AERATION OF RESERVOIRS AND RELEASES USING TVA POROUS HOSE LINE DIFFUSER

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Abstract

The Tennessee Valley Authority (TVA) has developed an efficient and economical aeration diffuser design that has been installed and operated successfully at five TVA hydropower projects, one TVA nuclear plant, and two non-power reservoirs. The line diffuser design transfers oxygen efficiently and minimizes temperature destratification and sediment disruption by providing a controllable flow rate and spreading the gas bubbles over a very large area in the reservoir. TVA test results have consistently indicated oxygen transfer efficiencies of 90 to 95%. The line diffusers are installed from the surface and can be retrieved for any required maintenance without the use of divers. The diffusers can be supplied with air or oxygen, either from a bulk liquid oxygen storage tank, an onsite air separation plant, or air compressors. A forebay diffuser system can be designed to continuously aerate a large volume in the reservoir to handle peaking hydroturbine flows. Aeration in the reservoir has the potential to eliminate hydrogen sulfide, iron, and manganese in the hypolimnion.

Introduction

TVA has over 25 years of experience in the design and installation of reservoir aeration diffuser systems. Ceramic diffusers exhibited problems with clogging, breaking, and leaking at Fort Patrick Henry Dam (Ruane and Vigander, 1972; Fain, 1978). Flexible membrane diffusers caused sediment disruption and therefore increased sediment oxygen demand when operated in a close-packed diffuser design at Douglas Dam (Mobley, 1989). A need for a means to economically and practically spread small oxygen bubbles over large areas led the TVA Engineering Laboratory to investigate the use of porous hoses. A porous hose design using a 120m x 30m (400' x 100') PVC pipe frame was unsuccessfully deployed at Douglas Dam in 1991. Successive porous hose diffuser designs using 36m x 30m (120' x 100') PVC frames were successfully deployed at Douglas and 16 frames are currently in operation (Mobley, 1994). Deployment of porous hoses in a line configuration was developed to meet the aeration requirements of the deep, serpentine river channel in Normandy Reservoir. Continuing design development has led to the application of the line diffuser at six, large TVA aeration projects in support of the TVA Lake Improvement Plan, a five-year plan that included dissolved oxygen improvements in the releases of 16 TVA hydropower projects.

Line Diffuser Design

Reservoir aeration diffuser systems consist of an oxygen or air supply facility, supply piping, and diffusers (see Figure 1). The diffusers are located near the bottom of the reservoir

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Submitted to: ASCE North American Congress on Water and Environment, Anaheim, CA, June 22-28, 1996

(Figure 2). Line diffusers provide a very disperse bubble pattern to transfer oxygen efficiently and to minimize temperature destratification and sediment disturbance. The line diffusers are constructed of inexpensive and readily available materials that are suitable for contact with oxygen and long-term use underwater: the diffuser piping is rugged polypropylene; all metal clamps are stainless steel; the porous hoses are made of recycled tires; and the anchors are plastic flower pots filled with concrete.

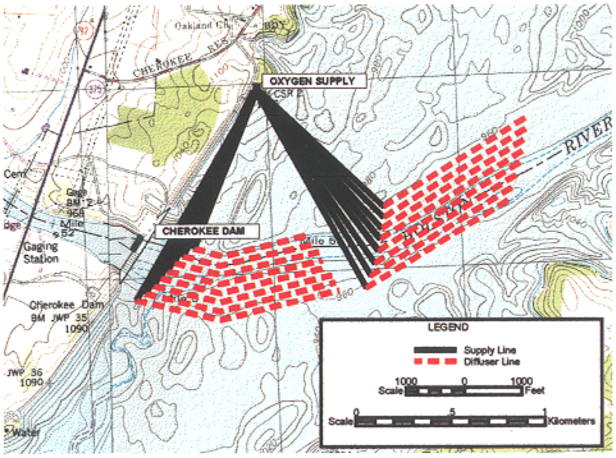

Figure 1. Line Diffuser Layout at Cherokee Dam

The line diffuser is a two pipe system, with a gas supply header pipe and a buoyancy chamber pipe, as shown in Figure 2. The diffuser can be assembled and deployed without divers because the buoyancy pipe supports the entire weight of the diffuser in water, including the concrete anchors. Once the assembled diffuser is positioned on the water surface above the desired location, the buoyancy pipe is flooded to allow the diffuser to sink in a controlled manner to the reservoir bottom. The process is reversed to retrieve a diffuser for repositioning or maintenance.

A line diffuser system can be sized to provide almost any aeration requirement with a high oxygen transfer efficiency and can easily be operated to meet changing daily requirements. The costs, however, will often escalate dramatically with each additional increment of aeration required from the system. Therefore, the aeration capacity and operation of a diffuser system should be optimized for a specific reservoir. The aeration capacity of the system must allow for organic loadings and other oxygen demands that may be present in the reservoir. The aeration capacity for large peaking hydropower projects can be minimized by designing a line diffuser system to aerate, over a 24-hour period, a reservoir volume equal to the average daily discharge of the project.

A line diffuser system can be supplied either from a bulk liquid oxygen storage tank, an onsite air separation plant, or air compressors. Liquid oxygen is often the most economical for high volume seasonal requirements, but onsite air separation plants using processes such as pressure swing adsorption are becoming more advantageous as the price of liquid oxygen increases. Installation of an onsite separation plant is expensive, but avoids dependence on liquid oxygen deliveries. Air compressors can be used to supply a diffuser system, but five times as much diffuser line length is required as for pure oxygen. Operating costs using air are most economical, but total dissolved gas and total dissolved nitrogen levels in the reservoir releases may limit the aeration capacity of the system.

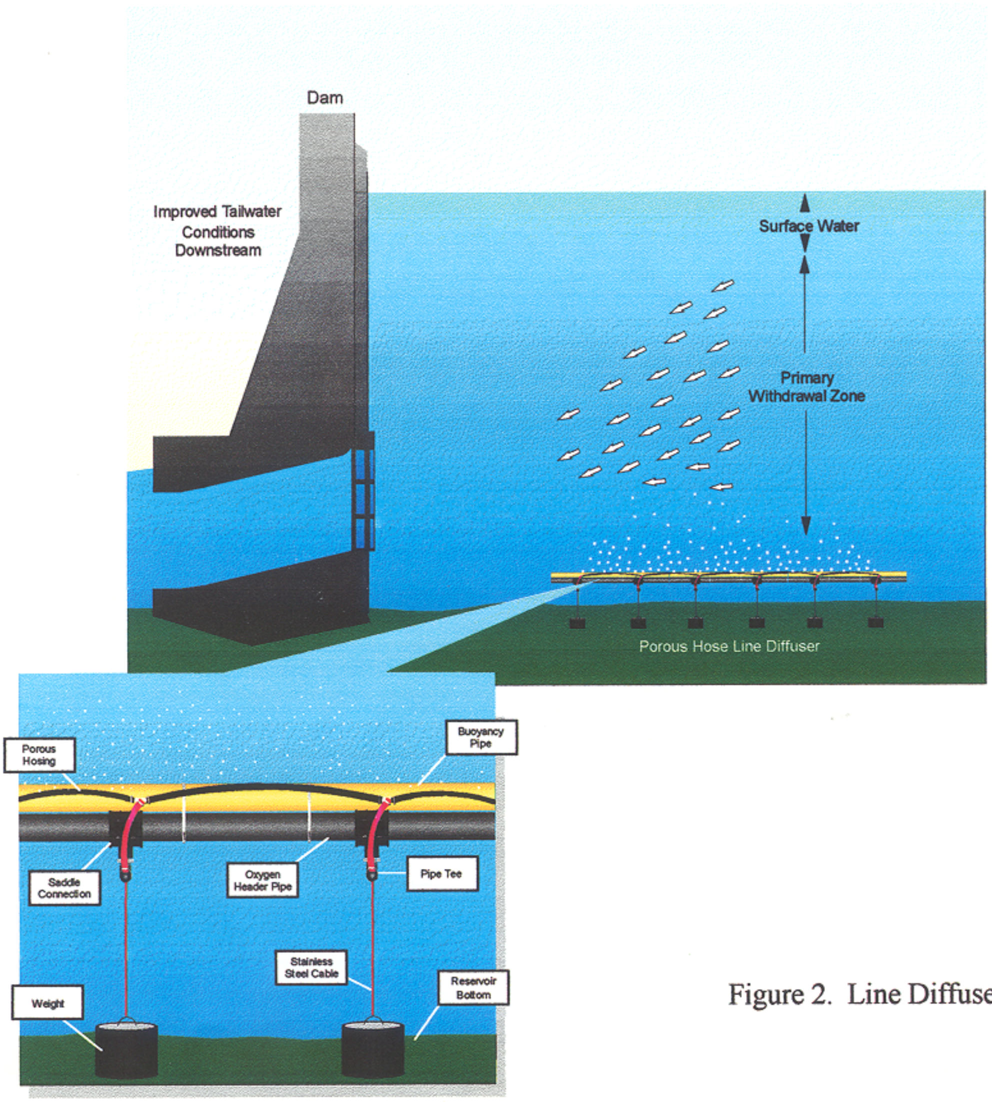

Figure 2. Line Diffuser Design

Line Diffuser Installations

TVA has installed line diffuser systems in Douglas, Blue Ridge, Cherokee, Fort Loudoun, and Hiwassee Reservoirs for aeration of hydropower releases. A total of over 25 kilometers (15 miles) of line diffusers have been installed. The largest system, located at Cherokee Dam (Figure 1), is capable of handling 136,000 kg of oxygen per day (150 tons/day). Another large oxygen diffuser installation is under construction at Watts Bar Dam. The TVA Lake Improvement Plan Task Force chose line diffusers for aeration of these projects after comparison with other alternative aeration systems.

The line diffuser has also been applied to several other projects to meet aeration requirements within reservoirs. TVA installed a line diffuser system supplied with compressed air at Normandy Dam, a non-power project, to precipitate hydrogen sulfide, iron, and manganese in the reservoir and improve the water quality of the releases from the dam. Another diffuser using compressed air was installed to provide aeration of an intake embayment at Sequoyah Nuclear Plant to prevent fishkills. A line diffuser system of TVA's design was installed in a water supply reservoir near Madrid, Spain, to reduce the treatment required for drinking water.

Installation And Operating Costs

The installation costs for a line diffuser system have been minimized by using a simple design and readily available materials. The costs incurred for the installation of an oxygen supply facility will often exceed the costs of building and installing the diffusers. The following are some estimated costs for a system with a 10,000 kg of oxygen per day (12 tons/day) aeration capacity, based on TVA experience to date.

	Line Diffusers	Supply Facility	Operating
Liquid Oxygen	$300,000	$600,000	$1,800/day
On-Site Oxygen	$300,000	$1,000,000	$450/day
Compressed Air	$1,200,000	$400,000	$300/day

These estimates could vary dramatically due to site-specific considerations.

Results

In four years of operating experience, TVA has obtained satisfactory results in the operation of the line diffuser systems. The porous hoses have maintained their bubble pattern and have proven to be resistant to clogging and damage. Reservoir water quality profiles have displayed dramatic increases of dissolved oxygen in the hypolimnion with insignificant disruption of thermal stratification. Representative reservoir profiles upstream and downstream of the oxygen diffuser installation at Cherokee Dam are shown in Figure 3. Several profiles along the length of the oxygen diffusers are shown for Blue Ridge Dam in Figure 4. These examples exhibit the desirable performance characteristics of the line diffusers with maximum aeration effects near the turbine intakes, and very little variation in the temperature profiles.

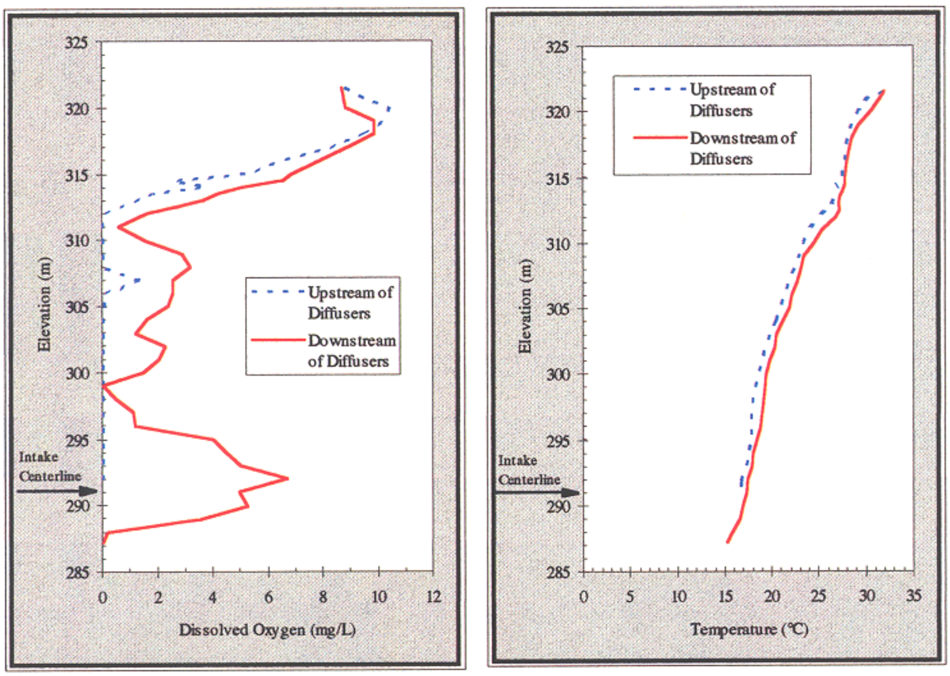

Figure 3. Reservoir Profiles at Cherokee Dam, August 14, 1995

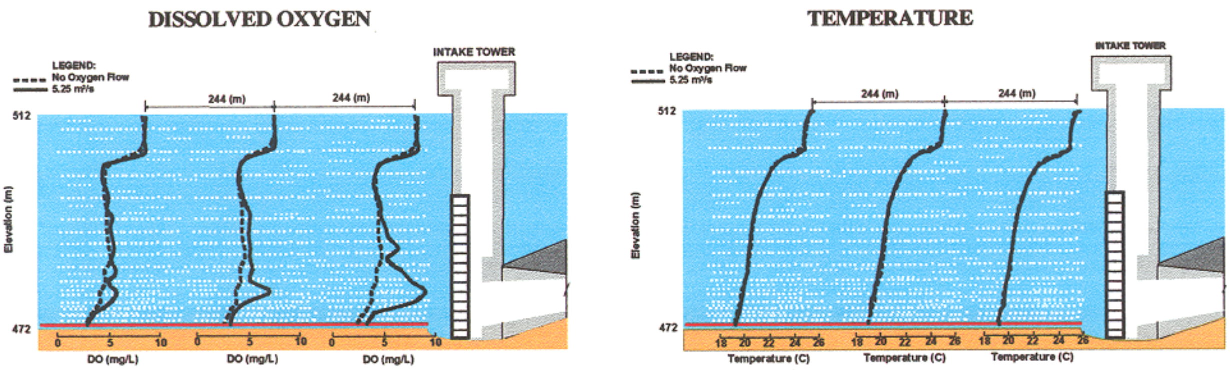

Figure 4. Reservoir Profiles at Blue Ridge Dam

The aerated hypolimnion around the diffusers can provide a cold water refuge for several fish species. The line diffuser installation at Cherokee attracted large numbers of striped bass and, consequently, striped bass fishermen (Simmons, 1995).

Dissolved oxygen improvements in the reservoir releases are the ultimate goal of the diffuser installations at hydropower projects. Results shown in Figure 5, from porous hose deployed in a square frame diffuser design at Douglas Dam, indicate a dissolved oxygen uptake of 2.3 mg/L and an average oxygen transfer efficiency of 93%. From average operating results thus far, the line diffusers at other projects are exhibiting an equivalent transfer efficiency.

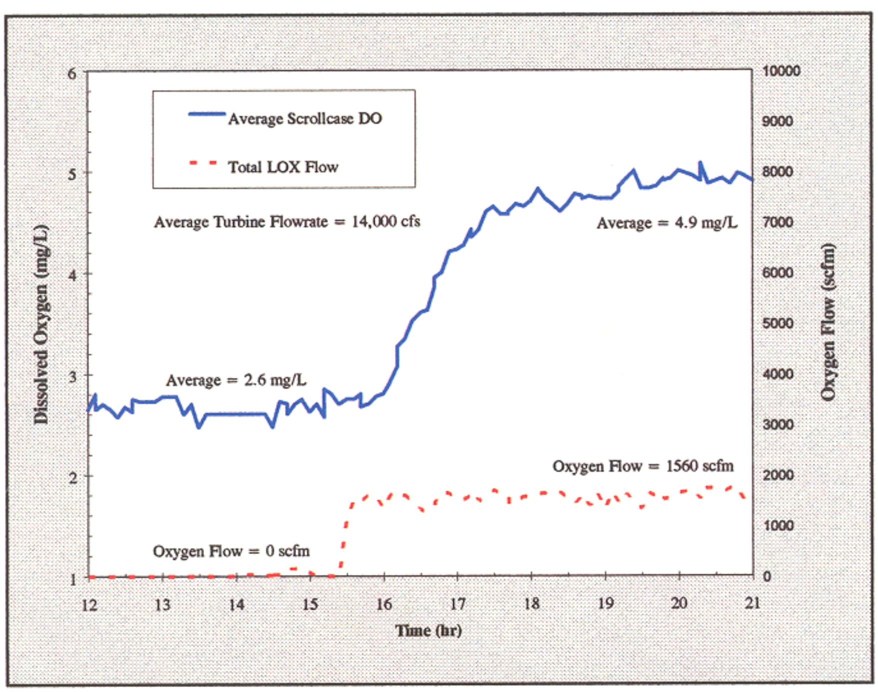

Figure 5. Porous Hose Diffuser Results at Douglas Dam, August 9, 1995

The reduction of iron concentrations in a water supply reservoir was one of the objectives of the line diffuser aeration system installed in Embalse de Pinilla near Madrid, Spain. Figure 6 presents a comparison of the total iron measurements obtained in August 1994, and after diffuser operation in August 1995 (Ruane, 1996). Total iron concentrations were dramatically reduced at the water intake elevation, 3 meters above the line diffuser. High concentrations were still evident below the diffuser elevation.

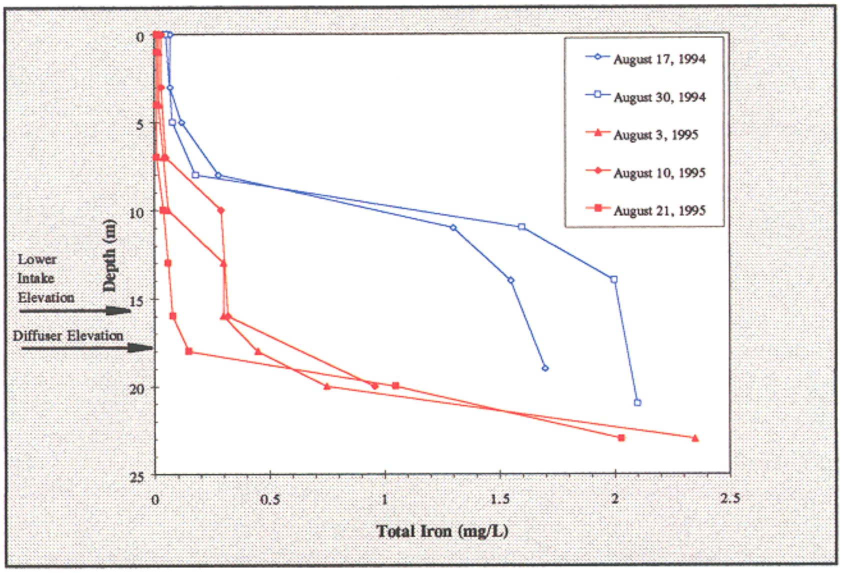

Figure 6. Total Iron Concentration, Embalse de Pinilla, Madrid, Spain

Conclusion

Line diffuser reservoir aeration systems within the Tennessee Valley and internationally have successfully achieved design goals of dissolved oxygen improvement in hydropower releases and reduction of anoxic products in reservoirs. Installation costs are economical due to the use of a simple design and readily available materials. The diffusers have demonstrated high oxygen transfer efficiencies and low maintenance requirements to minimize operating costs.

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