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## PURIFICATION OF WATER BY ELECTRO-OSMOSE

EDWARD BARTOW AND R. H. JEBENS

A new method for the purification of water was shown me in the summer of 1928 in the laboratory of Phillips and Pain in Paris, France. The process was just being developed in France. It had been discovered in Germany and was there controlled by the Elektro-Osmose, A. G. At the present time, May, 1930, it is reported that many installations are in operation in Germany and France. The International Filter Company has obtained the rights for the United States and is installing machines.

To prepare pure water by distillation, it must be vaporized and condensed. To change water from the liquid to the vapor state requires a considerable amount of heat and to condense the vapor requires a considerable amount of cold. Usually coal or some fuel is used to supply heat. If coal is replaced by electricity, it is only at a greatly increased cost and the method is not considered practicable. The use of electricity in the electro-osmose process accomplishes the removal of salts by the electric current, with very little increase in temperature and therefore with much less cost. The amount of water used in condensing the vapor in the distillation process is much more than the water wasted in the electro-osmose process and hence we have here a further saving.

The purification of water is accomplished by the removal of salts from a central section of a cell through diaphragms to cells containing anode and cathode poles. By passing the water through the central compartment of a series of cells the water in the central compartments becomes gradually purer and purer until the anions and cations are practically all removed. The water so purified, it is claimed by French<sup>1</sup> and German<sup>2</sup> writers is equivalent to distilled water and can be obtained at a much lower cost.

In order to check these claims, and to test the applicability of the apparatus to local water, an apparatus manufactured by Elektro-Osmose, A. G. was obtained from the International Filter Company. The apparatus which has been described elsewhere<sup>3</sup> is made up of ten cells placed side by side. The purified water passes

<sup>1</sup> Paul Patin, *Chimie et Industrie* 19, 205 (1928).

<sup>2</sup> K. Illig, *Z. Angew. Chem.* 23, 126 (1917).

<sup>3</sup> A. S. Behrman, *Ind. Eng. Chem.* 19, 1229 (1927).

by siphons through the central compartment of each cell. The anode and cathode waters are removed by wash water, which is fed from dripping nozzles and escapes from overflow pipes in the anode and cathode cells respectively. Cells 9 and 10 are washed with purified water.

The efficiency of the apparatus depends on the amount of current used, the amount and quality of purified water, and the amount of flow of the wash water. The quality of the water was judged by determining the electrical resistance, alkalinity, chloride, residue and ash. The resistance was determined by usual methods. The apparatus used gave a value of 176,000 ohms for the distilled water used in the laboratory. The temperature of the water tested was within  $\frac{1}{2}^{\circ}$  of  $25^{\circ}\text{C}$ . for all readings obtained. Other tests were made in accordance with methods given in Standard Methods of Water Analysis.

The apparatus is supplied with 110 volt generator current with a maximum capacity of 30 amperes. The current is passed through the cells with connections so arranged that the potential increases as the water becomes purer. When cells 1, 2, 3, 4 are in series, 5, 6, 7, in series, 8, 9 in series, and the last cell is across the buss bar, we have what is called the 4, 3, 2, 1 system of connection. The average voltage across the first four cells is 27.5; across the next three, 37; the next two, 55; and across the last cell 110 volts. As the resistance of each cell increases from cell to cell, the voltage across the first cell is considerably lower than that of the fourth cell.

The process was started by filling the cells uniformly with water in each chamber. Wash water was regulated to run at 24 liters per hour; that is 12 liters are used to wash the anodes and 12 to wash the cathodes. The current is turned on and when it begins to drop, feed water is added at 24 liters per hour. The above rates of make-up water and wash water were called standard conditions and variations in flow are compared with this standard.

Test 1. *Variation of wash water.* The wash water was varied from 12 liters to 200 liters per hour. From 12 to 49 liters per hour no difference was noted. With 200 liters, the resistance was lowered. A variation in rate from 12 to 49 liters per hour causes no change.

Test 2. *The effect of changing the rates of feed water.* Zeolite softened water was used and the rates were 15, 20, and 50 liters per hour. With 50 liters per hour, there was an increase in amperage required, an increase in the alkalinity, residue, and a decrease

in resistance. This shows the necessity for limiting the rate of flow of feed water.

Test 3. *Varying the method of connecting cells to the buss bars.* The best water was given by system 3, 2, 2, 1, 1, 1, but it required more amperes. The poorest was system 5, 3, 2. This required fewer amperes but the water contained chloride, was alkaline, had low resistance, and high residue and ash. We would conclude that the fewer number of cells connected, the better, and that the combination of many cells together, as for instance, 5, 3, 2, would be the least satisfactory.

Test 4. *Cathode wash water as feed water.* The rate of flow of wash water was made 50 liters per hour in order that sufficient cathode water might be made for use as feed water. The cathode water was collected in a drum and the precipitate allowed to settle while 50 gallons more were collected in another drum. A precipitate was formed in the center chambers of the first cells which drifted through to the rest of the cells. The precipitate consisted of calcium, magnesium, iron and aluminum, combined as hydroxides or carbonates. The quality of water deteriorated with time of operation. After 16 hours, the amperage had increased to 14, residue to 17, ash to 12.8, and methyl orange alkalinity to 4.6 with resistance decreased to 8070 ohms. At the end of 23 and 31 hours, when tests were made, the quality of the water was much worse. As would be expected the quality of the cathode water measured in terms of alkalinity was much worse than the original; the alkalinity increased from 652 to 1720 p. p. m. Under the conditions of the experiment, the use of cathode water is not to be recommended.

Test 5. *Carbon dioxide added to the cathode water with the hope of improving it.* Results were not entirely satisfactory. At first the resistance increased but at the end of 60 hours, it dropped to 2300 ohms and the alkalinity had increased to 1650 ohms. There would be no special advantage for continuous operation but a purer water was obtained during part of the test.

Test 6. *Cathode water used as feed water and zeolite softened water for washing.* No better results were obtained. The number of amperes required increased almost immediately, chloride was present in the purified water after two hours, and methyl orange alkalinity was 197. The methyl orange alkalinity of the cathode water increased from 1510 to 2500 p. p. m. There would seem to be no advantage in using this combination.

Test 7. *Effect on dissolved oxygen and other substances in solution.* The dissolved oxygen in the purified water is practically the

same as that of the feed water. The university supply from wells as used contained 1.56 p. p. m. of dissolved oxygen. The purified water contained 1.62 p. p. m. The cathode water contained 1.37 and anode water 2.63. Since oxygen is bubbling through the anode water and hydrogen through the cathode water, we would expect these changes. 15 to 20 p. p. m. of chlorine are dissolved in the anode water when the rate of flow of the feed and wash waters are each 24 liters per hour and the 4, 3, 2, 1 system of connection is used. The pH of the purified water is between 4.5 and 5 as determined by the LaMotte Standard pH indicators. The ash from the purified water is composed of from 90 to 95 percent of silica ( $\text{SiO}_2$ ).

*Observations on Operation.* When the machine is started with cells containing raw water, the current consumed is exceptionally high in some of the cells. With relatively high concentration of dissolved salts in the water, foam forms on these cells. As soon as the partially purified water reaches the foaming cells, the current used decreases and foaming ceases in an hour after the machine is started.

When zeolite water was used, a fine deposit formed on the diaphragms. Cleaning the diaphragms once a month would obviate this difficulty. If the water supply to the apparatus contains any suspended matter or sediment, the nozzles may clog. The apparatus should be seen at least twice daily to clean the nozzles. The supply tanks for washing the last two cells must be kept full of pure water. With the water used, it was found necessary to clean the cells themselves once in two weeks.

*Interpretation of Results.* In our experiments zeolite softened water and regular tap water produced water of the same quality. The current used varied from 8.7 to 9.7 amperes. Chlorides were zero, alkalinity to methyl orange was zero to 1 p. p. m; resistance 22,100 to 26,900 ohms; residues 12.8 to 14.3 p. p. m; ash 10.6 to 11.7 p. p. m. The ash from the purified water contained 90 to 95% of silica. The raw water has an average of 9.5 mgs. per liter of silica. Since 90% of ash will amount to 9.5 to 10.5 mgs. of silica per liter for the purified water, it is evident that little if any of the silica is removed from the water by the process. The material determined as silica is therefore not in solution in the water in ionic form but in molecular form, possibly of colloidal size. The residue is brown in color and turns black on heating. The ash is white or cream colored. Concentrated hydrochloric acid dropped on the ash does not cause effervescence. The loss of weight of this

residue on heating is assumed to be due chiefly to oxidation of organic material which is not removed by the electro-osmose process.

The electro-osmose process removes all but 2 or 3 mg. per liter of electrolytes. With a reduced flow of feed water, the residue and ash decreased. The resistance of the purified water did not increase. It would therefore seem that non-electrolytes were removed by the slower rate. The 3, 2, 2, 1, 1, 1 system of connection gave the purest product as measured by decrease in the amount of ash and increase in the amount of resistance.

Partially purified water obtained as with purified water at 50 liters per hour rate with a total residue of 65 mg. per liter, can be obtained at an operating cost of 43 cents per 100 gallons of water. This is on the basis of 4 cents per KWH, in a plant to give 1000 gals. of water per hour. Using barium carbonate and calcium hydroxide, the operating cost at the same rate would be 54 cents per 100 gallons of water (barium carbonate \$60 per ton, lime \$8.50 per ton.)

The cathode water contains hydroxide, the tap water contains bicarbonate. A combination of hydroxide and carbonate in the first cell in the presence of calcium causes a precipitate of calcium carbonate. Magnesium, iron, and aluminum will form precipitates in the presence of excess of hydroxide. The cathode water and tap water must therefore not be mixed in the machine. With carbonated tap water, there was less precipitation. The precipitates thus formed drift through the cells. If the solution is not saturated, they will tend to dissolve increasing the work of the last cells and some of the precipitate will eventually reach the purified water tank. If calcium, magnesium, iron and aluminum are removed by lime soda or lime barium treatment, the precipitation will be prevented. Cathode water which is essentially lime water can be used in conjunction with soda.

*Summary.* A water with a residue of less than 15 p. p. m. can be obtained from the water supply at the University of Iowa which has a total residue of 725 p. p. m. The residue is chemically inert; therefore the water will serve for most of the common uses of distilled water. Cathode water cannot be mixed with tap water for feed water without first treating the tap water with either the lime soda or lime barium treatment.

The advantages claimed by the Elektro-Osmose, A. G. were all substantiated but one. Time and energy are lost in starting the machine for the water produced is not of desired quality until an

hour after the machine is started. The cathode water could be used industrially in any process where lime water is used. The anode water could be used as bleaching and disinfecting wash water. Less than one-half the electrical energy would be required to reduce the residue from 600 to 300 p. p. m., than from 300 p. p. m. to zero.

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