Crawford.

Decomposition Products Of Sewage Disposal

# DECOMPOSITION PRODUCTS OF SEWAGE DISPOSAL

BY

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B. S. Wesleyan University, 1908

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THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN CHEMISTRY

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1916

# UNIVERSITY OF ILLINOIS

## THE GRADUATE SCHOOL

June 3 1916

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Frederick North Crawford

ENTITLED Decomposition Products of Sewage Disposal

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Chemistry

Edward Bartow
In Charge of Thesis

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Head of Department

Recommendation concurred in:*

| | |
|---|---|
| ........................................ | Committee on Final Examination* |
| ........................................ | |
| ........................................ | |

*Required for doctor's degree but not for master's.

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# DECOMPOSITION PRODUCTS OF SEWAGE DISPOSAL

## INTRODUCTION

Experiments by The Illinois State Water Survey in aerating sewage in the presence of activated sludge have shown remarkable results. A stable effluent has been produced which may safely be run into streams and the resulting sludge contains a high percentage of nitrogen and gives great promise as a fertilizer.

In order to gain a more complete knowledge of this process the effluent gases have been studied (1). During the fall of 1915 a similar investigation was carried on by W.D. Richardson, chief chemist Swift & Co. Chicago.* No systematic work had at that time been undertaken and only occasional analyses of the carbon-dioxide of the effluent had been made. It was considered that the increased carbon-dioxide in the effluent was due to moist combustion.

*Letter of Mr. W.D. Richardson.

## COLLECTING SAMPLES OF EFFLUENT GAS

Apparatus- The apparatus consisted of an Erlenmeyer flask (B) of 500 to 800 cc. capacity into which is inserted a two-holed rubber stopper (C). Into the holes are inserted glass tubes which extend a short distance within the bottle. A 6 inch glass funnel (A) is attached to one of these tubes by means of a flexible rubber tube (E). To the other tube is attached a flexible rubber tube (D) of somewhat greater length than the combined length of tube and funnel. This longer tube serves as the outlet of a siphon. (See next page, fig.1).

Proceedure- The Erlenmeyer flask is filled with the sewage and sludge and the stopper is inserted into the flask, both being held beneath the surface of the liquid in such a manner that the apparatus is completely filled. The flask is then raised above the liquid leaving the funnel just beneath the surface in a part of the tank where the gas bubbles are abundant. As the gas rises thru the funnel the other tube serves as an outlet for the sewage and sludge. When the liquid in the flask is all displaced the mouth is held below the surface of the liquid and the stopper is replaced by another rubber stopper having two holes plugged with short rods.

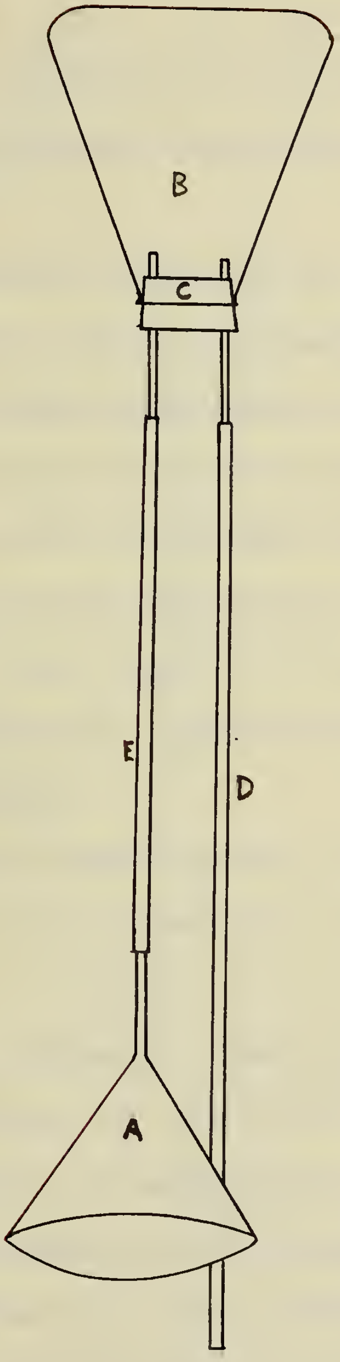
## METHODS OF ANALYSIS

### Determination of Carbon-dioxide

Carbon-dioxide is determined in the laboratory by the method Hesse (2).

Reagent:- Barium Hydroxide Solution, I.7 grams $Ba(OH)_2$ and $BaCl_2$, 20:I dissolved in one liter of distilled water and colored with phenolphthalein. The $BaCl_2$ prevents disturbance by the alkalis present.

Proceedure:- 25 cc. of the Barium hydroxide solution are added


B
C
E
D
A

to the sample of air thru one of the holes in the two holed stopper and any excess of air is released thru the other. The flask is then shaken frequently for 20 minutes to insure the absorption of the carbon-dioxide, care being taken to wash the sides of the flask and stopper.

The excess Ba(OH)2 remaining after absorbing the carbon-dioxide is titrated by means of standard oxalic acid, 0.56325 grams to the liter.

The figure thus obtained deducted from the amount of oxalic acid required to neutralize 25 cc. of the Barium hydroxide solution when titrated in the same way with oxalic acid in a I00 cc. flask without excess of air gives the amount absorbed by the CO2.

If we represent by <u>n</u> the difference between the number of cc. of the solution of oxalic acid required to neutralize the excess of Ba(OH)2 and the number of cc. required to neutralize 25 cc. of Ba(OH)2 the amount of CO2 in the sample may be calculated by means of the following proportion:

n/I0: vol. of the air sample taken :: X : I0000. X represents parts of CO2 per I0000 of air. Each cc. barium solution equals 0.I cc. of CO2.

Discussion of Other Methods- Dennis (3) considers the Hesse Method for CO2 determination (4) one of the most accurate tho he does not mention the degree of accuracy of which it is capable. He says that the method of Petersson and Palmquist (5) is accurate to one part in I0000. It has the further advantage of being self compensating but it has the disadvantage of requiring heavy apparatus not easily handled and with parts not easily replaced when broken. There appears to be little to choose in the way of accuracy between the two methods. The method of Hesse has the advantage of speed

and simplicity.

### Determination of Oxygen

The Oxygen was determined in the sample of gas in which the $CO_2$ had been determined. The sample flask was connected to a measuring burette and a quantity of gas removed by suction and measured(6). The Oxygen was determined by absorption with alkaline pyrogallol in a Hempel double absorption pipette for liquid reagents. Measurements were made over water in an unjacketed Winkler burette. The oxygen determinations were accurate to 0.2% to 0.3%. As the comparative determinations occupied but five or six minutes, corrections for temperature and barometric pressure were omitted.

Discussion of Other Methods- Methods for oxygen(7) other than the alkaline pyrogallol method might have been used but with no greater accuracy. Some of these methods involve the use of phosphorus and so are objectionable. Metallic copper or sodium hyposulphite ($Na_2S_2O_4$) would have been as satisfactory but the apparatus for the alkaline pyrogallol method is simple and the pyrogallol has good absorbing power for oxygen at the temperature at which the determinations were made, 20° to 25°.

Thruout the experiments the alkaline pyrogallol method when checked against the normal atmospheric oxygen content gave consistent results.

## EXPERIMENTS

The air used in aerating the sludge was drawn from the university compressed air supply. Numerous analysis showed its composition to be normal, containing 4.3 parts of $CO_2$ per 10000 and 20.5 percent oxygen.

### Aeration of Sludge

During December 1915 while no fresh sewage was added to the

activated sludge tanks the aeration of the old sewage was continued and at various times samples of gas were collected and the CO2 determined.

The following results are from Tank D and are in parts per 10000 per vol. but were collected at no regular intervals.

Table I.

Carbon-dioxide from Old Sludge.

| | | | | | | |
|---|---|---|---|---|---|---|
| Dec. 11 | 24.36 | | | | | |
| Dec. 13 | 17.91 | 20.18 | 21.81 | | | |
| Dec. 14 | 10.45 | 11.59 | 4.90 | 10.36 | | |
| Dec. 15 | 7.77 | 4.87 | 7.09 | 11.9 | | |
| Dec. 17 | 5.74 | 8.00 | 12.29 | | | |
| Dec. 18 | 11.3 | 15.2 | 9.00 | 14. | 12.2 | 11.8 |

There is no regularity in these results except that without exception the content of CO2 is above that normally in the atmosphere. The method of collection during this series was faulty. A flask of water was inverted in the air above the sludge when the water was replaced by air a stopper was inserted. The figures showed that some action is taking place which produces CO2 and warranted the use of a better collecting apparatus and a continuation of the experiments.

## AERATION OF SEWAGE AND SLUDGE

In January 1916, the regular schedule of aeration was resumed. Each aeration period was of five hours duration followed by a half hour sedimentation period. After this, during another half hour, the tanks were drained and refilled. Four complete aeration cycles could be made in 24 hours. The compressed air was generally turned on during 8 minutes while the tanks were being filled so that the aeration was in progress a little more than 5 hours of each cycle.

The air was measured by a common gas meter.

When a collection of air was to be made, the air was not turned on until the tank was full, so that the first bubbles could be caught. Collections were made during the aeration period from I0:00 A.M. to 3:00 P.M. and 6 hourly samples were secured for each aeration period.

Table 2- Carbon-dioxide Content of Effluent Air from January 6 to March I3, I9I6.

| | Carbon-dioxide in parts per I0000. | | | | | | Air Flow | Temp.C° |
|---|---|---|---|---|---|---|---|---|
| Date. | Start. | IHour. | 2Hours. | 3Hours. | 4Hours. | 5Hours. | in cu.ft. | Sewage. |
| Jan.6 | I4.2 | ---- | ---- | ---- | ---- | 8.7 | I6I | I6.I |
| " 7 | I9.7 | ---- | ---- | ---- | ---- | 20.8 | 82 | I2.5 |
| " 8 | 39.8 | ---- | 38.2 | ---- | ---- | ---- | 65 | I2.5 |
| " I0 | ---- | 32.4 | 30.8 | 38.4 | 40.0 | 45.6 | 240 | I5 |
| " I2 | 4I.2 | 33.0 | ---- | 44.2 | 36.8 | 50.6 | 89 | I3 |
| " I3 | 32.2 | 29.2 | 37.2 | 38.0 | ---- | ---- | I60 | I0.0 |
| " I7 | 25.8 | ---- | 29.8 | 27.2 | 20.6 | 2I.6 | I26 | 8.0 |
| " I8 | I9.6 | ---- | ---- | ---- | ---- | 32.4 | ---- | 8.0 |
| " I9 | 2I.4 | ---- | 29.4 | 23.6 | 28.0 | 28.8 | 2I2 | I0.0 |
| " 20 | 35.2 | 4I.6 | 45.0 | ---- | ---- | 4I.0 | I30 | I2.5 |
| " 22 | 52.8 | 33.2 | 46.0 | 43.0 | 48.0 | ---- | I76 | I2 |
| " 24 | ---- | 4I.2 | 33.0 | 44.0 | 38.6 | 36.6 | 222 | I2 |
| " 26 | ---- | 3I.6 | 42.8 | ---- | 56.2 | 5I.0 | I27 | I3.2 |
| " 29 | 43.6 | ---- | ---- | ---- | ---- | ---- | 8I | ---- |
| Feb.I | ---- | ---- | ---- | 38;I | 34.5 | 33.6 | --- | II.0 |
| " 3 | 42.6 | 39.5 | 40.8 | 40.7 | 4I.6 | 4I.9 | --- | II.0 |
| " 4 | 37.I | 36.6 | 33.9 | 37.I | 38.8 | 37.6 | --- | I2 |
| " 8 | 4I.3 | 38.3 | 37.0 | 38.3 | 43.5 | 42.2 | --- | II.0 |
| " 9 | 47.8 | 45.7 | 42.4 | 47.7 | ---- | ---- | --- | II.5 |

|  | Carbon-dioxide in parts per IOOOO. |  |  |  |  |  | Air Flow | Temp.C° |
|---|---|---|---|---|---|---|---|---|
| Date. | Start. | IHour. | 2Hours. | 3Hours. | 4Hours. | 5Hours. | in cu.ft. | Sewage. |
| Feb.IO | 45.4 | 45.4 | 46.3 | 49.4 | 50.7 | ---- | ---- | II.5 |
| " II | 35.I | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Mar. 6 | 30.6 | 31.8 | 33.3 | 32.2 | 30.0 | 30.3 | I24 | ---- |
| " I3 | 28.8 | 28.6 | 27.5 | 28.8 | 39.5 | 28.0 | II6 | ---- |
| Average- | 39.67 | 37.5 | 36.4I | 38.02 | 38.94 | 39.42 |  |  |

The average flow of air into 400 gal. sewage was I87 cu.ft. per hour at atm. pressure.

Discussion of Aeration Data:- During an aeration period when the tank was filled with sewage and no sludge the CO2 was highest at the beginning, dropping from I4.2 to 8.6 parts per IOOOO. (See Jan. 6). The second day after the sludge had begun to build up the CO2 at the beginning and end were substantially the same, I9.7 and 20.8 parts per IOOOO. (See Jan. 7).

In each aeration period there is usually an initial drop in the effluent CO2. Following this decline there is usually a marked increase, tho the final amounts are not always the highest. (See Jan. 24 and 26 and Feb. I and 4).

An occasional analysis showed an increase from the beginning. (See Mar. IO).

The rate of air flow has little or no relation to the amount of CO2 in the effluent air. On Jan. IO, with an air flow of 240 cu. ft. per hour, 45.6 parts of CO2 per IOOOO were obtained, on Feb. I2 with an inflow of but 89 cu. ft. per hour, 50.6 parts per IOOOO were obtained.

When the effluent CO2 had increased to 30 or more parts per IOOOO the oxygen was I.0 to I.2% lower in the effluent air than in the inflowing air. The effluent air contained from I9.2% to I9.9%.

of oxygen, thus about 5% of the oxygen was removed during its passage thru the tank.

## SOURCE OF CARBON-DIOXIDE

The increase of carbon-dioxide probably could not come by simple oxidation of carbonaceous matter alone without bacterial action. On the supposition that some of the carbon-dioxide might be obtained from solution in the sewage, tap water and sewage were aerated without sludge under the same conditions under which sewage and sludge were.

Aeration of Tap Water- A tank was filled with tap water, aerated, and samples taken each half hour for a period of 5 hours. The temperature remained constant thruout the period.

The CO2 in the effluent was secured and determined each half hour, and the oxygen determined hourly until it became constant. (See Table 3). Dissolved CO2 (6), methyl orange (7) and phenolphthalein alkalinity were determined hourly in accordance with the standard methods of Water Analysis. All observations were begun as soon after the beginning of aeration as possible. Hourly readings of the inflowing air were also taken and for the sake of comparison reduced to atmospheric pressure.

Table 3- Composition of the Effluent Air from Tap Water during Aeration,

Feb. 25, I9I6.

| Hours. | Dis. CO2. | Phe. Alk. | M. O. Alk. | Efflu. CO2. | Oxygen |
|---|---|---|---|---|---|
| 0 | 25 | 0 | 355 | 27.0 | 20.0% |
| I/2 | | | | 2I.I | |
| I | I4 | 0 | 352 | II.I | |
| I I/2 | | | | I0.8 | |
| 2 | 5.5 | 0 | 350 | I2.2 | 20.65% |
| 2 I/2 | | | | I0.0 | |
| 3 | 0 | I3 | 342 | 6.7 | |
| 3 I/2 | | | | 7.9 | |
| 4 | 0 | 33 | 3I9 | 7.0 | 20.6% |
| 4 I/2 | | | | ---- | |
| 5 | 0 | 32 | 322 | 4.I | 20.6% |

At the end of two hours the oxygen content of the air was normal.

Air in cubic ft. at atm. press.

| I hr. | 2 hr. | 3 hr. | 4 hr. | 5 hr. |
|---|---|---|---|---|
| I87 | 268 | 240 | 240 | 228, III2 cu. ft. total |

The temperature at the beginning and end was I5 degrees Cent.

On March 20 the above experiment was repeated and the same observations were made with similar results. Dissolved carbon-dioxide fell from I8.5 parts per million at the start to 0 in two and one-half hours.

Phenolphthalein alkalinity appeared in 2 I/2 hours at 8 parts per million and increased to 26 parts per million. The methyl orange alkalinity remained constant at about 360 parts per million. The carbon-dioxide in the effluent fell from 30.I parts per million to 9.0 parts per million. The oxygen increased from I9% to 20.6% at the end of 2 I/2 hrs., there was a total air flow of 629 cu. ft. at atmospheric pressure and the temperature remained constant at I4 C.

On March 27, I9I6 tap water was again aerated, the same observations made and similar results obtained. The dissolved carbon-dioxide fell from 25 parts per million to 0 in 2 I/2 hrs. At the

start the phenolphthalein alkalinity was 0. After the blowing had been in progress 2 I/2 hours 3 parts per million of phenolphthalein alkalinity appeared and it increased till 26 parts per million were reached at the end of aeration; the total alkalinity remained constant at about 350 parts per million.

During this aeration period three determinations of effluent carbon-dioxide were made on samples collected fifteen minutes apart, instead of each half hour. There was a slight increase in the carbon-dioxide at first, but there was a decrease half an hour after the blowing began, starting at 33.I parts per million the effluent carbon-dioxide rose to 35.6 parts per million. It then fell, tho not regularly to I0.8 parts per million. The effluent carbon-dioxide at the start was I9.0%. At the end of 3 I/2 hours it had increased to 20.6%. The temperature remained nearly constant thruout the aeration, increasing from I5 to I5.5°C. A total of 594 cu. ft. of air was used in the aeration, the pressure being atmospheric.

There was no change in the phenolphthalein or methyl orange alkalinity after the 5 hour aeration period under various conditions of continued aeration or rest even over a period of more than 24 hrs.

Summary- In the three experiments with tap water, the general average of dissolved carbon-dioxide at the start was 22.8 parts per million, at the end of one hour I4.I, at the end of two hours 6.4 parts per million, and then 0. When dissolved carbon-dioxide disappeared, alkalinity to phenolphthalein was at once evident,and it slowly increased to 26 to 32 parts per million at the end of the 5 hour aeration periods. The total alkalinity remained nearly constant at about 350 parts per million. The effluent carbon-dioxide averaged 30 parts per I0000 and fell steadily thruout aeration, tho in but one experiment did it fall to the amount normally in the

atmosphere. The oxygen content of the effluent air at the start of aeration was 19.6%, but before the end of aeration it had risen to 20.6%, the amount normally in the atmosphere. The low oxygen at the start was probably due to the use of a drift well water containing iron.

### Source of Carbon-Dioxide in the Effluent

The effluent carbon-dioxide is nearly equivalent to the dissolved carbon-dioxide for from the average carbon-dioxide in the effluent air and the volume of the air used the net weight of the effluent carbon-dioxide was 46 to 51 grams, and from the dissolved carbon-dioxide and the capacity of the tank, the weight of the carbon-dioxide originally in the water was 43 to 56 grams.

### Weight of Carbon-Dioxide in the Effluent

1112 cu. ft. of air were blown thru the tank in one experiment, this amount multiplied by 28.3 (liters per cu. ft.), gave 31469.6 liters. This amount multiplied by 11.81, the average parts per 10000 of carbon-dioxide in the effluent air,and divided by 10000, gave liters of carbon-dioxide (37.165), which in turn multiplied by 1.9652 grams, wt. of a liter of carbon-dioxide, gave the total grams of carbon-dioxide blown out. From this weight was deducted the weight of the carbon-dioxide normally in the inflowing air. This was obtained by multiplying the liters of inflowing air 31469.6 liters by the normal carbon-dioxide content of the air, 4.3, this amount divided by 10000 gave 13.53 liters of carbon-dioxide, or 26.588 grams. The difference was the net weight of the effluent carbon-dioxide.

### The Weight of the Dissolved Carbon-Dioxide

The capacity of the tank in liters, 2271, was multiplied by the parts per million of dissolved carbon-dioxide originally in the

water.(25). This amount divided by 1000 gives the weight in grams of the dissolved carbon-dioxide.

### Carbon-Dioxide formed by Bacterial Action

In order to determine the amount of carbon-dioxide formed by bacterial action fresh sewage was aerated under various conditions. When fresh sewage was added to a tank that had been in operation one week (see table 4), 125 grams of carbon-dioxide were blown out during the aeration period. The dissolved carbon-dioxide was 43 grams, leaving 82 grams of carbon-dioxide formed by bacterial action.

Table 4- Aeration of Sewage After Tanks Had Been in Operation One Week, March 6, 1916.

| | Start. | 1 hr. | 2 hrs. | 3 hrs. | 4 hrs. | 5 hrs. |
|---|---|---|---|---|---|---|
| CO2 blown out | 30.6 | 31.6 | 33.5 | 32.2 | 30.0 | 30.3 |
| Dis. CO2 ppm. | 12. | 22. | 23.5 | 21 | 14 | 14 |
| M.O. alk. " | 380 | 383 | 380 | 380 | 379 | 378 |
| Phe. " " | 0 | 0 | 0 | 0 | 0 | 0 |
| % eff. O | 194 | 19.2 | 19.4 | 19.4 | 19.5 | 19.7 |
| Temp. | 12 C. | | | | | 12.5 C |
| Air used | 830 cu. ft. at atmospheric pressure. | | | | | |

Similarly when sewage was added to a tank that had been in operation 4 days results comparable in every way with those obtained after a weeks operation were obtained.

A comparison was made of the carbon-dioxide obtained from sewage aerated with and without sludge, see table 5. One tank (C) was filled with fresh raw sewage while another tank (B) was filled with fresh sewage and activated sludge.

Table 5- Comparison of results obtained by aerating sewage with and without sludge Feb. 28, 1916.

Without Sludge

| | Start. | I hr. | 2 hrs. | 3 hrs. | 4 hrs. | 5 hrs. | |
|---|---|---|---|---|---|---|---|
| Dis. CO2 | I0.0 | 7.5 | 0 | 0 | 0 | 0 | ppm. |
| Phe. Alk. | 0 | 0 | I2 | 25 | 28 | 25 | " |
| M.O. Alk. | 440 | 440 | 432 | 425 | 4I2 | 4I2 | " |
| Eff. CO2 | xxx | 6.6 | 8.I | 23.8 | 2I.7 | 25.2 | ppI0000 |
| % eff. O | ---- | ---- | 20.0 | I9.9 | I9.7 | I9.7 | |

With Sludge

| | Start. | I hr. | 2 hrs. | 3 hrs. | 4 hrs. | 5 hrs. | ppm. |
|---|---|---|---|---|---|---|---|
| Dis.CO2 | 7.0 | 4.5 | 4.5 | 7.0 | 8.0 | 35 | " |
| Phe. alk. | 0 | 0 | 0 | 0 | 0 | 0 | " |
| M.O. alk. | 398 | 394 | --- | 390 | 39I | 400 | " |
| Eff. CO2 | I9.I | 26.8 | 33.6 | 3I | 42 | 66.8 | pp10000 |
| % eff. O | I9.5 | ---- | I9.4 | I9.5 | I9.4 | I9.2 | |

When sewage was aerated in the presence of the activated sludge the highest carbon-dioxide and the lowest oxygen recorded were obtained. The carbon-dioxide increased as the oxygen decreased.

The two parts of table 5 compared

1, Without sludge the dissolved carbon-dioxide disappears at the same time that it did in aerating tap water while in the presence of activated sludge it increased from beginning to end.

2, In the absence of activated sludge the phenolphthalein alkalinity did not appear until the blowing had been in progress some time as was the case with tap water. In the presence of activated sludge there was no phenolphthalein alkalinity at all. Methyl orange alkalinity, effluent carbon-dioxide and % effluent oxygen in both cases are comparable. The aeration was continued 24 hours after the regular 5 hour aeration period was over. Where no activ-

ated sludge was present the phenolphthalein alkalinity fell to 2 ppm. and the methyl orange alkalinity fell to 325 ppm. In the presence of activated sludge dissolved carbon-dioxide fell to 4.5 ppm., but the methyl orange alkalinity remained constant.

The phenolphthalein alkalinity observed in the tanks, results from the breaking down of the acid carbonates in the water. According to titrations in the experiments the reduction of the half bound carbon-dioxide varied from 52 to 64 grams. This gas according to the Law of Henry, (8) is not expelled from the solution because the inflowing air contains carbon-dioxide. The acid carbonates break up according to the equation $Ca(HCO)3 = CaCO3+CO2+HO2$, and its weight is obtained according to the following proportion- (Molecular Weight of CaCO3), 100: (Molecular Weight of CO2), 44 :: 2 x maximum of recorded phenolphthalein alkalinity: X where X equals milligrams per liter of carbon-dioxide. The number of milligrams per liter, multiplied by the number of liters in the tank, and divided by 1000, gives the number of grams carbon-dioxide that would result from the breaking up of the acid carbonates.

To ascertain whether acid carbonates could be broken up by aeration a known amount of pure sodium acid carbonate was dissolved in carbon-dioxide free water, and carbon-dioxide free air was drawn thru the solution, then thru barium hydroxide-barium-cloride solution which absorbed the carbon-dioxide.

After drawing carbon-dioxide free air thru the solution for more than six hours the phenolphthalein alkalinity had increased from 4 to 14 parts per million from which it was calculated that 7.9 grams carbon-dioxide had been liberated by the decomposition of the acid carbonates. Titration of the barium hydroxide solution showed that 6.4 grams of carbon-dioxide had been absorbed. The

difference was probably due to having insufficient depth of barium hydroxide solution to absorb all the effluent carbon-dioxide.

The rate of production of carbon-dioxide by bacteria is equal to the total carbon-dioxide produced less the free carbon-dioxide driven out of the sewage. The average hourly air flow was 188 cubic feet per hour at atmospheric pressure, see table 3, this multiplied by 28.3, liters per cubic foot, gives 5320.4 liters per hr. The average of carbon-dioxide in parts per 10000 for each hour, at the start, 39.87, multiplied by 5320.4 and divided by 10000 gives the liters of carbon-dioxide in the effluent at the start 21.2. The rate for other times has been obtained in the same way.

If the amount of carbon-dioxide in the effluent at the start, 21.2 liters, be divided by 60 and multiplied by 1.9652 grams, weight of one liter of carbon-dioxide, 687.22 milligrams, is the rate of production of carbon-dioxide at the start of aeration.

The dissolved carbon-dioxide in tap water averaged 22.8 parts per million at the start of aeration, which multiplied by the capacity of the tank, 2271 liters, and divided by 10000 gives carbon-dioxide, 51.77 grams, as the amount of dissolved carbon-dioxide expelled at the start. Since no carbon-dioxide is added during aeration and since the dissolved carbon-dioxide was expelled in two and one half hours the weight of carbon-dioxide at any time, as 51.77 grams at the start, divided by 150 gives 345 milligrams as the rate at which the dissolved carbon dioxide is expelled at the start.

The carbon-dioxide in the inflowing air passes thru the tank at a constant rate containing .43 parts per 10000 of carbon-dioxide which multiplied by the rate of air flow, 5320.4 liters per hour divided by 1000 gives 2.287 liters of carbon-dioxide, or 4.4 grams

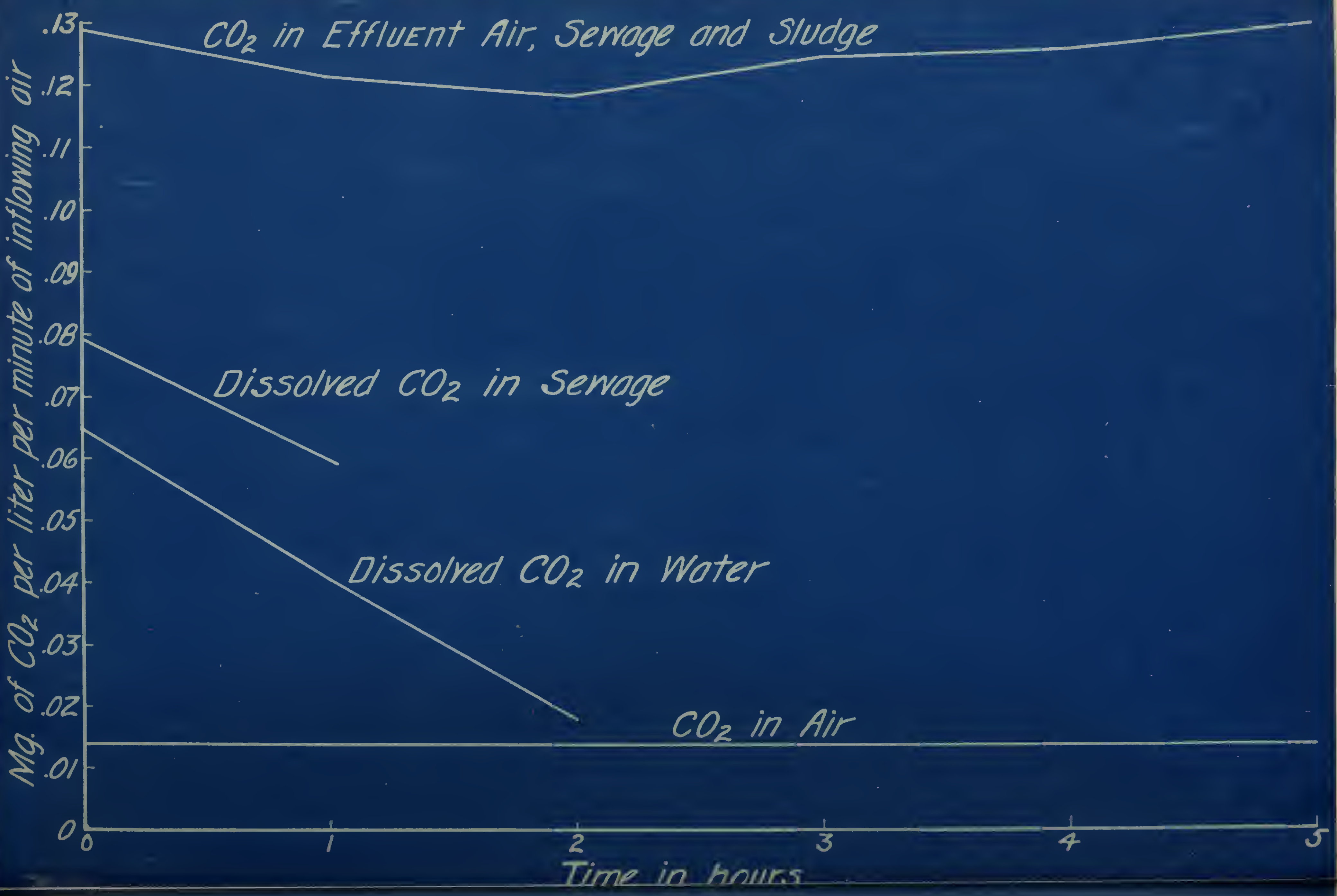
which divided by 60 gives 75 milligrams per minute as the rate at which the carbon-dioxide in the inflowing air is expelled.

When the rates of production of carbon-dioxide due to expulsion of half bound carbon-dioxide and rate of flow of the inflowing air be deducted from the total rate,the rate of production of carbon-dioxide at the start was 267.22 milligrams. The rate for other points in the aeration period was obtained in the same way.

When sewage was used in place of tap water, see fig., page ( 19 ), 378 milligrams of dissolved carbon-dioxide were obtained at the start.

To make the carbon-dioxide from the different sources comparable it was all calculated to the same standard,- milligrams of carbon-dioxide per minute per liter of inflowing air, by dividing the amounts of carbon-dioxide from the various sources for any particular point in the aeration period by the rate of air flow in liters.

When the carbon-dioxide in the effluent air, and in the sewage was calculated to milligrams of carbon-dioxide per minute per liter of inflowing air it was found that the effluent carbon-dioxide decreased, then increased during aeration, see fig., page ( 19 ). The drop in the amount of effluent carbon-dioxide early in the aeration periods was due to the expulsion of the half bound carbon-dioxide which decreases rapidly as aeration proceeds. If the carbon-dioxide from solution is deducted from the total, leaving the carbon-dioxide due to bacterial action, the amount of carbon-dioxide increases during the whole aeration period. The carbon-dioxide in the inflowing air remained constant thruout aeration, and is neglected.


Mg. of $CO_2$ per liter per minute of inflowing air
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
0
1
2
3
4
5
Time in hours
$CO_2$ in Effluent Air, Sewage and Sludge
Dissolved $CO_2$ in Sewage
Dissolved $CO_2$ in Water
$CO_2$ in Air

## CONCLUSIONS

The effluent carbon-dioxide comes from the carbon-dioxide dissolved in the water and from the effluent carbon-dioxide resulting from bacterial action. The later amounts to 2/3 of the total carbon-dioxide.

Raw sewage aerated in the presence of activated sludge during the first aeration period gives off carbon-dioxide just as tap water does. Carbon-dioxide disappears from the effluent, and phenolphthalein alkalinity appears.

As soon as the sludge begins to build up the character of the effluent gas changes, for sewage is then being aerated in the presence of activated sludge.

Five percent of the oxygen in the inflowing air is consumed in passing thru the tank, this decrease in oxygen is due to oxidation of organic matter in the sewage and is probably due to bacterial action.

Acid carbonates in the water in the sewage are broken up by aeration but as already explained this carbon-dioxide does not appear in the effluent air.

In conclusion I want to express my appreciation of Prof. Bartow's kind advice and assistance in outlining and supervising this work. My thanks are due to Mr. Mohlman of the Ill. State Water Survey whose knowledge of Activated Sludge was of value to me and to the other members of the Ill. State Water Survey, and to Dr. Broderson of the Dept. of Ind. Chemistry of the University of Illinois for his advise as to the methods of gas analysis, and to Prof. Washburn of the University of Illinois for his explanation of the phenolphthalein alkalinity in tap water.

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