

**Discussion of “Influence of Included Angle and Sill Slope on Air Entrainment of Triangular Planform Labyrinth Weirs” by M. Emin Emiroglu and Ahmet Baylar**

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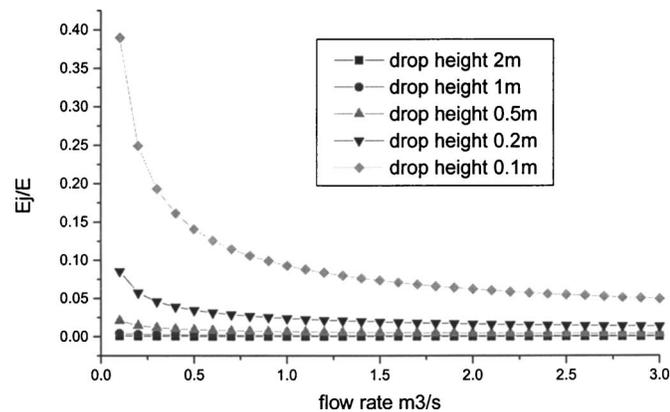
The authors are to be complimented on presenting the results of carefully conducted experiments on this important topic. The objective of the study is related to the oxygen transfer process associated with weir flow. Some comments might be added on the authors’ discussion and analysis of their results. These comments are concerned mainly with the oxygen transfer performance of a weir through air entrainment by plunging water.

The oxygen transfer through the bubble entrained by the plunging water can be estimated by using the authors’ experimental data. In this discussion, we estimate the aeration performance of a rectangular weir by using Emiroglu and Baylar’s data on the air entrained into the flume by weir falling water and compare it with the total aeration performance of the rectangular weir. The empirical correlation predicting the air entrainment rate developed for rectangular weirs, as given by Emiroglu and Baylar in the paper, is

$$Q = 0.0033 \cdot 1.193 \cdot q^{0.166} h^{1.955} \quad (1)$$

where  $Q$ =air entrainment rate in cubic meters per second,  $q$ =weir discharge in cubic meters per second, and  $h$ =drop height in meters.

P. D. Cummings, and H. Chanson (1997) reported a broad range for the size of the bubble entrainment by plunging jets, but they are mostly larger than 1 mm at a jet velocity of 2–8 m/s when the jet is plunging into the water. The size is similar to the bubbles created by plunging water over a weir. The aeration



**Fig. 1.** Ratio of standard oxygen transfer efficiency of weir between air entrainment process and total

caused by the bubbles thus created could be regarded as fine bubble (2–6 mm) aeration, as in wastewater treatment. According to U.S. Environmental Protection Agency (USEPA 1989), the standard oxygen transfer efficiency of fine bubbles (which is defined as the percentage of the oxygen transfer to water by bubbles in standard condition in wastewater treatment) is about 4.5% for a one-meter depth. So the DO in the flume water through air entrainment by plunging water can be estimated as

$$C = Q \cdot 1.225 \cdot 0.001 \cdot 0.21 \cdot 4.5 \% \cdot 2H/q \quad (2)$$

where  $H$ =average depth of air entrained into the flume. Since the optimum depth of the tailwater is about  $2h/3$ , according to Avery and Novak’s (1978),  $H$  can be estimated as half of the optimum depth of the tailwater; and the oxygen transfer efficiency of the weir through air entrainment by plunging water can therefore be estimated as

$$E_j = C/C_s = 0.0033 \cdot 1.193 \cdot q^{0.166} h^{1.955} \cdot 1.225 \cdot 0.001 \cdot 0.21 \cdot 4.5 \% \cdot 2 \cdot h/3/q / (9.17e-6) = 0.0033q^{-0.834}h^{2.955} \quad (3)$$

Avery and Novak’s formula, which is the best empirical formula for estimating the total oxygen transfer efficiency of the weir, indicates that the total oxygen transfer efficiency,  $E$ , of the weir is

$$E = 1 - [1 + 0.233H^{1.335}q^{-0.36}]^{-1} \quad (4)$$

The percentage of the oxygen transfer through air entrainment to the total oxygen transfer is  $E_j/E$  and can be calculated as shown in Fig. 1. In the low drop weir, the oxygen transfer through air entrainment is less than 25% of the total oxygen transfer efficiency when the flow rate is more than 0.1 m³/s. High oxygen transfer efficiency is obtained at a high dropping height and low flow rate. In this case, the water flying through the air provides high oxygen transfer efficiency as a result of nearly saturated dissolved oxygen content. Using experimental weir aeration data such as that of Wormleaton and Tsang (2000), which are similar to the authors’ experimental data about air entrainment, to replace Avery and Novak’s formula would give similar results. So the authors’ results show that air entrainment by plunging water is not very important in the aeration performance of the weir. This result may support the view of Novak (2003) that various three-dimensional effects introduced by the shape and width of the downstream pool may sometimes influence the aeration results more than the downstream depth.

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The writers thank the discussor for his interest in the topic and for his comments.

Empirical correlations predicting the air entrainment rate,  $Q_A$ , of triangular labyrinth weirs are given in Eqs. (1) and (2)

$$Q_A = 1.128Q^{0.696}h^{1.074}0.095^{\cos(\phi)}1.154^{\sin(\theta)} \quad \text{for } 22.5^\circ \leq \phi \leq 45^\circ \quad (1)$$

$$Q_A = 0.0033q^{0.166}h^{1.955}1.193^{\cos(\theta/2)} \quad \text{for } \phi = 0^\circ \quad (2)$$

where air entrainment rate  $Q_A$  is in cubic meters per second; weir discharge  $Q$  is in cubic meters per second; the drop height  $h$  is in meters; the weir sill slope  $\phi$  and the weir-included angle  $\theta$  in triangular labyrinth weirs are in degrees; and unit discharge  $q(q=Q/2b)$  is in  $m^2/s$ .

For a rectangular weir, substituting  $\theta=180^\circ$  into Eq. (2) yields

$$Q_A = 0.0033q^{0.166}h^{1.955} \quad (3)$$

There is an erratum in the equation given by the discussor. Thus, all analyses carried out by the discussor should be revised.

The discussor used U.S. Environmental Protection Agency (USEPA 1989) reports to determine the oxygen transfer efficiency of rectangular weirs. However, USEPA (1989) reports are related to design information on fine pore aeration systems. Fine pore aeration systems are upflow-type systems. However, weirs are downflow-type systems. In downflow-type systems, air bubbles are forced to move in a direction opposite to their buoyancy. These systems have the advantage that the air residence time is longer than that in upflow-type systems and that there is higher contact efficiency between gas and liquid. Thus, the equation given by USEPA (1989) cannot be used in weir aeration.

The discussor stated that air entrainment by plunging water is not very important in the aeration performance of the weir. However, Baylar and Bagatur (2000), Baylar and Bagatur (2001a,b), Baylar et al. (2001a,b), Baylar (2002), and Baylar and Bagatur (2006) revealed that air entrainment played a significant role in the aeration performance of the weir.

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## Discussion of "Open Channel Flow through Different Forms of Submerged Flexible Vegetation" by C. A. M. E. Wilson, T. Stoesser, P. D. Bates, and A. Batemann Pinzen

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The authors present a very important paper that discusses ecological hydraulics issues at a vegetated stream. They investigated the effect of submerged vegetation on the turbulence intensities in a water flow at an open channel with different flow depths and different plant simulations (with rod canopy and rod/frond canopy). In their flume study, the authors used *Laminaria hyperborea* for a model plant. This plant is found on bedrock or other stable substrata from extremely shallow water to depths that are dependent on light penetration and sea urchin grazing. The plant grows as dense forests under suitable conditions (Tyler-Walters 2003). This plant lives in the seas or forests, so are these plants suitable for simulating to the river and wetland vegetation? Indeed wetlands and rivers are completely different systems, that is, flow velocity in wetlands is very low and usual flow depths vary between 1 and 50 cm (Tsihrintzis and Madiedo 2000).

Vegetation is a channel boundary and has a resistance coefficient that varies with its physical condition (type, age, and density) (Yen 2002). The physical condition directly influences the water flow rate, which is one of the main important parameters during the design period of a hydraulic structure. Flow velocities are usually very low in vegetated areas or wetlands compared with in rivers, so turbulent characteristics become important be-

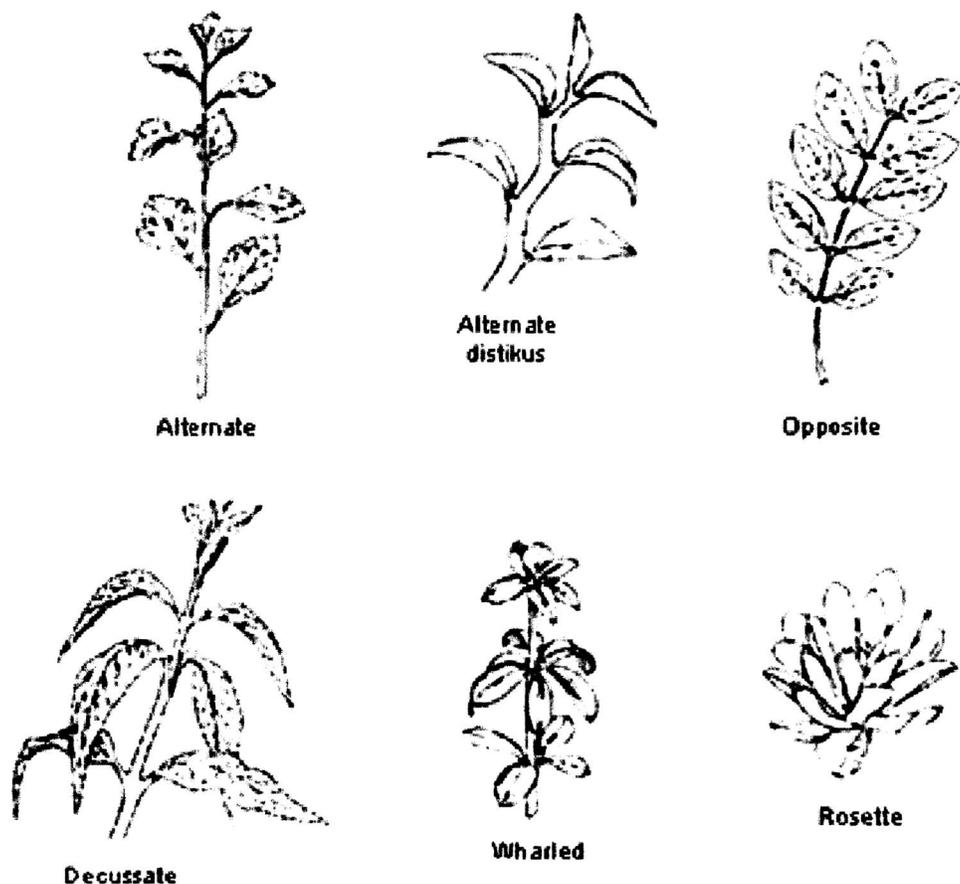


Fig. 1. Leaf arrangements in a plant (Ketenoglu et al. 1999, used with permission)

cause of the sediment deposition and erosion in the vegetation zone (Cokgor et al. 2003). In the literature, hydraulic studies about vegetation generally focused on wetland's plants (e.g., sedges, marshes, stems) because of the constructed wetlands establishments and on estimating the flow resistance that occurs because of interaction between the flow and plants.

In the paper, the authors state that "While here we use a marine species as a model plant, the simulated vegetation does bear a morphologic and biomechanical resemblance to commonly encountered riverine plants."

Plant diversity is a very complex phenomenon: climate, elevation, and soil structure have a great influence on plant species distributions. Even leaf arrangements and sizes vary over a wide range (Fig. 1). How can one kind of coastal plant represent such riverine plants as *populus*, *salix*, and *Polypodiaceae e.x.*

Also in the conclusion, the authors state "Dunn et al. (1996), Fairbanks and Diplas (1998), and Nepf (1999) are the only examples we have found . . . in the goal of building up a general picture of the interaction of flow with vegetation." The authors did not mention Jarvella's study (2002), which is a very detailed study that is concerned with the vegetation simulation. Jarvella (2002) investigated the effect of the vegetation on the flow properties (e.g., the Darcy-Weisbach number and the Reynolds number). Jarvella used real plants like willows, grasses, and sedges. He concluded that plant density increases the flow resistance by a factor of 2, whereas plant leaves increase it by nearly a factor of 3. In our perspective, in the present study, the authors deduce conclusions over too broad an area.

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We thank the discussers for their comments and appreciation of our work on the impact of plant forms on the velocity and turbulence structure in flexible submerged vegetation.

Most of the work conducted so far that has examined the momentum transfer between the vegetated and surface flow regions in submerged simplified vegetation has focused on one plant morphologic form per experimental study. Our study aimed to explore and compare the effect of two forms of flexible vegetation on the turbulence structure within the submerged canopy and in the surface flow region. We chose two simple plant structures: a rod and a rod with leaf canopy. The rationale was to look at simplified plant forms that are less complex than the morphological structures of natural aquatic plants but that display features intrinsic to them. Although *Laminara hypnorea* is a marine species, its simple physical structure, comprising a stipe (rod) and a single frond (leaf), does contain the basic elements of the plant species shown in Fig. 1 of the discussion by Kucukali and Cokgor and does, in our opinion, bear a resemblance to them. We do not claim that this model plant is representative of all riverine plants, such as the tree species *salix* and *populus* mentioned by the discussers, but that it is representative of a class of aquatic macrophytes and provides a good starting point in attempting to understand the complex phenomenon of velocity structure in submerged vegetated flows.

The advantage of using a real model for an aquatic plant, rather than an oversimplified model, is that it can highlight and address the scaling issues involved in using simulated plants to model real plants, with particular reference to the scaling of both the plant geometry and bending stiffness. The few experimental studies that have been conducted on flexible vegetation have generally not documented the bending stiffness or flexural rigidity of the simulated plants and how to scale them from real vegetation. Further, our paper outlines methods that were used in quantifying these parameters. The paper provides a new data set in this relatively unstudied area and complements the limited number of

existing studies (Dunn et al. 1996; Fairbanks and Diplas 1998; and Nepf and Vivoni 1999 are the only examples that we have found) with the goal of building a general picture of the velocity and turbulence structure in submerged scaled vegetation.

The discussers also draw attention to the study of Jarvela (2003), although this study appeared while our article was in press. Both Jarvela (2003) and Stephan and Gutknecht (2002) have examined the velocity profile in different forms of natural vegetation; and in combination with the work we have presented, they demonstrate the growing importance of this area of hydraulics research. Jarvela (2002) has shed light for the first time on unanswered questions relating to the impact of plant density and foliage on flow resistance; however, this approach is a one-dimensional one and is based on the area-mean velocity. In contrast, our work has examined the effect of different levels of submergence on the variation of velocity and turbulence with depth. We focused particularly on how simple plant form structures affect the momentum transfer between the plant canopy and the surface flow region above. Experimental results reveal that within the plant layer the velocity profile no longer follows the logarithmic law profile, and the mean velocity for the rod/frond canopy is less than half of that observed for the simple rod array. In addition to the mean flow field, the turbulence intensities indicate that the additional superficial area of the fronds alters the momentum transfer between the within-canopy and surface flow regions. Although the frond foliage induces larger drag forces, shear-generated turbulence is reduced because of the inhibition of momentum exchange by the frond surface area.

In conclusion, the interaction of flow and vegetation is an area deserving of much further study and is certainly one that cannot be tackled comprehensively by a single paper. Rather, recent studies have begun this process, and we encourage other researchers to build on these results with further theoretical, experimental, and modeling work

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