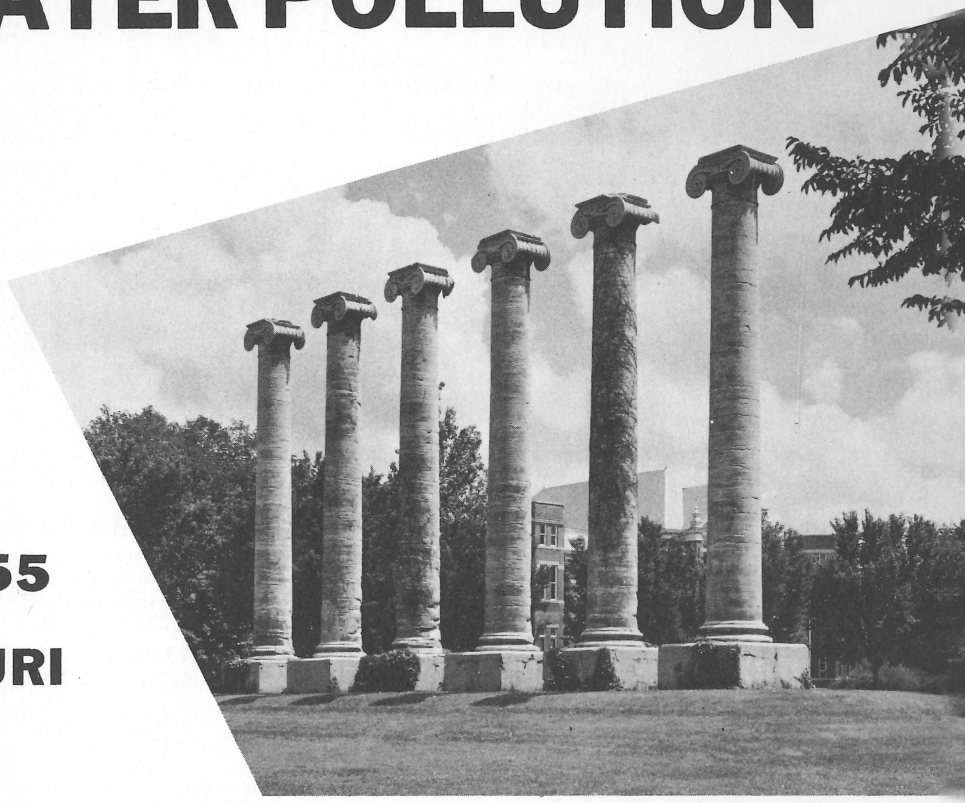
AIR AND WATER POLLUTION
Conference



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Engineering
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COLLEGE OF ENGINEERING
THE ENGINEERING EXPERIMENT STATION

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AIR and WATER POLLUTION CONFERENCE

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ADULT EDUCATION AND EXTENSION SERVICE
UNIVERSITY OF MISSOURI

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The Legal and Legislative Aspects Involved in the Pollution of the Waters of the State by Industrial Wastes

BY THE HONORABLE ROBERT C. SMITH
State Representative

YOUR CHAIRMAN has asked me to talk on the legal and legislative aspects of stream pollution. I was a little reluctant to make this talk for several reasons. In the first place, I was allotted twenty-five (25) minutes and it is a little difficult for a lawyer to discuss the legal aspects of anything in that period of time. Also, as an attorney I have an ingrained fear of chemical engineers with all of their precise formulas, since the practice of law is not something as precise as engineering, as it must deal with the unpredictable human equation. I was also a little reluctant to discuss the legislative aspects of this problem since all of our attempts to effect a satisfactory stream pollution bill have met with failure. However, since I am very much interested in the problem which is becoming more critical all the time, I was glad to appear and give what information I might have for the benefit of the organization.

First, with reference to the legal aspects of stream pollution, I would like to point out that most of our legal case law does not deal specifically with the question of stream pollution but primarily most legal disputes that have risen are with reference to the use of surface waters and underground streams. One of the first common law doctrines in this country with reference to the use of water supply was known as the "Riparian rule". Under this doctrine persons along a stream could make reasonable use of the water, as long as the use did not materially reduce the quantity and quality of the supply. This doctrine was good in theory, but there are considerable differences as to what constitutes a reasonable use.

Another legal doctrine followed in some parts of the country, which was referred to as the "Western" doctrine, which basically meant that in the dry areas of the west a person who wanted to use a stream must have a permit to do so with priority being given to the purpose and time of initial use. The biggest disadvantage of this theory was that it involved a considerable amount of red tape and tended to protect vested interests.

Neither of these doctrines actually, however, solved the problem of what policy the law should use with reference to a person who was polluting a stream to an extent that it could not be used properly by other persons. The purpose of stream pollution legislation was to set out by statute just exactly how far a person can go in polluting the waters of the state.

First with reference to the history of stream pollution legislation in Missouri; I am now serving my second term in the Missouri Legislature. In the Sixty-Seventh General Assembly I became interested in the problem particularly because of the pollution problems in the Boone County area, but also because I have felt that the waters of the state are one of Missouri's most important resources. When I was approached that session to handle the proposed bill, being new and green, I naturally accepted because I thought that everyone would feel the same way I did. After introducing the bill, however, I discovered that while there had been many such bills introduced, none had ever passed the House of Representatives and in attempting to get the bill passed through the House I had quite a battle on my hands. The active support for the bill in the Sixty-Seventh General Assembly came primarily from the Conservation Federation and the State Department of Health. The bill was opposed bitterly by the strip and tiff miners, but despite their opposition we were successful for the first time in getting the bill through the House of Representatives. However, when the bill got to the Senate it ran into what is known as "Senatorial Courtesy". The presiding officer delayed in referring the bill and finally referred it to the Judiciary Committee where no committee hearing was held. The bill therefore died when action was not taken at the termination of the five month's session.

In the Sixty-Eighth General Assembly in January of 1955, we resolved to introduce the bill earlier and to have the support better organized. An identical bill was introduced early in the session and received support from the following organizations:

Conservation Federation
Medical Association
Osteopathic Association
Veterinary Association
Federated Garden Clubs
Many Sports and Labor Groups
Missouri Farmers Association
Farm Bureau

These groups, however, did not actively push the legislation and the job of getting the bill passed devolved upon a small group of interested persons. Immediately opposition developed to the bill, primarily from a group of coal strip miners, certain oil interests, some other mining interests in the state and some question was raised by municipalities. It was apparent that the bill if drafted in its present form would not pass, so a committee substitute was written for House Bill 115.

The compromise bill basically authorized the setting up of a stream pollution control board under the Department of Health. Said board to consist of the fol-

lowing persons:

Director Division of Health
Director Conservation Commission
Commissioner of Agriculture
State Geologist—Director of Div. of Resources
6 persons appointed by governor
  2 represent industrial interests
  2 represent municipal interests
  1 represent agricultural interests
  1 represent recreational and wildlife interests

This board was to employ experts to conduct a survey as to the extent of stream pollution in Missouri and to set up standards of water purity. The bill also set up a permit procedure before large scale pollution would be approved. The bill also contained a "grandfather clause" which would allow persons already polluting the waters of the state to continue to do so, if it did not affect the public health. It also set up an appeal procedure by which an injured party could have appeal recourse to the courts of the state. Certain protection was also given to the cities of the state in that if a city was causing the pollution, they could only be required to hold an election for the purpose of financing the needed improvements.

The compromise bill eliminated the objection of the municipalities and certain of the mining interests; however the large strip mining companies, primarily in Henry County, still bitterly fought the bill. The bill, however, did pass the House of Representatives with a substantial majority. Again the bill ran into trouble in the Senate where it was late in being referred to committee and the proponents were unable to get a committee hearing on the bill and as a result it died under a five month's limitation rule.

Well, what are the prospects for the passage of stream pollution legislation in Missouri in the future? While perhaps we should be willing to concede defeat after two attempts, I am still an optimist and think there is considerable hope for the future. In the first place, Senator Jack Jones from Carrolton on the last day of the session introduced a Resolution calling for a Senate Committee to study the problem and report back at the next session. Also I think that through education more people every day are becoming aware of the problem. There have been a great number of conferences recently with reference to the problems of stream pollution. In addition, the water situation in the state is getting more critical all the time. The drouth has emphasized the need for control. Also the individual is using more water every day and the municipal uses of water are increasing. I believe also that industry is finally becoming acquainted with the problem and becoming aware that if it does not support a constructive pollution law the situa-

tion may get so bad that drastic steps will be taken that will result in too much regulation in certain quarters and that the federal government will usurp the field unless the state acts.

Well, what can this group do to help support adequate stream pollution legislation? I think that the members of this group can do a great deal to help the passage of such a bill in the state. This group of experts can do a great deal to educate the public to the need, and in working with other interested groups, your active support will be of considerable assistance. It is my hope that groups of interested citizens such as you gentlemen gathered here today will take an active part in seeing that the streams of this state are not polluted to the injury of everyone, but instead continue to be one of our greatest assets.

* * * * * *

How Serious is the Problem of Water Pollution by Industrial and Domestic Wastes in Missouri

BY JACK SMITH
Bureau of Public Health Engineering
Division of Health of Missouri

IN CONSIDERING stream pollution in Missouri our attention is first directed to the public health aspects of the problem. Inadequate disposal of domestic sewage may result in the spread of the filth-borne diseases such as typhoid fever, dysentery and diarrhea. Humans infected with these diseases excrete the organisms which cause these diseases. Well persons may become infected by direct contact with the sewage carrying such wastes. Animals and insects may also have access to contaminated water and they, in turn, may be the means by which the disease organisms are transferred to the water or food to be consumed by healthy persons. Virulent hepatitis is a disease that is suspected as being water-borne. It may be considered by some that the filth-borne diseases are no longer a problem. While the number of these diseases in Missouri is not large, typhoid fever is increasing in Missouri at the rate of 20% per year. Filth-borne diseases are increasing in many areas in the United States. In 1953 there were 52 deaths from typhoid fever. In the same year there were 49 cases of typhoid fever reported in Missouri. This increase is partly due to better reporting. It is also true that construction of sanitary sewers is not keeping pace with residential construction and as a result insanitary conditions caused by installation of septic tanks are increasing rather than decreasing.

The health aspects of industrial wastes have never been fully evaluated. It is known that some chemicals when ingested in food or water do cause illness. There is much to be learned regarding the effect of various chemicals upon our health. Atomic waste problems are increasing as fissionable material is made available for research and industrial needs. Methods of handling these wastes have not been solved. It has been said that use of fissionable material may be limited by our inability to efficiently and economically solve the waste disposal problem.

Another important aspect of stream pollution is the effect upon agriculture. Livestock will not drink some polluted waters. Animal diseases such as anthrax and cholera are transmitted by contaminated waters. Veterinarians report that cholera outbreaks in the State usually follow Missouri River floods. Sewage and industrial pollution renders water unfit for irrigation purposes. Sewage polluted waters can not be used for truck gardening. While irrigation is not of major concern at this time, there has been an increase of 100% in 1955 over 1954. In 1950 there were 10,000 acres of land under irrigation. In 1955 there are 40,000 acres

on 1,068 farms utilizing irrigation to supplement rainfall. In Bollinger County a farmer reports that a tract of land produced 100 bushels of corn per acre. By the use of irrigation on a similar tract the yield was increased to 196 bushels per acre. Agriculture is affected by the lack of sewage treatment by millions of tons of sludge that are wasted by discharging raw sewage to the streams. This sludge should be returned to the soil to provide much needed humus.

Stream pollution has a very marked effect on wild life. Sewage and industrial waste renders many miles of Missouri streams unfit for wild life. The Missouri Conservation Commission reports 1,275 miles of streams polluted at times in Missouri. Aquatic life has been virtually eliminated in 140 miles of the east and middle forks of the Chariton River. Fish kills have been reported in 16 stream reaches of the Osage basin, affecting more than 170 miles of these streams. Pollution detrimental to fishlife exists in most of the counties in the State. Pollution renders many streams unfit for irrigational use because of odors, unsightliness, and aesthetic values. The number of persons interested in wild life is increasing year after year. At the present time one out of five Missourians purchase hunting and fishing licenses.

We have outlined briefly the effect of pollution on our health, agriculture and wild life. Now let us consider how serious the problem is in Missouri. The Missouri River is polluted six-fold beyond acceptable limits for untreated water supplies. Approximately half of the people in the State use the Missouri River as a source of water supply. In a recent syndicated article by Roger D. Greene it was stated that of the ten most polluted areas in the United States, two of these areas existed in the State of Missouri. This is a record we can view with alarm and should provide emphasis to our programs for abatement.

Three-fourths of the people in the State are served by sanitary sewers. Of this number one-third are served by adequate sewage treatment plants. The strength of sewage is often referred to as population equivalent. This means that the amount of sewage either domestic or industrial, is equated to the amount of sewage contributed by one person in one day. The population equivalent of raw sewage discharged to Missouri streams in 1953 amounted to 1,637,396. This index does not measure all pollution—only the organic pollution.

While the figures stated above indicate there is much work to be done, we can take some satisfaction from the progress that has been made in recent years. Sixty waste treatment plants have been constructed and placed in operation in the past five years. Most Missouri cities on tributary streams have realized their responsibility and have constructed or have taken definite steps to provide sewage treatment. St. Joseph, Missouri has adopted a plan for sewage treatment and has agreed to have construction under way by January, 1959. Kansas City, Missouri

has secured plant sites and is actively cooperating through the Conference of Mayors to establish a Metropolitan Authority which is a first step in the solution to the sewage problem in the metropolitan area. The Metropolitan St. Louis Sewer District has been established for the specific purpose of solving the pollution problem created by numerous small sewage plants with the ultimate objective of serving the entire area with the minimum number of treatment facilities. All Missouri and Mississippi River cities have been advised of the need for sewage treatment. For the Missouri River definite dates have been established for compliance.

Industrial waste treatment plants have been installed at the following places:

TWA Overhaul Base, Platte County
Lake City Arsenal
Adams Dairy
Emma Creamery
Sugar Creek Refinery
McDonnell Aircraft
Ford Motor Company, Claycomo
MFA Fertilizer Plant, Joplin
and a government installation at Weldon Springs.

Missouri is shifting from an agricultural economy to increased industrial production. The Division of Resources and Development statistics reveal the following: Missouri is second only to Michigan in producing automobiles. We are second only to Wisconsin in the production of cheese. We are first in lead mining and 15th in coal production. Missouri is seventh in production of chemical products, third in leather and 14th in primary metals. In the year 1954-55 1,973 new industries were responsible for creating 89,834 new jobs. The taxable value of this expansion program amounts to $750,465,000. The annual wages of employees amounts to $232,400,000. A breakdown of the industrial growth from January 1 to December 31, 1954 shows the following:

	% total manufactured goods
Food products	4.74
Pulp, paper, paperboard	3.16
Printing and publishing	16.06
Chemical and allied products	30.18

From 1948 to 1952 new and expanded industrial investments ranged from $86,400,000 to $331,680,507.

Pollution control is everybody's responsibility. In order to conserve our water supplies it is essential that all interested persons actively participate in securing effective legislation. The time for this action to begin is now.

* * * * * *

The Nature, Prevention and Abatement of Liquid Industrial Wastes*

By Glen J. Hopkins,
Sanitary Engineer Director *

Today, more than ever before, the Nation is water conscious. During our country's early development, the abundance of this vital natural resource made it a "forgotten" one. Its importance was far over-shadowed by immediate concern with expanding land frontiers, searching out mineral reserves, and putting to use the vast forest resources.

Serious water problems have developed in many areas during the past few years, placing water resources in the national spotlight. This does not mean that there has been a lessening of the total water supply. Averaged over the years, the total supply remains fairly constant through rain and snow, and this constant total supply is more than sufficient to meet total requirements for the foreseeable future. Distribution and inferior quality are the causes of shortage. These problems will be intensified as continued population growth, industrial expansion, technological developments, higher living standards, urbanization, recreational pressures, and similar trends of our modern life make ever greater demands on our water supply.

Water resource development and pollution control are inseparable, for pollution is no respecter of water use. All beneficial uses of water are subject to the damaging effect of pollution. Conversely, abatement of pollution can redeem for use water now denied us. In parts of our country the only "new" water available for meeting critical needs is that which can come from cleaning up and reusing waters now despoiled.

The same factors that have created increased water demand—population growth, recreation pressures, industrial expansion, urbanization, and technological developments—have intensified water pollution. Population has more than doubled since 1900—from 75 million to 165 million—and is continuing to increase at a rate of about 2 million a year. This means a population of 210 million by 1975. Industry has grown 700 percent in the past 50 years; over half of this increase has occurred since 1940. Present production is expected to again double by 1975.

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Technological changes have brought new pollution problems. The rapidity of those changes during recent years has not permitted time in which to adjust and develop counter measures. Complex wastes resulting from the manufacture and use of the many new products of our expanding industries have presented real problems.

These industrial waste problems are far too complex for discussion on a national basis. On a local or state basis they may be discussed more precisely, with emphasis upon those industries of area importance. As Missouri's industry in the past has been closely allied with agriculture, industrial waste problems were principally related to disposal of organic wastes, for which conventional treatment practices are usually appropriate. Recently, considerable increase has occurred in Missouri's chemical industry, with the result that organic wastes, not amenable to reduction by conventional processes, are more commonly encountered. A natural consequence of this trend is increased emphasis on waste reduction through improved housekeeping, waste prevention, process changes, and by-product recovery rather than waste treatment per se.

Developments in the beet sugar industry is an excellent example of reduction of wastes by by-product recovery. By providing continuous diffusers instead of the battery type diffuser previously used, it becomes practical to dry spent beet pulp and pulp press water for livestock feed. This eliminates pulp press water and pulp silo drainage from the waste stream. Likewise, Steffen's waste is now concentrated at many beet sugar refineries and shipped to a central point for processing as monosodium glutamate and livestock feed. These two steps transfer more than half the total waste load from unwanted pollution to consumer goods, and at some profit. By providing sedimentation and incidental biological treatment for lime wastes and flume water through lagooning in simple earthen structures, the over-all pollution load can be reduced about 90% at reasonable annual cost. Conversely, conventional treatment would be both impractical and of prohibitive cost.

Waste prevention and salvage is good business, and, at the same time, good waste control. There is a growing philosophy in industry to "keep it out of the sewer" if it can be reclaimed and sold even at marginal profit. Actually it may be cheaper to sell a by-product at a loss than to reduce it through a costly disposal facility.

Packinghouses, when faced with an abatement program, usually find it good business to salvage blood, meat scraps, paunch manure, and other materials for use in tankage or fertilizer, rather than to treat these materials in a waste disposal plant. With the reduction accomplished by conscientious housekeeping, waste prevention, and waste salvage, packinghouse wastes may be treated at reasonable

cost by conventional processes. Plant scale experiments now being undertaken with anaerobic digestion hold much promise for the larger plants. Lagoons have been used successfully in South Dakota for small packing plants and slaughter houses not served by municipal sewers. The Missouri River is the last frontier where large meat packing establishments are permitted to despoil a water resource by gross discharge of waste materials with little attention to programs of waste salvage or prevention. Even on the Missouri River this practice is in its final stages as the five states concerned with the lower Missouri River have requested all industries to cooperate in a uniform abatement program.

Food Processing

Waste disposal from vegetable and fruit canneries present a special problem in that they are short term seasonal operations having sizable waste loads. Good housekeeping practices and screening precludes much waste material from the sewer. These materials may be disposed of by sanitary fill or in some cases, for hog feed. Lagoons and irrigation systems are utilized for disposal of the residual wastes. Both ridge and furrow and spray irrigation are used, although spray irrigation is gaining favor. The principal requirements for spray irrigation are suitable land within economical pumping distance; cover crop to aid absorption and cut down erosion, and a receiving tank with pumps and necessary piping. The wastes are sprayed on the land while still in fresh condition. Applications of three or four inches per week are common for agricultural lands, although absorptive soils will handle a heavier loading. Experience in New Jersey indicates that forest lands will absorb much greater loadings than will normal crop or grasslands.

Dairy Wastes

The dairy industry is important in Missouri, and problems of disposal of dairy wastes are frequently encountered. While these wastes are several times stronger than domestic sewage, conventional treatment as aeration, activated sludge and biological filters can be successfully modified to cope with the problem. Aeration is gaining favor. An experiment in Emma, Missouri, appears to confirm observation in North Dakota that dairy wastes can be successfully handled in lagoons. Because of its low cost and minimum operation requirements, this appears particularly feasible for the smaller plants not connected to a municipal system. The Emma experiment is the first lagoon known to handle dairy wastes without benefit of an appreciable admixture of domestic sewage.

Chemical Industry

For the chemical industry the job of reducing pollution is primarily one for the chemist, with emphasis on process modifications to reduce the volume of

wastes and control their character. With wastes reduced to a minimum, programs of treatment, salvage, or control are greatly simplified and made less costly. This field poses challenges to research, engineering analysis, economics, and design, and each industrial development constitutes an individual problem.

Some research is now being done on the handling of increased amounts of these wastes in municipal plants, with controlled release instead of batch dumping. Much additional study is indicated before this practice can be fully exploited.

Metal finishing wastes are usually reduced by chemical methods. pH control is used to break oil emulsions, speed reactions, prevent formation of dangerous gases, and to precipitate certain metallic constituents. Acids or alkalies are handled by neutralization. Cyanides are frequently oxidized. Sulfites are used to reduce hexavalent chromium to trivalent chromium, a substance of low toxicity which can be precipitated with lime treatment. Ion exchange is being used to recover metals from plating wastes. While this seems to be a very effective means of pollution control, equipment and operating costs may limit use of this method to large operations. Retention lagoons have also been used, particularly for smaller operations and for residual wastes surviving other waste reduction measures.

Oil Wastes

Oil processing and dispensing operations frequently discharge various oil-bearing wastes to sewers. Metal working wastes also contain machine oils, spent soluble oil coolants, cutting oils, and emulsion cleaners. Oil-water gravity separators can be effective in removing free oil from the waste stream. However, if the oil is in emulsified form, the emulsion must be broken to make gravity separation effective. Frequently employed for this purpose are pH control through successive stages, flocculation, flotation and other adaptions of conventional treatment. Lagoons are coming into increased use in this area, both as a principal control measure through retention, and as a polish treatment following more conventional practices. Biological treatment may be used for residual oil wastes after appropriate pretreatment.

Acid Mine Wastes

The acid waste-disposal problem of the mining industry is unique, compared with most other industries, in that the water pollution does not end when mining is discontinued. Abandoned and inactive coal mines are the principal sources of uncontrolled mine drainage. Acid water production is begun shortly after mining commences, and is still flowing from many of our oldest mines long after mining operations have been abandoned. The fact that acid discharge continues indefinitely is a major stumbling block to effective control of this pollution. Operations to stop the acid flow, or to treat it, may cost more than the value of the

acreage on which the abandoned mines are situated. Thus, the problem usually reverts to the state in which the property is located.

It has long been accepted that iron disulfide, or pyrite, commonly found in coal deposits oxidizes to form ferrous sulphate and sulphuric acid. Chemical reaction from pyrite to acid requires both oxygen and water, and control efforts have long been directed to eliminate or minimize the presence of one or both of these essential elements. While this type of control is very expensive, considerable progress was made in Pennsylvania, Ohio, West Virginia, and other States, principally under public works projects.

The amount of acid produced by mine drainage is phenomenal. In West Virginia alone it was estimated that mine drainage produces 600,000 tons of sulphuric acid each year. In Pennsylvania, Maryland, Ohio, Kentucky, Illinois, and Virginia, acid mine drainage is a principal industrial waste problem. The problem in Missouri has never been fully evaluated.

Damages from acid mine drainage are real and tangible. In small and large streams the effect is to reduce alkalinity, lower pH, increase hardness, and add to the water objectionable iron, manganese, aluminum, and sulphates. The water is rendered expensive and difficult to treat for municipal or industrial uses. It is highly corrosive to iron and steel structures, and damaging to concrete. Streams are rendered unfit for fishing, swimming, and boating. Normal biological processes in the stream are substantially altered or destroyed. The flushing action of heavy rainfall may extend damages far downstream.

Missouri's acid mine drainage problem results principally from strip mines. Strip mine operators are cognizant of the problem, and control is a matter of considerable concern to them. As with any other industrial waste, a corrective program, to be effective, must be practical. Neutralization of the acid is impractical, and was deemed infeasible even with prices prevailing in the depression. Controlled release of mine acid during periods of high runoff is applicable only in a very few cases. Any reasonable approach to the problem must be directed to preventing the formation of acid, rather than by treating it after it has formed. By carrying out recommendations appropriate to a given situation, strip mine operators can do a great deal to eliminate or reduce acid drainage from their mines.

A much publicized research program at John Hopkins University has identified chemical agents which apparently prevent the formation of acid from sulfur-bearing materials. The initial tests were carried out in the laboratory with "sulfur balls" and other sulfuritic material from coal mines. Limited field tests have been made at a selected mine in West Virginia. The work has been carried out by the

Interstate Commission for the Potomac River, and much more study is necessary to fully evaluate the applicability of this discovery to field conditions.

The nature of chemical agents has been a closely guarded secret, presumably because of patent considerations. In the practical use of this type of inhibiting agent, the major problem is to get it into contact with sulfuritic materials in the mines.

The three elements of acid making are sulphur-bearing materials, air, and water. The real basis of preventing or reducing acid formation in coal mines is to keep air and water out of contact with the sulphur-bearing materials. To keep these elements separated, surface water can be kept out of mine workings. This keeps drainage to a minimum and reduces acid formation. Of all the things that can be done to prevent acid formation, keeping water out of the pit is now the most practical and effective. If water does not get in, it won't drain out loaded with acid. Surface water can be kept out of the strip pit by providing adequate surface drainage away from the pit. Ditches or diking may be necessary, but experience in Pennsylvania has demonstrated that it is feasible to preclude surface drainage from strip pits.

Underground water from seepage or springs should be collected at its source and bypassed to a point of discharge outside the stripping area. If a stream or watercourse is encountered in the stripping process, steps should be taken to prevent the stream water from entering the strip cut. Usually this can best be accomplished by bypassing certain portions of the coal vein. Insofar as possible every precaution should be taken to insure that stream waters continue to flow in their natural and undisturbed channel, instead of entering into the strip pit and coming into contact with spoil materials.

If water is allowed to collect in pools, in the pit or on the spoil banks, acid will have opportunity to form. Spoil piles should thus be graded so that surface water will run off rapidly and not collect in pools and soak into the spoil bank.

Waste coal shale and other sulphur-bearing materials should not be permitted to accumulate on the pit floor, as it is subject to oxidation and the resulting formation of acid. Acid-forming refuse materials should be covered with a compacted fill. The collection and covering of sulphur-bearing material keeps out air and moisture, thus preventing acid formation.

The most important aspect of prevention is the back-filling of the last cut of the stripping operation. The final pit should be completely backfilled and all spoil banks leveled off and graded. A proper job of backfilling, graded to shed water, will stop the formation of acid and reduce the total amount of drainage discharged. The more quickly backfilling can be completed, the more effective

the measure.

Under the most recent regulations in some states, mining companies are required to back-fill excavations as soon as mining is completed, and to contour the back-fill as nearly as possible to the original topography of the mined-out area. This procedure has greatly reduced the quantity of acid mine drainage from strip-mining operations.

Another method, recently developed in Pennsylvania, is to have the back-fill operations follow closely on the mining operations. By this method the small amount of coal and refuse left on the mine floor is covered with earth before the sulfuritic substances are oxidized to soluble compounds.

In Indiana, Illinois, Ohio, Pennsylvania, and West Virginia, and probably other states, a good many of the strip-mined waste lands have been back-filled and planted with trees or made into pasture lands, and quite a few have been developed into parks and recreational areas. This eliminates the unsightly appearance of many strip-mine areas, and renders some of the land agriculturally productive and other sections useful for recreational purposes. This might be classed as "the modern trend" in handling the strip-mining problem.

Backfilling pits and leveling of spoil banks is good land conservation, as it permits use of land for recreational and certain agricultural pursuits. Otherwise this land is destined largely to be a wasted resource. It is regretted that agricultural programs geared to reclamation of deteriorated lands have not given greater attention to reclamation of abandoned strip workings. Particularly so, inasmuch as the problem of stopping acid discharge from long abandoned workings can be approached only as public problem. Recreational, agricultural, and water pollution control agencies have reason to work cooperatively in developing a permanent and satisfactory solution to the problem of acid drainage from abandoned mine workings through programs of land restoration and reclamation.

For mines now operating in Missouri, and certainly for those yet to be initiated, it seems that the interest of the State might well justify a requirement that appropriate spoil leveling and pit backfilling be accomplished for future operations. This action has been taken in several states, notably Pennsylvania, and has been found to be quite effective. Such action might well be considered in Missouri either as a part of an over-all program of water pollution or in separate legislation dealing with strip mine operations.

In final analysis, however, the problem must be considered as one of pollution. Its solution will include consideration of economic feasibility, practicability, effect upon mine operations, and the over-all interests of the State. Because of the difficulty of spelling out in legislation rules sufficiently comprehensive to

cover all the factors essential to a realistic program, it would seem to be appropriate to give this responsibility to a water pollution control board of broad interest and representation, having considerable discretion and freedom of action in the development of a general water pollution control program geared to reflect the needs at hand as well as the capabilities and interest of the industry concerned.

This general approach has been provided for all waste control operations in water pollution control legislation considered by the Missouri Legislature in recent years.

* * * * * *

A Survey of the Areas of Interest in Air Pollution Problems

BY JEAN J. SCHUENEMAN*
Public Health Engineer

WHAT IS AIR POLLUTION?

AIR POLLUTION is not something that can be clearly defined in a few words that will be acceptable to everyone. A dictionary definition of air pollution might be: The act of defiling, soiling, or staining the air, or making it unclean. However, depending upon the interests of the person using the term, various connotations are attached to it.

To define air pollution, it is logical to first define pure air. Many people think of pure air as that mixture of gases found over uninhabited or rural areas of the earth, consisting of nitrogen, oxygen, carbon dioxide, and water vapor, and perhaps, some include the rare gases. However, in these areas, there have always been other materials in the air, generally in smaller amounts, including a wide variety of gases and particles resulting from the life processes of animals and vegetation, wind, volcanic and wave action, forest fires, and lightning. These materials may or may not be called pollutants. If pure air can be defined, then air pollution can be construed as the addition to the air of any materials which will change its original composition.

The concept of air pollution that is in widest use by people involved in air pollution work, is one that considers the addition of any materials into the air as a result, directly or indirectly, of the activities of man as air pollution.

In the definition of "excessive" or "significant" pollution the variety of opinions is even greater. Suffice it to say that these differences of opinion involve such things as the past and present atmospheric environment of those defining the term; the effect the pollutants may be having on health, vegetation, and materials; the annoyance, if any, the pollutants are causing; the physical and mental condition of persons exposed to the pollution; the importance and reputation of the sources of pollutants; the cost of controlling the pollution, and who must pay for such control; and what others have said about the matter. This divergence serves well to point out the necessity of coping with individual problems as the circumstances and feelings surrounding them would indicate.

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What Events Fostered Interest In Air Pollution?

Interest in air pollution probably extends back to the early days of man on earth when he may have been dislodged from his cave by the smoke of a fire he or one of his associates kindled. Certainly, as man learned of the benefits of living close to other men in villages and cities, he also began to learn some of the disadvantages, among them being odors of food and fecal wastes improperly disposed of. Many old laws recognized the necessity of action to regulate such activities. Perhaps they were not known as air pollution control laws, but they did contribute toward the purity of the air. Formal air pollution control probably began with legislation regulating the use of fuels in England in the thirteenth century. As cities in this country grew larger, interest in the purity of the atmosphere over them became evident and studies were undertaken to find out what was in the air and what settled out of the air. Investigations were made into the sources of the pollution, and legislation to regulate those thought to be at fault was enacted. This interest began increasing markedly shortly after 1900. Early studies include those done on the amount and composition of particles in the air over 14 United States cities in 1931-33 by the U. S. Public Health Service (1), and the sulfur dioxide study done in a number of cities in 1936-37 by the Air Hygiene Foundation, located in the Mellon Institute (2). Many other studies were carried out by individual cities and interests. They were designed largely to determine dustfall, suspended particles, and sulfur dioxide.

In the Meuse Valley in Belgium in 1930, 80 people died and hundreds were made ill by breathing air heavily laden with an accumulation of atmospheric impurities.

In 1938 the City of St. Louis accelerated its activity in smoke control, and by carrying out a vigorous program accomplished a quick, impressive improvement in the air over St. Louis. Other cities soon followed this example.

About 1945, Los Angeles citizens became concerned about irritation of their eyes and reduction of visibility by atmospheric pollution, and since then a great deal of effort has been expended in that area to determine the nature and behaviour of the "smog" and to bring about its control.

In 1948, the Donora, Pennsylvania air pollution incident occurred. On this occasion, 20 people died, and nearly 6,000 were made ill. (3)

The impetus of the foregoing, added to by the Poza Rica, Mexico, incident in 1950, when 22 people died and 320 were hospitalized (4), and the London smog incident in December 1952, when 3,000 deaths in excess of the expected number were reported (5), led to a tremendous increase in interest and activity in all phases of air pollution work.

WHAT ARE THE EFFECTS OF AIR POLLUTION?

Air pollution causes certain effects on humans, animals, vegetation and materials. It can be said with certainty that air pollution can make people ill or cause their death under certain circumstances. The London, Donora, and Meuse Valley air pollution incidents substantiate this. Another type of air pollution, caused by failure of usually satisfactory industrial and transportation equipment, has caused illnesses and deaths to persons close to the source of pollution.

Irritation of the eyes during periods of high pollution concentrations has been observed rather frequently in Los Angeles, California, and on occasions elsewhere, because of the general pollution level existing over large areas. There is no doubt that such irritation of the eyes and respiratory system occurs in the immediate vicinity of many particular sources of pollution throughout the country.

The question of whether constant exposure to ordinary pollution levels, excepting the "incident" type of exposure, can cause illness, tissue changes, bodily malfunction, or premature death, has not yet been answered in a conclusive manner. Perhaps studies now in progress or in the planning stages will better illuminate this problem.

People are also subjected to psychological stresses and nuisances by air pollution situations. These effects arise from disagreeable odors, reduced visibility, the dreariness of a "smogy" day, dirtiness and damage of property, fears of the possible effects of pollution on health, and possibly the discomfort of unpleasant attitudes toward the parties involved in the discharge of pollution.

Injuries to the health and deaths of animals caused by pollution that have been reported are largely due to ingestion of forage that has been contaminated with atmospheric pollutants. The preponderance of investigative work has been on the effects of fluorine on animals in the vicinity of phosphate rock processing plants and aluminum production plants. Some instances have also been reported of deleterious effects from contamination of forage by lead and arsenic in the vicinity of smelters.

Much convincing evidence has been presented of damage by pollution to vegetation. Many cases have been described showing decreased growth rates, marking of foliage, and killing of plants. In certain polluted areas, some species of vegetation formerly raised will not grow because of the pollution. Some of the common materials causing damage to vegetation include sulfur dioxide, manufactured illuminating gas, hydrofluoric acid, chlorine, hydrogen sulfide, and ammonia. Recent work in Los Angles indicates that the rather extensive damage to vegetation occurring there is due, at least in part, to the reaction products of

ozone and either unsaturated hydrocarbons or automobile exhausts. (6)

Air pollution may cause other undesirable effects such as the blackening of building interiors and exteriors; soiling of clothing, furnishings, shelf stocks of merchandise, drapes, and curtains; accelerated corrosion of screens, metal roofs, gutters, wires, fences, auto body steel, and other metal articles; more rapid failure of house and automotive paints, fabrics, rubber articles, and building materials. Economic losses caused by air pollution are quite large and have been estimated at $1,500,000,000 per year in the United States. (7)

WHERE DOES AIR POLLUTION COME FROM?

A number of the types of activities engaged in by man that contribute to the contaminants in the atmosphere are listed in Figure 1. There are many others, and it can be seen that the sources cover a broad range of operations.

FIGURE 1

Some Sources of Atmospheric Pollution

Coal, oil, and refuse burning	Oil refineries	Flour milling
Grey iron foundries	Coffee roasting	Fertilizer manufacture
Blast furnaces	Paper pulp mills	Phosphate rock processing
Open hearths	Wood waste disposal	Alfalfa dehydration
Bessemer converters	Railroad locomotives	Coke plants
Asphaltic road mix plants	Marine vessels	Spray painting
Cement manufacturing	Rendering plants	Paint drying
Automobile, truck and bus exhausts	Meat packing plants	Quarrying
Calcining	Stockyards	Refuse dumps
Crushing	Garbage handling	Food processing
Grinding	Sulfuric acid manufacture	Wood working plants
Varnish manufacture	Gob piles	Ore smelters
	Cotton ginning and waste disposal	Streets and road dust
		A myriad of other chemical processes

WHERE DO AIR POLLUTION PROBLEMS OCCUR?

With the wide variety of pollution sources indicated in Figure 1, few localities can be considered free from some degree of pollution. Pollution problems can be generally divided into two classes. One is the type involving a broad area with a high general level of concentrations, typical of large cities and even of medium-sized and small cities with unfavorable topographic or meteorological features or with great pollution production. In such cases, pollution sources are so numerous and widespread that the entire mass of air over the city is polluted. The majority of cities of more than 100,000 population have or have had this problem. The other type of pollution problem is the localized one, wherein only a small area in the vicinity of a source or group of sources is affected. This type of problem can occur anywhere, in rural areas or in the largest city.

A recent report by Stern (8) of a survey in the State of New York has indicated the extent of air pollution problems. Some of the results he reported are shown in Figure 2.

FIGURE 2

Severity of Air Pollution in Urban Communities (Cities and Villages)
(From Reference 8)

Total Population in Thousands	Number in Study	Number of Communities in which the Air Pollution Problem is: Major	Minor	Negligible	Percent of Communities in which the Air Pollution Problem is: Major	Minor	Negligible
Over 25	30	21	8	1	70	27	3
10 - 25	40	16	13	11	40	33	27
5 - 10	54	5	20	29	9	37	54
3 - 5	50	6	30	14	12	60	28
1 - 3	127	6	36	85	5	28	67
Total	301	54	107	140	18	35	47

WHAT FACTORS AFFECT THE DISTRIBUTION OF POLLUTION IN THE AIR?

Pollutants discharged into the atmosphere are dispersed in diverse fashions, depending on the meteorological conditions prevailing, the manner and amount of discharge, and the characteristics of the surfaces over which the air is flowing, including both minor surface characteristics such as buildings and gross characteristics such as hills, mountains, valleys, and so on. Two general types of problems are of interest. One is the diffusion of the effluents in the vicinity of a particular source. The other is the distribution over a broad area of pollutants from a number of sources.

Distribution of material from particular sources in the nearby area is influenced by such factors as the mass rate, velocity, temperature, nature and height of the emission, horizontal wind speed and direction, horizontal and vertical wind turbulence, vertical temperature gradients, and the configuration of nearby buildings and topographic features. Considerable work has been done to develop means of estimating what distribution can be expected of materials from a source, using both mathematical and experimental approaches. Work has also been done on the development of techniques and criteria for the use of data obtained in a wind tunnel, using models, to predict the behavior of full sized installations.

Knowledge of the distribution of materials from sources under varying meteorological and stack discharge conditions can be used in selecting sites for new plants so as to minimize the risk of creating an air pollution problem. It has also been used to establish source operating patterns in certain cases whereby large emission rates are permitted only when meteorological conditions are favorable for dispersion.

The distribution, accumulation, fall-out, and removal of pollutants from a large number of sources in relation to a broad area such as a fair sized city are influenced by such factors as mass rate, location and nature of emissions into the air and speed, direction and turbulence of the wind at various elevations, as affected by vertical temperature gradient or lapse rate and its diurnal variations, uplift or subsidence in pressure systems and near frontal surfaces, convection currents, precipitation, cloud cover, and sunshine. Topography is also a significant factor. A very considerable amount of work has been done on evaluation of the relationships between these variables and pollution levels, and some few studies have yielded valuable information. However, it is not yet possible to state these relationships in most areas with a satisfactory degree of assurance.

WHAT PROVISIONS ARE EMBODIED IN POLLUTION CONTROL LAWS?

Air pollution control laws have been adopted in more than 80 localities in the United States, and in addition to these specific laws most cities have nuisance or general health laws which can be applied to some air pollution situaations.

Air pollution control laws may contain provisions covering the items indicated in Figure 3.

FIGURE 3

Types of Provisions that may be included in Local Air Pollution Control Laws.

A. "Whereas" clause
B. Definitions
C. Prohibited emissions
   1. Dense smoke
   2. Fly ash
   3. Nuisance
   4. Others
D. Creation of control agency
E. Establishment of control administrator and his duties
F. Creation of air pollution board, with powers and duties
G. Hearing procedures
H. Appeal procedures
I. Restrictions on fuel usage
J. Procedures and policy concerning variances
K. Means of dealing with existing equipment and facilities immediately after enactment of the law
L. Permit requirements
M. Inspections and fees
N. Penalties
O. Authority for administrator to seal non-conforming units
P. Separability clause
Q. Administrator's inspection authority
R. Conflicting law repeal
S. Effective date

Some laws provide authority for the administrator or board to make rules and regulations and leave many specific provisions out of the law.

Air pollution control laws are rightfully quite variable in nature. Each locality has different desires, resources, problems, and legislative arrangements, and the law should be drawn up accordingly. Careful drafting of these laws is of considerable importance, and the best competencies possible should be brought to bear in undertaking it.

In addition to air pollution control laws and nuisance laws, zoning laws sometimes have provisions restricting the location of facilities that could cause pollution problems. This important adjunct can be particularly helpful in preventing localized problems and may aid somewhat in controlling the area-wide situation.

Five states, Oregon, California, Massachusetts, New Jersey, and Kentucky, have enacted laws concerning air pollution matters, and it is expected that more will follow.

In the past summer, the 84th Congress passed a Federal law concerning air pollution. Its main purposes are to provide for Federal technical assistance to states and communities, research by Federal agencies, and the support of air pollution research by others.

WHAT IS BEING DONE TO CONTROL AIR POLLUTION?

A great deal of effort is being expended by governmental bodies to bring about the control of air pollution. There are more than 110 state and community agencies in the country now, and more are being added.

Local agencies range in size from a one-man staff, and he may be part-time, to the large Los Angeles County unit consisting of about 250 people. The cost of these programs, according to a survey made by the Air Pollution Control Association in 1952, of cities spending over $5,000 per year, (9) ranged from $5,050 to $644,889 per year. The latter figure was for the Los Angeles County program, which has now more than doubled its expenditures. The per capita cost to taxpayers in the localities ranged from 2 cents to $1.42, with the usual value being in the 5 to 15 cent range.

Although only five states have specific air pollution control legislation, many more are handling air pollution matters in conjunction with other programs. As with local laws, nuisance and perhaps other statutes on the state level can be applied to air pollution matters.

The Federal Government is spending about one and three quarters of a million dollars this fiscal year on work that is purely air pollution in nature including Federal research and technical assistance programs and in support of research by others. Work is also being done on air pollution in conjunction with other Federal projects.

Local programs are characteristically concerned primarily with the actual control of air pollution sources through educational and enforcement procedures. Many units also engage in projects to determine what materials are in the air,

and a few engage in or support basic and applied research on the various phases of the problem.

State programs are characteristically concerned with assistance to local agencies in carrying out their programs and also with appraisals of the state-wide aspects of the problem. Some enforcement and educational work is carried out in certain areas, and a few state agencies engage in or support research work.

In addition to the foregoing governmental activities, many universities, institutes, foundations, and other groups are doing research, as well as quite a number of industrial concerns and industrial and commercial associations. Interested citizens' groups are playing their role. Industrial, commercial, utility, and transportation concerns, private citizens and governmental agencies are spending large sums of money in actually reducing the amounts of material discharged into the air. The annual cost of industrial and governmental control programs was estimated as up to $100,000,000 in 1949 (7).

HOW CAN WE FIND OUT WHAT POLLUTION IS IN THE AIR?

The determination of the pollutants in the atmosphere is often a tremendous task, complicated by the wide variety of materials possibly in the air, the extremely low concentrations that may be of intereset (in the parts per billion range in some instances), possible reactions going on in the air, the large variation in concentrations which occur with time, variation in meteorological factors, and location, and so on. However, many means of determination and indication have been developed and used.

Basically, if the results obtained are to be of value, a number of factors, not involved specifically in the sampling or analytical means employed, must first be considered. These include the reason for taking samples, the environmental conditions that may prevail while sampling (such as human activity), meteorological patterns and the effects of their variation, where to sample, how many samples to take, when to sample, degree of precision required, and so on. These having been considered, a sampling means, a schedule, and an analytical procedure can be selected.

Probably the most widely used measure of pollution being emitted into the air is the Ringelmann Chart. This is a series of sheets of paper on which are placed black lines of graded widths. In use, it is placed sufficiently far from an observer to make the charts appear as varying shades of grey. These are then compared to the emission from a stack. Some of the instruments used in the measurement of particulate matter are shown in Figure 4.

FIGURE 4

Some Types of Instruments Used in the Measurement of Particulate Air Pollution

A. Smoke Density
1. Ringelmann Chart
2. Umbrascope
3. Smokescope

B. Settled Dust Collection
1. Wide mouthed cans or jars
2. Adhesive surfaces

C. Collection of Suspended Particulate Matter
1. Filters
   a. Paper
   b. Fiberglas
   c. Cloth
   d. Asbestos
   e. Membrane filters
   f. Soluble filters
   g. Other fibers
2. Electrostatic precipitators
3. Thermal precipitators
4. Small cyclones
5. Wet impingers
6. Dry impingers
7. Detectors of light scattering properties

Once collected, the particles can be weighed, analyzed chemically, counted, sized and inspected by optical and electron microscopes, in order to get information as to their physical and chemical properties. The collecting techniques, of course, must gather the material in a state suitable for the examinations desired. Often an exact and complete analysis is not possible.

Gaseous pollutants may be collected by passing air through such devices as bubblers, freeze-out traps, activated carbon, silica gel, and other adsorbents, chemically treated papers, and evacuated containers. Analyses of the material is undertaken by a wide range of techniques ranging from colorimetric titrations to complex spectrographic analyses.

Settled dust may be collected in wide mouthed jars or cans, or on any sticky material such as cellophane tape or petrolatum. After collection, the material can be weighed or analyzed chemically in any suitable manner.

Some automatic or continuous recording instruments have been devised that collect and examine material from the air. These include devices for the determination of sulfur dioxide, oxidants, nitric oxide, nitrogen dioxide, carbon monoxide, hydrocarbons and particle size and count. They are generally quite expensive, ranging in cost from $2,000 to $10,000.

After results have been obtained, adequate regard must be given to possible reactions taking place in sampling, false results due to interfering materials, the sensitivity and efficiency of the techniques employed, and the statistical significance of the results obtained.

The observed reactions of plants, animals, and humans may also be used in obtaining some indication of the materials present in the air. However, this field is quite complex and only slightly developed.

WHAT MEANS CAN BE EMPLOYED TO CONTROL AIR POLLUTION?

Means for the control of pollutants being discharged into the atmosphere can be provided for virtually all sources and to practically any chosen degree of efficiency. However, at some point the expense may outweigh the benefits derived. In air pollution control programs, in the final analysis, it is usually some segment of the public that benefits by any control measures employed, but it is also the public who pays for the control program, since the increased costs incurred by the source individual or organization are presumably reflected in the prices charged for any product or service rendered, or in taxes or the cost of maintaining a home. In a few cases, control measures pay for themselves and even show a net gain through value of the material collected or improved efficiency of operations. The basic question to answer in deciding upon a control program, therefore, is how much the public wants to pay for cleaner air. Decisions on this question are sometimes difficult, particularly in cases where only a few will benefit by the control of a situation and the costs involved in control are large.

Control measures, for purposes of this discussion, may be divided into three groups; changes in process materials, equipment, or operating technique; collection at the source; and dispersion. In the first group are such measures as the burning of a different fuel in the equipment being used and the rather impressive reduction in smoke emissions that can be achieved in some cases, by proper firing techniques as compared to improper techniques. Another example is the conversion from the use of cupolas to reverberatory furnaces in grey iron foundry practice. In general, consideration may be given to using different equipment, fuels, raw materials, operating practice and care, temperatures, pressures, velocities, times, and so on, in closely examining an operation to determine whether the same job can be done with the creation of smaller amounts or less offensive air pollutants. In many cases such a remedy is the most economical and practicable solution to the problem.

The collection of any material at its source requires first that it be confined in a duct or other enclosure so that it may be passed through a collector. This may involve the use of hoods and other enclosures.

Types of devices that may be used to collect gases and particulate matter are shown in Figure 5.

Before selecting a collector or train of collectors, a careful examination must be made of such factors as particle size distribution, density, shape; chemical nature, corrosiveness, and loadings of the material being handled; efficiency required; transport and disposal of collected material; operation and maintenance costs; and others.

FIGURE 5

Types of Equipment That May Be Used for the Control of Atmospheric Pollution

Particulates	Gases
A. Settling chambers	A. Scrubbers
B. Cyclone and other centrifugal	1. Packed towers
C. Impingers	2. Ejectors
D. Mechanical centrifugal	3. Spray chambers
E. Filter bed	4. Bubble cap tower
F. Fibrous filters	B. Adsorbers
G. Scrubbers	1. Activated carbon
1. Spray chambers	2. Silica gel
2. Wet cyclones	C. Incinerators
3. Packed towers	1. Plain
4. Venturi-cyclonic	2. Catalytic
5. Ejectors	D. Odor counteractants and masking agents
6. Wet impingers	
H. Ultra-sonic	

The third method of control, dispersion, consists of some means of discharging the pollutants at such a rate, height, velocity, and temperature that they will not, under the meteorological, topographical, and ground surface conditions which prevail, cause any undesirable effects of their own or in combination with other materials in the air.

In localities where general area pollution is of concern, dispersion of pollutants will seldom be the whole answer to a problem, for such dispersion does not remove the material from the large area but merely spreads it through a larger volume of air. However, if the material is unique in the area and causes no undesirable effects of its own or in combination with other materials in the air, the technique may have application. For abatement of unsatisfactory conditions in localities where broad area problems do not exist the technique often finds application.

Zoning programs, as described elsewhere herein, may also be considered as a control mechanism.

SHOULD A CONTROL AGENCY BE ESTABLISHED AND WHAT SHOULD IT BE?

In some localities the question of establishment of an air pollution control agency is or will be under consideration. Some of the factors that should be taken into account in so doing are mentioned here.

As stated previously, the air pollution situation differs with each locality. Some approaches may be suitable in a number of areas, but before applying techniques used in other areas to the one under consideration, a careful study of all of the factors surrounding the original establishment of the technique must be made to insure that it is applicable in the new location.

The first step in studying the possible establishment of a control program is

to appraise the general magnitude, character, contributing sources, and area of influence of situations which may be significant problems. Approximate answers to these questions can be obtained by interviewing reliable persons of the community, reviewing the human activity carried out in the area in a general sense as related to pollution, examining the topography and meterorological records, estimating the growth of the area, and careful discussion with persons in newspaper work, chambers of commerce, health departments, civic work, and legislative offices.

If the need for a control program, possibly of a preventive nature, is indicated the next step is to determine how much control is reasonable, knowing that the more control that is sought, the more the operation of the control agency and control measures will cost, and that both too much and not enough control are undesirable.

The third step is to examine existing legislation, administrative organization, and personnel and monetary resources. Based on this, and the other previously mentioned studies, a program can be planned including legislation, administration, financing, and operation.

SOURCES OF ADDITIONAL INFORMATION

Since it has been necessary to cover the material very briefly, a few references are listed for additional information. These are not the only valuable works in the field by any means, but they provide a sufficiently broad coverage of the field for starting purposes.

Davenport, S. J. and Morgis, G. G., *Air Pollution. A Bibliography, U. S.* Bureau of Mines Bulletin 537, Washington 25, D. C., 1954.

Manufacturing Chemists Association, Inc., *Air Pollution Abatement Manual.* Washington, D. C.

Heimann, H., Brooks, H. M. Jr., and Schmidt, D. G., *Biological Aspects of Air Pollution, an Annotated Bibliography,* Federal Security Agency, Public Health Service, Washington D. C., 1950.

McCabe, L. C., editor, *Procedings of the United States Technical Conference on Air Pollution,* McGraw-Hill Book Co., New York, 1952.

American Chemical Society, "Symposium on Processes and Equipment for Air Pollution Control", *Industrial and Engineering Chemistry,* Vol. 47, No. 5, May 1955.

SUMMARY

A review has been presented of a number of considerations entering into the total picture of the air pollution field of interest. Practically all details were omit-

ted in order to accomplish the purpose of this paper, which was to present an overall review of the matter, and to provide a starting point for further exploration into the field.

REFERENCES

1. Ives, J. E., et al. Atmospheric Pollution of American Cities for the Years 1931 to 1933. Public Health Bulletin No. 224, Washington, D. C., 1936.
2. Air Hygiene Foundation, Inc. Concentrations of Volatile Sulfur Compounds in Atmospheric Air. Special Research Series, Bulletin No. 1. Pittsburgh, Pa., 1938.
3. Shrenk, H. H., Heiman, Harry, Clayton, G. D., Gafafer, W. M., Air Pollution in Donora, Pa., Public Health Bulletin No. 306, Washington, D. C., 1949.
4. McCabe, L. C., and Clayton, G. D. Air Pollution by Hydrogen Sulfide in Poza Rica, Mexico, Arch. Ind. Hyg. Occup. Med. Vol. 6, pp 199-212, 1952.
5. Ministry of Health, Mortality and Morbidity During the London Fog of December, 1952. Reports on Public Health and Medical Subjects, No 95, London, H.M.S.O., 1954.
6. Stanford Research Institute. The Smog Problem in Los Angeles County. Western Oil and Gas Association (Jan., 1954).
7. Gibson, W. G. The Economics of Air Pollution. Proceedings of the First National Air Pollution Symposium, Pasadena, Calif., Nov. 10-11, 1949.
8. Stern, Arthur C. Air Pollution Control: Administrative Needs and Patterns. Paper to First International Congress on Air Pollution, New York City, March 1, 1955.
9. Air Pollution Control Association. Statistical Tabulation of Air Pollution Control Bureaus, United States and Canada. Pittsburgh, Pa., 1952

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What One City Has Done To Control and Reduce the Smoke Problem

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THE FIRST legislation aimed directly at the reduction of atmospheric smoke in St. Louis was enacted in 1893. It declared the emission of dense smoke within the city limits to be a nuisance and provided for a fine of ten to fifty dollars for violators. For four years the city enforced this measure and collected fines under it, until one offender balked and eventually carried his case to the State Supreme Court. Here the ordinance was declared invalid since no enabling legislation existed at the state level to give the city power to declare smoke to be a nuisance per se.

After this the ordinance was amended, in 1899, by striking out the invalid wording.

However, in 1901 the state legislature enacted a law which stated the emission of dense smoke in a city of 100,000 or over to be a nuisance. That year and the next, and again in 1904, St. Louis passed additional anti-smoke ordinances under that general authority. Although there was considerable subsequent agitation from time to time no new legislation was passed until 1913. In that year two ordinances were enacted, one of which is of interest today in view of the current activity in Los Angeles County and elsewhere, in that it prohibited the emission of "dense smoke or nauseous vapors" from motor vehicles. (1) The anti-smoke law of that year was replaced by a new one in 1918 and that in turn by another in 1924.

Now each of those ordinances differed in some respects from its predecessors and apparently was thought to be an improvement over anything before attempted. Yet they all depended upon the same means for abating smoke; they declared it to be a nuisance and its emission beyond certain limits of time and density to be punishable by fines.

A little reflection will convince one that no hope of ridding a city's atmosphere of smoke is held out by a program of that kind. Adhering strictly to his duties, the enforcement official should bring all offenders to the city courts. In a city as large as St. Louis, this is physically impossible. It is also psychologically distasteful. The chief smoke inspector in 1906 expressed this very well in a published defense of his office. "It has been our idea", he wrote "that while in deal-

ing with violators of the smoke ordinance, we were dealing with men who might be considered, technically, 'criminal', we at the same time had to do with the best citizens of St. Louis, the makers of the city and its prosperity, the manufacturers and business men whose money was invested here and whose interests were identical with the best interests of the whole city." (2)

But suppose some highly industrious and callous enforcement official did keep a steady procession of smoke offenders receiving justice before the bench. What then had been accomplished toward cleaning up the air? Paying a fine does not turn an average citizen into an expert fireman. He returns to his same equipment firing the same fuel just as ineptly as before his day in court. It was this fact that turned so many smoke abatement officials to the hopeless task of teaching all the firetenders in a city how to burn smokelessly an inherently smoky fuel. As late as 1924, the St. Louis Commissioner of Smoke Abatement publicly announced that his policy would be to educate firemen and engineers in stoking rather than to stimulate prosecutions. (3)

Strangely enough, all the while St. Louis was experimenting with one ineffective ordinance after another the city had before it the plan for the solution of its smoke problem. This solution had been presented even before the first anti-smoke ordinance was written. It was embodied in the report of a committee appointed by Mayor Edward A. Noonan to study the smoke question, submitted in 1892. (4) Nearly a half-century later the report of another committee appointed by another mayor for the same purpose would so nearly parallel this one in argument and recommendations that it will be worthwhile to take time to read a few quotations from the earlier one.

"Under the head of domestic fires may be included open grates, stoves, furnaces and ranges for heating or cooking, whether used in private houses, hotels or public institutions. In the abatement of the smoke nuisance this class is more difficult to deal with than any other for the reason that small quantities of fuel are burned at a time, in most cases slow combustion is required and excessive quantities of air are necessarily employed. The high temperature, therefore, so important for the combustion of the separated carbon which causes the smoke, is not readily attainable. It may be said also that this class of fires is very commonly in charge of people quite ignorant of the first principles of combustion and not particularly noted for their appreciation of the advantage derived from the application of intelligent effort. Any material improvement in the use of bituminous coal with a view to reducing the smoke due to domestic fires is not to be expected. The only complete solution of the problem so far as this class of smoke producers is concerned must be sought in the use of smokeless fuels such as anthracite coal, coke and gas."

Especially interesting are this committee's recommendations. After the adoption of anti-smoke legislation and the amendment of existing boiler inspection laws, they proposed:

> "III. That steps be taken at once to diffuse as thoroughly as possible among the public, especially housekeepers, manufacturers and railroad officials such facts and figures and right information concerning these as may aid them in the early general adoption of smokeless fuels so far as they may be applicable, as:
> A. In domestic establishments, anthracite, coke or fuel gas.
> B. In industrial furnaces, other than boiler plants, coke, fuel gas or oil.
> C. For all switch engines and such as operate within the City limits, coke."

(Note that they did not suggest that steps be taken to teach the people how to burn bituminous coal smokelessly, but rather that they be brought to the use of a smokeless fuel.)

The first really constructive legislation toward smoke elimination appeared in the ordinance of 1937. (5) This ordinance was drawn up under the direction of Raymond R. Tucker who had left the mechanical engineering department of Washington University to become secretary to Mayor Bernard F. Dickman. It was similar to preceding ordinances in many respects but it differed from them in one very important provision—it required that all coal used or sold for use in the City, if under 2 inch top size, had to be washed to an ash content of not over 12% on a dry basis.

Illinois coal is a fairly high sulphur coal. Washing it to this near an approach to its inherent ash content got rid of practically all of this sulphur which was not chemically combined. As this measure became fully operative, its effect upon the city's atmosphere became most noticeable. The smell and taste of sulphur, which had plagued the citizens all winter long for years, completely disappeared.

The washing clause served another useful purpose. It was attacked in Federal District Court by a coal producer who argued that it interfered with interstate commerce. The court found that the enactment of such a measure was entirely within the police powers of a city and thus insured the legality of St. Louis' first step toward control of the fuel burned within its borders.

Under the ordinance the newly formed Division of Smoke Regulation bent its efforts toward eliminating the smoke pouring from the chimneys of factories, commercial buildings, apartments, locomotives, etc. These efforts were not without success—but they did not eliminate the smoke palls. At least a million and a half tons of high volatile coal were being burned each winter in the heating plants and stoves of residential property against which no action was being taken.

This coal was being handled by the least skilled firemen in the most poorly adapted equipment. That it accounted for a disproportionate amount of atmospheric smoke seemed to be without question. One had only to tour the city during the morning and evening hours when fires were being tended, and witness the smoke trailing out of virtually every one of the city's thousands of chimneys, to convince himself of that.

For those who never visited St. Louis in those days, it is difficult to describe what the city was like under a smoke pall. Grimy clouds obscuring the sun, near-zero visibility, street lights and automobile headlights burning until noon, inside passages of the nostrils as black every evening as though the day had been spent in a coal mine, and always the characteristic odor and taste of bituminous coal smoke. "A city in decay" said one of the country's leading weeklies in January, 1940. (6)

But by the time that periodical appeared on the newstands events were already moving toward a solution. The preceding month (December, 1939) Mayor Dickman had appointed the St. Louis Committee on Elimination of Smoke. Under the chairmanship of James L. Ford, Jr., a banker, not a member had any connection with the fuel or heating business. Only one, Mr. Tucker, was an engineer. The mayor charged the committee with finding a workable remedy for the blighting smoke palls and promised that whatever they proposed, no matter how drastic, he would do all in his power to have it enacted into law. They reported to him in February, 1940.

During the forty-eight years elapsed since Mayor Noonan's committee, the picture with regard to burning bituminous coal had completely changed. Years and years of research had been spent on that very subject. Automatic stokers were now readily available on the market in sizes to serve all needs, from the largest central station to the smallest bungalow. The bright dream of 1892 had become the practical solution of 1940. This committee agreed with the first one that nothing worthwhile would be accomplished as long as the people were permitted to burn high volatile bituminous coal indiscriminately and, in their own words, made the following recommendations.

> "1st—That all those burning a high volatile fuel must employ mechanical fuel burning equipment to burn it smokelessly.
> 2nd—That all others must use smokeless fuel." (7)

These recommendations were enacted into law that spring (8) and went into enforcement the next heating season. The line of demarcation between a high and low volatile coal was set at 23% on a dry basis. Smoke in the city's atmosphere the first winter of the new ordinance, according to figures of the United States Weather Bureau, was reduced 72.5%. This reduction has been ex-

ceeded each succeeding year except one, during the war when war-time restrictions made enforcement difficult. By now the results achieved in St. Louis have been so widely heralded it will not be necessary to dwell on them here.

A great deal has been said about laws and ordinances in this paper but I would not have you think that the St. Louis achievement was a piece of legislative legerdemain. Neither should the impression be given that because this program worked in one city it will work anywhere. The plan of action followed in St. Louis was simply an application of the principles that must be followed whenever or wherever a nuisance is to be controlled.

1st—Find out the origin and cause of the nuisance.

2nd—Evolve an effective and workable plan to correct the trouble causing elements.

3rd—Put the plan into operation.

In the case of St. Louis, step two involved enacting an ordinance, and, step three, its enforcement. Enforcement meant not only patrolling the town to see that the people got the proper kind of fuel and used it. It meant reaching out into the coal fields of the east coast and of Arkansas and Oklahoma to sell those producers on St. Louis as a market for their wares in sufficient quantities to fill the city's coal bins. It meant convincing a well established and complacent retail industry that they must find new sources of supply at higher prices and higher freight rates and sell this fuel to their customers at higher retail prices. It meant standing firm against the antagonism—even the threatened boycotts—of a next door neighbor which for generations had been an important buyer of the goods of the city's industries. It meant enlisting the support of the press and radio, of civic associations, of influential citizens and, through them, of the general public. It meant working with this industry and that to help them adapt their processes to the requirements of the new law. It meant successfully defending the program before the State Supreme Court. (9) It meant the formulation of rules for the installation of mechanical fuel burning equipment— coal, oil and gas—and insisting upon strict adherence to these rules in every installation. It meant all these and more.

Today, I am sure, the skies over St. Louis are as clear as those over any industrial community of comparable size in the country. The finishing touches to this remarkable transformation were brought about by two developments for which the anti-smoke program cannot take direct credit. Yet I believe that both of these, while socially and economically inevitable, were hastened and aided in their spread by the desire for clean air which has been built up by the air pollution control movement, not only in St. Louis, but all over the United States.

One was the widespread distribution of natural gas as a heating fuel. At the

close of World War II about 5% of St. Louis' single family units were heated with gas. Today it is safe to say 40% to 45% use this fuel. Likewise the number of oil burners has more than doubled in the same period. No estimate is available of the number of industrial plants and large commercial buildings which have replaced coal with one of the above fuels, but the number would be impressive.

The other development has been the almost universal acceptance of the diesel locomotive. With the exception of one local passenger train in and out of the station during the night, all of the passenger, freight and switching service in St. Louis is diesel powered. This means the elimination of over 500 steam locomotives formerly busy in our yards every day. A steam engine is as strange a sight in St. Louis today as the first diesels were just fifteen years ago.

Still remaining in our air to cause complaints are dust and odors. The situation with regard to flyash from boiler plants is under control but several localized sources of atmospheric dust still exist. Whether or not we can get the air as free of particulate matter as the general public would like it to be is questionable. But we can and must try.

(1) St. Louis, Mo. Ordinance No. 26874, approved February 8, 1913.
(2) Smoke Abatement, A Study of the Police Power as embodied in Laws, Ordinances and Court Decisions, by Lucius H. Cannon, St. Louis Public Library, August-September, 1924, p. 223.
(3) Ibid. Page 227.
(4) Report of the Special Committee on Prevention of Smoke, St. Louis, March 8, 1892.
(5) St. Louis, Mo. Ordinance No. 40999, approved February 11, 1937.
(6) Life-January 15, 1940.
(7) Report of St. Louis Committee on Elimination of Smoke, Feb. 24, 1940.
(8) St. Louis, Mo. Ordinance No. 41804, approved April 8, 1940.
(9) Ballentine vs. Nestor, 164 S. W. (2) 378.

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HOW SERIOUS IS THE AIR POLLUTION PROBLEM IN MISSOURI?

BY LOUIS F. GARBER
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OUR INDISCRIMINATE use of the atmosphere as a disposal area for waste products of combustion, solid and gaseous by-products of industry, and the innumerable mists, fumes, gases, vapors, dusts and debris produced by our community way of living has resulted in a realization that this vast disposal area, just like our streams, has a limited capacity for such wastes. This concept of the atmosphere as a part of a sewage system has required adjustment in the planning done by state, county and municipal officials in discharging their responsibilities, more emphasis by industry in the fields of public relations and community planning and has created additional factors to be considered by designers and consultants.

It has, for example, required a considerable change in the application of basic principles in the field of industrial hygiene or occupational health. The purpose of this phase of a public health program is the prevention of occupational diseases. This objective could often be accomplished by limiting the exposure of the workman to toxic materials through the use of exhaust hoods, ducts and fans to remove the material from the working area. The only concern for final disposal of such material was that the discharge point be located so as to prevent the wind from blowing the material through open doors and windows back into the work room. Stacks extended above the building roof usually attained the desired result, and consequently we in Public Health were at times responsible for the action taken by management which resulted in the creation of neighborhood atmospheric pollution. We must now consider the effect of discharging this material and if considered necessary, the provision of collection devices to remove the objectionable material. Some caution is required in the selection of suitable collectors, as the use of wet collectors will produce a sludge, which in turn produces a disposal problem. As we learned this morning, the discharge of sludge into streams is an important factor in the current status of stream pollution in the state.

At the present time, we in the Division of Health do not know how serious the atmospheric pollution problem is in Missouri. The problem is relatively new, the significance of atmospheric pollution on the health of the public is not fully known and consequently the responsibilities of the Division have not been defined.

A study of sulfur dioxide concentrations in a number of United States cities made about 1935 by the Industrial Hygiene Foundation under the direction of the Mellon Institute included St. Louis and is believed to be the first detailed study of atmospheric pollution in the state. It is not known what part, if any, the results of this study contributed to motivating the action taken by the City which was described by Mr. Carter. Mr. Schueneman also made a study of sulfur dioxide concentrations in the city in addition to numerous local neighborhood studies of other pollutants during his employment with the St. Louis City Division of Health..

At the present time, Kansas City, St. Louis City and St. Louis County are participating in an atmospheric pollution study under the general direction of the United States Public Health Service. These are organized as area studies and include Kansas City, Kansas and East St. Louis, Illinois, and consist of the simultaneous collection of 24 hour samples on special filters and with equipment furnished by the Public Health Service. The analytical determinations which at present include total particulate loading and organic matter per cubic meter of air are done by the Public Health Service at Cincinnati and are, it is believed, subject to change as additional information on the problem of atmospheric pollution is obtained. One obvious omission in this program is the lack of information on gaseous contaminants, and it is hoped that the sampling program can be expanded in the near future to include such materials. You may be interested in knowing that Kansas City was near the median among some twenty odd cities participating in the study during the past 24 months.

Many of you may now have reached a conclusion that we have no atmospheric pollution problem in Missouri, and it can be agreed that we have no statewide problem. We do have many local atmospheric pollution problems, involving limited areas and specific operations, some of which the Division of Health has been called upon for consultation and evaluation. A review or tabulation of the incidents which the Division of Health has participated in is not considered pertinent as there have been too few to indicate any pattern in the state, but it is to be noted, that municipal operations such as city dumps and sewage treatments plants have been implicated almost as often as industrial operations. For example, you may recall the circumstances in St. Louis County during the past summer in an area identified as Maline Creek. This water shed has apparently been receiving untreated sewage from suburban developments for many years, and the stream was acknowledged to be highly polluted. According to newspaper reports, the smell of stagnant and decomposed sewage, and the discoloration of housepaint by sewage gas—that is atmospheric pollution —was the factor primarily responsible for demands for action by citizens living in the area.

As noted previously, the legal responsibility of the Missouri Division of Health has not been defined. No specific legislation has been passed designating the Division as the agency responsible for the control of atmospheric pollution and the Division has not adopted rules or regulations specifically concerned with this subject. The limited activities of the past are considered to be authorized by the broad authority of the Commissioner of Health to preserve and protect the health of the people of the state. For this reason we do not at present feel that we are authorized to demand corrective action unless our investigations disclose a known health hazard.

It is believed that the majority of the complaints concerned with atmospheric pollution will fall under the classification of constituting a nuisance. The provisions of a number of the Missouri Statutes authorize cities and counties to define and abate nuisances, and if this prediction holds true, control of atmospheric pollution may be best exercised by local authorities. The following statutes should be of interest to representatives of local government.

> Section 71.760 states that the emission or discharge into the open atmosphere of dense smoke within the corporate limits of any city in this state is a public nuisance. Unfortunately the term dense smoke is not defined.
>
> Section 71.780 grants to the legislative or governing bodies of cities the power to suppress all nuisances within the boundaries of the city and within one-half mile of the boundary of the city.
>
> Section 73.110 which defines general corporate powers authorizes cities of the first class to prevent, abate and remove nuisances within one mile of the city limits.
>
> Section 564.040 is concerned with the operation of offensive factories, but lists offensive factories as soap factory, candle factory, oil factory, glue factory, hemp factory, varnish factory, pork house, sausage house or lard house and further defines the offense as permitting the factory to remain unclean to a greater extent than is required for the necessary prosecution of their business.
>
> Section 564.080 establishes a procedure for regulation or licensing of any business or calling, with the reasonableness of the licensing to be determined by a court of general jurisdiction.

Based upon current legislation, the jurisdiction of the Division of Health is limited to conditions which place the health of the citizens of the state in jeopardy. Unfortunately, these limits are not known and one of the objectives of the current research program of the Public Health Service is to determine the pattern or relationship of disease and atmospheric pollution, or the epidemiology of atmospheric pollution. If we can accept the definition of the World Health Organization of health as constituting the physical and mental wellbeing of the individual, then nuisances will also fall within the jurisdiction of the Division

of Health.

An Interdepartmental Committee on Community Air Pollution defined community pollution as follows: "Community air pollution is the presence in the ambient atmosphere of substances put there by the activities of man in concentrations sufficient to interfere directly or indirectly with his comfort, safety, or health or the full use or enjoyment of his property." The Division of Health does believe that an atmospheric pollution problem exists in the state today. The problem is not a state-wide problem but exists in a number of isolated areas and consequently can be best solved by decisive action on the part of the local authorities. The Division of Health is available for technical and professional assistance in determining the extent and source of the pollution and in particular desires to determine the effect, if any, of the pollution on the health of the people.

It is our opinion that municipalities, industries, and individuals must recognize the atmosphere as a natural resource belonging to all citizens.

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PUBLICATIONS OF THE ENGINEERING BULLETIN SERIES

Copies of the complete list of publications may be secured from the Director of the Engineering Experiment Station, University of Missouri.

Bulletin
No.

* 1. Acetylene for Lighting Country Homes, by J. D. Bowles (1910)
* 2. Water Supply for Country Homes, by K. A. McVey (1910)
* 3. Sanitation and Sewage Disposal for Country Homes, by W. C. Davidson (1910)
* 4. The Heating Value and Proximate Analysis of Missouri Coals, by C. W. Marx and Paul Schweitzer (1911)
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* 7. The Use of Metal Conductors to Protect Buildings from Lightning, by E. W. Kellogg (1912).
* 8. Firing Test on Missouri Coal, by H. N. Sharp (1912)
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*25. Experiments on Sunflower Seed Oil, by H. E. French and R. O. Humphrey (1926)
*26. Directory of Alumni and Former Students, College of Engineering (1926)
*27. Tests on Lubricating Oils, by Dr. Mary V. Dover (1928)
*28. Reinforced Brickwork, by Mason Vaugh (1928)
*29. A Semi-Graphical Method of Analysis for Horizontally Curved Beams, by Robert B. B. Moorman (1938)
*30. Flood Flow on Missouri Streams, by Horace W. Wood, Jr. (1942)
*31. Cross-Connection Survey in Calhoun County, Michigan, by E. L. Stockton (1942)
*32. Cross-Connection Survey in Calhoun County, Michigan, by E. L. Stockton (1942) (Revised)
33. Supplemental Irrigation for Missouri and Regions of Similar Rainfall, by Harry Rubey (1945)
34. A New Transit Method for Realigning Railway Curves and Spirals, by Harry Rubey (1946)
35. Influence Lines for Horizontally Curved Fixed-end Beams of Circular-arc Plan, by Robert B. B. Moorman and Manford B. Tate (1947)
36. Stresses in a Uniformly Loaded Circular-arc I-Beam, by Robert B. B. Moorman (1947)
37. Thermodynamic Equilibrium Calculations for Combustion Jets, by Ralph Scorah and Jack T. Kimbrell (1950)
38. The Effect of High Temperature Steam on a Nickel-Chromium-Iron Alloy, by Paul Ogden and Ralph Scorah (1952)
39. Air and Water Pollution Conference (1956)

*Out of Print.