Ecological Engineering 95 (2016) 245–251

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

The promotion effect of aeration on the dissipation of supersaturated total dissolved gas

Yangming Ou[a], Ran Li[a,*], Youcai Tuo[a,*], Jinlan Niu[b], Jingjie Feng[a], Xunchi Pu[a]

[a] State Key Laboratory of Hydraulics and Mountain River Engineering, Sichuan University, Chengdu 610065, China
[b] Chongqing Research Academy of Environmental Sciences, Chongqing 401147, China

ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form 16 May 2016
Accepted 16 June 2016
Available online 2 July 2016

Keywords:
Total dissolved gas
Supersaturation
Aeration
Dissipation coefficient
Promotion effect

ABSTRACT

Supersaturation of total dissolved gas (TDG) is caused by high dam discharge, sudden increases in water temperature and extra photosynthesis of aquatic plants, which may lead to gas bubble disease and even cause mortality of fish. It is imperative to explore treatment measures to mitigate the negative impact of supersaturated TDG for the protection of aquatic organisms. Based on the knowledge of the promotion effect of the aeration bubbles on the mass transfer rate between gas-liquid interfaces, a series of experiments in an aeration column were carried out under different aeration conditions to explore the promotion effect of aeration on the dissipation process of supersaturated total dissolved gas. A quantitative relationship between the dissipation coefficient of supersaturated TDG and the aeration conditions, such as gas flow rate, water depth and pore size, was established. Within the variation range of the aeration conditions, the dissipation coefficient exhibits an exponential increase with the gas flow rate. For a certain gas flow rate, the dissipation coefficient decreases with increasing water depth and diffuser pore size. The exploration of the mass transfer of supersaturated TDG in the aeration tank column provides insight into the quantitative effect of aeration on the dissipation of TDG. This would be useful guidance for further research on the mitigation measures of supersaturated TDG.

1. Introduction

In past decades, a synergy of human disturbances has caused a series of impacts on many hydrological processes in multi-scale river basins, leading to many changes in the environment (Defries and Eshleman, 2004; Cai et al., 2009; Yang et al., 2015). Recently, extensive attention has been paid to supersaturated TDG problems caused by hydropower exploitation (Zhang et al., 2007). Supersaturation of total dissolved gas (TDG) may occur during spillway discharge, causing a sudden increase in water temperature and extra photosynthesis of aquatic plants (Weitkamp and Katz, 1980; Chen et al., 2012). Supersaturated TDG production at hydropower facilities is generally caused by the entrainment of air in spillway releases and the subsequent exchange of atmospheric gasses into solution during the transport of bubbles through the stilling basin. The produced supersaturated TDG cannot quickly dissipate in the process of transportation in the downstream river, and it consequently may result in fish mortality caused by gas bubble disease (GBD) (Weitkamp et al., 2003). The situation would be more serious if the river water downstream of the spill discharge was taken as the water intake source of fish ponds or the proliferation stations beside the river, or if it was taken for artificial water replenishment to wetlands (Boyd et al., 1994). To prevent river and reservoir ecosystem disruptions caused from supersaturated TDG, the United States Environmental Protection Agency (1986) established a limitation standard of 110% for TDG in the water quality criteria (WQC) based on a series of long-term observational studies. However, so far, an authoritative TDG water quality standard has not been established in China. In recent years, increasing construction of high dams has made the supersaturated TDG problem more serious, especially for the endemic fishes with high rarity in the river used for hydropower development, thus attracting more attention to this problem.

Great efforts have been made to explore the measures for alleviating the effect of TDG supersaturation downstream of the spillway, which mainly includes structural and operational alternatives. Orlins and Gulliver (2000) installed flow deflectors on the face of the spillway in the Wanapum Dam approximately 56 m high to prevent the flow over the spillway from entering the deeper part of the stilling basin. In this way, air bubbles cannot be transferred to the deeper water. Consequently, the bubble-water equilibrium pressure is not too large to generate high TDG supersaturation. Simulation results showed that a lower TDG level was generated compared with that without a deflector installed. Due to the

* Corresponding authors.
E-mail addresses: ou-yangming@stu.scu.edu.cn (Y. Ou), liran@scu.edu.cn (R. Li), tuoyoucai@scu.edu.cn (Y. Tuo), njl314@163.com (J. Niu).

http://dx.doi.org/10.1016/j.ecoleng.2016.06.041
0925-8574/

possible adverse impact of the deflector on dam safety, the universal application of this method to high dams was limited. Politano et al. (2012) presented optimization operational strategies through the numerical simulation method for the Wanapum dam that can lower the production of TDG supersaturation very efficiently. Feng et al. (2013) proposed that reasonable operation of spillways could alleviate the TDG saturation levels of the downstream reaches. High dams with high water head, large release discharge and deep water depth in the plunge pool can lead to high TDG saturation levels. Thus, the problem of TDG supersaturation could not be solved by a single engineering method. It is necessary to give extensive study to the combination of different types of engineering methods to resolve the TDG supersaturation problem.

Enhancing supersaturated TDG dissipation in downstream rivers is another critical way for limiting negative effects of supersaturated TDG on fishes. Colt and Bouck (1984); Bouck et al. (1984) and Hargreaves and Tucker (1999) studied the mitigation measures of supersaturated TDG through packed-column aerators. Excess air can be removed from water by allowing the supersaturated water to spill into tanks under reduced pressure, thereby driving the air from the water out into the gas phase. Due to the complexity of the device and its high cost, the application of that method is limited and not suitable for use in a large-scale supersaturated water body. In addition, Niu et al. (2015) demonstrated the promotion effect of supersaturated TDG dissipation by using activated carbon. Unfortunately, the method is also limited for experiments in the laboratory, and there is a long way to go for practical use.

Because the microbubble generated by aeration can offer collection sites for mass transfer between gas and liquid, aeration is widely used in wastewater treatment (Roberts and Dändliker, 1984). Most of the studies on the effects of aeration on the process of gas-liquid mass transfer are focused on the transition process from the under-saturated state to the saturated equilibrium state (Chern and Yu, 1997; Newbry, 1998; Demoyer et al., 2003; Li et al., 2008). In the laboratory experiment, Murphy et al. (2001) reported that excess dissolved gas in the supersaturated water could be removed, for which TDG saturation was reduced from 117.9% to 101.7% by introducing a certain size of microbubble in a glass cylinder with 1 L volume. However, no reports have been published about the effect of aeration on the dissipation process of TDG in natural rivers or reservoirs with high water depth and high levels of TDG saturation.

Comprehensive analysis shows that there are many effective measures for alleviating TDG saturation and for speeding up TDG dissipation. However, a high dam with a huge discharge will generate a high level of TDG supersaturation, resulting in slow dissipation in the downstream. In particular, supersaturated TDG is transported and dissipated more slowly in reservoirs because of a higher water depth and lower turbulence, and thus it may let the impact of supersaturated TDG become larger in terms of range and degree. So far, more effective mitigation measures should be studied based on the previous studies. Using bubbles generated by aeration to promote the dissipation of supersaturated TDG is a prospective method. One critical problem for the design and application of the measure is the quantitative relationship between dissipation rate and the aeration conditions. In this study, we carried out a series of experiments in an aeration column to investigate the effect of aeration conditions (gas flow rate, water depth and diffuser pore size) on the dissipation process of supersaturated TDG.

2. Materials and methods

2.1. Experimental apparatus and materials

Dissipation experiments on supersaturated TDG under different aeration conditions were conducted at the State Key Laboratory of Hydraulics and Mountain River Engineering (SKLH) in Chengdu, China. The experimental set-up is shown in Fig. 1, and its main apparatus is an aeration water column of 4.0 m in height and 0.4 m in inner diameter. The aeration distributor is placed at the 0.28 m distance from the column bottom, where there are 40 steel cylindrical aerators surrounding the central aerator with diameters of 0.84 mm and 0.41 mm. The air is injected into the steel cylindrical aerator through a plastic tube in which a gas rotameter has been installed to control the gas flow rate. The supersaturated water in the experiment was supplied by a supersaturated TDG generation system developed by Sichuan University (Li et al., 2012). Air and water were pumped into the supersaturated water reactor vessel through different inlets and mixed at high pressure so that supersaturated conditions were generated. A total dissolved gas pressure (TGP) detector (Oxyguard), where the probe was located at 0.15 m depth below the water surface, was used to measure and record the TDG saturation and water temperature of the water column in real time. The measuring range of the TGP was 0–200% of saturation, with a ±1% accuracy, and the accuracy of the water temperature measurement was ± 0.2 °C.

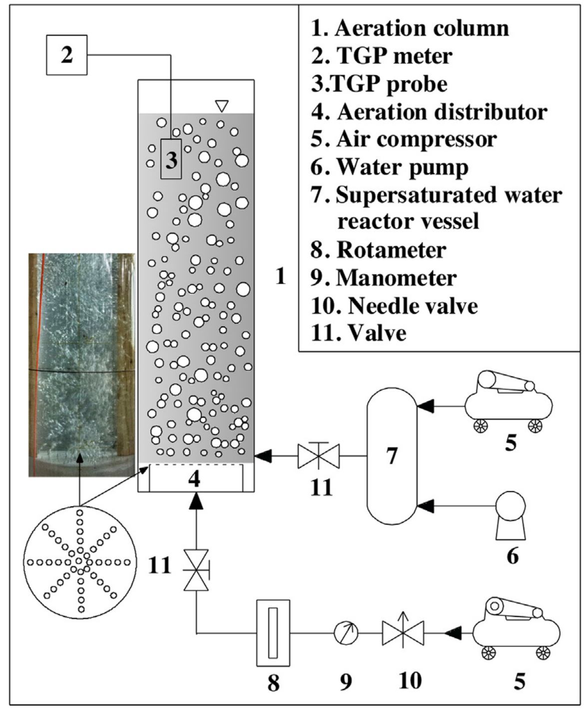

Fig. 1. Sketch of the experimental setup.

2.2. Methods

Before the beginning of the aeration experiment, the supersaturated water was injected into the water column with the water level controlled at the predetermined depth. The initial TDG saturation and water temperature were measured and recorded. After the readings of the TGP sensor became stable, the air compressor was started up and controlled by an air-controlling valve to provide a given gas flow rate. At the same time, the automatic counting function of the TGP sensor was turned on to record TDG saturation as a function of time.

In order to compare the effect of aeration on the dissipation of supersaturated total dissolved gas, a static experiment in the water column of 2 m depth without aeration (Q_a = 0) was carried out. The TGD variations at different water depth (Hp) were measured, and