PUBLIC HEALTH REPORTS

VOL. 53 SEPTEMBER 23, 1938 NO. 38

STUDIES ON DENTAL CARIES

VII. SEX DIFFERENCES IN DENTAL CARIES EXPERIENCE OF ELEMENTARY SCHOOL CHILDREN [1]

By HENRY KLEIN, *Associate Dental Officer*, and CARROLL E. PALMER, *Passed Assistant Surgeon, United States Public Health Service*

INTRODUCTION

Data available in the literature (*1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11*) clearly indicate that girls have more dental caries experience (greater number of permanent teeth decayed, missing, or filled)[2] at the same chronological age and erupt their permanent teeth at an earlier chronological age than boys. The first of these findings would appear to suggest that girls have a higher susceptibility to attack by caries. Before such a conclusion may be accepted, however, it is desirable to inquire to what extent the earlier time of eruption of the teeth in girls affects or determines their higher caries experience. Analysis of this question constitutes the purpose of the present paper.[3]

MATERIAL AND METHODS

The data on which the present analysis is based were derived from dental examinations of 2,232 boys and 2,184 girls attending the municipal elementary schools of a small urban community, Hagers-

[1] From Child Hygiene Investigations, Division of Public Health Methods, National Institute of Health U. S. Public Health Service.

The preceding papers of this series are as follows:

I. Dental status and dental needs of elementary school children. By Henry Klein, C. E. Palmer, and J. W. Knutson. Pub. Health Rep., 53: 751–765 (May 13, 1938).

II. The use of the normal probability curve for expressing the age distribution of eruption of the permanent teeth. By Henry Klein, C. E. Palmer, and M. Kramer. Growth, 1: 385–394 (1937).

III. The measurement of post-eruptive tooth age. By C. E. Palmer, Henry Klein, and M. Kramer. Growth, 2: 149–159 (1938).

IV. Tooth mortality in elementary school children. By J. W. Knutson and Henry Klein. Pub. Health Rep., 53: 1021–1032 (June 24, 1938).

V. Familial resemblances in the caries experience of siblings. By Henry Klein and C. E. Palmer. Pub. Health Rep., 53: 1353–1364 (Aug. 5, 1938).

VI. Caries experience and variation in the time of eruption of the teeth. By Henry Klein and C. E. Palmer. Child Development, 9: 203–218 (1938).

[2] Caries experience is defined as the total number of DMF permanent teeth or tooth surfaces (the number of permanent teeth or tooth surfaces decayed, missing, or filled). For a full discussion of the DMF concept, see reference (*5*).

[3] Stoughton and Meaker (*1*) write, "* * * a higher percentage of girls than boys have one or more permanent teeth decayed, missing, or filled * * *. As suggested in the preceding section, it may be that girls lose their temporary teeth somewhat earlier than boys, and consequently their permanent teeth erupt sooner and are exposed to caries over a longer period."

town, Md. The dental examinations were made with plain mirrors and fine-pointed pig-tail explorers under favorable lighting conditions. Observations were made on all teeth present in the mouth and, in addition, unerupted and extracted permanent teeth were noted. Pits and fissures in which the explorer caught, and which after thorough inspection were not considered definitely carious, were noted as separate items and were not counted as carious. Teeth designated as carious were those which showed actual cavities. The lesions recorded are those which are readily found on a careful clinical dental examination. The extent of caries in any single tooth was measured in terms of tooth surfaces involved. When such areas extended from one surface to others, the involved surfaces were counted separately as carious surfaces. Remaining roots were considered as equal to five carious surfaces. Records for filled teeth were made in a similar manner, that is, filled surfaces were counted as past carious surfaces. Full crowns, of which few were encountered, were considered equal to five filled surfaces (five surfaces affected by past caries). These procedures were designed to make possible the measurement and tabulation of caries experience.

ANALYSIS

In order to determine the effect of sex differences in the time of eruption of the teeth on the caries experience of children, it is necessary to collect and tabulate two major classes of data. The first of these, shown in table 1, makes it clearly apparent that, at the same chronological age, girls have more permanent teeth and tooth surfaces affected by caries experience than boys. The second tabulation of data, presented in table 2, makes available, for each sex, information which gives a measure of the length of time the teeth are exposed in the mouth (post-eruptive tooth age).[4]

In order to show whether or not girls have a greater susceptibility [5] to attack by caries than boys, it becomes necessary to inquire whether or not the number of tooth surfaces showing a history of attack by caries is greater for girls than it is for boys at points where *each sex has accumulated the same amount of post-eruptive tooth years of mouth exposure.* To make this determination, the caries experience values given in table 1 are plotted against the tooth age values given in table 2. The graph shown in figure 1 is thus obtained, from which

[4] The application of an epidemiological perspective to the finding of coincident sex differences in eruption and in caries experience leads directly to the suggestion that the teeth of girls, because they erupt earlier than those of boys, have been exposed in the mouth to the risk of attack by caries for longer periods of time than the teeth of boys. Because of the implications of this perspective in the analysis of the sex differences in caries experience, the collection of data on the mouth years of exposure of the permanent teeth of the separate sexes has been undertaken and the findings on this point have been presented in a previous publication (*13*).

[5] In the present analysis caries susceptibility is measured as the number of permanent teeth or tooth surfaces affected by caries experience expressed as a function of accumulated posteruptive tooth age.

may be read the average number of DMF permanent teeth and the number of DMF permanent tooth surfaces observed for each sex for specified average numbers of post-eruptive tooth years of mouth exposure.

TABLE 1.—*Numbers of children, numbers of DMF* permanent teeth, numbers of DMF permanent teeth per child, numbers of DMF permanent tooth surfaces, and numbers of DMF permanent tooth surfaces per child, by age and sex groups (4,416 elementary school children, Hagerstown, Md.)*

Item	Age (last birthday)										
	6	7	8	9	10	11	12	13	14	15	All ages
Number of children:											
Boys	171	197	231	253	270	262	299	267	199	83	2,232
Girls	156	206	256	240	259	269	297	278	165	58	2,184
Number of DMF permanent teeth:											
Boys	43	115	255	452	646	722	1,068	1,065	1,012	554	5,932
Girls	52	178	328	542	683	788	1,111	1,413	886	359	6,340
Number of DMF permanent teeth per child:											
Boys	0.25	0.58	1.10	1.79	2.39	2.76	3.57	3.99	5.09	6.67	2.66
Girls	.33	.86	1.28	2.26	2.64	2.93	3.74	5.08	5.37	6.19	2.90
Number of DMF permanent tooth surfaces:											
Boys	59	169	365	826	1,301	1,334	2,094	2,216	2,004	1,191	11,559
Girls	66	237	470	1,038	1,274	1,424	2,161	2,852	1,850	822	12,194
Number of DMF permanent tooth surfaces per child:											
Boys	0.35	0.86	1.58	3.26	4.82	5.09	7.00	8.30	10.07	14.35	5.18
Girls	.42	1.15	1.84	4.33	4.92	5.29	7.28	10.26	11.21	14.17	5.58

*See definition in the text.

TABLE 2.—*Accumulated post-eruptive tooth ages (in years) per child, by age and sex groups (4,416 elementary school children, Hagerstown, Md.)*

	Chronological age (years)									
	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5
Boys	1.87	7.41	16.94	29.18	44.09	62.47	84.68	109.96	137.15	164.95
Girls	3.16	9.76	20.18	33.49	50.15	70.71	94.65	120.87	148.26	176.08

Study of the data presented in this figure leads to the conclusion that no significant difference in caries susceptibility appears to exist between the two sexes. This conclusion is based on the fact that for equal numbers of years of accumulated post-eruptive tooth age, the caries experience of girls does not *consistently* exceed or fall below the caries experience of boys. The curve showing the increase of caries experience with increasing tooth age for girls (dotted line) for the first twenty years of accumulated post-eruptive tooth age almost exactly coincides with the curve for boys (solid line). With increase in tooth age, the crossing and recrossing of the lines representing the caries experience trends of the two sexes strongly suggest that the slight differences which are observable are due to chance variations and are not indicative of significant differences in the caries suscepti-

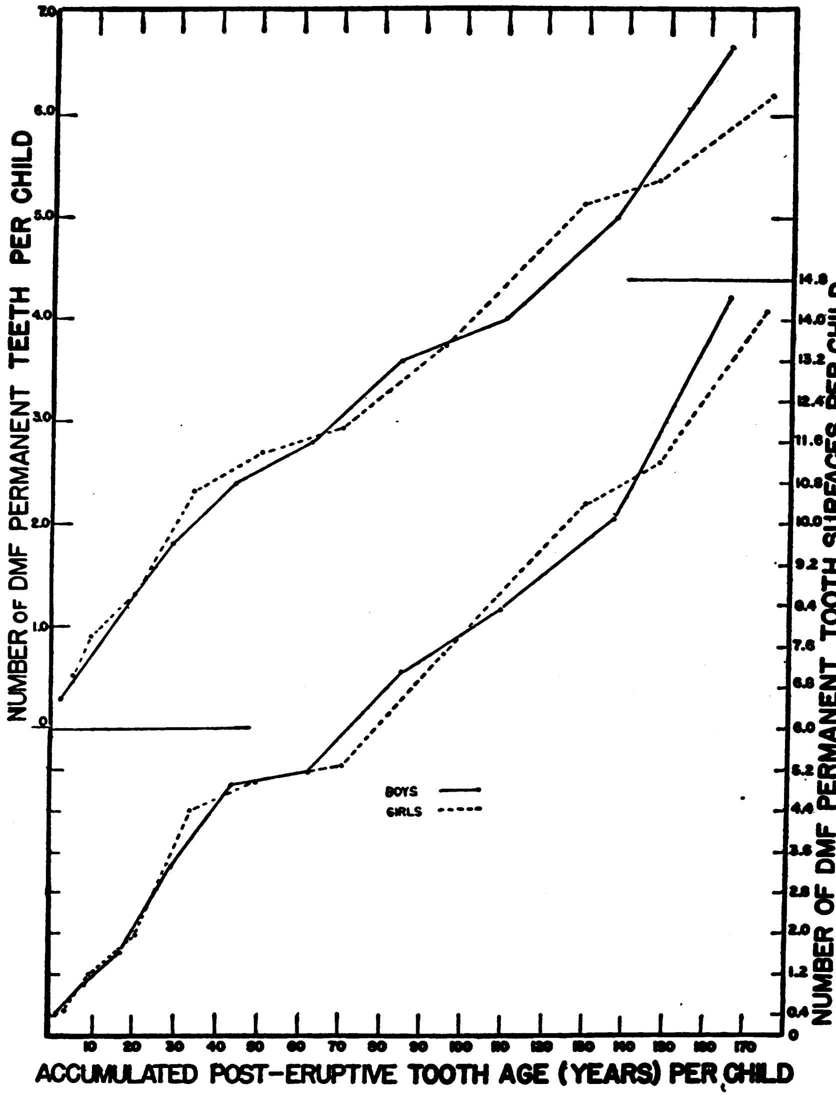

FIGURE 1.—The relations, per child, between accumulated post-eruptive tooth age and caries experience Data derived from dental examinations of 2,232 boys and 2,184 girls of ages 6 to 15 years, Hagerstown, Md.

bility of the two sexes. The actual observed finding that girls have more caries experience than boys of the same chronological age is explained, quantitatively, by the fact that the teeth of girls, because they erupt earlier, are exposed longer to the risk of attack by caries than those of boys.[6]

SUMMARY

Results derived from an analysis of dental examinations of 2,232 boys and 2,184 girls indicate that the higher caries experience of girls, as compared with that of boys of the same chronological age, is explained quantitatively by the finding that girls, because their teeth erupt earlier than do those of boys, are exposed longer (have a greater posteruptive tooth age) to the risk of attack by caries than are boys. On the basis of these findings, the conclusion is reached that girls show no greater susceptibility to attack by dental caries than boys.

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[6] In this connection, it is of interest to point out that boys (or girls) whose teeth erupt early have higher levels of caries experience than boys (or girls) whose teeth erupt late when the sexes are compared on the basis of chronological age. When the caries experience of late and early eruptors are contrasted on the basis of posteruptive tooth age (*13*), it is indicated that early eruptors have no greater susceptibility to caries than late eruptors.

(13) Klein, Henry, and Palmer, C. E.: Studies on dental caries. VI. Caries experience and variation in the time of eruption of the teeth. Child Development, 9: 203 (1938).
(14) Klein, Henry, and Palmer, C. E.: Studies on dental caries. V. Familial resemblances in the caries experience of siblings. Pub. Health Rep., 53: 1353 (1938).

STUDIES OF SEWAGE PURIFICATION

VII. BIOCHEMICAL OXIDATION BY ACTIVATED SLUDGE[1]

By C. C. Ruchhoft, *Principal Chemist*, P. D. McNamee, *Assistant Chemist*, and C. T. Butterfield, *Principal Bacteriologist, United States Public Health Service, Stream Pollution Investigations, Cincinnati, Ohio*

In a previous paper (*1*) it has been shown that when sterile sewage or synthetic sewage is aerated in the presence of pure cultures of bacteria isolated from activated sludge, very high rates of oxidation are obtained. The pure bacterial culture sludges consumed oxygen at a very low rate until bacterial food was added to the substrate. The increased quantity of oxygen used following the addition of the food was ascribed to the oxidation of this added material. It is the purpose of this paper to present a somewhat similar study of biochemical oxidation, using natural activated sludges obtained from sewage treatment plants. Without attempting to interpret the entire mechanism of the activated sludge process, data are presented that have been obtained in sewage and in sludge oxidation studies which are helpful for such purpose. As the method of determining the oxygen utilized by the activated sludges employed in the earlier and in the present paper has not been used extensively, a consideration of the precision of the method is presented.

It is generally accepted that, under natural conditions, the biochemical oxidation of organic matter in sewage, as shown by Theriault (*2*), follows the unimolecular expression,

$$y=L\ (1-10^{-kt}) \qquad (1)$$

where y=the B. O. D. satisfied in time t,
L=the initial total carbonaceous B. O. D.,
k=a velocity constant of 0.1 at 20° C., and
t=time in days.

The results of an experiment are introduced illustrating that biochemical oxidation rates are not necessarily limited to this established natural rate and demonstrating the acceleration of rates of oxidation of organic matter in sewage under artificial conditions of treatment. Data are presented to indicate that rates of oxygen utilization by the sludge in an experimental plant varied considerably, and that information in addition to that concerning the extent and rate of oxidation of

[1] The data on which this paper is based were presented and discussed before the Ninth Annual Meeting of the Central States Sewage Works Association, Indianapolis, Ind., Oct. 30, 1936.

a sludge mixture is required to evaluate the biochemical activity of the sludge. Consequently, comparable data on oxygen utilization of sludge alone and on the same sludge fed with single and multiple increments of various substrate nutrients were obtained and are presented as a contribution to our limited knowledge of the rates and extent of sewage oxidation in the activated sludge process. The proportion of the total purification of sewage accomplished by the activated sludge process which can be credited to oxidation will not be considered here but will be discussed in a later paper.

EXPERIMENTAL METHODS

The method of determining the oxygen utilized by sludge or mixtures of sludge and sewage in this study was the same as that used in the previous work (*1*) (*4*). Briefly, this consisted in aerating the material under study in a closed system and determining, periodically, the total quantity of oxygen remaining. To determine the performance of any mixture with different or multiple increments of substrate, the sludge with dilution water as a control and the sludge with the substrate feed added were always aerated simultaneously in two or more of these closed aeration bottles. Biochemical oxygen demand for various periods of incubation by the ordinary dilution method was also determined on the nutrient substrates used.

Activated sludge.—The activated sludge used in most of the experiments was obtained from the experimental plant at this station. In a few experiments, activated sludge from the north and south plants at Lancaster, Pa., was employed.

Dilution water.—The quarter strength phosphate buffer (*3*) (formula C) water was used throughout these experiments. This water was developed for use in the oxygen demand test, and it has been shown (*5*) that the presence of the phosphate did not exert any influence on the rate or extent of oxidation in aerated sludge.

Nutrient substrates.—All sewage was domestic sewage. The sewage was either filtered through cotton or allowed to settle to remove the coarse suspended matter and make it approximately comparable to the preliminary settled sewage available at sewage treatment plants. Unfortunately the B. O. D. of the sewage varied over wide limits. Sterile sewage was obtained by autoclaving settled sewage in 6-liter Erlenmeyer flasks at 15 pounds for 15 minutes. A nutrient substrate simulating sewage in B. O. D. but containing no suspended detritus and having its nutrient material in true colloidal and soluble form was also used in these experiments. This nutrient substrate will be referred to hereafter as synthetic sewage. It contained peptone and meat extract, as nutrients, besides small quantities of urea, disodium hydrogen phosphate, and the other inorganic salts usually found in sewage and had the same composition as that used in the pure culture work (*1*). The concentrated synthetic sewage contained 250 times the concentration of the same materials as the normal synthetic sewage. By the addition of 4 ml of this concentrated material to a liter of the sludge mixture, the B. O. D. load was increased by an amount equivalent to that of a liter of normal sewage but without the necessity of removing any supernatant from the mixture under aeration.

All of the experiments described were carried out in a 20° C. constant temperature room. Although pH determinations were made on the substrates during the course of oxidation in every experiment, the pH changes found were too small to affect the rate or extent of oxidation and will not be discussed in this paper.

EXPERIMENTAL DATA

Precision of oxygen absorption measurements.—Although an extensive series of tests has been made on the precision of the aeration method for the determination of biochemical oxygen demand during the development of the procedure, the results of which indicate an error not exceeding 5 mg, it seemed pertinent to repeat these tests using the identical materials employed in these studies. Accordingly, three aeration bottles were prepared containing as nearly as possible identical quantities of a sludge sewage mixture. Each bottle was prepared by settling for 30 minutes 1 liter of plant aeration mixture, siphoning off 800 ml of supernatant and adding 825 ml of sewage. After mixing, 25 ml were withdrawn for the suspended solids determination. The mixtures were aerated simultaneously. Suspended solids determinations were made at the start and at the close of the test. Determinations of amounts of residual oxygen were made at the intervals indicated in the table. The results obtained, including the mean and average and maximum deviations from the mean, are given in table 1.

TABLE 1.—*Indicated precision of aeration method—analytical results obtained from observations on 3 portions of the same activated sludge plus feed mixture with each portion treated and examined as a separate unit*

Bottle No.	Activated sludge p. p. m. suspended solids		Mg of O_2 used per liter in indicated time in hours				
	At start	After 24 hours	½	2	4	22.5	24
1	1,380	1,456	22.8	47.7	80.1	189.4	191.7
2	1,376	1,404	19.4	42.9	71.3	189.3	193.5
3	1,368	1,384	19.0	39.7	80.7	188.0	188.7
Mean	1,375	1,415	20.4	43.4	77.4	188.9	191.3
Average deviation	4	28	1.6	2.8	4.0	.6	1.7
Maximum deviation	7	41	2.4	4.3	6.1	.9	2.6

The maximum deviation from the mean varied from 0.9 to 6.1 milligrams of oxygen per liter, which is within the limits of the precision of the method originally established. The average deviations from the mean varied from 0.6 to 4.0 milligrams. As it is desired to observe differences in oxygen absorption results for dosed and control activated sludge mixtures, an average deviation of ± 4.0 milligrams in an observation introduces the possibility of considerable error for the first ½-hour aeration period. In the later experiments of this paper the observed increments of oxygen absorption resulting from the addition of the substrate food ranged from about 7 to 26 milligrams for the first ½-hour aeration period and the maximum percentage of error due to method are to be expected. From the 1½-hour observation period on, these increments of oxygen absorption produced by the addition of the sewage ranged from about 40 to 190 milligrams, and the probable error due to the method becomes a much smaller factor. It is believed that beyond the 1½-hour observation period the majority of the observations (obtained by differences) are subject to less than 10 percent errors. These limitations of the accuracy of the method should be considered in interpretation of short aeration period (30 minutes) observations. However, the probable errors are not serious for longer periods and do not in any way invalidate the results obtained.

DEMONSTRATION OF CHANGE IN BIOCHEMICAL OXIDATION RATES

Results of the first experiment are presented to demonstrate that decided changes in the rates of biochemical oxidation reactions are possible under artificial conditions such as are maintained in the activated sludge process. In this experiment four aeration bottles were prepared. These bottles, at the start, contained the basic components shown for the first aeration period for samples 1 to 4 in table 2. As indicated, these bottles contained no activated sludge at the start but each contained 1 liter of sewage. Small quantities, 4, 8, and 12 ml, of concentrated sterile synthetic sewage were added to samples 2, 3, and 4, respectively. The four mixtures were aerated for 27 hours, and during this period a number of observations on the amount of oxygen utilized were made. At the close of the 27-hour aeration period the bottles were opened and samples 2, 3, and 4 again received, respectively, 4, 8, and 12 ml of the same concentrated sterile synthetic sewage that had been added at the start. Nothing was added to sample No. 1. The samples were aerated again for an additional 22.5 hours and oxygen utilization determinations were made during this period of aeration. Table 2 shows the total carbonaceous oxygen demand of the sewage mixtures at the start of the first and second aeration periods calculated from a series of dilution method biochemical oxygen demand values for the components of the samples. The total L value of the sewage mixture at the end of the first aeration period was obtained by subtracting the quantities of oxygen used by each sample for the first 27 hours from the initial total L value for the corresponding sample. The total quantity of oxygen utilized at the end of each period of observation for each sample during the first and second aeration periods is shown in table 3. These data are plotted in figure 1.

TABLE 2.—*Experiment 1—Total carbonaceous B. O. D.* (L *values*) *on rapid development of activated sludge*

Sample No.	Basic components in ml			Total carbonaceous B. O. D. (L value) in mg					
	First aeration period		Second aeration period	At beginning of first 27-hour aeration			At beginning of second 22.5-hour aeration		
	Raw sewage	Synthetic sewage	Synthetic sewage added after first period	Raw sewage	Synthetic sewage	Total for mixture	Raw sewage[1]	Synthetic sewage	Total for mixture
1	1,000	0	0	[2] 552.9	0	552.9	339.4	0	339.4
2	1,000	4	4	552.9	[3] 268.9	821.8	457.6	[3] 268.9	726.5
3	1,000	8	8	552.9	537.8	1,090.7	591.2	537.8	1,128.0
4	1,000	12	12	552.9	806.7	1,359.6	700.6	806.7	1,507.3

[1] This value is obtained by deducting the quantity of oxygen used by each sample during the first 27-hour aeration period from the total L value for the corresponding sample at the start.
[2] Based on dilution method B. O. D. results for 3, 5, and 7 days.
[3] Based on dilution method B. O. D. results for 2, 3, 4, and 6 days.

TABLE 3.—*Experiment 1—Total oxygen utilized by each sample on rapid development of activated sludge*

[Results in Milligrams per iter]

Aeration time in hours	Results for first 27-hour aeration				Results for second 22.5-hour aeration			
	Sample No.				Sample No.			
	1	2	3	4	1	2	3	4
1	9.4	23.3	22.9	25.6	11.7	62.3	87.4	99.5
2	40.6	45.0	41.0	39.6	16.4	103.6	158.1	184.7
3	62.2	63.7	69.6	74.0	----------	----------	----------	----------
4	73.1	88.7	106.7	101.2	----------	----------	----------	----------
5	92.0	100.7	140.0	158.7	19.5	179.3	322.6	437.6
6	93.2	120.8	156.0	176.0	----------	----------	----------	----------
7	103.6	131.3	170.7	198.3	----------	----------	409.5	535.1
8	----------	----------	----------	----------	35.6	229.9	462.9	600.9
9	----------	----------	----------	----------			484.2	639.1
9.5	123.1	159.2	191.1	240.4	----------	----------	----------	----------
11	124.8	172.6	220.5	254.3	----------	----------	----------	----------
18	----------	----------	----------	----------	65.2	345.0	693.1	925.8
22.5	192.6	326.2	427.3	541.7	79.5	391.7	772.3	1,034.8
24	197.7	339.7	456.2	573.9	----------	----------	----------	----------
27	213.5	364.2	499.5	659.0	----------	----------	----------	----------

From the data presented in tables 2 and 3, the formulae representing the oxidation reaction for these samples have been derived. These formulae are, (A) a formula representing oxidation at a unimolecular

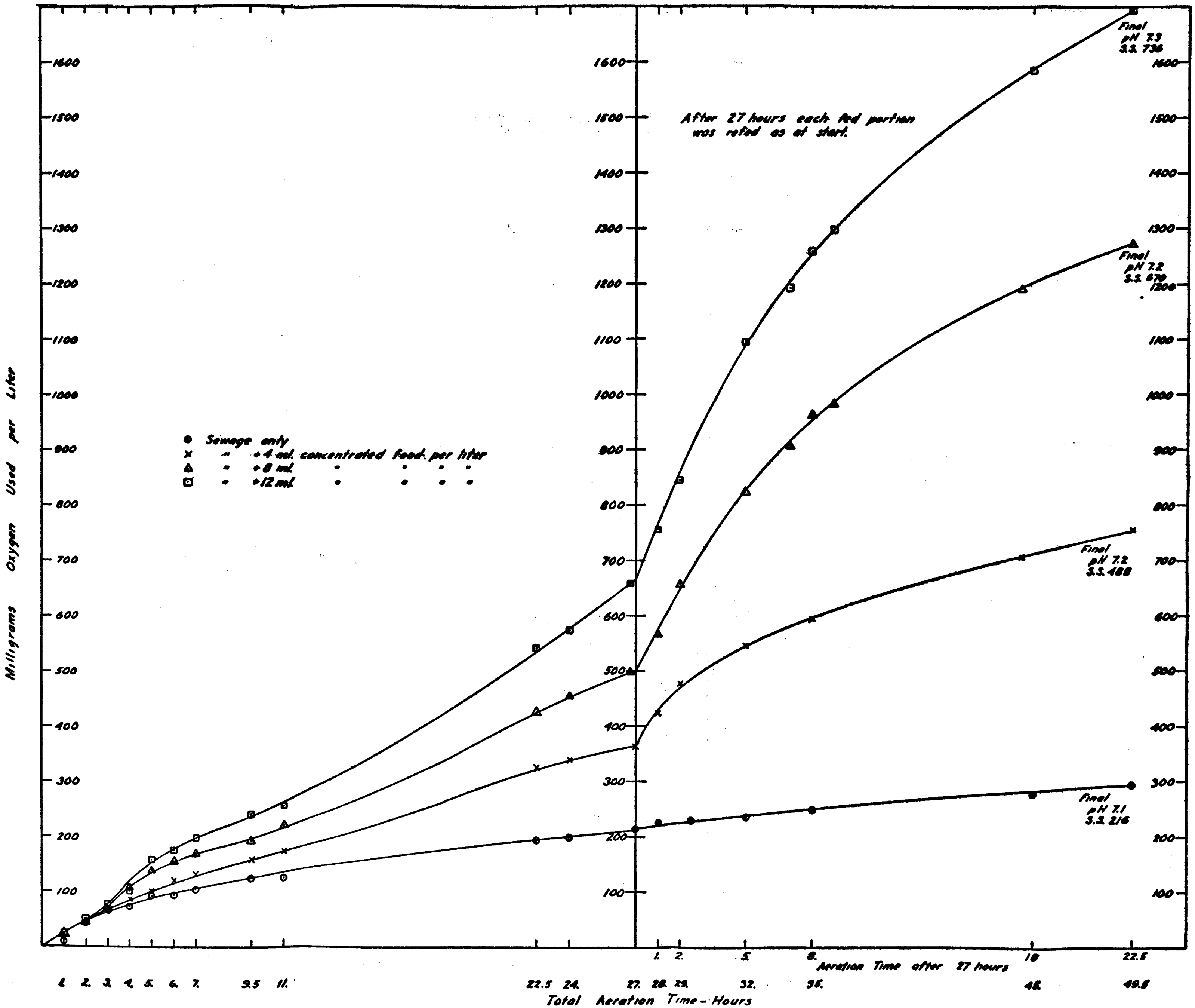

FIGURE 1.—Oxidation observed during rapid development of activated sludge by sewage fed with varying amounts of concentrated food.

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rate as already presented (*1*), and (B) a formula representing the oxidation as the sum of two unimolecular rates

$$y=L-[a(10^{-k_1t})+b(10^{-k_2t})] \qquad \text{(B)}$$

where y = the B. O. D. oxidized in time t,
L = the initial total carbonaceous B. O. D.,
a = a constant representing the portion of L oxidized at a high rate,
b = a constant representing the portion of L oxidized at a lower rate,
k_1 and k_2 = the velocity constants that apply to a and b respectively, and
t = time in days.

In formula B the rate at which the portion (a) of L is oxidized during aeration is very high compared with the rate at which (b) is oxidized. Because the rate k_1 is relatively large, the term $a(10^{-k_1t})$ rapidly becomes smaller and after a few hours is negligible indicating that (a) has been entirely oxidized. The constants for the formulae representing the oxidations for these samples are given in table 4. The data presented indicate that, at constant temperature and optimum pH, the rate of oxidation depends upon the relation between the microflora and the substrate food which prevail in the biochemical system, and that biochemical oxidation under the various states of equilibrium possible between these two factors does not always follow the unimolecular reaction.

In this experiment the original sewage aerated during the first 27-hour period was oxidized at a rate so much higher than the unimolecular one that the oxidation reaction could be fitted only by the formula (B), $y=L-[a(10^{-k_1t})+b(10^{-k_2t})]$. During the second period, however, the data for this sample indicated a unimolecular rate fitting the formula (A), $y=L-(1-10^{-kt})$. In samples 2, 3, and 4, to which additional concentrated food was added, a lag was observed for a few hours after aeration was started. The data for these samples during the first 24 hours indicated oxidation at slowly increasing rates. On the second day, however, when further increments of concentrated food were added, a marked immediate increase in the rate of oxidation was observed. During this period the data could not be fitted to unimolecular formulae but could be fitted by formula (B). This phenomenon of oxidation at greatly accelerated rates requiring the more complicated formula (B) to fit the data suggests that the velocity constants in this expression will vary considerably, depending upon a number of factors. Consequently no fixed formula can be given that will represent the oxidation of organic matter in artificially cultured systems such as the activated sludge process.

It may be justifiable to point out that the oxidation reactions occurring in the samples receiving concentrated food could not be explained on the basis of the so-called immediate chemical oxygen demand. They do seem rational, however, on the assumption that a population of microflora is developed during the first aeration period which is capable of oxidizing, at much higher rates, the food added on the second day.

TABLE 4.—*Experiment 1—Form of reaction curve and velocity constants for samples during the first and second aeration periods*

Sample No.	Form of reaction curve		Constants for reaction curve												
			Carbonaceous B. O. D. in p. p. m.						Velocity constants at 20° C.						
	First aeration period	Second aeration period	First aeration period			Second aeration period			First aeration period				Second aeration period		
			L	a	b	L	a	b	K[1]		K_1	K_2	K	K_1	K_2
									0–11 hour	*11–27 hour*					
1	B	A	553	53	500	339	-----	-----	-----	-----	4.0	0.194	0.121	-----	-----
2	A	B	822	-----	-----	726	98	628	0.206	0.206	-----	-----	-----	6.0	0.293
3	A	B	1,090	-----	-----	1,129	199	930	.167	.241	-----	-----	-----	3.2	.44
4	A	B	1,360	-----	-----	1,507	227	1,280	.112	.151	-----	-----	-----	3.3	.44

Curve (A): $y=L(1-10^{-k_1t})$. Curve (B): $y=L-[a(10^{-k_1t})+b(10^{-k_2t})]$.

[1] In samples 3 and 4 the K is rapidly increasing during the first 24-hour period and for periods indicated is about as given.

QUANTITIES OF OXYGEN USED BY ACTIVATED SLUDGE MIXED LIQUOR FROM THE EXPERIMENTAL PLANT

In a series of experiments in 1933, Theriault and McNamee (*6*) determined the rates of oxygen absorption in the mixed liquor of an aeration tank. The analyses of their data indicated the following:

(1) That the results of some experiments could be fitted to the unimolecular expression (A), but the velocity constants at 20° C. had a mean value of about 0.208, indicating, for the periods of observation, oxidation at higher rates than those obtained under natural conditions.

(2) That the data for most of the experiments best fitted the expression (B) indicating oxidation as the sum of two unimolecular rates.

Theriault and McNamee (*5*) were the first to show that the expression (B) was necessary to define the rates of oxidation occurring in an activated sludge. Recently Moore (*7*) has pointed out that the data of Kessler and Nichols (*8*) on oxygen consumption in activated sludge mixtures could be represented as the sum of three unimolecular rates.

A summary of the data obtained by Theriault and McNamee (*6*) on oxidation in the mixed activated sludge liquor from the aeration tank at this station is presented in table 5. Sixty-nine samples of mixed liquor taken from the same point in the aeration tank were studied. Nitrification occurred in 15 of these tests and did not occur in the remainder. The series showing no nitrification was divided into three groups according to the amount of oxygen used per gram of suspended solids in 4 hours. The mean quantities of oxygen absorbed for each group and the maximum and minimum quantities of oxygen absorbed in 48 hours per gram of suspended solids are plotted in figure 2. These data show the tremendous differences in oxidation taking place at various times in the sludge aeration mixture. They also indicate that it would be desirable to know the quantity of oxygen that was required by the activated sludge alone, and also the biochemical oxygen demand of the substrate that was applied.

TABLE 5.—*Oxygen used by activated sludge-mixed liquor from experimental plant*

[69 series of tests from January 1933 to September 1934]

Group	Nitrifying	Number of series	Result	Suspended solids, p. p. m.	Mg of O_2 used per gram suspended solids in indicated time (hours)					
					1	2	4	6	24	48
1	No	16	Mean	3,520	8.32	12.3	22.2	29.9	89.0	144
			Max	3,304	4.42	13.3	25.1	-------	136.0	258
			Min	3,932	6.31	-------	22.3	-------	74.2	119
2	No	25	Mean	3,030	9.65	18.3	35.4	48.7	142	225
			Max	3,320	6.80	16.4	38.0	-------	184	319
			Min	3,100	8.61	13.7	26.1	38.2	114	201
3	No	13	Mean	2,500	17.8	32.8	58.7	81.0	202	329
			Max	2,560	24.4	47.3	-------	91.5	258	435
			Min	2,230	14.9	30.5	55.4	80.8	187	308
4	Yes	15	Mean	3,695	7.09	12.8	22.2	30.2	97.7	142
			Max	3,296	5.50	8.65	20.4	-------	147	272
			Min	3,790	8.70	13.0	18.9	24.3	51.2	73.2

THE QUANTITIES OF OXYGEN USED BY ACTIVATED SLUDGE ALONE AND WITH THE ADDITION OF SUBSTRATE FOOD

A number of experiments were performed with activated sludge to which different amounts of substrate food were added. The data obtained in these experiments are presented in table 6. In experiments 2 and 3, three multiple increments of concentrated synthetic sewage were added to liter quantities of a well-aerated activated sludge mixture and these were aerated. Another liter of the same activated sludge mixture was aerated alone, simultaneously, as a control. In the remainder of the experiments, supernatant liquor was withdrawn from the aerated activated sludge mixture chosen for study before dosing with normal strength nutrient material. In each case the sludge mixture was distributed in 1-liter amounts into liter cylinders, care being taken to prevent settling during the distribution of these samples. The sludge was allowed to settle in the cylinders for 30 minutes before siphoning off the supernatant liquor. In experiments 4 and 5 the supernatant liquor was removed as described from liter quantities of aerated mixture and multiple increments of sewage were added to three cylinders. Dilution water was added to the fourth one, which served as a control. All samples were then returned to the closed system aeration bottles for further aeration. In experiments 6 to 10, sludge mixtures prepared as described and dosed with synthetic, raw, clarified, or Berkefeld-filtered sewage were aerated simultaneously with controls containing the same quantities of sludge and buffered dilution water. The data in table 6 indicate that in every experiment more oxygen was utilized in the dosed or fed mixtures than in the control mixtures.

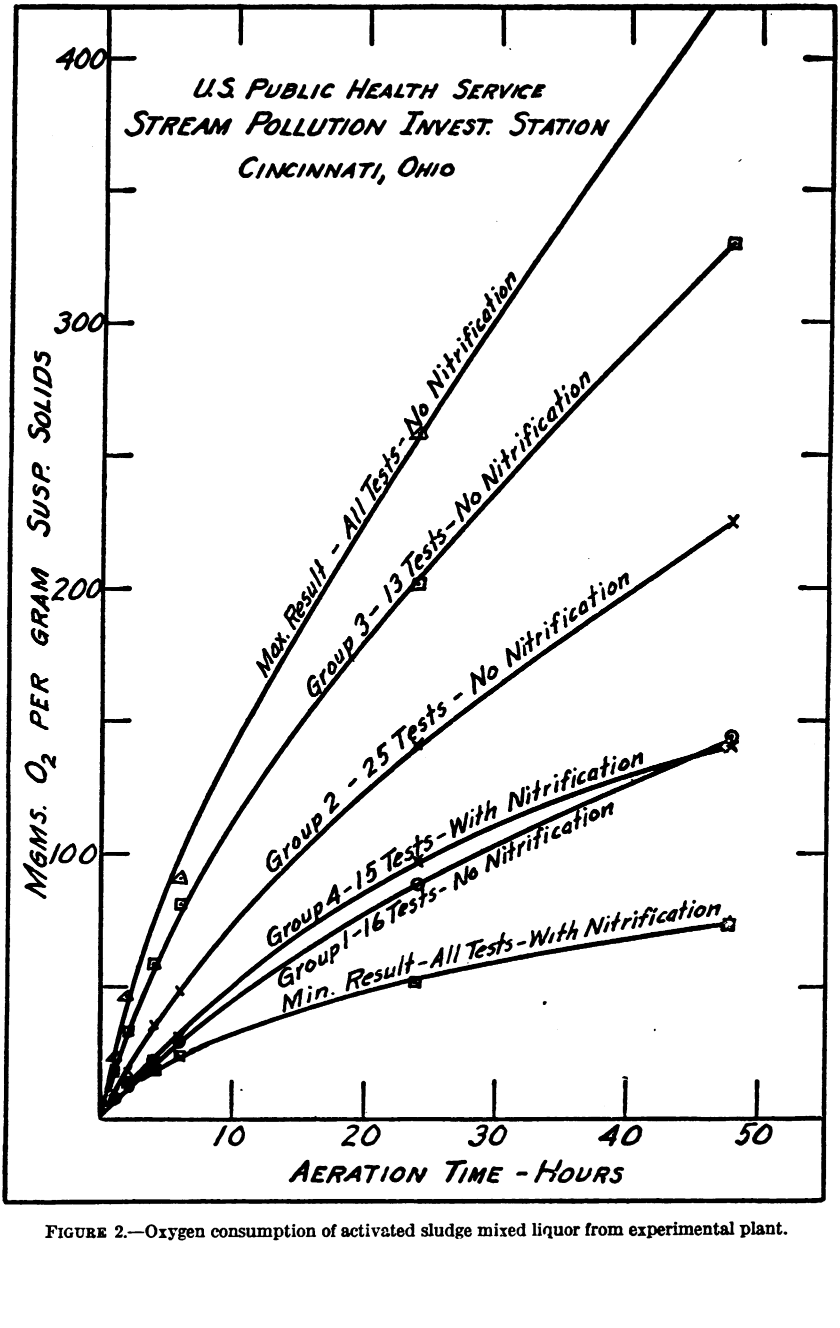

FIGURE 2.—Oxygen consumption of activated sludge mixed liquor from experimental plant.

TABLE 6.—*Quantities of oxygen used when substrate food is added to activated sludge*

Experiment No.	Mixture	Composition of mixture, in liters*	Suspended solids in p. p. m. of activated sludge (x)	5-day B. O. D.		20-day B.O.D.	Mg of O_2 used per liter in indicated time (hours)									
				Of residual supernatant	Of substrate food	Of substrate food	½	1½	2	3	4	5	10	11	22	24
2	A	$x+1.0y$			0		9.3	21.6		44.4	[1] 62.8		[2] 111.3	124.9	196.3	
	B	$x+1.0y+0.004z_1$	1,140		184		23.3	57.9		107.3	[1] 146.5		[2] 250.3	278.6	390.6	
	C	$x+1.0y+0.008z_1$	1,140		368		25.1	65.7		121.0	[1] 162.2		[2] 279.9	318.5	478.0	
	D	$x+1.0y+0.012z_1$	1,140		552		34.6	76.6		148.0	[1] 197.7		[2] 375.6	439.0	743.0	
3	A	$x+1.0y$			0		[3] 10.6		23.1	37.8		60.4	[4] 94.9	137.5	251.5	
	B	$x+1.0y+0.004z_1$	2,624		347		[3] 54.1		94.1	124.1		195.7	[4] 269.9	334.8	487.3	
	C	$x+1.0y+0.008z_1$	2,624		694		[3] 44.4		88.1	135.8		223.6	[4] 333.5	453.6	693.2	
	D	$x+1.0y+0.012z_1$	2,624		1,041		[3] 65.5		122.2	183.8		276.6	[4] 403.9	552.6	857.6	
4	A	$x+0.2y \quad +0.8d$		4.16	0		[3] 11.7		13.5	14.5	25.9		37.2			[5] 113.3
	B	$x+0.2y+0.2z_2 \quad +0.6d$	2,024	4.16	85		[3] 29.0		34.7	43.0	54.5		80.8			[5] 194.4
	C	$x+0.2y+0.4z_2 \quad +0.4d$	2,024	4.16	170		[3] 28.2		42.7	56.4	67.0		99.5			[5] 244.4
	D	$x+0.2y+0.6z_2 \quad +0.2d$	2,024	4.16	255		[3] 31.8		47.0	61.8	79.6		124.7			[5] 283.5
5	A	$x+0.25y \quad +0.75d$		2.40	0		4.4		28.7		37.7			[6] 91.7		134.8
	B	$x+0.25y+0.25z_2+0.5d$	3,564	2.40	31.5		26.6		60.8		91.2			[6] 179.4		285.2
	C	$x+0.25y+0.5z_2 \quad +0.25d$	3,564	2.40	63.0		38.6		85.3		127.6			[6] 236.8		301.6
	D	$x+0.25y+0.75z_2$	3,564	2.40	94.5		29.6		78.4		144.4			[6] 247.6		348.5
6	A	$x_1+0.25y \quad +0.75d$			0		5.6		10.6	19.9	30.5		45.9			88.6
	B	$x_1+0.25y+0.75z_1$	2,676		244	540	24.4		56.1	90.9	120.2		184.9			273.2
	A_1	$x_1+0.25y \quad +0.75d$			0		3.3		15.6		18.0		48.8			89.9
	B_1	$x_1+0.25y+0.75z_2$	2,268		233	370	10.4		56.8		106.7		194.4			279.7
	C_1	$x_1+0.25y+0.75z_3$	2,268		118	242	23.6		55.6		97.5		159.6			212.2
7	A	$x_1+0.3y \quad +0.7d$			0		14.7	30.2		50.6		63.8	115.2			
	B	$x_1+0.3y+0.7z_4$	2,504		62	174	36.7	74.3		131.3		171.1	239.6			306.9
	C	$x_1+0.3y+0.7z_2$	2,448		137	338	43.6	54.2		101.0		138.9	216.9			280.7
8	A	$x+0.5y \quad +0.5d$			0		13.2	22.9		35.0		45.8			[7] 114.2	
	B	$x+0.5y+0.5z_1$	2,828		107	140	31.0	56.7		78.6		101.4			[7] 182.2	
	C	$x+0.5y+0.5z_2$	2,816		173	256	36.9	73.4		112.5		138.0			[7] 234.1	

See footnotes at end of table.

TABLE 6.—*Quantities of oxygen used when substrate food is added to activated sludge*—Continued

Experiment No.	Mixture	Composition of mixture, in liters*	Suspended solids in p. p. m. of activated sludge (x)	5-day B. O. D.		20-day B.O.D.	Mg of O_2 used per liter in indicated time (hours)									
				Of residual supernatant	Of substrate food	Of substrate food	½	1½	2	3	4	5	10	11	22	24
9	A	$x+0.5y$ $+0.5d$			0		13.2	20.9		29.7		42.6				88.7
	B	$x+0.5y+0.5z_5$	2,780		171	252	33.4	57.7		75.5		94.0				181.6
	C	$x+0.5y+0.5z_2$	2,784		168	254	32.3	62.2		83.1		107.6				208.3
10	A	$x+0.5y+0.5d$			0		1.0	12.8		19.5		26.5				110.3
	B	$x+0.5y+0.5z_5$	2,840		180	247	23.3	54.0		83.0		106.2				221.5
	C	$x+0.5y+0.5z_2$	2,856		176	252	26.9	56.0		91.2		116.7				226.4

*See following explanation:
x=Suspended activated sludge from experimental plant.
x_1=Sludge from north-side plant, Lancaster, Pa.
y=Old supernatant in which the sludge floc (x) is suspended.
Substrate feed:
z_1=Synthetic sewage.
z_2=Raw sewage.
z_3=Berkefeld filtered sewage.
z_4=Sewage clarified by precipitation with iron salts.
z_5=Sterile sewage.
d=Dilution water used to make up volumes of sludge mixture to 1 liter.

[1] 4½ hours. [2] 9 hours. [3] 1 hour. [4] 8 hours. [5] 26 hours. [6] 12 hours. [7] 23 hours.

The quantities of oxygen that were used as a result of the addition of the food to the sludge obtained by subtracting the quantities used in the controls from the quantities used in the corresponding sludge nutrient substrate mixtures are shown in table 7. It will be observed in experiments 2 to 5 that doubling or tripling the B. O. D. of the substrate by the addition of food did not result in proportionate increases in the amount of oxygen utilized. In other words, the quantities of oxygen utilized as a result of the food added (B–A, C–A, and D–A, table 7) are not proportional to the B. O. D. of the food increments added. This is illustrated for experiment 4 by figure 3, which shows the quantity of oxygen utilized for each of the three increments of substrate food added. Although the 5-day B. O. D. of the substrate food was increased threefold in these experiments, the oxygen utilized during 4 hours aeration was only about double that required for a single food increment. For shorter periods of aeration, less than twice the amount of oxygen was required when a triple food supply was added. In experiment 5, nitrification was carried much further with a single increment of sewage than it was with larger doses. Nineteen parts per million of nitrate were produced in 24 hours by the addition of 1 increment of sewage, while with 3 portions, which proportionately provided for the formation of 57 parts, the sludge produced only 28 parts of nitrate in the same time. Experiments 2 to 5 illustrate that, for the aeration periods ordinarily employed, activated sludge has the capacity of oxidizing the B. O. D. of substrates applied to it at a rather high rate, but that the extent of oxidation of increments of substrate feed during the same periods of time is not proportional to their respective B. O. D. values.

The additional quantities of oxygen used when activated sludge is dosed with synthetic sewage, raw sewage, sewage clarified with ferric chloride, or Berkefeld-filtered sewage are shown for experiments 6 to 10 in table 7. It will be noted that with these substrates the additional quantities of oxygen used by the sludge mixture were of the same order of magnitude as for experiments 4 and 5.

The increased amounts of oxygen used as a result of the addition of the substrate is a useful index of sludge-oxidizing capacity. This involves the assumption that the same quantity of oxygen is required by the sludge control as for the sludge component of the feed mixture during the short periods of observation employed. The reasonableness of this assumption has already been discussed in the pure culture sludge paper (*1*). Although the validity of the assumption has not been checked as yet for carbonaceous material, it has been demonstrated as true for ammonia. However, it makes little difference whether this assumption is exactly correct or not for the purpose of a practical test. This has been demonstrated by our experience in the operation of the experimental plant and by the results obtained by Bloodgood (*9*) at Indianapolis.

Table 7.—*Additional quantities of oxygen used when various substrate foods were added to activated sludge*

Experiment No.	Computation of oxidation from table 6	Mg of oxygen used per liter in indicated time (hours)									
		½	1½	2	3	4	5	10	11	22	24
2	B–A	14.0	36.3	------	62.9	[1] 83.7	------	[2] 139.0	153.7	192.3	------
	C–A	15.8	44.1	------	76.6	[1] 99.4	------	[2] 168.6	193.6	279.7	------
	D–A	25.3	55.0	------	103.6	[1] 134.9	------	[2] 264.3	314.1	544.7	------
3	B–A	[3] 43.5	------	71.0	86.3	------	135.3	[4] 175.0	197.3	235.8	------
	C–A	[3] 33.8	------	65.0	98.0	------	163.2	[4] 238.6	316.1	441.7	------
	D–A	[3] 54.9	------	99.1	146.0	------	216.2	[4] 309.0	415.1	606.1	------
4	B–A	[3] 17.3	------	21.2	28.5	28.6	------	43.6	------	------	[5] 81.1
	C–A	[3] 16.5	------	29.2	41.9	41.1	------	62.3	------	------	[5] 131.1
	D–A	[3] 20.1	------	33.5	47.3	53.7	------	87.5	------	------	[5] 170.2
5	B–A	22.2	------	32.1	------	53.5	------	------	[6] 87.7	------	150.4
	C–A	34.2	------	56.6	------	89.9	------	------	[6] 145.1	------	166.8
	D–A	25.2	------	49.7	------	106.7	------	------	[6] 155.9	------	213.7
6	B–A	18.8	------	45.5	71.0	89.7	------	139.0	------	------	184.6
	B_1–A_1	7.1	------	41.2	------	88.7	------	145.6	------	------	189.8
	C_1–A_1	20.3	------	40.0	------	79.5	------	110.8	------	------	122.3
7	B–A	22.0	44.1	------	80.7	------	107.3	124.4	------	------	------
	C–A	8.3	24.0	------	50.4	------	75.1	101.7	------	------	------
8	B–A	17.8	33.8	------	43.6	------	55.6	------	------	[7] 68.0	------
	C–A	23.7	50.5	------	77.5	------	92.2	------	------	[7] 119.9	------
9	B–A	20.2	36.6	------	45.8	------	51.4	------	------	------	92.9
	C–A	19.1	41.3	------	53.4	------	65.0	------	------	------	119.6
10	B–A	22.3	41.2	------	63.5	------	79.7	------	------	------	111.2
	C–A	25.9	43.2	------	71.7	------	90.2	------	------	------	116.1

[1] 4½ hours. [2] 9 hours. [3] 1 hour. [4] 8 hours. [5] 26 hours. [6] 12 hours. [7] 23 hours.

For practical purposes, therefore, the difference between the quantities of oxygen utilized by the fed mixture and by the activated sludge control represents substantially the oxidation of the added substrate as produced by the activated sludge under aeration. If a substrate with a constant 5-day B. O. D. is used in the tests, the quantity of substrate oxidation determined as above is a direct index of the oxidizing capacity of the sludge. High values in general indicate a good sludge, while low values indicate a poor sludge. As the performance obtained is not independent of the B. O. D. of the substrate added, this factor must be taken into account in sludge substrate oxidizing capacity tests conducted with substrates having different B. O. D. values. In this study the quantity of oxygen used to oxidize the substrate has been calculated in percentage of the 5-day B. O. D. of the substrate that was added to obtain comparable data of sludge-oxidizing capacity. This has been done for experiments 2 to 10 and the results are shown in table 8. It will be noted that the percentage of oxidation of the substrate B. O. D. calculated as described, after ½-hour aeration in the presence of activated sludge varied tremendously, from 3.1 to 70.5 percent, depending upon the quantity and quality of the sludge present, the B. O. D. of the sub-

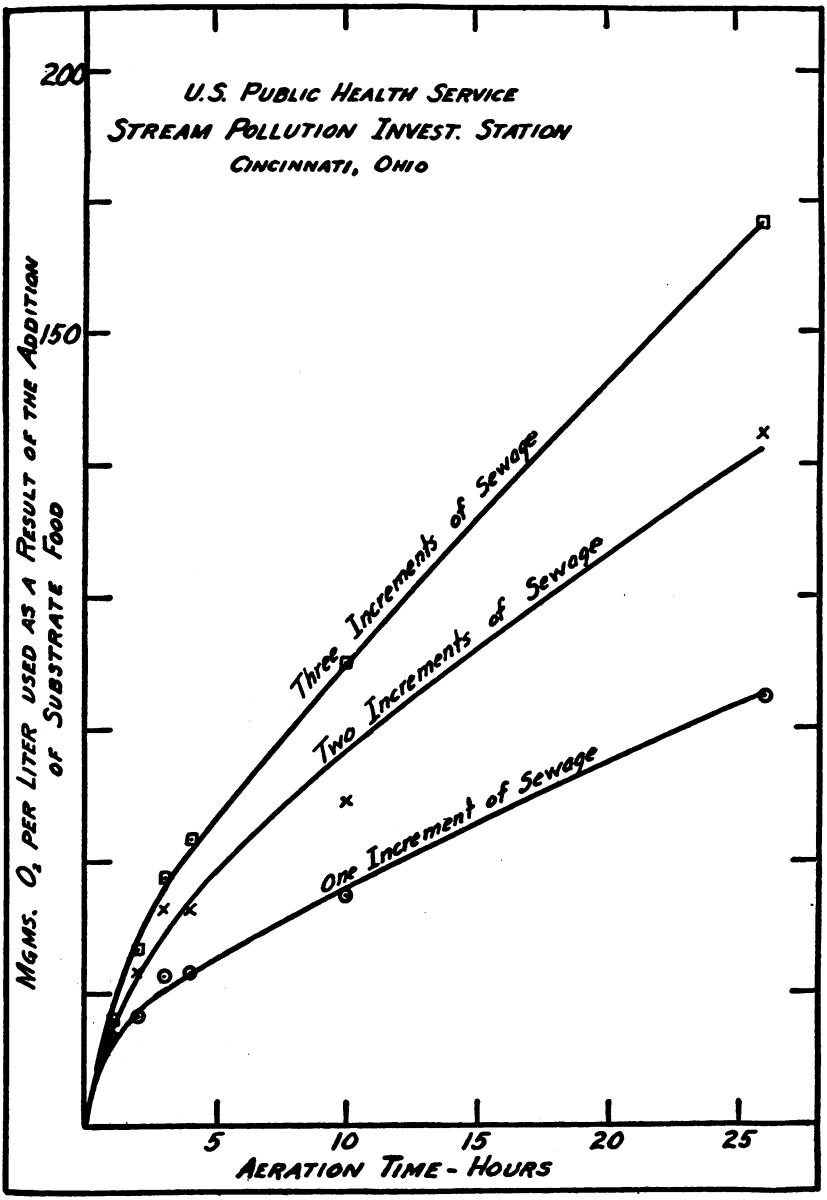

FIGURE 3.—Milligrams of oxygen used to oxidize increasing increments of sewage substrate feed by the same quantity of activated sludge. Experiment 1—non-nitrifying sludge.

strate applied, and upon whether the sludge was nitrifying or not. These great differences in performance are noticeable throughout the aeration periods employed in these experiments.

Table 8.—*Percentage of 5-day B. O. D. of substrate food oxidized by activated sludge*

Experiment No.	Substrate food: Nature	Substrate food: Ml per liter of sludge	Sludge nitrifying	Percentage of oxidation in indicated time (hours)*: ½	1½	2	3	4	5	10	11	22	24
2	Concentrated synthetic sewage	4	No	7.6	19.7		34.2	[1] 45.5		[2] 75.5	83.5	104.5	
	do	8	No	4.3	12.0		20.8	[1] 27.0		[2] 45.8	52.6	76.0	
	do	12	No	4.6	10.0		18.8	[1] 24.4		[2] 47.9	56.9	98.7	
3	Concentrated synthetic sewage	4	No	[3] 12.5		20.5	24.9		39.0	[4] 50.4	56.9	68.0	
	do	8	No	[3] 5.9		9.4	14.1		23.5	[4] 34.4	45.5	63.6	
	do	12	No	[3] 5.3		9.5	14.0		20.8	[4] 29.7	39.9	58.2	
4	Raw sewage	200	No	[3] 20.3		24.9	33.5	33.6		51.2			[5] 95.3
	do	400	No	[3] 9.7		17.1	24.6	24.2		36.6			[5] 77.1
	do	600	No	[3] 8.0		13.1	18.5	21.0		34.2			[5] 66.8
5	Raw sewage	250	Yes	70.5		98.5		170.0			[6] 278.0		470.0
	do	500	Yes	54.4		89.8		142.0			[6] 230.0		265.0
	do	750	Yes	27.6		54.3		116.0			[6] 170.0		232.0
6	Synthetic sewage	750		7.7	18.6		29.1		36.8	57.0			75.5
	Raw sewage	750		3.1	17.7				38.1	62.5			81.5
	Filtered sewage	750		17.2	33.9				67.4	93.9			104.0
7	Clarified sewage	700	Yes	35.5	71.1		130.0		173.0	201.0			
	Raw sewage	700	Yes	6.1	17.5		36.8		54.8	74.2			
8	Synthetic sewage	500		16.6	31.6		40.7		52.0			[7] 63.6	
	Raw sewage	500		13.7	29.2		44.8		53.3			[7] 69.3	
9	Sterile sewage	500		11.9	21.4		26.8		30.1				54.3
	Raw sewage	500		11.3	24.6		31.8		38.7				71.2
10	Sterile sewage	500		12.4	22.9		35.3		44.3				61.8
	Raw sewage	500		14.7	24.5		40.7		51.3				66.0
	Percentage of 20-day B. O. D. of substrate food oxidized by activated sludge												
6	Synthetic sewage	750		3.48	8.4		13.1		16.6	25.7			34.2
	Raw sewage	750		1.92	11.1				24.0	39.4			51.3
	Filtered sewage	750		8.39	16.5				32.9	45.8			50.5
7	Clarified sewage	700		12.6	25.3		46.4		61.7	71.5			
	Raw sewage	700		2.45	7.1		14.9		22.2	30.1			
8	Synthetic sewage	500		12.7	24.1		31.1		39.7			[7] 48.6	
	Raw sewage	500		9.26	19.7		30.3		36.0			[7] 46.8	
9	Sterile sewage	500		8.06	14.5		18.2		20.4				36.9
	Raw sewage	500		7.51	16.3		21.0		25.6				47.1
10	Sterile sewage	500		9.08	16.7		25.7		32.2				45.0
	Raw sewage	500		10.3	17.1		28.5		35.8				46.1

* Difference in the oxygen used by the sludge food mixture (2) minus the oxygen used by the sludge control $(x+y)$, divided by the 5-day B. O. D. of the substrate food multiplied by 100.

[1] 4½ hours. [2] 9 hours. [3] 1 hour. [4] 8 hours. [5] 26 hours. [6] 12 hours. [7] 23 hours.

When a substrate with a 5-day B. O. D. of 1,041 p. p. m. was fed to a mixture containing 2,624 p. p. m. of nonnitrifying activated sludge, as in experiment 2, using 3 increments (mixture D) of sewage, 20.8 percent of the 5-day B. O. D. was satisfied after 4 hours and 58.2 percent after 22 hours. On the other hand, when a portion of sewage with a 5-day B. O. D. of only 31.5 p. p. m. was fed to a mixture containing 3,564 p. p. m. of an actively nitrifying sludge, as in mixture B, experiment 5, 116 percent of the 5-day B. O. D. was satisfied after 4 hours and 480 percent after 24 hours. These two cases illustrate the extremes in substrate oxidation performance noted in these experiments.

Experiments 6 and 8 indicate that there is very little difference in the percentage of oxidation of raw sewage and synthetic sewage materials when similar doses of these substances are fed to similar quantities of activated sludge. Experiments 9 and 10 show that when sterile sewage is fed to an activated sludge, the percentage of substrate oxidation is approximately the same as when raw sewage is used as the feed. Although raw sewage ordinarily contains from 1 to 10 million bacteria per ml when added to an activated sludge, these experiments indicate that it is immaterial whether these additional bacteria are added or not so far as the success of the biochemical oxidation accomplished in the process is concerned. It would seem from this fact that the numbers of bacteria already present and functioning in activated sludge must be truly enormous.

The Berkefeld-filtered sewage used in experiment 6 and the clarified sewage used in experiment 7 had 5-day biochemical oxygen demands of 118 p. p. m. and 62.0 p. p. m., respectively. Dosing with these substrates contributed a much lower B. O. D. load than did the corresponding raw sewages. In accordance with the principle illustrated in experiments 2 to 5, it would be expected that the percentages of oxidation for these substrates would be greater than for the corresponding raw sewages, and the results indicate that this is actually the case. The sludge in experiment 7, dosed with clarified sewage, accomplished considerable nitrification, while the raw sewage mixture in this experiment failed to reach the nitrification stage during the 10-hour period of examination.

OXIDATION PERFORMANCE DURING THE DEVELOPMENT OF ACTIVATED SLUDGE IN THE EXPERIMENTAL PLANT

The oxygen requirements of dosed and undosed (control) sludges during the development of activated sludge in the experimental plant were studied in a series of tests. These tests were made in exactly the same manner as those already described. The first test was made after the plant had been operated on the fill-and-draw principle for several days and 182 p. p. m. of suspended solids had been built up and retained in the tank. Thereafter tests were made about once a week for 11 weeks. At the end of this period a fairly good nitrifying sludge had been developed. The quantities of oxygen used by the control and by the dosed sludge during this series of tests are shown in table 9. Table 10 shows the 5-day and 20-day B. O. D. of the plant effluent, the 5-day B. O. D. of the substrate feed added for the test, and the increased quantities of oxygen used as a result of the food added. The percentage of the 5-day B. O. D. of the substrate that is oxidized, calculated as has been described, is presented in table 11.

TABLE 9.—*Quantities of oxygen used by activated sludge control and activated sludge plus sewage during activated sludge development in experimental plant*

Time from start of aeration (days)	Test No.	Activated sludge suspended solids, p. p. m.	Mg of O_2 used per liter in indicated time (hours)									
			Activated sludge plus sewage					Activated sludge control				
			½	2	3	4	24	½	2	3	4	24
3	1	182	0.0	9.6	-------	20.7	84.4	1.5	2.3	------	4.7	37.8
12	2	300	8.1	29.2	-------	71.8	455.0	4.7	17.7	------	21.7	55.6
19	3	760	17.3	49.9	-------	76.5	179.2	.9	10.9	------	27.5	92.8
28	4	1,188	13.3	36.2	-------	59.8	190.5	12.9	26.2	------	46.0	174.1
35	5	1,462	28.7	59.7	-------	91.6	240.2	7.5	24.9	------	49.0	118.5
47	6	1,448	34.2	79.0	-------	86.3	209.8	13.7	22.5	------	40.7	115.2
56	7	2,300	38.5	63.0	-------	111.0	-------	17.9	32.1	------	69.7	241.7
70	8	2,920	[1] 68.5	------	130.4	[2] 162.5	321.0	[1] 21.5	------	45.6	[2] 69.7	231.8
83	9	2,864	[1] 73.2	------	189.8	[2] 232.9	472.9	[1] 44.1	------	52.5	[2] 74.3	246.0

[1] 1 hour.
[2] 5 hours.

TABLE 10.—*Additional quantities of oxygen used, as a result of the addition of sewage, by activated sludge during its development in the experimental plant*

Time from start of aeration (days)	Test No.	Activated sludge suspended solids, p. p. m.	B. O. D. of supernatant effluent in p. p. m.		B.O.D. of substrate feed, 5-day	*Mg of O_2 used per liter as a result of substrate feed addition in indicated time (hours)				
			5-day	20-day		½	2	3	4	24
3	1	182	16.0	106.8	112.0	0.0	7.3	--------	16.0	46.6
12	2	300	15.4	100.6	795.0	3.4	11.5	--------	50.1	399.4
19	3	760	12.0	99.4	233.0	16.4	39.0	--------	49.0	86.4
28	4	1,188	10.0	54.1	55.0	.4	10.0	--------	13.8	16.4
35	5	1,462	8.5	51.8	123.0	21.2	34.8	--------	42.6	121.7
47	6	1,448	11.3	11.5	78.0	20.5	56.5	--------	45.6	94.6
56	7	2,300	11.7	14.1	79.9	20.6	30.9	--------	41.3	--------
70	8	2,920	11.6	21.0	176.0	[1] 47.0	--------	84.8	[2] 92.8	89.2
83	9	2,864	22.3	25.1	136.0	[1] 29.1	--------	137.3	[2] 158.6	226.4

* Obtained by subtracting the activated sludge control data from the corresponding activated sludge plus feed data as given in table 12.
[1] 1 hour.
[2] 5 hours.

TABLE 11.—*Percentage of 5-day B. O. D. of substrate sewage oxidized by activated sludge during development in experimental plant*

Time from start of aeration (days)	Test No.	Activated sludge suspended solids, p. p. m.	Percentage oxidation during the indicated time (hours)[a]				
			½	2	3	4	24
3	1	182	0.0	6.5	----------	14.3	41.6
12	2	300	.42	1.45	----------	6.3	50.2
19	3	760	7.0	16.7	----------	21.0	37.1
28	4	1,188	.72	18.2	----------	25.1	29.8
35	5	1,462	17.2	28.3	----------	34.6	98.9
47	6	1,448	26.3	(72.4)	----------	58.5	121.3
56	7	2,300	25.8	33.7	----------	51.7	----------
70	8	2,920	[1] 26.7	----------	48.2	[2] 52.7	50.7
83	9	2,864	[1] 21.4	----------	101.0	[2] 116.6	166.8

[a] Difference in oxygen used by sludge feed mixture minus oxygen used by sludge control divided by 5-day B. O. D. of feed × 100.
[1] 1 hour.
[2] 5 hours.

During the period of sludge development covered by these tests the suspended solids in the aeration tank mixture gradually increased from 182 to 2,900 p. p. m. One difficulty with the tests was caused by the wide fluctuation in the 5-day B. O. D. of the sewage arriving at the plant. Thus on March 25 the sewage feed had a 5-day B. O. D. of 795 p. p. m., while on April 10 it had a value of only 55 p. p. m. A more uniform strength of the sewage used would doubtless have increased the significance of the tests. In tests Nos. 1 and 2, 14.3 and 6.3 percent, respectively, of the 5-day B. O. D. of the substrate feed was oxidized in 4 hours. In tests Nos. 3 and 4 the amount of sludge had increased and the 4-hour percentages o' substrate oxidation had increased to 21.1 and 24.7, respectively. Reference to table 9 indicates that, judged by the amount of oxygen necessary to stabilize the sludge alone, the quality of the sludge in test 4 had retrogressed since test 3 was made. The plant was, therefore, operated on the fill-and-draw principle for several days and then was returned to continuous flow operation. Test 5, made with a sludge of 1,462 p. p. m. suspended solids, showed a remarkable improvement in its substrate oxidizing capacity. In this test the percentages of the 5-day B. O. D. of the substrate feed oxidized during all periods had increased and in 4 hours had reached 34.5 percent. There was a further improvement in the substrate oxidizing capacity of the sludge in test 6. The data on tests 5 and 6 indicate that by this time the substrate oxidizing capacity had reached that of a normal nonnitrifying sludge. No significant changes appeared in the results from tests 7 and 8 except that, for some unexplained reason, no further substrate oxidation was noted in test 8 after the fifth hour. In test 9, however, the oxidation of the substrate organic matter was carried into the nitrification stage for the first time, as indicated by the presence of nitrates in the dosed mixture, and 116 percent of the 5-day B. O. D. of the substrate was oxidized in 5 hours.

SUMMARY OF SUBSTRATE OXIDATION PERFORMANCE

A summary of the mean substrate organic matter oxidation performance obtained with various sludges when dosed with different substrates and calculated as described, is shown in table 12 and illustrated in figure 4. The results obtained in the previous study (*1*) with pure culture sludges on synthetic and sterile domestic sewage are included in this table for comparison. In the tests made on sterile and synthetic sewage the data indicate that activated sludge did not quite equal the performance of pure culture sludge in substrate organic matter oxidation. The mean result of 11 tests with raw sewage substrate oxidized by nonnitrifying activated sludge gave lower satisfaction of 5-day B. O. D. for periods up to 3 hours, and higher proportions thereafter, than the tests on synthetic and on sterile sewage. With nitrifying sludges the highest percentages of 5-day substrate B. O. D. satisfaction were obtained. These sludges dosed with comparatively weak substrates indicated 5-day substrate B. O. D. oxidations of 54.3 and 115 percent in 1½ and 5 hours, respectively. These data indicate that the percentage of the B. O. D. of the substrate oxidized in activated sludge plant operation is much higher than has been generally realized.

TABLE 12.—*Summary of mean percentages of 5-day substrate feed B. O. D. oxidized as a result of its addition to various types of activated sludge*

Type of sludge	Number of determinations	Mean sludge suspended solids, p. p. m.	Substrate feed		Percentage of 5-day substrate feed B. O. D. oxidized in indicated time (hours)					
			Description	Mean 5-day B.O.D.	½	1½	3	5	10	24
Activated sludge [1]	2	3,214	Raw sewage	109	24.5	54.3	------	115.0	162.0	199.0
Do [2]	11	2,517	do	177	8.9	21.6	28.4	46.8	61.3	80.0
Do [2]	4	2,780	Synthetic and sterile sewage.	175	12.2	23.6	33.0	40.8	------	63.8
Pure culture sludge [3]	8	1,690	do	166	12.9	28.8	41.8	48.1	53.6	80.0

[1] Actively nitrifying sludge.
[2] Nonnitrifying sludge.
[3] Nonnitrifying zoogleal bacteria.

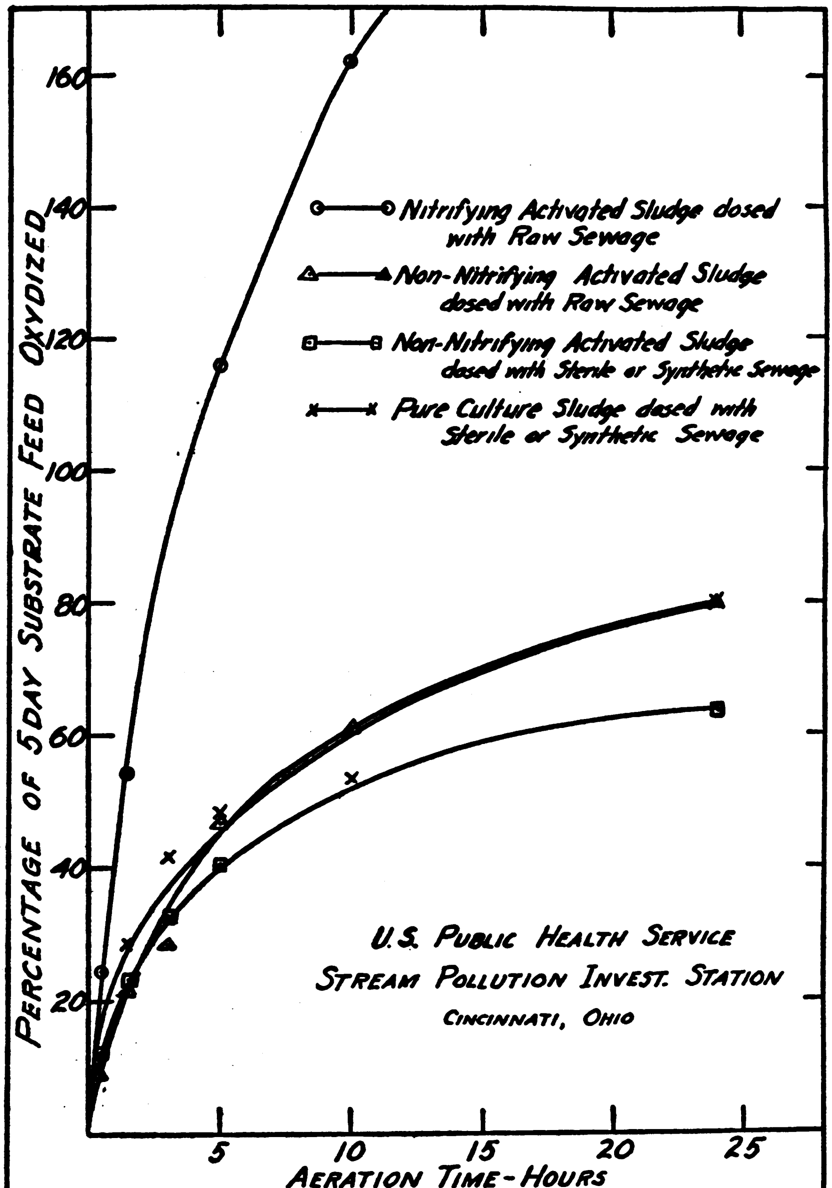

FIGURE 4.—Mean percentage of 5-day substrate feed B. O. D. oxidized by various types of activated sludge.

The control activated sludge mixtures used in all of these experiments contained the same quantities of sludge as the dosed mixtures and they were made up to volume with buffered dilution water after the old supernatant had been removed. Consequently the substrate liquor contained practically no organic food and the oxygen used by these mixtures can be ascribed to the oxidation of the sludge and to material previously adsorbed on the sludge floc.

The oxygen requirements of the sludge, obtained as described, are shown for experiments 2 to 10 in table 6 and for the series of tests on sludge development in table 9. From these data the quantities of oxygen used per gram of sludge have been calculated. The quantities of oxygen used per gram of sludge during activated sludge development are shown in table 13. It will be observed that the 4-hour oxygen requirement per gram of sludge was reduced progressively from 72.3 milligrams on the second test to 28.1 milligrams on the sixth test. During the same period the 24-hour oxygen requirement per gram of sludge was reduced from 185.3 milligrams to 79.6 milligrams. From the sixth to the ninth test there was little change in the oxygen requirements of the sludge. After the ninth test the plant was shut down for 38 days before it was started again. In August 1936, after the plant had been operating again for almost 30 days, tests 10 to 14 were made. During this period the plant was operated on an 8-hour aeration period and the tests show that the oxygen requirement of the sludge reached minimum values.

TABLE 13.—*Quantity of oxygen used to oxidize sludge during activated sludge development in experimental plant*

Time from start of aeration (days)	Test No.	Sludge index*	Suspended solids, p. p. m.	Percent ash	Mg of O_2 used per gram sludge in indicated time (hours)				
					½	2	3	4	24
3	1	--------	182	--------	8.2	12.6	--------	25.8	207.0
12	2	--------	300	--------	15.6	59.0	--------	72.3	185.3
19	3	--------	760	--------	1.18	14.3	--------	36.2	122.1
28	4	7.4	1,188	--------	10.8	22.0	--------	38.7	146.5
35	5	5.3	1,462	25.6	5.1	17.0	--------	33.5	81.0
47	6	2.7	1,448	22.3	9.5	15.5	--------	28.1	79.6
56	7	4.2	2,300	19.0	7.8	14.0	--------	[1] 30.3	105.1
70	8	4.6	2,920	18.7	7.3	--------	15.5	[1] 23.9	79.4
83	9	5.7	2,864	19.8	15.4	--------	18.3	[1] 25.9	85.9
151	10	3.6	2,982	28.5	[2] 4.1	6.5	8.1	[1] 11.0	35.3
152	11	--------	3,080	--------	5.1	5.6	7.3	[1] 11.9	35.9
154	12	3.4	2,784	26.8	[2] 4.7	7.5	10.7	[1] 15.3	31.9
155	13	--------	2,822	--------	[2] 4.7	8.1	12.4	[1] 16.2	40.5
156	14	--------	2,848	--------	.35	4.5	6.8	[1] 9.3	38.7

* P. p. m. suspended solids divided by sludge volume in milliliters per liter after 30 minutes' settling.
[1] 5 hours.
[2] 1 hour.

The quantities of oxygen used by sludges from other sources are shown in table 14. After the first 1½-hour period the sludge from the south-side plant at Lancaster, Pa., required more oxygen per gram than any other sludge examined. In 24 hours it required as much oxygen as the sludge in the experimental plant at the start of activated sludge development and twice as much as any activated sludge examined. From a biochemical standpoint this was the poorest of all sludges examined, for its substrate oxidizing performance, as heretofore defined, was nil. The north-side Lancaster plant sludge had oxygen requirements per gram of sludge of the same order of magnitude as the sludge from the experimental plant after an activated sludge had been developed. Several tests on sludge from the small experimental activated sludge plant at the station are also shown. On April 24, 1936, such tests were made on three multiple increments of sludge, the results of which indicate fair agreement.

TABLE 14.—*Quantities of oxygen per gram of sludge used to oxidize activated sludge from various sources*

Origin of sludge	Date, 1936	Mg of O_2 used per gram of sludge in the indicated time (hours)							
		½	1½	3	4	5	10	12	24
Lancaster, Pa., south plant	Feb. 13	6.0	16.6	29.1	------	42.5	77.2	------	177.3
Lancaster, Pa., north plant	Feb. 12	5.0	9.2	16.1	------	22.5	34.2	------	64.7
Do	Mar. 4	5.9	12.0	20.2	------	25.4	47.5	------	89.9
Do	Apr. 22	1.2	8.0	------	10.6	------	------	25.7	37.8
Small experimental plant	Apr. 8	6.0	[1] 15.7	------	27.4	------	------	------	91.6
Do	Apr. 9	6.1	[1] 11.7	------	20.4	------	------	------	86.3
Triplicate portions of same sludge with indicated suspended solids in p. p. m.	Apr. 24 (1632)	------	[1] 8.6	------	13.9	------	------	------	40.5
	Apr. 24 (3264)	------	[1] 6.1	------	10.4	------	------	------	40.6
	Apr. 24 (4896)	------	[1] 6.9	------	11.8	------	------	------	52.9
Laboratory sludge:									
Mixed sewage culture:									
Developed on raw sewage feed.	Apr. 7	5.5	10.0	------	13.7	------	------	------	31.4
Developed on sterile sewage feed.	----do	3.7	11.3	------	14.2	------	------	------	41.3
Pure culture zoogleal bact	------	5.7	6.1	7.0	------	11.7	13.3	------	23.7

[1] 2 hours.

If, as has been shown here, the oxidation capacity of an activated sludge for short periods of aeration is definitely limited, it follows that the higher the oxygen requirement of the sludge alone, the smaller will be the capacity remaining for immediate oxidation of added substrate. It would seem justifiable to conclude from the data presented that the oxygen requirement of the sludge is an important criterion of sludge condition. There is, apparently, considerable seasonal fluctuation, dependent upon temperatures, in the oxygen requirement of the sludge alone, and data are needed on a large variety of activated sludges before any conclusion can be reached regarding a mean oxygen requirement that would insure maximum efficiency in plant operation.

PERCENTAGE OF OXYGEN USED BY THE UNFED SLUDGE

The percentage of the total oxygen required by the fed sludge mixture that is used by the unfed sludge has been calculated for a number of experiments and the results are given in table 15. Similar percentage oxygen requirements of the pure culture sludge that was studied (*1*) are also shown. The data indicate that the percentage oxygen requirement of the unfed sludge is considerably higher for apparently normal nonnitrifying sludge than for pure culture sludge. There is, however, considerable variation in the percentage of oxygen required by the unfed sludge in the various experiments.

TABLE 15.—*Percentage of the total oxygen required by fed sludge mixture that is used by unfed sludge*

Activated sludge used (only nonnitrifying sludges were included)	Suspended solids, activated sludge, p. p. m.	5-day B. O. D. of substrate feed added, p. p. m.	Percentage of oxygen used by the sludge alone in indicated time (hours)					
			½ to 1	1½ to 2	3	4 to 5	10	24
Experiment 4 C raw sewage	2,024	170	41.5	31.5	25.8	38.7	37.2	45.9
Experiment 6 raw sewage	2,268	233	31.8	27.4	--------	16.9	25.1	32.1
Experiment 7 raw sewage	2,448	137	33.8	55.5	50.0	46.0	53.2	--------
Experiment 8 raw sewage	2,816	173	35.8	31.2	31.2	33.2	--------	48.7
Experiment 9 raw sewage	2,784	168	41.2	35.2	35.8	39.6	--------	42.6
Experiment 10 raw sewage	2,856	176	--------	22.8	21.3	22.8	--------	48.7
Sludge development test 5	1,462	123	34.8	41.8	--------	53.5	--------	49.4
Sludge development test 6	1,448	78	40.0	28.5	--------	47.2	--------	55.0
Sludge development test 7	2,300	79.9	46.5	51.7	--------	62.8	--------	--------
Sludge development test 8	2,900	176.0	31.0	--------	34.9	42.8	--------	72.2
Mean (nonnitrifying activated sludge)	2,333	151	37.0	36.2	33.2	40.4	--------	49.3
Mean (pure culture zoogleal sludge)	1,690	172.0	27.3	14.9	16.5	18.6	24.7	22.1

The following factors are apparently responsible for this variation:

1. The substrate oxidation capacity of the sludge;
2. The oxygen requirement of the unfed sludge;
3. The type of sludge (i. e., whether it is capable of nitrifying or not, if given the proper nutrient substrate);
4. The B. O. D. of the nutrient substrate; and
5. The concentration or quantity of sludge used.

The first three of these are primary factors, dependent upon the treatment that the sludge has undergone up to the time of the test. The first two factors are inversely related until (2) reaches a fairly low value where (1) is a maximum. As (2) falls below this point (1) also falls. An actively nitrifying sludge has a very high value for (1) (as ammonia is also being oxidized) and a fairly low value for (2). Factors 4 and 5 are dependent upon the proportions of sludge and nutrient substrate used in the test. If similar quantities of sludge are dosed with somewhat similar quantities of nutrient substrate, a direct relationship exists between the oxygen requirement of the sludge alone and the percentage that this quantity of oxygen is of the total used by the dosed mixture. This relationship is indicated in figure 5.

DISCUSSION

The oxidizing rates of good activated sludges are high after dosing when compared with the rate of natural biochemical oxidation. The capacity to oxidize substrate food at high rates is developed in the sludge as a result of continuous feeding and proper aerobic conditions which promote the development of enormous numbers of bacteria. However, this oxidation capacity developed by the sludge is definitely limited. This is illustrated by the multiple substrate food experiments which indicate that the oxidation obtained during the early

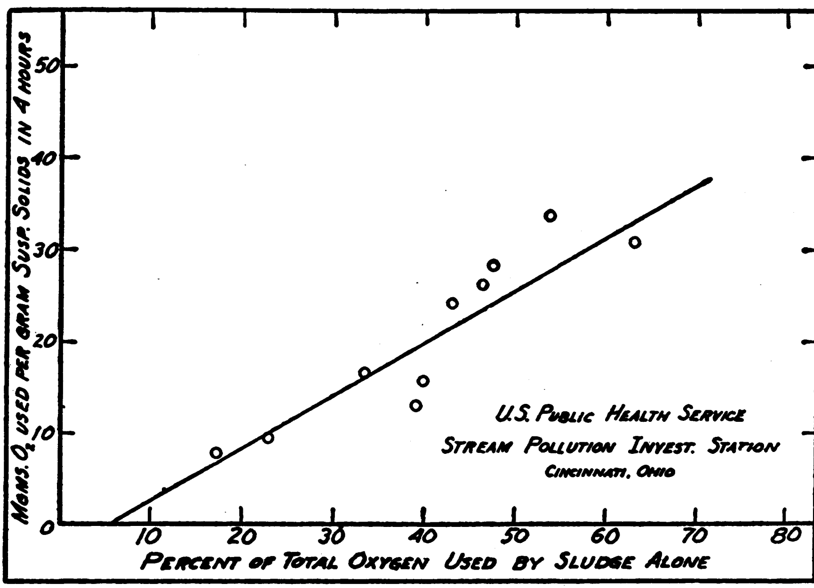

FIGURE 5.—Relation between the quantity of oxygen used to stabilize the sludge alone and the percentage that this oxygen is of the total oxygen used in a dosed aeration misture. (4-hour aeration time data.)

hours is not proportional to the B. O. D. of the substrate food added. On account of the high rates of oxidation obtained with freshly dosed activated sludge mixtures, the oxidation reaction results cannot be fitted by the unimolecular expression but require the formula $y=L-[a(10^{-k_1t})+b(10^{-k_2t})]$ to represent them. The velocity constants in the above expression for the oxidation reaction will vary considerably, depending upon a number of factors. Consequently no fixed formula can be given that will represent the reaction for activated sludge without further definition and limitation of the term activated sludge.

It has been shown that in 5 hours the increased quantity of oxygen used as a result of the addition of sewage to activated sludge varies from about 20 to more than 100 percent of the 5-day B. O. D. of the sewage. Also, that about 30 to 70 percent of the oxygen absorbed by a freshly dosed activated sludge is used by the sludge alone to oxidize previously adsorbed food material. The oxygen requirement of the sludge for 5 hours varies from about 10 to 40 milligrams per gram of sludge. If the oxygen requirement of the sludge falls too low, the substrate oxidation capacity also falls. This may happen during sludge reaeration. The harmful effect caused in this manner by reaeration has been demonstrated by Bottcher (*10*).

It would seem that, from the standpoint of economy of oxygen consumption, a plant will be operated most efficiently when the smallest quantity of activated sludge that will permit the maintenance of the sludge in an optimum oxidizing state is carried in the aeration tank. Operated in this manner, a plant will produce slightly larger quantities (dry weight, not volume[2]) of sludge. On the other hand, carrying higher concentrations of sludge in the aeration tank than necessary to maintain a maximum substrate oxidizing efficiency tends to oxidize larger quantities of the sludge itself, requires more air for the process, and will produce slightly smaller quantities (dry weight, not volume) of sludge to be wasted.

The variability of the oxygen requirement of return activated sludge and of its substrate oxidation capacity indicates that practical tests to measure these characteristics would be valuable aids in plant operation. Tests of this kind have been applied in the operation of the plant at Indianapolis and have been described recently by Bloodgood (*9*). Spiegel, Kappe, and Smith (*14*) have also presented studies on rates of oxygen utilization of sludge sewage mixtures with the object of plant control.

Additional studies on activated sludge which have been completed since the data presented here were obtained have confirmed the conclusion that the oxygen requirement of a sludge and the substrate oxidizing capacity are valuable and important measures of sludge condition. These criteria are more sensitive indicators of change in sludge condition than other chemical tests such as percentage of ash or substrate B. O. D. removal capacity. Practical tests for the determination of these criteria in conjunction with sludge index and the other common tests should be very valuable aids in plant operation.

The relative quantities of oxygen necessary for biochemical oxidation by activated sludge during successive portions of the aeration period are of practical interest in plant operation. Jenks and Levine (*11*) have discussed the theoretical rate of oxygen requirement of the activated sludge process on the assumption that the rate of air supply should be adjusted to the diminishing demand. They used a unimolecular rate curve for this reaction and according to their calculations 60 percent of the air used during a 5-hour period should be applied

[2] The total volume will depend upon other factors.

during the first hour, 24 percent during the second hour, and 16 percent during the last 3 hours. Grant, Hurwitz, and Mohlman (*12*) pointed out that this rapidly decreasing oxygen requirement would not be obtained in the presence of activated sludge. Their data indicate that the rate of utilization of the oxygen by activated sludge was linear and, therefore, the larger the proportion of sludge solids the more uniform the rate of oxygen utilization. When the mean rate of substrate oxidation by nonnitrifying sludges, as shown in table 12, was plotted, it was found that approximately 25 percent of the 5-day B. O. D. of the substrate was oxidized during the first 2 hours of the aeration period, 14 percent during the second 2-hour period, and 11.5 percent during the third 2-hour period. Accordingly, about 50 percent of the oxygen required for substrate oxidation in a 6-hour aeration period was used during the first 2 hours of the period, about 28 percent during the second 2 hours, and 22 percent during the third 2-hour period.

When the oxygen requirements per gram, as shown in tables 13 and 14 for sludge having low, average, and high oxygen requirements, were plotted, the milligrams of oxygen per gram of sludge necessary for each 2-hour aeration period were about as follows:

Oxygen requirement of sludge	Substrate oxidizing capacity	Plotted from data in—	First period	Second period	Third period
Low	Good	Table 13, tests 10 and 12	8.0	4.5	3.0
Average	Excellent	Table 14, Lancaster, north plant, Feb. 12 and Mar. 4.	14.0	8.0	7.0
High	Poor	Table 14, Lancaster, south plant	20.0	15.5	14.5

The percentage of the oxygen used during the 6-hour aeration period that was required in each 2-hour period for each of these sludges was about as follows:

Oxygen requirement of sludge	Substrate oxidizing capacity	First period	Second period	Third period
Low	Good	50	30	20
Average	Excellent	48	28	24
High	Poor	40	31	29

These data seem to indicate that the amount of air tapering permissible in a plant, from the standpoint of biochemical oxidation, is dependent upon the oxygen requirement of the sludge itself. With sludges of average or low oxygen requirements, the oxygen requirement of the mixed liquor for each 2-hour period will be very nearly equal to the proportional requirement of the substrate oxidation accomplished regardless of the quantity of activated sludge. Using a substrate feed with a 5-day B. O. D. of 175 p. p. m. and a nonnitrifying sludge of average oxygen requirement containing 2,500 p. p. m. of suspended solids, the number of milligrams of oxygen required per liter for each portion of the aeration period may be estimated as follows:

	Total required in 6 hours	First period	Second period	Third period
SUBSTRATE				
175 p. p. m., 5-day B. O. D.	175×0.50=87.5	87.5×0.50=43.7	87.5×0.28=24.5	87.5×0.22=19.3
SLUDGE (AVERAGE)				
2,500 p. p. m.	2.5×29 =72.5	72.5×0.48=34.8	72.5×0.28=20.3	72.5×0.24=17.4
Total for aeration mixture	160.0	78.5	44.8	36.7

This indicates that about 49 percent of the oxygen required during a 6-hour aeration period is used during the first 2 hours, 28 percent during the second 2 hours, and 23 percent during the third 2 hours.

If a mixture containing sludge with a high oxygen requirement was used, then, with increasing quantities of sludge, the proportion of oxygen necessary in each 2-hour period would tend to approach the values shown above for the sludge of poor substrate oxidizing capacity.

In any case the elapsed time and the nature of treatment of the sludge from the time it left the effluent of the aeration tank until it was returned to the influent would influence the proportion of oxygen required during the first 2 hours of aeration. Haseltine (*13*) points out that, at Salinas, Calif., from 55 to 70 percent of the total air was applied to the first half of the aeration tanks and that this percentage increased with high sewage flows or bulked sludge.

SUMMARY

The results and conclusions of practical interest that seem warranted from this study may be summarized as follows:

(1) That the oxidation rates in activated sludge vary considerably depending upon the conditions of operation.

(2) That oxidation rates are obtained in the activated sludge process very much greater than the normal biochemical oxidation rate observed in streams. The unimolecular expression $y=L(1-10^{-k_1t})$ with a k of 0.1 at 20° C. is accepted as representing normal biochemical oxidation as it ordinarily occurs in streams. When an activated sludge is dosed, however, the oxidation reaction data cannot be fitted to the above expression, but the formula $y=L-[a(10^{-k_1t})+b(10^{-k_2t})]$ with k values indicating higher rates, more nearly represents the reaction. The rates expressed in milligrams of oxygen per liter per hour are naturally very much higher in the activated sludge process than in streams.

(3) That the development of a mass of bacteria by the application of food and maintenance of proper aerobic conditions for their rapid propagation is the explanation for the high rate of biochemical oxidation obtained in the activated sludge process.

(4) That independent observations on the quantities of oxygen required by a fed and unfed portion of an activated sludge result in valuable information on sludge condition and plant operation. Such observations may be made with the methods and apparatus described in the previous paper of this series (*1*), with the apparatus described by Bloodgood (*9*) or by other apparatus and methods. It is probable that observations of oxygen utilization during an aeration period of 1 to 4 hours with the simplest apparatus would be most useful for practical plant control operations. After some experience has been obtained on any particular plant, the knowledge of the quantities of oxygen used by the control and fed sludge mixtures will enable the operator quickly and more effectively to control plant operation. This information is of particular value because it is obtained after a relatively short observation period, thus enabling a much quicker discovery of unsatisfactory conditions and a correction of the difficulties before they become unmanageable.

(5) That the quantity of oxygen used by the unfed or control sludge portion is a criterion of sludge condition. The quantity of oxygen used per gram of suspended solids for a good unfed (return) sludge seems to vary from about 10 to 30 milligrams in 5 hours. The limits given are rather wide, but it is possible that some activated sludges may have a 5-hour oxygen demand somewhat higher than 30 milligrams of oxygen per gram of suspended solids and still be fairly good sludges. Experience at any particular plant will indicate the optimum range of oxygen requirement of the sludge for the operation cycle at that plant.

(6) With good activated sludges the fed activated sludge portion uses considerably more oxygen than the control or unfed portion. With nonnitrifying activated sludges fed with substrates with a 5-day B. O. D. of 80 to 200 p. p. m., the control sludge required only about 30 to 50 percent of the oxygen used by the fed mixture during a 5-hour aeration period.

(7) It is shown that the quantity of oxygen utilized as a result of the addition of the substrate is not proportional to the B. O. D. of the substrate added but seems to be dependent upon the biochemical character and activity of the sludge used. The quantity of oxygen used as a result of the addition of a given increment of substrate is an index of the oxidizing activity of the sludge. The additional oxygen used by the sludge as a result of the addition of the substrate is tentatively ascribed to the oxidation of substrate.

(8) When the oxygen utilized as a result of the addition of substrate to activated sludge is taken as a measure of substrate oxidation and calculated in terms of the 5-day B. O. D. of the substrate added, it is found that usually from 40 to 50 percent of the 5-day substrate feed

B. O. D. is oxidized in 5 hours by nonnitrifying activated sludge. If a substrate having a rather low (100 p. p. m.) 5-day oxygen demand is added to a nitrifying activated sludge, a quantity of oxygen representing more than 100 percent of the 5-day B. O. D. of the substrate added may be used in 5 hours as the result of the addition.

(9) It is shown that the percentage of the 5-day B. O. D. of the substrate oxidized (determined as above) is gradually increased during the development of activated sludge in a plant until the above values are reached.

(10) The rapid reduction in the oxygen requirement of fed activated sludges due to the rapid oxidation of substrate indicates the practicability of tapered aeration in plant operation.

(11) The study indicates that there is no single optimum quantity of activated sludge that should be carried in all plants, but rather that each plant will require a different optimum quantity of sludge dependent upon the character and strength of sewage and cycle of operations of that individual plant. In general, no more sludge than is necessary to maintain a satisfactory plant effluent should be carried for the most economical operation.

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HOSPITAL FACILITIES IN THE UNITED STATES

To those persons interested in supply and demand as it applies to hospital facilities, and to those seeking a more adequate distribution of such accommodations, a recent bulletin [1] issued by the Public Health Service, entitled "Hospital Facilities in the United States," should present much valuable information. Inclusion of a number of charts and tables augments its usefulness as reference material. The first section of this publication, "Selected Characteristics of Hospital Facilities in 1936," gives a panoramic view of the medical type, size, control, and use of hospitals which operated in 1936 and the relationship of these facilities to population groups. The second section, entitled "Trends in Hospital Development, 1928–1936," presents information regarding the extent to which such factors as control, size, and location have motivated stability of existence during the indicated span.

Section I emphasizes the following points: The 4,841 registered general and special hospitals in the United States, one-half of which have less than 50 beds each, represent an aggregate capacity of 451,000 beds. Nonprofit organizations lead as the sponsors of general and special hospitals; on the other hand, mental and tuberculosis institutions are primarily tax-supported. The 597 mental hospitals have in excess of one-half million beds, thus signifying that their average size is large. Even so, mental hospitals are often filled to more than their rated capacity. Tuberculosis sanatoria are of moderate size, 506 registered institutions of this type having about 71,000 beds. The southern States have relatively few hospital facilities of all types, while States of the Mountain and Pacific areas and those of the middle Atlantic seaboard rank much more favorably when accommodations are related to population.

During the period covered by the study reported in the second section of the bulletin, about 60 percent of the 8,191 registered hospitals under analysis maintained continuous existence. The other 40 percent include a number that were newly established and many that were discontinued. The loss of facilities as revealed by the data is actually more apparent than real. The institutions that failed to survive were for the most part small ones, privately owned, and located in populous counties comparatively well supplied with hospital facilities.

[1] Public Health Bulletin No. 243. Government Printing Office, Washington, D. C. 10 cents.

DEATHS DURING WEEK ENDED SEPTEMBER 3, 1938

[From the Weekly Health Index, issued by the Bureau of the Census, Department of Commerce]

	Week ended Sept. 3, 1938	Corresponding week, 1937
Data from 88 large cities of the United States:		
Total deaths	7,080	[1] 7,478
Average for 3 prior years	[1] 7,052	
Total deaths, first 35 weeks of year	287,643	311,568
Deaths under 1 year of age	500	[1] 507
Average for 3 prior years	[1] 514	
Deaths under 1 year of age, first 35 weeks of year	18,585	20,038
Data from industrial insurance companies:		
Policies in force	68,328,766	69,770,573
Number of death claims	11,048	11,041
Death claims per 1,000 policies in force, annual rate	8.4	8.3
Death claims per 1,000 policies, first 35 weeks of year, annual rate	9.3	10.1

[1] Data for 86 cities.

PREVALENCE OF DISEASE

No health department, State or local, can effectively prevent or control disease without knowledge of when, where, and under what conditions cases are occurring

UNITED STATES

CURRENT WEEKLY STATE REPORTS

These reports are preliminary, and the figures are subject to change when later returns are received by the State health officers.

In these and the following tables, a zero (0) indicates a positive report and has the same significance as any other figure, while leaders (------) represent no report, with the implication that cases or deaths may have occurred but were not reported to the State health officer.

Cases of certain diseases reported by telegraph by State health officers for the week ended September 10, 1938, rates per 100,000 population (annual basis), and comparison with corresponding week of 1937 and 5-year median

Division and State	Diphtheria				Influenza				Measles			
	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933–37 median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937 cases	1933–37 median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933–37 median
NEW ENG.												
Maine	12	2	0	1	------	------	------	------	6	1	1	3
New Hampshire	0	0	0	0	------	------	------	------	------	------	3	------
Vermont	14	1	1	0	------	------	------	------	14	1	12	2
Massachusetts	4	3	2	3	------	------	------	------	35	30	11	15
Rhode Island	0	0	0	0	------	------	------	------	------	------	------	1
Connecticut	0	0	6	3	------	------	1	1	9	3	3	6
MID. ATL.												
New York	7	18	13	24	[1]1	[1]1	[1]2	[1]4	30	74	92	66
New Jersey	7	6	3	3	6	5	7	4	16	13	17	9
Pennsylvania	9	18	10	23	------	------	------	------	14	27	115	57
E. NO. CEN.												
Ohio	11	14	22	22	------	------	14	6	9	12	36	19
Indiana	11	7	12	19	21	14	11	11	9	6	7	7
Illinois [2]	7	11	8	20	6	9	7	7	14	21	45	16
Michigan	2	2	20	9	------	------	------	------	14	13	21	13
Wisconsin	4	2	4	4	16	9	30	13	53	30	28	31
W. NO. CEN.												
Minnesota	4	2	0	5	4	2	------	------	26	13	10	7
Iowa	27	13	1	5	10	5	------	------	6	3	3	3
Missouri	20	15	12	21	7	5	19	13	9	7	23	4
North Dakota	0	0	1	2	------	------	------	------	37	5	------	5
South Dakota	15	2	0	1	------	------	------	------	------	------	------	2
Nebraska	0	0	1	6	------	------	------	------	------	------	2	2
Kansas	8	3	8	7	------	------	4	1	11	4	1	5

See footnotes at end of table.

Cases of certain diseases reported by telegraph by State health officers for the week ended September 10, 1938, rates per 100,000 population (annual basis), and comparison with corresponding week of 1937 and 5-year median—Continued

Division and State	Diphtheria				Influenza				Measles			
	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933–37 median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937 cases	1933–37 median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933–37 median
SO. ATL.												
Delaware	20	1	0	0	-	-	-	-	-	-	-	-
Maryland [2] [3]	12	4	6	1	3	1	2	2	9	3	4	4
Dist. of Col	33	4	1	5	17	2	2	-	17	2	2	1
Virginia [3]	73	38	37	31	-	-	-	-	6	3	14	14
West Virginia	28	10	7	24	28	10	15	21	-	-	12	6
North Carolina [3]	118	79	36	38	6	4	-	-	22	15	9	9
South Carolina [4]	142	51	24	19	498	179	91	94	17	6	5	5
Georgia [4]	85	50	31	26	-	-	-	-	-	-	-	-
Florida [4]	25	8	4	7	-	-	-	1	103	33	-	1
E. SO. CEN.												
Kentucky	25	14	14	26	23	13	3	3	5	3	17	17
Tennessee	63	35	26	25	40	22	6	14	5	3	64	7
Alabama [4]	63	35	31	31	47	26	3	6	11	6	3	3
Mississippi [3] [4]	64	25	19	19	-	-	-	-	-	-	-	-
W. SO. CEN.												
Arkansas	59	23	9	9	31	12	-	2	10	4	2	2
Louisiana	10	4	4	10	-	-	3	5	7	3	5	3
Oklahoma	29	14	11	11	53	26	20	18	41	20	2	2
Texas [4]	36	43	29	38	79	94	58	36	3	3	30	14
MOUNTAIN												
Montana	0	0	1	1	87	9	-	1	145	15	2	2
Idaho	0	0	1	1	63	6	2	-	63	6	1	1
Wyoming [3]	22	1	0	0	-	-	-	-	89	4	-	1
Colorado	49	10	5	5	-	-	-	-	44	9	18	3
New Mexico	49	4	5	2	-	-	-	-	-	-	4	1
Arizona	13	1	0	2	177	14	12	6	63	5	3	2
Utah [3]	0	0	4	0	10	1	-	-	30	3	3	2
PACIFIC												
Washington	3	1	3	1	-	-	-	-	9	3	29	13
Oregon	5	1	1	0	20	4	7	7	46	9	2	4
California	11	13	20	24	5	6	11	12	63	74	23	23
Total	24	588	453	607	24	479	330	346	20	495	684	438
36 weeks	18	15,998	14,870	19,777	66	47,295	275,454	142,304	869	762,470	243,237	343,283

Division and State	Meningitis, meningococcus				Poliomyelitis				Scarlet fever			
	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933–37 median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933–37 median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937 cases	1933–37 median
NEW ENG.												
Maine	6	1	1	0	12	2	12	5	0	0	8	8
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	3
Vermont	0	0	0	0	0	0	1	1	95	7	1	3
Massachusetts	2.4	2	0	0	1.2	1	44	23	27	23	18	38
Rhode Island	0	0	1	0	0	0	0	0	8	1	5	8
Connecticut	3	1	0	0	9	3	13	6	30	10	7	8
MID. ATL.												
New York	0.8	2	3	4	4	9	91	91	25	61	55	88
New Jersey	1.2	1	0	0	2.4	2	13	13	20	17	18	19
Pennsylvania	0	0	2	2	4	8	37	9	46	90	52	76

See footnote at end of table.

***Cases of certain diseases reported by telegraph by State health officers for the week ended September 10, 1938, rates per 100,000 population (annual basis), and comparison with corresponding week of 1937 and 5-year median*—Continued**

Division and State	Meningitis, meningococcus				Poliomyelitis				Scarlet fever			
	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933–37 median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933–37 median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937 cases	1933–37 median
E. NO. CEN.												
Ohio	0	0	2	0	0.8	1	66	15	40	52	88	111
Indiana	0	0	1	2	1.5	1	18	3	53	35	17	40
Illinois [3]	2.6	4	1	5	7	10	130	22	61	92	78	128
Michigan	1.1	1	2	2	4	4	49	14	90	83	61	50
Wisconsin	0	0	1	1	4	2	19	4	82	46	26	41
W. NO. CEN.												
Minnesota	0	0	0	0	6	3	30	5	57	29	18	18
Iowa	0	0	1	0	6	3	26	4	45	22	25	18
Missouri	0	0	2	2	0	0	36	3	38	29	43	32
North Dakota	0	0	2	0	0	0	1	1	81	11	0	2
South Dakota	0	0	0	0	0	0	4	2	68	9	3	8
Nebraska	4	1	0	0	0	0	27	1	50	13	1	9
Kansas	0	0	0	0	0	0	20	5	87	31	37	18
SO. ATL.												
Delaware	0	0	0	0	0	0	5	0	40	2	0	1
Maryland [2] [3]	0	0	1	1	3	1	11	1	43	14	15	15
Dist of Col	0	0	2	0	17	2	0	0	8	1	3	6
Virginia [3]	4	2	2	2	4	2	3	4	35	18	16	19
West Virginia	11	4	1	1	0	0	2	3	53	19	29	29
North Carolina [3]	3	2	2	1	1.5	1	1	1	51	34	20	36
South Carolina [4]	0	0	0	0	6	2	1	0	33	12	1	3
Georgia [4]	1.7	1	1	0	3	2	0	0	22	13	15	9
Florida [4]	6	2	1	1	0	0	4	0	12	4	1	2
E. SO. CEN.												
Kentucky	1.8	1	2	0	0	0	4	4	79	44	26	42
Tennessee	1.8	1	1	1	0	0	3	4	50	28	25	27
Alabama [4]	1.8	1	2	1	7	4	7	2	20	11	17	17
Mississippi [3] [4]	2.6	1	0	0	0	0	10	1	23	9	12	9
W. SO. CEN.												
Arkansas	0	0	0	1	0	0	12	1	20	8	9	6
Louisiana	0	0	0	0	0	0	7	2	2	1	3	8
Oklahoma	0	0	0	0	0	0	14	1	27	13	8	8
Texas [4]	1.7	2	6	1	2.5	3	21	2	42	50	24	24
MOUNTAIN												
Montana	10	1	0	0	0	0	1	1	39	4	5	8
Idaho	0	0	0	0	0	0	0	0	11	1	2	2
Wyoming [3]	0	0	0	0	0	0	2	0	22	1	2	4
Colorado	24	5	1	1	5	1	21	2	24	5	8	8
New Mexico	0	0	0	0	12	1	1	0	62	5	5	5
Arizona	0	0	0	0	0	0	2	1	63	5	5	2
Utah	0	0	0	0	0	0	5	1	40	4	12	[illegible]
PACIFIC												
Washington	0	0	1	1	0	0	2	3	31	10	14	9
Oregon	0	0	1	0	0	0	4	1	20	4	7	11
California	0	0	1	2	4	5	37	25	36	42	65	65
Total	1.5	36	44	44	2.9	73	817	361	41	1,023	910	1,210
36 weeks	2.5	2,250	4,336	4,336	1.3	1,164	5,512	4,982	157	139,717	167,490	167,490

See footnotes at end of table.

Cases of certain diseases reported by telegraph by State health officers for the week ended September 10, 1938, rates per 100,000 population (annual basis), and comparison with corresponding week of 1937 and 5-year median—Continued

Division and State	Smallpox				Typhoid and paratyphoid fever				Whooping cough	
	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933-37, median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933-37, median	Sept. 10, 1938, rate	Sept. 10, 1938, cases
NEW ENG.										
Maine	0	0	0	0	18	3	8	1	158	26
New Hampshire	0	0	0	0	10	1	0	0	0	0
Vermont	0	0	0	0	0	0	0	0	368	27
Massachusetts	0	0	0	0	7	6	2	5	77	65
Rhode Island	0	0	0	0	0	0	1	1	46	6
Connecticut	0	0	0	0	9	3	5	2	156	52
MID. ATL.										
New York	0	0	0	0	18	44	20	30	[1] 279	[1] 398
New Jersey	0	0	0	0	7	6	14	14	318	265
Pennsylvania	0	0	0	0	9	18	33	33	129	252
E. NO. CEN.										
Ohio	1	1	0	0	17	22	101	68	77	99
Indiana	5	3	3	1	21	14	3	11	11	7
Illinois [2]	0	0	0	0	23	35	35	47	300	454
Michigan	1	1	0	0	12	11	10	16	249	231
Wisconsin	2	1	0	1	9	5	3	3	683	383
W. NO. CEN.										
Minnesota	6	3	4	0	6	3	2	2	85	43
Iowa	0	0	1	0	10	5	2	5	33	16
Missouri	0	0	3	0	37	28	23	23	31	24
North Dakota	0	0	2	1	15	2	3	3	207	28
South Dakota	0	0	0	0	0	0	2	2	15	2
Nebraska	0	0	1	1	4	1	0	1	42	11
Kansas	3	1	1	0	14	5	9	12	137	49
SO. ATL.										
Delaware	0	0	0	0	20	1	1	1	180	9
Maryland [2] [3]	0	0		0	28	9	12	12	53	17
Dist. of Col	0	0	0	0	67	8	0	2	58	7
Virginia [3]	0	0	0	0	44	23	13	34	62	32
West Virginia	0	0	0	0	87	31	19	19	75	27
North Carolina [3]	0	0	0	0	19	13	9	15	220	147
South Carolina [4]	0	0	0	0	70	25	19	19	245	88
Georgia [4]	0	0	0	0	56	33	23	23	44	26
Florida [4]	0	0	0	0	6	2	5	2	44	14
E. SO. CEN.										
Kentucky	2	1	0	0	68	38	40	52	132	74
Tennessee	0	0	0	0	50	28	39	39	63	35
Alabama [4]	2	1	0	0	25	14	21	19	23	13
Mississippi [3] [4]	0	0	0	0	18	7	13	13	-------	-------
W. SO. CEN.										
Arkansas	0	0	0	0	61	24	12	12	41	16
Louisiana	0	0	0	0	29	12	19	20	98	40
Oklahoma	6	3	4	0	59	29	18	23	47	23
Texas [4]	3	3	0	0	40	47	48	48	54	64
MOUNTAIN										
Montana	10	1	5	2	19	2	4	7	358	37
Idaho	0	0	10	0	32	3	0	2	42	4
Wyoming [3]	22	1	1	0	22	1	1	1	111	5
Colorado	10	2	4	1	63	13	2	6	151	31
New Mexico	0	0	0	0	99	8	6	7	86	7
Arizona	0	0	0	0	62	5	2	5	51	4
Utah [3]	0	0	0	0	20	2	1	1	191	19

See footnotes at end of table.

Cases of certain diseases reported by telegraph by State health officers for the week ended September 10, 1938, rates per 100,000 population (annual basis), and comparison with corresponding week of 1937 and 5-year median—Continued

Division and State	Smallpox				Typhoid and paratyphoid fever				Whooping cough	
	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933-37, median	Sept. 10, 1938, rate	Sept. 10, 1938, cases	Sept. 11, 1937, cases	1933-37, median	Sept. 10, 1938, rate	Sept. 10, 1938, cases
PACIFIC										
Washington	31	10	11	8	22	7	3	3	63	20
Oregon	25	5	4	3	10	2	3	5	132	26
California	3	4	2	2	13	15	27	15	98	116
Total	2	41	56	28	25	614	636	753	143	3,339
36 weeks	14	12,810	8,136	5,407	11	9,887	10,010	11,471	185	155,028

[1] New York City only.
[2] Rocky Mountain spotted fever, week ended Sept. 10, 1938, 13 cases as follows: Illinois, 3; Maryland, 1; Virginia, 7; North Carolina, 1; Wyoming, 1.
[3] Period ended earlier than Saturday.
[4] Typhus fever, week ended Sept. 10, 1938, 71 cases as follows: South Carolina, 4; Georgia, 30; Florida, 4; Alabama, 10; Mississippi, 3; Texas, 20.

SUMMARY OF MONTHLY REPORTS FROM STATES

The following summary of cases reported monthly by States is published weekly and covers only those States from which reports are received during the current week:

State	Meningitis, meningococcus	Diphtheria	Influenza	Malaria	Measles	Pellagra	Poliomyelitis	Scarlet fever	Smallpox	Typhoid fever
June 1938										
Arizona	1	20	88	3	64	2	1	14	45	40
Puerto Rico	0	29	50	2,445	18	2	0	0	0	41
South Carolina	--------	62	245	846	310	231	0	8	0	46
July 1938										
Arizona	2	6	57	2	103	3	1	12	--------	11
South Carolina	--------	93	366	1,764	229	363	3	11	0	86
August 1938										
Arkansas	3	44	64	1,243	37	110	4	32	2	102
Connecticut	1	2	8	--------	29	--------	3	22	0	12
Delaware	0	3	--------	3	1	--------	0	3	0	5
Indiana	3	26	14	1	23	--------	1	74	14	62
New Mexico	0	10	2	6	12	1	0	11	8	29
West Virginia	4	27	48	--------	7	2	3	45	1	118
Wyoming	0	2	--------	--------	3	--------	0	8	0	2

Summary of monthly reports from States—Continued

June 1938	Cases
Chickenpox:	
Arizona	72
Puerto Rico	54
South Carolina	45
Dysentery:	
Arizona	48
Puerto Rico	39
Encephalitis, epidemic or lethargic:	
Arizona	1
South Carolina	5
Filariasis:	
Puerto Rico	1
German measles:	
Arizona	29
South Carolina	12
Hookworm disease:	
South Carolina	76
Mumps:	
Arizona	10
South Carolina	31
Ophthalmia neonatorum:	
Puerto Rico	2
South Carolina	3
Paratyphoid fever:	
South Carolina	1
Puerperal septicemia:	
Puerto Rico	8
Rabies in animals:	
South Carolina	18
Tetanus:	
Puerto Rico	13
South Carolina	5
Trachoma:	
Arizona	45
Tularaemia:	
South Carolina	1
Typhus fever:	
South Carolina	9
Whooping Cough:	
Arizona	136
Puerto Rico	204
South Carolina	300
July 1938	
Arizona:	
Chickenpox	15
Dysentery	81
Encephalitis, epidemic or lethargic	1
German measles	3
Mumps	8
Trachoma	33
Undulant fever	5
Whooping cough	130

July 1938—Continued	Cases
South Carolina:	
Chickenpox	42
Dengue	1
Diarrhea	1,354
Dysentery	4
German measles	10
Hookworm disease	124
Mumps	93
Ophthalmia neonatorum	4
Paratyphoid fever	12
Rabies in animals	25
Tetanus	3
Tularaemia	2
Typhus fever	5
Undulant fever	1
Whooping cough	523
August 1938	
Chickenpox:	
Arkansas	4
Connecticut	25
Delaware	1
Indiana	9
New Mexico	12
West Virginia	6
Wyoming	5
Conjunctivitis, infectious:	
Connecticut	4
New Mexico	2
Diarrhea:	
New Mexico	26
Dysentery:	
Arkansas (bacillary)	20
Connecticut (bacillary)	12
Delaware (bacillary)	1
New Mexico (amoebic)	6
New Mexico (bacillary)	6
New Mexico (unspecified)	7
West Virginia (amoebic)	1
West Virginia (bacillary)	5
Encephalitis, epidemic or lethargic:	
Connecticut	2
Food poisoning:	
New Mexico	1
German measles:	
Connecticut	7
New Mexico	1
Wyoming	1
Hookworm disease:	
Arkansas	3

August 1938—Continued	Cases
Mumps:	
Arkansas	20
Connecticut	54
Delaware	2
Indiana	8
New Mexico	2
West Virginia	1
Wyoming	9
Ophthalmia neonatorum:	
Arkansas	1
New Mexico	1
Paratyphoid fever:	
Arkansas	4
Connecticut	5
Puerperal septicemia:	
Arkansas	1
Rabies in animals:	
Arkansas	11
Connecticut	4
Indiana	39
Rocky Mountain spotted fever:	
Delaware	1
Indiana	3
Wyoming	1
Septic sore throat:	
Arkansas	8
Connecticut	4
New Mexico	2
West Virginia	3
Tetanus:	
Connecticut	1
Trachoma:	
Arkansas	6
Tularaemia:	
Arkansas	7
New Mexico	1
Wyoming	1
Undulant fever:	
Arkansas	1
Connecticut	3
New Mexico	1
West Virginia	2
Wyoming	1
Vincent's infection:	
Wyoming	2
Whooping cough:	
Arkansas	41
Connecticut	260
Delaware	19
Indiana	40
New Mexico	70
West Virginia	108
Wyoming	13

PLAGUE INFECTION IN NEW MEXICO AND WYOMING

IN PRAIRIE DOGS AND IN FLEAS FROM PRAIRIE DOGS AND GROUND SQUIRRELS IN CATRON COUNTY, NEW MEXICO

Under date of September 7, 1938, Senior Surgeon C. R. Eskey, reported plague infection proved in prairie dogs (*Cynomys gunnisoni zuniensis*) and in pools of fleas from prairie dogs and ground squirrels (*Citellus grammurus*) in Catron County as follows:

In tissue from one prairie dog shot August 13, 3 miles north of Adams Diggings; in a pool of 12 fleas from 8 prairie dogs shot August 22, 25 miles northwest of Quemado; in a pool of 120 fleas from 16 prairie dogs shot August 22, 8 miles southwest of Adams Diggings; in tissue from one prairie dog shot August 24, 4 miles east of Quemado; and in a pool of 256 fleas from 10 ground squirrels shot August 24, 25 miles northeast of Reserve.

IN A POOL OF FLEAS AND A POOL OF LICE FROM GROUND SQUIRRELS IN LINCOLN COUNTY, WYOMING

Under date of September 7, 1938, Senior Surgeon C. R. Eskey, reported plague infection proved in a pool of fleas and a pool of lice from ground squirrels (*Citellus elegans*) in Lincoln County as follows:

In a pool of 106 fleas from 60 ground squirrels shot August 10, 6 miles northeast of Opal and in a pool of 5 lice from 57 ground squirrels shot August 11, 2 to 9 miles northwest of Fontenelle, Lincoln County.

WEEKLY REPORTS FROM CITIES

City reports for week ended Sept. 3, 1938

This table summarizes the reports received weekly from a selected list of 140 cities for the purpose of showing a cross section of the current urban incidence of the communicable diseases listed in the table.

State and city	Diphtheria cases	Influenza		Measles cases	Pneumonia deaths	Scarlet fever cases	Smallpox cases	Tuberculosis deaths	Typhoid fever cases	Whooping cough cases	Deaths, all causes
		Cases	Deaths								
Data for 90 cities:											
5-year average	111	47	14	154	282	279	2	346	95	1,012	-------
Current week[1]	64	28	15	98	299	243	7	316	73	1,659	-------
Maine:											
Portland	0	------	0	0	0	0	0	0	1	0	22
New Hampshire:											
Concord	0	------	0	0	0	0	0	0	0	0	14
Manchester	0	------	0	0	2	0	0	1	0	0	27
Nashua	0	------	0	0	0	0	0	0	0	0	7
Vermont:											
Barre	------	------	------	------	------	------	------	------	------	------	------
Burlington	0	------	0	0	0	0	0	0	0	3	9
Rutland	0	------	0	0	0	0	0	0	0	0	5
Massachusetts:											
Boston	0	------	0	3	8	8	0	9	2	17	176
Fall River	0	------	0	0	0	0	0	0	1	0	19
Springfield	0	------	0	1	1	1	0	1	0	11	19
Worcester	0	------	0	0	4	0	0	3	0	5	40
Rhode Island:											
Pawtucket	0	------	0	0	0	0	0	0	0	0	12
Providence	0	------	0	0	1	0	0	3	0	10	52
Connecticut:											
Bridgeport	0	------	0	0	1	1	0	1	0	1	28
Hartford	0	------	0	0	2	0	0	1	0	0	36
New Haven	0	------	0	0	1	0	0	0	1	8	37
New York:											
Buffalo	0	----	0	1	4	1	0	7	0	13	100
New York	7	1	2	24	60	8	0	66	15	327	1,200
Rochester	0	------	0	2	2	1	0	0	0	3	52
Syracuse	0	------	0	7	0	0	0	3	0	13	42
New Jersey:											
Camden	0	------	0	1	1	1	0	2	1	3	39
Newark	0	1	-------	3	0	1	0	5	0	62	84
Trenton	0	1	0	0	2	0	0	0	1	4	36
Pennsylvania:											
Philadelphia	2	------	2	1	7	14	0	18	4	72	342
Pittsburgh	1	2	2	0	4	8	0	4	0	19	120
Reading	0	------	0	0	0	0	0	0	0	1	12
Scranton	0	------	-------	0	-------	0	-------	0	0	4	-------
Ohio:											
Cincinnati	1	------	0	0	0	5	0	5	1	4	98
Cleveland	1	------	0	1	8	10	0	7	2	63	174
Columbus	1	------	0	0	3	1	0	2	1	3	63
Toledo	1	------	0	2	2	0	0	4	1	10	62
Indiana:											
Anderson	0	------	0	0	0	8	0	1	0	5	9
Fort Wayne	1	------	0	0	4	0	0	0	0	0	25
Indianapolis	2	------	2	1	12	6	3	4	0	3	105
South Bend	0	------	0	0	0	0	0	0	0	0	11
Terre Haute	2	------	0	0	0	6	0	0	0	0	28

[1] Figures for Barre, Vt., estimated; report not received.

City reports for week ended Sept. 3, 1938—Continued

State and city	Diphtheria cases	Influenza		Measles cases	Pneumonia deaths	Scarlet fever cases	Smallpox cases	Tuberculosis deaths	Typhoid fever cases	Whooping cough cases	Deaths, all causes
		Cases	Deaths								
Illinois:											
Alton	0	------	0	0	1	0	0	0	0	0	10
Chicago	5	5	0	6	22	37	0	30	0	363	549
Elgin	0	------	0	0	2	0	0	0	0	3	12
Moline	0	1	0	1	0	0	0	0	0	1	2
Springfield	1	------	0	0	0	1	0	0	0	0	24
Michigan:											
Detroit	1	------	0	0	9	12	0	18	3	177	221
Flint	0	------	0	0	0	3	0	2	3	11	21
Grand Rapids	0	------	0	1	2	6	2	0	0	4	31
Wisconsin:											
Kenosha	0	------	0	0	0	2	0	0	0	5	5
Madison	0	------	0	0	0	0	0	0	0	3	7
Milwaukee	0	------	0	2	3	7	0	3	1	185	96
Racine	0	------	0	1	0	1	0	0	0	45	8
Superior	0	------	0	2	0	2	0	0	0	3	6
Minnesota:											
Duluth	0	------	0	2	2	1	0	0	0	15	18
Minneapolis	0	------	0	6	2	6	0	4	0	11	84
St. Paul	0	------	0	0	2	1	0	1	0	7	45
Iowa:											
Cedar Rapids	0	------	------	0	------	0	0	------	0	1	------
Des Moines	0	------	0	0	0	4	0	0	0	0	26
Sioux City	0	------	------	2	------	2	0	------	0	8	------
Waterloo	12	------	------	0	------	0	0	------	0	0	------
Missouri:											
Kansas City	0	------	0	0	7	1	0	1	0	2	79
St. Joseph	0	------	0	0	1	1	1	0	0	1	33
St. Louis	1	1	0	1	4	8	0	1	1	10	180
North Dakota:											
Fargo	0	------	0	0	0	2	0	1	0	0	11
Grand Forks	0	------	------	0	------	1	0	------	0	0	------
Minot	0	------	0	1	0	0	0	0	0	1	5
South Dakota:											
Aberdeen	1	------	------	0	------	0	0	------	0	1	------
Sioux Falls	0	------	0	0	0	0	0	0	0	0	9
Nebraska:											
Lincoln	0	------	------	0	------	1	0	------	0	5	------
Omaha	0	------	0	2	6	1	0	3	0	0	52
Kansas:											
Lawrence	0	------	0	0	0	0	0	0	0	0	2
Topeka	0	------	0	0	0	3	0	0	0	1	10
Wichita	0	------	0	0	1	1	0	2	0	1	25
Delaware:											
Wilmington	1	------	0	0	0	0	0	1	0	3	25
Maryland:											
Baltimore	2	------	0	1	5	0	0	15	2	21	189
Cumberland	0	------	0	0	0	0	0	0	0	0	13
Frederick	0	------	0	0	0	0	0	0	0	0	7
District of Columbia:											
Washington	2	------	0	1	7	11	0	7	7	16	120
Virginia:											
Lynchburg	0	------	0	0	1	0	0	0	0	2	22
Norfolk	1	------	0	0	2	1	0	1	0	1	29
Richmond	2	------	1	0	4	3	0	4	0	0	47
Roanoke	2	------	0	0	0	0	0	0	0	1	9
West Virginia:											
Charleston	0	------	0	0	0	1	0	2	5	0	82
Huntington	0	------	------	0	------	0	0	------	0	0	------
Wheeling	0	------	0	1	1	0	0	1	0	3	18
North Carolina:											
Gastonia	0	------	------	0	------	0	0	------	0	0	------
Raleigh	0	------	0	0	1	0	0	1	0	2	17
Wilmington	1	------	0	0	1	0	0	1	0	1	11
Winston-Salem	1	------	0	0	1	0	0	0	0	2	14
South Carolina:											
Charleston	0	------	0	0	0	0	0	0	1	0	18
Florence	0	------	0	0	1	0	0	0	0	0	7
Greenville	0	------	0	0	0	0	0	0	1	2	4

City reports for week ended Sept. 3, 1938—Continued

State and city	Diphtheria cases	Influenza		Measles cases	Pneumonia deaths	Scarlet fever cases	Smallpox cases	Tuberculosis deaths	Typhoid fever cases	Whooping cough cases	Deaths, all causes
		Cases	Deaths								
Georgia:											
Atlanta	4	6	0	0	6	5	0	11	0	5	68
Brunswick	0	------	0	0	0	0	0	0	2	0	5
Savannah	0	------	0	0	0	1	0	2	1	0	25
Florida:											
Miami	0	------	0	0	2	0	0	2	0	0	29
Tampa	0	------	0	0	2	1	0	0	0	1	14
Kentucky:											
Ashland	0	------	------	0	------	0	0	------	0	0	------
Covington	0	------	0	0	1	1	0	0	0	6	14
Lexington	0	------	0	0	3	1	0	2	0	0	22
Louisville	0	------	0	0	2	1	0	0	1	3	58
Tennessee:											
Knoxville	1	------	0	0	0	1	0	1	4	6	25
Memphis	0	------	0	0	2	3	0	2	2	4	81
Nashville	0	------	0	0	2	3	0	2	0	10	45
Alabama:											
Birmingham	2	2	1	0	3	1	0	5	2	1	71
Mobile	0	2	0	0	2	1	0	1	0	0	29
Montgomery	0	------	------	0	------	0	0	------	0	0	------
Arkansas:											
Fort Smith	0	------	------	------	------	1	0	------	0	0	------
Little Rock	0	------	0	0	6	0	0	2	0	2	------
Louisiana:											
Lake Charles	0	------	0	0	0	0	0	0	0	0	4
New Orleans	2	1	1	0	19	4	0	5	1	20	167
Shreveport	0	------	0	0	3	0	0	2	1	0	44
Oklahoma:											
Oklahoma City	0	1	0	3	2	2	0	0	0	0	32
Tulsa	0	------	------	3	------	0	0	------	0	4	------
Texas:											
Dallas	0	1	1	0	2	3	0	1	1	7	53
Fort Worth	2	------	0	1	0	2	0	0	1	1	41
Galveston	0	------	0	0	2	1	0	2	0	1	14
Houston	6	------	0	0	10	2	0	6	4	0	84
San Antonio	0	------	1	0	9	0	0	6	0	0	71
Montana:											
Billings	0	------	0	0	1	0	0	0	0	3	7
Helena	0	------	0	0	0	0	0	0	0	2	1
Missoula	0	------	0	0	0	0	0	0	0	1	6
Colorado:											
Colorado Springs	0	------	0	0	1	0	0	2	0	5	10
Denver	4	------	1	1	3	3	0	3	1	19	78
Pueblo	2	------	0	0	2	0	0	0	0	0	12
New Mexico:											
Albuquerque	0	------	0	0	2	0	0	4	0	0	12
Utah:											
Salt Lake City	0	------	0	4	0	4	0	1	0	16	36
Washington:											
Seattle	0	------	0	0	1	4	0	4	1	1	87
Spokane	0	1	1	2	2	0	0	1	4	0	32
Tacoma	0	------	0	0	0	1	1	0	0	1	17
Oregon:											
Portland	0	------	0	1	2	2	0	5	0	2	84
Salem	0	------	------	0	------	2	0	0	------	0	------
California:											
Los Angeles	7	2	0	10	9	14	0	14	0	32	309
Sacramento	0	------	0	1	2	0	0	0	0	8	24
San Francisco	0	2	0	9	2	9	0	6	0	12	148

City reports for week ended Sept. 3, 1938—Continued

State and city	Meningitis, meningococcus		Polio-myelitis cases	State and city	Meningitis, meningococcus		Polio-myelitis cases
	Cases	Deaths			Cases	Deaths	
Rhode Island:				District of Columbia:			
Providence	1	0	0	Washington	0	0	1
New York:				Georgia:			
Buffalo	0	1	0	Savannah	0	0	1
New York	2	0	8	Alabama:			
Pennsylvania:				Birmingham	0	1	1
Philadelphia	0	0	5	Louisiana:			
Ohio:				New Orleans	1	0	0
Cleveland	0	0	1	Shreveport	0	2	0
Columbus	0	0	1	Texas:			
Illinois:				Houston	0	0	1
Chicago	0	0	4	Oregon:			
Michigan:				Portland	0	0	1
Detroit	0	0	2	California:			
Wisconsin:				San Francisco	0	0	1
Milwaukee	0	1	0				

Dengue fever.—Houston, 1 case.

Encephalitis, epidemic or lethargic.—Cases: Boston, 2; Detroit, 1; Grand Forks, 6; Minot, 3; Lawrence, Kans., 1; Atlanta, 1; Helena, 1; Denver, 1.

Pellagra.—Cases: Charleston, S. C., 1; Atlanta, 1; Mobile, 1; Los Angeles, 2.

Typhus fever.—Cases: Charleston, S. C., 7; Atlanta, 2; Savannah, 3; Miami, 1; Tampa, 1; Birmingham, 1; Mobile, 1; Houston, 1; San Antonio, 1.

FOREIGN AND INSULAR

CZECHOSLOVAKIA

Communicable diseases—May 1938.—During the month of May 1938, certain communicable diseases were reported in Czechoslovakia as follows:

Disease	Cases	Deaths	Disease	Cases	Deaths
Anthrax	2		Paratyphoid fever	15	2
Cerebrospinal meningitis	72	27	Poliomyelitis	6	1
Chickenpox	207		Puerperal fever	19	4
Diphtheria	1,939	82	Scarlet fever	2,118	18
Dysentery	1		Trachoma	68	
Influenza	27	6	Tularemia	2	
Lethargic encephalitis	3	2	Typhoid fever	307	31
Malaria	723		Typhus fever	1	1

JAMAICA

Communicable diseases—4 weeks ended September 3, 1938.—During the 4 weeks ended September 3, 1938, cases of certain communicable diseases were reported in Kingston, Jamaica, and in the island outside of Kingston, as follows:

Disease	Kingston	Other localities	Disease	Kingston	Other localities
Cerebrospinal meningitis	1		Leprosy		1
Chickenpox	3	7	Puerperal sepsis		2
Diphtheria	4		Tuberculosis	34	86
Dysentery	5	2	Typhoid fever	7	34
Erysipelas		1			

CHOLERA, PLAGUE, SMALLPOX, TYPHUS FEVER, AND YELLOW FEVER

NOTE.—A table giving current information of the world prevalence of quarantinable diseases appeared in the PUBLIC HEALTH REPORTS for August 26, 1938, pages 1544–1558. A similar cumulative table will appear in future issues of the PUBLIC HEALTH REPORTS for the last Friday of each month.

Cholera

China.—During the week ended September 3, 1938, cases of cholera were reported in China as follows: Canton, 5; Foochow, 11; Hong Kong, 19; Macao, 56; Shanghai, 421; Swatow, 5.

Indochina (French).—During the week ended September 3, 1938, cholera was reported in French Indochina as follows: Annam Province, 34 cases; Tonkin Province, 7 cases.

Plague

Brazil—Pernambuco State.—During the month of June 1938, 1 case of plague was reported in Pernambuco State, Brazil.

Hawaii Territory—Island of Hawaii—Hamakua District—Paauhau.—A rat found on August 26, 1938, in Paauhau, Hamakua District, Island of Hawaii, Hawaii Territory, has been proved positive for plague.

United States.—A report of plague infection in Catron County, New Mexico, and in Lincoln County, Wyoming, appears on pages 1726 and 1727 of this issue of PUBLIC HEALTH REPORTS.

Smallpox

Mexico.—During the month of May 1938, smallpox was reported in Mexico as follows: Aguascalientes, Aguascalientes State, 1 case; Ciudad Juarez, Chihuahua State, 4 cases; Mexico, D. F., 19 cases, 3 deaths; Monterrey, Nuevo Leon State, 4 cases; Morelia, Michoacan State, 5 cases; Piedras Negras, Coahuila State, 1 case; Queretaro, Queretaro State, 1 death; San Luis Potosi, San Luis Potosi State, 1 case, 1 death.

Typhus Fever

Iraq.—During the week ended August 27, 1938, 1 case of typhus fever was reported in Iraq.

Mexico.—During the month of May 1938, typhus fever was reported in Mexico as follows: Aguascalientes, Aguascalientes State, 3 cases; Guanajuato, Guanajuato State, 3 cases, 1 death; Mexico, D. F., 5 cases, 1 death; San Luis Potosi, San Luis Potosi State, 2 cases; Toluca, Mexico State, 7 cases.

Yellow Fever

Gold Coast—Ahliha.—On August 31, 1938, 1 fatal case of yellow fever was reported in Ahliha, Gold Coast, near Ho in British Togoland.

Nigeria (French)—Tahoua.—On August 22, 1938, 1 suspected case of yellow fever was reported in Tahoua, French Nigeria.

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