

relationship between alpha-cellulose content and solubility in hot 10 per cent potassium hydroxide, no attempt was made to duplicate the time curves for the oxidized cellulose and hydrocellulose series.

From the final results as given in Figures 2 and 3 the irregularities in the time curves do not appear to affect the relationship under investigation. The samples were evidently uniform throughout, as indicated by the agreement in analysis and also by the fact that the irregularities of the alpha-cellulose and potassium hydroxide solubility curves are such that these curves approximate mirror images.

In Table I alpha-cellulose content for the sample which had been acid-treated for 8 hours was omitted because such treatment resulted in a product of such short fiber length that filtration was precluded.

The coincidence of the relationship between alpha-cellulose content and solubility in hot 10 per cent potassium hydroxide solution to a point where the alpha-cellulose content was but 75 per cent in materials degraded by such widely different methods was an unexpected result. Since the preponderance of cellulose materials for technical use contain in excess of 75 per cent alpha-cellulose, the results give

promise of wide application if combinations of oxidation and hydrocellulose formation are found to give concordant results.

The divergence of these curves for more degraded materials may be due in part to the increasing difficulty in manipulation. This is especially true for alpha-cellulose determinations.

Although the alpha-cellulose content when the potassium hydroxide solubility is known may be calculated from the equation, in practice, it is probably preferable to read the values directly from the curve.

#### Acknowledgment

The authors wish to express their gratitude to R. E. Burroughs, of the Physics Department, Research Laboratory, Eastman Kodak Company, for the derivation of the equation represented by the curve shown in Figure 3.

#### Literature Cited

- (1) American Chemical Society, Cellulose Division, Standard Method, IND. ENG. CHEM., Anal. Ed., 1, 49 (1929).
- (2) Griffin, "Technical Methods of Analysis," 2nd ed., p. 492.
- (3) Murray, Staud, and Gray, *J. Am. Chem. Soc.*, **52**, 1508 (1930).
- (4) Staud and Gray, IND. ENG. CHEM., **17**, 741 (1925).

## Purification of Water by Electroösmosis<sup>1</sup>

Edward Bartow and R. H. Jebens

STATE UNIVERSITY OF IOWA, IOWA CITY, IOWA

THE purification of water by the removal of salts from a central section of a cell through diaphragms to cells containing anode and cathode poles has been developed in Germany. By passing the water from the central compartment of a series of cells, the water in this compartment becomes gradually purer until the anions and cations are practically all removed. The water so purified, it is claimed (2, 3), is equivalent to distilled water and can be obtained at a much lower cost.

#### Apparatus

In order to check these claims and to test the applicability of the apparatus to local water, an apparatus was obtained from Germany.<sup>2</sup> This apparatus (1) consists of ten cells placed side by side. The purified water passes by siphons through the central compartment of each cell. The anode and cathode water 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 0.5 degree of 25° 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 bus 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.

#### Standard Conditions

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

#### Tests

*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.

*Test 2—The Effect of Changing 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 and residue, and a decrease in resistance. This shows the necessity for limiting the rate of flow of feed water.

*Test 3—Varying Method of Connecting Cells to Bus Bars.* The best water was given by system 3,2,2,1,1,1, but it required more current. 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

<sup>1</sup> Received May 19, 1930.

<sup>2</sup> Manufactured by the Electro-Osmose, A. G.

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 (189 liters) more were collected in another drum. In the center chambers of the first cells a precipitate was formed, 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 Cathode Water with Hope of Improving It.** The 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 pure 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 required number of amperes increased almost immediately, chloride was present in the purified water after 2 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 was practically the same as that in 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 p. p. m. Since oxygen was bubbling through the anode water and hydrogen through the cathode water, we would expect these changes. From 15 to 20 p. p. m. of chlorine were dissolved in the anode water when the rate of flow of the feed and wash waters was each 24 liters per hour and the 4,3,2,1 system of connection was used. The pH of the purified water was between 4.5 and 5 as determined by the LaMotte standard pH indicators. The ash from the purified water was 90 to 95 per cent silica ( $\text{SiO}_2$ ).

#### Observations on Operation

When the machine was 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 formed on these cells. As soon as the partially purified water reached the foaming cells, the current used decreased and foaming ceased in an hour after the machine was 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 2 weeks.

#### Interpretation of Results

In the experiments described zeolite-softened water and regular tap water produced water of the same quality. The regular tap water at the time the experiments were made was obtained from two wells. The percentage from these wells varied from 40 to 60 per cent. The electrolytes were practically all removed. (Table I) 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 per cent of silica. The raw water had an average of 9.5 mg. per liter of silica. Since 90 per cent of ash will amount to 9.5 to 10.5 mg. of silica per liter for the purified water, it is evident that little, if any, of the silica was removed from the water by the process. The material determined as silica was therefore in solution, not in ionic, but in molecular form, possibly of colloidal size. The residue was brown and turned black on heating. The ash was white or cream-colored. Concentrated hydrochloric acid dropped on the ash did not cause effervescence. The loss of weight of this residue on heating is assumed to be due chiefly to oxidation of organic material which was not removed by the electroösmosis process.

Table I—Comparison of Water from Two Wells Which Supply University of Iowa Mains with Treated Water

ION	WELL No. 5	WELL No. 1	TREATED WATER
	P. p. m.	P. p. m.	P. p. m.
Potassium	11.7	0	
Sodium	14.2	43.7	
Magnesium	12	37.6	
Calcium	156	121	
Nitrate	0.6	0.5	2-3
Chloride	33	30	
Sulfate	176	189	
Carbonate	229	342	
$\text{Al}_2\text{O}_3$	16.4	2.2	
$\text{Fe}_2\text{O}_3$	8.5	0	
$\text{SiO}_2$	8.2	10.7	9.5
	665.6	778.7	
Residue on evaporation	684	791	

The electroösmosis process removes all but 2 or 3 mg. per liter of electrolytes. With a reduced flow of feed water the residue and ash decrease. The resistance of the purified water does not increase. It would therefore seem that non-electrolytes are removed by the slower rate. The 3,2,2,1,1,1 system of connection gives 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 (378 liters) of water. This is on the basis of 4 cents per kilowatt-hour in a plant to give 1000 gallons (3785 liters) of water per hour. Using barium carbonate and calcium hydroxide, the operating cost at the same rate would be 54 cents per 100 gallons (378 liters) 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 is 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 treat-

ment, the precipitation will be prevented. Cathode water, which is essentially limewater, can be used in conjunction with soda.

### Conclusion

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 manufacturers 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 limewater 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.

### Literature Cited

- (1) Behrman, *IND. ENG. CHEM.*, **19**, 1229 (1927).
- (2) Illig, *Z. angew. Chem.*, **23**, 126 (1917).
- (3) Patin, *Chimie & industrie*, **19**, 205 (1928).

---

## BOOK REVIEWS

---

**Principles of Engineering Economy.** BY EUGENE L. GRANT. 387 pages, 12 charts, 32 tables. The Ronald Press Company, New York, 1930. Price, \$3.75.

The author has produced a concise and very readable book. His theoretical discussions are well illustrated by concrete examples, with sufficient mathematics to aid the reader to a quick understanding of his arguments. It will not only be valuable to the third and fourth year engineering student, for which it is written, but can well be studied by the consulting engineer, the plant engineer, and the executive to whom the right solution of the problems discussed is of vital interest.

The book is divided into three parts—The Arithmetic of Engineering Economy, Fact Finding in Economy Studies, and Background for Economy Studies. Of particular interest in Part I is the author's able handling of the subject of depreciation, load factors, and obsolescence. Part II, on fact finding, deals with adequate records, cost estimation, statistical data, and their co-relation. Part III is a discussion of those judgment factors and their relation to engineering economics which deal with the broader and more humanistic aspects of engineering investigations.

A number of pertinent problems follow each chapter. It is obvious that these are for the engineering student, but the lay reader may often find his specific problem there outlined. The bibliography is broad and inclusive. The book will have its appeal in that it is written for the layman as well as the engineer. It is a plain, straight-forward discussion of the principles of engineering economy, with just enough mathematics to make it interesting and, fortunately, it is unusually free from that involved, pedantic, and wordful obscurity which often burdens the economical writings of the hour. The book is recommended as a textbook for engineering students. The plant manager and engineer will find it instructive reading and an excellent reference book for the library.—CHAS. W. CUNO

**A Condensed Outline of Modern Physical Chemistry.** BY FREDERICK HURN CONSTABLE. 153 pages. Ernest Benn, Ltd., London, 1930. Price, 10 s. 6 d., net.

This brief treatise contains the following chapters, some of which comprise only two pages: Dynamical Theory of Matter, Laws of Chemical Combination, Thermochemistry, Solution, Phase Rule, Osmotic Pressure, Methods of Molecular Weight Measurement, Dissociation in Gases, Theory of Electrolytic Dissociation, Law of Mass Action, Application of Thermodynamics to Strong Solutions, Surface Chemistry, Colloid Chemistry, Catalysis, Chemical Affinity, Electrochemistry, Structure of Atoms, Solid State, Photochemistry. As the preface states, it is designed as an outline for those preparing for examination in the universities of Great Britain.

The mathematical side of the subject is emphasized, and a good working knowledge of the calculus is required to follow the development of the numerous equations. Some chapters contain a list of useful equations without derivation. Examples are given, but not always worked out in detail. The chapters on Surface Chemistry and Colloid Chemistry are relatively long, seemingly overemphasizing this part of the subject. On the other hand, a few other chapters might be made more complete. For example, in the chapter on Solutions no mention is made of

the vapor tension and distillation of liquid mixtures. The chapters on Catalysis, the Structure of Atoms, and Photochemistry are the best short descriptive accounts of these subjects that have come to the reviewer's attention. There is a good index.

The value of the book to American students would be greatly enhanced if references were given to original articles. The selection of material is excellent and the condensation remarkably well done. Misprints are infrequent, but the consistent misspelling of the names of LeChatelier and Freundlich do not seem to belong to this category.—O. F. TOWER

**Mergers in Industry.** A Study of Certain Economic Aspects of Industrial Consolidation. 205 pages. Issued by the NATIONAL INDUSTRIAL CONFERENCE BOARD, INC., 247 Park Ave., New York, N. Y., 1929. Price, \$3.00.

In presenting this report the National Industrial Conference Board has done a most constructive piece of work. The method of attacking the problem is sound and the presentation is scholarly. The conclusions are based upon a mass of statistics which undoubtedly represent the best and latest figures available to the public, are free from bias, and are on the whole logical. These figures include considerable material which should be as valuable to the investor as to the student of industry or of economic and social progress.

Anyone who has been intimately concerned with the combination movement will immediately realize that the book constitutes a much needed piece of research. Heretofore the great mass of literature on the subject has represented the investigation of conditions in a past era or the presentation of theories principally by well-meaning individuals without industrial or financial experience, by sentimental uplifters, or by those possessed of some ulterior motive. Unfortunately the men who have been most concerned with this movement have been too busy effecting industrial combinations to write about them. If the book, therefore, accomplishes nothing but the destruction of the mass of propaganda and of "old wives' tales" which have accumulated in the absence of recent and honest attempts to reach a solution upon a basis of facts, it is well worth while.

One of the admirable things about the book is its restraint and its refusal to draw conclusions where the facts required are inadequate.

The authors clearly possess a conception of the immense amount of intangibles involved in the merger movement. They realize that it is quite possible for a combination to prove economically sound even though no distinct improvement immediately appears in the profit and loss statement or in the price of the stock. They realize that decreased earnings may be due quite as much to depressed general business conditions, to a disappearing economic reason for existence of the particular business, or to the weakness of the management, as to combination per se. They realize also that even less favorable results might be obtained had a merger not been effected.

The National Industrial Conference Board has done the best job possible, but those whose work brings them in daily contact with the movement know that only a small part of the story of industrial combinations can be told by published statistics. The proof of the economic advantage of the movement is its continuance. Its extension is as inevitable as the disappearance