THESIS.

A STUDY OF THE PURIFICATION OF WATER BY OZONE.

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A STUDY OF THE PURIFICATION OF WATER BY OZONE.

During the last fifteen years the purification of water by ozone has been studied by many experimenters in Europe and by a few in the United States. As several of these investigators have been associated with companies interested in the sale of ozone apparatus, their results are not altogether unprejudiced. The conclusions reached by these experimenters are quite different. A few claim it to be the best possible means of water purification and that it can be done at reasonable rates. Others believe this method of purification to be very impracticable. One advocate of ozone purification gives the following advantages, no objectionable chemical is used, large filter beds are not necessary, operating expenses are not high, the plant occupies a limited area, the plant is easily enlarged, sterilization is rapid and certain and the plant may be placed at any convenient point. It is quite evident that some of these advantages are correct and we have endeavored to prove or disprove the others by our experiments.

The main objects of our thesis are (I) to find the effect both chemically and bacterially of ozone upon polluted water,(2) to find the cost of the necessary amount of ozone to effect the purification,(3) to study the effect of ozone on different kinds of water and (4) to find the relative efficiencies of different methods of mixing the water and ozone.

BIBLIOGRAPHY.

Ozone was discovered in 1840 by Schoenheim, but it was several years before anything was known of its properties. This was due partly to the fact that the various ozonizing tubes were capable of producing only small amounts of ozone and also to the impossibility of keeping ozone in metal tanks over water. Ozone has been produced by the oxidation of phosphorous, by the action of fluorine on water, by the oxidation of essential oils like turpentine, by sudden transitions of air or oxygen from extreme heat to cold and by the influence of electrical stress.

One of the first men to experiment with ozone was Froelich, who was employed by the firm of Siemens and Halske of Berlin. During his course of investigations he found that ozone produced by subjecting a current of atmospheric air to the action of a silent discharge of electricity possessed the important property of destroying micro-organisms and that the action was most effective in the presence of moisture.

Froelich's efforts were especially directed to the development of an effective and economical apparatus for the production of ozone and the hygienic applications of ozone were not conclusively worked out by him.

In 1892 Ohmuller experimented on the sterilizing action of ozone for the Imperial Board of Health of Germany. The plant with which Ohmuller and his associates experimented was situated at Berlin, and consisted of a 1 H. P. gas engine, a 65 volt, 8 ampere dynamo and an induction apparatus. Siemens ozonizers were used, the air being measured by a gas meter. With this apparatus he was able to produce three milligrams of ozone per second. In his experiments on the purification of water with ozone he used water from the Spree and also distilled water to which known amounts of impurities were added. He sterilized Spree water in ten minutes with 83.6 milligrams of ozone, but was not able to sterilize sewage in an hour with 156.3 miligrams of ozone. Distilled water to which large numbers of bacteria had been added were sterilized most easily. In two minutes 12,247,000 typhoid bacilli were killed with 195 mgs. ozone, and in another case in two minutes 2,790,000 cholera were destroyed with 16.5 mgs. ozone. Ohmuller's conclusion was that where waters were not too contaminated with solid organic impurities, ozone would destroy nearly all the bacteria.

In 1893 Tindal built a plant at Oudshoorn, Holland. This plant was used by Professor Van Ermengen of the University of Ghent for a series of investigations.

The water for these experiments was taken from the Old Rhine, which at this point was a drain for the factories and towns in that vicinity. The quality of the water was very variable and contained much organic matter. It had a disagreeable odor and a distinct brown color. In order to remove the suspended matter the water was first stored in a small tank and then filtered at the rate of 2,500,000 gallons per acre per day. The water was then ozonized by allowing ozonized air to bubble up through it. The chemical change was very slight, but bacterially he was able to obtain 33%-100% sterile plates.

During these experiments Schneller, an electrician in the employ of Tindal, devised means whereby liquid cells could be substituted for solid dielectrics. The cell consisted of a thin glass tube 24 inches long filled with a mixture of glycerine and alcohol, and fitted at each end with wire connections. It was suspended directly above the ozonizer and attached electrically to the positive electrode, composed of a series of pieces of thin platimum foil enclosed in a metallic box from which it was separated at all points by a space of .08-.012 inches. The box was in electrical communication with the earth, and this served as a negative electrode. The electrical discharge took place between the sheets of foil and the metallic box. Air forced through this apparatus was ozonized. The air was first freed of dust by filtration through cotton, then dried by passing through dessicators containing calcium chloride and sulphuric acid and finally refrigerated by the aid of an ice making machine. The air was further chilled on its passage between the ozonizers. On leaving the ozonizer the ozonized air was forced by a pump to the sterilizers. Two models of sterilizers were tried. In one a spray of water met an atmosphere of ozone and in the other the ozone bubbled through a column of water. The bubbling system appears to have been the most economical and it was the one that Mr. Tindal afterwards used.

The first public demonstration of the Tindal system of purifying water by ozone was made at the Hygienic Exhibition in Paris in 1896. The line of investigation was similar to that pursued by Van Ermengen at Oudshoorn and the qualitative results were much the same. The water was filtered through sand before ozonization. Dr. Pepin, one of the men in charge of the experiment, said that where water did not contain more organic matter in solution than is represented by .004 grams of permanganate per liter, 5 cubic meters may be purified by the expenditure of 600 watts.

The third installation of the Tindal system was made at the Brussels International Exhibition by Professor Van Ermengen and Professor Leon Gerard of the University of Brussels. The research was made in order to secure information which would assist in improving the sanitary condition of towns on the Belgian coast, whose water supplies were known to be frequently inferior in quality. This apparatus had a capacity of II4,000 gallons of water per day. The cost of ozonizing water containing .I gram of organic matter per liter was about $7.25 per million gallons.

In I896 Siemens and Halske erected an experimental plant at Berlin and in I898 constructed another at Martinikenfelde. These plants proved so successful that larger ones were constructed for the towns of Paderborn and Wiesbaden. At Paderborn a battery of nine ozonizers and two sterilization towers were used. The Siemens ozonizers were made of outer glass cylinders forming one pole and an inner metal cylinder, cooled by circulating water, the other. The apparatus consisted of a cast iron box divided into three compartments. The lower compartment received the air and conveyed it to the tubes, the upper compartment was used to collect the ozone and between these two compartments was a hermetically sealed box in which the ozonizing tubes were inserted. In this middle air chamber cold water was kept in circulation and being in contact with the other high tension pole conducted the current to the glass cylinder. The ozonizers carried a current of 8000 volts. It required for the operation I H. P. per hour and gave from I3.5 to 27 grams of ozone per hour according to the amount of air passed through it and the degree to which it had been previously dried.

The sterilization towers used at Paderborn in which the water was brought into contact with ozonized air were four meters in height. They were constructed of concrete. Each complete tower was divided into three parts, a reservoir for raw water at the top, a sterilization tower and the receptacle for collecting the ozonized water. Each tower was divided by two partitions into four independent towers or shafts. The raw water flowed from the common reservoir through a four-branched supply pipe into the single towers. Here it passed through a seive and fell in a fine shower on a layer of pebbles, percolated through it, and passed when ozonized into the collecting basin, whence it flowed into the reservoir of the pumps. Each single tower was one square meter in cross section and from I5 to 20 cubic meters of ozonized air passed through it in one hour. The ozonized air circulated through the ozone apparatus and sterilization tower, a ventilating valve for admitting fresh air to replace the consumed oxygen being affixed to a suction apparatus. At the sides of every tower cascades were provided over which the escaping water flowed, thus losing any traces of dissolved ozone through contact with the atmosphere.

Elaborate precautions were taken to guard against disturbances arising from interruptions of the electric current or the action of the blowers. Arrangements were made whereby in case of such interruption the supply of water to the sterilizers was automatically shut off, thus preventing any inflow of unsterilized water into the town conduit system. If the current in one of the sets of ozonizers should be interrupted, thus stopping the formation of ozone, the lever of an electric magnet held by thecurrent dropped and closed an independent circuit, which in its turn, by electro magnetic action caused a floating conical india-rubber valve to drop and shut off the water supply to the four towers. If the air current from the blower failed a disk of aluminium, inserted into the principal air pipe and kept raised by the air current under normal conditions, dropped and likewise by electro magnetic action shut off the water supply to the towers. In either case the dropping of an indicator attached to a switchboard displayed the number of the set of the apparatus and of the tower where the trouble had occurred; while at the same time an alarm signal would ring until the cause of the disturbance was removed.

The ozone works at Wiesbaden were arranged in almost exactly the same plan as those at Paderborn. They were constructed for treating 250 cubic meters of water per hour. The plant was later given up because of the precipitate of iron brought about by the ozone. When the plant was built the water was free from iron but it gradually appeared in the water.

In I899 George A. Soper made a study of ozone purification at Columbia University. The ozone apparatus consisted of a motor circuit breaker producing 4,000 breaks per minute, an I8 inch Ruhmkorff coil and a Siemens tube. He tried several different methods of mixing the ozonized air and water but he does not give the relative efficiencies or costs. In his first experiments he simply passed the ozonized air through water in a bottle, but he soon discontinued this method owing to the difficulties of making temporary connections. He then used an atomizing process and found that the color could be reduced 83% and that the disagreeable odors were reduced a considerable amount. His analyses of Croton water before and after ozonization show a bacterial efficiency of only about 85%. His conclusions were that polluted water could be sterilized, and that colors and odors could be removed provided the water was free from organic matter.

In I903 M. Marius Otto gave an interesting paper before the Societe des Ingenieurs Civils de France entitled Les Progres Recents realises dans L'Industrie de l'Ozone. He first describes the different kinds of ozonizers and divides them into two groups;

Group I.

a. Medical apparatus.

b. Static ozonizers, cooled by air.

c. Static ozonizers, cooled by water.

Group 2.

a. Rotary ozonizers with dielectrics.

b. Rotary ozonizers without dielectrics.

After many experiments with these different machines he reaches the following conclusions;

I. The metallic rotary ozonizers are much superior from the point of yield and certainty of working to static ozonizers.

2. Although the yield of the static ozonizers or the rotary ozonizers with dielectrics is less high and their management very delicate he would always use them when electric power was fairly cheap.

He also says that the two important questions connected the ozone purification are the economic production of ozone and a proper means of mixture.

At the present time there is a five million gallon plant at Nice, France which uses the Otto-Abraham

Marmier system. In this ozonizer one set of electrodes is formed by two glass plates coated on the outside with tin-foil, and the other electrode is a set of grounded cooling coils. The ozonized air is drawn from the generator to a glass injector, which draws in the raw water at the same time. After this mixing the water passes through chambers filled with smooth flint stones.

The Russian Army uses an apparatus for ozone purification which is carried on two cars, an apparatus car and a sterilizing car. On the apparatus car is a benzine motor, an alternating current machine, a small water pump and a blower. On the sterilizing car are eight ozone tubes, a transformer, three preliminary filters and a sterilizing tower. This plant can purify 500-600 gallons per hour.

In 1906 Mr. George Whipple in an address before the American Water Works Association said "In the half dozen or so plants where ozone has been tried in Europe it is said only one is in regular use. A second one is used at intervals and a third is operated occasionally for the benefit of visitors."

In the United States an ozone plant has been built at Ann Arbor, Mich. The water is taken from the Huron River, and passed through a battery of aspirators in direct connection with an ozone chamber. The raw water in passing through the aspirators draws in the ozonized air, and then the water passes over baffle plates covered with gravel. The water is passed through three of these sterilizers in all. This plant is capable of treating one million gallons of water a day. The raw water contains about 2400 bacteria per c.c., while the average of the treated water is about 5. The exact cost of the ozone cannot be determined. The system used is known as the Bridge system.

An experimental plant of the same type has been built at Baltimore by the Baltimore County Water & Electric Co. They are able to treat 8000 gallons of water per day.

Another process known as the Gerard Process, which was designed by Prof. Leon Gerard of Brussels University Belgium, has been used to some extent in this country. The patent is held by the Gerard Ozone Process Co., who make small apparati for experimental and commercial use. A small one has been used in the Biological Department at the Institute, and we tried it with a few tests. The efficiency was very good, but we were unable to obtain the cost of the ozone.

The Gerard Co. has established a small plant in a Pittsburg hospital. This plant is used to fumigate rooms in the hospital as well as purifying water.

THE OZONE APPARATUS.

In our experiments the ozone was produced by a silent discharge of electricity through dried air. The electric energy required was furnished by the alternating current from the Institute power supply. The needed voltage was procured by the use of a transformer, built especially for the purpose. This transformer stepped the voltage up from 110 volts in the primary to 25,000 volts in the secondary. The supply wires were tapped and a volt-meter and a watt-meter inserted, so that the electrical energy used could be accurately determined. This information was necessary in computing costs.

The collecting and setting up of the apparatus required a great deal of time. There were many delicate glass joints to be made and it was necessary that they be made tight, so that air leakage would be eliminated. The use of so much glass in the apparatus made breaks frequent. Finally, however, this difficulty was to a large extent eliminated by the use of flexible aluminium tubing. The strong corrosive power of ozone gas made the use of either aluminium or glass very essential, these being two of the few materials available which are not rapidly attacked by ozone gas.

There were two sets of three tubes each used in the ozone generating apparatus. The electric discharge was passed through the dry air as it passed between the several tubes constituting a nest. Each set of ozone tubes consisted of two aluminium tubes and one heavy glass tube put together as follows:- each set was arranged concentrically. The innermost tube was a small aluminium one.seven sixteenths of an inch in diameter. This extended through a hard rubber cap placed over the upper end of the larger aluminium tube and reached to within about one quarter of an inch of a similar hard rubber cap covering the bottom end of the large aluminium tube. This small tube was supported just above the bottom rubber cap on a small hollow hard rubber block, containing four holes. One of these holes was so located as to be a direct contimuation of the aluminium tube, while the other three holes afforded ample space for the air to pass freely out from the supporting block. Outside of the small aluminium tube was fastened the heavy one quarter inch glass tube. This tube was spaced equidistant from the small aluminium tube on all sides. The space allowed between these two was one eighth of an inch. The glass tube was fitted close down on the hard rubber cap at the bottom, and a space of one quarter inch left between its top end and the upper hard rubber cap. This tube was connected at the top end to a hard rubber block similar to the one used at the base of the smaller aluminium tube. This second block, however, had to be made somewhat larger in cross-section. Later a glass tube three eighths of an inch thick and of a higher dialectric capacity was used in place of the old glass tube. This new one was found to give slightly better results. Outside of the glass tube was placed the second aluminium tube. This tube was about one and one half inches in diameter. The hard rubber caps used were fastened firmly to both ends of this outside tube, sealing wax being used to make them air tight. At the outset some trouble was experienced by this wax becoming cracked and allowing leakage. This difficulty was overcome by fastening the rubber caps on and clamping them in place. This arrangement did away with almost all leakage here. Passages cut in the rubber caps allowed the air to pass through them. The two sets of tubes used were connected at the bottom by means of a small aluminium tube running from one set to the other. This connection gave the air used a chance to pass through both sets of tubes before being led to the rest of the apparatus. This double passage of the air through the tubes was intended to give the ozone produced a higher concentration. Before being supplied to the tubes the air was passed through a sulphuric acid dryer. Once the acid from the dryer backed up into the generating tubes, causing the glass one to be broken when the current was turned on. By substituting lime as a dryer in place of the sulphuric acid, this trouble was overcome. The tubes as arranged allowed the dried air to enter at the top end of one of the smaller aluminium tubes. It then passed down through this tube and out at the bottom through the hard rubber block. From here the course of the air was upward through the space between the glass tube and the small aluminium one, and thence down again between the outside of the glass tube and the inside of the larger aluminium one. The air then passed through the rubber cap and the small aluminium connecting tube into the second set. Here the course of the air was in exactly the reverse order from that followed in the first tube. That is, it entered through the larger tube and came out through the smaller one at the top. Electric wires from the transformer were attached to the smaller and larger aluminium tubes. The discharge passing through the air between the tubes forming a set brought about the generation of ozone. The transformer and nests of ozone tubes were enclosed in an asbestos lined case, to provide proper insulation.

There were three principal methods used for applying the ozone to the water. One made use of a filter through which the ozone and water were both passed. A second method allowed the water and ozone gas to pass through a coil of glass tubing, and the third method made use of atomizers for breaking up the water into fine particles. The object of each method was to get the water and air into the most intimate contact possible.

In the filter method the apparatus used was as follows:- a glass receptacle about eight inches in diameter and similar in shape to a bell-jar, having a hole one inch in diameter in the top, was used to build the filter in. This glass container was supported on a wooden stand with the one inch opening downward. This opening was covered with several pieces of wire gauze to keep the sand and gravel which constituted the filter from passing through it. Sand and gravel varying in size up to one quarter of an inch were used in the construction of the filter. At the bottom of the filter below the gravel several glass baffle plates about three inches square were put in to give the ozone gas a chance to distribute itself more evenly through the filter. A layer of about one inch of gravel was then added. On top of this were placed several more baffle plates. Then another layer of gravel and baffle plates was used. This arrangement was followed until the filter had reached a depth of about seven inches. A one inch layer of sand was placed on top of this. The ozone supply pipe was fitted to the bottom of the filter, the water being supplied at the top. The first test showed that the pressure behind the ozone was not sufficient to force it up through the filter when the water was applied. On the contrary, the water carried the ozone out through the bottom exit of the filter with it, and scarcely any mixing of the two was accomplished. To remedy this fault the water supply pipe was changed to the point where the exit pipe had been, the one inch layer of sand on the filter was removed and a large eight inch funnel was fastened over the top of the filter in an inverted position, and sealed carefully to make the joint water tight. The funnel was fitted with a stop cock so that the effluent could now be drawn from the top of the filter. This arrangement made it impossible for the ozone to escape from the filter without passing up through it with the water. Thus quite good contact of the two was obtained. The ozone gas which passed up through the filter was allowed to escape through the funnel. This escape was fitted with glass tubing and a stopper so that the ozone could be led from here down into a flask of potassium iodide solution. This made it possible to determine the amount of ozone passing out from the filter by filtration. A plan tried for mixing sewage with the water supplied to the filter made use of an aspirator. The sewage supply tube was connected to the suction arm of the aspirator so that the sewage and water could become very thoroughly mixed before reaching the filter. The tendency of the aspirator to become clogged made its use of little value. One of the heavy glass ozone tubes was broken by the water from the filter running back into,it. Stop cocks were fitted into the ozone supply pipe, but these did not remedy the fault. Finally a trap made of a large two-holed flask was inserted between the filter and the ozone generator. This intercepted all of the water which tended to run back and thus obviated further difficulty.

In the second method, which made use of an aspirator and a coil of glass tubing, the aspirator was supported on a stand, and so arranged that it connected at the top with the resevoir from which the water was supplied. The ozone supply tube was attached directly to the suction arm of the aspirator. The coil of glass tubing was attached to the faucet end of the aspirator. Cocks on the water and ozone supply tubes allowed the flow through them to be so regulated that a large part of the ozone was used up. It was necessary to keep a fairly large head of water in the resevoir so that the pressure due to it would be sufficient to balance the tendency of the ozone to rise into the resevoir rather than follow the course of the water down through the coil of tubing.

The third method used tended to break up the water into very fine particles in an atmosphere of ozone gas. This breaking up of the water was accomplished by making use of atomizers. These atomizers were metal ones of about twenty-five cubic centimeters capacity. The spray was directed from an atomizer tube about six inches in length. The atomizer was tightly connected with a glass tube about thirty-three inches long and two inches in diameter containing two large and two small openings. The two large openings were used, one for the atomizer connection, and the other for the ozone outlet, while the two smaller ones were used to allow the ozonized water to run out. The water was supplied to the atomizer from a resevoir kept under pressure. This pressure was furnished by a connection with the compressed air pipe, the air being at about four pounds pressure. This was necessary in order to force the water from the resevoir to the higher elevation at which the atomizer was placed. The pressure used to force the water through the atomizer was that furnished by the ozone gas. By utilizing the pressure of the ozone gas in this way, there was but one connection required to both furnish the ozone and the pressure for atomizing the water. Connections at the end of the tube where the ozone escaped were so arranged that the unused ozone could be collected in a manner similar to that in which it was collected when the filter arrangement was used.

Our Experiments.

The results of our experiments are shown on the following pages. In every case the raw water and the ozonized water were tested bacterially by a 48 hour count on agre at 20 C. The amounts of organic matter in the raw and ozonized waters were determined and other chemical analyses made. Efficiency tests were made to find the cost of the ozone used, but owing to the limited size of the mixing apparatus we do not claim that the costs are the same as they would be in actual working plants. Readings of the wattmeter were taken and the rate of flow of water computed in order to determine the cost.

To determine the concentration of the ozone a known amount of ozonized air was passed through potassium iodide solution, and the amount of iodine set free by the ozone was determined by titration with sodium thiosulphate, using starch as an indicator.

In some of the experiments water from nearby sources was used, while in other cases specially prepared water was used by the addition of pure cultures of bacteria and known amounts of nitrites.

TEST #I.

In this test the filter was used to mix the water and ozone. The ozonized air was allowed to bubble up through the water for a certain length of time as shown by the tables, and then a sample was drawn off for testing.

	Bacteria per c.c. 48 hr. agar count.	Nitrites.	Oxygen consumed.
Raw.	378,000	.040	I2.6
I0 minutes.	I,400	.020	9.3
% reduction.	99.6	50	27.8
20 minutes.	I,300	.0I6	7.6
% reduction.	99.7	60	39.7

(Parts per million.)

Concentration of ozone- 3.2 milligrams per liter of air.
Cost of ozone- $I0.95 per million gallons of water treated. (For the ten minute period.)

TEST #2.

Charles River Water.

In this test the same method was used and the cost was about the same.

	Raw.	Ozonized.
Free ammonia.	.0I26	.0I26
Albuminoid ammonia.	.2480	.2440
Nitrates.	.240	.260
Nitrites.	.005	.004
Chlorine.	36.0	36.0
Hardness.	84.3	8I.4
Ox. consumed.	I0.8	7.5
Color.	Slight	Slight
Odor.	Slight	None
Bacteria per c.c. 48 hour agar.	I80	5

% Reduction of bacteria- 97.2

TEST #3.

In this experiment the aspirator and coil of glass tubing were used as a means of mixture. It was found necessary to run the water through the tubing several times to obtain a thorough mixing so that it brought the cost up to nearly half a cent a gallon.

Charles River Water.

Bacteria per C.C.	Raw.	Ozonized.	% Reduction.
" " " "	120	5	95.8
" " " "	190	16	86.3
" " " "	160	10	93.7

TEST #4.

Specially prepared water.

	Raw.	Ozonized.	% Reduction.
Bacteria per C.C.	57,000	1,000	98.4

TEST #5.

Charles River Water.

	Raw.	Ozonized.	% Reduction.
Bacteria per C.C.	164	0	100
" " " "	164	1	99.4
Ox. consumed	32.8	22.9	30.1
Color.	Slight	Slight	None

In the remaining experiments the atomizing process was used for mixing the water and ozone. We were unable to compute the cost of ozone used in this method.

TEST #6.

Specially prepared water.

	Raw.	Ozonized.	% Reduction.
Bacteria per C.C.	1,390	40	97.2
B. Coli " " "	10	0	100.
Ox. consumed.	20.6	14.0	32.0
Color.	Slight	Slight	None

TEST #7.

Specially prepared water.

	Raw.	Ozonized.	% Reduction.
Bacteria per C.C.	1,500	27	98.3
Ox. consumed.	19.5	14.5	25.6
Nitrites.	.02	.02	None
Odor.	Pungent	None	

TEST #8.

Saugus Branch Creek Water.

The purpose of this experiment was to find the effect of ozone on turbid waters. The water was forced through the atomizer at the same rate as in the other tests using this method of mixture.

	Raw.	Ozonized.	% Reduction.
Bacteria per C.C.	32,500	24,500	24.6

TEST #9.

Fenway Water.

	Raw.	Ozonized.	% Reduction.
Bacteria per C.C.	88,200	1,200	98.7
Ox. consumed.	10.5	7.2	31.4
Nitrites.	.020	.015	25.
Chlorine.	112	108	3.6

This water had a very disagreeable odor, but after ozonization the odor was very slight.

TEST #10.

This test was made to find the effect of ozone on water containing iron. Iron solution was added to distilled water, and after the ozonized air had passed through it for several minutes a dirty yellow precipitate formed which showed that ozone was unfit to use on water containing iron.

Results and Conclusions.

When clear water was used the bacterial content was reduced considerably, averaging about 98%. It seems as if the oxidizing action of the ozone destroyed the cell walls of the bacteria by changing them into mineral constituents. The odors present were almost entirely removed and the amount of organic matter was reduced about 30%. We were unable to remove the color.

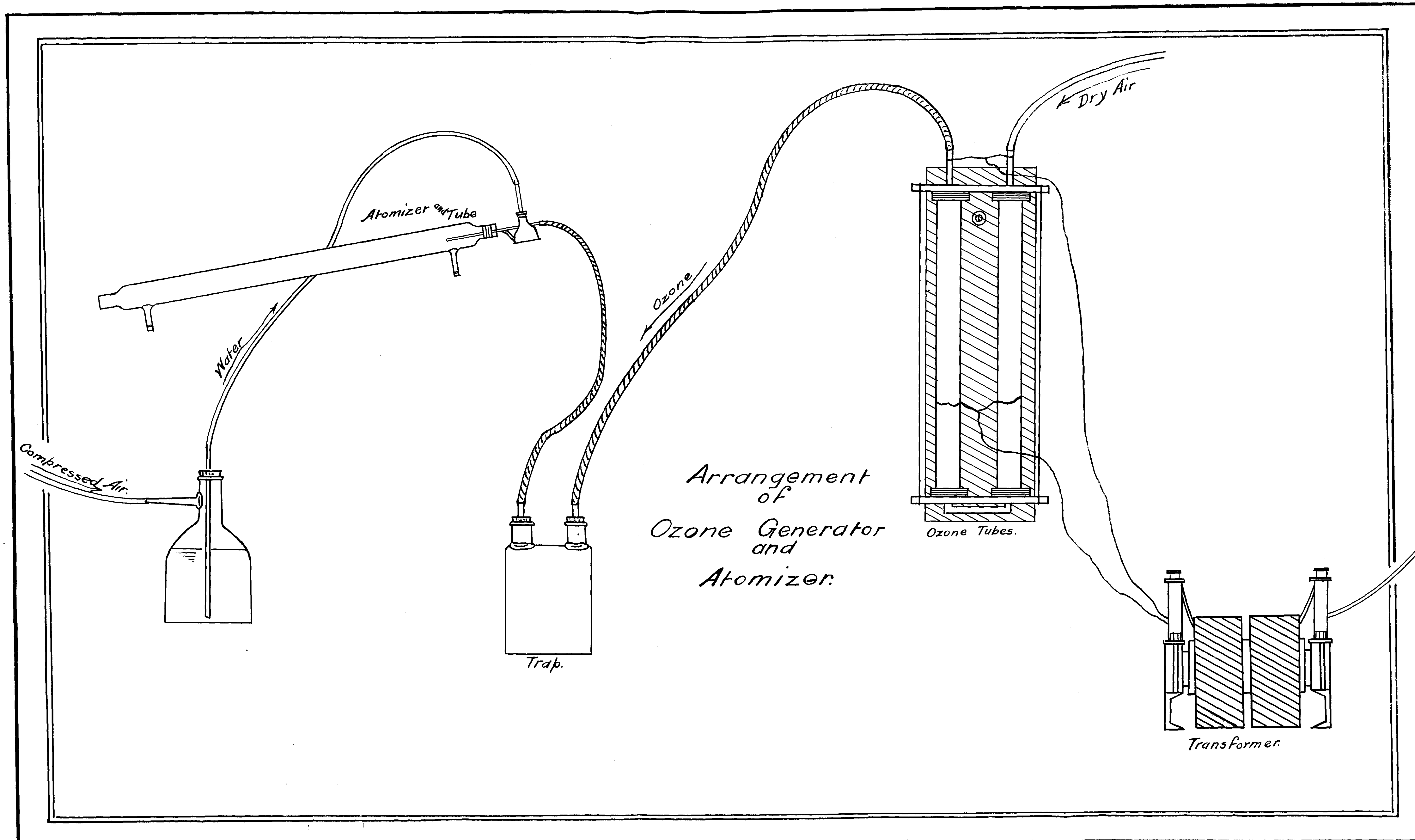
Of the three methods of mixture the method of using the glass jar filled with gravel and baffle plates was the best. The cost was quite excessive, amounting to $10.95 per million gallons. The cost of the aspirator method was so great as to be entirely out of question. The atomizing process was not satisfactory. It was very hard to keep the correct pressure in the reservoir which supplied the raw water to the atomizers, so that in some cases the ozonized air was forced through the atomizer without any water entering, while in other instances the water was forced through so rapidly that it was in the form of a stream rather than a fine spray.

When water turbid with organic matter was used the bacterial efficiency was only 24.6%, whereas by the same method an efficiency of 97.2-98.7% was obtained with clear water.

Regarding the practicability of water purification by ozone we belive that the process cannot be economically used until the cost of the production of ozone can be reduced and the manufacture and management of the apparatus can be simplified. There are several parts to the apparatus which easily get out of order, and it took a greater part of our time to repair such accidents. In any plant it would necessitate the services of an electrician in addition to the other employees. The need of preliminary filtration of turbid waters and its failure in water containing iron are great drawbacks.

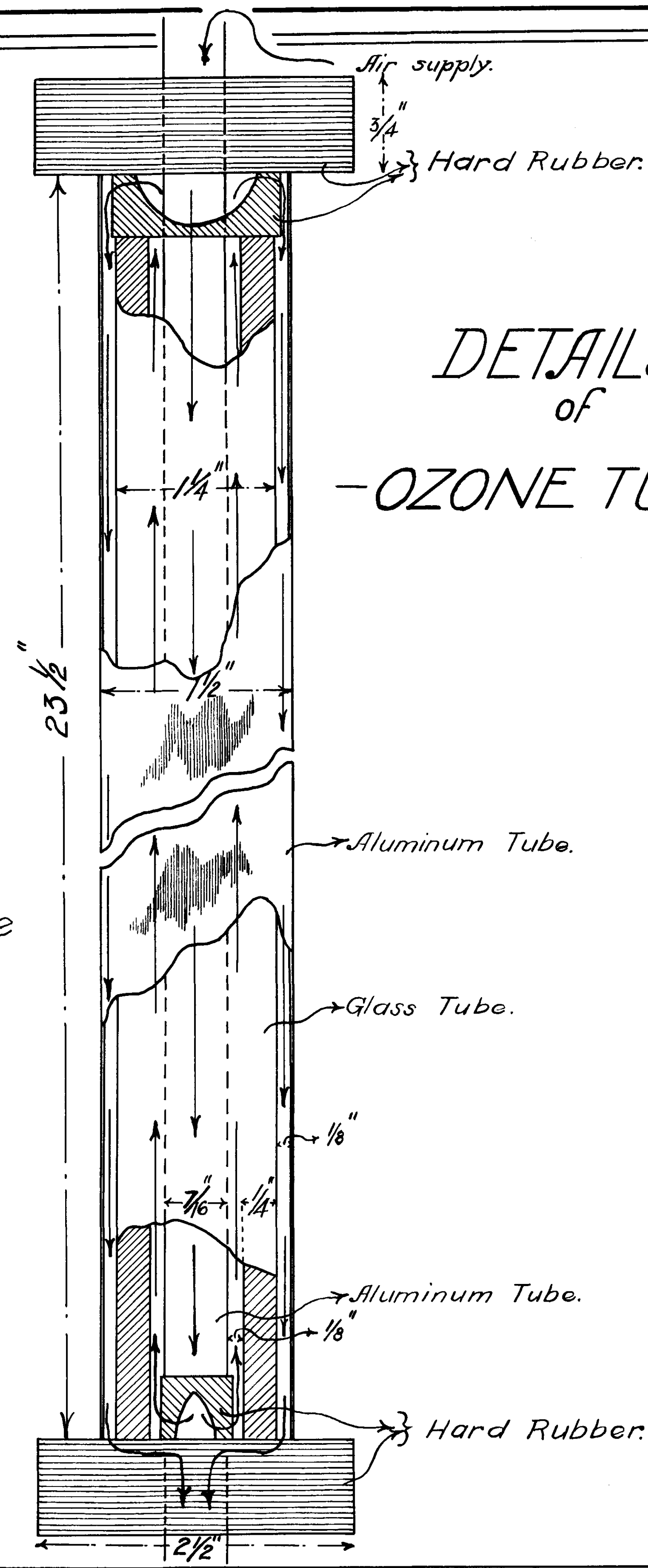
The ozone process might be used in a few instances such as an army camp, where the necessary apparatus could be carried about and where the high cost of ozone would be cheap as compared to a typhoid epidemic which it might prevent. It might also be used for sewage effluents and in factories where electric power was cheap.

We wish to thank Mrs. E. H. Richards for her kind suggestions and Mr. Royce W. Gilbert who designed the ozonizing apparatus.



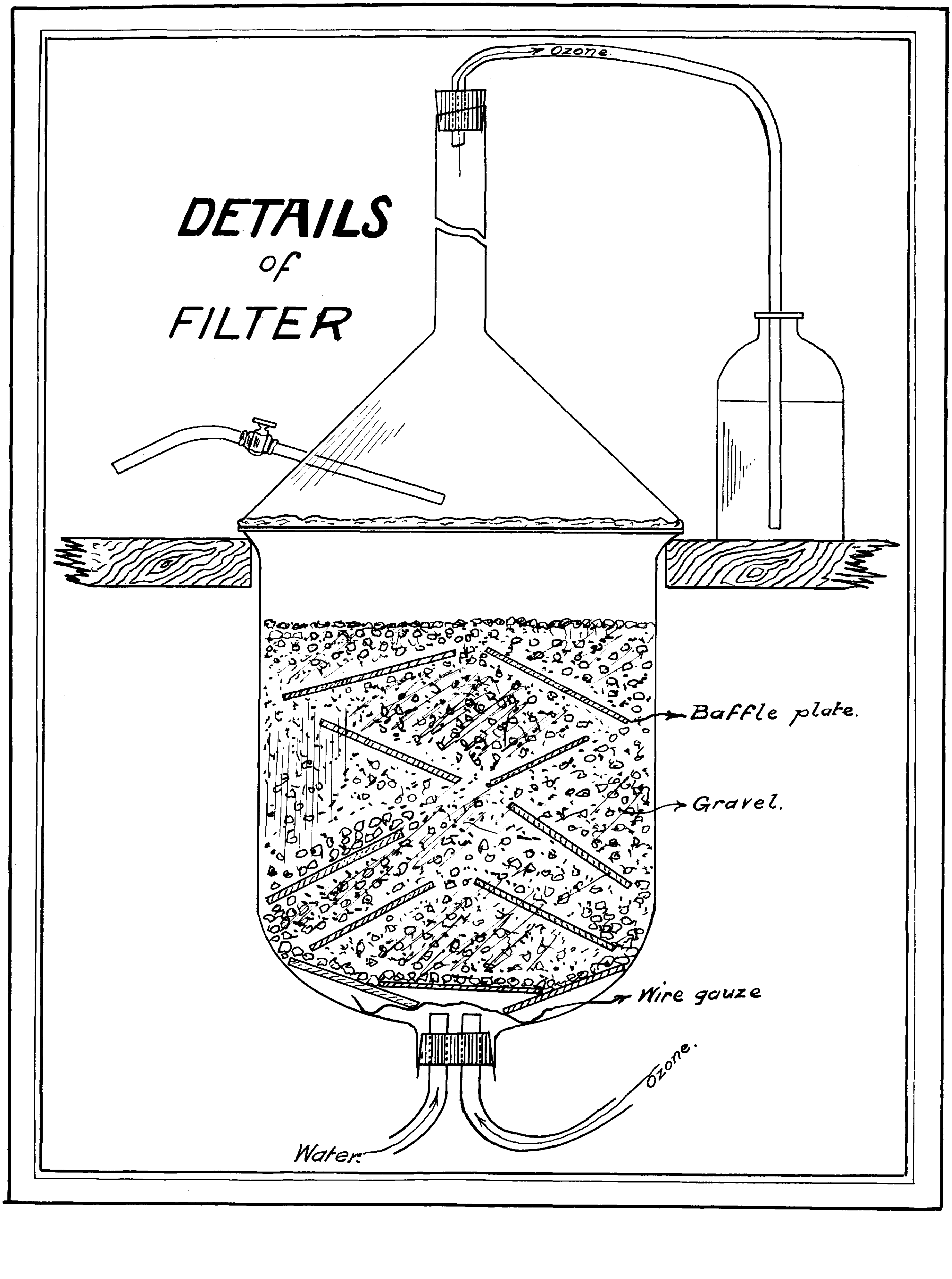
Arrangement of Ozone Generator and Atomizer.

DETAILS of -OZONE TUBE-



Note:—
Arrows indicate course of air.

Scale 3/4" = 1."


DETAILS of FILTER
Ozone.
Baffle plate.
Gravel.
Wire gauze
Ozone.
Water.