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Science

Comparisons of plumes from Cumberland Steam Plant before and after installation of Flue Gas Desulfurization indicate that the lower sulfur dioxide emissions have led to reductions in particle sulfate and a corresponding improvement in visibility within the plume.

Policy

TVA's system-wide sulfur dioxide (SO_2) emissions declined 48 percent between 1975 and 1990, and these emissions are projected to decline an additional 55 percent between 1990 and 2010. Although many questions remain unanswered, results from this study indicate that reductions in TVA's SO_2 emissions, while perhaps obscured by other sources of regional SO_2, should result in comparable improvements in regional visibility because of reduced formation of sulfate aerosols.

Reductions in Sulfur Dioxide Emissions From Cumberland Power Plant Lower Both Sulfate Aerosol Levels and Improve Plume Visibility

Background and Approach

Visibility impairment from power plant plumes can be classified in three categories. The first, opacity, occurs very near the stack (< 2 km) and is determined by a standardized EPA observation method. The second, plume blight, occurs at distances from 2 km to 1 day's travel downwind. Blight happens before the plume has been dispersed so widely that it is indistinct from the background. Once this happens, the effect of the plume on the third category, regional haze, is realized. This newsletter focuses on plume blight and regional haze.

Small particles are formed in plumes from coal-fired power plants when SO_2 is oxidized to sulfate (SO_4^{-2}) aerosol particles. In the eastern United States in particular, these sulfate particles contribute significantly to the concentration of very fine particle matter ($PM_{2.5}$), that causes reductions in visibility because of its light scattering properties (Table 1). On the very haziest days, sulfate aerosols may contribute more than 80 percent of the visibility reduction in the Tennessee Valley region.

Table 1. Pollutants that contribute to visibility impairment in the eastern and western parts of the United States, according to the 1997 National Air Quality: Status and Trends.

	West	East
Sulfates	25-65%	> 60%
Organic Carbon	15-35%	10-15%
Nitrates	5-45%	10-15%
Elemental Carbon (soot)	15-25%	10-15%
Crustal Material (soil dust)	10-20%	10-15%

In response to Title IV Phase I provisions of the Clean Air Act Amendments of 1990 (http://insidenet.tva.gov/org/resource/ontheair/title_iv.htm), many coal-fired power plants in the eastern United States have installed wet Flue Gas Desulfurization (FGD) equipment to reduce SO_2 emissions. The TVA Cumberland Power Plant (CUF) in central Tennessee began using FGD in 1995. While the SO_2 emissions were reduced by 95 percent, a critical environmental question is whether this reduction has had the anticipated linear benefit on secondary sulfate aerosols formed in the plume.

Researchers estimated the rate of SO_2 conversion to sulfate in the CUF plume before FGD installation from data collected during TVA's 1978 Tennessee plume study. Those results now can be compared to measurements conducted by TVA in 1998 and 1999, when SO_2 emissions were 20 times lower, to determine if aerosol formation was reduced by a similar magnitude.

In 1998-99, air sample measurements of the CUF plume were made at each of three distances selected to give plume ages of one, three to five, and six to ten hours. Although all measurements were taken in the plume blight regime, the data also can be applied to regional haze. The data for single flights—one each in 1998 and 1999—were analyzed to determine the changes in sulfate concentrations and volume particle size distribution that occurred at increasing distances from the plant. "Excess" concentrations and particle volumes in the plume were calculated by determining the values in the background air and subtracting these from the values found in the plume.

Results

Aerosol data from the 1998 and 1999 studies indicate that the plume of the Cumberland Power Plant is much cleaner when compared with data from measurements performed 20 years earlier. In fact, it was difficult to accurately estimate Cumberland's contribution to particle mass in this study because it was so small relative to variation in the background.

By comparing light scattering before and after the installation of FGD at CUF, TVA can assess the benefits (Figure 1). The light scattering in the 1978 plume, due to CUF emissions, was more than 2 times greater than in 1998 at the 0 to 20 km range, and over 6 times greater at the 20 to 60 km range. In 1978, the scattering grew worse the further downwind the plume traveled, while in 1998, the scattering actually improved as the plume drifted downwind (Figure 1).

Sulfate particles contribute significantly to light scattering in a plume after the plume has traveled some distance (as in the medium distance sampled in Figure 1). These particles can make the plume more visible if the light scattering in the plume becomes significantly greater than that in the background air, contributing to plume blight. The light scattering in the 1978 plume was 3 times that of the background air, while in 1998, plume light scattering was only 13 percent higher than in the background air. This was due, in part, to the fact that the background light scattering was higher on the 1998 day than in 1978.

Sulfuric acid emitted from the stacks was about two-thirds higher in 1978; and when it condensed to sulfuric acid droplets, it caused the increased light scattering measured in 1978 in the plume near the stacks (as in the "near" distance in Figure 1). Further

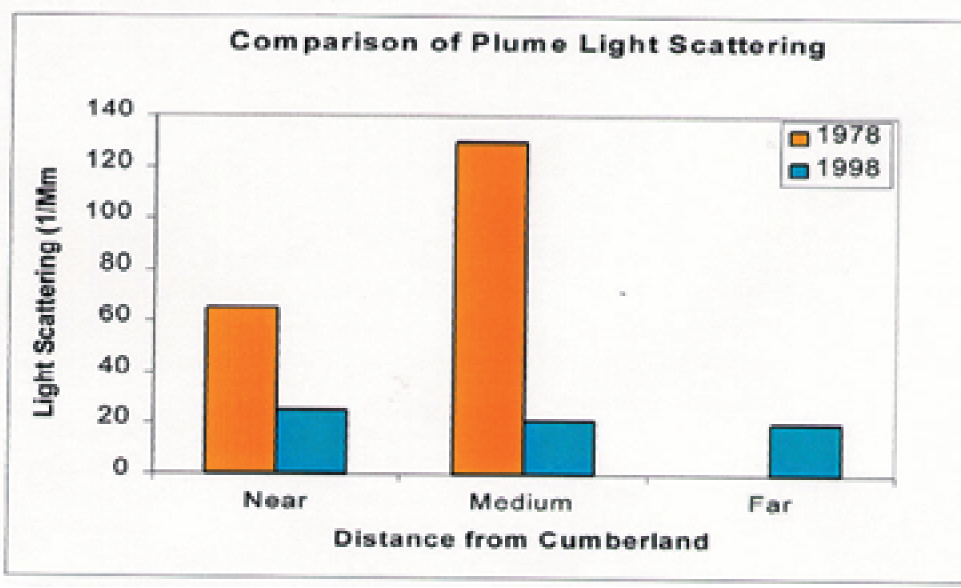

Figure 1. Comparison of light scattering (extinction) of the 1978 and the 1998 plumes at Cumberland. Light extinction is directly related to visibility. Near is within 20 km of the stack, medium is between 20 to 60 km downwind, and far is more than 60 km downwind. No measurements were taken beyond 60 km in 1978.

downward, however, at the "medium" distance (Figure 1), the 1978 plume scattered even more light because sulfate aerosols were made from SO_2 faster than they could disperse. The downwind improvement in the appearance of the 1998 plume occurred because the reduction in SO_2 emissions caused the amount of sulfate aerosols formed in the plume to be reduced.

The amount of particulate sulfate formed in a given time period depends on the amount of SO_2 present and the rate at which SO_2 is oxidized. This study examined the rate of SO_2 oxidation. Figure 2 plots the percent of the total sulfur in the plume present as SO_2 against downwind travel time. Time was used in this plot rather than distance because the conversion is time dependent. When the 1998 plume was five hours downwind, SO_2 only comprised about 62 percent of the total sulfur in the plume. In contrast, in 1978 at this distance, the plume SO_2 still made up 85 percent of the plume's sulfur—a larger reservoir for additional sulfate production further downwind. Because the improvement in appearance between the 1978 and 1998 plumes continued to increase with downwind distance, the beneficial results of the FGD in reducing sulfate particles increased with distance from the source.

The slope of the lines in Figure 2 represents the SO_2 to sulfate conversion rate for the 1978 and 1998 studies. The upper limit of the conversion rate for the 1998 data was 4.37 percent per hour. The conversion rate for the 1978 data was very similar at 4.43 percent per hour. The particle volume data for 1999 also yielded a comparable conversion rate. Hence, the results of the 1998 and 1999 measurements clearly suggest that the reduction in SO_2 emissions from the CUF from those existing in 1978 likely has been accompanied by a roughly proportional reduction of the amount of sulfate formation during plume dispersion into the environment.

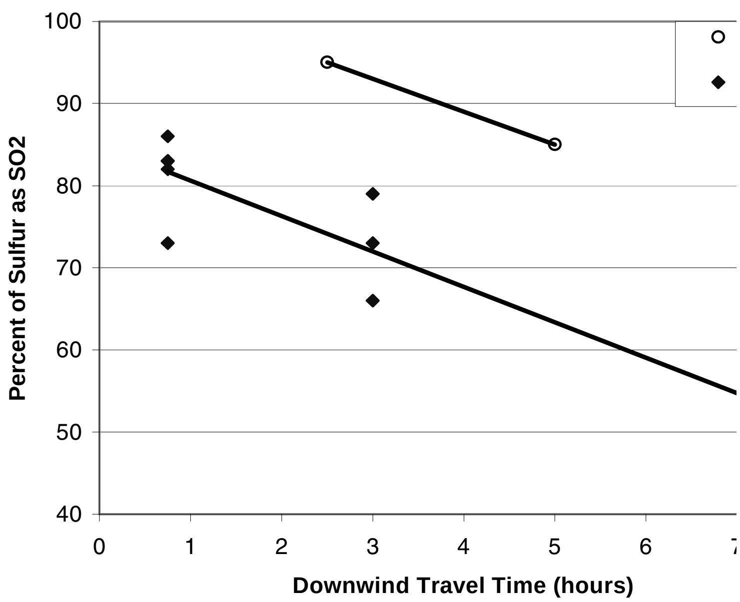

Figure 2. Rate at which SO_2 was converted to sulfate in the 1978 and 1998 plumes as a percentage of total plume sulfur.

However, these results are only for a single source and do not necessarily mean that an approximate linear benefit will occur under all conditions. Also, the regional concentrations of sulfate are due both to sources in the immediate vicinity as well as to sulfate from outside the region. Such imported sulfate could result in a reduced regional benefit.

Implications

Given the apparent proportional reduction in sulfate formation in the CUF plume following the installation of FGD scrubbers, coupled with large reductions in TVA's SO_2, emissions over the past two decades, leads one to wonder, "Why have the particulate sulfate levels in the atmosphere of the Tennessee Valley region and visibility in the Great Smoky Mountains (caused in major part by particulate sulfate) not improved significantly?"

Several plausible explanations exist for this apparent disconnect between CUF emissions of SO_2 and regional levels of sulfates:

- Results for a single source under dry conditions in the summer season do not mean that all sources would experience an approximate linear benefit in sulfate reduction from reduced SO_2 emissions, or that sulfate production in any plume would be linear in other seasons.
- Increases from emission sources outside the Valley, which affect local particulate levels, may have substituted for local reductions in SO_2 emissions.
- Fraction of SO_2 converted to sulfate before deposition may have gone up.
- Oxidation of SO_2 in ambient air no longer identified with a particular plume is now proceeding at a faster rate due to changing climatic conditions (e.g., temperatures, hydroxide levels, etc.).

Summers have become more humid than they used to be, leading to more rapid cloud-phase oxidation of SO_2 to sulfate. Also periods of late summer stagnations have become more frequent and sustained in recent years. Increased fossil plant emissions during summer to meet increasing summer demand for power.

Conclusions

Reductions in SO_2 emissions appear to have a proportional benefit on reductions in the production of plume sulfate particles.

The benefit of the Flue Gas Desulfurization scrubber on secondary $PM_{2.5}$ and visibility increases with distance from the stack.

How these reductions in SO_2 emissions interact with other regional variables requires much further research.

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Figure 3. Helicopter sampling air from a steam plant plume.