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Experimental Study on the Time Variation of Oxygen Content of Natural Water

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Abstract

On the diurnal variation of the amount of dissolved oxygen in the upper layers of the hydrosphere, the theoretically obtained results were verified in this paper by experiments carried out in water tanks kept in light and dark. Pond water in which phytoplanktons were flourishing was illuminated with a candescent lamp, and the time variation of dissolved oxygen was determined. The effect of escape from water surface due to diffusion of oxygen upon its time variation was clarified. Under a certain condition of illumination, no change of oxygen content was found in the 20 cm deep layer. It is noticeable that in this layer the time variation of oxygen content obtained experimentally agreed with the theoretical result. On the contrary, in an upper layer above the depth of 20 cm, the maximum amount of dissolved oxygen appeared earlier than was expected theoretically.

1. Introduction

In a previous paper, theoretical consideration was made on the diurnal variation of the amount of dissolved oxygen by the present author [1]. It was shown there that if diffusion, advection and/or convection which will later be briefly called a " physical factor ", produced no appreciable effects on the time variation of oxygen content, the following conclusions could be obtained. 1) The maximum amount of dissolved oxygen occurs one or two hours before the sunset and the minimum, one or two hours after the sunrise. 2) The amplitude of the diurnal variation is directly proportional to the quantity of light utilized for photosynthesis and to the population of phytoplanktons.

The primary purpose of this paper is to ascertain the preceding results and to show the effect of escape from water surface due to diffusion of oxygen upon its time variation by means of experiments.

2. Experimental procedure

Water to be studied was poured into two tanks of the same size (30 cm in diameter and 30 cm deep) and kept in the dark for 24 hours. Immediately before the commencement of illumination, the amount of dissolved oxygen was determined. The water contained in one tank was illuminated over the surface and the water in another kept in the dark. A candescent lamp was used for illumination. The voltage applied to the lamp was at first lowered and then raised gradually up to 100 volts. The water was illuminated continuously for one hour at 100 volts. Afterwards, the voltage applied was gradually lowered and at last the illumination was stopped.

The oxygen content was measured every one hour. As the sample we used the water of a pond, the diameter of which is about 10 m and the depth about 3 m. This pond is located in the grounds of the Meteorological Research Institute. A 500 W 'Reflector' lamp or a 200 W candescent lamp was used as light source. In the beginning of the experiment, the lamp was set up 20 cm above the middle part of the water surface. The lamp was connected with a transformer and a voltmeter, and 100 volts were applied to primary terminals of the transformer. A thermometer or a thermocouple was used for the measurement of temperature. The determination of oxygen content was made by the ordinary WINKLER's method. The accuracy of this method was 0.3 per cent at the 5 per cent confidence level, according to the author's measurement.

3. Results obtained

i) Experiment using pond water.

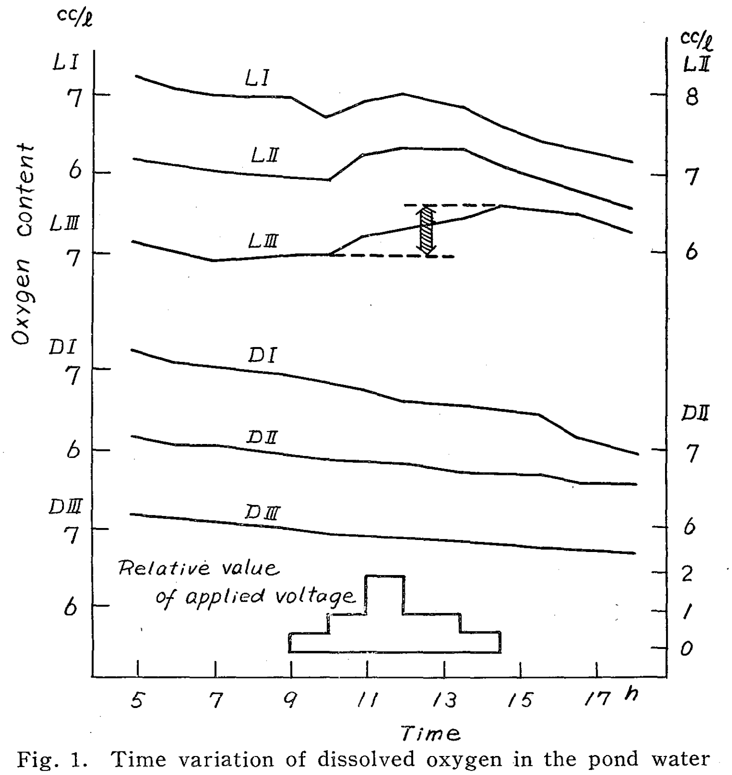

Fig. 1. Time variation of dissolved oxygen in the pond water illuminated with a 500 W lamp.

Fig. 1 shows the results of the experiments carried out with pond water. Here, a 500 W 'Reflector' lamp was used for illumination. In Fig. 1, the *L* curves show the time variations of the amount of dissolved oxygen in each layer of water contained in the illuminated tank, and the *D* curves show those in the dark tank. The curves denoted with the figures I, II and III show the time variations of the amount of dissolved oxygen in water layers of respectively 2, 12, and 22 cm below the surface. In this paper, the above layers will be called respectively the I, II and III layers.

As shown in Fig. 1, there are always maximum and minimum content of dissolved oxygen in the *L* curves. On the contrary, in the *D* curves oxygen content always decreases. In the *L* curves, it is noticeable that in the sample taken from a layer nearer to the surface, the maximum occurs much earlier than is expected theoretically. It is quite interesting that in the III layer, the minimum occurs a little after the commencement of illumination, and the maximum occurs a little before the extinction. These points can be seen in Figs. 2 and 3. Of these, the *L* III curves illustrate the trend of the diurnal variation of oxygn content in natural water free from the influence of physical factors. For the oxygen content in the III layer, unlike the I or II layer, as described in the section 2), does not change, if the biological factors *viz.* photosynthesis and respiration of life do not exist. And at the same time, it has become apparent that there is no effect of a physical factor upon the time variation of oxygen content in the III layer.

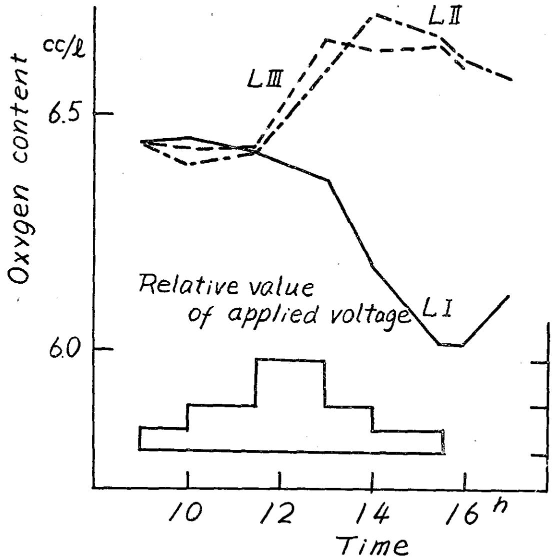

Fig. 2. Time variation of oxygen content in the pond water illuminated with a 200 W lamp.

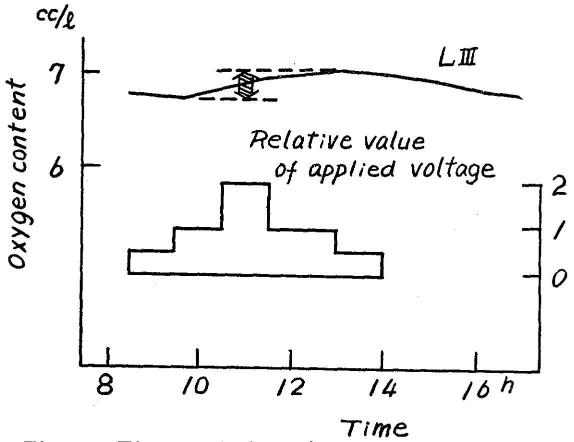

Fig. 3. Time variation of oxygen content in the pond water diluted with the same volume of distilled water illuminated with a 500 W lamp.

Fig. 2 shows the time variation of oxygen content in the water illuminated with a 200 W candescent lamp. In the I layer, the maximum appeared so much earlier. This may be explained by the fact that the oxygen loss from water mass through the water-air boundary by diffusion exceeds the oxygen gain by photosynthesis. Comparing the results in Fig. 3 with those in Fig. 1, it will become apparent that the amplitude of the diurnal variation of oxygen content is nearly directly proportional to the total quantity of light, as shown in Table 1.

Table 1. Relation between quantity of light and oxygen content.

Exp. No.	ΔS cc/l	ΔS ratio	A cc/l	A ratio	Quantity of light lumen, hr.	Quantity of light ratio	Lamp watt
1	0.65	3	0.65	2	18,700	2.3	500
2	0.21		0.31		8,250		200

ΔS: difference between oxygen content at the beginning, and that at the end of illumination.
A: difference between maximum and minimum oxygen content.

Here, some references must be made to the quantity of light. The voltage applied to the lamp was read instead of the quantity of light itself, and the quantity of light was obtained by calculation with using the known relation between applied voltage and luminous flux [2].

Fig. 3 shows the results of the experiment in which the pond water diluted with the same volume of distilled water was illuminated under the similar condition as that in the first experiment. In this case, the measurement was made only in the III layer. In this experiment, the total quantity of light equals to that in the first experiment, but the population of planktons are diluted to 1/2. It was ascertained by this experiment that the amplitude of the time variation of dissolved oxygen was directly proportional to the population of phytoplanktons. The relation is illustrated in Table 2. In the above experiments, nearly all planktons were identified as spherical cyanophyceae a kind of phyotplankton by R. MARUMO.

Table 2. Relation between population of planktons and oxygen contents.

Exp. No.	ΔS, cc/l	ΔS, ratio	A, cc/l	A, ratio	N, relative	Lamp, watt
1	0.65	2.5	0.65	1.8	2	500
3	0.25		0.35		1	500

N: population of planktons.

ii) Experiment using distilled water.

An experiment similar to the one mentioned above was done using distilled water. Here, we can not expect the biological activity in a water sample. The results are shown in Fig. 4. Fig. 5 shows the time variation of water temperature. The following are the points to be noticed in Fig. 4. The amount of oxygen escaping from the water surface was most remarkable at the time of extinction in the layers nearer the surface, and the change of oxygen content was not found in the 10 cm deep layer* in spite of the existence of the 7 per cent supersaturation of dissolved oxygen. In other words, in Fig. 4 we can see the time variation of oxygen content in water that is under no influence of a factor, physical or biological, except diffusion of oxygen. While, on the other hand, the time variation mentioned in the section 1)

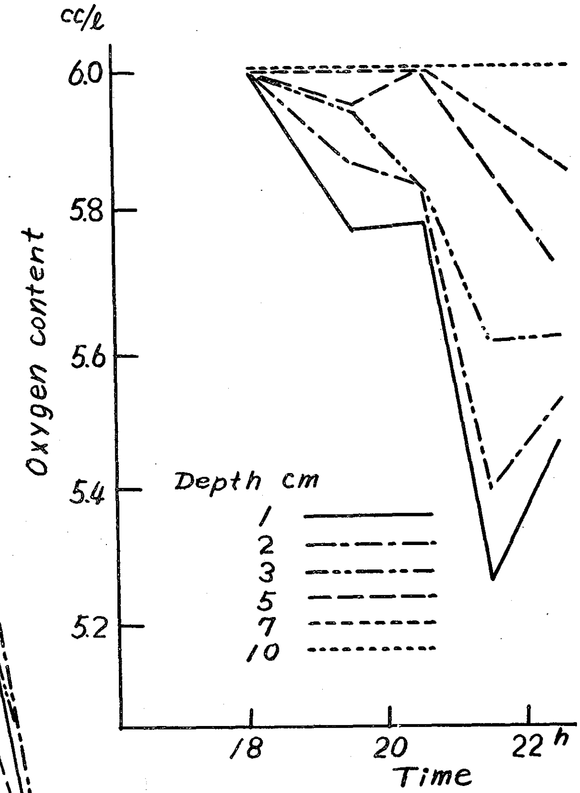

Fig. 4. Time variation of oxygen content in each layer of distilled water illuminated with a 500 W lamp.

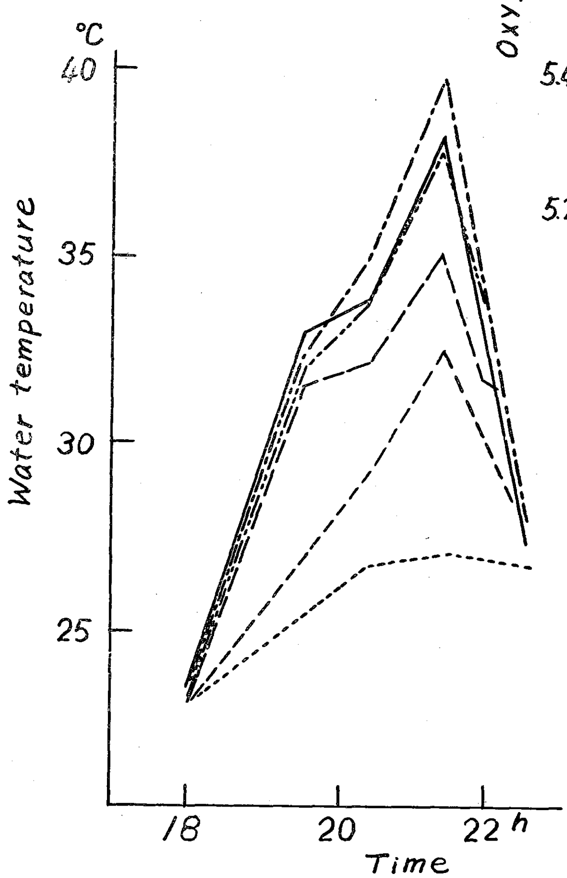

Fig. 5. Time variation of water temperature in each layer of distilled water illuminated with a 500 W lamp.

shows the additive effects of both the biological and the physical factors. The results from the I and II layers in Figs. 1 and 2 show the characteristics of the time variation modified with the effect of dissolved oxygen escaping from the water surface due to diffusion which can not be disregarded.

According to the author's observation, in the diurnal variation of oxygen content in the sea water around the coast of Hachijo-jima Is., the maximum occurs almost always at 14 h in all seasons. The

* It needs to be noted that the condition of illumination in case of Fig. 4 differs to some extent from that in case of Fig. 1. Because of this difference, the place under no influence of diffusion upon the time variation of oxygen content was found at a depth of 10 cm in one case and at a depth of 22 cm in the other.

cause of an earlier occurrence of the maximum may be attributed to escape from the water surface due to diffusion of dissolved oxygen. While, in a lake or a pond, e.g. the moat around the Imperial Palace, Tokyo, there seems to be no influence of diffusion upon the diurnal variation of oxygen content. It may be ascribed to a smaller value of the diffusion coefficient.

4. Comparison of gross production of oxygen with quantity of light

Without the change of oxygen content by the physical factor, the gross production of oxygen must be directly proportional to the quantity of light. To ascertain this idea the gross production of oxygen obtained from the results of Fig. 1 was compared with the quantity of light. The result is shown in Table 3.

Table 3. Comparison of gross production with quantity of light.

Time h	L cc/l	D cc/l	Gross production ($L-D$)		Accumulated quantity of light in an arbitrary unit	Rel.
			cc/l	relative		
0	7.00	7.00	0.00	0.00	0	0.00
1	7.00	6.95	0.05	0.07	10	0.05
2	7.20	6.93	0.27	0.4	38	0.2
3	7.30	6.90	0.40	0.6	138	0.7
4.5	7.47	6.86	0.61	0.9	180	0.9
5.5	7.65	6.81	0.84	1.3	190	1.0
6.5	7.59	6.80	0.79	1.2	190	1.0
7.5	7.53	6.74	0.79	1.2	190	1.0
9.0	7.30	6.64	0.66	1.0	190	1.0

L: oxygen content of water illuminated.
D: oxygen content of water kept in the dark.
Rel.: relative value calculated by taking the value at 9 h as the standard.

5. Conclusion

On the diurnal variation of dissolved oxygen, the theoretically obtained conclusions could be experimentally verified in this paper. The major points described in this paper may be summarized as follows:

1) Without the change due to diffusion, advection and/or convection of the amount of dissolved oxygen, the minimum of oxygen content may be found a little after the commencement of illumination and the maximum, a little before the time of extinction.

2) Under the same condition as that in 1), the amplitude of the time variation of oxygen content is nearly directly proportional to the population of phytoplanktons and to the quantity of light.

3) In the layer nearer the water surface, the maximum of oxygen content occurs earlier than is pointed out in 1). It is attributable to escape into the air due to diffusion of oxygen under the state of supersaturation.

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