

ALGAE ELIMINATION IN SPRAY PONDS
AND COOLING SYSTEMS

by

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INTRODUCTION

In this brief study of the methods of preventing algae growths, the writer has attempted to analyse the methods that have been successful in other fields and through this analysis arrive at some definite method of procedure that may be applicable in power plant operation and cooling systems where wide temperature differences are to be encountered. The conclusions are based on data obtained through experimentation. Although the methods herein described will not be applicable in a wide range of cases, the reader may be able to derive a plan of procedure to meet his own particular needs.

The author wishes to express his sincere thanks to those who have offered their assistance. Especially is he indebted to the Tennessee Public Service Company and the United States Aluminum Company for the use of their spray systems. To many others also he is indebted. Among them he wishes to mention the names of Prof. R. T. Brown who has assisted in estimating the comparative cost of systems herein described, and to Prof. W. R. Woolrich who has assisted in the organization and compilation of the material.

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Algae Elimination in Spray Ponds and Cooling Systems

General.--The algae growths in the basins of spray ponds and cooling systems present a serious obstacle in various plants depending on clean water for the most efficient operation. The National Electric Light Association has made special effort to obtain some dependable data on the subject, but very little work has been done in this field. An extensive study of various species of algae and the methods of preventing their growth has been made in connection with water purification in the impounding water supply reservoirs, but no study has been made where temperature differences are to be encountered as are characteristic of all cooling systems.

Comparatively little has been written in this country upon the biology of aqueducts and pipes. Yet it is an important problem in its hydraulic aspects. Fragile organisms, indeed, are broken up in the turbulent water and the phytoplankton is destroyed in the absence of light. If the conduits are covered, chlorophyllaceous organisms die off, but attached fungi and animal forms persist and sometimes develop in astonishing bulk. These fungi and animal forms depend for their food material upon the algae. It is through the growth of these organisms that various deposits are begun in closed pipe systems.

Most species of algae and animal organisms are known

to contain mineral matter, especially iron oxide and silicates. Water rich in carbon dioxide is able to dissolve iron and will carry it in solution as ferrous iron until it is oxidized to the ferric state in which iron compounds become insoluble in water and precipitate. Oxidation can be accomplished either by oxygen dissolved in the water or in its absence by iron bacteria. Iron is thrown out of solution and deposits of iron accumulate. In water pipes these deposits, together with the growth of the organisms themselves, encroach seriously upon the carrying capacity of the conduit.

A similar effect may be observed on the tubing in surface condensers. In addition to the mineral deposits, the organisms collect on the tubing. As a results, the heat transfer rate is considerably reduced. This reduction in the heat transfer rate results in a loss of condenser effect. The rate of condensation is retarded, and consequently, the desired back pressure may not be obtained. The elimination of algae growths will prevent, to a large degree, the corrosive effect commonly observed in water supply systems.

Algae.--The term "algae" is used to cover several phyla of primitive plants, capable of elaboration their own carbohydrate supply by means of photosynthesis, usually without highly differentiated vegetative structures. Most of them

live entirely submerged in water, and several groups including the most highly developed in their vegetative structures are almost exclusively marine. The method of reproduction varies very much in the different groups, from simple fission without even a well-developed nucleus, as in the cyanophyceae, to some of the most elaborate reproductive mechanisms known either in the animals or in other plant groups.

Classification.--Six classes of algae are commonly recognized:

1. Cyanophyceae (blue-green algae or Myxophyceae), usually blue-green in color but sometimes reddish or brownish, the pigment rather uniformly distributed in the cell. Mostly fresh-water organisms.
2. Chlorophyceae (green algae), usually bright green in color, the pigment collected into a definite structure in the cytoplasm known as the chloroplast. The stored product of assimilation is starch. There are both marine and fresh-water representatives.
3. Xanthophyceae (yellow-green algae), usually yellowish in color, due to relatively large amounts of xanthophyll present. The stored product of assimilation is a fatty starch. Mostly fresh water organisms.
4. Diatomaceae (diatoms or Bacillarieae), usually brownish in color, the chlorophyll of the chloroplast masked by the brown pigment. The stored product of

assimilation is a fatty substance. Universal both in fresh and salt water.

5. Phaeophyceae (brown algae), usually dark brown in color, the chlorophyll of the chloroplast masked by a brown pigment. The stored product of assimilation is starch. Mostly marine organisms.
6. Rhodophyceae (red algae), usually some shade of red, the chlorophyll of the chloroplast masked by a red pigment. Mostly marine organisms.

Under these six groups, all of the many species of algae are classified. The exact number of species has not been definitely determined. Each specie may be distinguished by cell arrangement and markings. The scope of this writing will not permit a detail study of the various species. Mr. G. C. Whipple has done considerable work in this field; also Mrssrs Moore and Kellerman have made an extensive study of algal growths in impounding water supply reservoirs. The reader is referred to texts prepared by these authors listed below for a detail discussion.

Relation of Temperature to Algal Growths.--The optimum temperature for the development of algal growths are not known. Particular species are characteristic in territories where certain temperatures are prevalent. For instance, Diatom growths have been observed at temperatures ranging from 35 degrees to 75 degrees F. The Chlorophyceae, or green algae,

are most abundant in water supplies during the summer. They are seldom found in winter. The maximum growth occurs usually in July or August, though the development of some genera culminates as early as June and that of others as late as September or even October. The optimum temperature for the different genera is not known. It seems probable that most of the common forms are able to grow vigorously between 60 degrees and 80 degrees F. if their food supply is favorable and the light is sufficient. It is possible for some of the green algae to become accustomed to considerable extremes of heat or cold. Some genera have been found in arctic regions, and others have been observed in water at a temperature of 115 degrees F. The blue-green algae seem to be attuned to a slightly higher temperature than the grass-green organisms. They often show a greater increase after a period of hot weather, and seldom give trouble unless the temperature of the water is above 70 degrees F.

Plankton Food Requirements.--The kind and abundance of food are the most important controlling influences in the life of the plankton. Fluctuations in the food supply, either qualitative or quantitative, affect growth and reproduction and largely determine the onset and number of recurrent pulses of growth. The phytoplankton, made up of plant forms of microscopic organisms, primarily requires water, carbon dioxide, oxygen, nitrates and phosphates. All of these in-

organic substances are found to some extent in the waters of ponds and reservoirs. Other common salts and compounds such as the bicarbonates, chlorides and sulphates of sodium, potassium, calcium, magnesium, and iron, together with silica, alumina and manganese compounds may exercise a stimulating effect upon certain species or be drawn upon when substances more easily utilized are deficient in amount.

The true animal forms of microscopic organisms, which make up the zooplankton, cannot as a class subsist upon inorganic food because of differing metabolism. Their requirements are principally met by consumption of the phytoplankton and bacteria, also, by utilization of other organic materials. In relation to aquatic life as a whole, the plant forms of the plankton are food producers, or synthetic organisms, the animal forms food consumers, or analytic organisms. The latter are the only forms that may persist in closed conduits.

Basis for Study.--From the foregoing discussion it may be understood that the particular species of algae present in any system are determined by the conditions of temperature and the abundance of food supply. This is true in every case. Truly there may persist at any one time several separate and distinct species if the conditions will inhibit their growth.

Destruction of Algal Growths by Use of Algicides.--The physical treatment of a water supply before it is brought into the plant or reservoir will help to retard the development of algal growth. Although much can be done in this way to reduce the number of organisms developing in reservoirs or drawn into service mains, it is either impossible or impracticable to avoid occasional growths of plankton in the best of reservoirs, except covered reservoirs storing ground water or filtered water. For full control of water supplies in open reservoirs, the use of algicides cannot be avoided and is often the quickest, cheapest and most reasonable means of preventing or remedying algal troubles.

An extensive study of the use of various chemicals as algicides has been made in connection with city water supply systems. Copper sulphate, chlorine, lime, formaldehyde, sulphuric acid and other chemicals have been used with varying success. The copper sulphate and chlorine treatment have given the best results in the above mentioned field. The relative value of chlorination and copper treatment for the control of algae in domestic water supplies has not yet been determined. Much work must yet be done and wider experience accumulated before definite procedures covering all possible circumstances can be established. The method of treatment adopted will depend upon the facilities for dosing the water with chemical and the general arrangement of the reservoir system. Finally, cost of operation must be balanced against

ease of manipulation and results.

Control of Algal Growths in Cooling Systems.--Considering the work that has been done in city water supply purification and the possible needs for a more efficient cooling systems in the power plant, the basis for a study in the latter field is at once apparent. A saving of a few degrees in the cooling effect in any system will compensate for the cost of any method that may be used to retard or prevent the corrosive effect caused by algal laden waters. A saving of 0.06 in. of Vacuum in a surface condenser will give the same results.

The purpose of the following series of experiments was to determine the relative value of the various chemicals as algicides. The conditions under which the work was done were not characteristic of the conditions analogous to the actions of a high vacuum condenser. However, only a slight variation in the general procedure will be necessary in any case.

Treatment With Copper Sulphate.--The first experiment with copper sulphate as an algicide was performed at the transformer station of the Tennessee Public Service Company, Knoxville, Tennessee. These transformers were water cooled, and the spray system was used to lower the temperature of the circulating water. A terminal difference of 10 degrees in temperature was the maximum to be expected. The system

contained 54000 cubic feet of water. The spray was effected by a single cluster of spray nozzles. Water was taken from the bottom of the basin and circulated by a centrifugal pump.

A sample of the algal was analysed. The cyanophyceae (blue-green algae) were found to be present. It was impossible to determine the exact species with the magnification possible with the available microscopes. The specimen were found clinging to the sidewalls and on the bottom of the tank. All living organisms were submerged. The total depth of the basin was three feet; therefore the effect of the sunlight was not lessened appreciably.

The first dose of copper sulphate was applied February 16, 1932. The charge consisted of 1 ppm. Observations showed slow results if any. The final observation February 25 showed slight discoloration to approximately 8 inches below the surface of the water. There was a tendency of the slime to pull away from the walls.

On February 25, the charge was increased by 2 ppm. Observation on Wednesday, March 2 showed the algae had begun to rise to the surface of the water. Observation on Friday, March 4 showed that all algae were dead. The dead algae and slime were separated from the bottom and the sides of the basin and removed. Regular operation of the system was continued throughout. Replacement water was added at regular intervals. Daily observations were made for the reappearance of the organisms. On April 4, new algae had begun to grow.

A second experiment was performed at the United States Aluminum Company, Alcoa, Tennessee. Their process water is being taken from Pistol Creek. The system contains approximately 3,000,000 pounds of water. The water is filtered through two pressure filters. The capacity of these filters is not sufficient to take care of the supply; consequently a large amount of mud flocculent passes through into the system. The conditions are quite favorable for the growth of algae.

The walls and bottom of the basin were covered with algal growths. A sample of the organisms was taken and analysed. The analysis showed the presence of Lyngbya and traces of Diatomes. The Lyngbya is classified as blue-green algae.

The process requires a total replacement of water once per week. Upon the recommendation of copper sulphate as an algicide, the company resolved to add 5 pounds of the sulphate each week. This gave a concentration of 1.67 ppm. The final observation showed that the algae had been eliminated.

The Corrosive Action of Copper Sulphate on Piping.--It is a common belief among plant engineers that copper sulphate has a corrosive effect on pipes and condenser tubing. No corrosive effects have been noticed throughout the above experiments. Mr. Robert Bruce, Supt. of Power, Memphis Power

and Light Company, Memphis,,Tennessee reports the use of 9.6 ppm. of copper sulphate without pipe corrosion. An extensive study of the reaction of the sulphate with iron piping has been made by the manufacturers of copper sulphate. These reports would indicate that there should be no trouble from the use of the sulphate as an algicide.

Nature of Reaction.--Just how the copper sulphate acts in the destruction of algae it is difficult to say, involving as it does intricate problems of cytological chemistry. The poison probably combines chemically with the cell plasm and produces compounds that interfere with the continuation of the life processes and thus cause death.

According to Mr. G. C. Whipple, the sulphate of copper that is left free in the water reacts with calcium bicarbonate, which is present to a greater or less extent in nearly all natural waters, to form sulphate of calcium and basic copper carbonate, some carbonic acid being liberated. The basic copper carbonate may then become decomposed, copper hydrate and carbonic acid being formed. Copper hydrate is almost insoluble in water, whereas basic copper carbonate is somewhat soluble in water that contains carbonic acid, especially if the hardness is low. Experiments have shown that in hard water the reactions above mentioned take place in the course of a few hours, the copper hydrate first becomes a colloid and then precipitating as solid matter in suspension.

In softer waters more time is required. Cold and the presence of organic matter in solution tend to retard the reaction. Heat and the presence of suspended matter tend to hasten it. These are all important considerations, as the quantity of copper sulphate required to remove the algae is closely related to the speed of the reaction.¹

Quantity of Copper Sulphate Required.--It is of great importance that just the right quantity of copper sulphate be used. If too little is applied the algae will not be destroyed; if too much is used, money will be wasted.

In deciding upon the dosage, several factors need to be considered; namely, the kind of algae to be eradicated, the character of the water as measured by the amount of organic matter present, the hardness, the carbonic acid content and the temperature, and of course the quantity of water to be treated. Of particular necessity is it to know what organisms are present and which of them need to be killed.

Organisms differ considerably in their susceptibility

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¹"Control of Algae", by C. G. Whipple, Microscopy of Drinking Water: John Wiley and Sons.

to copper sulphate. Some of the blue-green algae are destroyed by the application of only one part of copper sulphate in ten million parts of water, while other organisms seem to require as much as three ppm. No standard dosage can be set. A certain amount of experimental work will be necessary in any case. Tables have been prepared by Hale and others, but the methods should be varied to meet the requirements of different waters.

Chlorine Treatment for Algae.--Chlorine, today the most useful water disinfectant, is also a good algicide. Its value as such was first noted by Huston during the treatment of the Lincoln, England, supply in 1905. Since then it has been studied by many different observers. The most notable work in the field of chlorination, however, has continued to be done by Huston in the laboratories, reservoirs, purification works and distribution system of the London Metropolitan Water Works. The reader will do well to acquaint himself with these studies which have appeared in the Annual and Research Reports of the London Metropolitan Water Works. In America the full use of chlorine for the treatment of algae-laden waters was first developed in 1921 by Hale in connection with the elimination of tastes and odors from the New York Water supply.

Methods of Applying Chlorine.--Whereas copper sulphate

is more common

is more commonly applied directly to the water in reservoirs, chlorine as an algicide has, as a rule, been added to the water as it passes certain control points. This does not mean, however, that it is impossible to dose storage reservoirs with chlorine. Numerous methods of doing so suggest themselves. If chloride of lime is used, it can be dragged through the water in bags, or it can be dissolved and sprayed upon the water surface. If liquid chlorine is to be applied, the chloro-boat of Wallace and Tiernan or a similar device might well be employed.

A third experiment was performed using chlorine as an algicide. This experiment was conducted at the transformer station of the Tennessee Public Service Company, Knoxville, Tennessee. The procedure followed the use of copper sulphate as outlined above. The basin was drained and washed clean of any remaining algae or organic matter. Algae was allowed to grow before the chlorine was applied. A sample of the organisms was analysed, and the same specie of blue-green algae was present as in the former case.

On Tuesday May 3, a dose of 1 ppm was applied. Regular observations were made each day throughout the following week. The algae continued to grow, and the bottom and walls of the basin were eventually covered with the growth. On Thursday, May 12, the dose was increased by 2 ppm. Calcium hypochlorite (Ca O Cl_2) was used to generate the required chlorine concentration. Immediate results were obtained.

A final observation, May 14, showed that all algae were dead.

Time did not permit the writer to determine the period through which the water would remain free from algal growths, as the report on this work was due May 15, 1932. Experiments performed by other writers would indicate that the effect of the chlorine would last until the concentration was considerably lowered as in the case of the copper sulphate treatment.

Algae Prevention by Use of Hill-side Spray With Quick Return of Water to Closed Reservoir.--The most important safeguard in preventing the growth of algae is the exclusion of light. Darkness deprives the chlorophyll-bearing plankton organisms of energy for growth, and, since there are but few other troublesome organisms, the presence of algae are commonly eliminated by storing clean water in the dark.

This method of prevention is easily effected in areas where the power plant design may include a hill-side spray with a quick return of the circulating water to a closed tank. The required cooling range may be facilitated through the spray system and the water supply returned directly to a closed tank. A more constant temperature range may be obtained in this way. The only objection that might be offered against this method would be the comparative cost of the two systems.

For the purpose of presenting a comparative cost of the two systems, the writer, assisted by Prof. R. T. Brown of

the University of Tennessee, has made a detail calculation of the cost of both systems. This estimate was made to accommodate a 20,000-kw. steam generator unit. One system includes a combined spray and retaining basin. The other system includes a separate spray basin and a closed retaining reservoir. The cost of piping and spray nozzles has been omitted from the estimate. The cost of these fixtures will be approximately the same in either case.

In order to determine the requirements for the system, it is necessary to assume some standard operating conditions and from these conditions determine the required apparatus. For the purpose of this calculation, we must know the weight of cooling water necessary to cool and condense 1 lb. of steam under the following conditions: a 20,000-kw. steam turbine uses 12.5 lb. steam per kw.-hr., initial pressure 290 lb. per sq. in. abs., superheat 250 deg. fahr., initial temperature of cooling water 70 deg. fahr., vacuum 28.5 in. Hg. referred to a 30-in. barometer.

Solution.--Using Equation 146 and 204 taken from Steam Power Plant Engineering, by G. F. Gebhardt, and assuming e is 0.95,

$$H = 1352 \frac{3415}{12.5 \times 0.95} = 1065 \text{ B U.}$$

$$t = t_s - 10 = 81.75$$

$$R = \frac{1065 + 81.75 + 32}{81.75 - 70} = 86.5 \text{ lbs.}$$

Where H = the heat content per pound of exhaust steam

t = temperature of vapor at 1.5 in. abs.

t = temperature of discharge water.

Total water Required

$$= 20,000 \times 12.5 \times 86.5 = 21,625,000 \text{ lbs./hr.}$$

$$= 346,000 \text{ cu. ft./hr.}$$

$$= 2,588,200 \text{ gal./hr.}$$

In order to take care of all uncertainties, the system should be designed to facilitate a supply of 3,000,000 gal. or 400,000 cubic feet of water per hour.

Using clusters of 5-2" Spray nozzles each having a capacity of 40 G. P. M., the number of clusters needed is,

$$\frac{21,625,000}{60 \times 8.33 \times 200} = 216$$

Allowing 13 feet space between clusters and 30 feet from center of cluster to the outer edge of the basin, the outside dimensions of the basin are 276' $\times$ 203'

Estimated

Estimated Cost of Retaining Tank.--

Specifications:

1. Circular closed tank
2. Diameter 160', Depth 20'
3. Walls 8" at top, 18" at bottom. Average 13"
4. Floor 8" deep. Roof 6" deep.
5. 60 Column roof supports 8" $\times$ 8"

Estimated cost of items:

1. Reinforced concrete wall \$12.00 per cu. yd.
2. Reinforced concrete roof \$12.00 per cu. yd.
3. Concrete floor \$ 9.00 per cu. yd.
4. 60 footings \$ 9.00 per cu. yd.
5. Excavation \$ 0.35 per cu. yd.

Total estimated cost of:

1. Roof	\$4460.00
2. Walls	5030.00
3. Floor	4800.00
4. Excavation	5660.00
5. Column Supports	200.00
6. Footings	270.00
7. Drainage	<u>500.00</u>
Total cost	\$20920.00

Estimated Cost of Spray Basin Including 216 concrete piers.--

Specifications:

1. Catchment Walls 2' high
2. Dimensions 276'X 203'
3. Walls 6" at bottom 10" at top. Average 8"
4. Floor 4" deep.
5. Pipe and Spray nozzle supporting piers 4' high

Estimated cost of Items:

1. Reinforced concrete walls \$12.00 per cu. yd.

2. Concrete floor	\$9.00 per cu. yd.
3. Concrete piers	9.00 per cu. yd.
4. Excavation	0.35 per cu. yd.

Total estimated cost of:

1. Walls	\$420.00
2. Floor	6260.00
3. Piers	3460.00
4. Excavation	1470.00
Total cost	<u>\$11,610.00</u>

Estimated Cost of Spray Basin and Retaining Tank Combined.--

Specifications:

1. Walls 9' high
2. Floor 6" deep
3. Width 203' length 276'
4. 216 piers 11' high

Estimated Cost of Items:

1. Walls	\$7664.00
2. Floors	9338.00
3. Piers	13050.00
4. Excavation	7126.00
Total cost	<u>\$37178.00</u>

From the above estimations, it may be seen that the first cost of a spray pond and quick-return, closed retaining reservoir will be less than the first cost of the spray

basin an retaining tank combined. The total cost of the closed reservoir an spray basin is \$32530; the cost of the spray pond and retaining basin combined is \$37,178, or a total saving, in the former case, of \$4648. In addition to economy in first cost the system will be a safeguard against troublesome organisms at all times.

Conclusions.--The successful use of chlorine as an algicide naturally leads to an inquiry into the relative merits of chlorination and copper sulphate treatment for the control of algae. At the present time it is neither possible nor necessary to lay down fundamental rules governing the use of these two chemicals. Much work must yet be done and wider experience accumulated before definite procedures covering all possible circumstances can be established. Those in charge of reservoir operation should cultivate a spirit of research which will not only aid them personally in determining the best method of algae control for their own needs, but will also lead to new discoveries of practical value to others.

It appears that copper sulphate and chlorine will yield good results if used alone, or both chemicals may be used in combination. The method of treatment adopted, therefore, must depend upon the facilities for dosing the water with chemicals and the general arrangement of the reservoir system. Finally, cost of operation must be balanced against

ease of manipulation and results.

The difference in the cost of the two chemicals will not be appreciable. At the present time copper sulphate may be purchased at \$0.09 per pound. The commercial product is 99 per cent pure. If liquid chlorine is used, it may be purchased at \$0.12 per pound. The apparatus used to apply The chlorine will add an additional cost to the latter process; whereas the copper sulphate may be applied with little cost of labor. Where calcium hypochlorite (Ca O Cl_2) is used, it can be dragged through the water in a bag, or it can be dissolved and sprayed upon the water surface. A similar method may be used in case copper sulphate is applied.

It is quite evident that the amount of chemicals required to prevent the Algal growths will not be as large as the quantity required to destroy a heavy existing growth. A large amount of the dosage will react with the existing organisms. There will have to be a sufficient quantity added in order that a part of the chemicals will remain in solution after the algae growth has been destroyed. This will explain the high concentration required in the above experiments. Those in charge of the system should, through the spirit of research, determine the most economical method to be used.

If the plant is located in an area when the hill-side spray and closed-return tank are applicable, the troublesome organisms may be eliminated without further cost. In case the trouble is incurred after the plant has been de-

signed, the chemical treatment may be resorted to at an appreciable saving in cost of operation with little cost of application.

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APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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