SCIENCE

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The American Association for the Advancement of Science:—

MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

*THE PREVENTION OF THE POLLUTION OF STREAMS BY MODERN METHODS OF SEWAGE TREATMENT.**

Mr. President, Ladies and Gentlemen:

When the Council of the American Association for the Advancement of Science first asked me to address you on the subject of modern methods of sewage disposal, I felt that it was not a subject of sufficient general interest, and it was only after serious consideration and many misgivings that I consented to do so.

The pollution of streams by the discharge of crude sewage has, however, now reached such a point in the more thickly settled portions of our country, that public attention has at last been called to the subject, and very many of our inland cities are now finding themselves face to face with the problem: How can sewage be treated so that it can be emptied into a stream without causing offense? Such being the case, it may not after all be out of place at a meeting of an Association for the Advancement of Science, to consider very briefly what science has done and is doing towards solution of the problem.

Sewage can be defined as the water supply of a city after it has been used. It contains the solid and liquid excreta of the

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* Complimentary address to the citizens of Pittsburgh. American Association for the Advancement of Science, Pittsburgh Meeting, June 28 to July 3, 1902.

population, household waste, the washings of the streets, and the refuse of every branch of industry. The total amount of this refuse matter varies, but on the average the sewage of a city is pure water containing one tenth of one per cent. of city waste; seven pounds in 1,000 gallons. In addition to this refuse matter, sewage contains in immense numbers, approximately 150 millions to the liquid ounce, those microscopic organisms called bacteria, and in the perfect treatment of sewage the bacteria as well as the refuse matter must be removed.

The perfect treatment of sewage, the removal of the microorganisms as well as the polluting substances, *i. e.*, changing sewage back again into a water supply, is possible, but at the present time not practicable on account of cost, and all that so far has been attempted has been to remove the polluting substances of city waste, so that after treatment the sewage will not be offensive to the sense of either sight or smell and when emptied into a stream can cause no offense.

The earliest method of sewage treatment, which, in fact, was not treatment but merely disposal, was to carry the waste products of a community into the ocean or into the nearest stream. This method, known as dilution, is allowable for cities situated on the sea, or on rivers whose flow is very large as compared to the sewage, 100 to 1, and the unfiltered water of which is not used as a water supply.

Very few cities are so fortunately situated as to make use of this method, and for most cities the treatment or purification of sewage must be considered as imperative as the obtaining of pure water. How can this be accomplished? How can the polluting substances be best removed so that the sewage after treatment can, without causing offense, be emptied into a small stream? This is one of the great sanitary problems of the day, and I shall try to give you this evening an outline of the six principal processes by which the necessary purification is to a greater or less degree accomplished.

These methods in historical order are: Sewage farming, chemical precipitation, intermittent filtration, contact bed treatment, septic tank treatment, continuous filtration.

Sewage farming is applying the sewage to cultivated land. Chemical precipitation is the adding of certain chemicals to the sewage to remove or throw down the polluting substances. The four remaining methods, intermittent filtration, contact bed treatment, septic tank treatment and continuous filtration, the so-called modern methods, are all based on the fact that the microorganisms or bacteria always present in sewage will, under proper conditions, destroy all the obnoxious substances contained in sewage.

The earliest method of sewage disposal, as I have already said, was to run the waste products of the community into the nearest river or stream. In a sparsely settled region this caused little complaint; but as the district became inhabited and the towns and villages upon the stream increased in size, it became apparent that this method, though removing the filth from one's own door, would endanger the health and comfort of a large part of the community. It was then that the question of sewage treatment became the subject of scientific inquiry. Without going into any detail as to the early work done upon the subject, I will only state that it resulted in the general adoption of either sewage farming or chemical precipitation as the best means of destroying the polluting substances contained in sewage.

Sewage Farming.—This method was based on the idea that plant life was capable, in itself, of decomposing the complex matters contained in sewage, and that its capacity to do this work was almost without limit; consequently it was thought that sewage could be applied continuously to cultivated land, and, if vegetation was not drowned out, not only would perfect purification take place, but an immense profit could be derived from making use of the polluting substances for plant food. So firmly were these ideas, especially the manurial value of sewage, implanted in the English mind, that the most marvelous undertakings were planned, and to-day at Barking one sees a tunnel which was started to carry the sewage of London one hundred miles into the interior, with the idea that the tunnel should be tapped at certain intervals and the sewage sold, at I know not what price per thousand gallons, to fertilize the land. This is hardly less startling than the idea of recovering the gold that is in sea water.

It is now well known that plant life cannot assimilate the organic matter that occurs in sewage unless it is first decomposed by bacteria, and sewage farming has resulted in failure except in those few cases where the land was of an exceptional character and of very large area, compared to the population to be served, as one acre to fifty persons. The Paris sewage farms, of which we have all heard so much, are far from being a success.

Chemical Precipitation.—The chemical treatment of sewage consists in the adding of certain chemicals, usually lime and iron sulphate, to crude sewage, allowing the sewage to run into large open tanks, through which it flows with such slow velocity that the substances which have been thrown down by the chemicals subside, leaving the supernatant liquid clear and free from all suspended matter, but containing practically all of the soluble putrefying substances that were in the sewage.

Chemical treatment of sewage is costly, averaging between forty and fifty cents per year per head of the population, and the amount of organic matter removed is only about 55 per cent. of the total organic matter in the sewage. The effluent will putrefy, and consequently cannot be emptied into a stream where the dry weather flow is less than ten times the volume of the sewage. The precipitate thrown down is difficult to treat, and if it cannot be carried out to sea and dumped, as is the case of London and Manchester, it must be pressed, and then either carted away to some unoccupied and valueless land, or be burnt. Large plants still exist, however, for treating sewage chemically, the largest of all being the London disposal works, where 183 million gallons are treated chemically each day. The plant at Worcester, Massachusetts, the largest in this country, treats about fifteen million gallons per day. A few pictures of various parts of this plant may show you that treating chemically fifteen million gallons of sewage a day is a serious undertaking.

Sewage farming and chemical treatment are now considered as methods of the past, and all the modern methods of treatment are the so-called bacterial methods.

Intermittent Filtration.—The first of these methods was intermittent filtration. As early as 1865 Dr. Alexander Müller, of Berlin, showed that by passing sewage intermittently through sand, the obnoxious substances were removed, but the explanation of why the sewage could be thus purified is of much later date. It is now known that fresh sewage contains, in immense numbers, bacteria which live on dead organic matter and which cause its decomposition. These bacteria can be roughly divided into two great groups, each containing numerous species. These groups are called the anaerobic and the aerobic groups. The anaerobic group embraces all those species that live, grow and multiply out of contact with air and light; the aerobic, those species that live, grow and multiply only in contact with air. Each group plays its own special part in the destruction of the effete matter contained in household waste. The anaerobic bacteria act first. They disintegrate the solid animal and vegetable matters, liquefy them, and bring them into solution. The aerobic bacteria act upon the disintegrated and liquefied compounds and, by a process of oxidation, change them into harmless gases or mineral substances.

For the destruction of dead organic matter both groups of bacteria are necessary; the anaerobic to disintegrate and liquefy the complex organic substances, the aerobic to change those simplified and liquefied compounds into harmless products.

By passing sewage intermittently through sand, conditions favorable to the growth, retention and action of bacteria are brought about, and the obnoxious substances are destroyed by the aid of these microscopic organisms.

The credit of showing that sewage could be purified on a practical scale by intermittent filtration through sand is due to the Massachusetts State Board of Health.

Their experiments, published in 1890, showed that all that was necessary to destroy organic matter in sewage was to provide conditions favorable to the action of bacteria. These conditions they found were fulfilled by providing suitable material on which the microorganisms could be retained; surrounding these microorganisms at certain intervals with air, and providing periods during which they could rest. A suitable material was sand, from four to five feet in depth, and the surrounding the bacteria with air at definite intervals, and allowing periods of rest, was accomplished by underdraining the sand and by allowing the sewage to flow on the sand only six hours out of each twenty-four. The combination of these conditions gave us the process called intermittent filtration.

Plants built to answer the above conditions consist of a number of sand beds, each of about one acre superficial area, carefully leveled, underdrained and divided from each other by dikes varying from three to six feet in height. Crude sewage, after passing through a grit chamber and screens to remove road washings and large floating substances, as rags and sticks, is run successively upon the various beds, none of the beds receiving sewage for a longer period than six hours out of each twenty-four, for if the beds received the sewage continuously there would be absolutely no air present at any time in the bed, and air, as we have seen, is necessary for the life of the aerobic bacteria. By applying the sewage only six hours out of the twenty-four, as the liquid drains out of the bed, air enters to take its place, and the conditions favorable to the action of both anaerobes and aerobes are maintained.

By this process from 50 to 75,000 gallons of domestic sewage, sewage not containing a large proportion of manufacturing waste, can be purified each day on one acre of sand bed area, so that the polluting substances are to such an extent removed that the liquid, as it runs away from the bed, is clear, bright, almost odorless, and can be emptied into a very small stream without fear of causing trouble.

Intermittent filtration is undoubtedly the best method that is known for the purification of sewage of cities and towns which have in their neighborhood comparatively large areas of sandy soil, but is not applicable for cities or towns which would be obliged to construct beds with sand brought from any distance. This point was quickly perceived in England, where sand is not of common occurrence, and the bacterial sewage work in England started with the problem, Can the amount of land required by the intermittent filtration method be so reduced that the construction of artificial bacteria beds will be a practical possibility?

The results of the investigations started by this problem seem to show that by allotting distinct abodes to the anaerobic and aerobic bacteria, the work of purification can be more rapidly carried on. The abode allotted to the anaerobic bacteria is called the septic tank, that allotted to the aerobic bacteria, contact beds or continuous filters.

The Septic Tank.—The septic tank, about which we have all heard so much, is only a modified cesspool, and the changes brought about in the septic tank are only the changes that occurred in the old-fashioned cesspool of our forefathers, and it is most interesting, as well as somewhat amusing, to see how the old-fashioned cesspool, which only a few years ago was regarded as a breeder of all manner of ills, is now regarded by sanitarians as a most valuable adjunct in the disposal of filth.

A septic tank is only an open or closed tank through which the sewage is run continuously, but at so slow a rate that it requires from twelve to twenty-four hours for it to pass through the tank. The sewage itself, as we have seen, contains anaerobic bacteria, and by allowing the sewage to remain in the tank out of contact of air, these bacteria increase immensely in number, and acting upon the solid and liquid substances in the tank, bring about those changes which are grouped under the name of putrefaction. In other words, the sewage is purifying itself, or, as Professor Sedgwick has recently said, we have sewage in the septic tank 'working,' as it were, like apple juice when the latter is being fermented in a cask by wild yeasts. In cider-making, sweet apple juice, charged with microorganisms derived from the dust on the skin of the apples, or from the atmosphere, or from the sides of the cask, is slowly worked over by these organisms and turned into hard cider and eventually into vinegar. In a similar way, the sewage in a septic tank, charged with anaerobic bacteria, is worked over, or fermented, by these bacteria, which in this way remove or completely change a large amount of the polluting substances, and give a product which is no longer crude sewage, but a sewage in which a large amount of the solid matter has been liquefied or changed into gas.

The change which sewage undergoes in this fermentation process is very marked.

The carbohydrates, substances like starch, sugar, wood fiber, paper, are broken down into simpler substances and partially liquefied; the nitrogenous substances, the so-called proteids, are liquefied, much in the same way that the albumen of the egg is changed when an egg goes bad; and the fats, though not so quickly acted upon, are also partially decomposed. In this process, as in all processes of fermentation, gases are evolved, and the amount given off when the process is in the most active state is not small, equaling about one cubic foot for every hundred gallons of sewage passed through the tank.

The appearance of a septic tank in action is very interesting. The liquid in the tank is very dark and opaque, the surface being, as a rule, coated over with a thick layer or crust of solid matter, through which thousands of bubbles of gas are escaping, and the energy of the action that is taking place in the tank is shown by the continual rising of large fragments of the solid matter from the bottom of the tank, and sometimes with such force that they break through the crust. The gas which these masses contain escapes and they sink again to the bottom of the tank. The rising and sinking of solid matter, with the escape of gas, give almost a boiling appearance to the tank in hot summer weather. The gas which escapes from the liquid, when closed tanks are used, is conducted off, and, containing large amounts of marsh gas, often 76 per cent., can be used in the same way as natural gas for a fuel or for an illuminant.

This self purification of sewage accomplishes almost as much as chemical treatment, removing about 50 per cent. of the putrescible substances contained in the sewage, and besides saving the cost of the chemicals used in the chemical process, leaves very much less solid matter in the tank to be removed and pressed. The odor, however, from the liquid that leaves the septic tank is often most disagreeable, differing in this way from the liquid from chemical treatment, and with a sewage containing certain kinds of manufacturing wastes, as large amounts of free acid, 20 to 25 parts in 100,000 parts, or other substances which act as germicides, the septic tank can not be used.

The great practical value of the septic tank is that—removing, as it does, half of the impurities—it reduces the amount of sand area required for the purification of sewage. By the intermittent filtration process, where the anaerobic and the aerobic bacteria are working side by side, only 50,000 to 75,000 gallons can be treated per day on one acre of sand area; by the use of a septic tank, which is providing a separate work-house for the anaerobes, about five times as much sewage can be treated on the same area. Further, the septic tank has made the English method of contact beds possible.

The value of the septic tank is now fully recognized and the process is used not only in England, but in many places in this country, and a few of the photographs I have taken I will have thrown on the screen.

Contact Bed Treatment.—This method is the result of experiments made by W. J. Dibden on London sewage. It differs from intermittent filtration in that the sewage instead of being applied slowly and allowed to drain through a bed of sand, is run rapidly into a water-tight bed, filled with a coarse material as cinders, coke or broken stone, and retained in the bed for a given number of hours, after which the liquid is quickly run out of the bed.

An English contact bed is a water-tight bed, one fourth to one half an acre in area, three to four feet deep, thoroughly drained, and filled with almost any hard, jagged material, as burnt clay, coke, cinders, stone, broken to a size that will be rejected by a quarter-inch mesh, but that will just pass through a half-inch mesh. In most places the beds are built on two levels, so that if sufficient purification is not accomplished by the first bed, the liquid from that bed can be run upon a second bed at a lower level. Such a plant is called a double contact system.

This process is not adapted for treating crude sewage, as the action of the bed is intended to be very aerobic and the method of working the process is to fill the bed as quickly as possible, usually in one half hour, with septic tank or chemically treated sewage, allowing the bed to remain full of liquid for two or three hours, and then by opening valves in the drainage system, to empty the bed, in about the same time as was required for filling.

The same bed can be used only twice, or at most three times, in twenty-four hours, and to keep it in good condition it must be allowed to remain idle one day in seven. Working in this way, about 500,000 gallons of sewage can be purified on one acre of contact beds per day, which is certainly over five times the quantity that can be purified by the intermittent filtration process.

The action of a contact bed depends on the presence of aerobic bacteria. If the filling material of a contact bed in active condition be examined, every individual piece is seen to be coated over with a slimy growth, which if removed and dried cuts like a jelly. Under the microscope the slime is found to be chiefly composed of bacteria.

It is on the presence of this slimy material that the action of the bed depends; the greater in amount, up to a certain limit, the greater the efficiency. If, however, this limit is over-reached, the void spaces between the particles of the filling material become filled up and the liquid capacity is so diminished that the bed becomes spongy and will not allow the water to drain away.

Can this growth of organisms be regulated so that the bed will do its proper work and at the same time not lose its liquid capacity? Further, is serious trouble to be apprehended from the deposition of the non-putrescible part or ash of organic substances?

These are the two points about which there is a great difference of opinion among English sanitary engineers. Many believe from the results obtained at Manchester that the growth of organisms can be regulated and that no serious trouble will be caused by the ash of organic substances. Others, being influenced by the experiments at Leeds, take the opposite view and believe that the loss of liquid capacity depends as much on the retention of the ash of organic substances similar to the humus of the soil, as to the growth of organisms, and that consequently the loss in liquid capacity, or the clogging up of the beds, cannot be prevented no matter how carefully the process is worked. They regard this as so serious a matter as to prevent the contact method from being a practical process with many kinds of sewage, especially those containing iron liquors and acid waste.

My own opinion, after careful study of the whole question, is that crude sewage cannot be successfully treated by the contact-bed method, and should never be attempted, that clarified sewage, sewage from which the solid matter has been removed by chemicals, or sewage which has undergone fermentation in the septic tank, can be successfully purified on contact beds, and that with such sewage the contact method offers a solution to the problem of sewage purification for towns or cities where large areas of sand do not occur. It is not, however, a process which can be run successfully without care and attention, and to be successful requires, as does a slow sand-water filtration plant, the personal oversight of a well-trained sanitary chemist or engineer.

A very large contact bed plant for treating 15,000,000 gallons of sewage per day, costing about $1,500,000, is now being built at Manchester, England, and a few pictures showing the construction of these beds, as well as pictures of some plants in operation, may be of interest.

Continuous Filtration.—With the diversity of opinion regarding the practical success of the contact method of treatment, there has arisen in England during the past two years a growing interest in the so-called continuous filtration methods and the one question you are sure to be asked in England is, 'What is your opinion regarding continuous filtration of sewage?' Continuous filtration is an attempt to still further increase the amount of sewage that can be treated on a given area, to treat two to three million gallons in place of 500,000 gallons per acre per day.

The methods by which this is attempted are all based on the idea that if air is supplied to the filter at the same time that the sewage is being run upon the filter, and the filter is of such a construction and so drained that fresh air continuously remains in the filter, there is no necessity for periods of rest as required by the intermittent and contact-bed methods, as the only object of periods of rest in these methods is to supply sufficient air to the bacteria.

The continuous supply of air and the continuous retention of air in the filter, the advocates of continuous filters claim can be accomplished by applying the clarified sewage in the form of fine spray, so that each drop of liquid will be surrounded by air as it enters the filter, and that air can be retained in the filter by making the filter of so open a construction and so thoroughly underdrained that the liquid cannot fill up the void spaces between the particles of the filling material.

There is much to be said in favor of these ideas, for there seems to be no reason why if air is always present the bacteria should not act continuously and thus purify a much greater amount of sewage than is possible in those methods where sewage is only run on the filter six or seven hours each day.

Theoretically it would not seem difficult to construct a filter answering the conditions required. Practically, however, it is just otherwise. It has been found no easy problem to devise automatic apparatus to convert successfully large volumes of sewage into the form of spray, or to build filters sufficiently open to ensure air always being present, and at the same time to contain sufficient filling material so that the sewage will be retained in the filter the length of time required for the bacteria to remove the organic matter. The continuous filters now being tried in England are attempts to solve this problem.

Such filters are the Scott-Moncrieff, the Ducat, the Whittaker & Bryant, the Stoddart, and what may be called the Salford filter. Of these filters I consider the Whittaker-Bryant, the Stoddart, and the Salford filters as the most important, and these three different continuous filters are the only ones that I shall at the present time try to describe. They are all merely different methods of applying septic tank or chemically treated sewage in the form of spray to a filter bed of very open construction.

The Whittaker & Bryant filter is a circular or polygonal chamber, about sixty-one feet in diameter and nine feet high, containing a central air shaft. The bottom is made of cement with a collecting drain running along one diameter, connecting with which are tile drains set herring-bone-wise. The pigeon-hole walls of the chamber and air shaft are supported on short brick columns, so that there is an air space between the walls and the concrete floor. The filling material between the outside walls and the air shaft consists of coke one and one half inches or over in diameter.

The sewage is distributed on the surface of the filter by an automatic sprinkler, into the delivery pipe of which is placed a steam pipe, so that a small jet of steam can be blown into the sewage just before it is distributed on the filter in order to raise the temperature of the sewage to about 70°. The heat, according to Mr. Whittaker, 'not only keeps the bacteria at their fullest activity, but raises the temperature of the air in the filter, thereby causing it to rise through the filter, and fresh air to enter, rendering the filter self-ventilating and self-aerating.'

A filter like the one described is calculated to treat sewage at the rate of over one million gallons per acre per day.

The largest Whittaker & Bryant plant is at Church, near Accrington. A very interesting small plant has been erected at Hyde, and is being tested by Mr. Scudder, of the Mersey and Irewell Commission.

The Whittaker & Bryant filter does treat satisfactorily a very large amount of sewage on a given area, at least one million gallons per acre. It removes the putrescible substances from the sewage and gives a product that can be emptied into a stream without causing offense. On the other hand, the construction is costly. There is much difficulty experienced in automatically converting the liquid into spray, chiefly through clogging of the holes in the distributer, and being obliged to heat the sewage in winter, which must be done, makes the cost of treatment very large.

A form of continuous filter that has attracted much attention in England during the past year is the Stoddart filter.

This is essentially only a heap of coarse coke or hard cinder, diameter two to three inches, placed on a cement floor which has a fall of one inch in three feet from the center to the collecting drains which surround, but are entirely outside, the filter. As no liquid can remain in the filter no walls are necessary and the side of the filter can be made of large pieces of the filling material, with a slight batten to increase solidity. The essential points of the filter are the slope of floor, the collecting drains and the coarseness of the filling material, free from all small particles.

The method of distribution is patented by Mr. Stoddart, and is one of the most essential parts of the filter. In principle it is very simple. It is made of zinc or galvanized iron, and consists of a number of perforated gutters, eleven in each section, two inches wide and one and a half inches deep, arranged at right angles to the supply channel. The perforations are cut in diamond shape at intervals along the upper edges of the gutters. On the under surface of the gutters are a number of small points, 360 to the square yard. The distributer rests upon the margin of the supply channel and upon suitable supports at the further end, and must be perfectly level to secure equal distribution. The clarified sewage flows from the supply channel into the gutters and over the gutters through the diamond-shaped perforations, and falls from the small points in a series of drops.

A filter such as described, and six feet deep, Mr. Stoddart claims will treat septic tank or clarified sewage at the very high rate of five million gallons per acre.

A number of small plants have been built at different places in England, and experimental plants are now being tried at Manchester and Leeds. Opinions differ greatly as to the amount of purification that can be obtained by this form of continuous filter when run at the high rate of five million gallons per acre. I think, however, it is true that when the filter is in perfect running order, this method will purify sewage at a higher rate than any form of filter yet devised. The trouble is to keep the filter in perfect running order; if any solid matter lodges in the channels of the trays, or if the trays are not kept perfectly level, the distribution becomes uneven, and the successful working of the process depends on the even distribution of the sewage on the filter. To keep the channels free from sediment, and the plates from buckling, even if this is possible, must require constant attention. Further, in this process, there is no provision for heating the sewage in winter, and, in my opinion, in cold weather the whole filter would become one mass of ice, practically stopping bacterial action.

By far the most interesting experiment on continuous filtration that is now being tried is the one at Salford, Eng. In this city a plant has been just constructed by Mr. Jos. Corbett, Borough Engineer, which is to treat from eight to sixteen million gallons of crude sewage per day. The sewage is first to be subjected to chemical treatment, to remove the suspended matter, and the clarified sewage is to be distributed continuously, in the form of spray on the filter bed.

This bed is 500 feet long, 510 feet wide, 10 feet deep, and filled with cinders passed by one half-inch and rejected by eighth-inch mesh. The method of the distribution of the sewage is novel; the chemically treated sewage runs into two delivery mains, each thirty inches in diameter, one of these connected with seven horizontal pipes, the other with eight. These pipes run the whole length of the bed, dividing it into sixteen sections, and the flow in each pipe is controlled by a valve. From each of these fifteen pipes are raised vertical pipes ten feet apart and ten feet high. Each of these stand pipes is connected at right angles with four-inch horizontal pipes which run across the bed. On the top of the bed, therefore, there is a layer of horizontal pipes ten feet apart. These horizontal pipes are fitted with vertical spray jets at every five feet, each spray pipe having two quarter-inch holes set at an angle.

The floor of the filter has a fall of two feet from inlet to outlet, and is covered with tiles raised on feet sufficiently high, about three inches, to ensure air circulation beneath the filter. The drains are underneath the fifteen large horizontal pipes at the bottom of the chamber and all discharge into a main culvert which carries the effluent into the river.

The chemically treated sewage passes from the valve chambers into one or both of the delivery mains and is delivered to any or all of the horizontal pipes; from these it passes up the vertical pipes into the four-inch horizontal pipes, and then into the spray pipes. There is a sufficient head to cause the liquid to spout out of the spray pipes to a height of from five to eight feet, and it will then fall like rain on the surface of the filter.

The dry weather flow upon the bed is to be about two and one half million gallons per acre, to be increased when necessary to five million gallons.

There is no question but that the construction of this plant is costly, but it seems to me that the chances of successful treatment are greater with Mr. Corbett's plant than by any other method of continuous filtration.

Undoubtedly, continuous filtration has certain merits, especially that of being able to treat larger quantities of clarified sewage on a given area than any other bacterial process, but even if it accomplishes all that is claimed, it is a process that requires a great deal of oversight and attention. Further, I do not see how any of these filters can give satisfactory results in very cold weather unless the sewage is artificially heated, owing to openness of construction, and applying the sewage as spray.

In conclusion I would say regarding the present status of the sewage problem: That Sewage Farming as a general method of sewage treatment is not practicable and seldom possible. That Chemical Treatment only removes a part of the polluting substances in the sewage. It is a partial or preliminary treatment, advisable only in cases where sewage contains germicidal substances, preventing the use of the septic tank. That Intermittent Filtration is the best method for the treatment of sewage of cities where sand can be easily and cheaply obtained, though the amount of sewage that can be treated per acre per day is not over 75,000 gallons, unless the septic tank is used in connection with the process. That the septic tank process is a most valuable adjunct and almost an essential part to all bacterial methods of sewage treatment.

That the contact method is not adapted and should not be used for the treatment of crude sewage, but can be considered a very satisfactory method for the treatment of sewage after it has undergone putrefaction in the septic tank.

That continuous filtration, though capable of treating much greater quantities of sewage per acre than can be done by any other method, is still in the experimental stage.

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PHYSICS AT THE PITTSBURGH MEETING OF THE AMERICAN ASSOCIATION.

THE meetings of Section B were held in the Middle Lecture Room of the Carnegie Institute. The first session of the Section on Monday, June 30, at 2:30 P.M., was taken up with the address of the retiring Vice-President, Professor D. B. Brace, on the subject 'The Group-Velocity and the Wave-Velocity of Light.' Tuesday afternoon the Section adjourned to inspect the Westinghouse works at East Pittsburgh. Wednesday morning was devoted to a joint session with the American Physical Society and Thursday noon the Section took a final adjournment for the Pittsburgh meeting.

The Section program was an unusually full one. Its forty-five titles, together with the fourteen on the program of the American Physical Society in joint session with Section B, may be roughly classified as follows: 23 were in the domain of electricity and magnetism, 22 in optics, 7 in thermodynamics, 4 in general mechanics and 3 in acoustics. The titles and a number of abstracts of the papers presented are given below. The papers were presented by the writers, except as otherwise indicated.

Contributions to the Theory of Concentration Cells: HENRY S. CARHART, University of Michigan.

The paper dealt first with concentration cells of the first class, in which two electrodes of one metal are immersed in a solution of a salt of the same metal, the density of the solution being different at the two electrodes. The Nernst theory requires that the direction of the E.M.F. within the cell be from the dilute to the concentrated solution. The author has discovered a cell in which the E.M.F. is directed the other way, viz., from the concentrated to the dilute solution. It consists of nickel electrodes immersed in solutions of nickel sulphate or nickel chloride.

The explanation given depended on the thermal E.M.F.'s at the two electrodes. Curves were exhibited showing that these E.M.F.'s increase with the density of the solution. In most concentration cells the thermal E.M.F. is from the metal to the solution; in nickel cells it is in the other direction. Hence the reverse direction of the E.M.F. of these cells. Application was made of these new facts to the explanation of the dependency of the E.M.F. of the Daniell cell on the density of the two solutions, and to the reversal of the temperature coefficient of the Daniell cell when the density of the zinc sulphate solution is only slightly over unity.

The paper next took up the other class of concentration cells in which the two electrodes are amalgams of a metal of different densities, the two amalgams being immersed in a single solution of the same metal. In these the thermal E.M.F.'s *increase* when the density of the amalgams *decreases.* The direction of the E.M.F. within the cell from the concentrated to the dilute amalgam is thus explained.

Further, since the thermal E.M.F. increases with the density of the solution, and decreases with the density of the amalgam, it should be possible to make a concentration cell with the denser amalgam in the denser solution and the weaker amalgam in the weaker solution, so that the E.M.F. of the cell would be zero. This has been found to be true.

Curves of thermal E.M.F. were shown for amalgams of different densities.

A preliminary paper will be published in the *Proceedings of the American Electrochemical Society.*