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AIR POLLUTION: CAUSES, SOURCES AND ABATEMENT

I. AIR POLLUTION: A DEFINITION

This nation pours an estimated 400,000 tons of pollutants into its air each day.[1] Since the discovery of fire, man has been contaminating the atmosphere at an astonishing rate. Contaminants of increasing complexity and magnitude have been the handmaidens of such technological advances as the discovery of fossil fuels, the Industrial Revolution, and the internal combustion engine.

It is the purpose of this section of the symposium to investigate the phenomenon of air pollution: the nature, sources, and effects of pollutants and techniques designed to abate this problem.

Air itself is a mixture of gases—principally nitrogen, oxygen, and argon.[2] On the most basic level, a contaminant may be defined as anything which does not appear "naturally" in the air. Such a simplistic definition is useless, however, in formulating regulatory schemes. Particularly obnoxious contaminants must be identified and permissible pollution levels prescribed. One typical statute defines an air contaminant as including, but not limited to, "dust, fly ash, fumes, gas, mist, odor, smoke, vapor, pollen, microorganisms, radioactive materials,

1. Hendrick & Cowen, *Cities Designed for Breathing*, The Christian Science Monitor, March 31, 1965, at 9. The national bill for air pollution is estimated at eleven billion dollars annually, a figure arrived at by extrapolation of the cost of smoke nuisance in Pittsburgh in 1913 after a study by the Mellon Institute. These figures appear to be generally accepted; *see Pollution Effect*, St. Louis Post-Dispatch, Oct. 21, 1968.

2. Cadle & Magill, *Chemistry of Contaminated Atmospheres*, AIR POLLUTION HANDBOOK at 3-2 (P. Magill, F. Holden & C. Ackley ed. 1956). The principal components of air are nitrogen, 78.09% by volume; oxygen, 20.95%; argon, 9.3%; and carbon dioxide, 0.30%. In addition, air contains trace amounts of neon, helium, methane, krypton, nitrous oxide, hydrogen, and xenon.

ionizing radiation, any combination thereof or any decay or reaction product thereof."[3] Moreover, before such contaminants may be given the ignoble title of air pollution, they must be present

> in such quantities and of such duration as to (a) cause a nuisance; (b) be injurious or be, on the basis of current information, potentially injurious to human or animal life, to vegetation, or to property; or (c) unreasonably interfere with the comfortable enjoyment of life and property or the conduct of business.[4]

To determine the identity and tolerance level of chemical compounds falling within this class, pollutants must be classified and their effects studied.

II. POLLUTANTS AND THEIR EFFECTS

A. *Primary Pollutants*

Polluting substances are classified as either primary or secondary. Primary pollutants are relatively stable. They are formed at a particular source, rather than by transformation and reaction in the air. Because of this, primary pollutants may often be traced to their emission sources. The latter can then be identified and regulated. The class of primary pollutants includes particulate matter, certain aromatic hydrocarbons, and various compounds—particularly oxides—formed from sulfur, nitrogen, or carbon.

1. *Sulfur Dioxide*

Sulfur dioxide (SO_2) is by far the most common and harmful sulfurous pollutant. The annual emission of sulfur dioxide by industrialized countries is in excess of 80 million tons.[5] This toxic gas respects few substances; it has deleterious effects on humans, animals, plants, and many minerals.

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3. METROPOLITAN AIR POLLUTION CONTROL DISTRICT, DEP'T OF PUBLIC HEALTH, COMMONWEALTH OF MASSACHUSETTS, RULES AND REGULATIONS TO PREVENT POLLUTION OR UNDUE CONTAMINATION OF THE ATMOSPHERE WITHIN THE METROPOLITAN AIR POLLUTION CONTROL DISTRICT (undated).

4. *Id.* Consider also the definition of air pollution as "the presence in the air of any substance that is foreign to normal air." AMERICAN FOUNDRYMEN'S SOC., FOUNDRY AIR POLLUTION CONTROL MANUAL 3 (1956). The Massachusetts Dep't of Health definition is more comprehensive, for it integrates the concept of nuisance and defines air pollution in terms of the effects which the components have on property, vegetation, and enjoyment of life, property, and business.

5. Katz, *Some Aspects of the Physical and Chemical Nature of Air Pollution*, AIR POLLUTION 97, 101 (1961).

Sulfur dioxide is highly soluble in human body fluids and, if present in sufficient concentrations, causes irritation of the upper respiratory tract. Experiments have shown that inhalation of very small amounts of sulfur dioxide gas produces shallower, more rapid breathing in humans.[6] In animal studies, exposure of rats to SO_2 in air resulted in changes in skin and fur and respiratory distress. Significant reductions in the life span of these experimental rats were directly proportional to the concentrations of gas to which they were exposed.[7]

The toxic effects of sulfur dioxide appear to be accentuated when the gas is combined with aerosols.[8] The mortality rate in London was shown to have increased significantly when smoke and sulfur dioxide were simultaneously present. This atmospheric combination has also been blamed for the deterioration in health of patients suffering from chronic bronchitis.[9] A possible explanation may be that the sulfur dioxide molecules are capable of attaching themselves to the larger aerosol molecules, enabling a deeper penetration into the lungs than with the gas alone.[10]

Sulfur dioxide is absorbed and oxidized to a sulfate in the cells of plants. The presence of this sulfate in the cells may inhibit the normal process of photosynthesis.[11] Exposures of low concentration or short duration causes plant leaves to yellow, then whiten. Higher concentrations can kill plant cells. Plants with thin leaves, such as alfalfa, cotton, and certain grains, are particularly susceptible to absorption of sulfur dioxide.[12]

Sulfur dioxide and sulfuric acid mist are also responsible for accelerated corrosion and deterioration of materials. For instance, sulfur dioxide may combine with building materials such as limestone and marble, which contain carbonates that are converted to relatively

6. Amdur, Melvin & Drinker, *Effects of Inhalation of Sulfur Dioxide by Man*, LANCET, Oct. 10, 1953, at 758-59. *See also* Amdur, Silverman & Drinker, *Inhalation of Sulfuric Acid Mist by Human Beings*, A.M.A. ARCHIVES OF INDUSTRIAL HYGIENE AND OCCUPATIONAL MEDICINE 305-06 (Oct. 1952).

7. Ball, et al., *Survival of Rats Chronically Exposed to Sulfur Dioxide*, 3 PHYSIOLOGIST 15 (Aug. 1960).

8. "The aerosol, the collective term for particulate matter suspended in the air, comprises water droplets, ice crystals, dust, and condensation nuclei." Neuberger, Panofsky & Sekera, *Physics of the Atmosphere*, AIR POLLUTION HANDBOOK 4-1, at 4-35 (P. Magill, F. Holden & C. Ackley ed. 1956).

9. Lawther, *Compliance with the Clean Air Act: Medical Aspects*, 36 J. INSTITUTE ON FUELS 341 (1963).

10. Heimann, *Effects of Air Pollution on Human Health*, AIR POLLUTION 159, 164 (1961).

11. Thomas, *Effects of Air Pollution on Plants*, AIR POLLUTION 233, 274 (1961).

12. *Id.* at 236.

soluble sulfates and dissolved by rainwater.[13] Sulfides, which corrode electrical contacts, may also be produced.[14]

2. *Carbon Oxides*

Carbonaceous pollutants exist in two oxide forms: carbon monoxide and carbon dioxide. The former exhibits an affinity for hemoglobin in the blood. This displaces oxygen from the bloodstream. At concentrations of 1000 parts per million parts of air, carbon monoxide can kill quickly.[15] The upper standard for industrial safety is generally set at 100 parts per million (ppm).[16]

Carbon dioxide, a compound essential to plant life, is not normally considered a pollutant because it is found naturally in the air in concentrations of about 300 ppm. Carbon dioxide concentration in air would have to reach 5,000 ppm before adversely affecting the human respiratory system. Nevertheless, carbon dioxide emission—presently about nine billion tons per year—is increasing at an alarming rate and presents several other serious threats.

Carbon dioxide may react with water to form carbonic acid. When this acid collects on carbonate-containing building materials such as limestone, soluble bicarbonates are formed and then washed away, causing a gradual erosion of the material surface. Carbonic may also corrode structural metals.

A long range but frightening result of carbon dioxide pollution might be the upset of the heat balance of the earth. The sun's energy passes through the atmosphere and is absorbed by the earth, heating the surface. Some of this energy is then reflected or radiated by the earth in the form of infrared rays. This radiation is absorbed by water vapor, ozone, and carbon dioxide in the air to heat the surrounding atmosphere. As the concentration of carbon dioxide in the atmosphere increases, so might the temperature of the earth. One theory attributes today's higher temperatures to this blanketing effect which keeps the earth's heat from escaping.[17]

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13. STAFF OF SENATE COMM. ON PUBLIC WORKS, 88TH CONG., 1ST SESS., A STUDY OF POLLUTION—AIR at 214-15 (Comm. Print 1963).

14. *Id.* at 215.

15. Stokinger, *Effects of Air Pollution on Animals*, 1 AIR POLLUTION 282-334 (A. Stern ed. 1962).

16. *Threshold Limit Values for 1956*, 14 A.M.A. ARCHIVES OF INDUSTRIAL HEALTH 186-89 (1956).

17. Revelle, *Dynamics of the Carbon Dioxide Cycle*, PROCEEDINGS OF THE CONFERENCE ON RECENT RESEARCH IN CLIMATOLOGY 93-105 (Craig ed. 1957).

3. *Nitrogen Dioxide and Nitric Acid*

Nitrogen dioxide is produced in great quantities by high temperature fuel combustion and the gasoline engine. As a yellow-brown gas, aerosol form is not required to affect visibility. A concentration of nitrogen dioxide in air of 8 to 10 ppm would reduce visibility to about one mile. The gas is also highly noxious. Chronic lung disease has been produced experimentally by subjecting animals to nitrogen dioxide, and a high incidence of human pulmonary ailments has been noted during exposure to this gas.[18]

Nitrogen dioxide can react with water vapor to produce nitric acid. Even small concentrations of this acid in the air cause swift corrosion of metal surfaces. Its destructive effect on grain plants is indicated by the bright yellow color of the blades, which eventually develop brown margins and spots.[19]

4. *Carcinogens*

A carcinogen is a cancer producing substance. Most of these chemicals are formed by incomplete combustion of hydrocarbons and other carbon compounds.[20] Benzo [a] pyrene, an aromatic hydrocarbon found in polluted atmospheres, is a very potent carcinogen. At least five other less active carcinogens have also been isolated.[21] Fortunately, many potential cancer causing compounds are unstable in air and sunlight and are short lived.

B. *Secondary Pollutants: Smog*

Secondary pollutants do not arise directly from a given source, but are instead the products of reactions in the air. These reactions are either photochemical (in which light is the initiating factor) or physiological (in which heat or any other physiological occurrence is the initiating factor) in nature. Because secondary pollutants are spontaneous reaction products, they are particularly difficult to trace and identify. It is felt that a discussion of the photochemical formation and effect of smog sufficiently describes the characteristics of this class of pollutants.

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18. AIR CONSERVATION COMM'N, AM. ASS'N FOR ADVANCEMENT OF SCIENCE, AIR CONSERVATION 85 (1965); Cadle & Magill, *supra* note 2, at 3-12. But *cf.* Dorn, *Statistical Study of the Acute Effects of Air Pollution*, AIR POLLUTION 507, 514 (L. McCabe ed. 1952).

19. Magill, *Sampling Procedures and Measuring Equipment*, AIR POLLUTION ABATEMENT MANUAL ch. 6, at 10, Table V (1952).

20. Heimann, *supra* note 10, at 201-03.

21. AIR CONSERVATION, *supra* note 18, at 144.

1. *Photochemical Reactions*

The photochemical reaction process begins with the absorbtion of a quantum of light energy by a contaminant molecule, such as sulfur dioxide or nitrogen dioxide. Upon absorbing this light, the molecule is excited to a higher, unstable energy state.[22] The molecule may do one of several things to escape from its excited state: (1) It may dissociate, breaking up into component parts. (2) The extra energy may result in agitated movement of the molecule causing it to collide with other molecules with such force that an inter-molecular reaction occurs. (3) The molecule may rearrange itself internally. (4) Polymerization may occur, causing the formation of long molecular chains. Any of these alternatives can produce stable molecules directly, or they may yield unstable products which undergo further, secondary reactions.

2. *Smog Formation*

The Los Angeles smog problem is probably the most well-known example of air pollution. The term "smog," coined from a combination of smoke and fog, is apparently a misnomer. Although disagreement does exist, it is generally agreed that smog is the result of photochemical reaction processes. Three typical constituents of smog are sulfuric acid mist, nitrogen dioxide, and ozone. All of these may be classed as air pollutants, and all may be produced photochemically, using either excited sulfur dioxide or nitrogen dioxide as the starting reactant.[23] Laboratory experiments which have simulated this process have resulted in compounds which bear a marked similarity to the smog found in Los Angeles.

3. *Effect of Smog*

The most common effects of photochemical air pollution are eye irritation and decreased visibility. Almost three-fourths of the people living in metropolitan Southern California say they are affected by eye irritation.[24]

An experimental study in which ozone was used as a contaminant indicated that a concentration of as little as one part per million

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22. For a discussion of these reactions in greater detail, *see* LEIGHTON, PHOTOCHEMISTRY OF AIR POLLUTION (1961).

23. Katz, note 5 *supra*, at 150.

24. Goldsmith, *Effects of Air Pollution on Humans*, 1 AIR POLLUTION 335-386 (A. Stern ed. 1962).

caused chronic bronchitis in rats.[25] The gas reaches into the lungs more deeply than sulfur dioxide and may cause hemorrhage when in greater concentrations. Guinea pigs exposed to automobile exhaust fumes became susceptible to pulmonary infection,[26] and the results were more marked when photochemical reactions were initiated in the fumes. A third experiment produced lung cancer in mice by exposing them first to lung infection and then to air which contained ozone.[27]

The ozone in smog also readily attacks rubber, causing it to crack. This action is so rapid that crack depth may be used as a measure of the atmospheric ozone concentration.[28]

In studies which exposed plants to ozone, a splotched or stippled appearance of the leaves was noted, especially in tobacco and grape plants.[29] The so-called "smog injury" to plants can be duplicated in the laboratory by reactions using either ozone or nitrogen oxides as reaction compounds. This injury is characterized by the silvered, bronzed, or water-soaked appearance of the leaves.[30]

III. Sources of Air Pollution

Although allocation of air pollution to particular sources is extremely difficult, very general estimates attribute 19% (by weight) of the annual pollution to private industry. Electric power generation accounts for about 12%; space heating, 6%; and refuse disposal, 3%. Transportation was blamed for 60% of the annual air pollution, more than all other sources combined.[31] The manner in which pollution arises from these sources is discussed in this section.

25. Stokinger, Wagner & Dobrogorski, *Ozone Toxicity Studies. III. Chronic Injury to Lungs of Animals Following Exposure at Low Levels*, A.M.A. Archives of Industrial Health 514-522 (1957).

26. Albert & Nelson, *Special Report to the Surgeon General's Advisory Committee on Smoking and Health;* Murphy, Leng, Ulrich & Davis, *Effects on Experimental Animals on Brief Exposure to Diluted Automobile Exhaust*, presented at Air Pollution Research Conference (Dec. 9, 1961).

27. Wisely, Kotin, Fowber & Trivedi, *The Combined Effect of Repeated Viral Infection on Pulmonary Tumor Induction in C57 Black Mice*, 3 Proceedings of the Am. Ass'n for Cancer Research 278 (1961).

28. A Study of Pollution—Air, *supra* note 13, at 215.

29. *See* note 19 *supra.*

30. *See* note 19 *supra.*

31. Kalika, *Can Technology Clear the Air?*, 39 Machine Design, July 20, 1967, at 19-20.

A. *Fossil Fuel Combustion*

The element carbon is common to all fossil fuels, such as coal, oil, and natural gas. Whenever these carbonaceous fuels are burned, carbon dioxide is given off. The highly toxic carbon monoxide gas is also formed, particularly when the oxygen supply is inadequate to support the combustion fully. Nearly one-fourth (by volume) of the gas emitted from blast furnaces, for instance, is carbon monoxide.[32] When the fuel contains sulfur, sulfur oxides are formed, the chief pollutant being sulfur dioxide. When the system contains low quantities of fly ash, a moderate excess of combustion air, or a fuel of high sulfur content, sulfur trioxide is also formed.[33] This latter contaminant is short-lived but particularly harmful, for in combination with atmospheric water it reacts to produce sulfuric acid. In addition, industrial combustion processes will generate nitrogen oxides, a reaction product whenever atmospheric nitrogen and oxygen are heated in a high temperature flame.[34]

Fossil fuels occur and are used in all three physical states—solid, liquid, and gas. Coal is the most common solid fuel and, with respect to pollution, the most offensive. The sulfur content of coal used for electric power production in this country averages about 2.5% but sometimes reaches the 5% level. About 90% of this sulfur content is converted to sulfur dioxide during combustion.[35] Assuming severe but realistic controls with no change in technology, a 75% increase in sulfur dioxide emissions by 1980 has been predicted, with an additional 75% increase by the year 2000.[36] Most of this sulfur dioxide would result from the use of solid fuels.

While natural gas retains most of the liabilities of other carbonaceous fuels, it is considerably "cleaner"; substitution of natural gas for solid or liquid fuels where possible could, therefore, considerably reduce the rate of air pollution from fuel combustion. Most significant is the fact that gas contains very little sulfur,[37] resulting in correspondingly low SO_2 emissions.

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32. See the summary presented in Engdahl, *Combustion in Furnaces, Incinerators, and Open Fires*, 2 AIR POLLUTION 10, Table II (A. Stern ed. 1962).

33. Krause, A REVIEW OF AVAILABLE INFORMATION ON CORROSION AND DEPOSITS IN BOILERS AND GAS TURBINES ch. 2 (1959).

34. *See* Engdahl, *supra* note 32, at 16.

35. Kalika, *supra* note 31, at 28.

36. *Id.*

37. *Id.*

Many appliances and processes unable to use natural gas can use fuel oil. Fuel oil is flanked on the pollution scale by the fossil fuels discussed above; its sulfur content and potential as a polluter are greater than those of gas, but less than coal. In a study conducted on boilers and process heaters in 1958, it was found that oil produced twice the ammonia and nitrogen oxides and almost six times as much solids and organic acids as did fuel gases.[38] Although the 1958 tests contained no sulfur dioxide data, for such a comparison of fuels, a 1950 study indicated that sulfur oxide emission is 200 times greater for feul oil than for gas.[39]

B. *Other Major Industrial Pollution Sources*

Several specific industries expel pollutants in such significant quantities that special mention should be made. One such source is the refining of petroleum. Boilers, process heaters, and decoking operations cause emissions of sulfur dioxide in huge amounts. Sampling, storage tanks, catalyst regenerators, air blowers, and high pressure equipment are sources of hydrocarbon contaminants, while catalyst regenerators and process burners also emit nitrogen oxides.[40] Daily emissions from oil refineries may average 110 tons of hydrocarbons and 100 tons of sulfur dioxide for every 100,000 barrels of crude oil capacity.[41]

The mineral and metallurgical industries has also earned its place in pollution infamy. The mining, quarrying, crushing, grinding, and transportation of minerals and metal production cause great quantities of dust and dirt to be emitted into the atmosphere. The steel industry, for example, fills the skies with dense orange clouds of gases and particles during the production of iron and steel from raw ore.

C. *Refuse Disposal*

Still another source of air pollution is the incineration of private and community waste. Traditionally this process has been carried on at remote locations to reduce the obnoxious effect of burning waste matter. As population grows, however, the amount of waste matter increases exponentially, while available sites for this process

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38. *Emissions to the Atmosphere from Petroleum Refineries in Los Angeles County*, AIR POLLUTION CONTROL DISTRICT, Final Report No. 9, at 40 (1958).

39. STANFORD RESEARCH INSTITUTE, THE SMOG PROBLEM IN LOS ANGELES COUNTY 130 (1954).

40. Elkin, *Petroleum Refinery Emissions*, 2 AIR POLLUTION 138 at 145, Table II (A. Stern ed. 1962).

41. *Id.* at Table III.

become more scarce. Therefore, the design of incinerators must assume more importance; greater capacity and efficiency is needed. The techniques of incineration have changed little; combustible waste is burned into two odorless gases—carbon dioxide and water vapor. The residual ash is usually easily collected. Yet, the heterogeneity of common community waste defies specification of its content. Consequently, the composite of effluents includes such diverse gases as methane, acetylene, carbon monoxide, and nitrogen oxides.[42] All of these may contribute to some degree to the offensive odors which are associated with municipal incinerators.

The innocent-appearing backyard incinerator may be an even more offensive source of pollution, because there is little or no attempt by the private individual to employ pollution abatement techniques. Municipal realization of the impact of thousands of daily trash fires concentrated within residential areas has lead to the promulgation of local ordinances which bar open burning, replacing this with a city-operated collection system.

D. *Transportation*

It will be remembered that transportation accounts for more air pollution than all other causes combined.[43] Within this category, automobile exhaust is the greatest contributor. Although the major reaction products of the internal combustion engine are nitrogen, oxygen, carbon dioxide, water and hydrogen, these are accompanied by both primary and secondary contaminants such as carbon monoxide, nitrogen oxides, and hydrocarbons.

The great problem of regulation of pollution from automobile exhaust arises from the fact that this is a phenomenon of confounding complexity. A direct causal relationship exists between engine operating conditions and the composition of the exhaust fumes, as well as the volume of emissions. Tests show that the concentration of pollutants is dependent upon such factors as speed, acceleration, and the type of gasoline being burned.[44] For example, a steady cruising speed produces a high ratio of air to fuel and moderate to high exhaust gas

42. *See* Katz, *supra* note 5 at 102, Table 3, for estimated rates of emission of contaminants from incinerators.

43. *See* note 31 *supra* and accompanying text.

44. Rose, *Automotive Exhaust Emissions*, 2 AIR POLLUTION 40, 58-64, Table VII (A. Stern ed. 1962); *see* Katz, note 5 *supra* at 103.

flow; acceleration produces moderate air-fuel ratios and high exhaust flow; and idling and deceleration result in low air-fuel ratios and exhaust gas flows.[45]

Testing under these various conditions, it has been demonstrated that nitrogen oxides and hydrocarbons increase in both concentration and absolute weight as the cruise speed increases. In contrast, the concentration of carbon monoxide is greatest at lower cruising speeds. Carbon monoxide and nitrogen oxides increase during acceleration, but deceleration will cause a rise in hydrocarbon content. The latter varies depending upon whether free deceleration or mechanical braking was used, while this seems not to affect carbon and nitrogen oxides.[46] The lesson to be learned from these data is that any successful automobile abatement device must be capable of efficient operation under a great variety of conditions.

In addition to the above reaction products, automobile exhaust contains particulate contaminants. These are chiefly lead compounds which derive from lead additives used to impart anti-knock characteristics to gasoline. The magnitude of this lead discharge seems to be controlled by the severity of the operating conditions to which the engine has been subjected. Lead particulate emissions are smallest after extended engine service under severe city driving conditions. The greatest concentrations occurred after an extended moderate engine driving cycle. As the car has been through an extended driving cycle of 20,000 to 27,000 miles, the lead particulate emissions may reach a level of 72-79% of the total additives in the gasoline.[47]

Although available data is less abundant for diesels than for gasoline engines, present information indicates that concentrations of carbon monoxide, nitrogen oxides, and hydrocarbons emitted from diesel engines are lower, although particulate emission is somewhat higher.[48]

Exhaust gases are not the only source of pollution from transportation. Evaporation losses from the automobile fuel tank, carburetion system, and vents in the engine crankcase are both constant and significant. Many of the organic pollutants found in gasoline are very volatile, and openings of any kind in the system increase auto pollution.

45. Rose, *supra* note 44, at 41-42.
46. *Id.* at 41, Table I.
47. *Id.* at 51-52.
48. *Id.* at 52-54; Katz, *supra* note 5, at 103.

IV. The Interaction of Meteorology and Air Pollution

Meteorology may have a profound effect upon the existence or intensity of air pollution.[49] Conversely, the presence of air pollution in an area may affect the weather of that region. These phenomena may be due to non-varying factors, such as geographical location or topography, resulting in interregional differences in pollution problems; they may also be caused by such variables as temperature or pressure, producing intraregional pollution changes. This section attempts briefly to discuss the major features of this interrelationship.

A. *The Effect of Meteorology on Air Pollution*

Whether air contamination becomes sufficiently noisome to qualify as pollution may be determined by the weather and topography of the locality. Thus, even though the quantity of emission from a given source remains constant, the degree of pollution may vary greatly. Pollutants may be dispersed either in a vertical plane, into the upper reaches of the atmosphere where harm is minimal, or in a horizontal plane over the surrounding terrain. The one of these alternatives which occurs, and the specific mechanism by which dispersion takes place, will determine the severity of pollution.

1. *Dispersive Effect of Air Fronts; High and Low Pressure Centers*

Usually, we rely upon changing air masses and fronts to disperse concentrations of pollutants. An air mass is a vast body of air having very little variation in properties in the horizontal plane over a wide land area. A front is an imaginary line of demarkation between air masses. When an air mass becomes stable, it has a tendency to stagnate; contaminants are not dispersed. In contrast, an unstable air mass results in more favorable dispersion qualities. The passing of an air front represents a change in air masses over a region; the polluted air mass moves elsewhere and cleaner air is substituted.

Low barometric pressure areas are regions of high winds, cloudy skies, precipitation, and generally bad weather. High pressure areas, on the other hand, are systems of greater stability and are characterized

49. *See generally*, for a discussion of this area in greater detail and complexity, W. P. Lowry & W. Boubel, Meteorological Concepts in Air Sanitation (1967); Air Conservation, *supra* note 18, Part 3, ch. 1, at 23-58; Helmers, *The Meteorology of Air Pollution*, Air Pollution Abatement Manual ch. 8 (1952); Wexler, *The Role of Meteorology in Air Pollution*, Air Pollution 49-61 (1961).

by light winds, clear skies, and lack of precipitation. Since pollutants tend to be dispersed or diluted by turbulent mixing, dispersion by winds, and washing by rain, high pressure systems are generally accompanied by greater concentrations of atmospheric pollution than are low pressure areas.[50]

2. *Normal Dispersion by Heating and Cooling*

Topography may have a considerable effect on pollution. For instance, the unequal heating and cooling of air over land and water masses may produce beneficial breezes. Land, and therefore the air over it, heats and cools more rapidly than water. During the day, the warm air over land rises, leaving a partial vacuum which is filled by the cooler air over a nearby ocean or lake, creating a breeze from water to shore. At night, the opposite effect occurs. The land cools quickly, the air over adjacent water—being relatively warmer—rises, and a breeze toward the water is produced which flushes the polluted air over the land. Thus, a location near a large body of water will normally help to alleviate air pollution in the region.[51]

The circulation in valleys in which the prevailing winds are of low velocity also tends to be the result of heating and cooling. The sun heats the slopes which, in turn, heat the contacting air. This air, being less dense than cooler air, causes updrafts along the walls of the valley with a compensating downward vertical circulation toward the valley center. At night, the reverse process usually occurs, helping to cleanse the air.[52]

3. *Thermal Inversions and Analogous Effects*

A thermal, or temperature, inversion is a meteorological phenomenon which may produce seriously aggravated pollution conditions. The rate at which pollutants rise in the vertical plane is a function of the variation of air temperature with altitude. If the temperature drops more than 5.4 degrees per thousand feet of altitude (called the lapse rate), warm air will continue to rise, carrying contaminants with it. When the air temperature gradient falls below the above lapse rate, a stable condition occurs and pollutants tend to remain in the air layer into which they are discharged. The sluggish air acts as a "lid" to trap the pollution below. If the temperature due to this lid actually

50. Helmers, *supra* note 50, at 6.

51. *Id.* at 6.

52. *Id.* at 7.

increases with height, instead of decreasing, the condition is called a thermal inversion.[53]

Minor thermal inversions frequently occur in many urban areas, causing a temporary intensification until the system is broken up by winds or changing temperatures. The effects of a serious inversion may be illustrated by the 1948 disaster in Donora, Pennsylvania. In the four days during which this condition persisted over Donora in October of that year, many of the residents contracted respiratory illnesses. Seventeen deaths occurred in a period during which two would have been the normal figure; nearly six thousand persons exhibited symtoms of such illness.[54]

Analogous to the temperature inversion is the situation sometimes produced within a valley. It will be remembered that an upward circulation of air along the slopes adjacent to the valley is created as heating from the sun occurs. During the night, when the surface of the earth cools more rapidly than the air at greater altitudes, the denser cool air moves back down the slopes to accumulate in the valley. With cool air above in the higher atmosphere and cool air near the ground, a pocket of warm air sometimes exists between these layers. Under these conditions, temperature measurements for a time will show the air near the earth to be warmer than that directly over it—an inversion.[55]

In cities, an analogous effect occurs in the "valleys" formed between tall buildings. The phenomenon occurs in early morning and early evening, times during which fumes from traffic are at their heaviest.[56] The result is a notable intensification of rush hour pollution.

B. *The Effect of Pollution on Weather*

The two major effects of air pollution on weather are an increase in fog and reduction in visibility. The smoke pall which overlays an urban area may block out a great deal of sunlight. Accompanying this is an even more severe screening of the ultraviolet component of the light spectrum. This loss has opposing effects. It means that less energy will be provided for atmospheric photochemical reactions which release

53. AIR CONSERVATION, *supra* note 18, at 51; Helmers, *supra* note 49, at 11; Kalika, *supra* note 31, at 21.

54. A more detailed account is found in Heimann, *supra* note 10, at 165-172.

55. *Cf.* AIR CONSERVATION, *supra* note 18, at 41-54.

56. *See* LOWRY & BOUBEL, *supra* note 49, at 49-52.

pollutants, but in contrast, ultraviolet radiation is an important bactericide.[57]

Although fog is influenced by local topography and the proximity of large bodies of water, fog frequency and duration may be partially dependent on air pollution. Condensation nuclei are small particles found in the air which provide a surface area on which water vapor may condense. These nuclei may derive from many sources, among which is particulate pollution. Because industrial pollution provides a high concentration of condensation nuclei, an industrial region may have tenacious fog more often than would otherwise be expected.[58]

C. *Stack Meteorology*

Meteorology also plays an important role in the design and construction of smoke stacks and chimneys. Designing a simple looking stack is a task of surprising complexity, and a continued refinement and development of the techniques in this area is requisite to solution of the air pollution problem. Three important kinds of factors must be considered: (1) process factors include the rate of emission; temperature of the emission products; the form of emissions—dust, fume, gas, or spray; the concentration and size of emission particles; and the physiological and nuisance effects of the pollutants. (2) Source factors encompass stack height, diameter, and configuration and the relationship of the stack to surrounding terrain and structures. (3) Finally, meterological factors must be taken into account; these include wind speed and direction, temperature, humidity, atmospheric stability as measured by wind speed and lapse rate, and topographical considerations.[59]

Under normal wind considerations the plume of smoke emerging from a stack expands at a solid angle of about twenty degrees. Buildings or obstructions adjacent to the stack will cause strongly circulating drafts of air directed toward the ground. These downdrafts affect air currents to a height of one and one-half to two and one-half times the

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57. Hand, *Atmospheric Contamination Over Boston, Massachusetts*, BULL. OF THE AM. METEOR. SOC. 252 (Sept. 1949). *See also* Blum, *Effect of Loss of Sunlight on Human Health*, AIR POLLUTION (L. McCabe ed. 1952).

58. Landsberg, *Climatology and Its Part in Air Pollution*, METEOR. MONOGRAPHS No. 4, 7 (Nov. 1951); Neuberger, *Air Pollution and Fog Properties*, AIR POLLUTION 807-11 (L. McCabe ed. 1952).

59. Helmers, *supra* note 49, at 15-16. *See generally* Davidson, *Stack Meteorology as Related to Power Plants*, AIR POLLUTION 802 (L. McCabe ed. 1952).

height of the stack. Therefore, in designing a stack for a relatively isolated plant, the column should be at least two and one-half times the height of buildings within a proximity capable of affecting the smoke plume. This will prevent air currents from forcing the exhaust to ground level too quickly. Increased dispersion is achieved with added stack height.[60]

The stack itself will cause eddy currents of air moving toward the stack, in opposition to the main flow of emissions, instead of away from it. This effect can be eliminated by increasing the discharge velocity of the expelled gases by constricting the diameter of the stack at its mouth. Then, if gas flow per unit time is to remain constant, the exit velocity of the gases must increase at the constriction.

V. Procedures and Equipment for Sampling Air

The purposes of sampling the air are two-fold: (1) to determine the degree of contamination of the air sampled; (2) to determine the types and properties of the impurities, including the possible presence of toxic substances. Sampling provides quantitative data for remedial purposes, evidence for legal use, a basis for action for control, standards for equipment, and reference points for the future.[61]

Three general approaches are used for collecting pollution data. The difference in these techniques represents a subtle shift in emphasis, making the results of the respective sampling procedures most useful for differing purposes. Open atmosphere testing measures pollution in the open air near a source of contamination. The results of this method provide an index of the state of the air actually being used and breathed in the particular area tested. An alarmingly high reading relative to other small areas being tested might result in regulation of particular pollution sources in the region which appear to be responsible for the localized effect. This neighborhood-by-neighborhood testing approach might also produce changes in zoning laws.

A second method measures emissions from particular sources by

60. *See* authorities cited in note 59 *supra*. It should be added that the field of stack meteorology is extremely complex; this makes literally all general statements subject to qualification.

61. A more detailed discussion can be found in Organization for Economic Co-operation & Development, Methods of Measuring Air Pollution (1964); Cambi, *Sampling, Analysis and Instrumentation in the Field of Air Pollution*, Air Pollution 63 (1961); Magill, *Sampling Procedures and Measuring Equipment*, Air Pollution Abatement Manual ch. 6 (1952).

taking the samples from stacks, ducts, or vents before exhaust gases are discharged into the atmosphere. This method is most applicable to the testing of industrial installations. By gathering information on emissions from each potential industrial pollution source in a particular region, authorities may regulate the level of contamination of that region by (1) setting one emission rate which no source is allowed to exceed, or (2) regulating the sources individually or by classes to insure a predictably low final level.

Finally, pollution may be measured from *all* sources by sampling "receptors." This is a method for measuring the cumulative effect of pollution, rather than the level of contamination of the air. Anything which eventually feels the effects of contaminants in the air may be called a receptor; these include such diverse items as growing crops, which[62] may be analyzed chemically to measure ingested pollutants, and structural surfaces, upon which pollutants are deposited. Testing procedures which measure effects on animals and humans have already been discussed.[63] Results of such tests necessarily indicate long-range effects and are most useful in studying the ability of growing things to survive in polluted environments and the success or failure of extended programs to combat air pollution.

The most well-known technique for testing the emission source is a visual method called the Ringelmann scale. Briefly, this system utilizes a series of five numbered cards upon which are grid formations formed by black lines, or "cross-hatching," on a white background The ratio of black to white on the cards numbered one through five is 20%, 40%, 60%, 80%, and 100%, respectively. The observer places these cards at eye level, about fifty feet away from him and as near the smoke source as possible. The observer glances at the smoke and then at the cards, noting the number on the card whose illusion of blackness most nearly corresponds to the color of smoke. Thus, the absence of any black smoke is called 0% and designated "No. 0" on the Ringelmann scale. Similarly, emissions so dense that the smoke plume appears completely black would be designated "No. 5," the blackest card in the series. These comparisons are made at timed intervals; an average of the results gives an approximate measure of the density of the smoke from that source.[64]

62. *See* Thomas, *Effects of Air Pollution on Plants,* AIR POLLUTION 233 (1961) and the text accompanying note 11 *supra.*

63. *See* notes 6 & 7 *supra* and accompanying text.

64. Cambi, *supra* note 61, at 73-74. Magill, *supra* note 61, at 18.

The Ringelmann chart is particularly important, for permissible emission levels in many legal codes are defined in terms of Ringelmann number. The system is recommended by its simplicity and directness; it incorporates serious short-comings, however, which question the wisdom of its continued use. The results may be criticized as arbitrary because they are dependent upon the subjective view of the observer. The most serious objection to the system is its applicability only to sources emitting black smoke, a poor indicator of pollution.

Although clouds of dark smoke appear to be prima facie evidence of serious contamination, it has been shown that blackness is not necessarily an indicium of pollutant content. Even the most dense clouds seen emanating from smokestacks may contain only about one percent of solids, liquid aerosols, or pollutant gases. The explanation of this phenomenon is that particle size may determine the color of smoke. Particulate contaminants within a critical size range[65] exhibit a peculiar ability to scatter light very effectively, giving the illusion of greater density and blacker color than another smoke cloud which, although lighter in color, may be far more highly charged with pollutants.[66]

Other available techniques may depend upon the form in which contaminants are emitted. For instance, bubble trains may be used to measure gaseous contamination.[67] This technique recognizes that solubilities of various gases in liquids may differ markedly. The gas is bubbled through appropriate solvents, and chemical analyses are performed on these solutions to determine contaminant concentration. Using solubility charts, technicians can then determine the pollution concentration of the original emissions. This method has the advantage that results are reproducible and not dependent on the observer's subjective judgment; simple commercial equipment is available for sampling. One restriction on the technique is that the gas pollutant must not be reactive with the solvent.

An instrument called the Smith-Greenberg impinger is a commercially available particulate determination method in portable form.[68]

65. This range includes particles from 0.3 to 0.5 microns in diameter. A micron is a measurement of length equal to one thousandth of one millimeter (0.001 mm).

66. H. L. GREEN & W. R. LANE, PARTICULATE CLOUDS: DUSTS, SMOKES, AND MISTS 96-125 (1957); Magill, *supra* note 61, at 18. For a discussion of this and other faults with the Ringelmann chart, *see* Marks, *Inadequacy of the Ringelmann Chart*, 59 MECH. ENG. 681-685 (1937).

67. Magill, *supra* note 61, at 28-29, Table XII.

68. *Id.* at 21 & 28-29, Table XII.

This device employs a high velocity jet of air that impinges on a glass plate immersed in water or alcohol. The turbulence around the nozzle of this jet causes the particles to be collected in the surrounding fluid. Then, either a direct count or chemical analysis may be undertaken to determine pollutant concentration. The method is readily adaptable for both open air and stack collection, but it requires operators of considerable skill to produce accurate quantitative results.

VI. Abatement Techniques

From the viewpoint of industry it makes good sense to ameliorate the air pollution problem. Reducing the level of emitted particles during the industrial processes helps keep plant damage at a minimum. In addition, efficient cleaning equipment which effectively removes contaminants from the air will prevent this matter from finding its way back into the work areas. This feature is of importance in industries having high quality control standards. Also, materials recovered from emissions may prove a valuable source from which to reclaim usable material. Further, the fine dust or organic matter which might be found in pollutants are dangerously conducive to fire and explosion. Efficient removal of these contaminants can greatly reduce this hazard. Finally, efficient cleansing of the air may enable this air to be recirculated into the work areas.[69]

A. *Fuel Selection and Processing*

It will be remembered that the burning of coal emits such contaminants as carbon and particulate solids, sulfur dioxide, nitrogen dioxide, and organic pollutants such as organic acids and hydrocarbons.[70] Burning a ton of coal consumes about 27,000 pounds of air,[71] and the contaminants mentioned are released. Yet, there exist some techniques for converting this inherently "dirty" fuel to a form which is essentially cleaner.

Washing and grading coal is a useful method of reducing emissions. Washing removes some of the mineral matter and the finer particles. Grading is the process of segregating the coal according to size of the pieces. Grading is an especially important method, because it allows

69. Am. Foundrymen's Soc., Foundry Air Pollution Control Manual 26 (1956).

70. *See* notes 35-37 *supra* and accompanying text.

71. Staff of Senate Comm. on Public Works, 88th Cong., 1st Sess., A Study of Pollution—Air 192 (Comm. Print 1963).

more uniform selection and burning of equally sized pieces, which promotes a more uniform passage of air to support combustion in the fuel beds. The fine coal dust which is isolated may also be burned in special equipment.

Converting coal into coke is another way to make coal a cleaner fuel. Coal is heated in the absence of air and the volatile matter is driven off and collected in a condensation chamber to be used in the manufacture of other by-products. The end product of the heating process is coke, an almost pure form of carbon. When coke is later used as a fuel, few of the original contaminants remain.

A new process being investigated for converting coal into synthetic fuels employs a technique called magnetohydrodynamics. It contemplates making a plasma of the coal, from which are extracted compounds which will allow synthesis of gasoline, crude oil, jet fuels, pipeline gas, fuel gases, and by-product electricity. Another by-product is a char residue which can be used as a boiler fuel with much of the sulfur removed, thus resulting in a fuel to help reduce sulfur dioxide pollution.[72]

One of the most widely used of the proposed solutions to the problem of sulfur dioxide pollution from coal lies in the use of low-sulfur coal; it is elementary that a smaller initial sulfur content will produce less sulfur dioxide. However, the geographical distribution of coal presents an obstacle to this solution. The United States has tremendous reserves of all types of coal,[73] and almost two-thirds of these reserves have been estimated to be low-sulfur coal,[74] but most of these are in the West where industrialization is less prominent. Increased costs from transportation expenses discourage use of these low-sulfur reserves. This and the fact that large blocks of the eastern low-sulfur reserves in the Appalachian region are held "captive" under long-term contracts to supply the needs of the steel industry emphasize the need for methods of reducing the sulfur content of the economically available coal reserves.

Sulfur can be removed from coal in several different ways. One method removes the pyritic forms of sulfur, which are metallic sulfide compounds, by first crushing the coal to a fine stage; denser pyrites may then be removed by gravity separation processes. The fine particles

72. The Oil Daily, May 29, 1967.

73. The known recoverable reserves of coal total 83% of the total for all fossil fuels; *see* Perry & Decarlo, *The Search for Low Sulfur Coal*, 89 MECH. ENG. 22 (Apr. 1967).

74. *Id.*

may also be pretreated by addition of magnetic materials and the pyrites removed by magnetic separation.[75]

Still another technique of removing the pyrites is through oxidation. This is done by introducing microorganisms such as bacteria to oxidize the pyrites. Experiments with Kentucky coal indicate that up to 60% of the pyrites may be removed from the coal after exposure to the bacteria for one week; absent bacteria, only 10% of the pyrites were removed.[76]

The problem with these techniques is that they are not yet commercially feasible. The costs associated with abating sulfur oxide emission by these methods pass a considerable increase in operating costs to the users of coal. It was noted earlier that the burning of oil and gas releases considerably less of these contaminants than does the burning of coal.[77] Thus, fuel selection may offer the most practical present solution to sulfur oxide emission from coal combustion.[78]

B. *The Automotive Problem*

Burning fuel in the internal combustion engine is the single largest source of air pollution in the United States.[79] To reduce pollution from this source, the only methods which have shown significant promise are those which employ either a change in the operating conditions of the engine or oxidation of the exhaust gases.

1. *Fuel Flow Restriction*

Probably the most promising abatement device for cars is that which restricts fuel flow to the carburetor deceleration. Many of the hydrocarbons emitted under deceleration result from incomplete combustion of the extremely rich air-fuel mixture induced into the engine. If a slow, uniform closing of the throttle can be accomplished during deceleration, the air-fuel ratio will be improved, causing less pollution from unburned compounds in the gasoline.[80] One restrictive device operates to bleed air into the carburetor during deceleration, breaking suction to stop fuel flow by reducing the manifold vacuum. Another

75. *Id.* at 24-26.

76. *Id.* at 27.

77. *See* section III(A) *supra.*

78. *See, e.g.*, Goldner, *Air Pollution Control in the Metropolitan Boston Area: A Case Study in Public Policy Formation*, THE ECONOMICS OF AIR POLLUTION 127, 150 (Wolozin ed. 1966).

79. *Id.*

80. *See, e.g.*, Kalika, *supra* note 31, at 30.

device in this category, the positive fuel shut-off system, interrupts the fuel flow by mechanical means.

2. *Oxidation of Exhaust Gases*

All abatement techniques which oxidize exhaust gases employ some form of afterburner. One device recycles the exhaust gases to a point behind the carburetor so the unconsumed hydrocarbons can be reburned in the cylinders. This technique is estimated to reduce overall automobile pollution by 30%.[81]

In addition to the feedback method, tailpipe emissions can be reduced by either direct flame afterburning or catalytic afterburning. The former uses a direct flame in a very high temperature chamber to reburn the exhaust gases. The latter method adds a catalytic compound to promote combustion, thus enabling use of lower temperature combustion chambers. Depending upon the operating conditions of the engine, devices of this type may be from 40% to 90% efficient in removing the pollutants before the gas is expelled into the air.[82] Both of these methods are costly, and the lead compounds in gasoline severely limit the life of the system.[83]

3. *Remaining Problems*

In 1966 there were 85 million automobiles in the United States. It is estimated that by 1985 there will be 120 million. Thus, even if technological developments reduce pollution from automobiles by 50%, this would merely hold total auto emissions at their present level. There is also the problem of sustaining the operating efficiency of anti-pollution devices. Evidence from auto inspections in California (where new abatement devices have been affixed to autos sold in that state) indicates that 87% of the vehicles driven more than 20,000 miles fail to meet the state requirements.[84]

The ultimate solution to the automotive pollution problem may require abandonment of the internal combustion engine, at least for commuter use. In their stead, mass rapid transit systems must be developed. In the alternative, electric cars driven by batteries or some other source of electricity may eventually be used.

The present drawback in conveyances of this kind is lack of a com-

81. *Id.*

82. This dependency of efficiency upon engine operating conditions is a result of variation of pollutant kind and concentration during different stages of engine operation. *See* section III(D) *supra.*

83. *See* Kalika, *supra* note 31.

84. *Id.* at 32.

mercially feasible power source. A prototype built by Westinghouse and driven by conventional lead-acid batteries is a two-passenger vehicle with a top speed of only 25 m.p.h. and a range of fifty miles. Ford Motor Company has estimated that the frequent stops and starts of city driving would reduce by one-half the range of electric cars relying on conventional batteries.[85]

These stumbling blocks may eventually be removed by the development of more advanced fuel cells. This is an engine-generator system in which chemical energy is converted to electrical energy. Unlike the battery, fuel cells use hydrocarbon fuels and have twice the efficiency of the internal combustion engine.[86] Although many impediments to the practical application of these concepts remain, science continues to make impressive advances. It is to be hoped that technology can win the race against pollution.

C. *Industrial Abatement Devices*

The equipment for cleaning industrial exhaust may be categorized as follows: (1) electrostatic precipitators, (2) fabric filters, (3) wet collectors, (4) inertial collectors, and (5) combustion devices. These devices are used to separate contaminants from the exhaust from industrial processes.

1. *Electrostatic Precipitators*

Basically, the function of the electrostatic precipitator is the removal of solid or liquid particles from the stream of exhaust gas. This is accomplished by passing the stream of gas between a pair of electrode plates; these consist of one plate, called the discharge electrode, which bears a high negative electrical charge and another plate which is electrically grounded, called the collecting electrode. If the difference in voltage between these plates is high enough, a corona will surround the discharge electrode. Then, as the stream of gas passes through this corona, the gas will ionize, splitting up into charged particles which behave like little magnets. The electrical field between the electrodes causes these ions to migrate rapidly toward the collecting electrode. These contaminant particles may then be removed from the collecting electrode.

Electrostatic precipitators are capable of very high efficiencies—98% on some forms of fine dust pollutants. They are capable of handling large quantities of exhaust gas even though the gas may be at a

85. *Electric Autos Make a Comeback*, INDUSTRIAL RESEARCH 21 (July 5, 1967).
86. *Design in Transportation*, INDUSTRIAL RESEARCH 57, 58 (July 5, 1967).

high temperature. Operating and maintenance costs are low. Among the disadvantages are the high initial cost of the equipment,[87] large space requirements for installation,[88] and the hazard of explosion if the dust particles are in a finely divided state. The users of these devices include cement mills, paper mills, petroleum cracking plants, and sulfuric acid plants.

2. *Fabric Filters*

Filtration methods of removing dusts, mists, and fumes from gases are among the most well-known abatement techniques. The device consists of a chamber containing many filters constructed of fine mesh material through which the air to be cleaned must pass. As collection of the particles progresses, a filter cake—deposits of filtered matter which build up on the fabric—begins to accumulate. As the cake forms, the efficiency of the cleaning process improves, because the previously trapped particles act as additional filter material. Periodically, the filters are shaken and the accumulated contaminants collected in a hopper.

Filters are used particularly for extracting particulate matter from industrial gases; the efficiency may run very high, 99.99% not being unknown. Moreover, initial installation costs are low. Maintenance costs are also quite low if the temperature of the gases passing through the filter is minimized. At higher temperatures, however, the effective life of the fabric filter material may be reduced. Another limitation on the filtration process is the requirement that the velocity of the gas flow through the filter be low. The specific pollutants to be filtered must also be identified so that a non-reactive filter fabric may be selected.[89]

3. *Wet Collectors*

Wet collectors, or wet scrubbers,[90] may be defined as gas-cleaning devices in which the separated gas, vapor, or particulate matter is

87. *See* the data presented in A STUDY OF POLLUTION—AIR, *supra* note 71, at 243-47, Table 5, which cites figures on the costs of installing abatement equipment in the Los Angeles area. For instance, to install the electrostatic precipitator on fiberboard production equipment for the plant was only $10,000; *id.* at 245. It cost $150,000 to install this kind of device on an open-hearth furnace; *id.* at 246.

88. This follows from the fact that the efficiency of this device is a function of the geometry of the precipitator; *see* Rose, Stephan & Stenburg, *Prevention and Control of Air Pollution by Process Changes or Equipment,* AIR POLLUTION 307, 327 (1961).

89. *Id.* at 318-24.

90. *See* Ranz, *Source Control by Liquid Scrubbing,* 2 AIR POLLUTION 332-355 (A. Stern ed. 1962).

dissolved or suspended in a liquid. These devices require introduction of the gas at a very high velocity. As the gas stream is forced through the scrubber, a spray of liquid (usually water) is passed through the gas, inducing turbulence. The gases and vapors are absorbed by the liquid; the mist and dust particles may impinge on the surface of the liquid and be carried off; or the liquid may wash down the walls of the scrubber where some particles have adhered. Regardless of the precise mechanism which removes the contaminants from the gas stream, the separated materials are carried off with the liquid and disposed of as the liquid is discarded. The primary advantage of the scrubber lies in the fact that it can be continuously operated, and the waste materials continually separated.

A variation on the liquid scrubber mechanisms described above are the packed towers and plate towers. In the former, the liquid is allowed to trickle through layers of coarse particles such as crushed stone or ceramic pellets. Each packing particle is covered with a liquid film, and the contaminants adhere to this film and are removed. In the plate towers, the gas to be cleansed is bubbled up through the liquid and around plates to which the contaminants adhere.

4. *Inertial Collectors*

The most common form of inertial collector is the cyclone collector. The cyclone is simple, inexpensive, can be made of almost any kind of material, and has no moving parts. The gas to be cleaned enters the device tangentially through what are known as whirl vanes—surfaces set at angles to the gas flow which impart a rotational motion to the gas flow as it is forced around them. Centrifugal force then throws the particles toward the walls of the chamber. The solid particles or liquid droplets settle through air at a slow velocity under the influence of gravity to a collecting hopper below. The swirling flow of gas, called a vortex, is reversed at the bottom of the chamber by surfaces similar to the whirl vanes and is redirected toward an outlet conduit. The smaller the diameter of the cyclone tube, the greater the efficiency since the centrifugal acceleration increases with decreasing radius of rotation.[91]

5. *Combustion Devices*

Another way of handling certain volatile contaminants is to burn them before they can be expelled into the atmosphere. Most organic and inorganic combustibles can be incinerated to harmless carbon

91. Rose, *et al.*, *supra* note 88, at 317.

dioxide and water vapor. But hazards inhere in this method of disposal. Although the effluent may consist of a single chemical compound, discharge from an industrial process is more commonly a heterogeneous mixture. Vaporized combustibles usually present a fire or explosion hazard, and combustion disposal must be carefully designed to account for the explosive propensities of the different compounds present. Account must also be taken of the relative concentrations of compounds present in the discharge gas. Combustion temperature may be reduced to some degree by introducing a catalyst to the combustion chamber, further decreasing the chance of explosion.

D. *Balancing Efficiency With Cost*

Collateral to the question of the possibility of air pollution control is the question whether it is practical to require such controls. This is an economic consideration. Assume, for instance, that a given abatement device operates with 90% efficiency; this means that 900 of every 1,000 particles could be removed from the exhaust passed through it. If this were again passed through the device 90% of the remaining 100 particles would be removed. Similarly, three such devices hooked in series could remove all but one of every thousand particles in the gas. However, the cost to remove the last 9 particles would be equal to that of separating the first 900. This gain of less than 10% in efficiency would triple operating costs.

The lesson of the above example is two-fold. We first must strive to develop pollution abatement techniques which are economical as well as efficient. Secondly, the designation of permissible air pollution levels and standards must consist of a balancing process in which contaminant concentration is weighed against the cost of its reduction.[92] These problems of economics are considered later in the symposium.[93]

CONCLUSION

This section of the symposium has attempted to survey the types, sources, and causes of air pollution and possible abatement techniques.

92. KNEESE, WATER POLLUTION—ECONOMIC ASPECTS AND RESEARCH NEEDS 17 (Resources for the Future 1962); Mills, *Economic Incentives in Air Pollution Control*, THE ECONOMICS OF AIR POLLUTION 40, 42 (Wolozin ed. 1966); Teller, *Air Pollution Abatement: Economic Rationality and Reality*, DAEDALUS 1082, 1083 (Fall 1967); *cf.* Goldner, *supra* note 78, at 149, where it is stated that there was a proposal for providing state appropriations to finance part of the District's costs. This was dropped because of anticipated opposition from areas outside the District to using state funds to support a regional problem.

93. *See* Kohn, *Achieving Air Quality Goals at Minimum Cost*, 1968 WASH. U.L.Q. (*infra*, this issue).

There can be no doubt that conscientious application of existing abatement methods would produce a significant reduction in air pollution, both in the short run and the more distant future. Industrial and governmental research teams are taking rapid strides toward the development of new pollution control techniques with greater efficiency at lower costs. Industry is not unresponsive to this problem, and it is probable that public indignation would eventually compel big business to reduce contamination arising from its plants and products. But the problem, having reached emergency proportions in many areas, is immediate. Only through effective legislative action at all levels of government will needed relief be achieved in time to avert even more serious hazards to health and comfort. The succeeding sections of this symposium explore the feasibility and effectiveness of existing and proposed legislation for air pollution control at the local, state, interstate, and federal levels.