OPTIMIZATION OF A VACUUM DEVICE FOR ZEBRA MUSSEL CONTROL

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INTRODUCTION

General biology and ecology of zebra mussels have been described in the literature (Morton, 1969; Nichols et al., 1992; Griffith, 1992; Mackie et al., 1989). Zebra mussels are bivalve mollusks related to clams and native freshwater mussels. Unlike native mussels that have a single thin thread in the juvenile only, a zebra mussel retains its proteinaceous byssal threads as an adult for attachment to hard substratum. They can grow to 5 cm long, although most specimens collected in the United States have been no more than 3.8 cm (Nichols, 1992). As an exotic species, zebra mussels often achieve a great density after colonizing a new water body.

Zebra mussels feed on bacteria, algae, and fine organic detritus using a complex arrangement of cilia (Miller et al., 1992). Food particles are selected through the filtration by cilia in the mantle cavity. Although they have adapted to a freshwater habitat, zebra mussels have retained some primitive features, such as free-swimming veligers, simple mantle fusions, and functional byssus in the adults. Byssal threads are formed in the byssal groove of the foot from secretions of the byssal gland. Zebra mussels detach themselves from hard substrata by discarding the entire mass of old threads. This is followed by the secretion of a new series of byssal threads.

The reproduction of zebra mussels generally occurs over extended periods when water temperature reaches 11 or 12^{o}C. Adults become sexually mature in their second year of life (Mackie et al., 1989). A female can produce approximately 150 thousand eggs in her life time of 4 to 5 years. Fertilized eggs require calcium for development but are tolerant of low oxygen levels. The first appearance of free-swimming larvae, veligers, in the plankton form is temperature-dependent, preferably at 14 to 20 ^{o}C. In the United States, veligers of zebra mussels can be found from May to October.

The post veliger and settling larvae are the most sensitive stages to temperature shock and anoxia. It was shown that thermal shock would occur at a temperature of approximately 30^{o}C for zebra mussels acclimated to 5^{o}C and 15^{o}C, and around 35^{o}C for those acclimated to 25^{o}C (McMahon, 1991). Water temperature was used by Chang and Miller (1992) to develop the ZM Index for potential evaluation of zebra mussel infestation. Thermal processes for the removal of zebra mussels from water intakes have been demonstrated to be a successful control technology (Mackie et al., 1989; Walker et al., 1991), however, the use of high-temperature water may result in ecological impacts on other aquatic life.

Dissolved calcium in water is an essential constituent of shells for zebra mussels to grow from larvae to veligers and adults. It was shown that there is a significant relationship between calcium content and zebra mussel density (Mackie et al., 1989). Zebra mussels are not found in water with less than 10 mg/l or 10 ppm dissolved calcium. Hence, the dissolved calcium was used as an indicator by Chang (1995) for the evaluation of zebra mussel movement in water bodies. However, practical uses of dissolved calcium for the purpose of zebra mussel control is relatively limited.

Dissolved oxygen is essential for zebra mussels especially at the stage of their settling on hard substrata. Oxygen deprivation was recommended by Chang and Miller (1993) as a control technique for removing zebra mussels from infested piping systems. Zebra mussels are clean water inhabitants and usually thrive where the dissolved oxygen is greater than 90 percent saturation. They are stressed in water with less than 40 to 50 percent saturation. Therefore, the dissolved oxygen level can be a good indicator of the potential for zebra mussel presence.

The rapid rate of population growth and mobility of veligers are believed to be partially responsible for the quick spread of zebra mussels in the United States. Furthermore, the heavy traffic of our Inland Waterway System makes the dispersal of zebra mussels throughout adjoining river basins inevitable. Chlorine and other chemicals have been commonly used to prevent planktonic veligers of zebra mussels from settling in the piping systems (Lyons et al., 1991; Payne and Lowther, 1992). Unfortunately chlorine is highly toxic to other native aquatic life. Hence, other mechanical means for preventive measures of zebra mussel settlement would be highly desirable. This study proposed and tested a mechanical device based on the reduction of dissolved oxygen for the control of zebra mussels in the piping system.

DESCRIPTION OF THE VACUUM DEVICE

The supply of dissolved oxygen is essential for zebra mussels to remain active. Laboratory tests showed that the mortality rate of zebra mussels is about 3 times higher, when they are placed under vacuum, than when exposed to air (Chang and Miller, 1993). It is the absence of dissolved oxygen, not the air exposure that plays the key role in the elimination of zebra mussels. Therefore, a reduction of dissolved oxygen will have an adverse effect on zebra mussel activity and will lead to prevent them from attaching to piping systems.

A vacuum device proposed to reduce the dissolved oxygen of water was developed by Chang (1994). It consists of a water tank with a circulation system, a vacuum pump connected at the top, and a dissolved oxygen monitor on the outlet side. The inlet to the tank was placed at the opposite side of the outlet and its elevation was higher than that of the outlet. The tank was partially filled with water during operation. The size of the tank was determined by the discharge required in the piping system. The flow rate at the outlet was adjusted to be the same as the inflow rate. An additional air mixer can be used to disturb the oxygen contained in the water, which leaves the water body to the air space in the partially filled tank due to the vacuum pressure. The study showed that a circulation pump is effective for increasing the efficiency for oxygen reduction. The air pump maintains the vacuum pressure in the air space and to removes oxygen from the tank.

The vacuum pump was adjusted to keep a desired vacuum pressure of 10 psi, but not more than 14 psi to ensure only removal of air from the tank. Figure 1 show the relation between the saturation level of dissolved oxygen and the vacuum pressure. Initial tests conducted showed that a vacuum pressure of 9.5 psi was able to achieve a 50 percent reduction of the dissolved oxygen. A relation between the saturation level of dissolved oxygen and respiration rates of zebra mussels for varied shell lengths further showed the importance of dissolved oxygen to zebra mussels (Chang, 1994). It can be seen in Figure 2 that respiration rates of zebra mussels drop significantly at 30 percent saturation of dissolved oxygen. When applying the proposed device to a large piping system, several devices can be installed in parallel to increase the mechanical efficiency. For a long piping system, devices in series can be used to ensure the required dissolved oxygen level.

TESTING AND RESULTS

Various materials and dimensions were used to build a model tank capable of withstanding vacuum pressures up to 20 psi, where a DuoSeal Vacuum Pump, Model vs. vacuum pressure 1402, purchased from the Welch Vacuum Technology, Inc., was used to test the tank strength. Finally, a circular PVC tank, 18 in. in diameter, 24 in. and 1/4 in thick, reinforced by 3/4 in thick PVC plates at the both ends, was constructed meet the strength requirement.

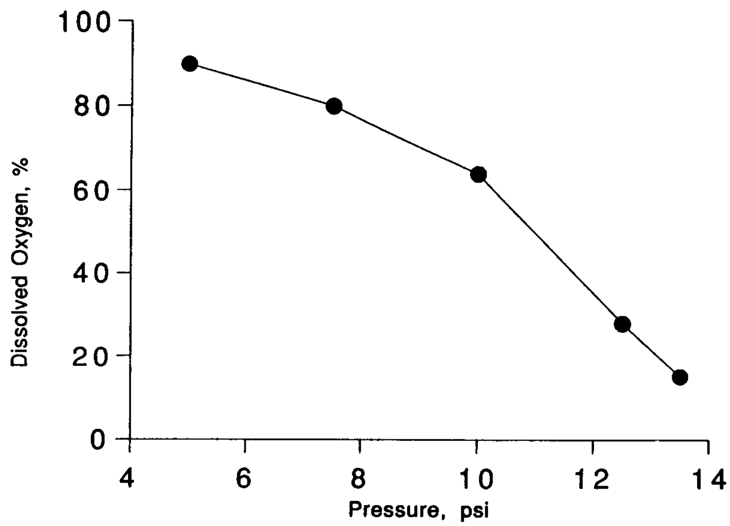

Figure 1. Dissolved oxygen (DO) saturation level vs. vacuum pressure

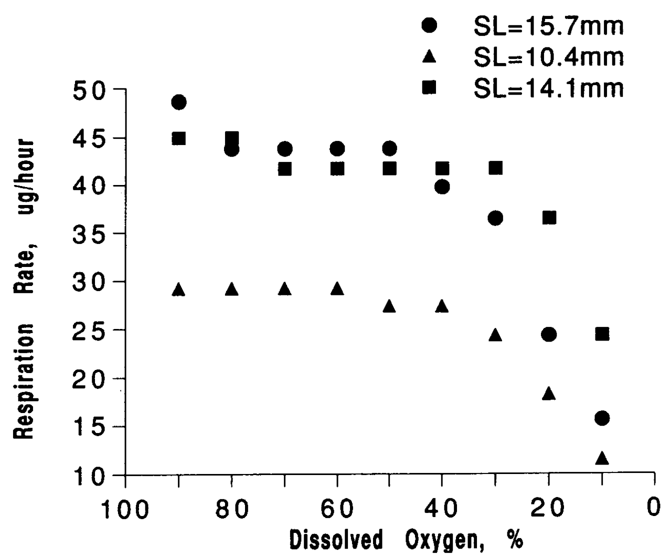

Figure 2. The relation between the respiration rate and the DO saturation level for varied shell lengths of zebra mussels.

A vacuum pressure gage, installed at the top of the tank, was used to ensure a specified vacuum pressure for each test. The tank was plumbed for the intake water that is saturated with air through a hydraulic system. A pump was installed to circulate the water in the tank to increase the efficiency of the originally proposed air mixer for the disturbance of water. The initial test was done by applying varied vacuum pressures to the partially water-filled tank, where 3/4 tank depth, i.e. 18 in depth of water, was used. A microprocessor-based auto-calibration dissolved oxygen meter, Model HI 9143 from the Hanna Instruments, Inc., was used to measure the dissolved oxygen (DO) level. DO was expressed by the percent of saturation level at the water temperature of 23^{o}C and the atmospheric pressure of 760 mm Hg height. The data show that the DO level can be reduced to 50 percent within one minute by a vacuum pressure of 10 psi and to 25 percent by the vacuum pressure of 12 psi. It was also found that constant water circulation in the tank was essential to reduce the time for the above achievement.

It is desirable to reduce the dissolved oxygen in the tank efficiently. Therefore, tests were conducted to determine an optimal air-water ratio for the purpose of dissolved oxygen reduction. The testing system was partially filled with air saturated water to a desired water level, which was expressed by the depth of water in inches or percent full of water. An electronic sensor and an automatic intake valve were installed to maintain a constant water level in the tank. Dissolved oxygen was measured at the outlet of the piping system until a constant dissolved oxygen concentration
was reached. The test were repeated for varied air-water ratios to determine a possible optimal value for the vacuum device, based on the least time used in the reduction process.

Five different water levels in the vacuum tank, i.e., depths of 12.7, 14.3, 16.1, 17.8, and 19.4 in or 53, 60, 67, 74, and 81 percent of the total capacity were used for the testing. The dissolved oxygen of the water before entering the vacuum tank was kept at about 95 percent saturation level at room temperature of 23^{o}C and a barometer pressure of 760-mm Hg. Tables 1 and 2 are examples of test results for water levels at 16.1 and 12.7 in or 53 and 67 percent of total capacity. It can be seen that the dissolved oxygen decreases significantly and approaches a constant level within 5 minutes for each test. Figure 3 gives a summary of testing results, where DO saturation levels in percent were plotted against time. It shows that all 5 tests of varied water levels in the vacuum tank resulted in varied constant DO saturation level. Table 3 lists constant DO saturation levels in percent corresponding to water levels in the vacuum tank. Figure 4 is a best-fit curve showing DO vs. water level in the tank. An optimal water level of around 65 percent in the vacuum tank was found to be optimum for the reduction of dissolved oxygen.

Table 1. DO vs. time for water Level at 16.1 in.

Time (min)	DO (%)
0	79.4
2.88	60.7
5.15	53.1
7.27	50.3
9.38	49.6
11.37	49.3
13.42	48.9
15.67	48.5
17.7	48.9
24.82	50.3
28.35	48.9
30.63	48.8
32.75	49.3
35.1	51.9
38.02	49.6
44.37	50.7
46.95	49.8
49	50.1
51.2	49.6
53.35	50.6
56.23	50.6
58.97	49.6
61.07	50.1

Table 2. DO vs. time for water Level at 12.7 in.

Time (min)	DO (%)
0.00	65.9
2.25	61.6
4.40	59.2
6.25	57.9
8.08	57.1
9.98	56.8
11.78	56.7
13.75	56.5
15.77	56.1
17.83	55.9
19.52	56.4
21.62	56.9
26.25	56.5
28.30	56.3
30.07	56.4
32.33	55.6
34.12	55.9
36.23	55.7
38.08	55.3
40.10	56.1
42.22	55.8
48.12	57.3
50.03	56.4
52.03	56.4
53.93	55.9
55.80	56.1
57.78	56.0
59.58	56.5

Table 3. DO vs. water level of the vacuum tank

Water level in inches (% full)	DO saturation level (%)
12.7 (53%)	56
14.3 (60%)	56
16.1 (67%)	50
17.8 (74%)	70
19.4 (81%)	68

CONCLUSION

The proposed vacuum device follows the guidelines of the Congress' Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 that specified interests to develop control strategies suitable for use in large waterways based primarily on physical rather than chemical methods. Testing results from the laboratory showed that the vacuum device could prevent zebra mussels from attaching to the piping system. It was also found that the water level of 65 percent full in the vacuum tank was optimal for the reduction of dissolved oxygen for controlling zebra mussel activities in the piping system.

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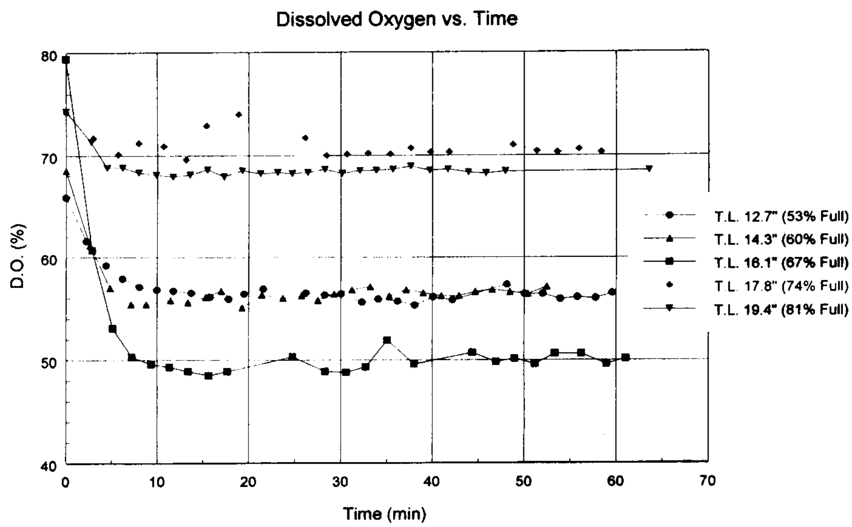

Figure 3. The relation between the reduction of dissolved oxygen and time at varied water levels

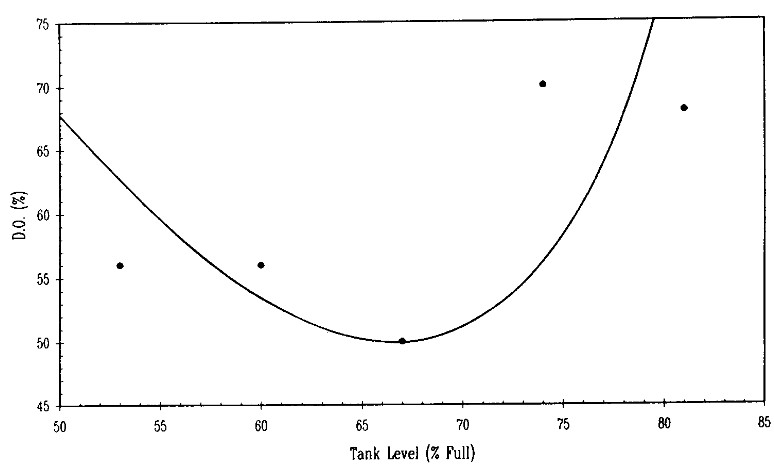

Figure 4. The relation of the air-water ratio in the vacuum tank and the dissolved oxygen reduction

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