Restoration of Lake Water Environments

The injection of oxygen microbubbles help reduce toxic substances by reinforcing nature's original self-restorative capacity.

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By increasing the number of lakes that can be used as a source of water, we can reduce the need to develop new water resources and avoid major environmental impact. However, in recent years, human activity has been steadily robbing such enclosed areas of their oxygen, and this oxygen-deficient water typically contains high levels of toxic substances such as metals and organic material. One approach to water treatment is to inject oxygen microbubbles. This dissolved gas oxidizes the metals and causes them to precipitate; the oxygen also stimulates the activity of microorganisms that break down and remove organic material. Determining the most effective and cost-efficient way to inject microbubbles was the subject of research where we found COMSOL Multiphysics made a key contribution.

Oxygen: An Inexpensive Cleaning Agent

Water "purification" means eliminating pollutants or transferring them away from the area concerned, and this has typically been done in water-treatment plants. While it's desirable to clean the water, it's also important to consider the pros and cons for the environment: if the required energy is derived from fossil fuels, the process might do more harm than good. Thus, we use oxygen, and if pollutants enter the water as a result of a natural disaster or climatic change, they can be quickly eliminated thanks to the water's high oxygen content. This is nature's original self-restorative capacity.

With the cooperation of the administrative agencies of Miyagi Prefecture, we are conducting field experiments at the Sounoseki Dam (Fig. 1). Our approach to the restoration of the water environment here involves the use of micrometer-sized microbubbles. A very large number of microbubbles results in a greater air-liquid interface area for the same volume of gas. Moreover, the smaller the bubble, the greater its internal pressure. These characteristics can be used to promote efficient dissolution of the gas held in the bubbles into the water. Furthermore, because the buoyancy force acting on microbubbles is small, they rise to the surface very slowly and can remain in the water for several minutes or even hours, allowing the dissolution of the gas to continue. In our experiments we create microbubbles through the high-speed mechanical agitation of water to which a gas is added (Fig. 2).

Fig. 2. Microbubble generator on the site.

Figure 1. Field experiments at the Sounoseki Dam.

Reservoirs and dams may contain anywhere from several hundred thousand to several million cubic meters of water. Oxygenating this much water requires a huge quantity of microbubbles. Even so, this does not mean that huge amounts of energy are required. For instance, in the validation field experiments we are conducting at the Sounoseki Dam, only 2 - 5 liters/minute of air are required for a lake containing a million cubic meters of water. We have been able to confirm that this rate of oxygenation has improved water quality with a sharp fall in the levels of toxic substances such as nitrogen, phosphorus, iron and manganese.

Multiphysics in the Water

In these trials, it is necessary to predict all the environmental phenomena that might affect the body of water (wind, water flow, temperature, chemical reactions, and diffusion). In particular, we must consider the way in which winds raise waves on the water surface; these, in turn, create currents. We then study how these currents stir up the sediment and alter water quality. The equations that govern these phenomena must all be solved simultaneously. In other words, this is a typical multiphysics problem. To deal with them, we have been using COMSOL's powerful multiphysics analysis technology as well as the CFD and Chemical Reaction Engineering modules.

This software has helped us to decide where, and at what depth and at what speed to introduce the microbubbles. As shown in Figure 3, a natural wind blowing from left to right raises waves on the surface of the water and creates currents that mix the bottom sediments. The simulated water currents in the Sounoseki Dam have revealed the existence of a large-scale recirculation region, and we utilize this current for the efficient diffusion of microbubbles throughout the entire dam (see Figures 4 and 5).

On the basis of the studies using COMSOL Multiphysics, we are currently conducting validation experiments of the oxygenation process involving large-scale test apparatus in collaboration with Institute of Ecological Engineering. Through oxygenation for a period of approximately 1 month while the reservoir was at maximum capacity (1 million cubic meters), we were highly successful in eliminating toxic substances (Fig. 6).

We intend to conduct further field experiments of this environmental restoration process in various locations with a view to the development of practical applications of the technology. These are large-scale and complex experiments, but with the support of COMSOL Multiphysics, we will continue to pursue our work. ■

About the Author

Dr. Shuya Yoshioka is Associate Professor in the Department of Mechanical Engineering, College of Science and Engineering, at Ritsumeikan University in Japan. He completed his doctorate at Keio University, and his main areas of research include the formation of nano-micro bubbles and their application, the development of efficient wind turbine system, and the control of unsteady turbulent flow.

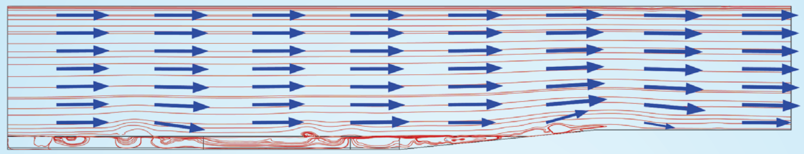

Fig. 3. Results of COMSOL Multiphysics numerical analysis of flow field within a cross-section of the reservoir bank (air at top, water at bottom, sand bank to right).

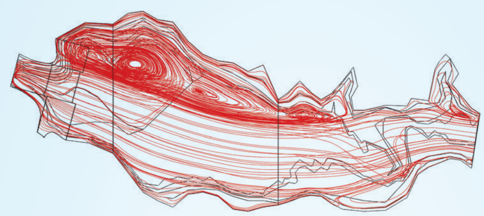

Fig. 4. Results of a simulation of currents within the Sounoseki Dam reservoir.

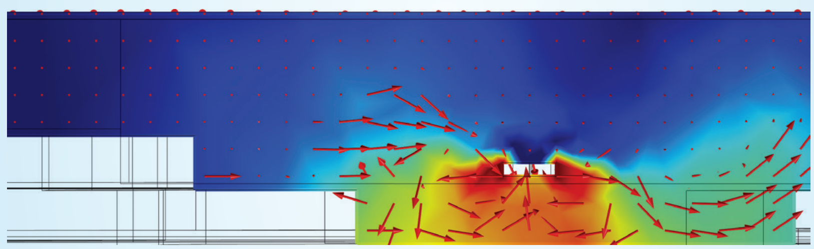

Fig. 5. Results of a simulation of mass (simulating microbubbles) diffusion over a cross-section of the Sounoseki Dam reservoir.

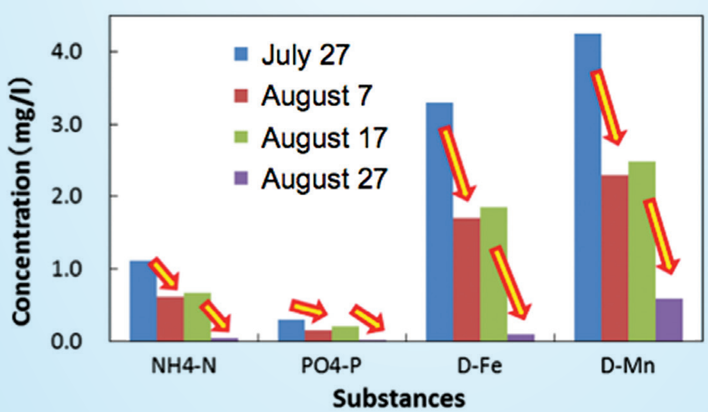

Fig. 6. The results of the trials show a reduction in the concentrations of various toxic substances (the experiment was suspended from August 7 to 17).