cover after a year or two that such duties offer no prospect of advancement, and add very little to their knowledge of engineering. In one case, after spending some years at the test-bed of a firm of steam turbine builders, an ex-student had not even learned the essential differences between a reaction and an impulse turbine. Such matters were not included in the curriculum of his college at the date of his graduation, and he added little or nothing to this ignorance by his years of testing."

With some of this we cannot agree, for no matter how poorly the laboratory may serve the purpose of profitable improvement, as is undoubtedly the case in many instances, and no matter how little may be the value of testing work to engineering graduates or to their employers, it does not follow that such considerations greatly restrict the applicability of organized research work in the field of mechanical engineering or in any other branch. The distinction here rests again on names; laboratories as generally understood are not essential to some very useful research nor is the existence of a testing department proof of the doing of research work. Forces of men may spend their lives making consumption tests of turbines, strength tests of metals or determining calorific powers of fuels in well equipped laboratories and improve related industries not one bit, and yet one man with no laboratory whatever may stroll leisurely through a few establishments or sit at his desk and evolve an improvement that may materially advance several industries at once when developed, though before getting it in shape for commercial use experimental development work is almost universally required. Depending on the case, this work may be most profitably done in laboratories, in shop or in the field, but it must be done. The International Harvester Company has added more to improvement of agricultural conditions by its machine and implement developments than any organization in the world, but it has no research laboratory, though maintaining testing and development departments. This does not mean that it does no research, for such results could not be produced without research, only it would be obviously absurd to try to develop standard plows, and tractors to pull them, suitable for every soil in the world by any laboratory tests; the machines must be planned, built and then tried and studied everywhere, then returned to the shops, changed to correct faults and tried again. The real research men here are those who plan and study operation in the plowing field, the only place where it can be studied, and who then analyze faults and plan again; these men spend most of their time in railroad trains rather than in laboratories; in the true sense their laboratory is the plowing field, as it should be.

Americans cannot agree with the idea that the fore-

man or superintendent or engineer, whose primary function is the production, at lowest cost, of goods of proper standard quality, is the best man to carry on research or development work; quite to the contrary, in fact he is the very worst. This is because, first, scheming always occupies the mind to the exclusion of executive routine, which is his main business, and second, but vastly more important, the type of mind and training that best fits for one is destructive, or exclusive, of the other. No man well adapted to pushing routine economic production can possibly discover faults and remedies with efficiency, and certainly the creative mind that can, becomes impatient with production routine and so neglects it.

RESEARCH AND THE PROFESSOR

"Experience in research work is often made a *sine qua non* for the holding of a professional chair at certain of our universities, and if the word 'research' be interpreted in a sufficiently liberal and comprehensive manner, the condition is, we think, a wise one. In many cases, however, the conduct of a few experiments on lubrication or on elastic moduli will be counted as research, though the experimenter may have displayed no deep knowledge of engineering and physical principles, and be quite incapable of giving material aid to the advancement of the art. He would, however, on the above basis, be preferred to a competitor who had never made a laboratory experiment in his life, but had been in responsible charge of, say, the bridge department of a large firm.

"On the other hand, there are men of exceptional ability in really original research who have not the gift of commending themselves to students and who fail accordingly to teach anything to any but a few exceptional men. At the same time they may do such good work in the study as to more than outweigh their class room deficiencies so far as the world at large is concerned, unfortunate as matters may be for the average student. It is important that work of this character should be done, but the difficulty is to reconcile the claims of abstract technics with the not unnatural demands of the average British parent. A University should certainly promote the former, but as teaching is also one of its functions, undergraduates have a right to demand that their interests shall not be wholly sacrificed to the claims of research."

It is true that a great many directors of engineering schools have insisted on a research record for newly appointed men without knowing just what they meant by the requirement, and while some still do it, times do change and so do standards. Few enlightened schools now fail to recognize that both teachers and investigators are absolutely necessary on the staff, and while it most commonly happens that ability in one line is inversely proportional to strength in the other, yet we know of quite a number of men who possess this dual power.

C. E. LUCKE

ORIGINAL PAPERS

THE BIOCHEMICAL OXYGEN DEMAND OF SEWAGES

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This paper represents the result of a study of a test to determine the biochemical oxygen demand made

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by a subcommittee of the laboratory section of the American Public Health Association.

Interest in this subject has recently been revived through the adoption of standards of permissible stream pollution by the English Royal Commission on Sewage Disposal, embodied in an appendix of the 8th report of

the commission. The test recommended by the commission will be hereafter referred to as the "English Incubation Test."

Before I go into the details of this test, it seems well to discuss briefly its meaning and importance.

As the title of the paper indicates, the oxygen referred to here is that utilized by microorganisms which take part in the decomposition of sewage. To what extent the reaction taking place is of a purely biological or chemical or physical nature is unknown. The process is most probably a combination of all three forces. In designating properly a test, which gives expression to the demand for oxygen such as is present in streams, one can hardly be criticized for using the expression "Biochemical Oxygen Demand." The danger of introducing the term "Oxygen Demand" alone is that it would be somewhat confusing with the time-honored expression "Oxygen Consumed." We know that "oxygen consumed" indicates the permanganate oxygen required for the oxidation of a small portion of the organic carbonaceous matter. This oxidation is a purely chemical reaction and bears no relation whatsoever to the "biochemical" oxygen demand. The biochemical oxygen demand of a sewage as a rule is much higher than the permanganate oxygen consumption and the figures bear absolutely no relation to each other. In certain cases the biochemical oxygen demand may be low and the permanganate oxygen consumption high. This may occur with trade wastes containing organic carbonaceous preservatives. The principal value of a test for the determination of the biochemical oxygen demand in a sewage lies in the fact that it is the best indicator of what may be called the "strength" of a sewage. Anyone who has ever employed one or the other of such tests is quickly convinced that none of the routine chemical determinations heretofore in use can furnish the same information. From the standpoint of stream pollution it means very little to the sanitary engineer and chemist to know how much organic nitrogen or "oxygen consumed" or chlorine a certain sewage will add to the stream. They are interested in the amount of oxygen that will be absorbed in the stream, particularly during the first stretch after discharge. Of the chemical constituents the suspended matter is of interest because of its relation to the aesthetic features of sewage disposal by dilution, and on account of its relation to the formation of mudbanks. Some instances of comparing the "strength" of certain sewages from the standpoint of the routine chemical analysis and the biochemical oxygen demand are indeed surprising. The writer has in mind one instance in particular, in which a certain sewage when compared to another from the standpoint of the routine chemical tests was twice as strong and when judged by the biochemical oxygen demand about forty times as strong. Personally, I do not advise chemists to disregard chemical determinations in sewages altogether; we surely want to know whether a sewage is alkaline or acid for instance. My principal plea is to subordinate the routine determinations of the chemical constituents to the determination of the oxygen-consuming capacity of a sewage.

The laboratory section of the American Public Health Association has recognized the importance of standardizing such a test and for some months past a subcommittee has devoted its attention to this question. The members of the subcommittee are: F. Bachmann, Chicago; R. H. Brown, New York City; J. W. M. Bunker, Cambridge, Mass.; Frederic Bonnet, Jr., Worcester, Mass.; W. M. Cobleigh, Bozeman, Mont., John R. Downes, Plainfield, N. J.; F. E. Hale, Brooklyn, N. Y.; C. B. Hoover, Columbus, O.; A. Lederer, Chicago; T. W. Melia, Brooklyn, N. Y.; F. W. Mohlman, Urbana, Ill.; John F. Norton, Boston, Mass.; E. B. Phelps, Washington, D. C.; and S. T. Powell, Baltimore, Md. A. Lederer is chairman of the subcommittee. The following sanitary engineers have been kind enough to give the subcommittee on various occasions the benefit of their valuable opinion: H. C. McRae, Baltimore, Md.; Langdon Pearse, Chicago, Ill.; and W. L. Stevenson, Philadelphia, Pa.

The standardization of a biochemical test differs from the standardization of a purely chemical test in various respects. One chemist might be put to work out a chemical method and his results would be of equal value anywhere. This is not the case with a biochemical test. Two sewages may be alike with reference to their chemical constituents and yet they may differ vastly in their biology. Rarely will two sewages be exactly alike in this respect. No biologic procedure can be expected to furnish ready formulae which would work out with mathematical precision everywhere at all times. Even if we had such a procedure at our disposal we would still have such factors to account for as obstructions in a stream, differences in velocity and temperature, influence of sunlight, absorption of oxygen by mud banks and other factors which of necessity are not represented in a laboratory procedure. It seemed evident, therefore, that in proposing and adopting a standard procedure we would have to confine ourselves for the present to methods furnishing fairly accurate, consistent results, comparable with each other. It could not be expected in the present state of our knowledge of self-purification of rivers with reference to oxygenation and de-oxygenation, that we should be able to work out a procedure which could tell us with certainty how much sewage is to be permitted in a stream to maintain a certain degree of purity further downstream. This could be done only if rivers in all parts of the country were alike with reference to temperatures, velocities, obstructions, etc. Any deeper study of de-oxygenation and oxygenation in a particular stream will apply only to another stream very similar hydrographically. With these conceptions in mind it seemed most advisable to standardize a procedure which would permit the expression of "total biochemical oxygen consumption" and to leave the practical application of this test for the purpose of controlling stream pollution to individual local study.

In order to compare the applicability of a standard procedure in various localities it is important to experiment with as many sewages as possible. Such tests were made with the sewages of Chicago, Ill.,

Plainfield, N. J., Champaign, Ill., Lawrence, Kan., New York City, Washington, D. C. and Worcester, Mass. Since the number of results obtained with Worcester and New York City sewage are too small, these sewages are not considered in connection with this study.

A method of determining the actual strength of putrescible material is given in the last edition of the "Standard Methods of Water Analysis." The method consists in making various dilutions of the putrescible material with aerated tapwater, adding methylene blue as an indicator, and calculating the oxygen demand from the "relative stability" figures obtained. The method is undoubtedly very useful and simple. It will be retained in the next progress report of the committee in a form elaborated upon by Prof. Phelps. The possible objections to this method are that the relative stability figures obtained are based upon empirical findings and that intermediate points of de-oxygenation, if such are desired, cannot be obtained.

The method proposed by the Royal Commission of Sewage Disposal contained much which seemed worthy of a study by American chemists. Briefly, the English procedure is as follows:

A definite volume of sewage or effluent is completely aerated by shaking. It is then mixed with a larger definite volume of tap water and the mixture again aerated. The dilutions recommended for raw sewages and settled sewages are about 99 to 1 and 49 to 1, respectively. The intention is to adjust the ratio of the aerated water to the sewage under test so that during the test only about 50 or 60 per cent of the oxygen in the diluting water will be used up. It is stated that if less than 30 per cent of the initial oxygen is absorbed the error of the experiment becomes large, but if more than 60 per cent is absorbed the error is even greater. A large dilution reduces the food supply of the bacteria and thus retards de-oxygenation. The prepared dilutions are carefully put into 4 clean glass-stoppered bottles holding 11 to 12 ounces. The bottles are left unstoppered for 5 minutes to give the entrapped air at the shoulder a chance to escape. Stress is laid on the importance of having all the liquids in the mixture and even the bottles at incubation temperature before beginning the incubation. The incubation temperature recommended is 65° F. (18.3° C.), this representing the maximum summer temperature of even the most sluggish English streams. The 5-day incubation temperature has been found to give a smaller experimental error than longer incubation periods. Two of the bottles are tested for oxygen at once; the other 2 bottles are tested for oxygen at the end of incubation. The determination of the free oxygen was made by the Winkler method as modified by Rideal and Stewart. The principle of the modification consists in the oxidation of the organic matter and the nitrites by the addition of permanganate in acid solution followed by the addition of 1 cc. of potassium oxalate previous to the addition of the standard reagents employed in the Winkler method. The English standard for sewage effluents

is one that absorbs less than 20 p. p. m. of oxygen in 5 days at 65° F.

It is not the purpose of this subcommittee to concern itself with the adoption of standards for sewage effluents but solely to fix a laboratory procedure which will give uniform results. It is thought that such a procedure will be a valuable aid to the sanitary engineer in establishing standards of permissible stream pollution.

There were a number of features in the original English test for the determination of the biochemical oxygen demand which did not appeal to the collaborators, and after considerable correspondence it was finally decided to do some comparative work with the method, employing, however, an incubation temperature of 20° C., and to extend the incubation period to 10 days in order to study the oxygen consumption from day to day. The assumption was that the oxygen consumption at the end of 10 days would be practically 100 per cent. It was also decided to work with three different concentrations simultaneously, so that the influence of concentration upon oxygen consumption could be studied. An ideal experimental series was to show oxygen absorptions of less than 30 per cent, between 30 and 60 per cent, and over 60 per cent, respectively. The preparation of the mixtures previous to incubation differed from the English procedure in that we employed aerated distilled water instead of tap water and 8-ounce bottles were used instead of 11-ounce bottles. The sewage was not aerated before mixing it with the distilled water, but the mixture was brought to the incubation temperature previous to incubation. The sewage was settled in the laboratory before the mixtures were prepared, for the reason that unevenly divided suspended matter might have introduced serious discrepancies in the final results. The original Winkler method was employed for the determination of the free oxygen. Later on, during the tests, it was recommended to employ Hale and Melia's modification of the Winkler method. Professor Phelps employed Rideal and Stewart's modification in the latter part of his series. A number of blue-printed record sheets were mailed to the co-workers in order to facilitate the compilation of the results obtained. It was suggested at the start that each collaborator should obtain at least 10 ideal series, but the time and labor involved was so great that it was impossible to live up to it. Unless one has worked with the same sewage for a considerable period it is almost impossible to prepare dilutions which will allow reductions of oxygen simultaneously to 30 per cent, to between 30 and 60 per cent and over 60 per cent. A great deal of time in such work is always lost with preliminary tests. In order to obtain an ideal series one has to incubate at least 30 bottles and preferably more in order to check doubtful results.

In his series, Mr. Mohlman recorded in addition to the oxygen consumption figures, Phelps' velocity coefficient "K" for each day. A subsequent calculation of K on all of the results obtained by the various collaborators gave some interesting information. The

TABLE I.—PERCENTAGE OF TOTAL OXYGEN ABSORBED AND PHELPS' VELOCITY COEFFICIENT, K, AFTER 24 HOURS AND 5 DAYS INCUBATION AT 20° C. Total Oxygen Consumption Compared with Initial Available Oxygen after 10 Days Incubation

Total Oxygen Consumption Compared with Initial Amount of Oxygen after 10 Days Incubation																		
LESS THAN 30 PER CENT						30 to 60 PER CENT						MORE THAN 60 PER CENT						
Date of sampling 1914	24 hours		5 days		K Average of 10 days incubation	24 hours		5 days		K Average of 10 days incubation	24 hours		5 days		K Average of 10 days incubation			
	% O abs'd	K	% O abs'd	K		% O abs'd	K	% O abs'd	K		% O abs'd	K	% O abs'd	K				
SERIES: Phelps. SOURCE: Screened Washington Sewage																		
April 21....												34	0.00052	78	0.00030	0.00032		
22....												23	0.00031	76	0.00027	0.00025		
24....	23	0.00031	75	0.00020	0.00020	23	0.00026	67	0.00015	0.00017								
28....	28	0.00026	61	0.00016	0.00018	26	0.00026	80	0.00019	0.00019								
29....						29	0.00037	77	0.00021	0.00022								
30....	38	0.00031	84	0.00015	0.00017													
	22	0.00018	88	0.00016	0.00016													
	20	0.00018	80	0.00016	0.00017													
May 1....						33	0.00034	85	0.00020	0.00018								
8....	17	0.00018	65	0.00016	0.00016	32	0.00037	77	0.00019	0.00019								
						25	0.00030	75	0.00021	0.00021								
12....	18	0.00018	52	0.00013	0.00014	30	0.00043	86	0.00030	0.00029								
13....	17	0.00013	60	0.00012	0.00011	37	0.00042	75	0.00019	0.00019								
						15	0.00015	81	0.00020	0.00017								
14....	47	0.00039	63	0.00010	0.00016	28	0.00042	88	0.00021	0.00023								
						41	0.00045	90	0.00024	0.00025								
15....	30	0.00031	86	0.00010	0.00018							34	0.00064	76	0.00037	0.00040		
16....						27	0.00043	79	0.00028	0.00028								
						23	0.00035	89	0.00030	0.00027								
23....						26	0.00034	77	0.00024	0.00023								
						23	0.00034	83	0.00028	0.00024								
25....						20	0.00024	71	0.00020	0.00021								
						21	0.00028	79	0.00025	0.00021								
26....												34	0.00054	84	0.00037	0.00036		
28....												36	0.00056	85	0.00035	0.00036		
												36	0.00057	80	0.00033	0.00036		
												46	0.00071	92	0.00038	0.00039		
SERIES: Young and Bruckmiller. SOURCE: Settled Sewage—Lawrence, Kansas																		
May 23....	25	0.0024	69	0.0015	0.0015	51	0.0060	51	0.0012	0.0020	63	0.0070	23	0.0027	0.0031			
26....	27	0.0024	74	0.0016	0.0016	50	0.0013	67	0.00079	0.00079	53	0.0062	68	0.0018	0.0025			
27....	14	0.0015	29	0.00049	0.00094	51	0.0058	65	0.0016	0.0022	59	0.0065	80	0.0021	0.0026			
June 9....						45	0.012	77	0.0046	0.0054	38	0.0031	87	0.0019	0.0020			
						33	0.0052	76	0.0027	0.0031								
10....	28	0.0015	77	0.0020	0.0018	38	0.0060	52	0.0017	0.0026	30	0.0024	89	0.0020	0.0018			
11....	29	0.0034	41	0.00096	0.0016	58	0.0068	90	0.0023	0.0025	61	0.0060	77	0.0016	0.0020			
SERIES: Downes. SOURCE: Screened Sewage—Plainfield, N. J.																		
May 2....	18	0.0011	66	0.00075	0.00087	23	0.00086	67	0.00057	0.00060								
						44	0.0014	84	0.00062	0.00064								
15....	26	0.0011	84	0.00082	0.00080	35	0.0010	71	0.00045	0.00052								
						35	0.00094	78	0.00051	0.00054								
26....	37	0.0014	84	0.00066	0.00057						44	0.0016	81	0.00072	0.00068			
											57	0.0018	89	0.0011	0.0010			
June 1....	37	0.0012	86	0.00060	0.00059						44	0.0015	79	0.00070	0.00077			
6....											28	0.0013	73	0.00099	0.0011			
12....						45	0.0012	84	0.00050	0.00058	41	0.0014	70	0.00062	0.00075			
SERIES: Mohlman. SOURCE: Crude and Septic Sewage—Champaign, Ill.																		
Septic																		
April 21....												34	0.0020	81	0.0013	0.0013		
21....												27	0.0021	75	0.0014	0.0015		
												25	0.0014	80	0.0013	0.0014		
25....												18	0.0013	76	0.0015	0.0014		
30....												14	0.0010	64	0.0011	0.0011		
						15	0.0016	56	0.0014	0.0014	25	0.0017	72	0.0012	0.0012			
Crude						17	0.0013	58	0.0010	0.0011	18	0.0010	86	0.0015	0.0011			
May 5....						38	0.0045	76	0.0017	0.0020								
						28	0.0036	66	0.0021	0.0021								
5....						17	0.0017	65	0.0015	0.0016	25	0.0014	82	0.0014	0.0015			
9....						26	0.0060	61	0.0031	0.0036	22	0.0035	61	0.0026	0.0028			
11....											25	0.0072	73	0.0052	0.0053			
14....						34	0.0058	60	0.0020	0.0025	14	0.0049	58	0.0025	0.0031			
						28	0.0079	55	0.0032	0.0040								
SERIES: Lederer and Bachmann. SOURCE: Crude Sewage (Settled)—Chicago, Ill.																		
April 20....	26	0.0012	78	0.00084	0.00088	16	0.00046	80	0.00051	0.00047								
	18	0.00059	76	0.00052	0.00049													
21....	28	0.0011	72	0.00057	0.00069	37	0.00074	74	0.00032	0.00036								
	26	0.00070	78	0.00045	0.00046													
22....	10	0.00036	78	0.00068	0.00055	11	0.00036	66	0.00043	0.00040								
						22	0.00043	81	0.00040	0.00043								
23....	24	0.0011	66	0.00063	0.00062	30	0.00086	70	0.00045	0.00046								
						33	0.00075	76	0.00039	0.00042								
28....	41	0.0011	91	0.00047	0.00049	25	0.00051	75	0.00037	0.00038								
	35	0.00069	91	0.00041	0.00039													
29....	22	0.00071	71	0.00044	0.00050													
	24	0.00056	68	0.00032	0.00036													
30....	44	0.0016	83	0.00066	0.00077	31	0.00069	92	0.00048	0.00041								
						42	0.00075	79	0.00032	0.00040								
May 1....	33	0.0010	84	0.00059	0.00058	24	0.00062	82	0.00048	0.00049								
						26	0.00060	82	0.00048	0.00049								
4....	29	0.0016	79	0.00089	0.00084	29	0.00082	90	0.00058	0.00058	33	0.00089	93	0.00067	0.00061			
6....	41	0.0016	94	0.00080	0.00088	26	0.00057	76	0.00039	0.00040								
						31	0.00062	94	0.00049	0.00051								
27....	30	0.00071	60	0.00031	0.00040	24	0.00032	79	0.00025	0.00023								
	30	0.00039	78	0.00022	0.00021													
28....	35	0.0012	65	0.00047	0.00055	33	0.00075	90	0.00051	0.00047	33	0.00096	81	0.00075	0.00065			
June 4....	41	0.0011	91	0.00050	0.00053	24	0.00059	88	0.00059	0.00050	19	0.00047	83	0.00070	0.00066			

factor K is part of a formula developed by Prof. Phelps and Col. Black during an investigation of the pollution of New York harbor in 1911. The method employed by Phelps and Black consisted in the incubation of suitable mixtures of the sewage with

aerated water for a specified time, say 24 hours. The oxygen is determined at the start and at the end of incubation. Considering the reaction between the organic matter of the sewage and the oxygen dissolved in the water, the following relation is said to hold:

$\log \frac{O'}{O} = KCl$. O' represents the initial, O the final amount of oxygen present. C expresses the concentration of the sewage, t the duration of the incubation in hours, and K the velocity constant of the reaction to be determined. Knowing the form of the reaction curve, one computes first K and then by extrapolation to an extended period the total oxygen demand of the organic matter in the sewage. Originally it was claimed that K is independent of the extent of dilution. This, however, was found later to be not quite correct. It was my experience

at the highest concentration of the sewage. After 24 hours, K is much higher than after 2 days and it decreases (this does not show in the tables given) continuously up to the last day of incubation. However, after the fourth or fifth day the differences are by no means as marked as they are during the first few days. In many cases, K is fairly constant after 5 days. K after 5 days of incubation coincides quite well with the average of the 10 days period.

These results are given without comment or recommendation, for the reason that the formula is now undergoing a very comprehensive study in connection with

TABLE II—PER CENT RELATION OF "MG. OXYGEN ADDED TO 1 LITER OF SEWAGE" TO "MG. OXYGEN ABSORBED PER LITER OF SEWAGE" AFTER 24 HOURS, 5 DAYS AND 10 DAYS INCUBATION AT 20° C.

AFTER 14 HOURS, 5 DAYS AND 10 DAYS INCUBATION AT 25° C.																		
DATE	COLLABORATOR	Mg. O Per added cent to 1 l. dilution	Mg. O sew- age	PER CENT O ABSORBED IN				DATE	COLLABORATOR	Mg. O Per added cent to 1 l. dilution	Mg. O sew- age	PER CENT O ABSORBED IN						
				24 hours	5 days	10 days	Av.					24 hours	5 days	10 days	Av.			
May 14	Mohlman	0.25	3488	10	10	20	20	36	36	April 20	Lederer and Bachmann	3.0	280	7	35	43		
23	Young and Bruckmiller	0.36	2111	5		14	21	21		21		287	11	23	31			
26			2111	2.5		18	24	24		May 6		280	10	9	28	29	36	
26			2111	5		14.5	20	20		April 21	Mohlman	282	28		66	80		
27			2111	2.5		5	18	18		21		276	21		68	87		
June 10			2111	2.5		18	24	24		30		276	15		70	82		
11			2111	7	4	9	13	22	21.5	May 5		275	21		69	68	84	
5	Mohlman	0.50	1680	9.5		26	34			2	Downes	352	21	21	40	40	47	
9			1512	15		35	57			15		4.0	252	19	43	54		
11			1580	18		51	70			26		225	30		55	69		
14			1688	16	15	26	34	45	51	June 1		226	28		54	63		
2	Downes		2132	3		10	16			6		230	26		66	90		
15			2080	3.5	3	11	10	13	15	12		225	23	26	43	51	65	
May 21	Young and Bruckmiller	0.72	1055	20		20	46			April 22	Lederer and Bachmann	210	9.5		36	44		
26			1055	20		26	40			23		215	15		35	45		
27			1055	21		28	42			May 27		202	9		22	28		
June 9			1055	19		42	55			28		210	15.5		43	48		
10			1055	21		32	55			June 4		202	12	12	46	36	52	
11			1055	24	21	37	31	41	46.5	April 24	Phelps	224	6		20	27		
May 26	Downes	1.00	938	7		16.5	20			28		222	6		16	25		
June 1			959	7	7	16	16	18	19	30		224	7		16	25		
April 30	Mohlman		856	8		31	55			May 8		217	4		16	25		
30			854	7		24	41			12		210	4		13	25		
May 5			884	22		38	57			13		221	4		12			
9			836	9		34	51			14		219	8		11	17.5		
14			728	18		50	82			16		228	7		19	22		
April 20	Lederer and Bachmann		826	24	15	50	38	86	62	28		228	9		27	34		
21			870	7		21	26			29		219	7	6	28	18	32	
22			890	6		15	20			April 28	Lederer and Bachmann	5.0	166	13	19	40	53	
23			870	2		17	22			30		168	19		36	45		
28			890	6		16	24			May 1		168	15		36	58		
29			870	6		13	14			4		166	22	17	60	45	65	
30			860	3.5		12	16			26	Downes	6.0	150	54	85	96		
May 1			880	8		17	20			June 12		146	37	45	64	79	92	
4			880	6		17	20			May 6	Lederer and Bachmann	135	18.5	18.5	55	55	59	
6			870	8		22	28			April 24	Phelps	147	8		22	33	59	
27			860	8		20	20			28		146	9		26			
28			840	4		12				29		147	11		30	39		
June 4			870	7		13	20			30		148	6		24			
April 20	Lederer and Bachmann	1.5	840	6	6	13	16	14	19	May 1		146	11		28	33		
21			573	5		20	25			5		139	5			26		
May 23	Young and Bruckmiller	1.8	586	6	5.5	17	18	21	23	8		146	11		27	35		
26			422	50		73	79			13		141	13		27	35		
27			422	46		59	87			14		143	13		30	48		
June 9			422	47		64	80			15		144	14			49		
10			422	26		61	70			23		144	11		32	42		
11			422	21		63	71			23		141	10	10	37	28	44	
2	Downes	2.0	422	45	39	57	63	73	77	27	Lederer and Bachmann	7.0	111	11		38	49	
15			530	9		27	40			28		116	31		77	94		
April 21	Mohlman		512	12	10.5	22	24	30	35	June 4		111	17	19	74	63	90	
21			429	20		55	73			8	Phelps	8.0	107	13		38	50	
25			409	14		58	75			12		101	17		49	57		
30			372	11		46	70			13		102	6.5		36	44		
22	Lederer and Bachmann		430	17	15	48	52	67	71	14		109	18		41	45		
23			425	3.5		21	32			15		103	25		58	73		
30	Phelps		435	9	6	22	21	31	31	25		108	10		36	51		
May 5			422	2		8				25		104	11	14	42	43	53	
April 28	Lederer and Bachmann	2.5	437	1	1.5		8	11	11	April 21	Phelps	10.0	87	25	56	72		
29			340	9		25	27			22		82.5	16		52	69		
30			336	7		20	30			May 26		82	26		64	76		
May 1			344	9		28	30			28		83	26		62	72		
4			344	8			34			28		80	27		60	75		
			340	11	9	33	26	36	31	28		80	32	25	65	60	70	72

that K decreased as the concentration increased, and the results obtained in Tables I and II bear this out uniformly. To meet this objection, Phelps recommended that C in his formula be effected by a concentration exponent n , which would have to be determined for each particular sewage by a study of a series of dilutions.

In making a study of K , obtained in the experiments of the collaborators, the following facts present themselves very strikingly. K is almost invariably lowest

the work of the U. S. Public Health Service on the self-purification of the Ohio and Potomac rivers. Possibly, the results obtained in connection with the investigation of the English incubation test will be of some service to the students of the formula.

Before discussing the results obtained by the collaborators and giving their comments, the results are compiled in Table I.

In some cases, as can be noted, the number of determinations was rather small, and in such cases one

is hardly justified in drawing an average. The heading "Per Cent of Total Oxygen Absorbed" serves to indicate the per cent ratio of absorption, assuming that it is 100 per cent after 10 days. For instance, the column "Per Cent Oxygen Absorbed in 24 Hours" indicates the per cent ratio between the oxygen absorbed in 24 hours and 10 days.

Table II shows the per cent of oxygen absorbed after 1, 5 and 10 days incubation.

Table I shows very strikingly that the rate of absorption in certain dilutions with certain sewages is fairly uniform but that there is no uniformity whatsoever in this respect when comparing different sewages with each other. In other words, one might incubate a certain dilution of a certain sewage for 24 hours and assume with fair certainty the approximate oxygen consumption in 5 days and 10 days, provided he has once established the relation in preliminary tests. This, of course, implies a good deal of work which the busy works-chemist is not always in a position to do.

In all of the experiments, the number of mg. of oxygen absorbed per liter of sewage was lower the higher the concentration. The percentage of oxygen absorbed by the sewage increased with the concentration.

Some experiments were omitted in the tabulation, for the reason that there was a discrepancy in the results which apparently seemed illogical. Such discrepancies were noted in nearly all of the series. There is no doubt that some of these discrepancies are not merely analytical errors but due to reasons which still lack satisfactory explanation. It often happened that the oxygen consumption would suddenly increase on one day, to drop down to a logical figure on the next day. The greater part of the consumption has been reached as a rule by the fifth day. The consumption between the fifth and tenth day amounted to about 20 to 25 per cent of the total. On the whole the concentration did not matter greatly when comparing the per cent oxygen absorbed in 24 hours and 5 days (Table I). When the incubation was such that less than 30 per cent and between 30 and 60 per cent of the initial oxygen was consumed, the "per cent oxygen absorbed in 24 hours" was about 30 per cent (variation 17 to 46), and the "per cent oxygen absorbed in 5 days" about 75 per cent of the total (variation 58 to 81). When more than 60 per cent of the initial oxygen was absorbed, the ratio of absorption was somewhat higher. For the 1-day period the ratio was on the average 35 per cent (variation 22 to 51) and for the 5-day period, about 80 per cent of the total per cent consumption (variation 73 to 86). That this method furnishes only approximate figures at the best is apparent.

Some of the collaborators have given a more detailed opinion on the result of their tests, excerpts of which are given herewith.

Mr. Mohlman, who employed Jackson's bulb pipettes as seals for the bottles during incubation, states that "A number of runs were spoiled by variations in incubation temperature." Instead of preparing the required dilutions for each individual bottle, Mr. Mohlman prepared a larger quantity of the desired mixture

and siphoned the solution into the 8-ounce bottles. (The procedure has been employed by the writer on previous dilution tests and seems much simpler and quicker than preparing individual mixtures. If carefully done, there need be no additional aeration and this procedure has the advantage of furnishing an absolutely uniform liquid.) "The most striking conclusion is the variability in the amount of oxygen used by the undiluted sewage, as it varies in every case directly with the amount added and is always higher in the higher dilutions."

Dr. Hale writes: "The parts per million of oxygen absorbed obtained with different dilutions by the English method do not agree. As such a result is not reasonable, instead of carrying out more series, we began to investigate immediately as to the cause of these discrepancies. We have found that aerated distilled water, even though not saturated when put into bottles and incubated at either 20 or 37° C., loses a certain amount of oxygen which varies with the temperature, with the initial oxygen, and with the type of the stopper. We have tested the rubber bulbs, rubber stoppers, glass stoppers, open bottles, and open tubes (Phelps) and found varying losses. We believe that oxygen collects under the stopper and, upon the introduction of solutions for testing is forced out of the bottle and lost. This occurs whenever the oxygen in the bottle has not been exhausted. Such a correction would then apply to all determinations made by the English method, but as the correction is very uncertain, it makes the English method very unreliable and my conclusions at present are that the dilution method is the only reliable standard, that the English method cannot be recommended unless extensive experiments find a way of eliminating this uncertainty"..... "There is also another reason why the English method is unreliable and that is that different amounts of sewage require different lengths of time to reach the endpoint, consequently if such a method is adopted we shall have to choose a certain dilution, say one per cent, and determine the length of time it takes that dilution to reach completion, besides eliminating previous error of loss of oxygen that I have mentioned. It may be that by filling bottles and allowing them to stand in the incubator for three days before the addition of sewage, the error may be eliminated, since the loss appeared to be constant in two to three days. This means, however, a troublesome procedure."

Mr. Downes feels that efforts should be abandoned to secure absolute oxygen capacity figures. "On the other hand, I feel that we should work towards the shortest incubation period which will give compatible results indicative of the effect of the sewage in question on the stream which it is to enter. In plant and stream control the value of the results increase in proportion to the speed with which they can be obtained. I suggest a 24-hour period for routine work as best adapted to our American needs. From past experience I had been led to hope that I could show that such a period was more independent of the dilution than longer periods. This I have not been able to do to my satisfaction. On the other hand, results for 24-hour tests

are just as compatible and just as reliable as results from longer periods. In cases when a comparatively stable condition of the sample has been reached between the fifth and tenth day without exhaustion of the available oxygen, the 24-hour results are about 40 per cent of the whole." "It seems that we can hardly do better than to adopt a dilution that will leave a 30 per cent to 60 per cent residual oxygen in 5 days as the English do, for it is certain that too high a concentration would interfere with the life of the oxidizing organisms."

Mr. Hoover would prefer the term "dissolved oxygen consumed" to "biochemical oxygen demand."

Prof. Phelps finds the work not very satisfactory and it is his intention to develop some method which will take us entirely away from oxygen determinations.

Notwithstanding the shortcomings of the method, it is of some advantage to be able to know even approximately the 24-hour and total oxygen consumption of the sewage. As long as we lack proven methods which will give us this information accurately, the introduction of the "Modified English Incubation Test" as a provisional method at the next annual meeting of the American Public Health Association ought to serve some useful purpose. A method developed by me for the determination of the oxygen demand consists in the addition of saltpeter, the oxygen of which is utilized during incubation just as the oxygen in diluting water is used. The method has been published in the May number of the *Journal of Infectious Diseases*. The method has since been simplified by me and has given satisfaction in determining the strength of sewages in polluted waters. Various chemists are employing the method at present and their criticism and results will help to decide whether the method is of sufficient value to supplant the one discussed at length in this paper, or whether it is to serve as a matter of choice. It is also to be hoped that Prof. Phelps will be successful in his endeavor to originate a reliable method for the determination of the oxygen demand and the ratio of oxygen absorption.

It is the intention to present the provisional procedure as the "Modified English Incubation Test" for the determination of the biochemical oxygen demand in the following form:

"A definite volume of sewage or effluent is mixed with aerated distilled water or tap water, free from nitrites and nitrates, in such proportion that between 30 and 60 per cent of the available oxygen is consumed at the end of 10 days incubation at 20° C. Care should be taken to store the diluting water for some time (one or two days) at the constant temperature of 20° C., previous to the preparation of the mixture. The sewage and even the bottles which are to be incubated should be of the same temperature to obtain satisfactory results. The sewage may be added directly into the bottles or else a larger quantity of the mixture may be prepared and the mixture siphoned into the bottles, care being taken to avoid aeration. A bottle of 250 cc. capacity with a seal such as is often used for the methylene blue putrescibility test is employed. It is necessary to establish the ratio of ab-

sorption in a definite concentration for each particular dry weather flow sewage before resorting to short time incubation. Having established the per cent ratio of absorption for 1, 5 and 10 days at the proper concentration at various times, it may then suffice to incubate the mixture for 24 hours at 20° C. The results after incubation of 24 hours can be converted into approximate results obtainable after 5 and 10 days incubation by multiplying by the proper factors. It is assumed that a 10-day period of incubation coincides with the complete oxidation of the sewage mixture, which is correct for all practical purposes. Results should be expressed in "milligrams of oxygen absorbed per liter of crude sewage or effluent." For purposes of comparison with other sewages, it is desirable to state the oxygen consumption in milligrams for 24 hours and 10 days. The 10-day consumption figure may either be actually determined or obtained by calculation with the factor established in the initial experiments."

The writer wishes to thank heartily all those who have coöperated in this work by actual experiment and by suggestions. On the whole, the results of the experimental work have not been very satisfying to the collaborators, including myself. Even though we did not decide on a method which promises to be of a permanent character, I feel that we shall be able at least to obtain more uniform results by establishing a standard concentration, incubation temperature and period. If all those who are interested sufficiently in this test will establish the approximate ratio of oxygen exhaustion in their sewage during a 10-day period, the results obtained in various places ought to be fairly comparable with each other.

THE SANITARY DISTRICT OF CHICAGO
39TH ST. AND LAKE FRONT

NOTES ON THE COMPOSITION OF MIDCONTINENTAL PETROLEUM¹

By F. W. BUSHONG

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The crude oil from which the products described herein were derived came from the wells of the Alluwe Oil Company in Oklahoma. It is a typical Oklahoma oil of specific gravity² 0.8513 at 15°/15°.

Although the writer is firmly convinced that a thorough series of fractional distillations begun on a factory scale and carried out to the highest limit of efficiency would richly reward the immense labor involved by opening up a new world of possibilities in the way of chemical products to be manufactured from petroleum he keenly feels his helplessness in the face of the enormity of such an undertaking. The time at his disposal permitted only a series of four distillations.

Two 8-liter portions of the crude oil were subjected to distillation from a copper retort until the temperature of the vapors reached 315° C. The distillates were collected in 10 fractions of 5 per cent each by volume. The redistillations were carried out in Jena

¹ This work was done under the J. R. Greenlees Temporary Industrial Fellowship, established under the direction of the late Dr. Robert Kennedy Duncan, in the University of Kansas, 1908.

² There was a loss of gasoline during shipment. The oil at the well is lighter.