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**“The Purification of Water by Metallic Iron in
Mr. Anderson's Revolving Purifiers.”**

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It is not the object of the present Paper to enter more fully than is absolutely necessary into the chemical reactions involved in the purification of waters by metallic iron, but rather to record the results actually obtained with a considerable number of specimens of water, of various degrees of impurity, on exposing them for a time to the action of iron in a moderately fine state of division.

The Author's reasons for desiring to confine himself within these limits, are, first, considerations of space, and then, that the changes which take place under these circumstances have not been thoroughly investigated. It has long been known that important effects were produced, in depriving impure water of its dissolved organic matters, by permitting it to remain in contact with clean iron surfaces for a time. Some thirty years ago, Medlock, in a patent for water-purification, described a mode of employing iron-turnings for the purpose, which up to a certain point was no doubt successful. It was not, however, largely adopted, probably on account of the impossibility of keeping the surface of the iron free from oxidation, by which its efficiency was soon impaired, and improvements were not introduced in the methods, probably because less attention was paid to the question of pure water than is now the case. It does not seem to have been seriously pursued so far as the Author is aware, until Professor Bischof introduced and patented the use for this purpose of a form of iron now called spongy iron, iron, that is to say, which has undergone incipient fusion only, after its reduction from the ore. The iron so prepared was mixed by Professor Bischof with fine gravel to keep the individual masses apart, and was used as a filter-bed of about 3 feet in thickness. This form of filter has been successfully employed in dealing with the water of the River Nethe, which now supplies the town of Antwerp; and was continued in use there until the new revolving purifier was introduced a short time ago, on increased quantities of water being required by the town. The difficulty experienced in mere filtration through a bed of iron, is in a great measure a financial one. A

large space is occupied by the filter-beds, and a great quantity has to be employed of the rather costly material.

A full description of the works at Antwerp has been laid before the Institution by Mr. W. Anderson, M. Inst. C.E.,¹ from which it will be gathered that the great original cost of laying out the large filter-beds and stocking them with iron, interposed serious obstacles to the introduction of that system in many situations, and has led to a search for a mode of utilizing the purifying power of metallic iron, in which the necessary apparatus would be less costly, occupy less space, and employ less material. Successful experiments in this direction led to the construction of the revolving apparatus invented by Mr. Anderson, which quite fulfils all the required conditions.

About three years ago the late Professor Way and the Author, whilst experimenting upon the subject, separately made the observation, that with clean and finely-divided iron the destruction of the organic matter in water, as indicated by the reduction of the so-called albumenoid ammonia, was much more rapid than had hitherto been supposed; and a great number of experiments showed that the extreme effect must have been produced almost instantaneously, since less than half a minute's agitation brought down the albumenoid ammonia to its lowest point. The Author may at once say, that it appears never to be absolutely removed; but there is good reason for believing, as the result of experiments to be described further on, that the actively injurious forms of organic matter are destroyed. These observations led to a variety of experiments on the best mode of using pure iron.

Simple filtration through a sufficient quantity was of course amply effective for a time; but, as had been shown, the practical adoption of that system was out of the question, on account of the liability to oxidation and cementation together of the metallic particles remaining without movement. Several forms of moving apparatus were suggested, but the apparatus patented by Mr. Anderson, which embodies also an idea of Sir Frederick Abel, Hon. M. Inst. C.E., overcomes all difficulty in dealing with iron as a purifier.

The main objects in view in the employment of this revolving apparatus were to keep the iron in motion, and to be assured that the whole quantity of water passing through should be in contact with the metal for a sensible time; and further, whatever iron is brought into solution should, with the mechanical impurities, be

¹ Minutes of Proceedings Inst. C.E. vol. lxxii. p. 24.

continually carried away by the stream, to be afterwards separated by filtration through sand filters in the form of ferric oxide, to which condition it is quickly brought by exposure to the air. Mr. Anderson has fully described the apparatus in his Paper; and it only remains to say, therefore, that the perpetual friction of the particles of iron over one another, whilst the cylinder revolves, and their contact with the shelves, which, during work, lift the iron from the bottom and allow it to fall in a shower through the water, keep the surfaces of the separate grains always bright and active. The form in which iron is most effective, and, for several reasons, appears best adapted for use in this apparatus, is the borings of cast iron. In action the particles break up into small fairly-smooth plates, with few irregularities; so that by the rubbing of one grain against another the whole surface is kept clean and bright. Wrought-iron turnings do not expose so much surface in relation to their weight, and much of that surface escapes any rubbing action from the form of the coils. Granulated iron, formed by pouring molten iron into water, as suggested by Sir Frederick Abel, answers well, and, when properly prepared, exposes a fairly large surface. The material called spongy iron does not answer so well on account of the roughness of the individual masses. By friction only the prominences are brightened and a good deal of the surface becomes ineffective from the retention in the interstices of the suspended impurities of the water. On the whole, therefore, cast-iron borings are to be preferred.

The experiments now to be mentioned have all been made in the Author's laboratory, with a model apparatus constructed by Mr. Anderson, and used in every way as the large forms (Plate 12) would be used; with the same rate of flow, and the same quantity of iron in relation to the water to be purified, differing only, in that the experiments were necessarily interrupted from day to day, instead of being continuous, as in practical work they would be.

The capacity of the model revolver is $3\frac{1}{2}$ lbs., and this quantity of water passes through in from three to five minutes.

It has not up to this time been possible to examine a large number of waters, but those that have been dealt with present a considerable variety in composition, and are probably fairly representative of waters commonly met with. The first obvious effect of the iron upon an impure water is to deprive it of any colour it may have. A minute quantity of the iron is immediately dissolved, probably as ferrous carbonate, and almost immediately thrown down as ferrous oxide. After a short exposure this becomes ferric oxide, which is deposited and separated with great

ease by filtration through a very shallow layer of sand. The Author has found 4 inches of sand generally sufficient to produce a perfectly bright sample at a rapid rate of filtration; the time required for subsidence and oxidation before filtration is from five to six hours. The effect of this treatment upon the waters that have been examined is, to deprive them entirely, as seen through a tube 2 feet long, of the colour due to the presence of dissolved organic matter; and this removal of colour is accompanied by the breaking up of certain nitrogenous compounds, as shown in the analytical results, and by a great reduction in amount of the albumenoid ammonia. The Author has chosen this mode of expressing results because the method of analysis by which they are obtained permits the examination of a large number of samples, and indicates, in his opinion, the degree of impurity in ordinary waters very completely. It has been said that the action of the iron is almost instantaneous; and in some cases it is astonishingly rapid, whilst with highly polluted waters a distinctly longer time is necessary for the full effect to be produced, so that from eight to ten minutes may be required in extreme cases, in others a third of that time being sufficient. It is proved that, whilst much of the organic matter is affected by the iron, a certain proportion of it either resists its influence altogether, or undergoes only partial change; this proportion is generally represented by from one-third to one-half of the quantity that would have appeared under the head of "Albumenoid Ammonia," but the waters are in all cases deprived of the colour that impure water possesses, and are reduced to the pale-green tint of pure water.

The following Table shows the amount of albumenoid ammonia, in a million parts, in several waters that have been analysed, and includes samples varying greatly in composition, and in the original quantity of organic nitrogen.

		Before Purification in Revolver.	After Purification in Revolver.
Water from Zurich	. . . .	0·020	0·010
„ Ostend	. . . .	0·140	0·080
„ Laeken	. . . .	0·185	0·060
„ Thames	. . . .	0·150	0·060
„ Malines	. . . .	0·260	0·060
„ Antwerp	. . . .	0·200	0·080
„ Northwich	. . . .	0·110	0·040
„ Itchen	. . . .	0·080	0·040
„ New River	. . . .	0·030	0·015
„ Hertford sewage	. . . .	0·330	0·080

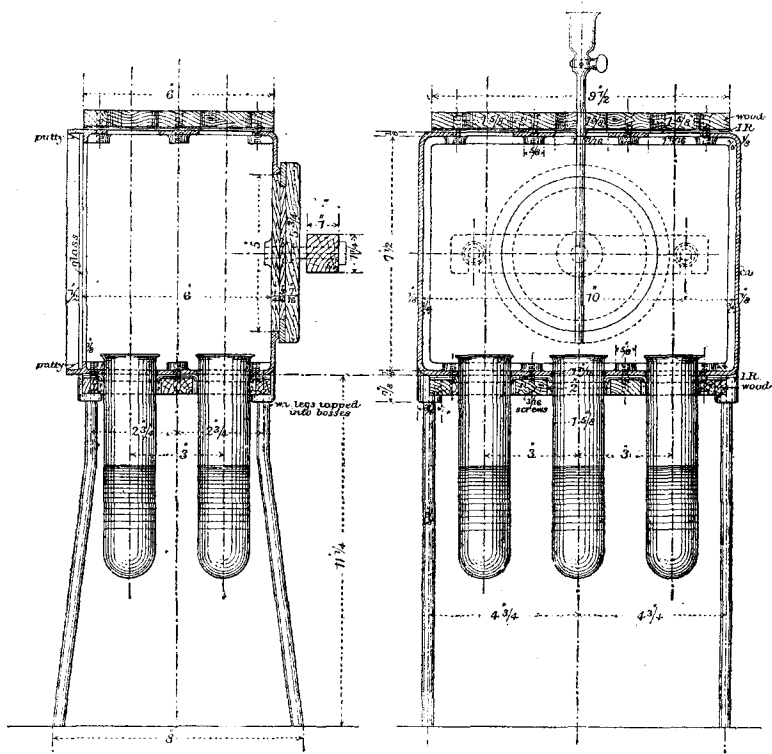
Why a certain proportion of these nitrogenous compounds resists the action of the iron, whilst the larger portion is broken

up, is not clear, but the Author hopes at a future time to be able to acquire some information upon these points. It is plain that there are two classes of compounds, one of which only gives up its nitrogen readily, either as free nitrogen, or in the form of nitric acid, or of ammonia, and it would be of the greatest importance to show, if possible, that the more stable forms are less to be dreaded in a potable water than those which are more easily decomposed. To fix upon any particular quantity of organic matter as it is now determined, or to describe the special form, that can be positively said to be injurious to health, is beyond the powers of the chemist; but if a water contains distinct evidence of animal pollution, it can be said there is danger that the source whence the pollution is derived may supply the poisonous germs of disease, whenever sickness occurs within the drainage area of that district. The time indeed seems to be near when, by the aid of the physiologist and the microscopist, it may be possible to say what special danger is to be feared from a polluted water. In the case of one of the samples on the list, viz., the Zurich water, this is said to have been done. It contains, as will be seen, less albumenoid ammonia than any other sample, and less indeed than it is usual to find in the best waters; but the report of a German physiologist shows that typhoid fever had occurred in the district supplied with water from this source; and that he had found in it a form of bacterium which, when multiplied by pure cultivation, induced characteristic symptoms in the lower animals. He was thus able to recognize as dangerous a water, which by analysis appeared to be exceptionally pure. With the knowledge of what had been done by Dr. Frankland, Professor Bischof, and the late Mr. Hatton in regard to the proof of the destructive effect of spongy iron upon the bacteria existing in water, the Author instituted some experiments upon the waters which had been treated in the revolving purifier, to ascertain if these microscopic organisms were affected by so short an exposure to the action of iron as was sufficient to effect the changes already described. The test was to be the relative power of the water, before and after treatment, to set up putrefactive fermentation in a properly prepared meat-extract. Whatever views may be held as to the germ theory of the propagation of disease, it is certain that decomposition of animal matter quickly occurs on its exposure at common temperatures to moisture and ordinary air, from which the usual dust has not been separated; but that, if the air has been deprived of dust and the organisms inseparable from it, by filtration or other effectual means, organic substances may be

freely exposed to it without undergoing change. So with water, if it be filtered through a medium sufficiently fine in texture to retain the microbes—biscuit porcelain, for instance—or be sterilized by repeated boiling, it will not induce decomposition in meat-extracts rendered specially sensitive even, and may be considered to be preservative in its effect. On the other hand, as all natural waters contain a greater or less number of the organisms that cause, or at all events accompany, fermentation or putrefactive change, either derived from the air, or more directly from drainage sources, it will be of great importance if it can be shown that they can be got rid of, or rendered innocuous, by an easily applied purifying process. Although the microbes that induce decomposition in the test meat-extracts are not necessarily, or even probably, identical with those that occasion actual disease, it is not unfair to suppose that the agency that destroys or renders inert one class of bacteria, will be fatal to all classes of them; and that if a polluted water, after being submitted to this system of purification, is incapable of inducing putrefaction, all organisms originally present have been destroyed, and that the germs of special disease acquired from drainage sources have therefore been got rid of.

The experiments, made by the Author upon waters after being in contact with metallic iron, lead him strongly to the belief that this treatment completely destroys the microbes. In most of the experiments the water, after passing through the revolver, was incapable of setting up fermentation in either hay infusion or meat-extract, although occasional failures in the experiments occurred, especially at first. These were mostly to be traced to the difficulties of excluding access of air during the operations, and to defects in the apparatus employed for the demonstration. Several forms of apparatus were used, but the two ultimately preferred by the Author may be described. The first of these, shown in the annexed figure, p. 291, provided by Mr. Anderson, resembled almost exactly the sterilizing boxes employed by Professor Tyndall, and consisted of a box, in the first place made of teak wood, and later on of thin cast iron in one casting, raised on four legs about 12 inches from the table. The front was glazed, and made perfectly air-tight with cement; in the back there was an aperture $4\frac{1}{2}$ inches in diameter, closed by a disk capable of being pressed by a cross-piece and screws tightly against an india-rubber washer, this aperture being necessary for the introduction of the test-tubes containing the meat-extract, &c. The top and bottom of the box were pierced with six holes $1\frac{1}{2}$ inch in diameter, and covered with sheets of vulcanized india-rubber $\frac{1}{8}$ inch thick;

this was firmly held by covers of wood $\frac{1}{2}$ inch thick, screwed to the top and bottom of the box, and having in them holes corresponding with those in the box itself. From the bottom sheet of rubber, disks were cut out less than an inch in diameter, so that when test-tubes of rather more than an inch across were forced through the apertures thus made, they were secured



DETAILS OF STERILIZED CHAMBER.

Scale $\frac{1}{2}$.

perfectly against access of air by the contraction of the india-rubber. Before being introduced, the tubes were filled with meat-extract or hay infusion to about one-half of their capacity. The box was now closed by screwing on the cover at the back, and the solution in each of the tubes boiled for six or seven minutes gently. It was then allowed to rest for three days. When it was known by experience that the contained air would have deposited all its

dust, with whatever germs or spores might be associated with it, and would be therefore incapable of inducing fermentation of any kind, the solutions were again boiled very gently, to destroy whatever might have fallen directly into the tubes, and the arrangement was complete. Eight or ten of these boxes so prepared were available at any time for the various trials. The Author should have said that at one upper corner of the box a small hole was made, into which was fitted a quill glass tube, bent two or three times, and stopped at the extremity with cotton-wool. This allowed the escape or entrance of air during change of temperature and barometric pressure without the introduction of dust. The water to be tested was received direct from the exit-tube of the model revolver in a test-tube sterilized by being baked in an oven, reserved for the purpose, at a temperature of 320° Fahrenheit for five hours. The tube was stopped by cotton-wool, treated in the same way, and the water to be tested was withdrawn, by forcing through the wool a pipette made of very fine tubing drawn to a point (at the upper end this pipette was also stopped with sterilizing wool), and by means of an india-rubber tube, sucking up about 1 cubic centimetre. A stout pin being now pushed through the india-rubber in the top of one of the boxes, the hole so made closing up immediately by the contraction of the india-rubber, the point of the pipette was forced through, and, when sufficiently far, directed to one of the test-tubes, any of them being able to be reached by a tube 10 or 12 inches long, owing to the flexibility of the material. Upon removing the pressure of the fingers upon the tubing attached to the pipette, the water passes in, and the air taking its place is filtered through the cotton-wool stopper, and so deprived of its dust. In the case of a considerable number of the experiments, the pipette was expanded in its upper part into a tube 1 inch in diameter, and 5 inches long, which was converted into a sand filter, so as more nearly to represent what occurs in practice, it being necessary to filter water after the iron treatment, to separate the deposited oxide of iron, &c. After filling in the sand to form the filter, the whole was sterilized in the usual way by baking for five hours. Upon the introduction into the apparatus of the water to be tested by the mode described, means were taken to maintain the temperature at about 80° Fahrenheit, and almost invariably at the end of two days a corresponding quantity of the water which had not been purified, had rendered its tube of meat-extract cloudy from the swarms of bacteria produced, whilst, if the experiment was successful, no cloudiness either in the tubes to which no

addition had been made, or in those to which purified water had been added, was perceived.

A second, and more simple, arrangement has been employed with success in many instances. It consists only of a flat glass plate 4 inches square, and a hemispherical cover accurately ground on its edges, $3\frac{1}{2}$ inches in diameter. The plate is supported upon a large sheet of thick glass, capable of holding six or eight of the smaller ones, and by screws adjustable so as to be made exactly level. This precaution is necessary, because the Author prefers to use a meat-extract, which when cold is still fluid, so that any water added to it may diffuse itself throughout the whole, without its being necessary to expose it to air long enough to mix them together by stirring, and if the arrangement is kept quite level, 3 to 4 cubic centimetres of solution may be placed in the centre of the plate, without danger of its running out to the edges. The plates and covers, being sterilized, were placed upon the larger sheet to cool; 4 cubic centimetres of the meat-extract were withdrawn from the stock preserved in a flask, by pushing a pipette through the cotton-wool stopper, and deposited in the centre of the plate, the cover being momentarily removed for the purpose. By another pipette, $\frac{1}{2}$ cubic centimetre of the water to be tested was added to the extract with the same precautions, and immediately covered up. Besides the purified water, there was always prepared at the same time for comparison, the water in its original condition, and some of the meat-extract without addition. The meat-extract employed by the Author, made according to the directions of Dr. Koch, was of beef, and neutralized, to which was added the necessary quantity of gelatine. It was, after boiling, filtered, so as to be absolutely bright, and the strength was arranged that at a temperature of 60° Fahrenheit it was just fluid.

The waters upon which most of the experiments have been made, to which the Author desires to draw attention, have been, water from the Thames, as being easily obtainable, and water from Laeken (Belgium), an impure water, of which the Author had a quantity at his disposal. In the case of the Thames water, five experiments out of seven in which it was passed through the revolver were successful, the water being completely sterilized, whilst two failed. In the Laeken water, which is taken from a stream supplying the lake in the park of His Majesty the King of the Belgians, three experiments succeeded, and one experiment failed. With the Zurich water, remarkable as being almost free from organic matter, and supposed to have occasioned much disease, the only experiment made showed that in its original

condition it rapidly developed bacteria in the meat-extract; but that it was completely sterilized after purification. With water from Northwich, in two experiments, the sterilizing effect was produced, and in one case it failed. Throughout the trials, in about four cases out of five, the mode of treating the waters that has been described has completely sterilized them; it must be understood that in every case the water not so treated was active in determining the decomposition of the meat-extracts under similar circumstances, and that comparative trials were always made with the samples in the two conditions side by side. In spite of all precaution, it is very difficult to exclude the momentary access of air during the various transferences of the water and meat-extract from the revolver to the testing-glasses, and the Author attributes most of the failures to this cause. It seems that if in the great majority of cases the organisms are destroyed, the effectiveness of the agent is established, since it is not at all likely to be capricious in its action. Considering these facts, and considering also the great reduction effected in organic nitrogen, and the removal of colour from impure waters, there appears to be reason for the belief that an economical and efficient method of water purification has been found in this mode of treatment by metallic iron; indeed, it would seem that impure waters purified by means of iron will prove safer for dietetic purposes than even good deep well or spring water, because after treatment the water can be preserved from contamination by means of covered reservoirs, or in the mains and pipes, whereas wells and springs, as numerous cases prove, may become dangerously contaminated.

The only specimen of true sewage the Author has been able at present to deal with in this way is that from Hertford, taken from the Manifold ditch below the town. The result of experiments with this liquid, so far as they were carried out, was very satisfactory. The albumenoid ammonia was always reduced to 0·08 in a million parts, and of the two experiments that were able to be made with it, after purification, one was completely successful in destroying all organisms. The second experiment, which exhausted the supply of sewage, failed from an accident to the apparatus. In the case of a water so highly polluted as this, no doubt a comparatively prolonged contact with the iron is necessary, and with this particular sample fifteen minutes were allowed.

The Paper is accompanied by a drawing from which the figure in the text has been prepared.