THE AERATING INFUSER FOR INCREASING DISSOLVED OXYGEN CONCENTRATIONS

Authors:
Gary E. Hauser and W. Gary Brock

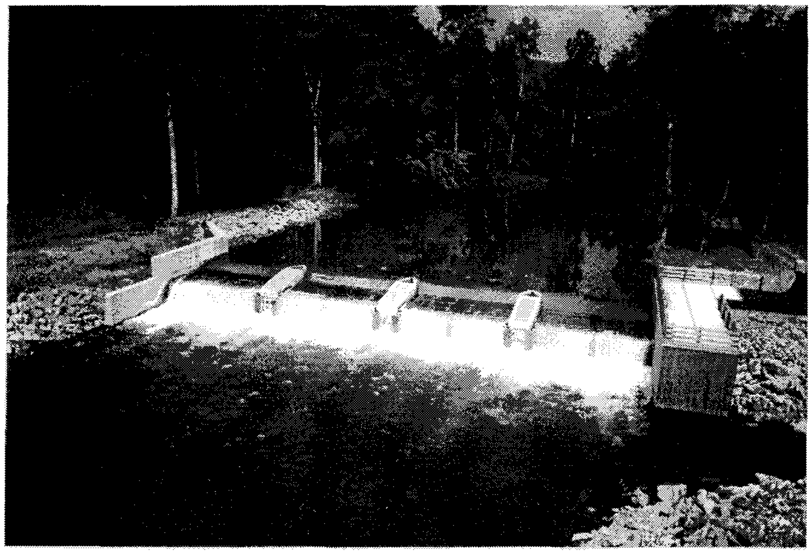
Introduction
Two of the most significant environmental impacts of hydropower dams on downstream aquatic resources in the Tennessee River Valley are low dissolved oxygen (DO) concentrations during hydroelectric generation; and lack of suitable minimum flow between generating periods. High-performance weirs are one of several technologies now considered at hydropower dams as part of TVA's Lake Improvement Plan, which is implementing various DO and minimum flow technologies at 16 hydropower dams by 1996. TVA has been developing, testing, designing, and constructing innovative aerating weirs since 1990 as one technology for meeting oxygen and minimum flow objectives.

The aeration potential of conventional weirs is well known and has been documented by numerous investigators, including Avery and Novak (1978), Kobus and Markofsky (1978), and Nakasone (1987). With weirs, aeration of oxygen-deficient turbine releases is achieved during generation by water overtopping the weir and plunging into a downstream pool in a process similar to natural waterfalls. Minimum flow is sustained downstream of the weirs during periods of no generation by slow drainage of the weir pools through low-level pipes fitted with float-actuated valves. These valves open gradually as the weir pools drop, maintaining constant flow from the weirs over the drain cycle.

Aerating weirs are attractive compared to in-reservoir and in-hydroplant aeration methods because they are passive, reliable, low maintenance, free from turbine cavitation damage, and capable of meeting both DO and minimum flow objectives with a single technology. Weirs aerate flow from the dam regardless of outlet of origin (when constructed from bank to bank), in contrast to in-plant methods requiring individual treatment of each outlet with potential for low DO releases. A weir's foremost operational impact on power costs is from a loss of effective turbine head created by backwater from the weir, but this loss can be minimized by siting the weir sufficiently downstream and by using gates to enable flow through rather than over the weir during the high DO season when aeration is not needed.

TVA research has focused on ways to improve weir aeration beyond that of conventional weirs while maintaining safe flow conditions in the vicinity of the structure. TVA has designed, constructed, and tested two different kinds of aerating weirs: 1) the labyrinth, which assumes a "W" shape in the channel; and 2) the infuser, which has equivalent waterfall length to a labyrinth, but is constructed within a much more compact area, and which resembles the shape of a broadcrest weir. The use of labyrinth weirs for aeration has been previously described by Hauser, et al. (1993a, 1993b). This report focuses on the developmental features, advantages-disadvantages, and performance results of the infuser, which is the more recent innovation in aerating weir technology. The infuser is designed to occupy much less space in the channel than a labyrinth, and it is more cost-effective than the labyrinth in high flow applications. The labyrinth, however, can be more cost-effective in low flow applications. As will be discussed later, both weir types have unique advantages and disadvantages that determine their relative economy and suitability in particular applications.

Figure 1 shows TVA's prototype infuser weir below Chatuge Dam, on the Hiwassee River, with and without turbine flow.



a) during generation

b) between generating periods

Figure 1. Photographs of Chatuge Infuser Weir

Description of Chatuge Infuser Weir

An infuser is, in essence, a hollow, broadcrest weir with specially-designed transverse openings in its crest that create a series of transverse water curtains that fall through the crest to a plunge pool beneath the crest. The Chatuge prototype infuser employs a slotted infuser deck attached to the downstream face of a conventional linear weir to achieve these flow patterns, as shown in the elevation view in Figure 2. The weir component is a stepped timber crib filled with loose rock and lined with tongue-and-groove timbers along its upstream face to make it impermeable. Timbers are also used to support the steel foot grating on the attached infuser deck. The spaces between the deck timbers allow flow through, creating a series of turbulent waterfalls during hydrogeneration. These deck openings increase in size in the downstream direction to maintain approximately uniform flow in each as the head on each opening decreases in the downstream direction. The timbers creating the blockages between deck openings are supported by concrete beams and columns.

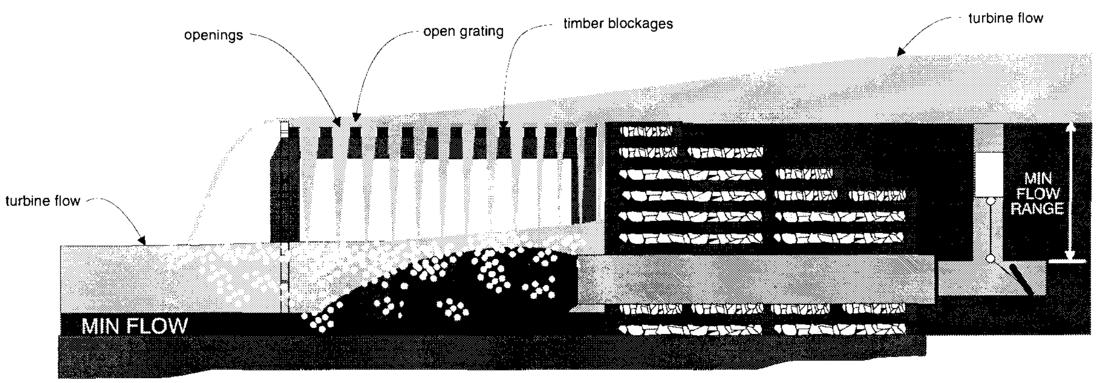


Figure 2. Chatuge Infuser Weir - Elevation View

The steel foot grating overlying the infuser deck prevents footfall into the deck openings for boaters and others who may venture on to the infuser deck. However, the grating plays a significant additional role for aeration. The grating creates water curtains that are highly turbulent compared to the laminar nappes characteristic of free overfall weirs. This turbulence creates higher nappe perimeter to flow ratios that increase aeration efficiency as the water curtains impinge on the plunge pool. Rising, coalescing bubbles are re-entrained and re-sheared again and again by successive water curtains along the bubble flow path in a very turbulent plunge pool.

The aeration chamber beneath the infuser deck is ventilated using open chimneys that punctuate the infuser deck in three locations and using additional vents in the two abutments. These five air pathways allow air to circulate freely with minimal losses from the atmosphere to the areas between the water curtains. Unauthorized access to the area under the infuser deck is prevented via the tubular steel cage on the downstream face of the infuser. This area is accessible for maintenance during minimum flow via a gate in the tubular steel cage.

Important geometric and hydraulic characteristics of the Chatuge prototype infuser weir are given in Table 1.

Table 1. Physical Characteristics of TVA Prototype Infuser (Chatuge)

distance downstream of hydropower dam (km)	1.2
channel width at weir site (m)	35
crest height (m)	2.9
overflow crest length (m)	30.8
drop height (m) headwater to tailwater	2.1
turbine discharge (m^3/s)	37
specific discharge (m^2/s)	1.2
head on crest at turbine discharge(m)	0.76
plunge pool depth - turbine flow (m)	1.8
minimum flow target (m^3/s)	1.7
drain time between pool refills (hr)	13

Performance of Chatuge Infuser Weir

The infuser weir below Chatuge Dam has demonstrated encouraging aeration results in recent performance tests. Aeration tests of this weir have shown that 65-70 percent of the oxygen deficit is recovered at turbine discharge flow. Figure 3 shows results of a recent aeration test using continuous DO monitors located in mid-channel upstream and downstream of the infuser weir. These results show that the aeration efficiency reduces to between 30-40 percent of the deficit during the hours that the turbines are off, when water from the weir pool is being released through the low-level pipes for minimum flow maintenance. Although the aeration efficiency is reduced during minimum flow, shallow channel depths cause the minimum flow to aerate rapidly shortly downstream of the weir.

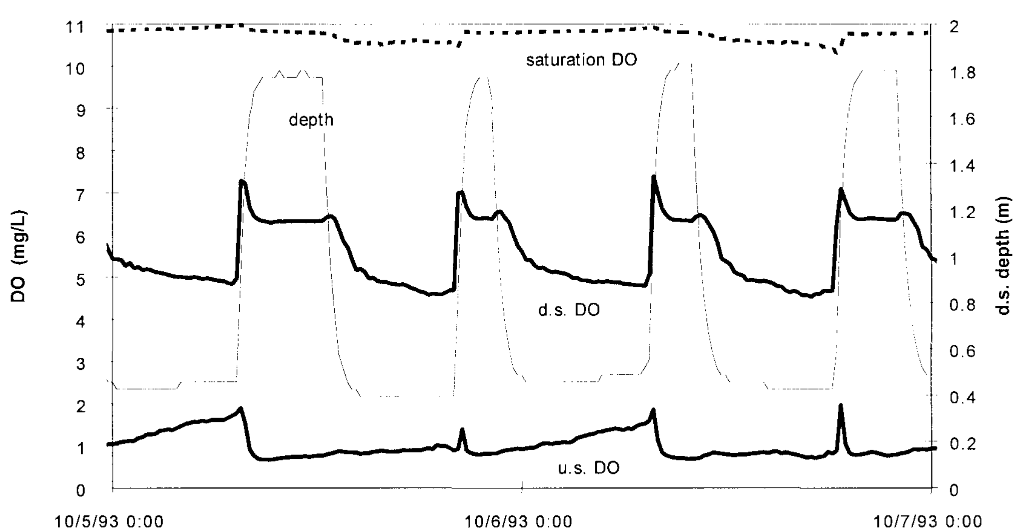


Figure 3. DO Measurements Above and Below the Chatuge Infuser

At this writing, available performance data for infusers is limited to that from field testing of TVA's prototype infuser below Chatuge Dam by Hauser (1993) and from TVA laboratory tests conducted by Rizk and Hauser (1992). An analysis of the combined results from these tests has shown the infuser aeration efficiency to be predictable across the range of hydraulic parameters tested to within about 10 to 20 percent accuracy. Equations describing the aeration potential are being developed by TVA, and they should provide a useful tool for preliminary design in the future. However, laboratory aeration and hydraulics testing at near full-scale conditions over the range of flow conditions that the weir will experience are recommended prior to design and construction of a prototype.

Important parameters from infuser investigations thus far appear to be stream power per wetted length (upstream to downstream) of infuser deck and the total discharge per wetted area of the infuser deck. One might also expect the grating material to affect aeration beyond the effect of stream power and deck flux noted here. However, TVA tests focused largely on standard steel foot grating. Thus, there was not enough range in grating variables in the TVA tests to provide such distinction in the predictive equation beyond their indirect influence on deck flux. When tests were run with other grating materials, results were similar to those obtained using predictions with the deck flux and stream power variables.

Summary and Conclusions

The infuser is capable of safely aerating much higher turbine flows than the labyrinth, because the labyrinth length (i.e., cost) required to maintain a safe specific discharge becomes excessive at turbine discharges in the range of several hundred m^3/s. Operating costs with the infuser can be higher than the labyrinth due to the hydraulically less efficient infuser crest, which induces greater backwater on the turbine and greater property inundation during flood flows. The infuser deck grating also has a tendency to clog with leaves during the fall and with other debris like tree branches throughout the year, requiring frequent cleaning; while the labyrinth weir has operated with little or no such maintenance.

The labyrinth has a more efficient overflow than the infuser (i.e., more flow per unit head), and can therefore be located closer to the hydropower dam with less penalty in backwater on the turbine. The labyrinth has little effect on property inundation during high flows because the weir tailwater increases more quickly than the weir headwater, causing complete submergence of the structure at lower heads. The labyrinth is generally considered more aesthetically pleasing by the general public due to its extended waterfall length.

The substantial crest length required for a labyrinth is necessary to reduce the specific discharge to a level that reduces the intensity of the downstream recirculation, or "roller", to a safe level. The required labyrinth crest length is that needed to yield a safe specific discharge--i.e., turbine flow divided by the "safe" specific discharge of 0.14 m^2/s (Hauser, 1991). In contrast, the infuser crest length is approximately the channel width. The labyrinth crest length required for safety can therefore easily be ten times that of an infuser. However, the construction cost per unit crest length of infuser is about ten times that of a labyrinth. Labyrinths are well-suited, therefore, for low specific discharge applications, while the infuser is well-suited for high specific discharge applications.

Experience with the South Holston labyrinth and the Chatuge infuser has revealed a rough rule of thumb, regarding the relative cost of these two weir types, that may be useful for evaluating them at other sites. Based on cost per unit length comparisons and crest length requirements, a labyrinth will typically be more economical than an infuser in situations where the channel specific discharge (turbine flow divided by channel width at weir site) is *less than* 0.9 m^2/s (10 ft^2/s), while an infuser will be more economical when the specific discharge is *greater than* 1.9 m^2/s (20 ft^2/s). In the midrange between these two thresholds, either of these two types can prove to be the more economical, depending on site-specific factors and how the weir is constructed.

For a given drop height (headwater to tailwater), labyrinth and infuser weirs can achieve similar aeration efficiencies in the turbine flow ranges studied. As constructed, the Chatuge infuser aerates better (65-70 percent of the deficit) than the South Holston labyrinth (55-60 percent of the deficit) due to its higher drop height (2.1 m at Chatuge infuser compared to 1.4 m at South Holston labyrinth). The South Holston labyrinth actually provides more aeration per unit drop height than the Chatuge infuser (42 percent per m at South Holston compared to 32 percent per m at Chatuge). Also, the South Holston turbine flow is about twice that at Chatuge.

Laboratory and field investigations of the infuser indicated an important relationship between aeration efficiency (fraction of oxygen deficit that is removed by weir aeration) and deck flux. For each plunge pool depth, there exists a deck flux for which aeration efficiency is maximized. The optimal aeration efficiency increased with tailwater depth in the TVA tests, as did the deck flux at which the optimal efficiency occurred. These results suggest that where the weir tailwater is sufficiently deep, a shorter, more open (higher flux) infuser deck may achieve better aeration via its tendency to drive the bubbles deeper and use the full tailwater depth. However, if the tailwater depth is shallow, a longer, less open (lower flux) infuser deck may be necessary to achieve optimal aeration. Further research over a wider parameter range is appropriate to help confirm the significance of these early indications.

Related Investigations

As a host utility and contractor to EPRI, TVA is conducting laboratory tests, conducting field tests of recent prototype aerating weirs, and developing design procedures that will culminate into an aerating weir design manual for utilities. Laboratory tests include crest modifications to safely allow higher specific discharges over labyrinth weirs without aeration penalty, exploration of the effects of plunge pool depths, and the effects of labyrinth shape. Field tests include South Holston labyrinth (TVA), Chatuge infuser (TVA), Canyon Dam labyrinth in Texas (Guadalupe-Blanco River Authority), and the Lloyd Shoals labyrinth in Georgia (Georgia Power). This three-year project is scheduled for completion in December 1995. An interim manual will be completed shortly, and the final manual is scheduled for early 1996. A follow-up project to conduct broader laboratory testing and to develop improved design procedures specifically for the infuser technology has been proposed as a tailored collaboration project among various utilities and EPRI.

TVA's Lake Improvement Plan program is continuing to monitor, maintain, and document performance and unique operating characteristics of the South Holston labyrinth and the Chatuge infuser weirs. This program will shift its emphasis from implementation to operation and maintenance after 1996.

References

Avery, S. and P. Novak (1978), "Oxygen Transfer at Hydraulic Structures," J. ASCE Hydraulics Division, November.

Hauser, G. (1993), field test results from Chatuge infuser, October.

Hauser, G. and W. G. Brock (1993a), “Aerating Weirs for Management of Reservoir Releases,” North American Lake Management Society Proceedings from 1993 NALMS Symposium, Seattle, Washington, December.

Hauser, G., W. Proctor, and T. Rizk (1993b), “Performance of Prototype Aerating Weirs Downstream from TVA Hydropower Dams,” Hydraulic Engineering ‘93 Conference of ASCE Hydraulics Division, San Francisco, California, July.

Hauser, G. (1991), "Full-Scale Physical Modeling of Plunge Pool Hydraulics Downstream of a Vertical Weir," TVA Engineering Laboratory, Report No. WR28-1-590-153, Norris, TN.

Markofsky, M. and H. Kobus (1978), "Unified Presentation of Weir-Aeration Data," J. ASCE Hydraulics Division, April.

Nakasone, H. (1987), "Study of Aeration at Weirs and Cascades," J. Environmental Engineering, February.

Rizk, T. and G. Hauser (1992), "Chatuge Aerating Infuser Physical Model Study," TVA Engineering Laboratory, Report No. WR28-1-17-101, Norris, TN, June.

Author Biographies

Gary E. Hauser is responsible for technical leadership of a team of water quality modelers at the TVA Engineering Laboratory in Norris, Tennessee, which is operated by Hydraulic Engineering, a part of TVA Resource Group. Mr. Hauser has been involved with design and testing of operational and hardware solutions for reservoir release improvement, including reservoir and tailwater quality modeling and weir design leading to the development of TVA’s South Holston labyrinth and Chatuge infuser weirs. Mr. Hauser is currently involved in a three-year project sponsored by the Electric Power Research Institute to develop aerating weir design procedures for utilities.

W. Gary Brock is responsible for management of TVA’s Lake Improvement Plan, which is a $50 million program that is implementing oxygen and minimum flow improvements at 16 hydropower dams, scheduled for completion in 1996. This program performs development, testing, and implementation of aeration and minimum flow devices in the reservoirs, hydroplants, and tailwaters of hydropower facilities. Mr. Brock has been involved for many years with optimization of TVA’s multipurpose, integrated reservoir and power systems, hydropower planning, and modernization of TVA’s hydropower facilities.