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COMPARATIVE AEROSOL STUDIES OF PACIFIC RIM CITIES—SANTIAGO, CHILE (1987); MEXICO CITY, MEXICO (1987–1990); AND LOS ANGELES, U.S.A. (1973 AND 1987)

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Abstract—The UC Davis Air Quality Group has performed studies on urban air quality since 1973. Recently, with the active collaboration of scientists in Mexico and Chile, these studies have been extended to other Pacific Rim cities of similar climate. From such comparisons, the successes (and failures) of control strategies can be inferred and compared to Los Angeles' progress, 1973 through 1987. An early and rather surprising result is the rough equivalence between Los Angeles, Mexico City, and Santiago in terms of several classes of fine ($D_p < 2.5$ μm) particles. However, coarser particles are far more prevalent in Mexico City and Santiago than Los Angeles. Finally, in many ways, Los Angeles of 1973 was worse than Mexico City and Santiago today. Thus, the progress of Los Angeles gives hope for similar improvement given suitable policies.

Key word index: Aerosols, inhalable particles, fine particles, mass, chemical species, PIXE, PESA, LIPM, Santiago, Mexico City, Los Angeles.

INTRODUCTION

Air quality continues to be one of the most evident impacts in the formation of urban metropolises or mega-cities. The degradation of visibility is readily evident to the visitor and resident alike, while air pollution episodes of primary (carbon monoxide) and secondary (ozone) species gain international notoriety. Furthermore, behind the obvious impacts of air pollution lies a worrisome melange of toxic metals, mutagens and carcinogens. That is the ensemble that threatens the health of every long-term resident.

It is clear to the agencies responsible for health and welfare that actions must be taken to ameliorate the situation. But the nature of actions, their cost and effectiveness, are not always obvious. One approach is to examine efforts of similar cities and gain perspective from their efforts. Such an approach faces the problem, however, of the uniqueness of each urban area. Thus, information on ambient air quality for similar urban areas can aid in identifying similarities and differences in the situations and put in better focus similarities and differences in potential control efforts. For a number of primary pollutants such as carbon monoxide (CO), this approach is straightforward, since the instrumentation is standard and interferences are few. But for more complex species, such as ozone (O_3) and fine aerosols, comparisons are more difficult and the number of parameters that must be considered, large. For example, meteorology plays an enormous role in ozone formation and the same pollutants that in one case can help form ozone, can, in different situations, destroy ozone.

The situation is similar for aerosols. Aerosol particles dominate the transport of toxic metals, mutagens and carcinogens, lead to acid fog and rain, and cause poor visibility. But particulate monitoring often involves merely collecting all particles, regardless of size, in the so-called high volume (Hi-Vol) samplers. These samplers are notoriously sensitive to local dust sources, and many of the particles are too large to enter the human lung, cause visibility reduction, or cause other aerosol impacts. These processes are dominated by particles below 10–15 μm diameter (PM-15; PM-10), while deep lung deposition, visibility, and acid fogs depend on even finer particles, $D_p < 2.5$ μm (PM-2.5). Finally, total mass, even respirable PM-10 or fine PM-2.5 mass, tells little about the composition of the aerosol and therefore little about potential control measures. Compositional analyses are also required. Fortunately, rapid advances have been made in the past decade in the collection and analysis of fine particles. Those techniques are now being applied to Pacific Rim cities.

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In this paper, we will attempt to perform a comparative analysis of fine aerosols in three cities: Santiago, Chile (January–February 1987) (Rojas *et al.*, 1990), Mexico City (July–August 1987–1990) (Aldape *et al.*, 1991a, b; Miranda *et al.*, 1992) and Los Angeles (August 1986) (Cahill *et al.*, 1990). Earlier data from Los Angeles (July–September 1973) (Flocchini *et al.*, 1976) are also included for a comparison of the progress made in that city in the past 15 years.

COMPARATIVE AEROSOL DATA

Table 1 gives the data on comparative fine aerosols for Santiago, Mexico City and Los Angeles. Each city represents summer data only and winters (especially in Mexico City and Santiago) may be worse for many pollutants. All compositional data, except Los Angeles 1973, are given for fine particles, $D_p < 2.5$ μm.

The most striking result is that there are great similarities between all three cities. One should not put too much faith in the precise figures, since the cities are all very extensive and sampling sites are certainly not representative of the entire urban area. However, in each case an effort was made either to average together central city satellite sites (Santiago, Los Angeles 1973) or to pick an intermediate site that is neither central city or suburban (Mexico City, Los Angeles 1986).

Mass data were directly measured gravimetrically from the aerosol filters. The elemental data were connected to proposed spectra by the standard IMPROVE protocols. These protocols, while not always correct, are a good to very good approximation in over 90% of the sites. Organic carbon was derived from carbon and hydrogen measurements (Cahill *et al.*, 1989) while soot carbon is inferred from optical absorption (Campbell *et al.*, 1989). $(NH_4)_2SO_4$ is inferred for S by multiplying by the factor 4.125, while soils are Al, Si, K (corrected for smoke), Ca, Ti, Fe, with typical oxides. In several cases, direct comparison between the sum of inferred species and gravimetric fine mass can be made, yielding 80–90% of the total mass explained by the species. The remainder are volatile species, mostly water, since the elemental measurements are usually done in vacuum.

It is also important to note that between 43 and 90 individual samples were examined and all data presented for tracer species represent the average values, thus presenting a statistically sound picture of tracer element profiles. These species are the ones that allow identification of specific sources and thus are of most help in control strategies.

Table 1. Comparison of urban aerosols (Summer)

	Santigo	Mexico City	Los Angeles	
	1987	1987–1990	1987	1973*
Mass ($\mu g\ m^{-3}$)				
Total $D_p < 15$ (μm)	100†	133	60‡	NA
Coarse $2.5 < D_p < 15$	66	85	23‡	NA
Fine $D_p < 2.5$ (μm)	34	48	37	NA
Major fine sp.				
Organic C	NA	17.3	18.5	NA
Soot C§	NA	7.4	5.7	NA
$(NH_4)_2SO_4$	8.7	14.7	10.3	14.3
$(NH_4)NO_3$	NA	NA	1.2	NA
Soil	2.9	3.6	3.2	(14.1)
Salt	NA	0.08	< 0.1	0.2
Tracer Fine sp.				
Smoke	0.880	0.297	< 0.050	< 0.10
Vanadium	0.016	0.068	NA	0.038
Chromium	0.006	0.008	NA	NA
Manganese‖	0.017	0.017	0.014	0.036
Nickel	0.003	0.007	0.014	NA
Copper	0.026	0.048	(0.040) ††	0.012
Zinc	0.220	0.341	0.240	0.135
Bromide	0.090	0.067	0.039	0.238
Lead	0.260	0.383	0.250	1.385
	38%**	81%	91%	NA

* Los Alamitos, Los Angeles, Azusa, Riverside.
†PM-10.
‡PM-10, Azusa, annual geometrical mean.
§ b(abs) measured by Integrating Plate Method; C (soot) inferred, 10 $m^2 g^{-1}$.
¶PM-15 affects soil strongly.
‖Mn -mostly soil.
**No organic carbon.
††Local copper pollution at site due to nearby Hi-Vol samplers.

Nevertheless, even with all these caveats, it is clear that there are great similarities between all these cities. The differences stand out in stark relief; i.e. heavy wood/grass smoke signature of Santiago, Chile, and Mexico City, and the high soot vanadium content (fuel oil) of Mexico City. In other cases, agreement of data may be merely fortuitous. The lead level in Los Angeles was in rapid decline as lead was being phased out of gasoline. There are far fewer gasoline powered vehicles in Santiago and Mexico City, but they largely use leaded gasoline. Conversely, these cities have a heavy proportion of diesel engines. The most surprising agreement was for soils and sulfates. One has the strong impression in Santiago and Mexico City of loose soils on or near streets and many unpaved roads. Yet, the fine soil aerosols are similar to that of Los Angeles with few unimproved roads. Likewise, the equivalence of sulfates demands further analysis, especially since sulfates usually dominate visible hazes and contribute to acidic fogs and rain. Finally, the changes seen in Los Angeles between 1973 and 1986 show that progress can be made despite a great increase in population. For example, both Chile and Mexico have programs for reducing or eliminating lead in gasoline.

INTERPRETATION

For the reasons given above, one should not put too much emphasis on any one value. But some points are evident. First, there appears to be much more mass above 10 or 15 μm diameter in Mexico City (and probably Santiago) than Los Angeles. In Los Angeles, old Hi-Vol data are less than a factor of 2 greater than PM-10 data, while Hi-Vol data from the other cities are much higher. We must also reiterate that these data are for summer only. In areas of strong winter inversions, such as Mexico City and Santiago, primary pollutants can reach high values. For example, an average lead value of 5.1 $\mu g\,m^{-3}$ was reported for Mexico City during the winter of 1968 (Bravo *et al.*, 1968) (corresponding to 2.5 $\mu g\,m^{-3}$ in Los Angeles, 1973) while carbon monoxide reaches alarming levels at the same time. Such dramatic values were not seen at the Mexico City site. However, extreme values reached 1.5 $\mu g\,m^{-3}$ winter vs 0.5 $\mu g\,m^{-3}$ summer at this site, almost a factor of 3.

CONCLUSION

It is clear that further comparative studies, including winter, would help clarify the source and effects of these aerosols. But we also propose that such comparative studies can help put urban air pollution problems in a rational perspective that might allow better transfer of successful control methods and avoidance of ineffectual measures.

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