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Original Research Paper

Experimental Research on the Promotion of Supersaturated Total Dissolved Gas Dissipation by the use of Activated Carbon

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ABSTRACT

Spill discharge and abrupt water temperature rising may result in total dissolved gas (TDG) supersaturation, which can lead to gas bubble disease (GBD) and even cause mortality of fish. Studies on the mitigation measures about how to promote the dissipation process of supersaturated TDG are essential for the protection of fishes. In this paper, the experimental research about the promotion of supersaturated TDG dissipation by using activated carbon was conducted in static water and stir-induced turbulent water respectively. Supersaturated TDG dissipation processes with different content of activated carbon have been monitored and the dissipation coefficients of supersaturated TDG under various conditions were obtained. The results indicate that the activated carbon can increase the dissipation speed of TDG obviously. The higher the activated carbon content is, the greater the dissipation coefficient is. It can be concluded that the TDG supersaturation problem can be mitigated by introducing activated carbon and enhancing water turbulence when supersaturated TDG occurs in the fish ponds or fish proliferation stations. This study can provide scientific data for the exploration of mitigation measures of supersaturated TDG, which is fundamental for the protection of fishes.

INTRODUCTION

With more and more large-scale water conservancy and hydropower projects put into operation, it brings huge economic and social benefits, inevitably having an adverse impact on the environment at the same time, where the TDG caused by the dam sluice has won gradual concern of people. Spill discharge may result in supersaturated TDG, which cannot quickly dissipate in the process of transportation to downstream river, leading to gas bubble disease (GBD) and even mortality of fish (Feng et al. 2010, Weitkamp & Katz 1980, Weitkamp et al. 2003). Meanwhile, the river water downstream of spill discharge may be the water intake source of fish ponds or the proliferation stations beside the river, which will have an adverse impact on farmed fish due to supersaturated TDG. In addition, supersaturated TDG caused by abrupt water temperature rising in fish ponds will also have negative effect on fish. Therefore, the research of conducting the mitigation measures of the supersaturated TDG impact is imperative.

At present, the mitigation measures for the negative impact of supersaturated TDG focused on two kinds, which include the design improving of the discharge structure and the optimization of sluicing operation. The relevant researches with respect to low dams and sluices are carried out at abroad. Orlins & Gulliver (2000) suggested that by setting the flow deflectors on the face of the spillway, the quantity of air bubbles entrained into the depth of the stilling basin can be reduced, which can reduce the generation of supersaturated TDG. This kind of measure has been applied to Wanapum Dam. Many researches have been carried out on the exploration of the operational measures of supersaturated TDG. Politano et al. (2012) presented optimization operational strategies for the Wanapum Dam by the numerical simulation method. Cheng et al. (2005) and Chen et al. (2009) concluded that reasonable operation of spillways could slow TDG saturation of the downstream reaches. Based on prototype observations and numerical predictions, Li et al. (2009) and Qu (2011) put forward some optimal suggestions to alleviate TDG saturation. Peng et al. (2012) proposed that the dynamic operation of the reservoir flood control is effective in reducing TDG supersaturation.

Comprehensive analysis shows that most studies about the supersaturated TDG mitigation measures focus on reducing the generation of supersaturated TDG. While measures on how to speed up the dissipation process of supersaturated TDG in the downstream river have not been reported. As an adsorbent with high quality and reasonable low price, activated carbon is widely used in water treatment industry. For this reason, the activated carbon was used as the adsorbent material in the experiments on how to promote the dissipation of supersaturated TDG in static water and stir-induced turbulent water respectively.

EXPERIMENTS IN STATIC WATER

Apparatus and methods: Experiments were conducted in a walk-in constant temperature and humidity laboratory. Ambient temperature was kept at 20.0°C ± 0.2°C, and the relative humidity was controlled at 70%.

The device of the experiment in static water is shown in Fig. 1. The experimental device includes a big constant temperature bath, four rectangular plexiglass containers (250 mm in length and 250 mm in width and 400 mm in height) and a supersaturated TDG generation system developed by Sichuan University (Li et al. 2011). The columnar activated carbon made in Shanghai Xinlian Chemical Plant was used in the experiment, the diameter of which is 3 mm. In order to compare the adsorption activity of the activated carbon after different pretreatments, three pretreatment ways of the activated carbon were designed (Table 1). The activated carbon in Case 2 was not pretreated. The activated carbon in Case 3 was soaked in normal saturated water for 1-2 hours before the experiment began. The activated carbon in Case 4 was immersed in saturated water for 6 hours first, and then soaked in TDG supersaturated water for 1-2 hours before the test began.

Experiments of the four cases with different pretreated carbon were conducted simultaneously. At the beginning of the experiment, supersaturated water was drained into the four plexiglass tanks with a water depth of 350 mm. The variation of supersaturated TDG level and the temperature in the 4 experimental tanks were monitored. The conditions are given in Table 1.

Water temperature was measured by using L93-22-type temperature recorder made by Hangzhou Loger Technology Co. Ltd. The measuring accuracy is ± 0.2°C. TDG saturation level in water was measured with a TGP (Total Dissolved Gas Pressure) detector made by Point Four Systems Inc. (Canada). The measuring range of TGP is 0-200% and the accuracy is 1%.

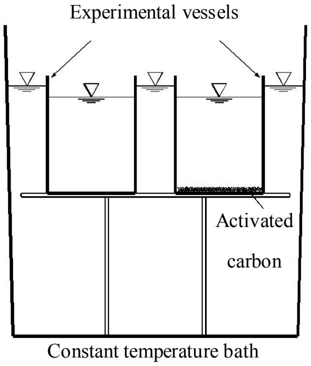

Fig. 1: Sketch of experiment facility of supersaturated TDG releasing in static water.

Results and analysis: The temperature monitoring results confirmed that water temperature in the water bath was kept at 20.0°C ± 0.2°C and the temperature in the experimental water tank was controlled at 20.0°C ± 0.3°C in the whole process.

The dissipation processes of TDG supersaturation under various experimental conditions are shown in Fig. 2. The dissipation curves show that the TDG supersaturation levels were gradually decreased over time. Comparison between the cases shows that the duration time of Case 1 without activated carbon was 5.6 times as slow as that of the Case 2 with dry activated carbon. The time of the Case 1 was 1.5 times as sluggish as that of the Case 3 with activated carbon pretreated in normal saturated water. The time of the Case 1 was 1.2 times as slow as that of the Case 4 with activated carbon pretreated in supersaturated water.

It was reported that the supersaturated TDG dissipation process is complied with one order kinetics according to the studies of the U.S. Army Corps of Engineers (2005), which is given as follows.

$$\frac{\mathrm{d}\left(G - G_{eq}\right)}{\mathrm{d}t} = -K_T\left(G - G_{eq}\right) \qquad ...(1)$$

Where, t represents dissipation time, h; G represents TDG saturation of t ,%; G_{eq} represents equilibrium saturation with TDG; K_T represents the dissipation coefficient.

The dissipation process of the various conditions was fitted by using eq. (1), and the dissipation coefficient of each condition was obtained, as given in Table 1.

From the experimental data, we can see that the dissipation coefficients of the experimental cases with activated carbon (Case 2, Case 3 and Case 4) were obviously higher than that of Case 1. This happened due to the large specific surface area and the hydrophobic nature of the activated carbon. For this reason, the activated carbon exhibits excellent adsorption performance and a large amount of free-state gas was adsorbed onto the surface and the inner pores of the activated carbon, prompting the continuous degasification of supersaturated TDG.

The dissipation rate of Case 2 with non-pretreatment dried activated carbon was significantly higher than that of pretreated active charcoal (Case 3 and Case 4). The TDG dissipation process of Case 2 was observed with a steep drop shortly after the beginning of the experiment. It is analysed that with the osmotic action, the water was infused into the pores of the activated carbon and the air inside the pores was driven out of the pores, generating a large amount of fine bubbles in the process. The degasification of supersatu-

Table 1: The experimental conditions and results in static water.

Case number	Pretreatment conditions of activated carbon	Carbon content in per unit water body (g/L)	During time of TDG saturation from 131% to 105% (h)	Dissipation coefficient (h^{-1})
1	Without activated carbon	0	70.5	2.54×10^{-3}
2	Dry activated carbon without pretreatment	34.3	12.5	8.60×10^{-3}
3	Activated carbon pretreated by normal saturated water	34.3	46.5	3.87×10^{-3}
4	Activated carbon pretreated by supersaturated water	34.3	58.5	3.22×10^{-3}

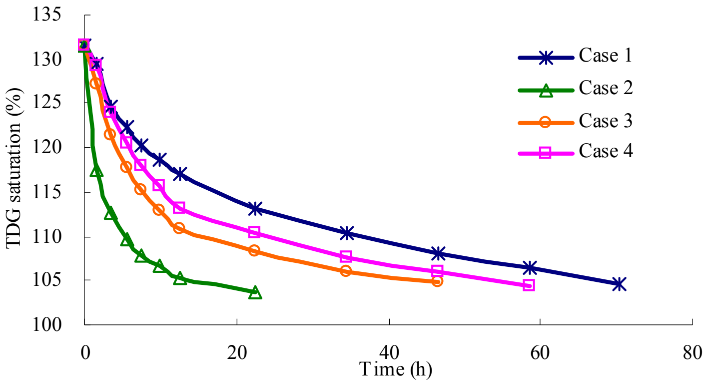

Fig. 2: Dissipation processes of supersaturated TDG in static water.

rated TDG can be accelerated during the ascent process of these tiny bubbles and the degasified TDG was driven to the free water surface by the tiny bubbles. The idea was supported by the research of Rösch (1999), who regarded the air as a stripping gas.

Within the first 2 hours, there were no significant differences between Case 4 (with pretreated active charcoal by supersaturated water) and Case 1 (without activated carbon). But with the growth of time, the dissipation rate of Case 4 experienced a faster acceleration than Case 1. Analysis shows that the pretreated active charcoal of Case 4 had absorbed a certain amount of gas and reached to a saturation state during the pretreatment process. After a period of time in the supersaturated water, the free-state gas absorbed on the activated carbon surface gradually gathered, formed into bubbles, and got away from the water. It made possible for the activated carbon to play its adsorption effect continuously, causing the TDG saturation continues to decrease faster than that of Case 1 (without activated carbon).

The experimental results demonstrate that the activated carbon exhibits a good adsorption effect for supersaturated TDG which can last very long time.

EXPERIMENTS IN STIR-INDUCED TURBULENT WATER

Experimental device: Experiments were conducted in a walk-in constant temperature and humidity laboratory. Ambient temperature was kept at 20.0°C ± 0.2°C, and the temperature of water was controlled at 20.0°C ± 0.4°C.

The experimental device is shown in Fig. 3. The experimental device includes a constant temperature water bath, a rectangular plexiglass water tank (250 mm in length and 250 mm in width and 400 mm in height), an electric stirrer, a stirrer stand, and the supersaturated TDG generation system (Li et al. 2011).

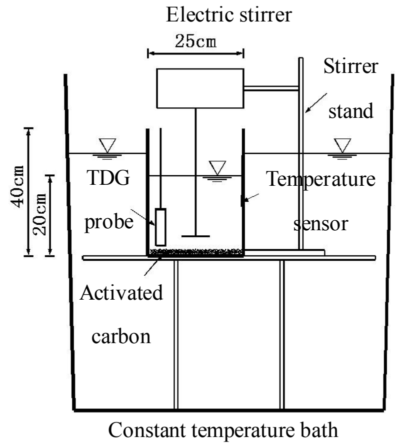

Fig. 3: Sketch of experimental facility of supersaturated TDG dissipation in stir-induced turbulent water.

Table 2: The results of dissipation coefficient in stir-induced turbulent water.

Case number	Rotation speed (RPM)	Content in per unit water body (g/L)	Average dissipation coefficient (h^{-1})	Variation range of dissipation coefficients of parallel experiments (h^{-1})
1-1	600	0	0.439	0.435~0.443
1-2	600	12	0.480	0.432~0.528
1-3	600	24	0.575	0.547~0.603
1-4	600	36	0.683	0.617~0.749
1-5	600	48	0.762	0.600~0.992
1-6	600	60	1.043	1.067~1.019
1-7	600	72	1.127	1.078~1.176
2-1	750	0	0.542	0.532~0.552
2-2	750	12	0.690	0.500~0.842
2-3	750	24	0.767	0.762~0.777
2-4	750	36	0.863	0.854~0.873
2-5	750	48	0.912	0.814~1.082
2-6	750	60	1.080	1.026~1.134
2-7	750	72	1.142	1.096~1.187
3-1	900	0	0.814	0.794~0.835
3-2	900	24	0.961	0.961
3-3	900	36	1.212	1.112~1.306
3-4	900	48	1.344	1.282~1.405
3-5	900	60	1.451	1.381~1.521
3-6	900	72	1.635	1.571~1.699

Methods and conditions: Prior to testing, a specific quantity of dry active carbon and 12.5 L supersaturated water were introduced into the rectangular plexiglass water tank, and then stirrer was adjusted to a fixed speed. The variation of the supersaturated TDG saturation versus time was monitored by using a PT4 tracker sensor.

Three groups of speed conditions were conducted, which are 600 rev/min (denoted as RPM), 750 RPM and 900RPM. For each turbulence Case, 6 to 7 different levels of activated carbon content were conducted. To ensure the accuracy of the experiment, 2-4 groups of parallel experiments were carried out at each condition.

The error of the stirrer rotation speed is less than ± 2RPM in the experiment.

Results and analysis: Figs. 4, 5 and 6 show the dissipation processes of supersaturated TDG under three turbulent conditions of 600RPM, 750 RPM and 900 RPM. The dissipation coefficients under different conditions were fitted by using the first-order kinetic equation. The average dissipation coefficient of parallel experiments was taken as the dissipation coefficient value corresponding to the specific turbulence and activated carbon content. The results of the coefficients are given in Table 2.

The results demonstrate that the existence of the activated carbon accelerates the dissipation process of supersaturated TDG and the dissipation coefficients increase with the turbulence intensity.

The results of the dissipation coefficients are listed in Table 2. The dissipation coefficients of supersaturated water without activated carbon were 0.439 h^{-1}, 0.542 h^{-1}, 0.814h^{-1} respectively at conditions of 600RPM, 750 RPM and 900 RPM. The corresponding dissipation coefficients of the supersaturated water with an activated carbon content of 12 g/L were 0.480 h^{-1}, 0.690 h^{-1}, 1.635h^{-1} respectively. The corresponding dissipation coefficients of the supersaturated water with an activated carbon content of 72 g/L were 1.127 h^{-1},1.142 h-1, 1.635h-1 respectively. By comparison, the values of the dissipation coefficients increase as the content of activated carbon increases in water. The dissipation process of supersaturated TDG was markedly enhanced with the increase of the activated carbon content.

According to the experimental results in various conditions, relationship between the dissipation coefficient of supersaturated TDG and the content of activated carbon by fitting method are obtained as follows:

$$K_G = K_0 \, \mathrm{e}^{-0.01G} \qquad ...(2)$$

Where, K_G represents the dissipation coefficient of water with activated carbon, h^{-1}; K_0 represents the dissipation coefficient of water without activated carbon, h^{-1}; and G represents the content of activated carbon in per unit water body, g/L. It could be seen from the formula that the supersaturated TDG dissipation coefficient presents exponential growth with the activated carbon content in the experimental condition.

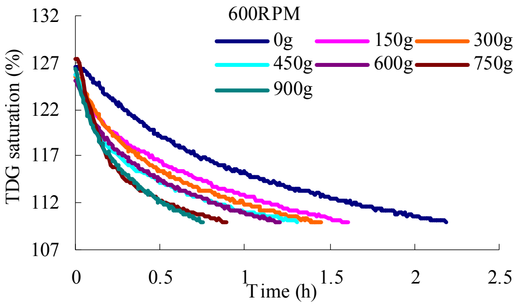

Fig. 4: Supersaturated TDG dissipation process at different content (600RPM).

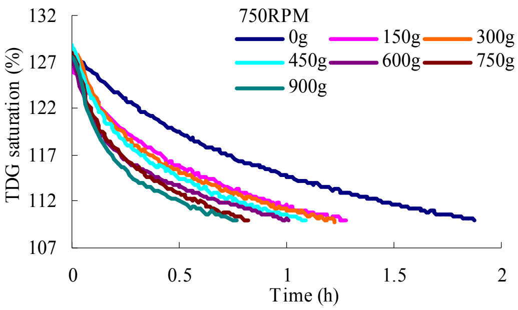

Fig. 5: Supersaturated TDG dissipation process at different content (750RPM).

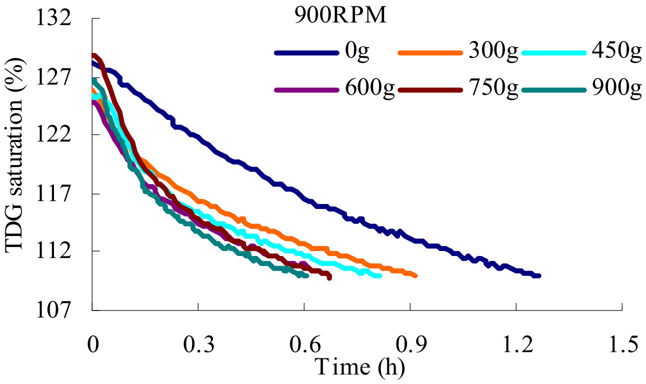

Fig. 6: Supersaturated TDG dissipation process at different carbon content (900RPM).

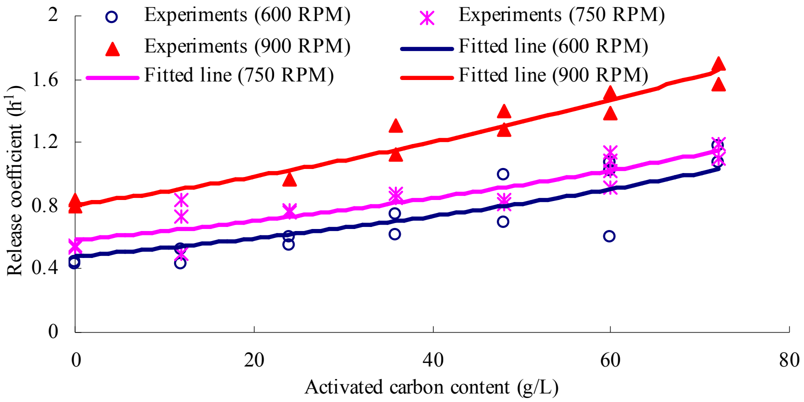

Fig. 7: Relationship between the dissipation coefficient and the activated carbon content.

CONCLUSIONS AND PROSPECTS

The experimental research on how to promote the dissipation process of supersaturated TDG by use of activated carbon was conducted in static water and stir-induced turbulent water respectively. The results show that activated carbon can promote the dissipation of supersaturated TDG effectively. Analysis shows that a large quantity of free-state gas was absorbed onto the surface or inside the pores of the activated carbon. The gas gathered gradually, formed to be bubbles and leave away from the water eventually. Further analysis of the test results show that the dissipation coefficient of supersaturated TDG increases with the content increasing of the activated carbon. The results suggest that the TDG supersaturation problem can be mitigated by introducing activated carbon and enhancing water turbulence when supersaturated TDG occurs in the fish ponds or fish proliferation stations. This study can provide reference data for the exploration of mitigation strategies of supersaturated TDG.

The study in this paper is preliminary for the solution of the TDG problem. The agitation speed was between 600RPM-900RPM and the activated carbon content in unit water was between 0 g/L and 72g/L . A wider range of the activated carbon content and more complex turbulent conditions remain to be further studied. The applicability of activated carbon is limited only in fish ponds rather than natural rivers. Therefore, further exploration for more effective and feasible materials in natural water is necessary.

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