THE REDUCTION OF MANGANESE IN RESERVOIRS BY THE GASEOUS BY-PRODUCTS OF ANAEROBIC BACTERIAL ACTIVITY

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SUMMARY

The problem of manganese in water has become increasingly important to the waterworks industry because it is a by-product of many of the large flood control and power developments that have been built in recent years. Manganese may dissolve in the lower layers of reservoirs during the period of the year that an anaerobic condition exists. Water used for power is commonly drawn from these layers and released into the river. Such water is objectionable to the consumer because the soluble manganese will form a dark brown precipitate when oxidized. The brown precipitate stains plumbing, stains laundry, causes colored water, and interferes with industrial processes. Water plant removal of manganese is possible, but is difficult, expensive and often uncertain.

The exact mechanism of solution of manganese in the hypolimnion of lakes is unknown. This phenomenon has been studied by many fields of science with the result that several theories have been established. Experiments by biochemists have shown that manganese can be used as a terminal hydrogen acceptor in biological systems and is reduced to manganous form as a result. Several sanitary engineers are of the opinion that the solution of manganese is due primarily to the action of carbon dioxide and organic acids found on the floor of a reservoir as a result of biological activity.

Limnologists have attributed pH the primary role in manganese solution.

The objective of the present study was to determine if manganese could be reduced by sludge gas, independent of the sludge itself. Sludge was chosen because it produces gases of the same composition as are evolved from decaying organic matter in lake beds. The experiment was designed to show whether these gases were a possible cause of manganese solution. Since other experimenters believe the reduction of manganese to be part of biological systems, this variable was eliminated by isolating the sludge from the manganese.

The experimental setup consisted of a digester connected to a diffusion tube containing water and reagent grade manganese dioxide. The diffusion tube was connected to a calibrated tube which measured gas by water displacement. In addition to gas, manganese and pH of the water were measured periodically. Controls using nitrogen, carbon dioxide and air were used.

Results indicate manganese is readily reduced either by sludge gas or pure carbon dioxide. The theoretical explanation of the reaction is not clear at the present time. No manganese was reduced even at artificially lowered pH by nitrogen or air. The results cannot be directly applied to lakes because a number of variables exist.

Further study is needed to determine the mechanics of the reduction of manganese by carbon dioxide, and to

eliminate some of the variables in this experiment. Results indicate, however, that carbon dioxide as a bacterial by-product may be a primary agent in the reduction of manganese under anaerobic conditions in lakes.

CHAPTER I

INTRODUCTION

The purpose of a water system is to provide consumers with a product which will meet their requirements. Consumers of water from a municipal water supply require a product which is potable, palatable, and free from annoying mineral content. Industrial water consumers may not necessarily require a potable water; however, such users do require a product which is free from mineral substances which will interfere with their processes. Therefore, high concentrations of calcium and magnesium, and low concentrations of iron and manganese, when present in municipal and industrial water supplies are commonly removed.

Interest is directed toward the problem of manganese because the presence of manganese in waters in this area is becoming more prevalent (1). Manganese is one of the more objectionable elements commonly found in water and is one of the more difficult to successfully remove. Manganese is objectionable because, when oxidized, it forms a dark brown precipitate which imparts color to water, stains fixtures and stains laundry (2). It will impair industrial processes, particularly in textile bleaching, dyeing and finishing operations, and in the production of medium and high grade paper (3). The United States Public Health Service (4) recommends a combined maximum limit of 0.3 parts per million of iron and manganese in water to be used for interstate commerce.

Recent advances in the water works industry such as prechlorination (2) and the use of copper sulphate as a catalyst (3) have simplified the removal of manganese from water. However, the removal process is expensive and requires careful operation. Furthermore, the occurrence of manganese in a water supply is seasonal, unexpected and may appear at a different time each year, depending on weather conditions of the preceding winter (5).[1]

Manganese is most prevalent and can be expected seasonally in water supplies obtained down stream from large hydro-electric developments located in crystaline rock areas (6) where soils contain manganese dioxide. The presence of soluble manganese in the hypolimnion is due to reduction of manganese dioxide in the soils to divalent manganese (1). This always occurs during the warmer months of the year when the hypolimnion is anaerobic. Anaerobisis is due to the action of bacteria on organic debris when the reservoir is in a stratified condition (1). As the ambient temperature decreases in the fall of the year the epilimnion of the reservoir becomes cooler and denser than the hypolimnion, and the reservoir "turns over" (6), thus re-oxygenation of the lower levels is accomplished and the entire reservoir

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[1] Excerpts given in Appendix

becomes aerobic. There is another reservoir "turn over" in the spring due either to the melting of ice or wind action on the unstratified reservoir. The "turn over" is not as pronounced in Southern climates, and density currents from inflowing water may disturb the hypolimnion in some cases (7). Anaerobisis and the resultant reduction of manganese does not occur in the winter because of fall re-oxygenation of the reservoir, and low water temperatures which inhibit biological activity.

The mechanism of the reduction of manganese dioxide has been studied by engineers, limnologists, biochemists, agronomists and others. The results of these studies advance several theories of manganese reduction. Quastel (8, 9) shows that such organic by-products of bacteria as cystiene may reduce manganese dioxide to form manganese oxide. Manganese oxide, an insoluble compound, will then react with carbon dioxide to form soluble manganous carbonate. Quastel further shows that manganese dioxide may be used as a terminal hydrogen acceptor by anaerobic bacteria. This experimental work was conducted in the Warburg apparatus using an atmosphere of 93 per cent nitrogen and 7 per cent carbon dioxide. The amount of manganous carbonate produced was then measured by the carbon dioxide uptake. It is assumed that Quastel also analyzed the solution for soluble manganese. In this work the rate of carbon dioxide uptake was primarily used to measure the rate of manganese dioxide reduction. Ingols (1) agrees that manganese dioxide may be used as a hydrogen acceptor by bacteria. He has developed tables showing that, under anaerobic conditions, bacteria may utilize manganese dioxide as a hydrogen acceptor to greater advantage than sulphates and to a lesser advantage than nitrates. Ingols, however, indicates that the insolubility of manganese dioxide may make it unavailable to bacteria. Yoshimura (10) reached a similar conclusion. Murata (11) describes the reduction of manganese as due to the lowered oxidation-reduction potential induced by anaerobic bacteria. Wilcomb (12) and Purcell (13) indicate from observations of various lakes which contained manganese, that carbon dioxide, a by-product of bacterial respiration, is an important factor in the reduction of manganese dioxide. Purcell believes that organic acids may also have an effect on this reaction. Einsele (14) in studies of eutrophic lakes, advances the theory that the reduction of manganese is primarily dependent upon pH. He also gives data indicating that hydrogen sulphide has no importance in the reduction of manganese dioxide except as it affects pH. Tanaka (15), Goldschmidt (16) and Sherman (17) are also of the opinion that pH of the solution is an important factor in the manganese cycle.

If the exact mechanism of manganese reduction were known it might enable water works engineers to predict the occurrence of manganese or to inhibit its reduction in reservoirs.

A study of the mechanism of manganese reduction in reservoirs is complex and contains many variables. This study is an attempt to isolate a system of these variables, and to investigate their effect on manganese reduction. Previous studies by others (8, 9, 12, 13) indicated that carbon dioxide is important in the manganous-manganic cycle. Observations have shown (10) that the reduction of manganese in reservoirs occurs under anaerobic conditions. It may be therefore, that the carbon dioxide present under anaerobic conditions in reservoirs is produced by anaerobic bacterial activity. Some investigators believe that the reduction of manganese is part of a biological system.

The effects of the gaseous by-products of anaerobic bacterial activity on the manganese concentration in water were to be studied in this experiment. It was necessary to isolate these gaseous by-products from the producing medium since the producing medium itself might have an effect on the manganese concentration.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

The effect of the gases of sludge digestion on the soluble manganese concentration in water was to be determined in this investigation. Measurement of soluble manganese, pH and amount of gas used was necessary in order to evaluate the effects of the gases.

The apparatus used for an individual sample is diagramed in Figure 1. A two liter bottle (a) containing a mixture of digested sewage sludge and proteose peptone was used as a gas source. Controls using compressed carbon dioxide, nitrogen, and air were used. The gas was passed through connecting tubing, through a diffuser (b) into the sample (c). The excess gas went into a calibrated collection tube (d).

Before each run the collection tube, a one-liter tube about three feet long, was filled with water containing green dye to indicate cross connections. The water remained in the tube until it was displaced by gas. Water was kept in the tube by surface tension on the outlet tube (e). This tube was small enough to resist the hydrostatic pressure in the tube by surface tension.

Corrections could be made for pressure in the tube and for vapor pressure of the water to establish the volume of

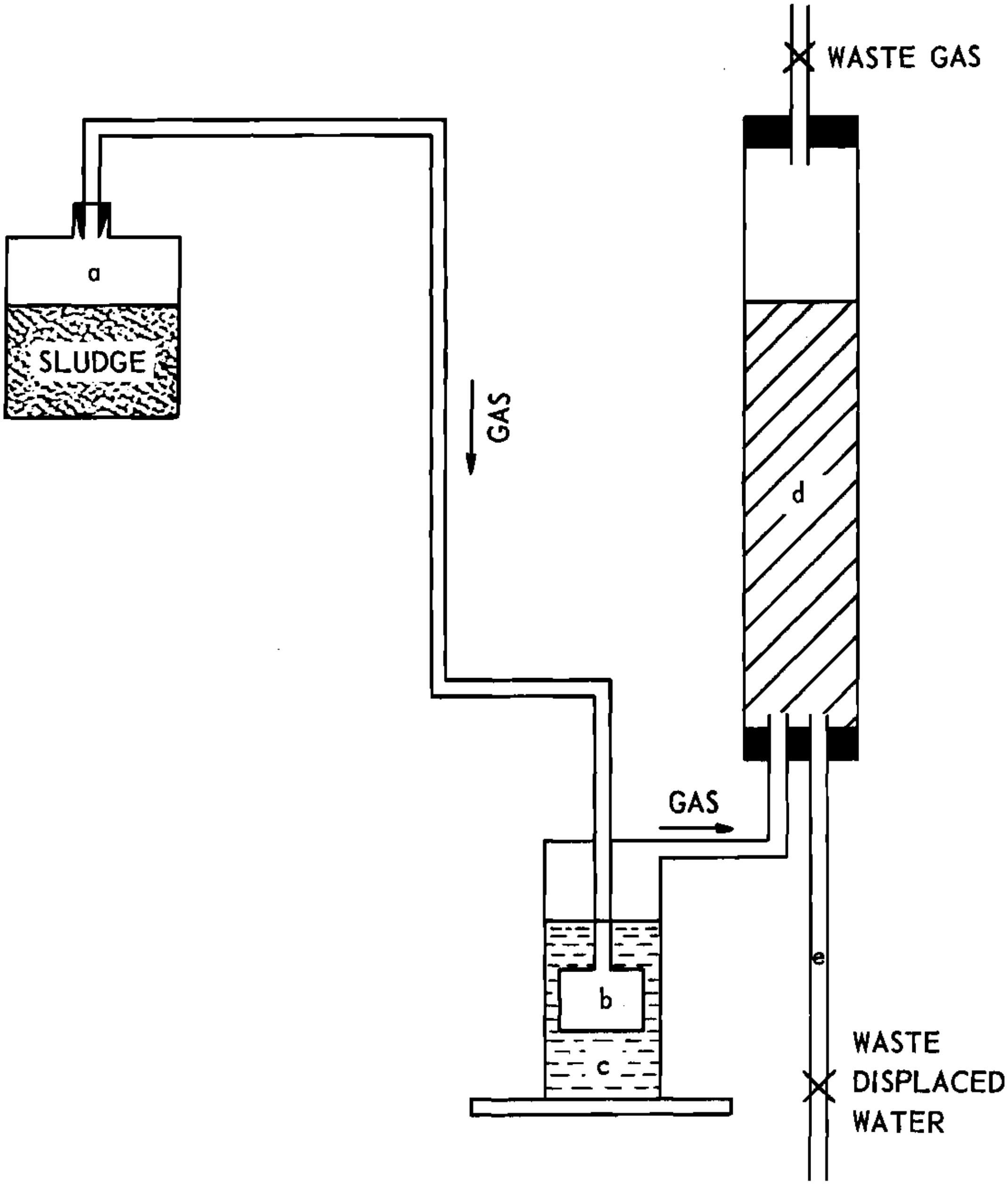

Figure 1. Diagram of Apparatus.

gas at standard or other conditions.

The diffuser assembly (b) and sample container were of glass with ground glass connections so the diffuser assembly could be removed for cleaning or sampling. The gas diffuser was of fritted glass.

CHAPTER III

PROCEDURE

The experimentation consisted of measuring daily the manganese content of a sample of water through which gas had been passed. The quantity of gas and the pH of the sample were measured as supplementary data.

Manganese was determined by the persulphate method. The determination was done with the reagents specified in Standard Methods for the Examination of Water and Sewage, Tenth Edition (18). The only departure from the procedure was that only three standards were used. Each of the samples and each of the standards were compared colorimetrically. A Lumetron, a device which measures the depth of color electronically, was used. The Lumetron was model 450 manufactured by the Photovolt Corporation, New York City. The optical densities of the solutions were measured by the Lumetron and a calibration curve (Figure 2) was prepared by plotting optical density against concentration of known standards. The curve was then used to determine the manganese concentration in the samples. Standards of 0.25, 0.50 and 1.0 ppm were used. The average content of manganese in the samples was 0.50 ppm with a maximum of 1.0 ppm.

The quantity of gas was measured by visual observation. pH was measured by a Beckman glass electrode pH meter model

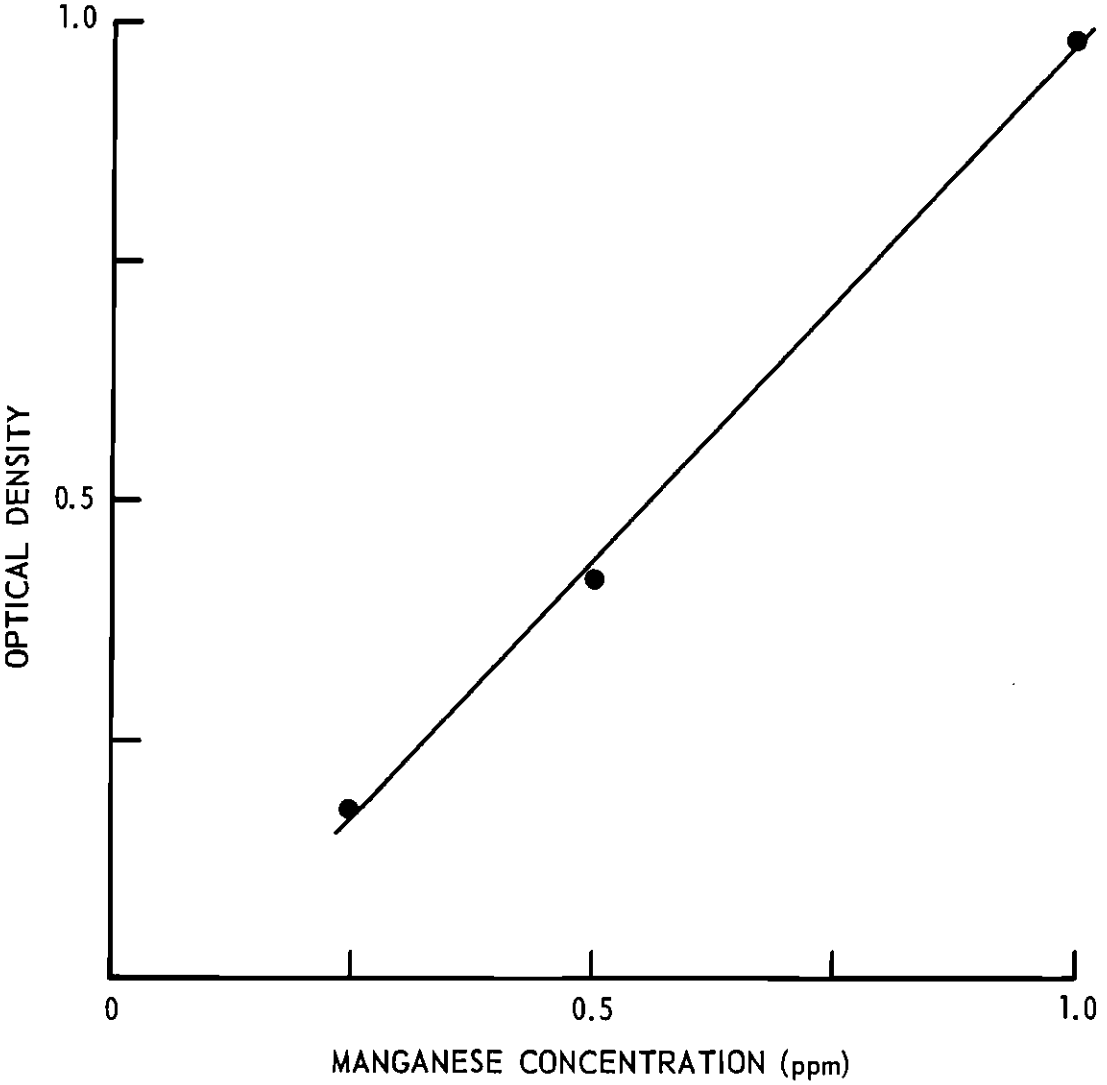

Figure 2. A Typical Calibration Curve.

H-2 manufactured by Beckman Instruments, Inc., Fullerton, California. The pH meter was standardized by a pH 6.7 phosphate buffer before each series of measurements.

The daily test procedure consisted of removing the water sample, dividing it into two 50 milliliter portions and then analyzing one for pH and the other for manganese content. The one to be analyzed for manganese was filtered through Whatman number four filter paper, manufactured in England. The sample vessel containing manganese dioxide was replaced in the apparatus after 100 ml. of boiled Atlanta tap water was added. The tap water had been boiled for ten minutes and sealed after cooling. The final step in the procedure was to measure the gas and refill the collection tube. Another run was then begun. Except in Run V the gas was allowed to bubble through the sample for twenty-four hours.

CHAPTER IV

DISCUSSION OF RESULTS

Five runs were made in this experimentation. Each of these runs consisted of a series of individual experiments using the same materials. The quantities measured were: the amount of gas used, the pH of the sample and the manganese concentration (see Tables 1, 2, 3, 4 and 5).

In Run I the gas production on consecutive days was as follows: 300 ml, 420 ml, 320 ml, 220 ml, 400 ml, 550 ml, 80 ml, 370 ml, 150 ml, and 300 ml. The pH of the samples on consecutive days were as follows: 5.2, no reading, 5.5, no reading, 6.2, no reading, 5.3, 5.3, 5.6, and no reading. The manganese concentration on consecutive days was: none, 0.5 ppm, 0.6 ppm, 0.4 ppm, 0.3 ppm, 0.5 ppm, 0.2 ppm, 0.3 ppm, 0.3 ppm, and 0.3 ppm.

In Run I sludge gas was bubbled through the water-manganese sample for about twenty-four hours before tests were run. The daily amount of gas bubbled through the sample varied; the maximum amount was 550 ml per day for the ten days of the runs. There seems to be no correlation between the rate of gas diffusion and either the pH or the soluble manganese concentration. The lowest pH was on the eighth and ninth day of the run when 80 and 370 ml of gas, respectively, were produced. The manganese concentration was

Table 1. Soluble Manganese, pH, and Gas Used for Run I (sludge gas)

Time (days)	gas[a] (ml)	manganese (ppm)	pH
1	300	0.0	5.2
2	420	0.5	-
3	320	0.6	5.5
4	220	0.4	-
5	400	0.3	6.2
6	550	0.5	-
7	80	0.2	5.3
8	370	0.3	5.3
9	150	0.3	5.6
10	300	0.3	-

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[a] Gas measured at approximately 22°C and 79 cm of mercury

Table 2. Soluble Manganese, pH, and Gas Used for Run II (carbon dioxide)

Time (days)	Gas[a] (ml)	manganese (ppm)	pH
1	180	0.5	5.4
2	850	0.5	5.2
3	740	0.8	4.6
4	980	0.3	5.1
5	900	0.5	3.6[b]

[a] Gas measured at approximately 22°C and 79 cm of mercury

[b] pH of the sample was adjusted to 3.9 before the run began

Table 3. Soluble Manganese, pH, and Gas Used for Run III (nitrogen)

Time (days)	gas (ml)	manganese (ppm)	pH
1	950	0.0	6.5
2	850	0.0	6.8
3	620	0.0	7.0
4	830	0.0	7.2
5	1000	0.0	5.6[a]

[a] pH of the sample was adjusted to 3.9 before run

Table 4. Soluble Manganese, pH, and Gas Used for Run IV (air)

Time (days)	gas (ml)	manganese (ppm)	pH
1	425	0.0	6.8
2	720	0.0	6.8
3	620	0.0	6.9
4	980	0.0	6.9
5	840	0.0	6.0[a]

[a] pH of the sample was adjusted to 3.9 before run

Table 5. Soluble Manganese, pH, and Gas Used for Run V (sludge gas)

Time (days)	Gas (ml)	manganese (ppm)	pH
5	900	0.9	5.5
10	2400	1.0	5.2
14	5050	1.0	4.6

[a] pH of the sample was adjusted to 3.9 before run

0.2 ppm and 0.3 ppm on the eighth and ninth days. On the fifth day of the run, 400 ml of gas was used with a pH of 6.2 and 0.3 ppm of manganese in the sample. On the third day of the run the highest manganese concentration was recorded, 0.6 ppm. At this time the pH was 5.5, which was higher than the ninth and tenth day, and lower than the fifth day. Thus, the third day's test had more manganese than either the fifth or eighth day's tests with pH and gas production bracketed between the two days.

The variations in Run I may be because of the daily change in sludge gas composition. If one of the components of sludge gas reduces manganese then a variation in gas composition might result in a variation in manganese concentration. The same is true for pH.

The results in Run II, which used carbon dioxide gas instead of sludge gas were as follows: manganese concentration on consecutive days was 0.5 ppm, 0.5 ppm, 0.8 ppm, 0.3 ppm, 0.5 ppm; the pH on consecutive days was 5.4, 5.2, 4.6, 5.1, and 3.6; the gas used on consecutive days was 180 ml, 850 ml, 740 ml, 980 ml, 900 ml. On the last day of the run the pH was lowered by sulphuric acid before the daily experiment was begun.

Run II showed that reduction may be caused by carbon dioxide one of the principal constituents of sludge gas. The result of using carbon dioxide instead of sludge gas gave about the same quantity of soluble manganese as did sludge gas. An average of about 0.5 ppm of manganese for Run II and about 0.4 ppm average for Run I was found. The average pH resulting from Run II was lower than the average pH of Run I. The pH in Run II seemed to have no effect on the manganese concentration. The largest amount of manganese was reduced on the third day of the run, 0.8 ppm. On this day the pH was 4.6, and 740 ml of gas was used. On the last day the manganese concentration and pH were lower, and more gas was used than on the third day. The manganese concentration of the last day was 0.5 ppm. The first day of the run had 0.5 ppm of manganese and a pH of 5.4; 180 ml of gas was used. Thus the manganese concentration resulting from the use of carbon dioxide seems to be independent of either pH or amount of gas used within the limits of the run.

Run III used nitrogen as the gas which was diffused through the sample. No manganese was reduced in any of the tests in this run. The consecutive daily pH was 6.5, 6.8, 7.0, 7.2, and 5.6. The consecutive daily gas used was 950 ml, 850 ml, 620 ml, 830 ml and 1000 ml. The pH of the last day's test was lowered before the test was begun.

Run III showed that nitrogen did not have the same capacity to reduce manganese as carbon dioxide did. There was no manganese reduction in any of the samples in Run III. The pH did not seem to have any effect in this run either. On the last day of the run the pH was 5.6 which was lower than the pH at which manganese was reduced by sludge gas.

The highest pH at which manganese was reduced by sludge gas was 6.2. Carbon dioxide produced a positive test when the pH was artificially lowered with sulphuric acid. The pH in Run III was artificially lowered with sulphuric acid on the last day expressly to study pH effects. No manganese was reduced.

Run IV used air as the gas to be diffused through the water-manganese sample. The individual tests during the run produced negative results for manganese. The pH on consecutive days was 6.8, 6.8, 6.9, 6.9 and 6.0. The gas used on consecutive days was 425 ml, 720 ml, 620 ml, 980 ml and 840 ml. The pH of the last day was artificially lowered.

Run IV was a control designed to show the importance of oxygen in the manganese cycle. Air was used. Air contains about 78 per cent nitrogen and 21 per cent oxygen. The only other gas of importance to this problem in air is carbon dioxide. The carbon dioxide content of air is about 0.03 per cent. Nitrogen under low temperature and pressure is considered chemically inert. Carbon dioxide will contribute to the reduction of manganese as was shown in Run II. It would seem, therefore, that oxygen inhibits formation of divalent manganese. The pH of the manganese-water sample was lowered to 6.0 and still no manganese was reduced.

Run V was designed to study variation of contact time between manganese and sludge gas. The consecutive daily gas readings were not taken because the digesters of Run V and

Run I had identical contents. The tests were taken in Run V at intervals of five, ten and fourteen days. At the end of five days the manganese content was 0.9 ppm, the pH was 5.5 and 900 ml of gas had been produced. At the end of ten days 2400 ml of gas had been used and the pH was 5.2. At the end of fourteen days 5050 ml of gas had been used and the pH was 4.6. The manganese content of the ten and fourteen day tests was 1.0 ppm. The increase of the amount of manganese as a fraction of time with the final values of 1.0 ppm for ten and fourteen days would seem to indicate a chemical reaction in which an equilibrium condition is reached in from ten to fourteen days. Figure 3 shows the one day averages plotted with the ten and fourteen days values of manganese concentration. The curve of Figure 3 is similar to the curve of a first-order reaction.

The results show that, under the conditions of the experiment, manganese may be reduced as a result of carbon dioxide being bubbled through water in contact with reagent grade manganese dioxide. A reaction between tetravalent manganese and carbon dioxide is difficult to explain theoretically. Using the same flow-rate, sludge gas diffusion through the sample produces a manganous-manganic equilibrium within ten to fourteen days. Carbon dioxide seems to be the causative agent in the reduction of manganese dioxide by sludge gas because sludge gas and carbon dioxide produce almost the same amount of manganese under the same conditions, and carbon

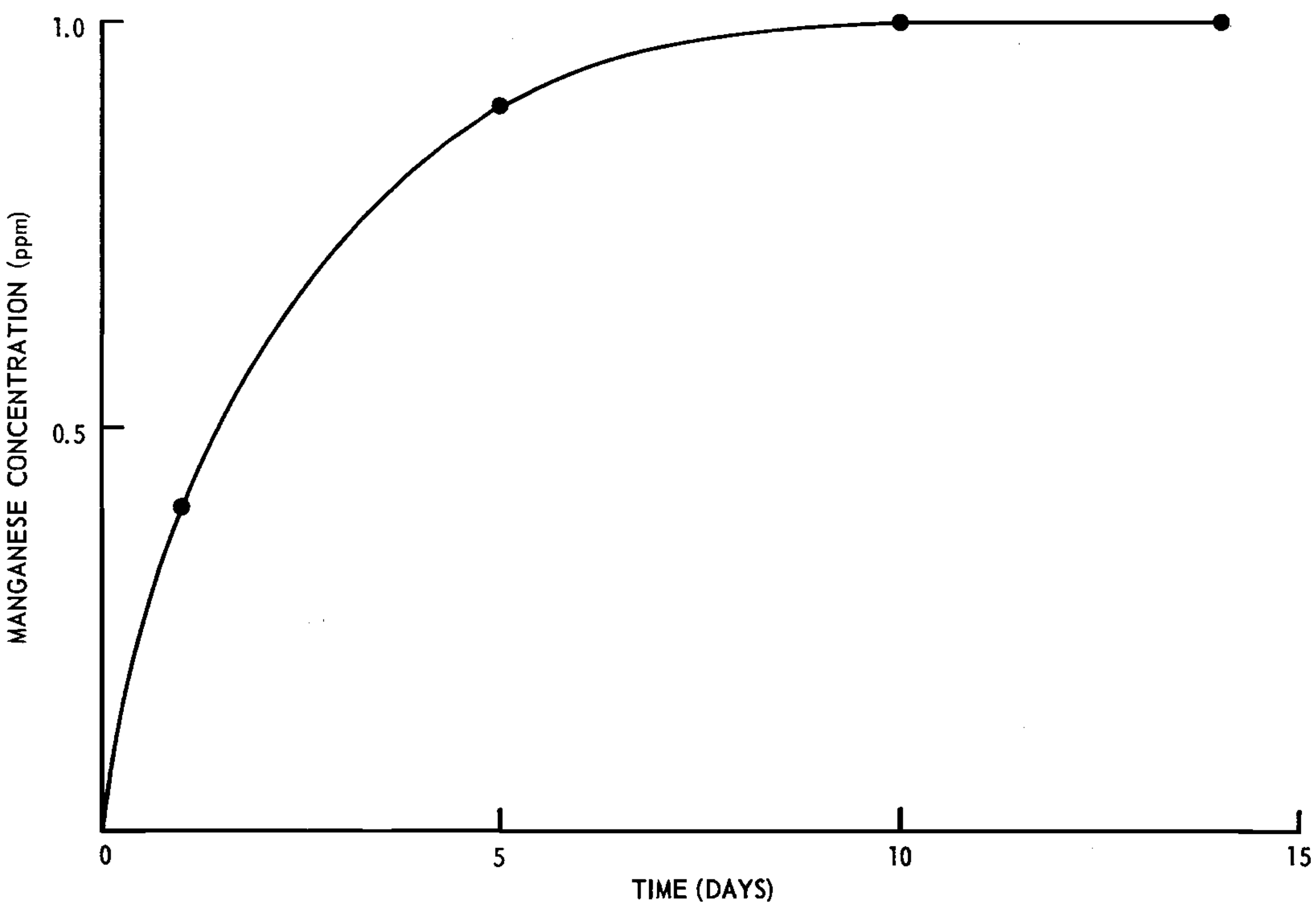

Figure 3. Concentration of Manganese Produced in Run V as a Function of Contact Time.

dioxide is one of the principal constituents of sludge gas. The hydrogen ion concentration within the range of this experiment seemed to have no effect.

It is difficult to relate these data to lake conditions. The conditions on a lake bottom do not match the conditions of this experiment in many respects. Rate of gas diffusion and concentration of the reactants are greater in the laboratory experiments. The time allowed for reaction, pH and pressure are less in the laboratory. Whether a change in the conditions of the experiment would change the quantity of manganese reduced is unknown; however, the results seem to indicate there would be some reduction of manganese under reservoir conditions.

The puzzling matter of the nature of the indicated reaction between manganese dioxide and carbon dioxide is made more complicated by the amount of impurities present in the manganese dioxide (see Table 6). Quastel (8), in his studies of the manganese reduction problem, was forced to manufacture manganese dioxide from potassium permanganate and manganous sulphate to get reproducable results. In the present study, even using pure gas and the same reactants, the results vary considerably. The purpose of this study was not to determine the mechanics of the manganese dioxide-carbon dioxide reaction, but rather to show that such a reaction exists. In order to relate the reaction in the laboratory as closely as was possible to the reaction that

Table 6. Impurities contained in the Manganese Dioxide used in all Runs

Amount of impurities in one gram of manganese dioxide (calculation from analysis on label)

Impurity	Amount (mg)
Chloride	6
Nitrate	40
Sulphate	37
Iron	100
Earths and Alkalies	100

occurs in lake bottoms, impure manganese and water were used. Quastel (8) calls the commercial manganese nothing more than ground-up pyrosulite. Atlanta water which was used in this experiment is typical of many waters in which reduction of manganese occurs. Buford dam, several miles upstream from the Atlanta water intake, according to samples taken in the tailrace, has reduced a small amount of manganese.

CHAPTER V

CONCLUSIONS

Manganese dioxide in contact with water can be reduced to the divalent state by sludge gas.

Carbon dioxide, one of the principal constituents of sludge gas, will reduce manganese dioxide in contact with water in about the same quantities as sludge gas.

Oxygen seems to inhibit the formation of divalent manganese in water.

The amount of manganese reduced in contact with water seems to have no relation to pH of the solution between the limits of 5.2 and 6.8 with sludge gas and 3.6 to 5.4 with carbon dioxide.

The quantity of manganese reduced by sludge gas reaches a limit of 1.0 ppm using the same quantities of materials and the same rate of gas production.

The data indicates that carbon dioxide may be a factor in the reduction of manganese dioxide in reservoirs.

CHAPTER VI

RECOMMENDATIONS

Further experiments are needed to correlate the information given in this research to actual lake conditions. If there is a correlation, then research is needed to determine the mechanics of the reaction.

APPENDIX

APPENDIX I

DAILY LUMETRON READINGS

Date	Lumetron Readings								
	Standards				Unknowns				
	Blank	0.25	0.50	1.0	Run I	Run II	Run III	Run IV	Run V
11-1	0.0	0.50	0.75	1.30	0.0	-	-	-	-
11-2	0.0	0.50	0.80	1.35	0.78	-	-	-	-
11-3	0.0	0.50	0.80	1.35	0.92	-	-	-	-
11-4	0.0	0.30	0.74	1.45	0.60	-	-	-	-
11-6[a]	0.0	0.18	0.45	0.95	0.28	-	-	-	0.80
11-8	0.0	0.18	0.45	0.95	0.50	-	-	-	-
11-10	0.0	0.18	0.42	0.98	0.11	-	-	-	-
11-12	0.0	0.19	0.45	0.95	0.25	-	-	-	-
11-14	0.0	0.19	0.45	0.95	0.22	-	-	-	-
11-16	0.0	0.21	0.45	0.95	0.25	-	-	-	-
11-26	0.0	0.25	0.65	0.95	-	0.60	0.0	0.0	1.00
11-27	0.0	0.16	0.45	0.88	-	0.50	0.0	0.0	-
11-28	0.0	0.30	0.55	0.90	-	0.75	0.0	0.0	-
11-29	0.0	0.35	0.42	0.85	-	0.40	0.0	0.0	-
12-1	0.0	0.40	0.62	1.08	-	0.60	0.0	0.0	-
12-10	0.0	0.20	0.50	0.95	-	-	-	-	0.95

[a] Light bulb replaced in machine on this day.

APPENDIX II

EXCERPTS FROM MONTHLY REPORTS ON WATER PLANT OPERATIONS

Excerpts from records of the Augusta Water Plant
15 miles below Clark Hill Reservoir

Month	Temp °F	pH	Mn
1953			
January	54	7.0	0
February	55	7.0	0
March	57	6.9	0
April	62	7.1	0
May	70	7.0	0
June	73	7.0	0
July	73	6.9	0
August	79	6.7	0
[a] September	75	6.7	0.6
October	72	6.7	0.4
November	61	6.9	0.2
December	57	7.0	0.1
1954			
January	52	7.0	0.1
February	54	7.0	0.1
March	55	6.9	0.1
April	62	7.0	0.1
May	64	7.0	0.1
June	72	6.9	0.1
July	73	6.9	0.1
August	79	6.9	0.2
[b] September	79	6.8	0.5
October	72	6.8	0.4
November	61	7.0	0.3
December	54	7.0	0.1

[a] Maximum of 1.0 during this month

[b] Maximum of 0.6 during this month

EXCERPTS FROM MONTHLY REPORTS ON WATER PLANT OPERATIONS (Continued)

Excerpts from records of Lamar Ham water plant
in Milledgeville, Georgia, just below Sinclair Dam

Month	Per cent wash water	Avg. pH	Avg. CO_2 content	Avg. temp
1954				
December	5.0	7.1	3	55
1955				
January	4.0	7.1	3	49
February	3.2	6.9	3	49
March	2.0	6.6	5	53
April	2.5	6.6	6	58
[a]May	4.7	6.6	6	78
June	5.9	6.5	8	72
July	5.3	6.6	8	78
August	11.9	6.6	8	79
September	10.9	6.6	8	78
[b]October	10.0	6.6	8	72
November	6.7	6.8	5	60
December	6.4	6.9	4	52
1956				
January	6.5	6.9	4	51
February	7.6	6.9	4	52
March	6.1	6.7	4	56
April	1.9	6.6	4	61
May	1.6	6.5	4	67
June	1.1	6.4	5	68
[c]July	5.1	6.4	13	71
[d]August	8.4	6.5	10	76

[a] Manganese began about May 27; at this time the temperature was 71°.

[b] Manganese stopped about October 17; at this time the temperature was 70°.

[c] Manganese began about July 12; at this time the temperature was 70°.

[d] Manganese continued past September 14th when these records were copied.

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