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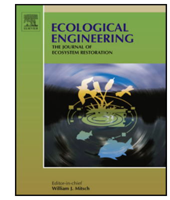

Comparison of water-lifting aerator type for algae inhibition in stratified source water reservoirs

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ABSTRACT

Non-submerged and submerged water-lifting aerators have been recently developed to improve the water quality of source water reservoirs, but the non-submerged aerator has the drawbacks of higher initial investment and being more difficult to operate and maintain compared with the submerged aerator. To explore whether the submerged water-lifting aerator also has better performance on *in-situ* algae inhibition in source water reservoirs, the effects of submerged and non-submerged water-lifting aerators on algae inhibition were numerically investigated under different hydrological and operational conditions. Taking Jinpen Reservoir as a study case, under different conditions of water depth, temperature gradient and inlet velocity period, the flow outside the aerators, core algae inhibition zones and mixing of algae were numerically analyzed, and the simulated results were validated against the measured data. Simulated results showed that the flow outside any water-lifting aerator was characterized as one large clockwise circulation under a stable state, but the circulated flow was developed further for the submerged case. When the water depths were 77.25 m, 87.25 m and 97.25 m, the percentages of the core algae inhibition zone to the whole flow domain were 39.71%, 41.14% and 42.73% respectively, which were 5.88%, 3.68% and 1.15% larger than those for the non-submerged case; the periods required for complete mixing of algae were 10 days, 12 days and 14 days respectively for the submerged case, which were 8 days, 7 days and 6 days shorter than those for the respective non-submerged cases. Algae were transported from the surface layer to the bottom layer mainly by advection generated from the circulated flow arising from water-lifting aeration. Under similar hydrological and operational conditions, the core algae inhibition zones were larger and the mixing of algae was quicker for the submerged case. Submerged water-lifting aerators have advantages over the non-submerged aerators in the investment required and the operation and performance of algae inhibition and are recommended for *in-situ* algae inhibition in stratified source water reservoirs.

1. Introduction

Algal pollution is a threat to the quality and safety of drinking water worldwide (Ding et al., 2007; Kraus et al., 2011; Lui et al., 2012; Zhang et al., 2012). High concentrations of algae in raw water would not only directly influence the safety of drinking water, but also increase the difficulty and cost of water purification in the water plant (Codd, 2000; Dittmann and Wiegand, 2006; Campinas and Rosa, 2010; Gao et al., 2010; Ma et al., 2012). At present, the *in-situ* algae inhibition is mainly achieved by physical, chemical and biological methods (Ferrier et al., 2005; Xu et al., 2007; Kotopoulis et al., 2009; Cao et al., 2011; Chen et al., 2012; Lundgren et al., 2013; Yajima and Choi, 2013), during which chemical removal would inevitably pollute the environment.

In deep stratified reservoirs, the main method of *in-situ* algae control is artificial mixing, which has been applied in countries such as Japan and Korea and has shown good algae control effects (Heo and Kim 2004; Liu et al., 2012). Pipe mixing was successfully applied to decrease the planktonic microorganism concentration by 66% in reservoirs in Britain (Simmons, 1998). Chlorophyll A concentration and total algae biomass in a deep reservoir decreased significantly using a pumping tube along which the toxic algae biomass reduced by 95% (Jungo et al., 2001). The water-lifting aerator is a newly-designed mixing and oxygenating device incorporating *in-situ* reservoir eutrophication inhibition technology with a broad application prospect (Cong et al., 2009, 2011a,b; Huang et al., 2013).

As shown in Fig. 1 (Cong et al., 2011b), a water-lifting aerator consists of an air-releasing tube, aeration chamber, return

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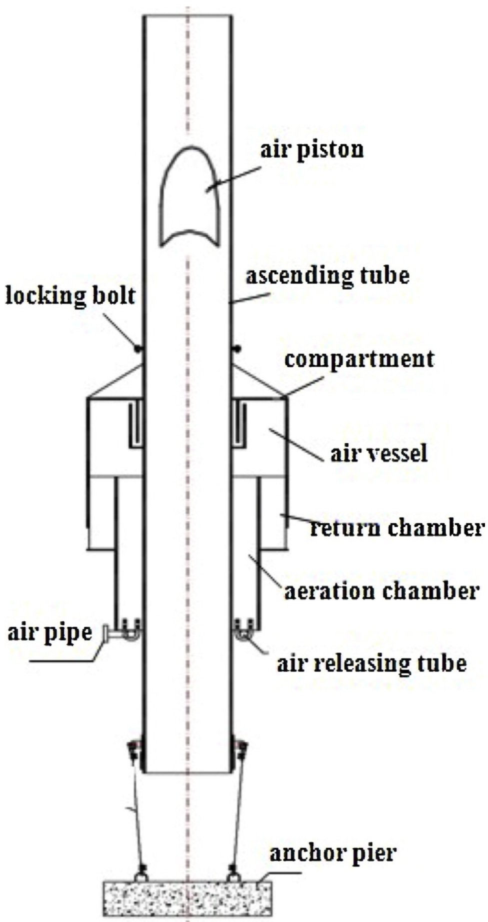

Fig. 1. Diagram of the water-lifting aerator's configuration.

chamber, air vessel, ascending tube, compartment, air pipe and anchor pier. The aerator is fixed to the anchor pier on the reservoir bottom with steel chains. The compressed air is continuously delivered to the aeration chamber in the form of minute bubbles through the air-releasing tube. When the air bubbles go up in the aeration chamber, the oxygen is dissolved and transferred into the water, the undissolved air is accumulated in the air vessel and the water is pushed out from the top zone of the aeration chamber. The oxygenated water flows out of the aeration chamber through the return chamber and this hence increases the content of dissolved oxygen in the bottom water layer. Once the air vessel is filled with undissolved air, the gas is released to the ascending tube instantaneously, then the large air piston forms, rises quickly and finally flies out of the ascending tube's outlet. Undissolved air is released periodically, carrying the water upward from the bottom to the surface of the reservoir and generating a circulated flow outside the water-lifting aerator. Mixing and oxygenation can be obtained at the same time with this aerator to improve the water quality of a reservoir.

Microcystis aeruginosa is the dominant species of algae in most drinking water source reservoirs and it can float upward in the water (Cao et al., 2008; Cong et al., 2011a; Catherine et al., 2013). The mechanism of inhibiting algae growth by water-lifting aeration is achieved through a circulated flow from top to bottom caused by a rising air slug in the central riser (Cong et al., 2011b); the algae are transported to the lower water layer and eventually die due to unfavorable growing conditions. Cong et al. (2011a) carried out the pioneering study on the floating characteristics of *M. aeruginosa* under still and flowing conditions. They found that the *M. aeruginosa* can float upward at a speed of 0.000275 m/s in the still water. To prevent this, a minimum downward flow velocity of 0.000275 m/s is required. The flow field outside the water-lifting aerator directly influences the effectiveness of algae inhibition.

Two types of water-lifting aerators have been developed to improve the water quality in stratified reservoirs: submerged (Cong et al., 2009, 2011b) and non-submerged (Huang et al., 2013). For the non-submerged aerator, the buoyancy is provided by the watertight cabin in the upper structure. As the non-submerged aerator runs, the rising upward flow generated by the rising air slug periodically impacts on the watertight cabin on top of the equipment, a huge impact force (maximum 3000 N under typical operational conditions) then acts on the aerator, and much flow energy is also lost in the upper watertight cabin (Sun et al., 2014a). Hence, the aerator is unable to run stably over an extended period due to the periodic impact and cannot run efficiently due to the high energy loss. From the perspective of economic costs, the initial investment and operating costs of a submerged aerator are about one third of that of a non-submerged aerator. Moreover, it is also easier to install and maintain. From the perspective of water quality improvement, the function of hypolimnetic aeration is the same for each type of aerator, but the mixing between the upper and lower water layers is different, so the effectiveness of mixing as a means of algae inhibition will be different for the two types of aerator.

To select the more effective and efficient water-lifting aerator for algae inhibition in a stratified source water reservoir, the effectiveness of algae inhibition using submerged and non-submerged water-lifting aerators was systemically compared under different hydrological and operational conditions like water depth, temperature gradient and water flow velocity. There are several challenges to investigating the effect of aerator type on the algae inhibition, including manufacturing the pilot model to simulate the stratified reservoir, performing extensive field work and avoiding many adverse factors that can exist in reservoirs. On the contrary, it is convenient to accurately calculate the flow field under complex geographical and operational conditions using a computational fluid dynamics (CFD) method; thus, CFD is an important and useful tool for investigating this kind of water environment problem (Sun et al., 2010b; Liu et al., 2013). Little numerical work has been done on investigating the effectiveness of *in-situ* algal inhibition by water-lifting aeration. Commercial software (FLUENT) was used in this study (Fluent Inc., 2006a). The outcomes of this study will provide a helpful guide to selecting the water-lifting aerator with lower running and maintenance costs for more effective inhibition of algal growth in stratified reservoirs.

2. Numerical methods

2.1. Simulated domain

The peripheral flow field around an aerator was simulated with an axisymmetric model and only the right part of the water body was studied. Based on previous simulated results for a non-submerged water-lifting aerator, the effective influencing radius of the core algae inhibition zone was less than 150 m (Sun et al., 2014b). The computational domains were simplified to have a radius of 300 m and varying water depths of 77.25 m, 87.25 m and 97.25 m. The aerator was simplified to a cylinder with a radius of 0.375 m and part of the ascending tube (10 m above the aerator's outlet) was treated as a black body, only partial inner flow was considered. The outlet of the aerator was considered as the inlet of the computational domain, and the inlet of the aerator was considered as the outlet of the flow domain. The outlets of the submerged and non-submerged aerators were both 6 m above the