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The body of information presented in this paper is directed to those individuals concerned with estimating total air pollution. A method for estimating total air pollution is described and is applied to three examples. The method is called "pindex" and is based on proposed air quality standards and other generally accepted tenets of air pollution technology. Pindex sums air pollution contributions from particulate matter, sulfur oxides, nitrogen oxides, carbon monoxide, hydrocarbons, oxidant, solar radiation, and particulate-sulfur oxides synergism.

Within the pindex method, oxidant is synthesized from nitrogen oxide and hydrocarbon precursors, the degree of conversion being controlled by a solar radiation term. Next, tolerance factors based on air quality standards are used to reduce all the pollutant levels to an equivalent basis. Tolerance factors vary from 214 for oxidant to 40,000 for carbon monoxide. The synergism term is set equal to the concentration of the limiting reactant (sulfur oxides or particulate matter). Finally the six equivalent concentrations plus the synergism term are summed to yield the pindex level.

When using a gross weight basis, transportation is responsible for 60% of total USA emissions. Most of this pollution is carbon monoxide. However, when these data were subjected to pindex evaluation, the transportation category dropped to 19% of the total behind the industrial and electric power generation categories. Because of their lower tolerance levels, particulates, sulfur oxides, and nitrogen oxides all surpassed carbon monoxide in pollution severity.

When the pindex method was applied to air quality data for ten individual cities, Chicago and Los Angeles ranked highest, while San Diego ranked lowest. The results of the pindex evaluation were roughly comparable with those published in an earlier U. S. Public Health Service study which used a different ranking method.

Jet engine emission data were also subjected to pindex evaluation. Use of "clean" burner cans eliminated 99% of the hydrocarbon emissions, but the pindex evaluation showed that much of the hydrocarbon reduction was neutralized by increased nitrogen oxide emissions.

The pindex method is an attempt to use present knowledge to fill a great need for overall air pollution assessment. Without overall pollution measuring methods, priorities cannot be properly set. Formulators of pollution control policy must be able to trade off one pollutant against another, always being aware of the effect of a change in one pollutant upon overall air quality.

The pindex method is easily revised so that tolerance factors may be updated, or additional pollutants may be added in the future.

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Evaluating overall air pollution can be a complex undertaking. Urban air pollution consists of an often ill-defined mixture of several pollutants emitted from different energy and industrial processes. Additional secondary pollutants are created in the atmosphere. Synergisms can occur between certain pollutants. Despite these complexities, efforts should be made to total the effects of the individual pollutants. This paper presents such an attempt. Only with a usable total air pollution yardstick can we get the most from pollution control expenditures. In addition, a total air pollution measure enables one to compare overall air pollution in different localities.

Overall air pollution measures serve at least two purposes. First, they can be used to give the layman a more meaningful assessment of air pollution severity. The layman wants to know "how bad it is." He may even object to the control agency hiding behind individual part-per-million numbers which the layman does not understand. Several partial indexes are now in use by specific control agencies.

Second and perhaps more important, a combined air pollution measure or index enables evaluation of the trade-offs involved in alternative air pollution control policies or in evaluation of control equipment which, for instance, reduces levels of certain pollutants while increasing levels of others. The combined air pollution index, called pindex in this paper, can serve as both a lay information tool and as a technical tool.

Three examples are used to show the difficulties encountered in the absence of an overall pollution measure. Next pindex is defined. Finally pindex levels are determined for each of the three examples.

The simplest measure of total air pollution unfortunately is in wide use and involves the simple summation of individual pollutant emission weights. A familiar summary of USA emissions[1] is shown on the upper half of Table I. Quite clearly, when using an uncorrected weight basis, the USA air pollution problem consists largely of carbon monoxide emanating from automobile engines. Note that oxidant does not appear in Table I. Worse, relative toxicities are not considered in gross weight comparisons.

The second example is illustrated in the upper half of Table II. Approximations of ambient pollution levels[2-4] are tabulated for several USA cities. Large differences are apparent despite the use of annual averages. Chicago leads in sulfur oxides and in carbon monoxide. Los Angeles has a different problem with low sulfur oxides but with the highest oxidant level. Cincinnati and Philadelphia are highest in particulates; San Diego is highest in hydrocarbons. Which city has the highest level of overall air pollution? Meaningful total pollution levels could be determined if each pollutant level were converted to an equivalent basis prior to a summation.

The third example deals with jet engines, a relatively recent source of air pollution. George, Verssen, and Chass[5] compared the effects of fuel type and burner-can design upon emissions from 4-engine jet aircraft. Some of their results are shown in the upper half of Table III. These authors summarized their work in part as follows:

> Substitution of the new "smokeless" burner cans . . . reduced emissions of total air contaminants from this engine by nearly 75%. Emissions of particulates were reduced by 23%, carbon monoxide by about 23%, and hydrocarbons and organic gases by 99%; *nitrogen oxides showed an increase of about 40%.*

First, what is the most serious emission from a jet engine? Second, how much of the commendable reduction in hydrocarbons is counteracted by the increased emission of nitrogen oxides? Questions such as these should be answered before wholesale engine conversions take place. A similar trade-off exists for some automobile emission control devices.

Air Quality Standards

Air pollution standards provide the basis for combined pollution indexes. There is fair agreement as to the levels at which individual pollutants begin to endanger the breathing public. The recently issued NAPCA air quality criteria[6-10] attempt to summarize the effects of individual pollutants. Several agencies have adopted air quality standards. Standards proposed for the State of California[4] are representative and are shown in Table IV. These standards are fairly comprehensive, but note that no standard was proposed for hydrocarbons, and there is no common time basis.

Presumably, when the ambient level of a given pollutant exceeds the standard, a dangerous or unhealthy situation exists, and some corrective action is taken. Standards then give us a way to reduce different pollutant concentrations to the same basis. In California, for example, equivalent unpleasantness or severity is thought to occur at 0.5 ppm sulfur dioxide or 0.25 ppm nitrogen dioxide or 0.1 ppm oxidant. Unfortunately such standards often say nothing about combinations of pollutants. Even aside from the synergism question, could 0.24 ppm nitrogen dioxide *and* 0.09 ppm oxidant together (both below the standard) be worse than 0.51 ppm sulfur dioxide alone (above the standard)?

Existing Combined Indexes

There have been relatively few attempts to go beyond the standards step. Yet it seems logical to use the standards to arrive at a combined pollution level. The few existing combined indexes are specialized, being based on specific existing instrumentation and upon specific local situations.

Green[11] developed an index which combined coefficient of haze with sulfur dioxide. The Columbia-Willamette Air Pollution Authority uses an index based on the integrating nephelometer[12] developed by Charlson and Ahlquist.[13] Perhaps the ultimate index will indeed be one that uses a single instrument to measure total air pollution. The nephelometer actually measures light scattering due to particulate matter

Table I. USA air pollution source distribution.[1]

	PM	SO_x	NO_x	CO	HC	Total
Uncorrected Basis (10^6 tons/year)						
Transportation	1.8	0.5	3.1	59.6	9.7	74.7
Industry	6.0	8.7	1.6	1.8	3.7	21.8
Power plants	2.4	10.2	2.4	0.5	0.1	15.6
Space heating	1.2	3.4	0.8	1.8	0.5	7.7
Refuse incineration	0.6	0.2	0.1	1.3	1.0	3.2
Total	12.0	23.0	8.0	65.0	15.0	123.0
Pindex Levels (percent of grand total)						
Transportation	6	1	7	2	3	19
Industry	22	11	4	0	1	38
Power plants	11	12	6	0	0	29
Space heating	5	4	2	0	1	12
Refuse incineration	2	0	0	0	0	2
Total	46	28	19	2	5	100

Table II. Air quality data for USA cities.

	PM ($\mu g/m^3$)	SO_x (ppm)	NO_x (ppm)	CO (ppm)	HC (ppm)	Oxidant (ppm)	
	Annual Averages (approximated from 1962 to 1967 data [2–4])						
Chicago	124	0.14	0.14	12.0	3.0	0.01	
Cincinnati	154	0.03	0.06	6.0	3.0	0.02	
Denver	126	0.01	0.07	7.9	2.4	0.03	
Los Angeles	119	0.02	0.13	11.0	4.0	0.05	
Philadelphia	154	0.08	0.08	6.8	2.0	0.01	
Saint Louis	143	0.04	0.07	5.8	3.0	0.04	
San Diego	69	0.01	0.05	3.0	6.0	0.03	
San Francisco	68	0.01	0.14	3.2	3.0	0.02	
San Jose	92	0.01	0.12	5.0	4.0	0.02	
Washington	77	0.05	0.07	6.0	3.0	0.02	
Pindex Levels							Total
Chicago	0.47	0.42	0.56	0.38	0.11	0.10	2.04
Los Angeles	0.34	0.06	0.52	0.34	0.15	0.50	1.91
Saint Louis	0.42	0.14	0.26	0.18	0.11	0.36	1.47
Philadelphia	0.49	0.24	0.32	0.21	0.07	0.10	1.43
San Jose	0.26	0.03	0.48	0.16	0.15	0.30	1.38
Denver	0.35	0.03	0.29	0.25	0.09	0.29	1.30
Cincinnati	0.44	0.09	0.24	0.19	0.11	0.20	1.27
San Francisco	0.19	0.03	0.56	0.16	0.11	0.20	1.25
Washington	0.26	0.15	0.28	0.18	0.11	0.20	1.18
San Diego	0.19	0.03	0.20	0.09	0.22	0.30	1.03

in the air. It does not assess the invisible toxic gases such as oxidant, sulfur dioxide, and hydrocarbons. However, an index based on a nephelometer is useful because visibility is a property easily understood and of concern to the lay public.

In New York City the alert system[14] is based on several combinations of sulfur dioxide, carbon monoxide, and coefficient of haze. Here the combined effects are recognized, but several major pollutants are not included.

Perhaps the most comprehensive system in use by an agency is that of the Bay Area Air Pollution Control District.[15] This index sums four pollutants after weighting them as follows:

Oxidant	200
Nitrogen Dioxide	100
Carbon Monoxide	1
Coefficient of Haze	10

The weighting factors are gross attempts to order the pollutants according to the standards in Table IV. Again, not all the major air pollutants are included, but the index is said to be useful as a public communications tool. A level of 100 indicates severe air pollution.

Prodehl and Lowry[16] have developed an index which describes "geophysical potential" for air pollution. This index does not involve pollutant levels *per se* but rather temperatures at the surface and aloft are used to predict inversion severity. If a combined index included such meteorological terms, it could be used as a forecasting tool.

Table III. Emissions from 4-engined jet aircraft[5]

	PM	SO_x	NO_x	CO	HC	Total
Uncorrected Basis (pounds/flight)						
Uncontrolled	19.3	4.0	12.4	26.3	172.8	234.8
With JP-4 fuel	12.3	2.8	12.9	31.9	37.0	96.9
With "Clean" burner cans	14.9	4.0	17.4	20.4	1.1	57.8
Pindex Level (normalized)						
Uncontrolled	53	4	26	1	16	100
With JP-4 fuel	34	3	27	1	9	74
With "Clean" burner cans	42	4	35	0	2	83

Pindex, a New Combined Air Pollution Index

The overall area of research involved generalized computer simulations of cities. The goal was to evaluate the air pollution propensities of different city designs and different energy mixes. For this work it was essential to have an overall measure of air pollution. For instance, a switch to private electric vehicles or to public electric transportation would decrease oxidant and hydrocarbon levels (from reduced gasoline consumption) at the expense of increased sulfur oxides and particulate matter (from increased coal consumption). Pindex was developed to enable assessment of such trade-offs. Another integral part of this research involved comparing pollution levels in different existing cities. Again a combined index was essential.

None of the existing indexes seemed applicable. They either stressed the photochemical pollution of the West or the coal combustion pollutants of the East. In addition, it was doubtful whether coefficient of haze, used in most of the indexes, could meaningfully be related to raw particulate emissions.

The purpose of pindex then is to sum the contributions of all the major combustion emissions: particulate matter, sulfur oxides, nitrogen oxides, carbon monoxide, and hydrocarbons. In addition, provisions for oxidant as either a primary or secondary pollutant and a term representing particulate matter-sulfur oxides synergism are included.

Nitric oxide and nitrogen dioxide were lumped together to simplify calculations. In particular, problems with the changing nitric oxide-nitrogen dioxide-oxidant equilibria[9] are avoided. Without specifying the mechanism, pindex assumes that both nitric oxide and nitrogen dioxide contribute to oxidant formation. Sulfur oxides similarly were lumped together. The method for measuring particulate matter is

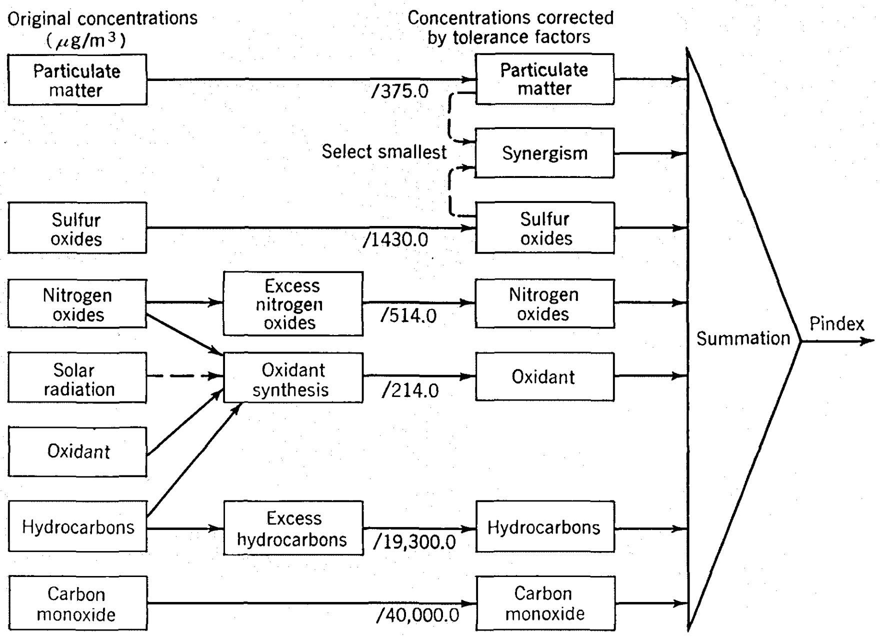

Figure 1. Pindex calculation scheme.

not specified although a weight concentration is required. Data could be derived from a direct measurement instrument such as a high volume sampler or from an indirect instrument such as a nephelometer.[17]

The calculation scheme is shown schematically in Figure 1. Moving from left to right, the inputs include the raw emissions plus solar radiation. Solar radiation influences the amount of hydrocarbons and nitrogen oxides converted to oxidant. Alternatively, oxidant can be considered an input as in air quality data. Next the revised concentrations of pollutants are weighted by their tolerance factors. Finally each corrected pollutant plus the particulate-sulfur oxides synergism term are summed to yield the pindex level.

Derivation of Factors and Coefficients

Where applicable, the proposed California standards[4] shown in Table IV were used as the bases for the tolerance factors. Levels for oxidant, nitrogen oxides, and sulfur oxides were used directly. The other factors were first adjusted to a one hour basis as described below:

Particulate Matter. The proposed standard is exceeded when visibility is 7.5 mi or less for 12 hr (below 70% relative humidity). An earlier standard was 3.0 mi or less for 1 hr. The early standard was chosen and converted to particulate concentration using the Charlson equation:[17]

$$\begin{aligned}\text{Mass concentration} &= 1.8 \times 10^6/\text{distance in meters}\\ &= 1.8 \times 10^6/(3.0 \times 1609)\\ &= 375\ \mu\text{g/m}^3\end{aligned}$$

The synergism term increases the effect of particulates when sulfur oxides are present.

Sulfur Oxides. The proposed California standard of 0.5 ppm was selected. More stringent standards have been proposed and enacted, but 0.5 ppm was retained because of the additional synergism term in pindex. This extra term in effect reduces the sulfur oxides tolerance level to 0.25 ppm when particulates are present in excess.

Hydrocarbons. California has no proposed standard for hydrocarbons; the hydrocarbon problem is complex. The mixture of organic compounds called hydrocarbons includes compounds of widely variable molecular weights, toxicities, and photoactivities. The tolerance value of 19,300 μg/m^3 was contrived for use in pindex. This value is equivalent to 6 ppm gasoline (molecular weight of 72) or 27 ppm methane (molecular weight of 16). At any rate, the tolerance factor chosen lies, as it probably should, intermediate between sulfur oxides and carbon monoxide.

Carbon Monoxide. The proposed California standard is 20 ppm for 8 hr. This value was extrapolated, using the sulfur oxides gradient, to 32 ppm for one hr.

Creation of Oxidant. It was assumed that nitrogen oxides and hydrocarbons contribute to oxidant formation on a one to one molar basis.[18] The extent of conversion is controlled by incident solar radiation (USA annual average is about 375 cal/cm^2 day). The conversion coefficient varied from 0.00024 to 0.00098 when calculated for each city listed in Table II. The arithmetic mean of 0.0006 was used in the pindex calculations.

Particulate Matter-Sulfur Oxides synergism. It seems well established that sulfur oxides are more harmful when in the presence of particulate matter.[6] Quantitative information is sparse. This effect was included in pindex by adding a synergism term assumed equal to the smaller concentration: either particulate matter or sulfur oxides.

Given information

Particulate Matter	(PM) =	143.0 $\mu g/m^3$
Sulfur Oxides	(SOX) =	123.0
Nitrogen Oxides	(NOX) =	136.0
Carbon Monoxide	(CO) =	7250.0
Hydrocarbons	(HC) =	2157.0
Oxidant	(OOO) =	43.2
Solar Radiation	(SR) =	400.0 cal/cm^2 day

Convert reactants to $\mu mol/m^3$

$$NOX = 136.0/46.0 = 3.0\ \mu mol/m^3$$
$$HC = 2157.0/16.0 = 134.5$$
$$OOO = 43.2/48.0 = 0.9$$

Determine limiting reactant for oxidant synthesis (NOX or HC): NOX is limiting

Create Oxidant

$$OOO = 0.0006 \times SR \times (\text{limiting reactant})$$
$$OOO = 0.0006 \times 400.0 \times 3.0 = 0.72\ \mu mol/m^3$$

Determine total oxidant and excess HC and NOX:

$$OOO = 0.9 + 0.72 = 1.6\ \mu mol/m^3$$
$$HC = 134.5 - 0.72 = 133.8$$
$$NOX = 3.0 - 0.72 = 2.3$$

Convert reactants back to weight basis

$$OOO = 1.6 \times 48.0 = 77.3$$
$$HC = 133.5 \times 16.0 = 2140.0$$
$$NOX = 2.3 \times 46.0 = 105.0$$

Apply tolerance factors

$$PM = 143.0/\ 375.0 = 0.381$$
$$SOX = 123.0/\ 1430.0 = 0.086$$
$$NOX = 105.0/\ 514.0 = 0.204$$
$$CO = 7250.0/40000.0 = 0.181$$
$$HC = 2140.0/19300.0 = 0.111$$
$$OOO = 77.3/\ 214.0 = 0.361$$

Determine synergism term (SYN)

$$SYN = SOX \text{ or } PM \text{ (whichever is smaller)}$$
$$SYN = SOX = 0.086$$

Sum terms to determine pindex

$$\text{Pindex} = PM + SOX + NOX + CO + HC + OOO + SYN$$
$$\text{Pindex} = 1.41$$

Figure 2. Sample calculation of pindex.

The tolerance factors are summarized in Table IV with both volume concentrations (ppm) and weight concentrations ($\mu g/m^3$) listed. The weight concentration values are used to calculate pindex. A large tolerance factor indicates high tolerability or low toxicity or unpleasantness. The values range from 40,000 for carbon monoxide to 214 for oxidant.

A sample calculation of pindex is shown in Figure 2.

Results

Pindex levels were determined for the three examples mentioned earlier.

USA Source Distribution

USA nationwide emissions, before and after adjustment by pindex, are summarized in Table I. The pindex results were normalized such that the grand total became 100%. Although not shown separately, the oxidant and synergism terms were calculated and added back into their respective precursors.

Use of tolerance factors plus inclusion of oxidant and synergism terms has completely reordered the USA air pollution problem. Carbon monoxide which dominated the source distribution based on emission weights became almost insignificant after pindexing. Particulate matter became the most serious USA air pollution problem, with sulfur oxides second, and nitrogen oxides a strong third. Despite its essential contribution to photochemical oxidant synthesis, hydrocarbons have assumed a low value only slightly ahead of carbon monoxide.

Among the sources, transportation remains a significant pollution category, but pindex lowered its ranking to third behind both industry and power plants.

Air Pollution in Individual USA Cities

Application of pindex enabled air pollution ranking of the cities in Table II. In the lower half of Table II cities are listed from highest to lowest in total air pollution according to pindex. In addition, the corrected contributions of each pollutant are shown. Chicago ranks highest with high levels of all pollutants except oxidant. Air pollution in Los Angeles is nearly as great with the low sulfur oxide level more than compensated by high oxidant.

Despite high levels of particulates, Philadelphia and Cincinnati have intermediate rankings. The equal particulate loadings (154 $\mu g/m^3$) of these two cities were not equivalent according to pindex because of the higher sulfur oxide synergism in Philadelphia. For an eastern city, Cincinnati shows a low sulfur oxides level. San Diego exhibits a typical California photochemical problem, but low levels of the other pollutants caused San Diego to rank as the cleanest city listed in Table II.

The U.S. Public Health Service published an air pollution ranking of 65 USA cities in 1967.[19] Their weighting and calculation system was based on gasoline consumption, sulfur dioxide emissions, and emission densities as well as ambient particulate and sulfur oxide levels. In all, eight categories were scored. Cities were ranked in each category and the eight individual rankings were summed to arrive at the total pollution score for each city. For example, Chicago was scored 63 in gasoline consumption, 65 in sulfur dioxide emissions, and 64 in sulfur dioxide ambient air concentration (65 is highest). When these ranks plus those for the five other categories were summed, Chicago achieved a score of 422 placing the city number two in air pollution behind the New York City score of 458.

The USPHS method coupled available census information with the most common air quality measures. Pindex can be derived from emission and meteorological data, but in this study, only cities with measurements for all six pollutants were evaluated. Rankings according to pindex and those of the USPHS system are compared in Table V. Of the cities listed, both systems put Chicago at the top and San Diego at the bottom. The largest deviation is that of San Jose. Pindex may weight photochemical pollution heavier than the USPHS method did, or perhaps San Jose received pollution from beyond its boundaries. Inverse arguments might be used to explain the deviation exhibited in the opposite direction by Washington, D. C.

Note that the USPHS system gave a relative position, while pindex gave an absolute pollution level. Pindex can be used to evaluate a single city. Table V shows a large gap between Los Angeles and the group of cities bunched between Saint Louis and Washington. The USPHS system merely attempted to put cities in their proper order. With 65 cities, large differences can be minimized and small differences magnified. No doubt the USPHS would have selected a more quantitative approach had the necessary data for a large number of cities been available.

Table IV. Derivation of tolerance factors.

	Proposed California Standards[4]	Tolerance factors (ppm)	Tolerance factors ($\mu g/m^3$)
Oxidant	0.1 ppm for 1 hr	0.10	214
Particulate matter	Visibility below 7.5 miles for 12 hr, below 3 miles for 1 hr	—	375
Nitrogen oxides	0.25 ppm for 1 hr (for nitrogen dioxide)	0.25	514
Sulfur oxides	0.1 ppm for 24 hr 0.5 ppm for 1 hr (for sulfur dioxide)	0.50	1430
Hydrocarbons	—	—	19300
Carbon monoxide	20 ppm for 8 hr	32.0	40000

Emissions from Jet Aircraft

Emission levels of jet aircraft before and after the pindex corrections are compared in Table III. On a weight basis, hydrocarbons accounted for 74% of the uncontrolled total. Use of JP-4 fuel significantly reduced hydrocarbon emissions. The use of "clean" burner cans effectively eliminated hydrocarbon emissions but increased nitrogen oxide emissions. Unfortunately, the pindex evaluation also in Table III tells us that the particulates and nitrogen oxides are the most important jet engine emissions with hydrocarbons amounting to only 16% of the total.

In the pindex comparison, use of JP-4 fuel caused significant reductions in both the particulate level and the hydrocarbon level without increasing the nitrogen oxides problem. The "clean" burner cans were less effective in reducing particulates, and 64% of the commendable hydrocarbon reduction was neutralized by the increase in nitrogen oxides. Pindex at least, suggests preference for the JP-4 fuel. It would be of interest to obtain emission data from the combination wherein JP-4 fuel was used in an engine equipped with "clean" burner cans.

As a sidelight, JP-4 fuel, largely a kerosine fraction, is in demand by the military and is in short supply. In order to supply the demand, kerosine base turbine fuel is normally extended with more volatile gasoline fractions. Use of blended fuel not only aggravates air pollution problems, but the more volatile fuel also increases fire hazard in the event of an aircraft crash.

Implications

Pindex enables one to rationally determine the contributions of individual pollutants to the overall air pollution problem. If the results are meaningful, such a tool can assist in determining air pollution control priorities. As in the examples described, priorities may be somewhat off target already. Programs to reduce carbon monoxide emissions from automobiles or hydrocarbon emissions from jet aircraft may be disappointing, even if the control goals are attained. Pindex doesn't say such pollutants should be neglected, but it points to more important pollutants which may deserve higher priorities.

Pindex evaluations showed particulate matter to be our most serious air pollution problem. In Table I, particulate matter accounted for 46% of pindexed USA emissions. Even in the transportation category, particulates amounted to one-third of the total. In Table III, particulate matter was 53% of the jet engine pindexed total. Finally, in Table II particulate matter was the major pollution problem in four of the ten cites. Despite long effort and well understood technology, particulate matter remains our most serious air pollution problem.

Concern about nitrogen oxides surfaced more recently. Current attention given to nitrogen oxides seems well warranted. The pindex evaluation revealed two reasons for the importance of nitrogen oxides. First, criteria and standards indicate that nitrogen oxides (nitrogen dioxide in particular) are potent, lying intermediate between oxidant and sulfur oxides. Second, in almost all cases, nitrogen oxides are the limiting reactants in oxidant synthesis. If the pindex model is at all meaningful, essentially complete removal of hydrocarbons must be accomplished before oxidant levels will decrease. Alternatively, any decrease in nitrogen oxides should show a proportional decline in oxidant levels.

Limitations

Pindex may be a useful tool, but caution must be used when applying it. The assumptions made and the inherent limitations of the method must be kept constantly in mind. Pindex calculations lie at the end of a long and tenuous chain which begins with emission factors or air pollution monitoring equipment. Any errors, or inaccurate assumptions may be magnified before or during the pindex calculations.

Original Data

The data evaluated in this paper were derived from emission averages and ambient air quality measurements. Emissions based on a few source measurements or upon fuel data may or may not accurately reflect nationwide averages. Further, differences in monitoring instrumentation and technique exist; results from one urban sampling station may not be directly comparable with measurements in another city. Finally, improper placement of sampling stations may result in readings which do not represent average air pollution in a given locality.

Table V. Air pollution ranking of USA cities.

	Pindex level	USPHS rank[19]
	2.20	
Chicago		2
	2.00	
Los Angeles		
	1.80	
	1.60	
Saint Louis		10
Philadelphia		3
	1.40	
San Jose		47
Denver		27
Cincinnati		19
San Francisco		35
	1.20	
Washington		18
San Diego		60
	1.00	

Photochemistry

Oxidant is the most heavily weighted pollutant in pindex. But oxidant is not directly emitted from sources, and there is considerable confusion over the factors which control its synthesis in the actual atmosphere.[9] Hydrocarbons, nitrogen oxides, and solar radiation are all involved; crude terms representing these variables are included in pindex. NAPCA criteria documents[9,10] shed light on the problem, but they conclude by pleading for more research. Thus some of the assumptions in pindex regarding photochemistry may be groundless. This possible situation should not detract from the concept of a combined index. At worst, use of pindex can show where research should be concentrated.

Tolerance Factors

In a pindex evaluation, the data are adjusted by tolerance factors; the problem is one of comparing human health, plant toxicity, animal toxicity, safety, economic, and aesthetic effects of different pollutants. A combined pollution index is only as meaningful as the standards upon which it is based. Fairly comprehensive California proposed standards served as the basis for pindex, but determination of standards is quite subjective; standards are subject to significant change in the future. Tightening or loosening of the standards in concert does not affect pindex. However, a significant revision for a single pollutant relative to the other pollutants would necessitate adjustment of the affected factor.

Certain control equipment or a city can be made to look good or bad simply by adjusting the tolerance factors. For instance, "clean" burner cans for jet engines would become more attractive if the nitrogen oxides tolerance factor were increased. Such an adjustment may be warranted, since one might assume that the dioxide was the only harmful nitrogen oxide. Nitric oxide was included on the assumption that nitric oxide was potential nitrogen dioxide.

Additional Considerations

Despite my claims, pindex can evaluate just part of the air pollution puzzle. When comparing cities, their size, population, and meteorological fluctuations must also be considered. Pindex assumes all the people are subjected to all the pollutants. The synergism term and oxidant synthesis assume that all the pollutants are well mixed. But people and pollution are not distributed uniformly in a city. The problem is three dimensional; some pollutants released from tall stacks might affect visibility without becoming part of the breathing air. Other pollutants are released at ground or "nose" level. Such considerations might reduce the pindex disparity between automobile and power plant pollution.

Conclusions

Combined pollution indexes seem to be an overdue necessity. Formulators of pollution control policy must be able to trade off one pollutant against another, always being aware of the effect of a change in one pollutant level on overall air quality.

Pindex combines the more generally accepted tenets of air pollution technology and, despite definite limitations, could be a useful tool for assessing total air pollution levels. The merit of pindex will be measured only when it is put to use. Some may consider the method to be grossly oversimplified, but complexity should be added only when shown to be necessary. Hopefully pindex is a versatile framework general enough so that it may be updated when its shortcomings become apparent and as new information becomes available. In addition to revising existing factors and relationships, provision for additional pollutants might be added in the future.

Even if results from pindex are seriously questioned, at least the tool has served the useful purpose of showing where standards might be faulty or where research is needed.

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