AN ASSESSMENT OF SOME AEROSOL PROPERTIES IN MIDWESTERN POWER PLANT PLUMES

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I. INTRODUCTION

In the course of conducting case studies relating to inadvertent weather modification in the St. Louis metropolitan area under the auspices of Project METROMEX, it has been possible to obtain airborne aerosol measurements describing the plumes from the several fossil-fueled power plants operating in the area. The purpose of this paper is to provide some additional insight into inadvertent weather modification by examining the transport and detection of Aitken Condensation Nuclei (ACN) within these plumes; in addition, one case study illustrating the evolution of the aerosol spectra in the downwind plume from a 2400 MW plant will be shown. It is anticipated that the general description of plume behavior rendered herein will find utility in the prediction and modeling of such meteorological phenomenon.

II. METHODOLOGY

Our observations taken from 10 test cases were conducted within the well-mixed layer, typical of midsummer climates in the Midwest during Augusts 1974-76; typical flight altitudes were 1500 ft. (450 m) agl.

Details of the full experimental procedures may be found in Shea (1976) or Komp (1977).

Real time output from the airborne meteorological system aboard the University of Wyoming's Queen Air research aircraft was used to monitor and update traverses within the power plant plumes. Transport winds, derived from a Doppler navigation system, Aitken nucleus concentrations, and aerosol spectra from optical probes were the principle parameters monitored, although other meteorological parameters along with flight experience were also used. Once the mean transport winds within the mixing layer were predicted by antecedent winds aloft observations and confirmed by the aircraft, the aircraft would fly a grid pattern downstream for an appropriate distance corresponding to several hours of transport time for a parcel traveling with the mean transport wind. This grid pattern, designed for studying the total urban plume, also resulted in the detection of power plant plumes.

Aerosols were continuously monitored for size and concentration. A PMS* axially scattering spectrometer probe (ASSP) was used to continuously measure

*Particle Measuring Systems, Inc., Boulder, Colorado
in situ the number of aerosols between 0.5 - 5.0 μm by measuring the amount of light energy they scatter out of the laser beam. An additional PMS probe, an active scattering aerosol spectrometer (ASAS), located inside the aircraft, was capable of measuring aerosols from 0.08 - 3.0 μm sampled with an isokinetic inlet. Concentrations of ACN were measured with an Environment One Continuous Condensation Nuclei Monitor. Essentially, such concentrations of ACN represent the total particulate content of the air because supersaturations greater than 250% attained by the Environment One activate all particles > 0.0025 μm in diameter. The Environment One has a response time of seven seconds for detecting 90% of an instantaneous change in ACN concentrations. The total Aitken nuclei number was used to extend the log diameter-number distribution to the smallest diameters under the assumption that the diameter interval of the Aitken nuclei is \( \Delta \log D = 1 \).

Thus, aerosol size distributions can be generated from the Aitken nucleus concentrations and the ASSP and ASAS data evaluated for 3-5 min. averages for each transect of the plume.

All reference to ACN concentrations reported in this paper are based on the mean of 15 consecutive one-second samples and correspond to a length of about 1 km.

No data was acquired on the chemical species of the aerosol, nor on their water or ice nucleating capabilities.

All transport times (computed by dividing the downwind distance along the mean wind direction by the wind speed and the mixing layer) are with respect to the given power plant.

Within the St. Louis metropolitan area and environs there are seven fossil-fueled power plants. These plants and their MWe ratings during the period of study are: Labadie, 2400 MW; Baldwin, 1800 MW; Portage des Sioux, 1000 MW; Meramec, 880 MW; and Wood River, 500 MW. Two other plants, Doffeen (900 MW) and Rush Island (600 MW), were operational but were not studied specifically. All the plants burn 3% sulphur content Illinois coal and employ electrostatic precipitators with efficiencies > 99.5% except the Meramec plant with an efficiency of 97.5%.

III. RESULTS

Figure 1 illustrates the variation of the total ACN concentrations as a function of the transport time downwind (i.e., residence time). Linear best-fit equations have been derived for describing the plume ACN concentrations for the two larger plants (Labadie and Baldwin), a smaller plant with a precipitator (Portage des Sioux) and a smaller plant with a less efficient precipitator (Meramec). The typical background mid-summer ACN concentrations of 6000 cm\(^{-3}\) in the mixing layer has been entered on Figure 1 as a reference.
Figure 1. Variation of the maximum total ACN concentrations as a function of the transport time in the plumes downwind from the power plants. The linear best-fit equations are: $N = 21,300 - 4,100t$; $N = 34,000 - 15,900t$; and $N = 28,100 - 21,100t$. 
It can be seen that the extent to which the ACN plumes remain detectable above background concentration increases with the MWe rating of the plant and its precipitator efficiency. The 1800-2400 MW plants have ACN plumes detectable above background for over 3.5 hours while the ACN plume of the 1000 MW plant is noticeable for only about 1 hour. The 880 MW Meramec plant with its less efficient precipitator produced the greatest concentrations for up to one hour of any of the plants and its plume did not fall below ambient background ACN concentrations until after 1.7 hours.

Figure 2 is similar to Figure 1 except that the maximum excess ACN in the plume has been found by subtracting the actual regional background ACN concentrations from the maximum total for each individual case. In Figure 2, then, a zero excess of ACN is equivalent to the concentration of the prevailing background ACN. It is expected that similar interpretations should be evident and such is the case for the 1800-2400 MW plant plumes and the 880 MW plant plumes, approaching background concentrations at 4 hours and 1.5 hours, respectively. The data in Figure 2 now suggest that the Portage de Sioux plume would linger to two hours before background concentrations were again attained.

A description of the ACN plume width downwind of the power plant source is offered in Figure 3. Here the plume width of the isopleth of ACN concentration corresponding to 10,000 cm$^{-3}$ at various downwind distances for a 5 m per second transport wind is shown for the Labadie and Baldwin plants. It is suggested from Figure 3, particularly by examining observations from individual case studies, that the ACN plume width increases with distance downwind out to about 25 km (or 1.4 hrs. transport time). For the neutral stabilities of the mixing layer in which the observations were made, the horizontal angle of dispersion is estimated at 16° up to 25 km. Beyond this distance, the plume width remains unchanging at 7 - 10 km out to at least 50 km. The values for plume width up to 10 km downwind agree favorably with values from a survey of silver iodide dispersion data, under comparable atmospheric criteria, given by Auer et al., (1970). The reason for the Baldwin plant to exhibit smaller width than the Labadie plant is unknown.

A second phase of our investigation into the downwind aerosol characteristics in power plant plumes around St. Louis is revealed by the case study of 16 August 1976, addressing visual range anomalies downwind of the metropolitan area. A full description of the urban/industrial associated visibility anomalies on this day has been addressed elsewhere (Komp and Auer, 1977). Figure 4 shows the area of reduced visibility discovered to exist between 2 and 3 hours transport time downwind of the Labadie plant; values of minimum visibility were observed to be equivalent to a reduction of 40% of the surrounding regional visibilities. The visibility anomaly was further studied by investigating the characteristics of light scattering aerosols over and downwind of the Labadie plant. Such aerosols are in the size range of 0.4 - 1.2 μm. Smaller particles < 0.2 μm showed a decrease after 2.6 hrs. The detection of the downwind changes of the aerosol spectra can more readily be ascertained by converting the number distribution to surface and volume distributions, assuming spherical particles; such surface and volume distributions are shown in Figure 6 and 7. These figures suggest that the total aerosol loading

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1 Greatest distance at which prominent objects can be seen by eye.
Figure 2. Variation of the maximum ACN excess above local background as a function of the transport time in the plume downwind from power plants. The linear best-fit equations are:\[ \Delta N = 12,800 - 3,000; \quad \Delta N = 23,800 - 15,500t; \] and \[ \Delta N = 10,200 - 4,600t. \]
FIGURE 3. Plume width of the 10,000 cm$^{-3}$ ACN isopleth versus distance downwind for the 2400 MW Labadie (solid) and 1800 MW Baldwin (open) power plants. Similar shaped symbols indicate observations from a single case study.
Figure 4. Visibility analysis (st. mi.) for 16 August 1976 between 1430-1800 cdt. Note visibility minimum 2-3 hrs. downwind of Labadie plant (★).
Figure 5. Number distribution for aerosols sampled in the center of the visibility anomaly at specified downwind times of the Labadie power plant.
Figure 6. Surface area distributions for aerosols sampled in the center of the visibility anomaly at specified downwind times. 16 August 1976.
Figure 7. Volume area distributions for aerosols sampled in the center of the visibility anomaly at specified downwind times. 16 August 1976.
characteristics [the total aerosol surface area and aerosol volume (i.e., mass)] maximize in the range of 0.2 - 5.0 μm and that there is a shift toward larger sizes downwind. From the evolution of the volume distributions, it is seen that while the mass distributed in the range of aerosols < 0.2 μm is decreasing up to 3.4 hrs. residence time, the overall volumetric conversion rate for diameters < 0.2 μm is increasing up to 3.4 hrs. This increase in the volumetric conversion rate implies the existence of an aerosol growth mechanism(s) responsible for the time-coincident visibility anomaly.

A comparison of the evolution of the aerosol distribution for size, surface area, and volume with those derived from laboratory studies (e.g., Husar and Whitby, 1973) suggest that these light-scattering aerosols are of secondary origin produced by heterogeneous gas-to-particle conversion.

It should be noted that this example of regional visibility reduction downwind of a power plant is the only such case documented by our experience in METROMEX. Presumably, it is related to the impact of the urban-association generation of aerosols some 50 km upstream. Similar studies under wind regimes of different directions yielded no accompanying regional visibility minimums downstream of the local power plants.

IV. CONCLUSIONS

Case study analyses have revealed some consistent evidence describing the transport and detection of Aitken nuclei within the plumes of fossil-fueled power plants in the mixing layer on fair weather summer days:

1) large power plants (2000 MWe capacity utilizing electrostatic precipitators with > 99.5% efficiency) produce ACN plumes whose maximum concentration exceeds mid-western regional background concentrations for up to 4 hours transport time downwind;

2) mid-size power plants (1000 MWe capacity) produce ACN plumes whose maximum concentration exceeds mid-western regional background concentrations for up to 1 - 2 hrs., depending upon electrostatic precipitator efficiency; and

3) the width of the ACN plume (2X background values) increases gradually up to 25 km downwind, thereafter remaining unchanged at 7 - 10 km out to 50 km.

Case studies (not presented here) designed to investigate the effect of smaller power plants (< 500 MWe) revealed that these plants did not significantly perturb the ACN loading of the regional background concentrations. Often, the plumes from these plants are completely obscured by the ACN output of the metropolitan area.

By extrapolating the evidence put forth into regions of the western United States with lower ACN background concentrations (e.g., 1000 cm⁻³), it is implied that these "cleaner" air masses might extend the detectable
limit of the ACN plumes from large and mid-sized power plants to 5 and 2
hrs. downwind, respectively.

The evolution of the volumetric conversion rate in the first 3.5 hrs.
of residence time strongly suggests active aerosol growth mechanism in
power plant plumes, without regard to chemical identities of the aerosol.
Although the aerosol growth is confined to those particles which are optically
significant, reduction in visual range are normally not noted in power plant
plumes unless an interaction occurs with plumes emanating from other large
industrial/metropolitan area sources.

The assessment of the ACN loading and its downwind extent should be a
useful contribution for determining the impact of air quality by the
approximately 500 fossil-fueled power plants in this country. Obviously
the input may be expected to be more detrimental in areas with lower regional
background aerosol concentrations.

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