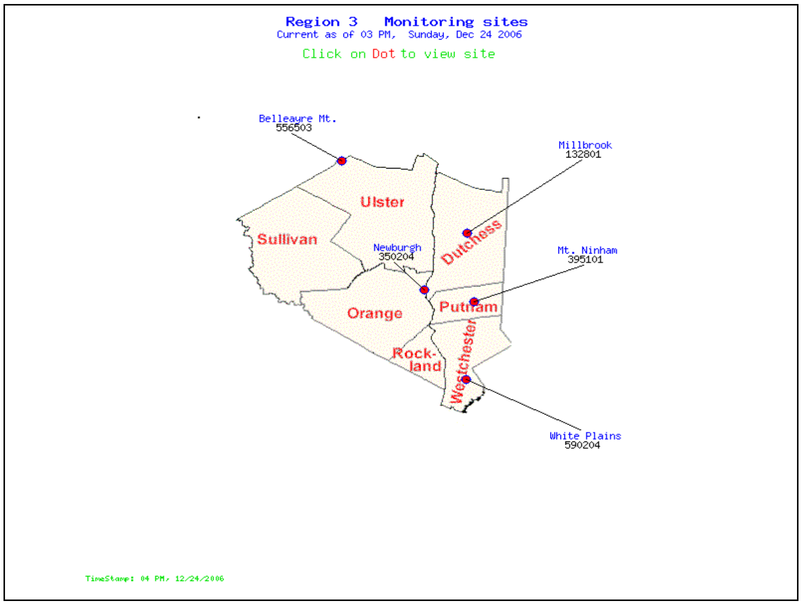
Table 1 - Current Primary National Ambient Air Quality Standards (as of Jan. 2010)

Compound	Standard	Averaging Time
NO_2	100 µg/m^3	annual
SO_2	80 µg/m^3 365 µg/m^3 1,300 µg/m^3	annual 24 hours 8 hours
CO	10 mg/m^3 35 mg/m^3	8 hours 1 hour
PM-10	150 µg/m^3	24 hours
PM-2.5	35 µg/m^3 15.0 µg/m^3	24 hours annual
Ozone	0.075 ppm	8 hours
Lead	0.15 µg/m^3	Rolling 3-month

Some states have developed their own state ambient air quality standards to supplement the federal NAAQS. Also, there are primary and secondary standards. Primary standards were developed to protect public health, while secondary standards exist to protect public welfare, such as wildlife and forests.

As discussed above, all 50 states operate monitoring stations to keep track of ambient concentrations of these compounds on a continual basis and report whether the particular area is in or out of attainment with the applicable standard. The figure below is a map of a local area with its monitoring stations indicated. Stations are placed in all different types of environs from urban to rural and often specialize in measuring certain pollutants typical of that environment (i.e., CO and NO_x in an urban environment; PM in a rural environment).

Figure 1 – Typical Monitoring Station Locations



NON-CRITERIA POLLUTANTS

Does this mean that all other pollutants with potential adverse health effects do not have any criteria allowable ambient air standards? Does that mean that all such pollutants have no acceptable exposure level as far as the public is concerned? Generally, without defined criteria standards, all other pollutants (non-criteria pollutants) are considered by some as air “toxics”. If the answers to these questions are yes, then emissions of all other compounds would need to be banned. However, many industries are dependent on using and therefore potentially emitting many of these compounds. Many items we take for granted could not be produced. Therefore, environmental regulations allow the emissions of non-criteria pollutants, as long as the emission rate leaving the stack or the ground-level exposure of the public is minimized.

The USEPA has defined a set of compounds as “hazardous air pollutants” or “HAPs”. There are currently 188 such compounds. The list is mainly composed of specific organic (carbon-containing) molecules and metals, all known to have adverse health effects. Federal regulations currently mandate minimization of emissions from major sources of HAPs by installing efficient reduction technology. These Maximum Achievable Control Technology (MACT) standards initially do not address actions that need to be taken if ground-level concentrations build up to levels that put the public at risk. The USEPA does have the right to require further control of these compounds if a health risk is perceived despite the implementation of MACT technology. Given the relative lack of regulation concerning the potential health effects of air toxics, a number of states have developed health-based air toxic regulations or guidelines that require a facility planning to emit a certain air toxic to prove that it will not have an adverse health effect on the neighboring public.

There is also a concern about another type of air pollutant, ozone-depleting chemicals (ODCs), a group of chemicals including chlorofluorocarbons (CFCs), halon, carbon tetrachloride, and other compounds, mainly from aerosol cans. The most infamous effect of these compounds is their reaction with ozone. They have been linked to damage of the ozone layer in the stratosphere, which blocks harmful ultraviolet rays. The Montreal Protocol was a worldwide effort to diminish and stop the use of these compounds. Published papers state that the effort has been successful and the ozone layer is slowly returning toward its earlier size and depth.

One other class of harmful compounds that has gotten worldwide publicity in recent years is greenhouse gases (GHGs). These are compounds that in most cases have no adverse impact on public health, but have indirect effects. They are capable of absorbing infrared radiation that normally exits to space, trapping its energy as heat in our atmosphere. The majority of the scientific community believes that this is a significant reason to explain the overall warming of the earth in the last century.

HISTORY OF AIR POLLUTION

While air pollution is very much in the public’s mind these days and while air pollution science is a viable specialty for many engineers and scientists between researching the subject and designing and installing air pollution control equipment, concern about air pollution goes back quite a bit of time. Archeologists have found devices to minimize air pollution in ancient civilizations in Asia and Mexico. Discussions of air pollution and ways to minimize it have been found in Talmudic texts dating back to the 3rd century A.D. For example, even back then, farmers were required to ply their trade in such a way to minimize volatilization of dust that may land in their neighbor’s property. The problems of urban air pollution in London were recorded back in the 16th century. With the industrial revolution, the link between industrial growth and environmental harm and adverse public health effects became more obvious. The first modern environmental regulation was the Public Health Act in England in 1875.

In many respects, excess air pollution and other environmental problems were historically dismissed as something that was inevitable and for which nothing could be done to remedy. The turning points toward changing this attitude and garnering greater public concern about air pollution occurred with two highly publicized incidents on two continents and the publication of a book. In the mid-20th century, a series of severe smog and haze incidents affected London, England and Donora, Pennsylvania. Low wind speed and an inversion of warm air over cool occurred, trapping highly polluted air for several days over each city. In fact, in London these events occurred with regularity. The Great London Smog of 1952 was estimated to have killed over 4,000 people as breathable air in this megalopolis was filled with high concentrations of toxic products of combustion of wood and coal; the most common fuels used in the city. In Donora, the breathable air was filled with emissions from several nearby steel mills and quickly killed nearly 100 people. In both series of incidents, many more people had their lives shortened and suffered long-term adverse health effects because of the smog incidents.

In 1962 Rachel Carson published the classic book “Silent Spring” describing the potential horrors of growth without concern for the environment, as applied to unbridled pesticide use. It became a manifesto for environmentalists to demand action to care for the environment. Greater protest and activities by environmentalists culminated in the first “Earth Day”, April 22, 1970, with a massive protest concerning the environment in Washington, DC. Simultaneous to these protests, the federal government debated and eventually passed the first Clean Air Act and first Clean Water Act to provide minimal nationwide standards for the two media. The federal government created an agency, the Environmental Protection Agency, to enforce these rules and standards. As discussed above, the USEPA oversees the air program of determining NAAQS for criteria pollutants and standards for air toxics, as well as the monitoring stations to measure real time levels of these pollutants throughout the country.

SOURCES OF AIR POLLUTION

This section will focus on common anthropogenic or manmade sources of air pollution. (Natural sources such as volcanoes, decay of organic matter, etc. are not discussed here).

Air pollution sources are generally classified as stationary or mobile sources based on its ability to move. Ground-level impacts of compounds are different (and more difficult to estimate) from moving sources compared to stationary ones.

Sources are also classified as being point sources (emissions entering the atmosphere from stacks or vents) or non-point or “fugitive” sources (large open areas, such as a wastewater treatment plant clarifier or a leaking pump or valve). Emissions from point sources are easier to measure.

The frequency of emissions may be classified as either routine, meaning continually or on a regular intermittent schedule or accidental, or released on an unplanned basis.

Most air emissions that are studied derive from stacks. In practice, taller stacks are more beneficial as the pollutants must drop down a greater height before reaching the ground, giving it a better chance to be diluted by the ambient air, lessening its potential toxic effects. Dispersion modeling (to be discussed later) can be performed to quantify this effect. The two main detriments to a tall stack are aesthetic (community opposition to the tall stack blocking its view and the industrialization it represents) and the energy needed to transport the exhaust air to the top of the stack.

Although tall stacks have a bad reputation, their impacts are potentially much less than mobile sources. Although an auto exhaust may emit much less pollutants on a mass basis than a typical utility or industrial stack, mobile source exhausts are at ground level and can result in potentially greater exposure to the public.

Another way that air pollution is differentiated is the type of process from which it derives. Air emissions generally derive from combustion sources or process sources. The most common air pollutants formed from the byproducts of combustion include CO, SO_2, NO_x, and PM. Emissions from combustion generally are related to the nature and composition of the fuel and the combustion process (temperature, exhaust residence time, consistent flame).

Process-derived air emissions are based on the physical action and volatilization of chemicals during different types of industrial processes. The most common pollutant from process sources are VOCs which are used in many applications in the liquid form, but volatilize into a gas, depending on physical forces, temperature, and pressure.

MEASURING AIR EMISSION RATES

Given the saying “You can’t manage what you don’t measure”, it is critical to measure accurately emission rates of air pollutants, so as to more effectively and less expensively determine the best tactics to minimize their emissions.

How do we measure the degree of air pollution? The intention of measuring air pollution is to get an idea of what the effects are on the public, but do so in a way that emitters can measure against production parameters. The two most common measurements for air pollutants are:

- a mass rate leaving a process or a stack (i.e., lb/hr or tons/year) and/or
- a concentration leaving the stack (i.e., ppmv, $\mu g/m^3$)

It is often helpful to relate emissions to a common manufacturing parameter in order to compare pieces of equipment, processes, or even plants. This is called normalized emissions. An example, would be expressing emissions of a certain pollutant from a boiler in terms of pounds per million BTU input. Then different boilers can be compared. Other examples of normalized emissions include pounds per “widget”, pounds per ton of chemical produced, pounds per square foot of space, even pounds per $ revenue. All these parameters can potentially achieve the same goal of comparing different processes or facilities.

There are a number of recognized techniques to estimate emissions. Some are more appropriate and accurate to certain applications than others. It is certainly possible that several different techniques will be necessary to estimate emissions from a typical, diversified plant.

Common emission estimation techniques may be summarized as follows:

- Material balances;
- Published emission factors;
- Engineering equations and
- Stack testing

Material balance: What goes into a process or a piece of equipment must leave that process or piece of equipment unless it is converted by a chemical reaction. Leaving may be by way of the product or through the waste. The waste is defined as through solid waste, wastewater, or through evaporation (the air). Measuring the loss in the air is often the most difficult. If one can measure the others, the balance would be air emissions. Fortunately, the quantity entering the process or equipment can be accurately measured, as can the quantity leaving as product. The contaminants leaving the process can reasonably be measured in the solid and liquid waste, leaving the air emissions. The advantage of this technique is simplicity. It is easy and inexpensive to perform as not many measurements need to be taken.

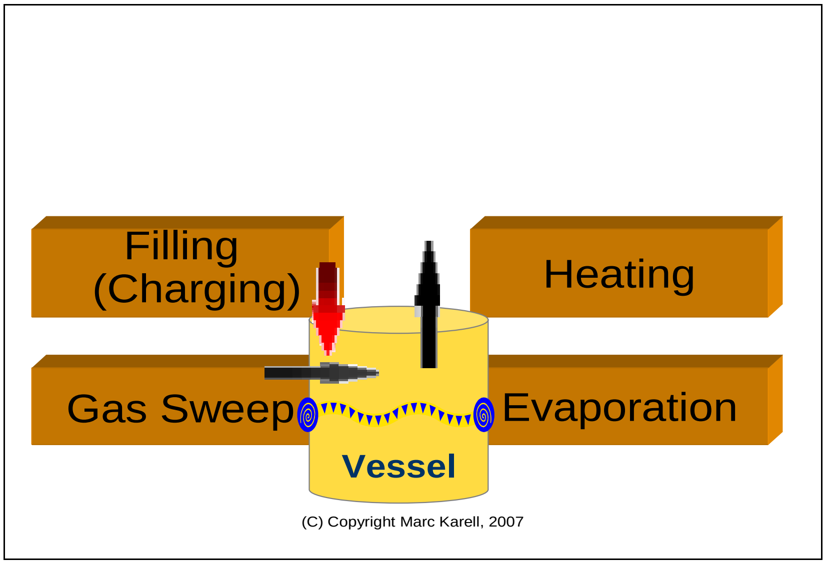
The major disadvantage of material balance is accuracy. Often air emissions are the smallest component of the material balance. Measuring the other components has errors. It is possible to end up with unreasonably high or low air emissions just because of the errors involved in measuring the other parameters. In fact, sometimes “negative” emissions are calculated (which is incorrect).

Therefore, material balance should only be used in simple systems where there are not many pathways for the chemical. One example is painting (coating). All of the solvent in a paint applied to a substrate will evaporate into the air. So the solvent portion of the paint used would equal the air emissions since it all volatilizes into the air. Caution should be taken not to use material balance for much more complicated systems than this unless accurate measurements can be assured.

Published emission factors: A growing number of emission factors have been published for a greater diversity of equipment and process situations. These are generally an average of compiled emission tests of similar equipment. They are published to save facilities time in determining emissions and in “leveling the playing field” allowing many firms to use the same emission factors. These are often calculated and published by equipment vendors, trade associations, the USEPA and other agencies. Often these emission factors are published in normalized terms such as lb of pollutant per 1000 gal of a certain fuel combusted, lb per Kw electricity produced, etc. Manufacturers often provide emission factors as guarantees to enable the user to properly estimate emissions from the proposed equipment and to permit the unit. The USEPA has a well known compilation of emission factors called AP-42. The advantage of emission factors is, like material balance, their simplicity as they allow the user to readily calculate emissions. However, their disadvantage is that they are applicable to a limited number of situations or pieces of equipment. In many cases, such as AP-42, the emission factors are based on dozens of measurements of emissions from related equipment, sometimes used back in the 1950’s when pollution minimization was not a design consideration. In addition, equipment vendors who use their emission factors as guarantees against which additional effort and cost is possible, will wish to make these factors high to better ensure their equipment will "pass". Therefore, emission factors tend to be "conservative" (overestimated emissions) and not accurate. This may be advantageous in terms of ensuring compliance, but may be a detriment if accuracy is necessary.

Engineering equations: Equations exist to estimate emissions from a process based on the likely chemical and physical properties and degree of volatilization of the contaminants during their processing. These are specific in terms of the evaluation of what really "goes on" in the reactor, tank, etc. (See illustration below). There are equations that estimate the degree of volatilization of different compounds at different temperatures, pressures, and other external factors. Engineering equations are most commonly used in the chemical and pharmaceutical industries, as the equations estimating solvent volatilization can be applied to the many transfers, heating, and other related steps such potential contaminants undergo. Most of these equations derive from the Ideal Gas Law. Commercial software exists to conveniently input chemical and physical data and develop emission rates. A major advantage of engineering equations is that while these are theoretically derived, they are considered fairly accurate (provided accurate process and chemical data is inputted) when compared to actual measurements. The disadvantage is that these may need to be applied to dozens of potential emissions steps in a process, resulting in the necessary gathering or estimation of enormous process data, requiring additional time and effort. Software systems do ease this burden somewhat.

Figure 2 – Common industrial process operations leading to volatilization



Direct measurement (stack testing): Direct measurement of the emission concentration leaving the stack or the rate of mass flow of emissions in the stack is considered the most accurate means to estimate emissions as "real time" data of contaminants being emitted from an actual process is being collected. The USEPA and other agencies have published detailed methodologies to most accurately measure emissions of a wide range of compounds. These methodologies concentrate on the exact procedure how to collect the exhaust data, how it is chemically treated to remove potential compounds that may interfere with the intended compound's measurement, and the measurement procedure. Measuring real time data is a major advantage of stack testing. One major disadvantage however, is the cost associated with it. Most procedures are complicated and require special equipment, necessitating the use of a specialty firm to conduct the testing. For a large plant with many emission points, processes and steps, it is cost prohibitive to directly measure every potential process exhaust for every process at each different piece of equipment. Direct measurements are usually measured in concentration (ppm). If the exhaust flow rate is also simultaneously being measured, then the mass flow rate (lb per hour) can be calculated. Although measuring real time emissions is considered to be the most accurate, direct measurement has its own potential for error as well. The complex number of steps and preparation for testing may result in many opportunities for potential (even small) errors, which overall results in a potential significant error. What a stack test measures, therefore, is not necessarily the true emissions. Generally, stack testing is performed for large sources which are critical for demonstrating compliance.

One particular type of direct measurement is a continuous emissions monitor (CEM). A probe to collect exhaust continually draws out a given sample of exhaust. At a regular interval (once per minute is common), a sample is analyzed for the contaminant in question, an estimate of the concentration is then made, and the reading is recorded and kept for historical trending. CEMs can continuously measure and record emissions over a very long period of time. CEMs are generally used for gaseous contaminants (i.e., CO, NO_x, etc.). For compliance purposes, the USEPA and the states have stringent calibration procedures to ensure that, over the long run, a CEM is developing accurate data. Typically, the CEM is audited with a gas sample with a known concentration of the contaminant in question using the first three quarters of the gas sample. On the 4th quarter, an analysis of drift (whether zero is really zero or has drifted) is performed, as well as a relative accuracy test which is a stack test simultaneous to the CEM recordings.

AIR POLLUTION EMISSION CONTROL

This is the effort or the science to reduce or minimize emissions leaving a process or a stack. It may be mandated by a regulation or done to achieve an internal business goal.

There are two main approaches to air pollution control: modifying the process that contributes to emissions or add an "end-of-pipe" technology to remove and treat contaminants. The first approach is nicknamed "Pollution Prevention" or "P2". The approach is that it is more effective to prevent the formation of contaminants than to control it later after it is formed ("An ounce of prevention is worth a pound of cure.").

Potential changes to a process to prevent pollution include:

- Minimize fuel use
- Minimize material use or use less toxic compounds

- Reduce formation of byproducts; capture and reuse byproducts, if feasible
- Capture potential pollutants as part of process

Ultimately, the choice of implementing a strategy for “P2” comes down to economic viability. This approach goes beyond the “Air” medium and can be applied to waste management, water, etc.

However, there are limits to how one can prevent formation of pollutants and sometimes there may be no choice but to install and operate air pollution control (APC) equipment. APC equipment may:

- Capture and destroy pollutants
- Convert pollutants to less toxic compounds
- Remove pollutants from the air and capture it in another media
- Concentrate pollutants

Factors in choosing the right APC equipment include:

- Chemistry of the contaminant to be controlled
- Rate or concentration of the contaminant entering the APC
- Presence of other compounds in the exhaust
- Cost
- Disposal of potential waste product of APC operation

There is no single APC device that can address all of these issues satisfactorily. Different technologies apply better in different situations. In fact, in many cases, a facility may need to operate multiple APC equipment to satisfy a regulatory requirement.

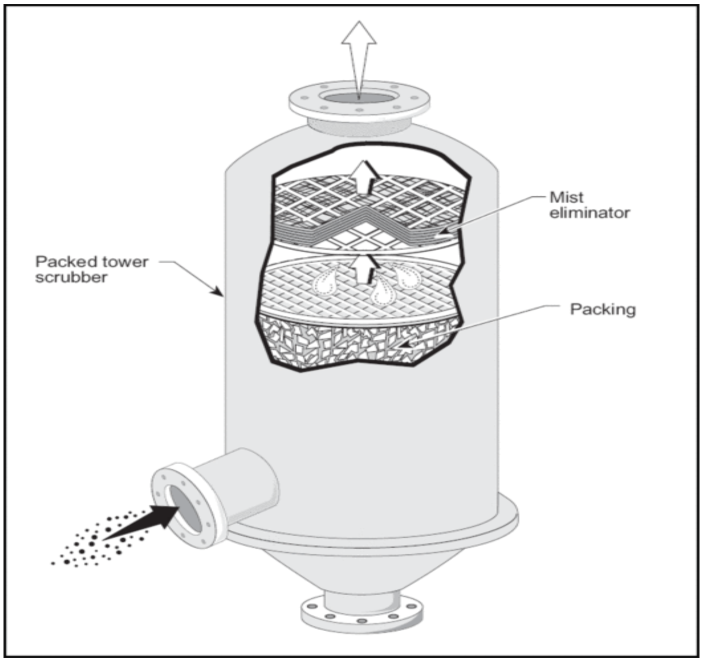
While not exhaustive, here is a list of some major types of APC equipment and their relative applications.

Gas Absorption (Scrubbing): Gas absorption works by interacting a scrubbing solution (scrubbant) with the exhaust and removing the contaminant which eventually dissolves in the scrubbing solution. Commonly, the scrubbant is water, and therefore, gas absorption is most effective on water-soluble compounds, including particulates and certain VOCs. To remove certain specific contaminants, the water scrubbant may be acidic, basic or diluted with another chemical, such as hypochlorite for odor (sulfur) control at a wastewater treatment plant. These additives also neutralize or react with the compound in question after removal from the exhaust.

Commonly the scrubber is designed to have maximum water surface area in contact with the contaminant molecules flowing through the equipment. To maximize contact, most scrubbers either contain inert packing material to maximize the hold up of the exhaust and scrubbant and allow more time to contact. A “packed tower” scrubber is indicated in Figure 3 below. Another common scrubber design is to direct the exhaust and scrubbant to be in contact in the very narrow “neck” of the scrubber. This is called a venturi scrubber and is particularly effective in removing particulate matter from an exhaust.

If designed properly, a scrubber can have a very high control efficiency (99% or more of the inlet pollutants removed). Two major disadvantages of a scrubber are: 1) it is effective for only certain water-soluble contaminants; therefore, it is less or ineffective for water insoluble VOCs such as benzene and toluene, and 2) the user must now collect, manage, and dispose of the newly created wastewater containing the contaminants and other chemicals; it may potentially require pre-treatment before discharge from the plant.

Figure 3 – Packed Tower Scrubber



Electrostatic Precipitator: An electrostatic precipitator (ESP) is an effective control device, specializing in particulate control. The ESP ionizes the air by conferring a charge on the particles in the exhaust entering the device. Then plates attract the charged particles to the side preventing it from leaving in the exhaust. An automatic rapping system frees the collected particle from the ESP allowing easy capture in a bag, removal, and cleaning of the plates. One design combines the concepts of a scrubber and an ESP, called a Wet ESP or WESP. The exhaust is wetted before it enters the ESP, lowering the electrical resistance and improving performance.

ESP is a fairly simple device and relatively reliable for PM control. One disadvantage of ESP is that it is most effective for large-sized particles but less overly effective for small diameter particles, which is of greater concern to the public and regulators, particularly for many combustion processes.

Thermal Oxidizer (Incinerator): In a thermal oxidizer, the exhaust’s temperature is raised to a high value such that the VOCs in the exhaust flowing through it are destroyed by being permanently oxidized to water and CO_2. Depending upon the nature of the stream, an exhaust temperature in the furnace (combustion chamber) in the range of 1,200˚F to 1,800˚F or greater must be maintained. VOC oxidation itself releases heat. Therefore, if the inlet concentration is sufficient, this heat may reduce slightly the fuel combustion requirements.

VOC destruction efficiency of 99% or greater can be achieved by a thermal oxidizer. Besides the importance of maintaining the necessary high temperature, another important feature in the design of such a unit is the residence time of the exhaust stream in the combustion chamber. Chamber design to cause the exhaust to “hold up” and maintain an average residence time of 0.5 to 2.0 seconds in the chamber allows the proper time for the very large percentage of the VOC components to completely oxidize and not form toxic byproducts of combustion.

Obviously, the furnace of a thermal oxidizer must be fabricated from special high temperature-resistant materials. Several features can be included in the design to raise the energy efficiency. For example, some of the heat energy of the exhaust leaving the combustion chamber can be captured and used to pre-heat exhaust entering the chamber, thereby saving fuel combustion. Regenerative thermal oxidizers (RTOs) have been designed to recover and reuse as much as 95% of the thermal energy from the combustion chamber. Recuperative units use a shell and tube formation to capture the excess heat and pre-heat the incoming stream.

One other feature to reduce heat input is to use a catalyst, which may be made from certain plastics or from precious metals. The catalyst attracts the contaminant, raising its residence time and allowing a lower heat input to result in the oxidation. For catalytic units, temperatures may be maintained at only 650˚F to 900˚F to achieve the high level of VOC destruction indicated above, resulting in a significant fuel savings. One disadvantage of the catalytic system is the fact that the catalyst may “plug up” and be ineffective in VOC control, particularly in the presence of particulate matter. Pre-cleaning of the exhaust with a filter or a scrubber can relieve this problem. Another problem is the disposal of spent catalyst. For the catalysts that contain precious metals, disposal may be an expensive proposition.

As mentioned above, thermal oxidation can reliably achieve 99% or greater VOC destruction (if the appropriate temperature and residence time are maintained). However, a thermal oxidizer burns fuel which has become relatively expensive these days. In addition, it causes emissions of other compounds (such as greenhouse gases and NO_x) into the air. Furthermore, halogens (such as chlorine and fluorine) present in the exhaust stream are converted at high temperatures to their acid components (i.e., HCl, HF). This may need to be controlled (by a scrubber or the like) before being emitted into the atmosphere, as it can potentially damage the material downstream of the oxidizer (such as the stack).

Carbon Adsorption: Certain contaminants have an affinity to granular carbon, physically adsorbing (without undergoing any chemical change) onto its surface. These are mainly

VOCs. “Activated” carbon is particularly effective because it has a very large surface-to-volume ratio, with a large number of active sites for adsorption before all of the sites are used. An exhaust stream can be pulled through a carbon bed (with appropriate holding time) for a large percentage of compounds with an affinity toward carbon to be controlled.

An advantage of carbon is that the adsorbed contaminants can be desorbed (generally with steam or hot water) and can be captured and, if in the right situation, reused in the original process. Carbon is often used to remove water-insoluble VOCs from an exhaust stream. Therefore, when desorbed by water, it will separate allowing water recovery and reuse as well as potential VOC recovery and reuse, allowing for easier waste management. Most commonly, carbon adsorption systems are sold in pairs of carbon beds, one desorbing while the other is in operation.

A disadvantage of carbon adsorption is that many compounds do not adsorb at all or not very effectively onto carbon. Therefore, before committing to carbon adsorption, the user should thoroughly research all possible exhaust concentrations and be sure that all compounds that must be controlled have an affinity to carbon. In addition, the carbon unit must be sized properly so that it is not constantly desorbing. Finally, the exhaust may need to be pre-filtered to remove certain PM that may “plug-up” the carbon beds.

Condensation: Bringing the exhaust to a very low temperature or increasing significantly its system pressure will cause a certain quantity of certain compounds to condense out of the exhaust as droplets which can be captured and treated. Generally, condensation will work for certain VOCs. Condensation is most effective for high concentration contaminant streams. If the exhaust contains a single appropriate compound, it can be captured in pure form. If the exhaust contains several different compounds, they may be separated based on the selected temperature and system pressure.

A major disadvantage of condensation is that the degree of control is variable based on the inlet concentration which for many processes changes over time. The amount of contaminant controlled may not be predictable. Also, causing the appropriate low temperature or high system pressure has a large energy penalty. Commonly, refrigerants (some of which have onerous requirements of their own) may be used to lower the temperature. For certain larger molecular weight, less volatile compounds, a large amount of energy may be needed to significantly reduce the emissions of these compounds.

MOBILE SOURCES

Although the focus of most environmental engineers is large scale emissions from industrial stacks, a significant portion of our air quality problems are caused by emissions of mobile sources. As mentioned earlier, although a single mobile source unit emits much less in the way of pollutants compared to a large industrial stack, the mobile source’s point of release into the atmosphere is typically at or very close to ground level, preventing much dilution before the general public is exposed to these contaminants. In addition, transportation sources are a major contributor to greenhouse gas emissions.

While we are most familiar with the automobile as the most common mobile source, one should be aware that there are many different types of mobile sources that contribute to air quality, including trucks, motorcycles, buses, boats, lawn mowers, leaf blowers, snow mobiles, dirt bikes, forklifts, mobile electric generators, and mobile equipment used in farms, construction, and mining.

The USEPA defines "on-road vehicles" as light duty vehicles (passenger cars), light duty trucks (pickup trucks, minivans), medium duty passenger vehicles (passenger vans and "SUVs"), heavy duty vehicles (delivery trucks, buses, "RVs"), and motorcycles.

Mobile source emissions derive from two main sources: engine combustion of gasoline or diesel fuel causes emissions of the byproducts of combustion, a cacophony of hundreds if not thousands of compounds, many of which are considered toxic. The levels of these compounds change from mobile source to mobile source, from fuel type to fuel type, and even based on the way the source is operated (speed, temperature, etc.). In addition, fuel from the fuel tank evaporates and thus contributing to air pollution rates even when the source is not operating. Finally, fuel is volatilized into the air during the "fueling-up" process as the liquid displaces vapors in the tank, laden with fuel vapors.

The ways to reduce emissions from an on-road vehicle is to:

- require better fuel economy (more miles per gallon of fuel or mpg);
- minimize the emissions from each gallon of fuel combusted; and
- encourage less total vehicle miles driven.

According to the USEPA, fuel economy of the average US automobile has improved by 90% since 1970. The USEPA publishes a fuel economy guide of each year's model cars. The USEPA recently changed the way it computes fuel economy in mpg, taking into consideration real life driving factors such as driving in cold weather and air conditioning use. For the first time the USEPA will require fuel economy labels on large vehicles, such as trucks and SUVs, beginning in 2011.

The federal government enforces Corporate Average Fuel Economy standards ("CAFÉ"). This rule requires vehicle manufacturers to comply with the Department of Transportation (DOT) fuel economy standards. CAFÉ values are obtained using city and highway fuel economy test results and weighted average of vehicle sales. Tests are conducted in a laboratory by the USEPA. The National Highway Traffic and Safety Administration (NHTSA), as part of DOT, is authorized to assess penalties (based on the information USEPA supplies) and to modify standards.

The current CAFÉ standard for passenger vehicles is 27.5 mpg which has remained unchanged for the last 15 years. This is easy to achieve as this is a weighted average of different fleets of vehicles. Manufacturers who sell "gas guzzlers" can still meet the CAFÉ standard if they also sell an appropriate number of hybrid cars. Consumer groups are demanding that passenger vehicle CAFE be raised to as much as 44 mpg to spur auto makers into more innovations.

Light trucks, vans, and SUVs are currently undergoing a mandatory increase from 20.7 to 24.1 mpg for model year 2011 vehicles. Auto manufacturers are expected to meet this new standard based on better engine efficiency and lighter weight vehicles.

Although there is some limited progress in terms of fuel economy, there are other factors that make mobile sources a significant contributor toward air quality. What is it about motor vehicles that cause it to contribute to our air quality problems so inordinately?

- The number of vehicles on US roads and the number of miles traveled continues to increase, resulting in numerically more emissions. As discussed earlier, these emissions released much closer to ground level than typical industrial stacks, resulting in greater exposure than ever to the public.
- Mobile sources using smaller engines than large industrial or utility engines result in greater emissions of products of incomplete combustion, many of which are toxic. This exacerbates health problems already in urban areas.
- Similarly, emissions of NO_x and VOCs, the precursors of ground-level ozone, from small engines are greater on a mass basis. High emissions of CO, which has effects on people who live near the source; particularly those that live near highways and toll booths, also results. Mobile source engines do not have the maintenance routines that large industrial ones do.
- Millions of mobile source engines represent high emissions of CO_2, the major greenhouse gas contributor to climate change.

One area of mobile sources that is beginning to attract more attention is idling, the use of an engine (or any piece of equipment) without the benefits of its use. It is common that cars, school buses, trucks, etc. idle for sometimes long periods before they actually travel. One hospital recently discovered that its ambulances idle next to the intake of their HVAC system for hours at a time. Some states and communities are promulgating rules to limit idling, generally to 3 to 5 minutes. Many manufacturers recommend against long idling in terms of wear and tear on the vehicles.

Recent studies have shown that idling has significant effects. Typically, idling consumes ½ gallon of fuel per hour, which can be significant given the recent rise in the cost of fuels. Also, it has a significant environmental effect, as many vehicles idle in areas populated by people (buses idling near school children, trucks idling near workers, etc.). Furthermore, it generates non-necessary emissions of ozone precursors, CO, etc.

What can be done to minimize air emissions and impacts from on-road vehicles?

- Drive fewer miles.
- Buy/use more fuel-efficient cars. Keep track of fuel economy.
- Perform regular maintenance.

- Reduce idling time. Emission rates are higher during initial idling because engine is cold, fuel is burned less efficiently. Driving warms up car faster.
- Drive at moderate, steady speeds.
- Use oxygenated and, if allowable, alternative fuels.

Off-road vehicles potentially contribute to air pollution, as well, such as locomotives, forklifts, marine crafts, farm tractors, construction equipment, snowmobiles, dirt bikes, lawn mowers, and leaf blowers. These sources are important because:

- according to the USEPA, cumulatively, they contribute as much as 44% of nationwide diesel PM emissions; and
- their impacts are disproportionally higher than other sources given emissions are at ground level and in residential neighborhoods, and not isolated in or industrial areas.

The USEPA has promulgated rules to minimize emissions from these sources, dividing off-road vehicles into the following categories:

- Large spark-ignited units (forklifts, generators)
- Small spark-ignited units (lawn mowers, leaf blowers)
- Recreational vehicles (snowmobiles, dirt bikes, ATVs)
- Compression ignition engines (farm, construction, mining)
- Marine and aircraft engines

The basic principle of the rules is that the onus of compliance is on the manufacturer to comply with basic pollution emission limits. This is different from the majority of air quality rules which puts the responsibility of compliance on the owner/operator of equipment. For off-road vehicles, the owner/operator must only operate the equipment per the manufacturer's recommended practices (which should result in meeting the standard) in order to comply. The manufacturer must send to the USEPA conformity reports that the equipment complies. The retailer/repair shop must test for compliance and report any tampering. Recent rules going into effect in 2008 model equipment of some types require installation of fuel tanks to minimize fuel evaporation.

DETERMINING GROUND LEVEL IMPACTS

Now that emissions from a variety of sources have been studied and the effectiveness of various controls has been evaluated, how do the emissions that reach the atmosphere impact people at ground level? What concentrations of these contaminants can be predicted to build up where people are exposed? What can a facility do to minimize these concentrations?

Ground-level concentrations of compounds that the public are potentially exposed to are called "impacts". Emissions from a stack are diluted by and directed toward a location based on the ambient air's characteristics (wind). Together this is called "dispersion", the spreading of material (gases or particles) once released into the atmosphere.

As mentioned earlier, some major air quality public health events were influenced by these dispersion factors. The events in London and Donora, PA in the mid 20th century were not caused by excessive emissions those days compared to others. The operations of the coal and wood-fired boilers in London and the steel mills in Donora were not any different from other periods. However, a combination of factors caused the contaminants not to disperse and to dilute significantly as well as increase in concentration over time.
As a result of these incidents, governments and the public in some instances are less concerned about the actual emissions from stacks and are more concerned with protecting the public from exposure to high levels of contaminants. For example, in Ontario, emissions are not regulated by emission rate from the stack but by point of impingement, the ground level concentration. Ground level impacts are addressed in several US air quality rules, such as NAAQS, where air toxic guidelines and odor rules are stipulated.

It is important to estimate the potential impacts of contaminants, particularly before a major new source is designed and installed. Regulatory agencies need to know that the public is not endangered by the project. Critical stakeholders of the facility must be informed. It is generally unfavorable to change how a source is used if it is discovered after it is built that the impacts are exceptionally high. Therefore, estimating ground level impacts during the design phase is critical.

There are two ways to estimate the ground level concentration of a contaminant exiting a source: either measure its concentration over time with a continuous emissions monitor (discussed earlier) or calculate the concentration using a computerized model taking into account the information needed to estimate the dilution by the time the compound reaches ground level. Maintaining a group of monitors throughout the potentially impacted area for a period of time could be a significant expense and only offers a "snapshot" of impacts, and may not be the worst case scenario. Dispersion modeling is most often used to estimate impacts because data based on worst case conditions can be used to better ensure that the estimate is truly worst case.

The most common type of dispersion model to estimate ground level impacts is an empirical model based on a Gaussian distribution of contaminants traveling from the source of emissions. While emissions may leave a source at a point (stack), the components will spread (taking into consideration wind and other factors) in all directions. Therefore, the ambient concentration of a compound is directly proportional to the emission rate from the source. If the emission rate is doubled, the concentration at ground level is doubled. Therefore, what determines what that concentration should be is the dispersion factor (DF), which is how much of the compound reaches the point of consideration. It is the DF that the modeler tries to obtain. Given all other considerations, this factor can be applied to any emission rate to estimate the ground level concentration. DF is a complicated function influenced by a number of physical factors.

Dispersion of contaminants is influenced by the following factors:

- rate of emissions of compound in question;
- chemical nature of compound, such as its density relative to air;
- weather conditions, such as wind, temperature, and precipitation;
- background levels of the chemical in question;
- physical characteristics of stack(s) or fugitive sources from which compound is emanating (height, flow rate, etc.);
- geography or immediate region (mountains); and
- obstructions and other interferences of the ambient air (presence of buildings).

These factors can be quantified to produce an estimate of impacts.

Obviously, these are many factors to quantify, particularly in a changing environment (emissions, manufacturing conditions, weather, etc.). Therefore, the best way to estimate impacts is to model the dispersion of a plume of exhaust based upon data that the user inputs. The quality of the dispersion modeling is proportional to the quality of the data, as well as whether the data represents worst case or other conditions of the plume. A number of computer programs can use data described above to estimate ground level concentrations of compounds.

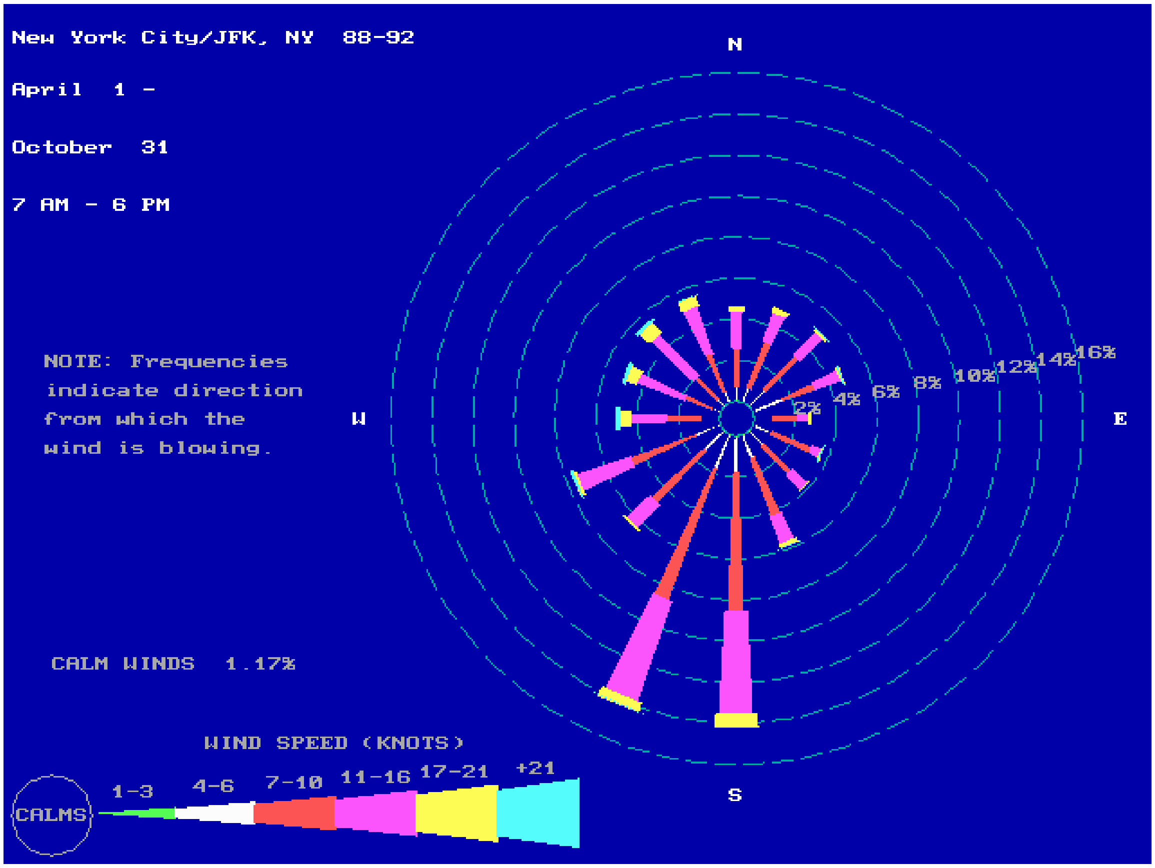
To understand dispersion modeling, one needs to understand basic terminology. Emissions derive from a “source”. The “plume” is dispersed, and the user wants to know the concentration when it reaches the nearest person at an off-site accessible location (the “receptor”). Dispersion modeling studies generally are aimed at demonstrating the highest, worst case short-term ground level concentration to which the public may be exposed. Some studies concentrate on long-term potential exposure over a one-year period or “lifetime” (generally defined as 70-year exposure). Some studies need to determine both.

The type of source influences the dispersion of the compound whether the exhaust exits a point source (stack or chimney) or an area source (a pond or contaminated soil). The nature of the point of release influences dispersion whether it is a vertical stack (pointing up), a horizontal stack or a wide area, and whether emissions are passive (evaporation) or forced in a direction (typically by a fan).

Emissions may be regular, short-term, or intermittent in duration and frequency, also affecting dispersion. The gas’ physical properties influence its dispersion, particularly whether it is more or less buoyant (dense) than air. Also, the concentration of the compound at release affects the final ground level concentration.

Meteorology plays a major role in affecting dispersion characteristics, in particular the wind direction, speed, and ambient temperature throughout the dispersion zone. Wind direction is defined as the direction from which it comes. Generally, wind direction data in an area is studied over a multiple-year period to define long term trends. The dispersion modeler creates a “wind rose” which shows relative frequencies of speeds and directions.

Figure 4 – Example of a wind rose for the New York City Metropolitan Area (Source: www.epa.gov/ttn/naaqs/ozon)



Wind speed is directly related to dispersion. The greater the speed, the more atmospheric air mixes (and dilutes) the plume. Worst case short term impacts are sometimes modeled using a default wind speed of 0.1 miles/hr.

Finally, the temperature of the plume relative to the ambient air is a critical factor. If the plume temperature is higher than the surrounding air, then it will tend to rise, and vice versa. Therefore, a strategy to cause greater dispersion and reduced ground level impacts is to release the exhaust at an elevated temperature (heating it or not recovering heat). Of course, there is an energy penalty in doing so. For visible plumes, the temperature relative to the atmosphere may influence its behavior, whether it fans out straight and horizontally, fumigates (moves downward), lofts (moves upward), or cones (drifts in both directions).

The nearby topography around the stack and plume influences the wind speed and direction. Other tall stacks, buildings or natural obstructions (such as mountains) will cause the wind not to follow the “normal’ straight path and affect how it carries the plume. The wind may travel around the obstruction (such as up and over it) or may become streamlined along its surface. Multiple tall obstructions (such as in urban area areas) may have a strong influence. Buildings, which are much smaller and sharper relative to mountains, have their own unique influences. Wind often does not "turn the corner" well on sharp corners like buildings, creating an area of relatively low pressure. This can trap contaminants in its wake. This area of potential high concentration of compounds is called the "cavity." Wind direction and speed are also influenced by localized temperature, such as cooling at night and warming during the day. Finally, coastal influences may influence local wind patterns. Land tends to gain heat during the day and lose (radiate) heat at night creating localized winds (sea breezes).

To summarize, the modeler needs the following data to successfully run the model:

- emission rate
- location
- stack height
- stack diameter
- plume velocity and direction
- exhaust temperature
- wind direction and speed
- atmospheric stability
- ambient temperature
- relative location and dimensions of nearby tall buildings and mountains
- receptor location

The sheer volume and diversity of data gathering makes dispersion modeling a technically difficult undertaking. It also gives the modeler opportunities if solid data is not available to vary the input data to see the effects of different factors or include worst case conditions.

There are different types of models that give different types of results and require different levels of input data. A "screen" model is one that lacks solid, accurate data of several parameters listed above. While a modeler can easily obtain the stack height, diameter, exhaust flow, emission rate, and relative location to receptors, some of the other required data, such as ambient temperature, average wind speed and direction, exact locations of potential obstructions, etc., are more difficult to determine and require much data gathering or investigation. Therefore, while a screen model's results are not considered to be an "accurate" picture of predicted worst case ground level impacts, one can use either generic or default data and/or estimated data to represent worst case conditions (i.e., low wind speed or greater predicted cavity effects) to predict highest or worst case impacts.

"Refined" modeling has detailed information concerning all of the necessary information. This results in a more "accurate" prediction of ground level impacts. In general, meteorological data is considered sufficient for refined modeling based on the average of five years of recent wind and temperature data from the nearest approved meteorological station (most commonly an airport) or one year of approved onsite meteorological data.

The facility that conducts the dispersion modeling must choose between the two approaches. This choice usually must be approved by an environmental regulatory agency. Some will approve a screen analysis knowing that the impact results are “conservative” and unlikely to be exceeded at any future time. On the other hand, if such a large impact is potentially “embarrassing” in the public domain and the facility wants lower, more “accurate” numbers to be submitted to the agency (for example, in an urban area, it wants to demonstrate that its contribution to ground level impacts is small compared to other sources), then a refined model is necessary taking into account that this takes a considerably greater amount of labor hours to gather and QA/QC the necessary data.

There are many commercially available dispersion models that can be used for such studies. Currently, the most popular refined model is AERMOD, whereas, the most popular screen model is SCREEN1. While these models and others may be downloaded for free from the USEPA and other sites, some software firms offer for a fee these models on a more user-friendly platform, ultimately saving the user much time and effort.

HEALTH EFFECTS OF AIR POLLUTANTS

We are concerned with exposure to air toxics or contaminants that have potential harmful effects. As we mused in the beginning of this course: What is an air toxic? Virtually all chemicals have the potential for some health effects. As Paracelcus, a physician from the 16th century, said: “All substances are poisons; there are none which are not a poison. The right dose differentiates a poison and a remedy.”

It is self-evident that the main path for an air toxic is through the respiratory system. This pathway is particularly effective for chemicals to enter and affect our bodies. Drawing in air down to our lungs and eventually to our bloodstream (from which it distributes throughout the body) is very rapid and efficient. Lung tissue is very sensitive and vulnerable to obstruction, infection, and destruction by chemical changes. Of particular concern in today’s age is respirable particulates (PM-2.5), which can penetrate our natural defenses (nose hair, saliva, etc.) and penetrate directly deep into our lung tissue.

The potential adverse effect of a contaminant to a person’s or public health is proportional to four factors:

- concentration of pollutant in the air
- period of time of exposure
- air consumption rate (volume of air taken in by the respiratory system)
- efficiency of absorption of chemical

The latter two factors are constant and do not change over time. The first two factors are influenced by the ambient concentration of the particular contaminant that people are exposed to. It is generally believed that the four factors are about equal in intensity.

Health effects may be designated as local (affecting only where the person is exposed) or systemic (spreading generally via the bloodstream) and also as acute (short-term, high intensity exposure) vs. chronic (longer term exposure). Finally, effects may be reversible or irreversible. The latter is more common with exposure to air contaminants as the lung is a sensitive organ and many contaminants are carcinogenic in certain parts of the body which can be reached via the bloodstream.

There is considerable research performed on the health effects of air contaminants and their potential effects on a human population. Many experiments are done on animals. The USEPA and other agencies keep track of such data and develop risk factors. For example, a given ambient concentration of a contaminant and length of exposure would result in one person per million (10^{-6}) developing a certain type of cancer vs. a higher concentration or exposure leading to 10^{-5} chance of developing that cancer. With these established studies, mandatory or recommended guidelines are published such that facilities cannot exceed these guidelines. Facilities must then develop strategies (such as reducing emission rates, raising the stack height, etc.) to prevent the ambient air (which the public is surrounded with) from reaching a determined dangerous level.

HOW TO EFFECTIVELY REDUCE AIR EMISSIONS

Given this background, how can a society most effectively and efficiently have a productive economy, supply jobs, produce products available to the public and, at the same time, minimize air emissions to keep society healthy?

As discussed in this course, one approach is the continuation of scientific studies to understand the effects of air pollutants on people and what levels of exposure can the general public be exposed to without a significant public health threat. This is what led to our NAAQS standards that have resulted in areas being designated as non-attainment and led to more stringent air pollution laws.

Another approach is commonly called “command and control.” Regulatory agencies set emission standards that are consistent and feasible within an industry and which all members must meet. The standards are often a level of control that is readily available. An example is our air regulations pertaining to painting/coating. Most state rules proscribe a VOC content limit in coatings of different applications in terms of lb VOC per gallon of coating as applied. Such coatings are available and have been shown to work in the application. All facilities performing this operation must use compliant paint even if the cost of the paint is high or the product finish is unfavorable. There is very little leeway. On the other hand, these standards do neither necessarily protect public health nor are NAAQS compliant. For example, once a facility uses a compliance coating, it may apply as much of it as needed (without any regard to the amount of tons of VOCs being released) unless other regulations impose a specific restriction.

A more recent regulatory approach is to set an emission standard that represents a fairly stringent standard and allow each affected facility to determine how it will comply. The

NESHAP MACT standards are an example of this approach. These rules contain emission standards for federal HAP compounds for different industrial applications applicable to existing facilities that represent the top 12 percentile of what has been accomplished nationwide. The rule does not dictate how to meet the standard (such as implementing process modifications, utilizing specific control equipment, etc.), as long as it is met. Given that 12 percent of the facilities exceed this standard also indicates some flexibility.

A more recent approach is called “cap and trade.” A group of facilities as a whole must meet a cumulative reduction in emissions of a certain pollutant, say by 50%. Every facility is given a goal of reducing their own emissions by 50% from their baseline. However, facilities are given not only flexibility in terms of how to achieve this, but also the right not to meet the reduction standard. A facility is allowed to reduce emissions by, say, only 30% as long as they buy credits (the right to pollute) equal to the difference between what it achieved and what it was supposed to achieve from other regulated facilities that have overcontrolled (i.e. reduced their emissions beyond the 50% required). This encourages facilities to invest more money in controlling emissions, as this overcontrol could become a source of income; paying for the added costs to reduce. Depending on the market, some facilities have used this as a source of income. Others have made the business decision to undercontrol and see how the market responds. This approach began in the 1990’s with the Acid Rain Program. Midwestern and southern power plants, whose NO_x and SO_2 emissions (acid precursors) impacted northeastern forests and lakes, were required to reduce their cumulative emissions using this approach, initially by 50%. The program was an environmental success as ambient levels of acid rain components were truly reduced; yet the affected facilities felt they had more economical options to meet these goals than they had before. Many aspects of current international and future US climate change rules are/will likely use cap and trade.

One aspect of air quality regulations that is paramount whatever the approach is documentation. Virtually all rules require the affected facility to track emissions or the appropriate parameter and regularly report complete and accurate data to the regulatory authority. In many cases, the reports must be certified by a “Responsible Official”, often a senior corporate official, under potential criminal penalties if incomplete and/or inaccurate information is certified and submitted. Much time of a corporate or facility environmental manager is spent collecting data, performing calculations, and assuring that the procedures and conclusions are correct for submittal. Environmental data management systems exist to better automate and ensure accuracy of the process.