WEIR AERATION: MODELS AND UNIT ENERGY CONSUMPTION[a]

Discussion by Hubert Chanson[4]

The authors' paper is based on empirical correlations for the flow aeration [i.e., (3)–(6)]. The discusser wishes to comment on the basis of these correlations because they do not take into account the hydraulics of the flow.

The most simple flow situations above a weir are the flow above a smooth weir [Fig. 5(a)], the nappe flow regime above a stepped weir [Fig. 5(b)], and the skimming flow regime above a stepped weir [Fig. 5(c)]. The flow characteristics become more complex with pooled steps and at weirs with teeth.
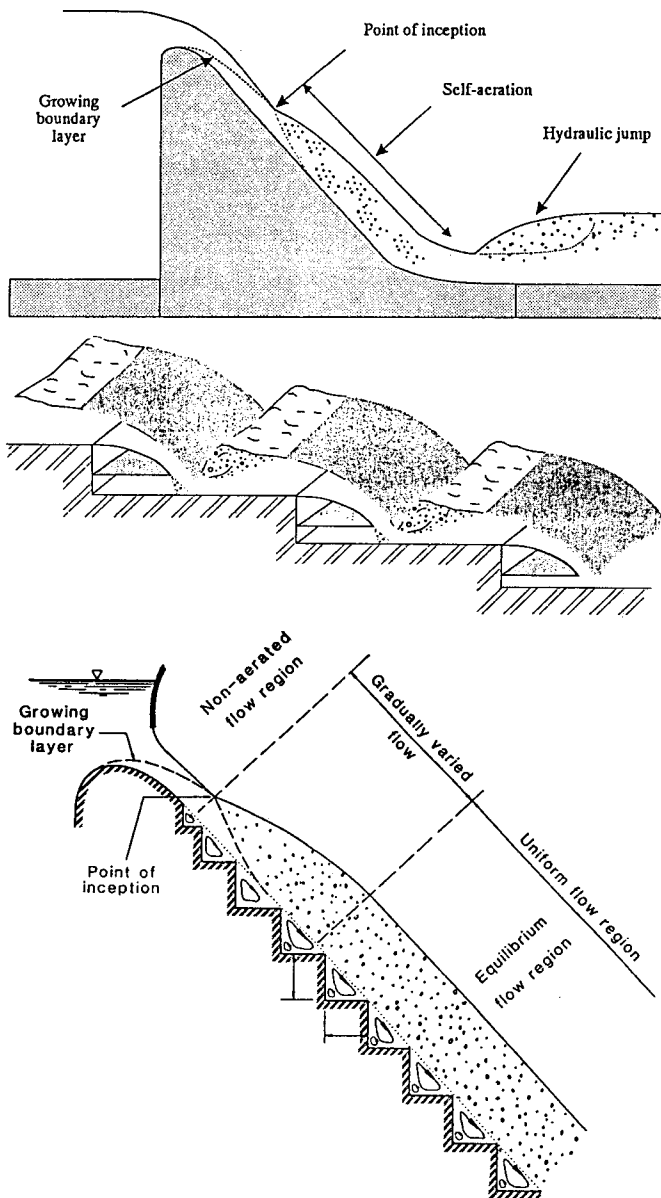

FIG. 5. Sketch of Flow over Weirs: (a) Flow above Smooth Weir: (b) Nappe Flow above Stepped Weir; (c) Skimming Flow above Stepped Weir

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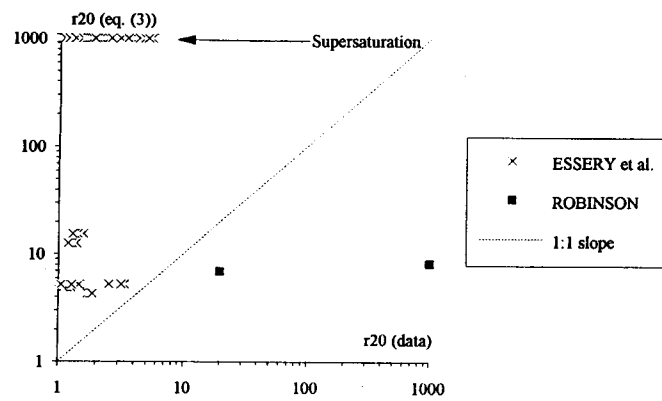
FIG. 6. Dissolved Oxygen Transfer on Stepped Weirs: Comparison between (3) (Vertical Axis) and Dissolved Oxygen Measurements (Essery et al. 1978; Robinson 1994)

A single drop structure is a form of nappe flow above a single-step chute. Photographic evidence [e.g., Wood (1991) for smooth chutes and Chanson (1995a) for stepped chutes] shows clearly that waters flowing above weirs are often characterized by a substantial amount of free-surface aeration (i.e., undissolved air-bubble entrainment, also called white waters). On small weirs and dams, white waters are usually observed at low to medium flow rates. Free-surface aeration induces a substantial increase of the air-water interface area and contributes largely to the transfer of volatile gases (e.g., oxygen and volatile organic compounds). For smooth weirs, Chanson (1995b) predicted the air-water interface area at any position along the chute, and showed that free-surface aeration contributes to a large part of the oxygenation taking place at hydraulic structures for small water discharges. For large discharges, the reduction or the disappearance of free-surface aeration affects substantially the aeration efficiency. The complete gas transfer calculations were successfully verified with field measurements (Butts and Evans 1983; Rindels and Gulliver 1989). On stepped chutes, Chanson (1995a) showed that the type of flow regime (i.e., nappe or skimming flow) modifies completely the dynamics of free-surface aeration and hence of air-water gas transfer.

The discusser is very critical of the authors' approach based on purely empirical correlations. Several researchers measured upstream and downstream dissolved oxygen contents in laboratories and on prototype weirs [e.g., Essery et al. (1978), Butts and Evans (1983), Rindels and Gulliver (1989), and Robinson (1994)]. In Fig. 6, the authors' (3) is compared with model and prototype data. The data are both nappe and skimming flow regime. Supersaturation predictions (?!) are highlighted. The results (Fig. 6) indicate a huge scatter, indicating explicitly that the empirical correlations can be completely inaccurate because they do take into consideration the type of flow. The discusser openly questions the validity of the authors' method and their calculations of energy consumption based on inaccurate correlations.

APPENDIX I. REFERENCES

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APPENDIX II. NOTATION

The following symbol is used in this paper:

$r20$ = deficit ratio at 20°C.

Closure by Ning H. Tang,[5] N. Nirmalakhandan,[6] and R. E. Speece[7]

We would like to thank Professor H. Chanson for his interest in this subject. Discusser Chanson states that the correlations used in our study "do not take into account the hydraulics of the flow." He refers to pooled steps, single-step chutes, smooth chutes, and stepped chutes. Further reference is made to air-bubble entrainment above the weir. We agree with the observations he has made with regard to these types of water fall structures.

However we strongly disagree that these references have relevance to the data used in our correlations. Our correlations do not pertain to pooled steps or smooth or stepped chutes. Only single-step, free-fall weir aeration is addressed. There was absolutely no air-bubble entrainment above the weirs in the test system for these single, free-fall studies, as suggested by Chanson.

The quality of the data from which these correlations emerged is excellent, and accounts fully for the hydraulics of the flow therein. We continue to maintain the fidelity of the correlations and usefulness to practitioners of the graphs developed for single-step, free-fall weir aeration.

OXYGEN UTILIZATION OF TRICKLING FILTER BIOFILMS[a]

Discussion by B. E. Logan[3]

Although Hinton and Stensel have conducted very unique and interesting experiments examining the interactions between substrate and oxygen transport to biofilms grown on plastic trickling filter media, their interpretations of their data are misleading and their conclusions far exceed the parameters of their study. Many statements made in their paper are therefore unsupported by their own data. For example, in their analysis they dismiss the maximum oxygen transport model developed by Logan et al. (1987b) as predicting oxygen transport rates "too high for typical cross-flow media," yet their estimate of oxygen transport using this model is 650 mg m^{-2} h^{-1}, a rate that is actually lower (by 5%), and not significantly

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different than their maximum observed rate of 680 mg m^{-2} h^{-1}. A more realistic conclusion based on their results would have been that agreement between their experimental data and this model was excellent considering the disparity in types of wastewaters considered (saccharide solutions versus domestic wastewater).

The two main issues addressed in this discussion are whether oxygen or substrate produced the maximum removal rates observed in their studies; and to what extent their results on saccharide solutions can be used to interpret oxygen transport in trickling filters. The central issues is this: did substrate or oxygen diffusion through the fluid film control soluble chemical oxygen demand (SCOD) removal in the Hinton and Stensel study? I think data in their study indicate that substrate, and not oxygen, concentrations accounted for the observed removal rates.

To show substrate concentrations can account for removal observed in their study, I compared their measured substrate removals with those predicted using the TRIFIL2 model. The TRIFIL2 model was developed by myself and coworkers (Logan et al. 1987a,b; Logan 1993) in order to predict soluble biochemical oxygen demand (SBOD) removal in plastic media trickling filters treating domestic wastewater. The conditions tested by Hinton and Stensel are consistent with most model assumptions except that the wastewater was not domestic wastewater but two types of saccharide solutions. Although details of the model development are presented elsewhere (Logan et al. 1987a), assumptions related to the present discussion are that substrate kinetics are first order and not saturable and that oxygen does not limit substrate uptake. This assumption of first-order and nonsaturable kinetics is important for modeling saccharide solutions versus domestic wastewaters, because this assumption does not hold for high saccharide concentrations. TRIFIL2 model simulations, when compared to laboratory data of several researchers using glucose as a carbon source, indicated that above 85 mg L^{-1} the assumption of first order kinetics was questionable for synthentic (saccharide) wastewaters (Logan et al. 1987a). Thus, at glucose concentrations above 85 mg L^{-1} we recognized that the biofilm kinetics could produce substrate removals lower than those predicted by our first-order kinetic model.

Is there a maximum substrate uptake rate (SUR) produced only by substrate, and not oxygen, limited transport into the biofilm? Yes. If a Michaelis-Menton kinetic model is used instead of a first-order kinetic model, however, a maximum substrate uptake is not easily calculated because substrate uptake decreases in a nonlinear manner with influent substrate concentration and only approaches (hyperbolically) the maximum rate. However, a reasonable simplifying assumption is that the maximum substrate flux to a biofilm for saccharide-type synthetic wastewaters occurs at roughly twice the point at which deviations from first-order kinetics behavior are observed, or at $2 \times 85 = 170$ mg L^{-1}. Therefore, if the TRIFIL2 model is used to predict substrate uptake over the range examined by Hinton and Stensel, I would expect the TRIFIL2 model to work for sucrose concentrations below 85 mg L^{-1}, and to see maximum substrate utilization rates—caused by saturation of biofilm substrate kinetics, not oxygen limitations—somewhere around 170 mg L^{-1}.

In comparing TRIFIL2 model predictions with their data, I found that there was no statistically significant difference (Mann-Whitney Rank Sum test) between substrate utilization rate data (both sucrose and dextrin obtained from Figs. 3 and 4) and TRIFIL2 model predictions (Fig. 5) over the complete substrate concentration range. As expected, the best agreement between the model and data occurred at SCOD concentrations <100 mg L^{-1}. It looks as if a maximum sucrose SUR was reached at sucrose concentrations between 120 and 200 mg