Mellon Institute of Industrial Research and School of Specific Industries

Smoke Investigation Bulletin No. 7

The Effect of the Soot in Smoke on Vegetation

By
J. F. CLEVENGER, M. A.

University of Pittsburgh
Pittsburgh, Pa.
1913

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Note by the Editor

The investigation described in this bulletin was undertaken by the Botanical Department of the Pennsylvania State College in co-operation with the Department of Industrial Research of the University of Pittsburgh, now known as the Mellon Institute of the University of Pittsburgh. The investigation was begun in March, 1912, and continued about one year and a half.

The Mellon Institute desires to express its appreciation of the co-operation of State College and to thank Mr. J. F. Clevenger, who carried on the investigation.

John O'Connor, Jr.

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Introduction

The present paper attempts to determine, primarily, the effect of the soot in smoke and included materials upon plants. General observations have been made by the writer in the following localities: certain of the public parks in Chicago; in Pittsburgh and vicinity; along the railroad between Pittsburgh and Tyrone; and at State College and vicinity. Specific observations by means of controlled laboratory experiments were made at State College, Pennsylvania. While the observations have not been so numerous as might be desirable, yet the writer feels that they will warrant the conclusions drawn. He has the feeling that the data obtained have been somewhat meager owing to the fact that the investigation has not been prolonged over a sufficiently long period of time.

Fig. 3. Oak.

Fig. 4. Nine Mile Run

Plate I

PLATE I.

Fig. 3. Shows a dead oak on the hillside of Munhall Run about one mile from the mills at Homestead, a common sight.

Fig. 4. Shows a view of the hillside and hilltop near Nine Mile Run across the river from the mills in Homestead. This shows the almost complete destruction of the trees at this place.

Fig 5 Ulmus

Fig. 6. Ulmus.

Plate II

PLATE II.

Fig. 5. Cross sections of an Ulmus (American elm) growing in region 6 of the Aliquippa district near the mill and showing the distinct effect of smoke and gases.

Fig. 6. Cross sections of an Ulmus (American elm) growing on the hillside in region 5, Aliquippa district. Shows a tendency toward a narrowing of rings. Evidently effected by the smoke and gases from the trains.

Historical Review

Various phases of this subject have been studied from time to time by different investigators, the most of whom agree on many of the more important points. The effect of various gases upon plants must be considered in connection with the effect of soot because with the soot in smoke there are always associated various gases, as Crowther and Ruston (5) have shown. Crocker, Knight and Rose (4, 9, 10, 11) by their several and conjoint investigations and discussions of literature have established beyond reasonable doubt the high toxicity of certain gases to plants, especially ethylene, and the injury done by greater quantities of other gases. Their first paper deals with illuminating gas and its constituents, while a later paper deals with the effect of smoke, and particularly tobacco smoke, upon etiolated pea seedlings. Although the various responses which they obtained were, for the most part, with etiolated seedlings, yet information concerning the effect upon normal plants is not lacking, as is evidenced by the almost complete destruction of certain plants by acute poisoning in a greenhouse during the fumigation with tobacco smoke. Buckhout (2) has pointed out the destruction of vegetation in the neighborhood of the chemical works at Natrona, Pennsylvania. This he attributes to the Sulphur trioxide (SO_3) and sulphur dioxide (SO_2) fumes. Haywood (8) observed similar effects in the neighborhood about the smelters near Redding, California. He went further, however, and obtained evidence bearing on the specific injury suffered by plants from SO_2 and SO_3 fumes. He demonstrated that these gases were responsible for at least a major part of the injury suffered by the plants in the vicinity. Widstoe (8) found that SO_2 in small quantities acting for a long time is toxic to plants. Peirce (14) believes that the cement factories in the San Bernardino Valley of Southern California caused a decrease in crop production by covering the leaves with an incrustation of dust and thereby interfering with the energy relations. Parish (15) estimated that the lemon crop in the vicinity of the Stower Mountains was cut down one-fourth on account of the presence of a large cement factory. He points out that while the stomata are not clogged with dust, nevertheless this interferes with photosynthesis. Ruston (17) found in the vicinity of Leeds, England, that a black adhesive film covers the leaves of many tress, particularly evergreens, and thereby interferes with photosynthesis. He further reports that eighty per cent. of the Fir leaves had their stomata clogged. Crowther and Ruston (5) found that impurities in the air were present in large quantities in and about industrial centers. They found that the suspended matter brought down by rains has an injurious effect upon vegetation, by direct action on the leaves; and indirectly by reducing the activity not only of the necessary ammoniacal fermentation of the soil humus, but even more of the beneficial nitrifying and nitrogen-fixing organisms in the soil. Gatin (6, 7) found that various tar products used in road pavements were injurious to vegetation and that the effects might be produced by the action of the various gases; and by the action of the dust. He found that the fumes of tar brought about the alteration in the size and number of layers in the cortex and other regions of the stem, and the transformation of doubly compound leaves into singly compound leaves. He also reported the disappearance of starch and the formation of cork in leaf organs and stems. Molisch (13, 14) found that tobacco smoke had a marked injurious effect upon micro-organisms. Cohen and Ruston (3) brought together the records of their observations which had been carried on at intervals during the past twenty years. They gave data concerning the composition of soot collected from the bottom and top of chimneys of dwellings as well as from the boilers of a number of factories, finding, of course, that the soot varies considerably, depending upon the conditions under which the coal was burned. They also obtained data relative to the amounts of solid impurities found in the air at a number of stations. They attributed the observed injury on vegetation to the blocking up of stomata, thus impeding the process of transpiration; to the coating of the leaf, thereby reducing the intensity of sunlight and at the same time affecting the diffusion of carbon dioxide into the leaf; and to the corrosive effect of the acid it contains. The injury took the form of a general reduction in the size of the leaves and plants. It was also seen in the narrowing of the annual rings in trees.

Observations and Experiments

Aside from the general observations and experiments which were carried on, circular letters were sent out to various florists and gardeners in and near Pittsburgh. Following is a sample of the inquiries in the circular letters and of the replies received:

1. Date of reply: A. About July, 1912.

2. State your general business (such as Florist, Gardener, etc.):

A. About thirty replies were received, these being almost equally distributed between florists and gardeners.

3. What plants native to Pittsburgh and vicinity do you consider grow poorly or not at all, because of the smoke, soot and gases?

A. Evergreens, Sugar Maples, and other plants in more or less impoverished condition.

4. What plants introduced into Pittsburgh and vicinity thrive poorly or not at all, because of the injurious effects of smoke and gases?

A. Evergreen trees, Spiraea and White Oak.

5. What plants native to Pittsburgh and vicinity thrive well in spite of the smoke and gases?

A. Rhus, Salix, and grasses.

6. What plants introduced into Pittsburgh and vicinity do well in spite of the smoke and gases?

A. Ailanthus, Norway Maples, Platanus occidentalis, and Syringa.

7. What is the character of the injury done to your plants, or any plant which you have observed?

A. Stomata stopped, buds and foliage have the appearance of being subjected to intense heat or fire, and dying of trees from the top down.

8. How much of this injury do you attribute to smoke, and how much to gas and other causes?

A. The general opinion is that the injury is due collectively to the smoke and gases.

9. Have you lived in other places where these conditions of smoke and gas do not exist?

A. They usually had.

If so, state where, when, and how long, and give the general conditions which existed at this place.

A. Most had lived in other localities where they did not have to contend with smoke and gases.

The writer's observations in the main confirm these replies. The specific causes for these injuries may not be so easily fixed, for it must be recognized that there are a number of factors which must be considered, such as rainfall, temperature, humidity, transpiration, various soots and gases liberated from chimneys and smokestacks, and dust.

In order to show that plants are injured by various by-products given off into the air by the industrial establishments, specific locations were selected and kept under constant observation during the summer of 1912 and certain data, which will be presented later, were obtained.

To get some general notion of the climatic conditions of these regions, atmometer cups of the Livingston type were employed and weekly readings were made. In addition to this, The Annual Meteorological Summary of Pittsburgh for the past four years was consulted. The atmometer readings are given in the form of curves. The amount of evaporation is given in cubic centimeters per 25 square centimeters of evaporating area. The time intervals are approximately seven days (Fig. 1).

By referring to Figure 1, we note, in the first place, that the curves for the most part run low, indicating a comparatively high humidity for all of the districts, and that each curve bears a strong resemblance to the average curve. In the second place, the periods when the transpiration was excessive were few and short.

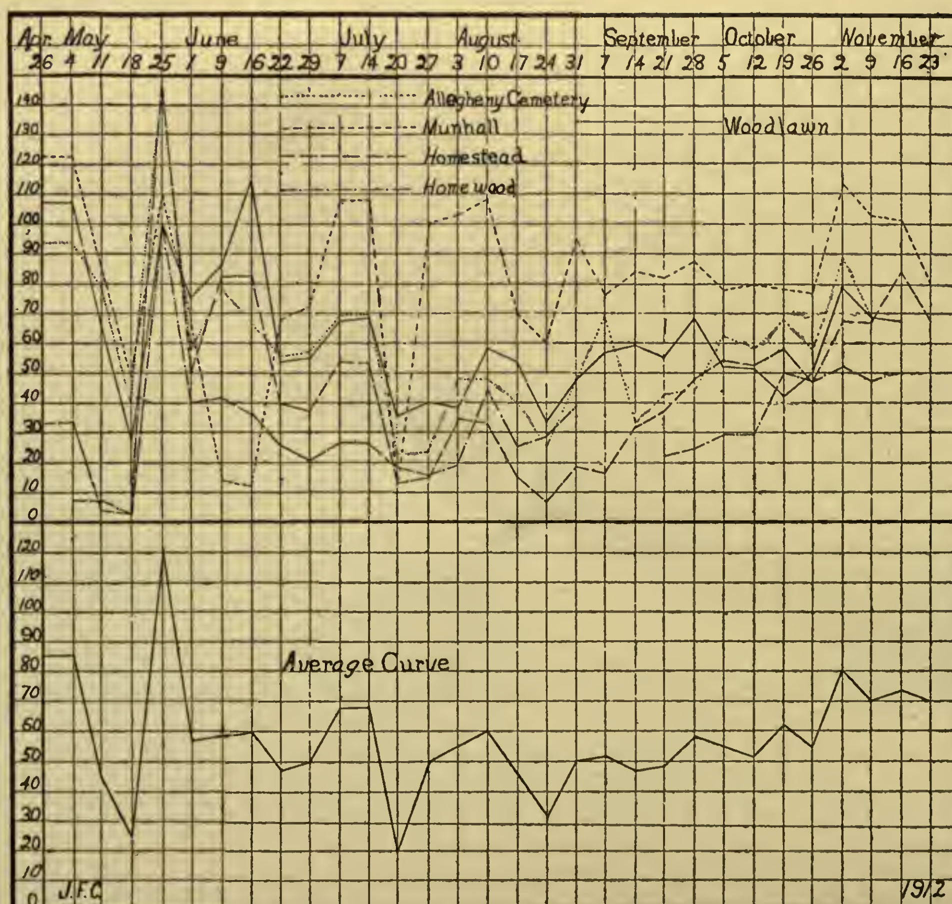

FIG. 1. CURVES OF EVAPORATION.

By referring to the Annual Meteorological Summary of Pittsburgh we find that the annual rainfall has amounted to approximately 36 inches during the year and that this has been uniformly distributed throughout the year, and has not varied a great deal from year to year.

In like manner, the monthly temperature reported shows the same general uniformity as the other records. Therefore these records will not account for the variations noted below.

THE REGIONS SELECTED.

The following places were selected in Pittsburgh: (a) Allegheny Cemetery, which is almost in the center of the town and nearly surrounded by large mills which emit considerable quantities of smoke. This locality was selected because it was believed that an idea could be gleaned concerning the effect of smoke upon introduced plants. Here no special injury to these plants was noted, save a general impoverished condition. (b) Homewood Cemetery, which is in the eastern part of the city about midway between the Allegheny and Monongahela rivers and almost two miles from any large mills. Here it was found that native conditions were fairly well maintained and the plants presented approximately normal conditions. (c) Munhall Run is located where the smoke has been spread over the region from the large blast furnaces and steel mills in Homestead for several years. Here it was found that the vegetation and particularly the trees were almost entirely killed for a distance of almost a mile (Fig. 3). Across the river from these mills and near the river is the Baltimore and Ohio Railroad, the smoke from the trains of which, together with that from the mills, has killed practically all the trees on the hillside and hilltop (Fig. 4). Neither of these places enabled one to fix the cause for the trouble quite so well as that of Aliquippa and the nearby vicinity, about twenty miles down the Ohio river from Pittsburgh. By referring to the map the topography as well as the direction of the prevailing winds may be understood (Fig. 2). The particular regions of the Aliquippa district to which attention is to be directed may also be seen by referring to this map. These regions were selected in order that a number of different conditions might be secured. They were as follows: Region 1 is on the spur of the hill extending southward toward the mill and about 1500 feet a little northwest of the mill. Region 2 is about one-half of a mile north of region 1 and, on account of the prevailing winds, receives very little smoke and fumes from the mill. Region 3 is approximately 900 feet west of region 1. Region 4 is about 1,300 feet northwest of region 3 on the slope of the hill and seemed to be well protected from the smoke and fumes from the mill. Region 5 is on the slope of the hill near the Pittsburgh & Lake Erie Railroad and about 1,500 feet southwest of the mill. Region 6 is in the valley near the mill and receives the full effect of the smoke and fumes. The mill referred to is Jones and Laughlin, which has been established there since 1909.

Besides these blast furnaces, there are railroads on either side of the river over which trains run at frequent intervals. The prevailing winds, being northwest, are effective in carrying smoke and gases from the trains and furnaces, resulting in the destruction of most of the trees on the hillside and ravines east of the river. On the west side of the river rather extensive observations were made in the regions corresponding approximately to the numbers on the map (Fig. 2). In these regions, studies of annual rings and of the anatomical structure of leaves were made. Realizing that anything which would cut off the food making in the plant would diminish the width of the annual ring and that this might be produced by an accidental breaking of a limb or top of a tree, the writer took cross sections of the stems at different points, as Figs. 5-14 will show. It was found that in region 4 no noticeable injury could be detected either in the general character of the trees or in the width of the annual rings. The difference in width of annual rings was found to be well marked in certain

Fig. 7. Ulmus

Fig. 8 Ulmus

Plate III.

PLATE III.

Fig. 7. Cross sections of an Ulmus (American elm) growing on the campus at State College, Pennsylvania, showing wide and rather uniform rings. Here the conditions for growth are favorable.

Fig. 8. Cross sections of an Ulmus (American elm) growing on the hillside at Nine Mile Run across the river from the mills at Homestead. Shows a decided irregularity in the character of the annual rings.

Fig. 9 Locust.

Fig. 10. Hicoria

Plate IV.

PLATE IV.

Fig. 9. Cross sections of a Locust growing in region 4 of the Aliquippa district, showing a tendency toward a narrowing of annual rings.

Fig. 10. Cross sections of a Hicoria growing on the hilltop near Nine Mile Run. Shows a general tendency toward narrow annual rings on account of the unfavorable conditions due to smoke and gases.

Fig 11. Hicoria

Fig. 12. Hicoria

Plate V

PLATE V.

Fig. 11. Cross sections of a Hicoria growing on the hillside near region 3, Aliquippa district, showing a narrowing of rings during the past three years.

Fig. 12. Cross sections of a Hicoria growing in the mountains near State College, Pennsylvania, showing wide and rather uniform annual rings. Here conditions for growth are favorable.

Fig. 13 Pinus

Fig. 14. Pinus

Plate VI

PLATE VI.

Fig. 13. Cross sections of Pinus strobus (White Pine) growing on the hilltop at region 3, Aliquippa district. Shows the tendency toward the narrowing of annual rings.

Fig. 14. Cross sections of Pinus strobus growing on the mountains near State College, Pennsylvania, showing wide and rather uniform annual rings. Here the conditions for growth were favorable.

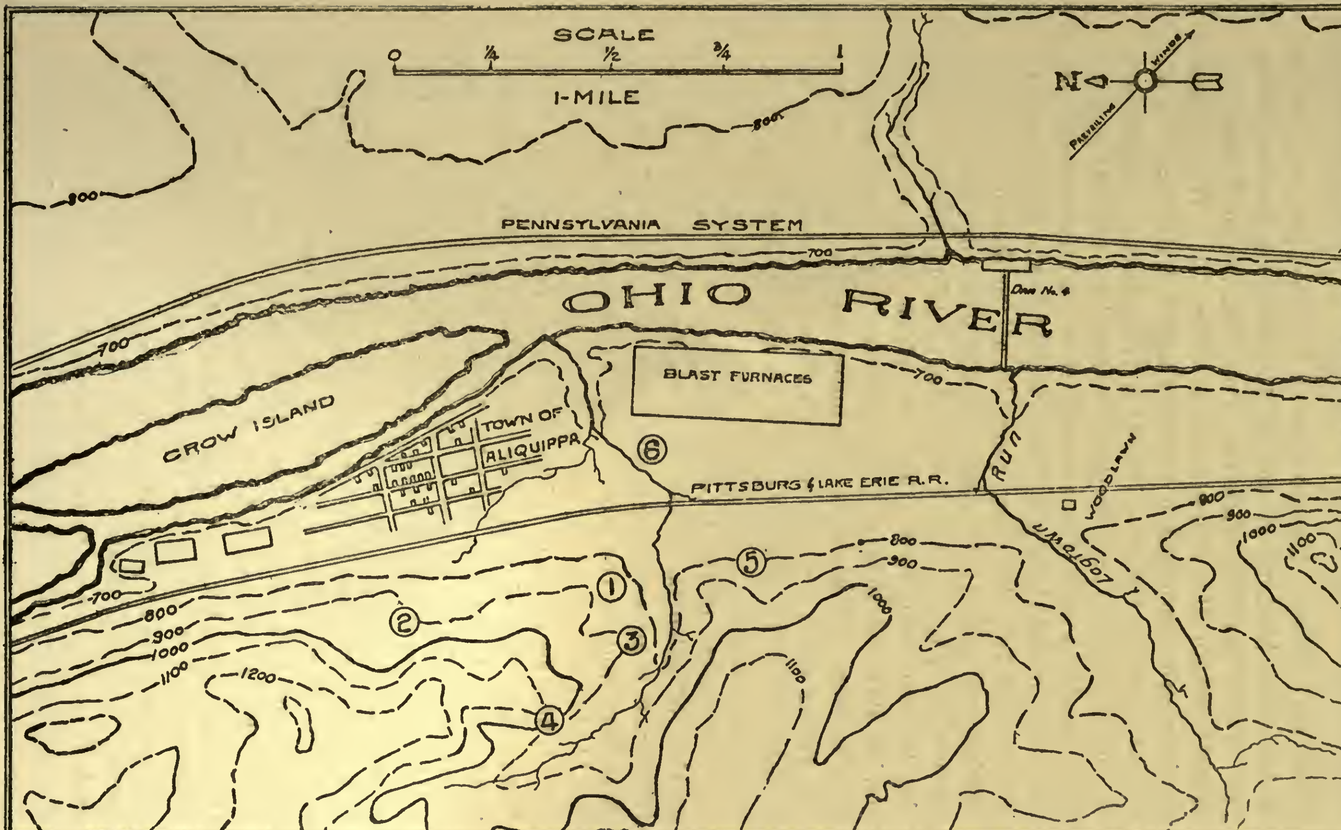

FIG. 2. MAP OF ALIQUIPPA DISTRICT.

Elms and Pines. The sections of Elm taken at region 6 show a decided narrowing of the rings for the last three years corresponding with the time that the mill has been established in the neighborhood (Fig. 5). When these sections are compared with sections of a similar tree obtained at State College, it will be found that this feature is lacking (Fig. 7); here the tree was in a favorable place for growth. Fig. 6 illustrates sections of an Elm obtained from region 5, Aliquippa district, which show evidence of injury due for the most part, in all probability, to the smoke and gases from the trains which run at frequent intervals. Fig. 8 shows sections of Elm obtained from the hillside at Nine Mile Run which bear evidence of smoke and gas injury. This is shown by the irregular and narrow annual rings. It indicates, furthermore, that the young trees are injured less than older ones, thus accounting for the presence of a number of scrubby plants in many places.

The same general conditions are found when cross section of Hicoria collected at region 3, Aliquippa district, are compared with similar ones collected at Nine Mile Run and on the mountains near State College (Figs. 10, 11, 12).

When sections of pines collected from region 3 are compared with similar ones collected in the mountains near State College it will be found that this narrowing of annual rings is present in the former, while a wide uniform annual ring is seen in the latter (Figs. 13, 14). A locust, which is commonly thought to be and apparently is sensitive to the effects of smoke and gases, found growing in region 4, bears evidence of this narrowing of annual rings (Fig. 9). Other plants in this region did not show this condition. At a distance of 1,500 feet from the mills very little of this effect could be observed and is explained of course on the ground that the winds blow the major part of the smoke and gases away from the stations. A large number of wood sections were examined and Figs. 5-14 are a fair representation of the lot. They, for the most part, tell their own story.

Another common condition met wherever there is smoke and gases is the dying of the leaves from the tips down (Fig. 16). This is well marked in the rhododendrons, pines and many deciduous trees. The leaves of Gingko in the Allegheny Cemetery were found not only dying at the tips but many showed dead spots in the leaves.

Anatomical study of leaves collected at the different stations did not show any unusual cork formation either in the blades or petioles. In certain plants (e. g., the pines) the stomata are in pits which might be expected to be filled with soot held there by tarry substances. Examination and comparison of leaves collected at these stations, with similar leaves collected on the campus in State College and from plants experimented with in the nursery of the Department of Forestry, Pennsylvania State College, do not show any marked difference. To be sure, in each instance a few of the stomata appeared to be clogged, but in no case were more than approximately twenty-five per cent. found in this condition.

CONTROLLED FIELD EXPERIMENTS.

In order to determine more specifically the effect of soot upon plants, controlled field experiments were performed in the following manner. Cases of the sort shown in Fig. 17 were placed over plants of suitable size and in good condition. On the ground within each case and on opposite sides of the plant were placed two crystalizing dishes for the purpose mentioned below. A thermometer was hung in each case. A tin tube connected at one end with a funnel shaped piece was passed through the upper crossbar of the case. This funnel shaped piece was within the case and was turned upward at an angle of about 30°. On the same tin tube and outside of the case another funnel shaped piece was attached. The soot was applied to the plants in the following manner: small quantities were placed in the funnel on the outside of the case and subsequently driven into the case by means of a small stream of air entering at a high velocity. By this means the soot was distributed uniformly over the plant. To determine the amount applied, weighings of the soot collected in the crystalizing dishes were made and these computed to unit area. The soot was applied at daily intervals usually extending over about one week. In each experiment four cases were used, one as a control and three for the application of soot. In order to keep down the temperature in the cases they were protected by shades of cheese cloth.

ANALYSES OF SOOT [1].

The samples of soot used had the following analyses [2]:

	Tar	Ash	Fixed Carbon
Sample A.	6.12%	28.1%	65.78%
Sample B.	6.70%	5.5%	87.75%
Sample C.	1.12%	26.0%	72.88%

EXPERIMENTS IN NURSERY AND GREENHOUSE.

The following experiments will indicate the general results obtained. Care was taken in selecting plants which were similar and in good condition in the beginning of each experiment.

EXPERIMENT I.

Begun July 2, 1912. Selected Jack Pine seedlings in the College nursery. Applied small quantities of soot July 2, 3, 4, 11, 12. Continued experiment until July 23. Quantities of soot of sample A used as follows: In case No. 1, 2.412 gm. per square meter. No. 2, .438 gm. per square meter. No. 3, .438 gm. per square meter. No. 4, Control [3].

(1) Volatile matter refers to that portion of the dried sample which was driven off by heating in a tightly closed platinum crucible in the full flame of a Bunsen burner for seven minutes. The residue remaining in the crucible is coke. This is burned by heating in the air, and the percentage of ash is determined. The percentage of coke minus the percentage of ash gives the percentage of fixed carbon.

(2) All of the analyses were furnished by the Industrial Research Laboratory of the University of Pittsburgh and were made under the supervision of Dr. R. C. Benner.

(3) Applications of .438 gm. per square meter is sufficient to make a continuous black coating over the entire plant.

At end of time all plants were alive. The leaves of the plants treated displayed a tendency to drooping. Many leaves began to die at the tips. Those near the ground were completely dead. Old leaves seemed to suffer most from treatment. The control remained normal.

EXPERIMENT II.

During August, 1912, under similar conditions with the same kind of seedling and in the same nursery. The soot applied of sample B. Quantities of soot used as follows: In case No. 1, .219 gm. per square meter. No. 2, .219 gm. per square meter. No. 3, .439 gm. per square meter. No. 4, Control.

The results were like those in experiment 1.

EXPERIMENT III.

During March, 1913. In the College greenhouse. Potted plants of tomato used. Other conditions similar to the above. Soot applied of Sample C. Quantities applied as follows: Case No. 1, 7.2 gm. per square meter. No. 2, 23.04 gm. per square meter. No. 3, 3.6 gm. per square meter. No. 4, Control.

At the end of the experiment the plants exhibited no differences and all were in good condition.

EXPERIMENT IV.

Begun July 21, 1913. Selected Jack Pine seedlings in the nursery as above. Soot applied of sample C. Applied July 21, 22, 23, 24, and experiment continued until August 26, 1913. The following quantities of soot were used: Case No. 1, 23.4 gm. per square meter. No. 2, 11.7 gm. per square meter. No. 3, 12.96 gm. per square meter No. 4, Control.

At the end of the experiment although all plants were alive, nevertheless many of the older leaves were entirely killed and ready to fall off. The younger leaves on the whole endured the treatment better than the older ones.

Experiment V.

Begun July 2, 1913. Selected Fir plants in the College nursery. Applied small quantities of soot every other day until about July 21, 1913. Quantities were of Sample C. The following amounts were used: Case No. 1, 3.78 gm. per square meter. No. 2, 2.97 gm. per square meter. No. 3, 3.6 gm. per square meter. No. 4, Control.

At the end of the experiment all plants seemed to be in good condition. No difference could be seen among them.

EXPERIMENTS WITH PEA SEEDLINGS.

(a) Samples of soil taken from the surface and at a distance of two inches from the surface from near the mills at Homestead and tested for the presence of toxic gases by a method devised by Crocker, Knight and Rose (8) gave negative results.

(b) A few experiments with etiolated seedlings gave slightly positive results. They consisted of a modified Crocker type as follows: A can of 50 liters' capacity was placed over the etiolated seedlings and sealed around the bottom with oiled clay. It was further provided with an opening through the upper edge which permitted the application of soot to the seedlings. At right angles to and below this opening a shaft passed through the can and bore a fan on the inside. On the other end of this shaft was a pulley to which a motor was attached. This motor was also connected with a blower which in turn was connected to the can by means of a rubber and tin tube (Fig. 16). The tin tube was similar to the one used in the field experiment. The soot was applied by placing small quantities in the tin tube. It was then forced and distributed into the case by running the blower at high speed simultaneously with the rotation of the fan.

These experiments were repeated a number of times with similar outcome so that one experiment will suffice to illustrate the character of the results obtained. Etiolated seedlings of sweet pea grown on moist cotton were used. After they had grown 2 to 3 cm. they were placed under a dark chamber sealed around the bottom with oiled clay. Daily applications of soot were made for seven days. At the end of two weeks observations were made. Quantities of soot used of Sample C were as follows: Case No. 1, 3.78 gm. per square meter. No. 2, 2.97 gm. per square meter. No. 3, 3.24 gm. per square meter. No. 4, Control.

At the end of the experiment the only visible difference was an apparent checking of growth in the case of the plants treated with soot. This condition became more apparent when the plants thus treated were allowed to grow in the open for a few days.

SOOT FALL FOR WOODLAWN.

In addition to other data obtained open glass jars twelve inches deep and four inches in diameter were placed at each station under observation and analysis made of the matter collected in each jar placed in the region of Woodlawn. Similar records were made for various stations in Pittsburgh and are given in another report of this investigation.

STATION AT 3.

Total deposit for 4 months, June, July, August and September, 1912, was 1.1442 grams—93 tons per square mile per year.

ANALYSIS.

Tar,	1.86%	
Fixed carbons,	28.34%	
Ash,	68.8 %	
Iron in ash,	12.7 %	Fe_2O_3.

STATION AT 5.

Samples taken July, June and October, 1912. Other samples not good (contained leaves and bugs).

Total weight of solids—6.6250 grams—68 tons per square mile per year.

ANALYSIS.

Tar,	6.5%	
Fixed carbons,	41.1%	
Ash,	51.4%	
Iron in ash,	8.3%	Fe_2O_3.

General Considerations

It follows from the above data that injury to vegetation is caused by the smoke and gases given off by industrial establishments. In many instances the injury, and sometimes the complete destruction of the vegetation, can be traced directly to smoke and gases accompanying the smoke. In this particular all investigators agree. But this alone does not give much insight as to the specific cause or causes for the injury. It has been determined that smokes vary widely in composition both quantitatively and qualitatively, and that several gases may be variously associated with each other and with the solids present. This being the case the problem then is to determine the extent of the injury of the several substances. On account of the different compositions of smokes in different localities the problem is a complex one, one which at the present moment is only partly solved. Many valuable data have been obtained, but for the most part from the study of the gases occurring with the smoke and only to a slight extent with reference to its solid components. The writer has undertaken to determine the extent of the injury to plants caused by the soot, *i. e.*, by the "fixed carbon" as elsewhere defined and as supplied the writer for this investigation by Dr. R. C. Benner. It is the opinion of the writer that the final word has not been said in this regard.

The objection may be raised that the effect of a small amount of soot applied over a long period will not be the same as when applied in large amounts during a shorter period, the conditions namely of the experiments. This objection may be well taken, but the writer thinks it not unlikely that there is less weight to be attached to it than at first sight appears. The conditions of the experimentation were, however, unavoidable, and the conclusion must rest on the probability that the larger

Fig. 15 Leaves of Rhododendron

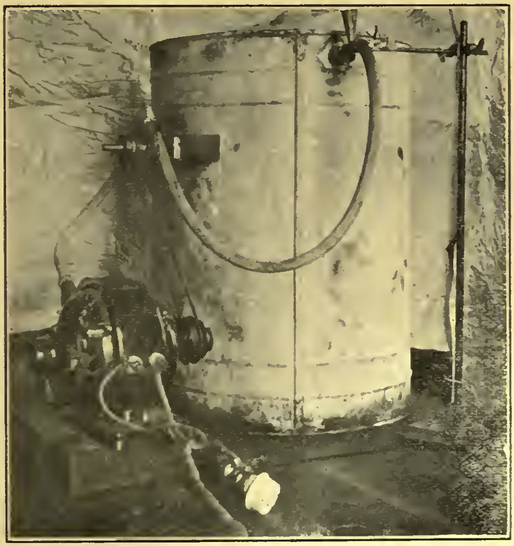

Fig. 16. Laboratory Apparatus

Plate VII.

PLATE VII.

Fig. 15. Leaves of Rhododendron growing at region 1, Aliquippa district, showing how the leaves die from the tips back.

Fig. 16. Shows a view of the apparatus used in the laboratory to experiment with etiolated seedlings.

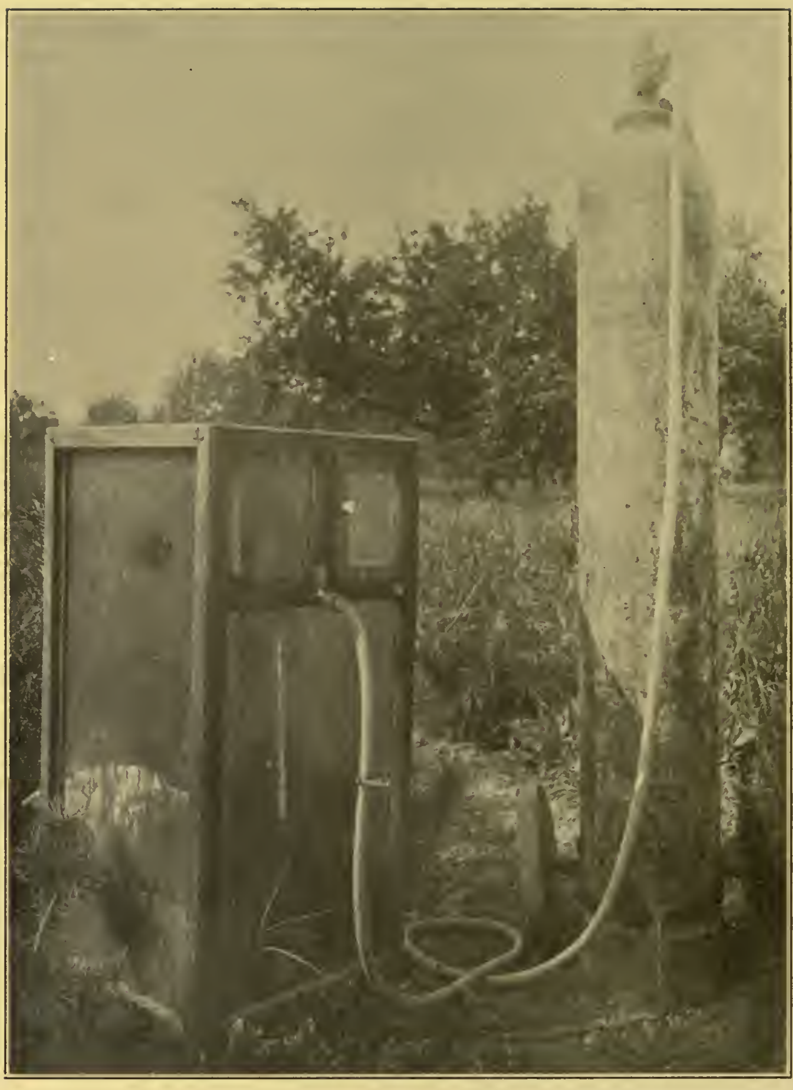

Fig 17. Field Apparatus.

Plate VIII

PLATE VIII.

Fig. 17. A view of the apparatus used in the field experiments, showing the method of treating plants with soot. The glass case is on the left and the pressure tank is on the right.

amounts of soot used did in large measure compensate for the shorter periods of exposure. In the determined soot fall, computed for one year, it was found that the tar and "fixed carbon" amounted to 10.8 gm. per square meter in one instance and 11.52 gm. per square meter in the other. In the experiments tar and "fixed carbon" were used in amounts varying from .21 gm. to 17. gm. per square meter. The amounts of soot generally used in the experiments were therefore about equivalent to an entire year's soot fall, and in consequence may be regarded as more toxic because (1) under experimental conditions the soot falling on the plants was more likely to remain, wind and rain being absent, and because (2) the amount used fell on the plants in a much shorter period of time. In each instance the plants were completely covered with soot during the experiments. Therefore, it appears that so far as the amount of soot is concerned, the obtaining of equivalent conditions has been approximately secured.

It may be maintained that the injury is purely or partly a mechanical one brought about by the plugging of the stomata, the plant consequently suffering from the suppression of the free exchange of gases. But inasmuch as a very small percentage of the stomata in the leaves collected in the field and from the plants experimented with in the nursery were found to be clogged, this opinion finds little or no support. Nor did soots of varying percentages of tar and "fixed carbon" display any differences in this respect.

In localities where smoke and gases are a nuisance there is a general though vague impression that soot and tars are toxic or otherwise injurious to plants. If this be the case, the writer would have expected to have obtained much more pronounced results in the above experiments, that is to say with solids and semi-solids. The question of the effect of gases has not been considered in this paper.

Conclusions

1. It is a matter of general opinion that smoke from mills injures nearby vegetation. That this opinion is justified is evidenced not only by the general external appearance of many of the constituent plants, but also by their internal appearance, as shown by the size of annual rings and by lesions in leaves.

2. The experiments described in this paper show that, especially in the case of pines, when soot is applied in small quantities over a considerable interval of time, measurable injury follows. Soot is therefore poisonous to vegetation.

3. Soot is a mixture of pure, finely divided carbon, ash, tar and gases. Since, however, pure carbon can not be regarded as poisonous, its effect on plants, if indeed it has any, must be charged to the mechanical clogging of stomata, or to the ash, which may, in the presence of water (rain) provide solutions injurious to leaves. Aside from this latter possibility, which has not been investigated in this study, actual observation reveals the fact, that only a small percentage of the stomata were clogged, from which it is inferred that little or no interference with interchange of gases occurs. It is true that a certain number had the appearance of being clogged, nevertheless it is doubtful, in the opinion of the writer, that there was an efficient hindrance to the diffusion of gases in view of the studies of Brown and Escombe (1) and Lloyd (12). It is of course obvious from results of such studies that the effect of the interference by small particles on diffusion through a minute opening can not be inferred but must be made the subject of specific investigation.

4. The injury done by the soot of smoke to vegetation, is therefore, probably due chiefly, if not entirely, to the accompaning ash, tar and gases.

5. It is a well established fact, based upon results of other studies, that fumes containing sulphur dioxide and sulphur trioxide do considerable injury to vegetation. It is also known that the gases, ethylene, a constituent of illuminating gas; carbon monoxide, benzene, hydrogen sulphide, and carbon bisulphide are injurious to plants.

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