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ELECTRICAL TREATMENT OF SEWAGE: THE LANDRETH DIRECT OXIDATION PROCESS.*†

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I. INTRODUCTION.

THE first mention of the use of electricity in the purification of sewage is contained in an English patent, No. 1499, issued to J. Chisholm in 1856, for a process of disinfecting and deodorizing by electric or galvanic agency noxious or infected matters, such as occur in cesspools or sewers. No successful application seems to have been made of this process or of a number of other similar processes patented between the years 1870 and 1886.

Among the best known of the electrical processes is that invented by Webster, and installed experimentally at Crossness, England, in 1889, to treat London sewage. In this process the raw sewage flowed, in contact with iron electrodes, through long

* Communicated by the Author.

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troughs, each section of which was made of two, four or more longitudinal parts bolted together but insulated from each other. In the electrolysis cell a current density of 0.9 ampère maintained by an electromotive force of about 2 volts was employed. For the treatment of raw sewage it was estimated that 240 pounds of iron and 450 kilowatt hours of electrical energy would be consumed per million gallons. In this process most of the nascent oxygen liberated at the anode was consumed in oxidizing the iron of the electrode, and the oxide thus formed acted as a precipitating agent on the sludge of the sewage. The process, therefore, was mainly one of chemical precipitation by means of the oxide of iron formed by the action of the electric current.

Plants operating along the general lines of the Webster process are in use in Santa Monica, California, and in Oklahoma City, Oklahoma. While no careful studies have been reported from either of these plants, it is understood that, for a time at least, both gave satisfactory results so far as purification was concerned.

To a second type of so-called electrical process for the purification of sewage belong those in which nascent chlorine, liberated by the electrolysis of a chloride, acts as a disinfectant. A process of this kind was first developed by E. Hermite, in 1887. The sewage was mixed with chlorides of magnesium, calcium or sodium, and the liquid thus charged was passed in thin sheets or streams between electrodes. In a similar process invented by A. E. Wolff, a strong brine solution was electrolyzed, and the resulting chlorine and caustic soda were allowed to recombine in the form of sodium hypochlorite, the solution of this latter substance being used for purifying the sewage. In 1893, the sewage of about thirty dwellings at Brewster, N. Y., was treated by the addition of hypochlorite solution made in this way, under the direction of the Health Department of New York City.¹ For every million gallons of sewage treated, 1600 pounds of salt were used, and the plant required an electric current of 700 ampères at 5 volts. "This seems to have been the first plant established for the specific purpose of destroying bacteria. Before that time the removal of organic matter had been the aim."²

Extensive investigation has shown that electrical treatment of sewage is capable of practical use, but that the precipitants and disinfectants prepared by electrolysis will have the same efficiency

¹ *Eng. News*, 30, 41 (1893).

² *Water Supply Paper* No. 229, p. 27, U. S. Geol. Survey.

and no greater efficiency as when manufactured outside. As Kennicut, Winslow and Pratt point out,³ "the important question is whether electrolysis in the presence of the sewage is or is not the most economical method of preparing and applying such precipitants and disinfectants as are needed. If the problem is regarded from this practical standpoint and without vague mystical conceptions of the purifying agency of electrical energy as such (which are apt to cloud the matter in the lay mind), a sound conclusion may be reached in any given case by a careful consideration of operating costs; and this conclusion will not generally be in favor of electric treatment."

The failure of sedimentation to clarify sewage thoroughly led to the introduction in England, about 1860, of a method known as the chemical precipitation of sewage. This consists in adding to the sewage certain chemical compounds which produce a voluminous flocculent precipitate which, when the sewage thus treated is allowed to remain quiescent in a large tank for some time, settles to the bottom of the tank, carrying down with it the suspended solids of the sewage, leaving a clear supernatant liquid. The chemical compound first employed for this purpose was lime, which was added to the sewage in the form of milk of lime. The action of lime depends upon its combining with the carbonic acid and soluble carbonates in the sewage to form insoluble calcium carbonate, which in settling out carries down with it the suspended solids. The quantity of lime which it is necessary to employ depends upon the character of the sewage, an acid sewage requiring more than one which is neutral or alkaline. If too little lime is added to the sewage, sedimentation takes place slowly and it is impossible to obtain a clear effluent; on the other hand, with the addition of too much lime, varying quantities of the suspended organic matter in the sewage are rendered soluble, thus causing the effluent to be more putrescent and obnoxious than that from ordinary sedimentation.

In the Landreth Direct Oxidation Process for the treatment of sewage, both electricity and lime are employed. The efficacy of the process, as will be seen later, depends upon the combination of these agents, neither electricity nor lime alone producing such good results. The electric current liberates at the electrodes oxygen and hydrogen which in the nascent state are claimed to

³ Kennicut, L. P., Winslow, C. E. A., and Pratt, R. W.: "Sewage Disposal," 1919. John Wiley & Sons, New York.

promote the destruction of pathogenic bacteria, and a reduction of the nitrogenous organic matter to albuminoids, peptones and amino compounds, which are subsequently oxidized to nitrites, nitrates and carbon dioxide. The presence of lime furnishes not only an alkaline medium which lowers the electrical resistance of the sewage and renders the electrodes passive, thus very greatly

FIG. 1.

decreasing the quantity of iron which passes into solution from the anode, but it also aids in sedimentation. The process differs from others that employ electricity, in that purification is effected neither by the action of dissolved iron as a coagulant, nor primarily by the disinfecting action of nascent chlorine produced by electrolysis.

The Landreth process has been extensively studied at the 750,000 gallon unit installed at Elmhurst, Long Island, in 1915, by Messrs. Mason, Olsen and Mailloux, and by the Bureau of Sewer Plan of New York City; and later at Decatur, Illinois. Since then the process has been somewhat altered, and in the Spring of 1918 a plant with a million gallon unit embodying the

inventor's improvements was erected at Easton, Penna., by Mr. Landreth for demonstration purposes.

FIG. 2.

II. DESCRIPTION OF PROCESS AND PLANT.

The plant at Easton occupies a corner site, at Front and Spring Garden Streets, adjoining one of the city recreation parks, and is only two squares distant from the business centre of the city.

Its location in the heart of the residential district and the entire absence of complaints and unfavorable comments indicate that the plant is not considered a nuisance, and that the nearby residents are not annoyed by odors or other objectionable features. The plant consists of a one-story frame building, 48 feet long and 33 feet wide (Fig. 1), the interior construction of which is illustrated by the plan shown in Fig. 2.

Sewage is obtained from the Front Street sewer, an 18-inch concrete dam having been placed below the lateral which delivers it to the plant. The area drained by this sewer is 104 acres and includes two hotels and one brewery. The approximate estimate of the population tributary to the sewer is 7000.

On entering the plant the sewage passes through a coarse screen 3'6" x 4', framed with bars 0.25" thick and 1.5" deep, placed 1.5" apart from centre to centre, and is elevated by means of a 6" submerged centrifugal pump to the raw sewage flume, from where it flows throughout the plant by gravity. The raw sewage flume distributes the sewage over a flat inclined screen, 6'6" x 8', having six 0.25" perforated holes to the square inch. These perforations are made so that the smooth surface is upwards. The material caught by this screen is removed continuously by five brushes 60" in length arranged on a traveler. The sewage passes through this screen to a grit chamber and then on to a 3-foot measuring weir, the crest of which is of steel. The gauge for measuring the flow is placed four feet back from the crest of the weir, the zero of the gauge corresponding to the elevation of the weir crest. The discharge has been calculated by the Bazin formula which gave results proportional to the depth of the discharge over the weir. After being mixed with milk of lime at the spillway of the weir, the sewage passes through the electrolytic apparatus and enters the observation flume, from which it can be either passed through a sedimentation basin or discharged directly into the river.

The solid material obtained from the bar-screen which protects the centrifugal pump consists largely of paper and labels from the bottling house of a nearby brewery and amounts on an average to about 20 pounds per million gallons. Above the grit chamber the flat screen collects from two to three pails, each of three gallons, per 24 hours. The greatest part of these screenings consists of grain and hops from the brewery and vegetables from the hotel kitchens, very little faecal matter being found.

The electrolytic apparatus (Fig. 3 and Fig. 3a) consists of a horizontal cypress box, 27'3" long, 3' wide and 2'9" deep, mounted on supports 18" above the floor. The top of the apparatus, which is removable, is made in two sections bolted to the sides and made water-tight with a rubber gasket. Vents are provided in each section of the top for the gaseous products of electrolysis, and a series of valves in the bottom of the tank serve to remove any sediment that may be deposited.

FIG. 3.

Internally, the tank is divided into eleven spaces, each of which contains two banks of electrodes (Fig. 4.) mounted one above the other, giving a total of twenty-two banks of electrodes arranged in two horizontal rows of eleven each. These banks of electrodes, each of which consists of 48 mild steel plates, 10" x 16" x 3/16", spaced 3/8" apart, are placed across the tank, the plates being vertical and parallel to the sides. The 48 plates of each bank are electrically connected so that alternate plates have the same polarity. The spaces between the banks and the sides of the tank are blocked up, compelling the sewage to flow between the

$\frac{3}{8}$ " spaces between the electrodes. There are no partitions or baffle plates, the sewage flowing straight through the tank from one end to the other. The electric current passes through the twenty-two cells in series, but as these are all in the same body of liquid there is necessarily some leakage of current from one set of electrodes to another through the liquid, and the electricity which leaks in this way performs electrolysis less than twenty-two times.

FIG. 3a.

In each of the $\frac{3}{8}$ " spaces between the electrodes, two paddles or agitators are revolved, being attached to shafts passing through holes punched in the electrodes to receive them. These paddles are placed between the electrodes when the banks are assembled, their hubs being so shaped and interlocked that they remain in position to receive the shaft and insulate it from the electrodes. An electric motor drives the paddles at a speed of 20 R.P.M., the power being transmitted through the double reduction gear box and the two banks of protected bevel gears shown in Fig. 3a and Fig. 4. The two shafts for revolving the paddles are, for each two

banks of electrodes, electrically connected by means of braces in the outside mechanism for driving them; each pair is insulated from the next by a leather coupling. The voltage between two neighboring pairs of shafts is about 6, or about equal to that of two cells. This necessarily gives rise to internal cross-currents which reduce the electrolytic action, but this reduction is probably not large. A more serious result is that those shafts which act as anodes to this leakage current will become corroded electrolyti-

FIG. 4.

cally. This could be avoided entirely by omitting the connecting braces, thereby insulating each shaft from all of the others, leaving only the leakage current which may enter the same shaft, which is presumably very small, if indeed it exists at all.

As each electrode has an unobstructed area of 120.2 square inches per side, and as the 48 plates of each bank of electrodes are electrically connected so that alternate plates have the same polarity, each bank contains 5649.4 square inches of positive and negative electrode area respectively. The total positive and negative electrode area in the electrolytic apparatus, which contains 22 banks of electrodes, is, therefore, 124,286.6 square inches, respectively. The total number of paddles is 2068.

With the arrangement just described, the sewage is brought into intimate contact with the electrodes, thus enabling the nascent oxygen and hydrogen to be used effectively. In its course through the tank the sewage flows for 14 feet 8 inches between electrodes, and for 11 feet 10 inches through the spaces at the ends, in the middle and through the spaces between the banks of electrodes, which latter spaces are 7 inches. Hence during about 55 per cent. of the time or distance of flow through the tank, the sewage is under electrolytic treatment, and during 45 per cent. it is not.

Experiments carried out by the inventor for the purpose of determining the life of the mild steel plates which constitute the electrodes, have shown that the total amount of iron removed from the electrodes by the current amounts to 1.41 pounds per 24 hours, and is not in any way influenced by the volume of sewage treated. This figure has been substantiated by tests made by the writers. As each plate weighs 8.33 pounds, and there are 48 plates in each of the 22 banks of electrodes, the total weight of the electrodes is, therefore, 8796.5 pounds. Assuming that two-thirds of the metal can be removed from the electrodes without rendering them useless, it follows that 5864.3 pounds of iron can pass into solution without destroying the electrodes. On account of frequent reversal of polarity, the loss of iron is distributed between all the electrodes. From the figures just given, it is evident that the life of the electrodes should be about 11.4 years, and that the electrolytic corrosion of the iron is a negligible factor. The electrodes of the tank at Easton were examined by the writers, after having been in use for many months, and showed no visual signs of wear, the edges being still sharp.

At this plant provisions are made for using either lump or hydrated lime. When lump lime is used the lumps are broken up on a 3-inch grid placed over the crusher, which reduces it to the size of cracked corn and discharges it into the boot of an elevator. A spout is provided so that hydrated lime may enter the elevator directly. The crushed or hydrated lime is elevated to a divided overhead hopper mounted above the two slaking tanks (Fig. 5), each of which is 7 feet in diameter and 3 feet high, only one of which is used at a time. The lime is discharged from the overhead hopper into either of these slaking tanks at their sides by adjustable feeding devices which are mounted on trusses supported by the sides of the tanks, and are actuated by the same motor that drives the agitator in the bottom of the tank.

Either city water or, as is generally the case, the effluent from the process is used for slaking the lime. The effluent is pumped into the bottom of either of the tanks by a one-inch centrifugal pump connecting with the observation flume and the milk of lime is discharged from the top of the tanks through suitable piping into the spillway of the weir or into the outlet pipe of the electrolytic apparatus.

The construction of the feeding device is very simple, consisting of a reciprocating link driven by an eccentric, which by

FIG. 5.

means of pawls and a ratchet actuates the feed worm. The quantity of lime discharged into the slaking tanks depends upon the number of revolutions of the feed worm and this may be controlled by changing the position of the eccentric or by varying the number of teeth engaged on the ratchet by changing the position of the pawl arm, permitting a total of 87 adjustments.

It has been mentioned previously that one of the functions of the lime is to render the electrodes passive, so that they will not be corroded by electrolytic action. After the electrodes have become passive, the crystalloids of calcium carbonate produced by the action of the lime on the sewage begin to accumulate on them. This increases the power required to rotate the paddles, which

is indicated by a watt-meter placed in the circuit of the motor that drives them. When this motor indicates 2000 watts, the addition of lime to the spillway of the weir is discontinued and it is then admitted to the outlet pipe of the electrolytic tank. Under these conditions the acid content of the sewage dissolves the crystalloid deposit without affecting the production of nascent hydrogen and oxygen. As soon as the watt-meter reading becomes normal (1000-1200 watts), the lime is again admitted to the spillway of the weir and its addition to the outlet pipe of the electrolytic apparatus discontinued.

The normal operation of this process requires that the effluent from the electrolytic apparatus shall contain 30 p.p.m. excess CaO . Should this excess be decreased, the resultant coagulation is poor, and when greatly increased the coagulation is not improved, but the crystalloid deposit upon the electrodes forms very rapidly, necessitating the reversal of the point of lime dosage at shorter intervals.

During the operation of the electrolytic apparatus, the occlusion of hydrogen and oxygen by the electrodes causes a considerable increase in resistance, and it is therefore necessary at four-hour intervals to change the polarity of the electrodes by a switch on the powerboard in order to counteract this phenomenon. This maintains the electrodes in a passive condition and keeps the resistance of the apparatus practically constant, while the production of nascent hydrogen and oxygen is unimpaired. An increase in resistance is also occasioned by electrolytic depositions on the electrodes taking place. This is indicated by a rise in the voltage of the electrolytic apparatus and a fall in the current strength. When, therefore, the voltage and the current strength attain certain values, the direction of the current is reversed and then these deposits re-dissolve.

The method of operation that has been adopted at Easton to take care of the wide variations in both the flow and the character of the sewage is exceedingly simple and ensures satisfactory results at all times, but it is much more expensive than would be the case were the sewage flow equalized, as more lime is required continuously to take care of the variations of the sewage.

The total consumption of energy *chargeable directly to the process* is that used for electrolysis, that for driving the paddles, that for pumping a portion of the effluent into the lime-mixing tank, and that for driving the stirrer and feeder of this tank.

All this energy, and none other, is measured in a sealed General Electric Company's kilowatt-hour meter attached directly to a three-phase, 60-cycle, 220-volt alternating current. Part of the current which passes through this meter operates a motor generator, which furnishes the direct current for electrolysis. That portion of the total power which as direct current passes through the electrolytic tank, is read separately on a voltmeter and ammeter; that portion which is used for driving the paddles located between the electrodes is measured on a separate indicating wattmeter.

The voltage of the individual cells ranges from 2.5 to 3.7 volts, averaging about 2.82 volts, while a current of 34 ampères is flowing.

III. EXPERIMENTAL RESULTS.

In order to determine the efficacy of the Landreth Direct Oxidation Process, an investigation was carried out at the demonstration plant at Easton, on February 18th, 19th, 20th and 21st, during which time the plant was operated under the direction and constant supervision of one of the writers and his two assistants, Messrs. O. R. Quayle and J. D. Ballard. Composite samples of both the raw sewage and the effluent were prepared from half-hour samples of these liquids, and the chlorine, nitrite, nitrate, required oxygen and dissolved oxygen were determined in the former samples immediately after obtaining them. Portions of these composite samples were sent at once to Mr. James DeLong, at Lafayette College, Easton, Pa., who made determinations of albuminoid and free ammonia. The bacteria content was determined by Dr. E. Q. St. John, of Philadelphia, in samples of both the raw sewage and the effluent taken every two and one-half hours, or oftener, during the runs. The bacteria samples were kept on ice and sent to Philadelphia daily by special messenger.

One litre of each composite sample of raw sewage and of effluent was placed in bottles of that volume, with only a small air space at the top to allow for expansion, and sent to the Chemical Laboratories of Swarthmore College, where the dissolved oxygen remaining in the samples at the end of five days and the suspended matter were determined.

Owing to the fact that the composition of the raw sewage delivered to the plant was liable to vary greatly from moment to moment, it was necessary, in order that the influence of the elec-

trolytic-lime treatment might be ascertained, to determine the time required for the sewage to pass from the point where the samples of raw sewage were collected, to that point where the samples of effluent were taken. This was accomplished by adding a suitable dye to the sewage at the first point and noting the time required for the color to appear at the second point. From the spillway of the weir, and from the entrance to the grit chamber, points at which samples of raw sewage were collected, 95 seconds, and 3 minutes, respectively, were required by the sewage to pass to the observation flume where the samples of effluent were taken. Therefore, by allowing this time to elapse between taking the samples of raw sewage and effluent, there were obtained corresponding samples. It might be of interest to mention that several of the dyes employed, as well as phenolphthalein, were decolorized while passing through the electrolytic apparatus. The individual samples of both raw sewage and effluent, of which the respective composite samples were composed, were made by dipping up three portions of 250 c.c., thirty seconds elapsing between each dip.

During the tests covered by analyses 1 to 9 inclusive, the hydrated lime was fed into the mixing vat at the rate of 856.4 pounds per 24 hours, or an equivalent of 672 pounds 90 per cent. CaO lump lime. The milk of lime so formed was added to the raw sewage at the spillway of the weir at the rate of 30 gallons per minute. The lime was found on analysis to contain:

	Per cent.
CaO	71.36
Fe ₂ O ₃ +Al ₂ O ₃	2.47
Cl	0.5
CO ₂	0.0

The purification process, *operated in the manner recommended by the inventor* (i.e., the use of electricity and lime), was tested over a period of 35.5 hours, this period being made up of a run of 14.5 consecutive hours on February 18th, during which three composite samples for chemical analysis and six samples for bacteriological examination were taken; and a run of 10 and another of 3 consecutive hours on February 19, covered by three composite samples for chemical analysis and nine samples for bacteriological examination; and a run of 5 and another of 3 consecutive hours on February 19th, covered by two composite samples for chemical analysis and 6 samples for bacteriological examination. During these three days the weather was cold and fine.

FIG. 6.

FIG. 7.

Variations in the flow of sewage during these periods are shown by the curves in Fig. 6. In this figure are indicated by the numerals, 1 to 8, the periods covered by the composite samples taken for chemical analysis, and by the letters, *a* to *u*, the times at which samples were taken for bacteriological examination.

In Fig. 7 are shown graphically the variations in the voltmeter, ammeter and wattmeter readings. The hours at which the direction of the current through the electrolysis tank was reversed are indicated by the heavy vertical lines. It will be seen that, for the most part, the current was reversed when the voltage was high and the ampérage low. Further, it will be observed that the form of the voltage and ampérage curves on February 20th is quite different from those for the two preceding days, a high voltage being necessary to maintain the normal operating current. On this day a considerable quantity of grease was observed in the effluent. It is believed that the presence of the grease considerably increased the electrical resistance of the sewage.

In Table I are given the analytical data and the average of the bacteriological data obtained for the periods indicated, for both the raw sewage and for the effluent.

As it had been suggested that the efficiency of the process was due primarily to the action of the lime which was thoroughly mixed with the sewage in the electrolytic apparatus, electricity playing but a minor part, the examination at Easton included an investigation of the efficacy of the apparatus in the purification of sewage, (1) when the raw sewage, after having been mixed with the usual quantity of lime suspension, was passed through the tank and subjected to thorough mixing by the paddles, without electricity; and (2) when the raw sewage to which no lime had been added was subjected to the action of the electric current in the tank. As the inventor was of the opinion that the electrode would be damaged by allowing the lime-containing sewage to flow through it in the absence of the electric current, or by operating it with electricity in the absence of lime, for periods longer than one hour, the tests just mentioned each extended over a period of sixty minutes. During these two periods composite samples were prepared by taking portions of both the raw sewage and the effluent at intervals of five minutes, while for bacteriological examination samples were taken every ten minutes during the

TABLE I.
Lundreth Direct Oxidation Process.
Regular Practice: Electrolytic-Lime Treatment.
R = raw sewage, E = apparatus effluent.

No. of composite sample	1	2	3	4	5	6	7	8	Average	Change	
										P. P. M.	Per cent.
Nitrogen as —	Chlorine, R	65.6	64.6	60.5	70.3	64.5	56.5	58.1	61.9	+ 1.2	+ 1.9
	P. P. M. E	77.6	65.2	44.6	60.3	61.8	64.8	67.9	63.1		
	Nitrite, P. P. M. R	0.009	0.025	0.035	0.025	0.019	0.033	0.028	0.024	+ 0.014	+ 58.3
	E	0.028	0.043	0.050	0.030	0.028	0.023	0.040	0.038		
	Nitrate, R	0.62	0.50	0.46	0.75	0.67	0.50	0.41	0.55	+ 0.13	+ 23.6
	E	0.77	0.60	0.50	0.63	0.85	0.83	0.63	0.68		
	Free Ammonia, R	17.2	.....	17.0	.....	17.8	19.8	.....	18.0		
	P. P. M. E	15.6	.....	13.9	.....	14.4	14.8	.....	14.7	- 3.3	- 18.3
	Albuminoid NH ₃ , R	27.9	.....	32.2	.....	29.3	29.6	.....	29.8		
	E	26.3	.....	28.1	.....	25.2	25.3	.....	26.2	- 3.6	- 12.1
Dissolved Oxygen	Required oxygen, R	71.2	65.8	61.9	74.9	64.5	59.0	59.5	63.5	- 13.0	- 20.5
	E	54.1	58.6	43.6	55.4	51.2	52.0	46.2	50.5		
	Determined immediately, P. P. M. R	3.88	(6.55)	4.26	5.09	5.22	3.98	4.14	4.35	+ 1.78	+ 40.9
Dissolved Oxygen	E	7.39	5.76	5.76	6.40	6.20	5.14	6.22	6.13	Standing: in P. P. M. R = 4.17, E = 0.77; in % R = 95.9, E = 12.6	
	Determined after 5 days (10-15), P. P. M. R	0.21	0.19	0.15	0.22	0.28	0.09	0.05	0.18		
	E	6.70	5.57	4.11	6.14	5.75	4.06	4.98	5.36		

Suspended solids, P. P. M.	256	268	169	293	271	193	251	182	235		
Temperature, °C.	7.4	7.5	7.5	7.7	7.9	7.9	8.9	9.1	8.0		
	8.1	8.3	8.4	8.6	8.8	8.8	9.7	9.9	8.8		
Total count per c.c. at 37°	215000	155000	250000	312000	475000	425000	527000	603000	370000		
Total count per c.c. at 20°	28000	6000	27400	25000	37000	20300	32300	37300	26800		-343200
B. coli per c.c.	500000	455000	625000	530000	550000	757000	1017000	1533000	746000		-688000
	82000	40000	42000	91000	62000	47000	47000	51000	58000		-92.7
	100000	100000	55000	100000	55000	70000	100000	40000	78000		-92.2
	<10	<10	<10	250	<10	<10	670	0	120		-99.85
Period in hours	4.5	5	5	5	5	3	5	3			
No. half-hour samples in composite	9	10	10	10	10	6	10	6			
Average flow of sewage in 1000 gals. per 24 hrs.	543	446	358	468	481	388	532	496	464		213 kw. h. for 686,000 gals.
Power consumed, kw. hours	29	26	29	28	33	21	33	24			
Kw. h. per hour	6.4	5.2	5.8	5.6	6.6	7.0	6.6	8.0	6.4		
Kw. h. per 1000 gals. sewage.	0.29	0.28	0.39	0.29	0.33	0.43	0.29	0.38	0.335		

hour. These tests were made on February 21st, on which day there was a light fall of snow which melted rapidly. The variations in the sewage flow during the two tests are shown graphically in Fig. 8, and the electrical data are shown in Fig. 9. The results of the chemical analyses and the bacteriological examination which cover the two tests are given in Table II.

FIG. 8.

FIG. 9.

IV. DISCUSSION OF RESULTS.

Various standards for the purity of sewage effluents have been formulated from time to time. Kinnicutt, Winslow and Pratt state in their book just published that "in the United States the usual requirement is that the effluent must be non-putrescible, or must contain only that amount of organic matter which, when

TABLE II.

	Lime treatment. Only in the Landreth Apparatus. Composite sample No. 9			Electrical treatment. Only in the Landreth Apparatus. Composite Sample No. 10		
	P. P. M.	Change P. P. M.	Change per cent.	P. P. M.	Change P. P. M.	Change per cent.
Chlorine.....	67.7	+12.3	+18.2	70.8	+1.6	+2.2
Nitrogen as	R 80.0			72.4		
	E 0.050			0.050		
	R 0.045	- 0.005	-10.0	0.040	-0.01	-20.0
Nitrate.....	E 0.62			0.75		
Free NH ₃	R 0.625	+ 0.005	+ 0.8	0.60	-0.15	-20.0
	R 15.6			13.5		
Albuminoid NH ₃	E 15.8	+ 0.2	+ 1.3	14.4	+0.9	+ 6.6
	R 23.8			22.2		
Required oxygen.....	E 23.4	- 0.4	- 1.7	21.7	-0.5	- 2.3
	R 84.6			64.5		
Determined immediately.....	E 76.9	- 7.7	- 8.9	58.0	-6.5	-10.0
	R 4.88			4.01		
Determined at end of 5 days..	E 3.95	- 0.93	-19.1	5.62	+1.61	+40.1
	R 0.03			0.08		
	E 0.03			0.45		
Bacteria *	Absorption of oxygen on standing: in P. P. M. R=4.85, E=3.82; in % R=99.4, E=96.7			Absorption of oxygen on standing: in P. P. M. R=3.93, E=5.17; in % R=98.0, E=92.0		
	Total count per c.c., at 37° C.	1,180,000		437,000		
	R 453,000		-82.4	272,000		-37.8
	R 1,192,000			908,000		
	E 118,000		-90.1	273,000		-70.0
B. coli per c.c.....	R 100,000			55,000		
E 3,700			-92.3	10,000		-81.8

R=Raw sewage. E=Effluent.

* Bacteria values are the average of six samples taken every 10 minutes during an hour.

the effluent is emptied into a stream, can be oxidized by the oxygen contained in the water at the time of the minimum flow; and that it must be sufficiently freed from suspended solids to avoid the accumulation of sludge banks or the creation of surface conditions offensive to sight and smell. In certain cases, as when the effluent is emptied into a stream in the near neighborhood of a point at which water is taken for domestic use, or is emptied into salt water in the neighborhood of shellfish layings, the effluent must also be freed from the great majority of the sewage bacteria."

"The International Boundary Commission, as a result of its study of pollution in the Great Lakes, suggested that the raw water to be treated by a purification plant should contain not over 500 *B. coli* per 100 c.c. as an annual average, and should not show *B. coli* in more than half of a series of 0.1 c.c. samples if satisfactory results are to be secured. According to this standard it would naturally be required that sewage treatment should be carried far enough so that after dilution has taken place the effluent discharged shall not produce, at any neighboring water works intake, a raw water of greater bacterial impurity than that specified above. The requirement of the Commission is perhaps an unduly strict one since many filtration plants (such as that of Cincinnati) are treating waters much more polluted than this with success."

"Authorities in America generally consider that more valuable information can be obtained from the study of the nitrogen data than from any of the other factors, while in England and Germany greater importance is placed on the oxygen consumed. If total carbon could be determined easily, this determination would probably be most valuable. Oxygen consumed, however, does not bear a constant relation to total carbon and is open to the same objections as albuminoid nitrogen."

"The latest and most authoritative standard of this kind is the one formulated by the Royal Commission on Sewage Disposal in its Eighth Report (R.S.C., 1912). It provides as a general standard that a sewage effluent must not contain as discharged more than 30 parts per million of suspended matter and must not take up more than 30 parts per million of dissolved oxygen in 5 days at 18.3° C. If the volume of diluting water available is 150-300 times the volume of the effluent the dissolved oxygen

test may be omitted and 60 parts of suspended solids would be permissible; if the volume of diluting water is 300-500 times the volume of the effluent the limit of suspended solids may be raised to 150 parts; while if the diluting volume is 500 times that of the effluent all standards might be dispensed with provided necessary screens and detritus tanks were provided."

In Table III are compared the changes brought about in raw sewage by:

1. Electrolytic-lime treatment with the Landreth apparatus;
2. Lime alone with the Landreth apparatus;
3. Electricity alone with the Landreth apparatus.

TABLE III.

Change Produced in Sewage by the Landreth Apparatus Operated With:

		Lime and Electricity		Lime alone		Electricity alone	
		P. P. M.	Per cent.	P. P. M.	Per cent.	P. P. M	Per cent.
Chlorine.....		+ 1.2	+ 1.9	+12.3	+18.2	+1.6	+ 2.2
Nitrite.....		+ 0.014	+58.3	- 0.005	-10.0	-0.01	-20.0
Nitrate.....		+ 0.13	+23.6	+ 0.005	+ 0.8	-0.15	-20.0
Free ammonia....		- 3.3	-18.3	+ 0.2	+ 1.3	+0.9	+ 6.6
Album. NH ₃		- 3.6	-12.1	- 0.4	- 1.7	-0.5	- 2.3
Required oxygen..		-13.0	-20.5	- 7.7	- 8.9	-6.5	-10.0
Dissolved O ₂		+ 1.78	+40.9	- 0.93	-19.1	+1.61	+40.1
Dissolved ... R =		4.17	95.9	4.85	99.4	3.93	98.0
O ₂ absorbed in 5 days..... E =		0.77	12.6	3.82	96.7	5.17	92.0
Bacteria Reduction {	Total count at 37° C., per c. c.	-343,200	-92.7	- 373,000	-82.4	-165,000	-37.8
	Total count at 20° C., per c. c.	-688,000	-92.2	-1,074,000	-90.1	-635,000	-70.0
	B. coli at 37° C., per c. c.	- 77,880	-99.85	- 96,300	-92.3	-45,000	-81.8

From a comparison of the results recorded in Table III, it will be observed that with electrolytic-lime treatment the quantities of nitrite and nitrate in the sewage are increased, while with lime alone and with electricity alone a material decrease or but a slight increase is effected. With the electrolytic-lime treatment there is a marked decrease in free ammonia and albuminoid ammonia, whereas with the lime or with the electrical treatment

there is a small decrease in albuminoid ammonia, and an increase in free ammonia. The required oxygen is decreased by all three treatments, but that effected by the electrolytic-lime treatment is approximately double that brought about by either of the other methods. Due to the production of oxygen by the electric current, an increase in dissolved oxygen of about 40 per cent. is effected by the electrolytic-lime treatment and by the purely electrical treatment; while with lime alone a decrease of 19 per cent. in dissolved oxygen occurs.

The amount of the dissolved oxygen absorbed by the effluent in five days at a temperature of 10° C. to 15° C., affords very important information regarding the efficiency of the three methods of treatment. Indeed this test is regarded by many authorities as one of the most important standards for determining the purity of an effluent. The results recorded in Table III show that while practically all of the dissolved oxygen in the raw sewage is absorbed during the five-day period, that in the effluent produced by the electrolytic-lime treatment is reduced only 0.77 part per million, or 12.6 per cent., a figure which lies far below the limit allowed by the Royal Sewage Commission. On the other hand, nearly all of the dissolved oxygen in the effluents produced by the lime treatment and by the electrical treatment is absorbed in the five-day period, showing that by these methods the unstable organic matter in the sewage was but partially oxidized.

It will be observed that electrolytic-lime treatment brings about a reduction of over 92 per cent. in the total bacteria count, while the lime treatment effects a reduction of 82 per cent. at 37° C. and 90 per cent. at 20° C., and the electrical treatment produces a reduction of only 38 per cent. at the higher temperature and 70 per cent. at the lower temperature. The reduction in *B. coli* per c.c. amounts to 99.85 per cent. with the electrolytic-lime treatment, and to 92.3 per cent. and 81.8 per cent., respectively, with the lime treatment and with the electrical treatment.

It may be of interest to mention that the effluents produced by the different treatments were examined after having been kept in stoppered bottles for five weeks. Those obtained in runs 1 to 8 (electrolytic-lime treatment) had little or no odor; that obtained in run 9 (lime treatment only) had a very disagreeable odor, while that obtained in run 10 (electrical treatment only) smelled strongly of hydrogen sulphide, and had turned black

owing to the conversion of the iron dissolved from the electrodes into iron sulphide.

It is evident from the data recorded in Table III that not only is an highly satisfactory effluent produced by the Direct Oxidation Process, but that the combination of lime and electricity, when employed in the apparatus described, is much more effective in purifying sewage than either lime alone or electricity alone when employed with the same apparatus.

In judging the efficacy of the Direct Oxidation Process, it must be remembered that the data given in the preceding tables refer to the effluent as it comes from the electrolytic tank, and that by the conjunctive use of a sedimentation basin the suspended solids, consisting largely of lime, could be considerably reduced. This reduction would also be attended by a further decrease in albuminoid ammonia, required oxygen and the bacteria.

In order that the results obtained with the Direct Oxidation Process of sewage treatment may be compared with those obtained with other methods, analytical and bacteriological data relating to a number of methods are given in Tables IV and V.

V. COSTS AND COMPARISONS.

After a careful study of 16 different plants for sewage treatment in this country, varying in cost from \$40,000 to \$9,000,000, we still find it extremely difficult to make a comparison in cost either of construction or of operation of the electrolytic process of sewage treatment with other methods, since the conditions affecting the installation of a sewage treatment system vary greatly and frequently involve factors which in the aggregate are more costly than the construction of the plant.

Take, for instance, the selection of a site for a treatment plant. It must be sufficiently remote to avoid offense; its elevation should be low enough to receive the sewage by gravity or at least to minimize the cost of pumping; and it ought also to be reasonably close to a stream furnishing a proper outlet for the effluent. To meet these general conditions, heavy costs may be incurred in the purchase of land suitable for the purpose and frequently tracts thus acquired must be largely in excess of the actual needs of the plant so as to avoid the depreciation of adjacent land values. The cost also may be increased by the construction of long and expensive trunk line sewers; the construction of collecting basins and pumping stations for the purpose of lifting

TABLE IV.
Effect of Various Processes for the Treatment of Sewage.

Process	Location	Suspended solids	Nitrogen as—			Nitrites	Required oxygen	Authority
			Albuminoid NH_4	Free NH_3	Nitrates			
			in parts per million					
Chemical pptn. $\text{CaO} + \text{FeSO}_4$	London, 1894	441	4.9	34.8	...	...	53.1	Dibdin, 1903.
Sewage.		87	3.9	28.9	...	...	44.5	
Effluent.	Lawrence, Mass., average 4 years (1894-1898)	...	6.4	30.8	...	...	38.8	Winslow and Phelps, 1906.
Coke strainer:		...	3.3	31.8	...	...	22.2	
Sewage.	Lawrence, Mass., average 5 years (1898-1903)	232	7	38.1	...	...	49.5	Winslow and Phelps, 1906.
Effluent.	Birmingham, England	107	3.3	37.7	...	...	27.3	
Sedimentation:								
Sewage.		686	14.2	39.3	7	...	66	Watson, 1903.
Effluent.		346	10.9	37.7	7.3	...	...	
Broad irrigation:	South Norwood, England	219	6.7	35.4	...	...	77.1	Royal Sewage Commission, 1904.
Sewage.	land	...	1	8.7	3.9	...	14.4	
Effluent.		...						
Contact beds:	Mansfield, Ohio, 1907.							Kimberly.
Sewage.		74	7.8	...	0.4	0.2	37	
Effluent.		40	3.6	...	2.6	0.04	9.2	
Intermittent filtration:	Worcester, Mass., 1904	...						Kinnicutt,
Sewage.		...	8.1	18	0.6	0.1	138.7	Winslow and Pratt.
Effluent.		...	0.9	10.9	2	0.3	18.1	
Trickling filters:	Worcester, Mass., 1913							Kinnicutt,
Sewage.		144	6.7	24.3	0.7	...	119	Winslow and Pratt.
Effluent.		43	2.3	17.8	6	...	29	

the sewage across divides from one drainage area into another, so that treatment can be obtained at a central plant; and the property damages which in some cities result from the widening of streets and the changes of grades made necessary to accommodate concentrated drainage.

TABLE V.
Bacteria Reduction by Various Methods for Treating Sewage.

Intermittent Filtration at Brockton, Mass.		
Kinnicutt, Winslow and Pratt.		
	Total count per c.c. at 20	<i>B. coli</i> per c.c.
Raw sewage.....	3,150,000	150,000
Effluent A.....	1,900	400
Effluent B.....	6,300	15
Effluent D.....	125	0
Effluent E.....	1,400	5
Effluent F.....	2,000	1
Results of Experiments at Lawrence, Mass.		
Metcalf and Eddy.		
		Per cent. bacteria removed
Regular sewage, as received from force main at station.....	2,095,600	
Settled sewage.....	1,386,300	33.80
Effluent, strainer E (12" depth buckwheat coal, rate 800,000 gals. per acre per day).....	874,200	58.50
Fresh sewage (from toilet room at station).....	3,241,600	
Effluent, Imhoff tank.....	1,700,300	46.60
<hr/>		
Effluent, sand filters.....	2,565	99.88
Effluent, contact filters.....	1,105,600	47.20
Effluent, trickling filters.....	254,500	81.70

While it is true that in the electrolytic process described in this paper, a number of units are eliminated which are required in ordinary treatment systems, yet in a small electrolytic plant this saving is more than offset by the cost of the protective building which is necessary. In addition there is the constant employment of skilled labor which such a plant requires. Where it is possible to combine a water pumping station, an electric lighting plant, and a Landreth Direct Oxidation sewage treatment plant under one roof, the proportional cost of the protective structure, as well as operation, is reduced, making it a probable advantage to employ this method. When this cannot be done, the Landreth Direct Oxidation process is not in our judgment economical if the population tributary to the plant is very small.

Our experience at the Landreth Direct Oxidation plant in

Easton fully justifies the statement that a plant of this type can be installed and operated in any densely populated section without detection by the public.

The importance of this advantage is evident when it is considered that an inexpensive property of a few thousand square feet conveniently situated near outlets of main sewers is all that is required for this electrolytic process compared with the large areas at a distant point demanded by ordinary methods of sewage disposal.

TABLE VI.

Comparison of Cost of Operation Between 2,000,000 Gallon Plant and 10,000,000 Gallon Plant.

Capacity	2,000,000 gallons per day.
Population	20,000.
The operation cost is based upon the following daily items:	
1600 lbs. 90 per cent. lime per day at \$6 per ton	\$5.33
Current, 282 k.w. hrs. per day at 2 cents	5.64
Heat and light per day	2.00
Renewals	2.00
Maintenance and repairs	1.00

Labor:

3 men—8 hr. shifts, at \$5, \$4, \$4.	
1 laborer at \$3	16.00

Total\$31.97

This is 58 cents per capita per year for operation, of which about 51 per cent. is for labor alone.

Capacity	10,000,000 gallons per day.
Population	100,000.
The operation cost is based upon the following daily items:	
8000 lbs. 90 per cent. lime per day at \$6 per ton	\$26.75
Current, 1410 k.w. hrs. per day at 2 cents	28.00
Heat and light per day (estimated)	2.00
Renewals	10.00
Maintenance and repairs	6.00

Labor:

1 superintendent	5.00
3 operators at \$4	12.00
1 laborer	3.00

\$92.75

This is 34 cents per capita per year for operation, of which about 22 per cent. is for labor.

TABLE VII.
Cost of Operation, Allowing Interest at 4 per cent. and 2½ per cent. Depreciation.

Location	Cost of plant	Population	Int. and dep. per cap.	Cost of oper. per cap.	Total cost per cap.	Authority	Remarks
Chicago.....	\$9,258,600.00	1,600,000	\$.38	\$.27	\$.65	Hering & Fuller	Includes intercepting sewer and pumping station.
N. Dist. Boston, Mass.....	7,126,000.00	601,810	.77	.29	1.06	H. P. Eddy	Water dilution.
S. Dist. Boston, Mass.....	8,944,000.00	438,580	1.33	.25	1.58	H. P. Eddy	Water dilution.
Worcester, Mass.....	1,956,000.00	162,697	.79	.37	1.16	H. P. Eddy	Chemical precipitation and sand filters.
Fitchburg, Mass.....	815,000.00	39,655	1.34	.26	1.60	H. P. Eddy	Imhoff and trickling filters.
Gloversville, N. Y.....	378,000.00	21,178	1.16	.27	1.43	H. P. Eddy	Sedimentation and trickling filters.
Clinton, Mass.....	149,000.00	13,192	.73	.57	1.30	H. P. Eddy	Sand filters, and pumping station.
Lebanon, Pa.....	80,000.00	15,000*	.34	.65	.99	P. A. Voleknor	Imhoff and trickling filters.
York, Pa.....	194,500.00	30,000	.42	.11	.53	J. K. Geisey	Imhoff and pumping station.
West Chester, Pa.....	162,000.00	12,000	.88	.30	1.18	N. R. Rambo	Pumping plant and septic tank.
Indiana, Pa.....	40,000.00	8,000	.32	.10	.42	Metcalf & Eddy	Septic tanks and trickling filter.
Typical plant†.....	431,710.00	55,000	.51	.31	.82	H. P. Eddy	Imhoff and trickling filter.
Typical plant†.....	313,880.00	55,000	.37	.73	1.10	H. P. Eddy	Activated sludge.
Electrolytic plant†.....	219,050.00	55,000	.26	.38	.64	Landreth	Electrolytic.

* Refers to population served by plant.

† No main sewer lines included in estimates of costs.

TABLE VIII.
Cost of Construction.

Location	Cost	Population for which plant was designed	Cost per cap. at time of use	Authority	Year of establishment	Remarks
Chicago, Ill.	\$9,258,600.00	1,600,000*	\$5.78	Hering & Fuller	1907	Includes trunk line sewers and trickling beds.
N. Dist., Boston, Mass.	7,126,000.00	571,000	12.48	H. P. Eddy	1916	Dilution in harbor.
S. Dist., Boston, Mass.	8,944,000.00	986,000	9.07	H. P. Eddy	1916	Dilution in harbor.
Worcester, Mass.	1,966,000.00	.....	9.31	H. P. Eddy	1916	Chemical precipitation and sand filters.
Fitchburg, Mass.	815,000.00	.....	12.88	H. P. Eddy	1916	Imhoff tanks, etc.
Gloversville, N. Y.	378,000.00	.....	15.26	H. P. Eddy	1916	Sedimentation tanks and filters.
Clinton, Mass.	149,000.00	18,700	7.96	H. P. Eddy	1916	Sand filters and pumping station.
Lebanon, Pa.	80,000.00	17,500	4.57	P. A. Volckner	1916	Does not include outfall sewer.
York, Pa.	194,463.58	30,000	6.48	J. K. Geisey	1916	Includes outfall sewer and sand filters.
West Chester, Pa.	162,000.00	12,000	13.50	N. R. Rambo	1915	Includes outfall sewer and pumping station.
Indiana, Pa.	40,000.00	8,000	5.00	Metcalf & Eddy	1914	Plant only.
Typical plant.	431,710.00	55,000	7.85	H. P. Eddy	1916	Imhoff tank and trickling filter.
Typical plant.	313,880.00	55,000	5.71	H. P. Eddy	1916	No trunk line sewer.
Electrolytic plant.	219,050.00	55,000	3.99	Landreth	1916	Activated sludges. No trunk line sewer.
					1916	Does not include outfall sewers.

* Estimated.

In the operation of this electrolytic process it is imperative to have skilled labor in constant attendance, although the duties imposed upon it are light. However, in this process the number of units can be largely increased without any appreciable increase in the amount of labor necessary to operate the enlarged plant. This is illustrated by the data contained in Table VI showing comparisons between the operating costs of 2,000,000 gallon and 10,000,000 gallon plants.

In Table VII is given the cost of construction of various sewage disposal plants in the United States. It has not been possible in this table to indicate in every case the actual cost of the disposal plant alone, eliminating property values, trunk lines, costs, etc., and on that account the per capita costs show such great variations. It is evident, however, that the per capita cost of the construction of a Direct Oxidation plant compares favorably with that of any other process.

The data in Table VIII indicate the actual cost of operation per capita of a number of sewage disposal plants in the United States with the additional costs for interest and depreciation. An examination of this table indicates that the economy resulting from the use of the Landreth Direct Oxidation process is effected largely through a saving in the cost of construction.

Fire Engines and the Essentials of Fire Fighting. CHARLES H. FOX. (*The American Society of Mechanical Engineers*, Spring Meeting, June, 1919.)—Steam power was not successfully applied to fire engines until the beginning of the year 1853. Up to that time the so-called "hand engines" were used exclusively and it should also be understood that at that time the present-day system of water-works, was still in its infancy and, therefore, the chief dependence for a supply of water for fire-extinguishing purposes was upon methods of storage in vogue before water mains came into general use.

The conventional hand fire engine of that day comprised a rectangular wooden box suitably mounted on four low wheels. Pumps, of the piston type, were housed within and firmly fixed to the floor of the box; working levers were provided and motion was imparted to the pistons by a host of firemen lined up on opposite sides of the apparatus. At this early period fire hose was not plentiful, the best was crudely made up of leather, and the pumps were, therefore, placed close to the scene of the fire. Water, largely conveyed by a