ELECTRIC POWER
RESEARCH INSTITUTE

Power Plants and Particulate Matter

Fine particles in the air have been associated with adverse health effects; hence, EPA has established regulations to limit the amount of fine particles to which people are exposed.

The Earth's atmosphere contains particulate matter (PM) composed of many chemical compounds. These particles can originate from both natural sources (such as wind-blown dust, pollen, or from gases emitted by trees and vegetation) and human activities (for example, burning fossil fuels, garbage, or crop wastes; driving our cars; using fireplaces; cooking food, and numerous industrial activities). Fine PM, commonly referred to as $PM_{2.5}$, consists of particles 2.5 micrometers and less in diameter, or about 20 to 40 times smaller than the width of a human hair. $PM_{2.5}$ tends to be inhaled into the lungs more readily than larger particles present in the atmosphere and has been associated with adverse health effects such as respiratory and heart disease.

In 1997, the U.S. Environmental Protection Agency (EPA) established the first national ambient air quality standards (NAAQS) for $PM_{2.5}$. In 2006, EPA modified the $PM_{2.5}$ NAAQS by lowering the daily maximum concentrations to which the public would be exposed. EPA measures atmospheric $PM_{2.5}$ mass concentrations throughout the country to determine which regions are in compliance with the standard and which regions fail to meet it. In regions that do not meet the NAAQS, individual states must develop and enforce plans to control the sources of fine particles so that air quality improves to the level of the standard within a prescribed timeframe. State implementation plans (SIPs) for the 1997 NAAQS were due in April 2008. Issuance of attainment or non-attainment designations for the 2006 standards is expected in 2010 with corresponding SIPs due in 2013.

Power plants emit several types of fine particulate matter, which are classified according to physical characteristics.

PM in the atmosphere is a combination of particles emitted directly, called primary PM, and particles formed in the atmosphere via chemical reactions involving emitted gases, commonly referred to as secondary PM. Power plants contribute primarily to secondary PM, but also are minor contributors to primary PM.

The primary PM emitted from power plants and other sources can be further classified into one of two types. Primary PM exists either in solid or liquid form in the stack (filterable PM), or assumes particulate form shortly upon release from the stack (condensable PM). Filterable PM can be measured by traditional filter sampling methods. Condensable PM (CPM) is formed when certain substances in stack gases cool, dilute, and condense (without chemical reaction) as the emitted plume mixes with ambient air.

Fossil-fuel burning power plants emit both types of primary PM. Filterable PM emitted by power plants consists of very small amounts of inorganic (non-combustible) matter in the fuel that remains in the combustion gases after the fuel is combusted and passes through the power plant's particulate collection and other control devices. Fossil fuel combustion in the boiler transforms sulfur in the fuel to sulfur oxides (SOx, consisting of SO2 and SO_3). The major chemical form of SOx emitted by power plants is sulfur dioxide (SO_2), representing over 98% of SOx emissions. However, a small fraction of the total SOx released is in the form of sulfur trioxide (SO_3); it mostly reacts with the water in combustion gases to form dilute sulfuric acid (H_2SO_4) as the gases cool before reaching any SO_2 control equipment or exiting the stack. Both SO_3 and H_2SO_4 are considered condensable PM.

Fossil fuel combustion also transforms nitrogen present in the fuel and in the combustion air to nitrogen oxides (NOx). Most of the NOx in the stack is released as nitric oxide (NO), although nitrogen dioxide (NO_2) is also released. Reactions in the atmosphere convert a portion of the SO_2 and NOx emissions released from the power plants to secondary sulfate and nitrate PM, respectively. These are considered components of secondary PM.

Although it is difficult to determine how much of the PM present in the atmosphere results from power plant emissions, a significant fraction of atmospheric sulfate is due to SOx emitted by power plants.

Sulfates and nitrates from all combustion sources (such as power plants, motor vehicles, industry, and airplanes) comprise varying amounts of the $PM_{2.5}$ mass in the United States, depending on the region and meteorological conditions. Other important components of $PM_{2.5}$ include carbon-containing compounds (such as organic matter from natural and human activities as well as a black carbonaceous material commonly referred to as "soot") and soil dust. The relative mix of sulfates and nitrates differs in urban and rural areas and with season, with nitrates being relatively higher in urban centers (especially during the winter months) and sulfates being relatively higher in rural regions. Several techniques exist to estimate the amount of sulfate and nitrate PM attributable to power plant SOx and NOx emissions. These include mathematical constructs that use sophisticated statistical analyses to link the composition of measured ambient PM to the composition of PM from various sources. Another technique uses advanced atmospheric computer models that simulate the evolution of gaseous emissions to particles and the resultant impact on atmospheric PM. Using these techniques one can estimate the contribution of different sources to ambient PM. Although the contribution of power plants to PM can vary depending on location, season, and meteorological conditions, power plants have been shown to contribute significantly to the sulfate present in PM mass.

Power plant emissions of primary PM and secondary PM precursors are controlled through various regulatory mechanisms.

In addition to the NAAQS, which regulates the amount of *ambient* PM measured at monitoring sites, the amount of emissions of PM and PM precursors by power plants is also controlled by various other regulatory mechanisms. Total primary PM mass emission rates are limited by the New Source Performance Standards (NSPS), the most recent update of which was promulgated in 2005. Often these limits are set at lower levels by regulators that write the permit limits for power plants. If significant modifications are made to an existing power plant, an additional New Source Review (NSR) permitting process may be required. As part of the NSR process, new or significantly modified units placed in non-attainment areas must offset any additional emissions in some way. New or significantly modified units placed in attainment areas must also meet the requirements of the Prevention of Significant Deterioration (PSD) process. Emission rates of the $PM_{2.5}$ and PM_{10} fractions of primary PM, secondary PM precursors, and other compounds regulated by the NAAQS (such as SO_2 and NO_x) are similarly limited by the NSPS, NSR, and PSD processes. Volatile organic compounds (VOC) and ammonia may also be regulated if a state can demonstrate they are a significant precursor to formation of $PM_{2.5}$. This would mainly affect other emission sources, as VOC and ammonia emissions from power plants are negligible.

Regulatory programs beyond those directly prompted by facility or unit construction also exist. Both primary PM and secondary PM precursors are subject to limits established under the SIPs to meet the NAAQS for ambient PM concentrations. Secondary PM precursors are also subject to emission caps specified in the Acid Rain Program, as well as the NOx Budget Trading Program under the NOx SIP Call. The Regional Haze Rule regulates emissions through SIPs, Federal Implementation Plans (FIPs), and Best Available Retrofit Technology (BART) requirements. State or local programs may also apply, such as the Regional Clean Air Markets (RECLAIM) program for emissions trading in Southern California, which also requires offsets for additional emissions related to new or modified construction.

As a result of these so-called "on the books" regulations, power plants have substantially reduced, or are in the process of reducing, SO_2 and NOx emissions that contribute to secondary PM levels in ambient air. Through investments in scrubbers and operating strategies to accommodate lower-sulfur fuels, the U.S. electric power industry has cut its SO_2 emissions while increasing power output and reliability. Analogous investments and operating changes to reduce NOx emissions have also been successful. By 2006, power plants reduced SO_2 emissions by 44% relative to 1980 levels (the reference year cited in the 1990 Clean Air Act Amendments) and reduced NOx emissions by 48%, all while increasing power-plant output by more than 75%. Power plant emissions reductions will continue throughout the remainder of the decade and beyond due to existing acid rain, ozone, and $PM_{2.5}$ regulations, including any future regulations that would govern interstate transport of air pollution.

Power plants use a number of techniques to reduce primary PM and secondary PM precursors before they reach the stack exit.

Controls for Primary PM

Particle removal equipment (also called control devices), such as electrostatic precipitators (ESP) or fabric filters, are installed on virtually all power plants and are very effective at reducing the filterable PM portion of primary emissions. In fact, more than 99% of the ash present in exhaust gases is typically captured. Thus the ash particles which escape from the stack account for an extremely small amount of ground-level fine particulate matter in the air. One EPRI study showed that power plant ash emissions account for much less than the 1% of ambient fine particulate mass.

Controls for the Condensable Portion of Primary PM

New approaches are being developed to control the condensable PM fraction of primary PM emissions from power plants. Although the amount of sulfur-derived condensable PM emissions is only a very small portion of the total SOx emissions, the H_2SO_4 aerosols can form visible plumes and may contribute a major fraction of the allowable primary PM emissions in newly-permitted power plants. EPRI and other organizations are developing techniques to reduce condensable sulfur species. For example flue gas sorbent injection to reduce SO_3 levels is being increasingly deployed, while other approaches are still being researched. It is possible that sorbent injection could increase filterable PM by providing additional PM to the ESP, which removes a constant percentage of the PM mass it receives. However a growing body of evidence suggests that the choice of sodium-based sorbents may even decrease filterable PM emissions because they can improve ESP performance through increasing electrical conduction.

Controls for Secondary PM Precursors

Power plant emissions of the SO_2 and NO_X that act as gaseous precursors to secondary PM are also controlled in a variety of ways. SO_2 emissions are substantially controlled by flue gas desulfurization "scrubbers" or reduced through the use of low-sulfur fuel. NO_X emissions are decreased via "low-NOx burners" or other furnace modifications, as well as by the use of exhaust gas catalysts. These are similar to the catalytic converters found in automobiles, and use a process known as selective catalytic reduction (SCR). Control devices based on selective non-catalytic reduction use high-temperature chemical reactions instead of a catalyst to achieve similar NOx reductions. It is possible that SCR and SNCR devices can emit residual amounts of ammonia and SO_3, which could potentially form additional PM. However, the ammonia is unlikely to form PM, as it would either be adsorbed onto acidic fly ash and removed, or the chemical with which it could react, HCl, would be adsorbed onto alkaline fly ash. Additionally, residual SO_3 emissions have been significantly reduced in recent years with the formulation of new catalyst materials that minimize SO_3 while continuing to provide efficient NO_X reduction.

Contact Information

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com).

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