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DESIGN OF PNEUMATIC DIFFUSER SYSTEM

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Abstract

During non-generation periods, leakage through the wicket gates of a hydroturbine often results in very poor quality water (low or zero dissolved oxygen) in the tailrace of the hydropower facility. Generally, the leakage rate is relatively small, usually about 5-10 cfs per turbine. A bottom-mounted diffuser system was designed based on laboratory-measured and manufacturer-supplied specifications about the gas transfer characteristics of the bubble plume generated by an 11-inch flexible head diffuser. The design criteria and the overall effectiveness of the system were evaluated in field tests at Lake Eufaula, Oklahoma. The analysis of field data is reported herein.

Introduction

Low dissolved oxygen (DO) concentrations in the tailwaters of deep reservoirs with hydropower is not an uncommon occurrence. Even during non-generation periods, low DO can present a problem for managing the tailwater fishery. In most cases, the source of the low DO water is the hypolimnion of the reservoir. A number of alternatives exist that may prevent the development of low DO in the tailrace area. Some may be implemented in the reservoir, in the release structure, or in the tailrace area. The most appropriate technique must be selected based upon clear identification of the source and extent of the low DO water and upon the operational and water quality objectives of the project.

Eufaula Reservoir, located on the Canadian River in Oklahoma, is a hydropower and flood control project operated by the Corps of

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Engineers. During the summer months, low DO conditions have been reported in the tailrace area of the project. The cause was identified as leakage of hypolimnetic water through the wicket gates of the hydroturbines during periods of non-generation. The severity of the low-DO problem prompted supplemental releases through a spillway sluice as a mitigative measure. Tailwater aeration held several advantages over in-reservoir enhancement techniques. Specifically, in this technique, only the water being released is aerated rather than treating a significant volume of water in the hypolimnion.

This paper reports on the design, installation, and pilot tests of a tailwater aeration system for Eufaula Reservoir.

System Concept and Design

A floating tailwater aeration system was tested at Denison Dam (Price 1990) in north Texas. Operational considerations dictated that an alternative design be developed. The concept of a bottom-mounted flexible-head diffuser system was developed. The diffuser heads would be mounted in a structural steel member and lowered to the draft tube bottom in the bulkhead slots (Figure 1). The system would remain in place during turbine operation and only be removed for bulkhead placement, diffuser maintenance, and during the winter when the aeration system is unneeded. For Eufaula, draft tubes of the turbines are divided by a center pier; thus, two diffuser systems would be installed for each turbine, one in each bulkhead slot.

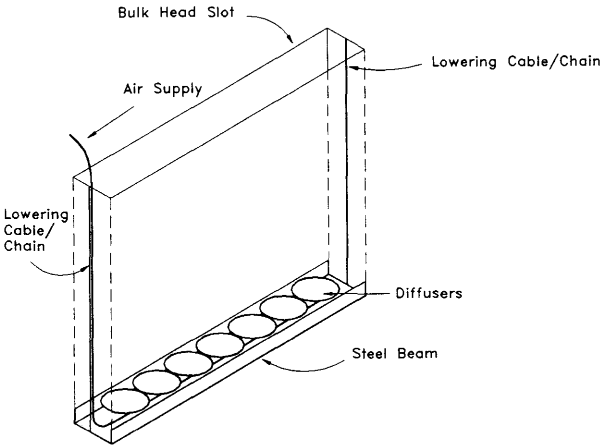

Figure 1. Conceptual design and placement of system

According to Nolen et.al. (1989), the leakage rate through the

Eufaula turbines was approximately 1 m^3/s . Since there are three turbines at the project, the total leakage was assumed to be divided equally among the three turbines. Since two diffuser systems would treat the leakage through each turbine, each diffuser system was designed with the capacity to treat approximately 0.17 m^3/s. From DO observations (Nolen 1989) the following criteria were established: DO in the leakage - 2.0 mg/l, DO required - 5.0 mg/l, and required DO uptake - 3.0 mg/l. Performing a mass balance of the required DO uptake and the leakage rate to be treated by one diffuser system indicated that 510 mg/s of oxygen would have to be absorbed to provide the required DO.

The depth of the diffusers would be approximately 12 m. According to Price and Tillman (1991), the oxygen absorption efficiency[3] for a diffuser in this depth ranges from 30 to 40 percent. Using the lower bound, the rate of oxygen supply to the diffuser system should be 1,700 mg/s. Because air is only 20 percent oxygen the rate of air supply must be approximately 8,500 mg/s. At atmospheric pressure and ambient water temperature (16 °C), this translates to an air flow rate of 420 l/m. The loading rate of the flexible-head diffuser selected for this test ranged up to 42 l/m, indicated that at least 10 diffuser heads would be required for each diffuser system.

In summary, for the required DO uptake outlined earlier, the complete system would consist of six diffuser systems: two for each of the three turbines. Each diffuser system would have at least 10 diffuser heads to deliver an air flow rate of 420 l/m.

System Fabrication and Installation

The pilot study was conducted with only one-third of the required system, i.e., two diffuser systems were fabricated and installed in the draft tube slots of one turbine. However, the pilot study diffuser systems were purposefully over-designed. Each system was fitted with fifteen 23-cm-diameter flexible-headed diffusers permitting a maximum air flow rate of approximately 630 l/m. The fifteen diffuser heads were mounted on three 5-cm-diameter PVC pipe manifolds. A 1.25-cm-diameter high-pressure hose supplied air to each manifold.

The channel beams, in which the diffuser heads were mounted, were cut to fit the width of the bulkhead slot with guides welded on each end. An alternative system is required because of the vibrational and uplift forces on the beams. Because of the experimental nature of the pilot study, the gantry crane was used to lower the diffusers in place, instead of installing a more permanent winching system.

Operation and Observations

During the field tests of the aeration system, the DO concen-

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[3] The mass of oxygen absorbed as a portion of the mass of oxygen available.

tration of the hypolimnetic leakage was lower than that used in the design ranging from 0.3 mg/l to 0.9 mg/l with a water temperature of 21.5 °C and 21.75 °C, respectively. DO concentration profiles were measured at several locations in the tailrace area just downstream of the hydropower plant. Observations were made prior to system start-up and are characterized by Figure 2. The very low DO observed below a depth of about 7 m represents the hypolimnetic leakage. The higher DO from the surface to a depth of 6 m was due to aerated releases through the sluiceway. The end sill of the tailrace area is located at an elevation approximately 6 m below the tailwater surface.

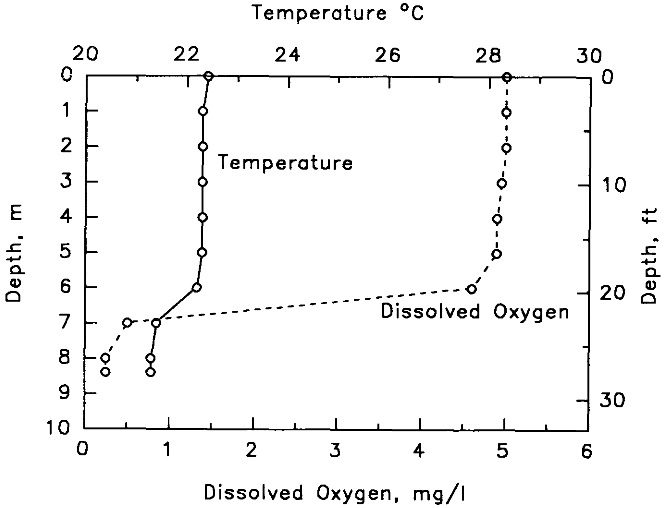

Figure 2. DO profile at tailrace end sill before aeration

The system was operated with an air flow rate of 616 l/m per diffuser system. After approximately 8.5 hours of operation with no sluiceway releases, the DO below a depth of 6 m had increased to 2.0 mg/l, while the DO between the surface and 6 m decreased to just over 2.0 mg/l (the result of losing the sluiceway's contribution to the oxygen in the surface layers. The observations are characterized by Figure 3.

Conclusions and Recommendations

The aeration system added a significant amount of oxygen to the leakage water, contributing approximately 1.7 mg/l. This represented about 36 percent of the DO required to raise the concentrations to a minimum of 5.0 mg/l. In other words, the system was approximately one-third the necessary size to accomplish the objective. In fact, an analysis using the design procedure outlined in a previous section shows that the release DO should be 2.0 mg/l, if the actual DO concen-

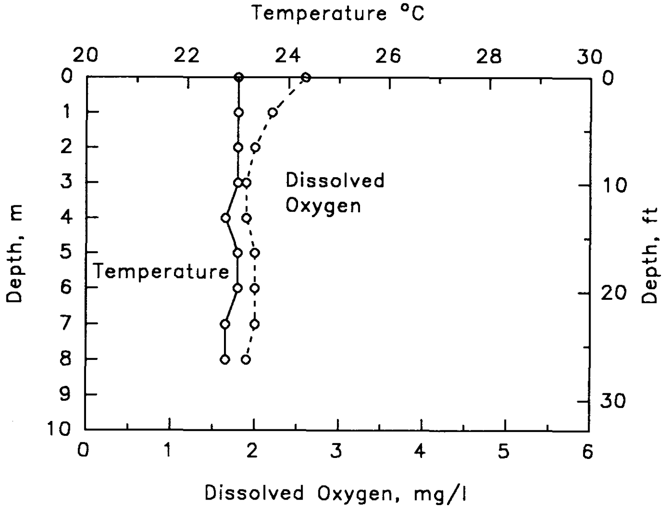

Figure 3. DO profile at tailrace end sill after 8.5 hours of aeration

tration of the leakage is 0.3 mg/l, the DO objective is 5.0 mg/l, and the air flow rate is 616 l/m. Thus, the system was performing as expected, verifying the applicability of the design procedure.

The air flow required to bring the DO of the water in the tailrace to 5.0 mg/l can be estimated at 2400 l/m. At least 80 diffuser heads would be required to deliver this air flow. From a practical perspective, a slightly over-designed system would be preferable, since it would allow more flexibility in operation and provide redundancy in the case of partial system malfunction.

A redesigned anchoring system is a requisite for a permanent installation. The channel beam proved to be inadequate for the dynamic forces and vibration to which is was subjected. An alternative winching system for raising and lowering the diffuser systems in the bulkhead slots is also required.

Acknowledgements

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