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THE PURIFICATION OF WATER BY MEANS OF METALLIC IRON.

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*[A Paper read at the Stated Meeting of the FRANKLIN INSTITUTE, held
Wednesday, March 19, 1890.]*

JOS. M. WILSON, President, in the Chair.

MR. DEVONSHIRE—MR. PRESIDENT AND MEMBERS OF THE INSTITUTE:

The purifying properties of the metal iron, and its beneficial action in the natural soil are well known. I desire this evening to explain to you a method by which these natural properties can be artificially applied to the purification of water. The great need of some practical method of restoring to their pristine purity sources of water supply, which have become elements of dangers and causes of disease to the numerous cities and populous centres which are

dependent upon them for the first and greatest of their daily requirements is, I think, sufficient apology for bringing the subject of my paper before your honorable INSTITUTE.

Dr. Medloch was probably the first who endeavored to make practical use of metallic iron as a purifier of water. He took out a patent in 1857 for a process in which iron wires or plates were to be suspended in tanks through which the impure water was to pass. In 1867, Dr. Thomas Spencer brought out a material which he named magnetic carbide, in which iron was the active reagent. Little, however, was accomplished on a practical scale previous to the invention by Prof. Gustav Bischof, of the material known as spongy iron.

Spongy iron is produced by heating hematite ore to a temperature of a little below that of fusion, and thus rendering it porous, or spongy in form. Dr. Bischof's material has long been utilized in domestic filters, and the spongy iron filter is at the present time second to none in its remarkable purifying properties, and in the permanence of its action during the whole period that the mass of the material remains porous.

In 1879, when a concession was obtained by an English firm for the construction of water works to supply the city of Antwerp, in Belgium, it was found that the only available source of supply was of such a nature that some method would have to be adopted to improve its appearance sufficiently to compete with that of the shallow well waters with which every dwelling in Antwerp was provided. The river Nethe, a tributary of the Scheldt, was the source selected. The water of this river is subject to various deleterious influences. It is colored with a yellow color, exceedingly difficult to remove, by the peaty nature of the country through which the river flows. It carries down at times large quantities of silt and finely divided clay. Being subject to the influence of the tide, it is affected by sewage pollution, both above and below the point where it was necessary to establish the in-take of the water works.

The commercial value of such water in a city so amply supplied with wells, as Antwerp, was from the first recog-

nized by the concessionnaires of the water supply as being very small, and it was decided to endeavor to artificially improve the water before sending it into the city. Bischof's spongy iron was the material selected as the most likely to give the desired results, and in 1879 an experimental spongy iron filter was erected at Waelhem, the site of the proposed works. Experiments were carried out on a considerable scale for several months, and gave most remarkably successful results, the impure and discolored water of the Nethe being changed into a bright, sparkling and chemically pure liquid. As a result of these experiments, permanent works were at once commenced, embodying Prof. Bischof's process. Three pairs of filters were constructed, each pair consisting of an upper basin containing a mixture of spongy iron and gravel three feet in thickness, and a lower basin containing a bed of river sand two feet thick. The river water was pumped into the upper basin, flowing through the bed of spongy iron on to the sand filter, where the oxide of iron was retained. The chemical results and the great improvement in the appearance of the water were all that could be desired, and for nearly two years it seemed that a practical process of purifying foul water on a large scale had been found. After a time, however, as the demand for water increased in the city, and the filters were required to approach their calculated output, it was found that the mass of the spongy iron mixture was caking together and becoming daily less porous. Matters at length became so serious that it was with the greatest difficulty that sufficient filtered water could be obtained to meet daily requirements. The spongy iron beds had to be dug over by manual labor, so as to loosen the material and restore in some degree its porosity.

After many expedients had been tried to overcome the mechanical difficulty of working these otherwise most efficient and valuable filters, it was pointed out by Sir Frederick Abel that means should be sought to keep the particles of iron in movement, so as to prevent their cohesion and also to maintain their surfaces clean and active.

The Consulting Engineer of the works, William Ander-

son, at the present time Director-General of Government Ordnance Factories in England,* after many experiments, hit upon the simple and ingenious plan of accomplishing the desired end by the invention of the apparatus known as the *Revolving Purifier*. Instead of allowing the water to flow downwards through a motionless mass of the purifying material, Mr. Anderson adopted as the principle of his invention *the showering down of finely-divided particles of the purifying material through a flowing stream of water*. A reference to the diagram will render the explanation of the apparatus easy of comprehension.

The apparatus (Plate I) consists of a cylinder *A*, supported in a horizontal position by hollow trunnions *B' B''*, which are capable of revolving in pedestal bearings *C' C''*. Attached to the internal periphery of the cylinder is a series of short, curved shelves *D D D*, arranged either in horizontal or diagonal rows at equal distances. A sixth row of curved shelves is replaced by a line of small square plates *H H H* which, by means of nuts outside the cylinder, can be set at an angle with the axis of the apparatus. By regulating the inclination of these plates, the shower of iron can be directed back to the inlet end of the purifier, and the tendency of the flow of water to carry forward the purifying material counteracted. Inlet and outlet pipes, *E* and *F*, enter the hollow trunnions and admit and discharge the water to be purified. As the water enters the cylinder it strikes against the circular distributing-plate *G*, and is caused to flow radially through an annular space five-eighths inch or three-fourths inch in width, the formation of a central current along the axis of the purifier being prevented by this means. The inner end of the outlet pipe carries an inverted bell-mouth *K*, which catches the fine particles of the iron carried forward by the water, and causes them to fall again to the bottom of the cylinder. One end of the cylinder is encircled by an annular spur-wheel *I*, working into gearing through which a slow rotary motion is given to the appa-

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ratus. On being started to work, sufficient metallic iron to fill one-tenth of the cylinder is introduced through the man-hole, the iron being in a suitable state of subdivision. The purifier is then filled with water through the sluice-cock *L*; the air-cock *M* being left open to allow the cylinder to fill completely. The apparatus is then set in motion, the rate of rotation being about six feet per minute at the periphery. The effect of the rotation is to scoop up the iron particles and to shower them down through the flowing water.

When designing the original spongy iron filters, at Antwerp, the calculations of their size and capacity were based upon the opinion that, in order to obtain the best results, a contact of forty-five minutes between iron and water should be allowed. Following this idea, Mr. Anderson commenced by placing spongy iron in his revolving purifier and regulating the speed at which the water flowed through the cylinder so as to obtain a contact of forty-five minutes. It was at once evident that under these conditions the apparatus would have to be of such a size as to render it impracticable for any but small volumes of water. Experiments were, therefore, made to see whether the contact might not be shortened and, to the surprise of all concerned, it was found that a contact varying from three and one-half to five minutes was sufficient to effect the complete purification of great majority of waters. Under these altered conditions, the revolving purifier became of practical utility. Further, it was discovered that when used in the revolving purifier, spongy iron had no special merit; any form of waste iron, such as cast-iron borings or plate punchings, gave equally good chemical results and were in fact preferable to spongy iron, the irregularity of whose form interfered with one of the objects aimed at in the invention, viz: *the automatic and continuous renewal of the active surfaces of the particles of purifying material by causing them to rub one against another.*

As a result of this invention, the spongy iron filters at Antwerp were replaced by a battery of revolving purifiers, three cylinders of a medium size, and contained in a building 31 feet long by 26 feet wide, being found capable of doing twice the work of three spongy iron filters whose united

area was 24,000 square feet, and in which the spongy iron alone had cost \$40,000.

The theory of what takes place in the revolving purifier and during the subsequent stages of the process is as follows :

The action on the iron in the purifier is one of reduction, the carbonic acid brought by the impure water dissolving a minute portion of the metal and forming a protosalt of iron. On issuing from the cylinder into the open air, the protosalt is gradually converted by the action of atmospheric oxygen into the insoluble form of ferric oxide (Fe_2O_3) with which we are all familiar under the name of iron rust. I need not remind any of my audience who have experience of house-keeping what are the destructive effects of iron rust on linen, the fibres of which are in general highly indestructible. The action of the ferric oxide in its nascent state in impure water is analogous to this and burns up, as it were, the organic matter. There is, however, a further action of very great importance, that of coagulation. In its formation, the ferric oxide encases in its flakes the finely divided matters held in suspension by the water, in many cases in a condition of such minute subdivision that they cannot be removed by the most efficient of mechanical filters. These matters are collected together or coagulated and form with the ferric oxide a flocculent precipitate of such a nature that it can readily be removed by rapid mechanical straining. The purification of the water is accomplished as soon as the whole of the protosalt of iron is converted into the insoluble form of ferric oxide, but to complete the process it is necessary, in the case of water intended for supplying a city, to strain out the precipitate. This is done by passing the water through filters composed of sand. Such filters may be as shallow in depth as will insure a homogeneous layer of sand. In the laboratory I have generally found three or four inches of sand ample to retain the iron precipitate, which forms a thin film on the top of the sand, leaving the lower portions of the filter perfectly clean. With large filters it would be impossible to maintain a homogeneous layer of sand as thin as this, and a depth of eighteen inches is desirable.

It will be seen that the revolving purifier is in no sense a filter and has no power of retaining any impurities in it. On the contrary, mud or other matters in suspension in the water pass freely through the cylinder, their bulk being added to it in a minute degree by the iron dissolved by the water. It is, therefore, evident that, in order to spare the sand filter, it is advantageous with waters of this description to retain as much as possible of the mud and finely divided matter in a settling trough or reservoir, to the bottom of which they will fall by their own weight when collected together into coarse flakes. Until the spring of 1889, the purified water at Antwerp flowed direct on to the sand filters along a shallow trough. Under those conditions the filters had to be cleaned on the average once a fortnight. Latterly, two subsiding reservoirs have been utilized for receiving the purified water before its filtration, and the sand filters now run six weeks without cleaning. An absolute distinction must be made between sand filters as utilized with the iron process and sand filters used alone in the ordinary way, as at London or Berlin. In the latter case, the sand bed, several feet thick, is looked to to effect, in some degree, the purification of the water. With this view the sand has to be frequently cleaned by washing it through its whole depth and exposing it to the air. With the iron process the sand serves only as a support to the film of iron oxide which it strains out of the water at its surface. It is well known how rapidly an ordinary sand filter will become foul through its whole depth; how, if water be forced through such a filter after a certain point of foulness has been reached, the filtered water will be worse than the unfiltered. With the iron process this is not the case. Purification is completed by the time the water reaches the sand. As a proof of this I may mention that sand filters have been at work at Antwerp for more than five years, that they have never been cleaned below the surface, and yet, at the present time, the water issuing from them contains no free ammonia at all and less than $\frac{1}{10}$ of a part in a million of albuminoid ammonia; the river water containing on the average $\frac{3}{10}$ of a part in a million

of each of these forms of ammonia. In the process of purification the aeration of the water as it leaves the revolving purifier plays a very important part. Purification can hardly be said to commence until the oxidizing action of the air begins the conversion of the protosalt into ferric oxide. To aid the natural aeration it is frequently advantageous to resort to artificial means by blowing air through the water. On Plate II, which gives a view of the general arrangement of purifiers at Antwerp, is shown a simple method by which artificial aeration may be accomplished. The first portion of the shallow trough which receives the water issuing from the purifiers is provided with a perforated false bottom through which air from a rotary blower rises in countless bubbles.

Time will not allow of describing the numerous applications of this process on the large scale to waters of very varied compositions, but I may state that the average results obtained are as follows: Firstly, all color is removed from water. Secondly, oxidizable organic matter, as measured by its power of reducing permanganate of potash, is reduced in proportions varying from forty-five to ninety per cent., according as the organic matter is principally of vegetable or of animal origin. Thirdly, free ammonia and nitrous acid are entirely removed. Fourthly, albuminoid ammonia is reduced from sixty to ninety per cent. Lastly, but in the opinion of, I believe, the majority of scientific men of the present day, most important of all, micro-organisms are entirely destroyed or removed by this process. As Resident Engineer and Manager of the Antwerp Water Works from the date of their construction, I have followed both the spongy iron process and the Anderson's revolving purifier in all their stages. Knowing what a remarkable standard of purity we had reached, I asked the Board of Directors of the company to appoint a commission of the most eminent chemists in Belgium to make weekly analyses of the water, both as to its chemical purity and as well as to its freedom from micro-organisms. This was done, and analyses were made weekly during the whole of last year by Prof. C. Blas, of Louvain University; Jorissen, of Liege University; Swarts

and Van Ermengem, of Ghent University. The last-named is recognized in Europe as a great authority on microbes. The examination of the water for microbes was made by Dr Koch's celebrated gelatine test, which is no doubt familiar to most present. Quarterly reports were made by the Commission, giving the results of the weekly analyses. Each of these reports stated that the very impure and dirty water of the river Nethe was transformed by the process of purification into a liquid equal, from a hygienic point of view, to the purest and most healthy spring water. I have here the final report of the Commission, which gives a *résumé* of the weekly analyses of the whole of the year 1889. The authoritative statements it contains are of such great importance that I may be permitted to translate extracts from it:

"The analyses were made every week, thus constituting a sort of permanent inquiry into the chemical and hygienic quality of the water.

"The concordant results of these numerous analyses have once more confirmed the opinion of all those who have studied the Anderson process of purification. This process, as applied at Waelhem, is of remarkable efficiency, the coefficient of purification is very high, and the water pumped into the Antwerp mains is irreproachable in every respect. The Nethe water, even after being deprived by twenty-four hours' settlement of the matter it holds in suspension, is yellow and thick, and opaque when examined through a depth of two feet. It has a flat taste. After a few days a deposit of brownish flakes forms in it. It shows an average of eighty milligrams of oxidizable organic matter to the litre, of 0.3 milligram of free ammonia, the same of albuminoid ammonia, and marked traces of nitrites.

"After purification, the water becomes limpid and brilliant in appearance. Its taste is fresh and agreeable; when seen through a depth of two feet it is transparent and of a pale green tint. After being kept for several months exposed to the light in bottles stoppered with cotton-wool, it remains perfectly limpid. This water contains, on an average, forty milligrams to the litre of oxidizable organic matter. The water never contains more than $\frac{1}{100}$ of a

milligram of free ammonia or one-tenth of a milligram of albuminoid ammonia in a litre. It is absolutely free from nitrous acid. The results of the bacteriological examination corroborate those of the chemical analysis. The purifying action of the Anderson process is here most manifest, as is shown by the almost total elimination of all micro-organisms. The water of the Nethe contains a great number of microbes. It may be estimated at an average of 50,000 colonies per cubic centimetre. After purification, water taken from taps in the city, and which has circulated through a great length of mains, contains an average of seventy-five colonies only. This number of germs is, indeed, small when compared to the number of micro-organisms which pass through filters reputed as the most perfect. But still fewer germs are found when the water is taken immediately on leaving the sand filters at the pumping station. Under the strictest conditions of experiment, we find that this water may be considered practically sterile. The number of colonies which it supplies varies from two to twenty per cubic centimetre. In no case has the Antwerp water supply disclosed the presence of bacteria of a suspicious or pathogenic kind, such as those of typhoid fever, for which search has been made with special care. It is, therefore, beyond all doubt that the process employed at the Waelhem Pumping Station offers the most complete guarantee that can be desired, in the present state of science, from the point of view of public health."

This is the result obtained under the ordinary conditions of the supply of a large city, and after the process has been continuously at work for five years. I think it may fairly be claimed for the Anderson process of purification that it has proved the possibility of overcoming and counteracting, in a practical and economical manner, the great objections which generally exist to drawing the water supply of cities from the most convenient and abundant source—that furnished by the rivers on whose banks the cities have grown up.

The revolving purifier is made in various sizes designated by the diameter of the inlet and outlet pipes. These range

from the one-inch apparatus, capable of treating 5,000 gallons to the fourteen-inch apparatus, which purifies 1,500,000 gallons per twenty-four hours. The power required for rotating the cylinder is very small, ranging from 690 foot-pounds per minute for the smallest purifiers to 28,500 foot-pounds for the largest. The quantity of metallic iron used up in the process varies with the nature of the water under treatment, and with the form of iron used. At Dordrecht, in Holland, where a fourteen-inch apparatus has been in use since 1886, the consumption of iron is at the rate of fifteen pounds per 1,000,000 gallons purified, "burrs" from punching machines being the form of iron used. At Antwerp cast-iron borings are mostly used, being readily obtainable. Owing to the nature of the Nethe water more iron is dissolved, and there is a considerable waste due to the breaking up of the friable particles of the metal in this form—the total loss being about six times that of Dordrecht. Cast-iron borings are, however, considerably cheaper than plate punchings.

When sand filters already exist, as is the case with the great majority of the European cities or towns, where the water supply is drawn from a river, the capital outlay involved in applying the revolving purifier process is approximately, \$5,000 per 1,000,000 gallons required per day. When no sand filters exist, the further outlay for these varies considerably with local conditions, and with the size of the plant required. In cases where no settling basins are provided to catch the precipitate formed by the iron oxide, shallow filter beds are required of sufficient area to limit the speed of filtration to 100 gallons per square foot of sand surface per twenty-four hours. If the heaviest portions of the precipitate be arrested in settling tanks, the speed of filtration may be increased up to 200 gallons per square foot, or more with some classes of water, so that the cost of sand filters will be reduced in a more or less regular ratio to the extent of settling basins provided. For works whose output is small, say 3,000,000 or 5,000,000 gallons per day, the cost of sand filters, either with or without settling basins, may be estimated at \$15,000 per 1,000,000 gallons of daily

consumption. The whole capital outlay, therefore, for applying the revolving purifier process to small water works, would be approximately \$20,000 per 1,000,000 gallons of daily consumption. For larger quantities of water the cost per 1,000,000 gallons would, of course, be reduced.

The principal item of expense in working the revolving purifier process, is the periodical removal of the film of iron oxide from the surface of the sand beds. The cost of this may vary fifty per cent. or more, according to the provision made for arresting the precipitate by settlement in an open channel, or in a settling reservoir, before the purified water reaches the sand filters. It also varies somewhat with the nature of the water treated, the precipitate being of a finer nature in some cases than in others. At Dordrecht, in Holland, where the river water is charged with very finely divided clay, the precipitate forms with great readiness into coarse flakes, easily retained in an open trough provided with baffle boards placed six feet apart. There is no settling reservoir in this case, but the sand beds require cleaning once in three months only, the total working cost being slightly under \$2 per 1,000,000 gallons, the maximum output of the works being 1,500,000 gallons per diem. At Antwerp, previous to the use of settling reservoirs before filtration, the cost including supervision was \$4 per 1,000,000, calculations being based on an output of 2,000,000 daily. Of this sum \$1 was for supervision, an item which would not be increased were the output ten times as great. The recent introduction of settling reservoirs has more than doubled the life of the filtering beds, and expenses are being brought down proportionately. It may be safely estimated that for quantities of 5,000,000 gallons per day and over, working expenses will in no case exceed \$2 per 1,000,000 gallons.

Various methods are adopted for providing the small power required for the rotation of the apparatus. At Antwerp, motive-power is given by a steam-engine bolted to the wall of the purifier-house, and driving the five purifiers through a counter-shafting carried on wall brackets (Plate II). At Dordrecht, where there is a single purifier, capable of treating 1,500,000 gallons per day, the water issuing from

the cylinder actuates a reaction-wheel, which in its turn rotates the apparatus and at the same time drives a Roots air-blower.

Time allows me to give but a general description of this valuable process; more detailed information may be found by those interested both in the practical and scientific aspects which it presents, in the pamphlet published by me in 1888, and in the circular issued by the present holders of Mr. Anderson's patents, copies of which I have had the honor of presenting to your library.

It remains for me to express my most sincere thanks for the great kindness shown by the officers of this world-famed INSTITUTE, in allowing me, a foreigner, the privilege of reading this paper, and to thank you, Ladies and Gentlemen, for the kind way in which you have listened to me.

THE ELECTRICAL EXHIBITS AT THE UNIVERSAL EXPOSITION IN PARIS, 1889.

[*From the Report of Mr. CARL HERING, Delegate of the INSTITUTE.*]

ELECTRIC ORGANS.

Historical.—The first application of electricity to musical instruments having a key-board is said to have been conceived more than 100 years ago by a priest from Nivernais, named Jean Baptiste Laborde, but how it was to be applied, the record unfortunately does not state; it was, presumably, a mere vague prophecy. The real history appears to have begun in 1867-68, when an Englishman named Barker, aided by a barrister named Peschard, constructed the first electric organ in the church of St. Augustin at Paris. The principle appears to have been simply to open the valves of the organ pipes by electro-magnets, the circuits of which were closed by contacts at the key-board. This did not prove very satisfactory, owing to the large battery-power required, not only in the number of cells but also in their capacity. To overcome this important objection, Messrs. Schmoele & Mols, of Philadelphia, devised an