Appendix 7A - Air-water mass transfer in air-water flows

Air-water flows in rivers and hydraulic structures have great potential for aeration enhancement of flow because of the large interfacial area generated by entrained bubbles (CHANSON 1997, Fig. 7-8).

The mass transfer rate of a chemical across an interface varies directly as the coefficient of molecular diffusion and the negative gradient of gas concentration. If the chemical of interest is volatile (e.g. oxygen, nitrogen, chlorine, methane), the transfer is controlled by the liquid phase, and the gas transfer of the dissolved chemical across an air-water interface is usually rewritten as :

$$\frac{\partial\ C_m}{\partial t} \ = \ - k_L * a * (C_m - C_{sat}) \qquad\qquad (7A-1)$$

where k_L is the liquid film coefficient, a is the specific surface area defined as the air-water interface area per unit volume of air and water, C_m is the local dissolved gas concentration, and C_{sat} is the concentration of dissolved gas in water at equilibrium (App. 7B) (e.g. GULLIVER 1990, CHANSON and TOOMBES 2000, CHANSON 2002). Mass transfer at bubble interface is a complex process. KAWASE and MOO-YOUNG (1992) reviewed several correlations for the liquid film coefficient calculations in turbulent gas-liquid flows. They showed that the mass transfer coefficient k_L is almost constant regardless of bubble sizes and flow situations. The transfer coefficient may be estimated by :

$$k_L \ = \ 0.28 * D_{gas}{}^{2/3} * \left(\frac{\mu_w}{\rho_w}\right)^{-1/3} * \sqrt[3]{g} \qquad\qquad d_{ab} < 0.25 \text{ mm} \quad (7A-2a)$$

$$k_L \ = \ 0.47 * \sqrt{D_{gas}} * \left(\frac{\mu_w}{\rho_w}\right)^{-1/6} * \sqrt[3]{g} \qquad\qquad d_{ab} > 0.25 \text{ mm} \quad (7A-2b)$$

for gas bubbles affected by surface active impurities, where μ_w and ρ_w are the dynamic viscosity and density of the liquid, D_{gas} is the coefficient of molecular diffusion (App. 7C), d_{ab} is the gas bubble diameter, g is the gravity acceleration, all variables being expressed in SI units. Equation (7A) was compared successfully with more than a dozen of experimental studies.

Equation (7A-1) is very general. Importantly, it includes the effect of air bubble entrainment and the drastic increase in interfacial area. Experimental measurements in supercritical flows down a flat chute recorded local specific interface area of up to 110 m^2/m^3 (m^{-1}) with depth-averaged (bulk) interface area ranging from 10 to 21 m^{-1}. Larger specific interface areas were recorded in developing shear flows. Local interface areas of up to 400 m^{-1} were observed in hydraulic jumps and maximum specific interface areas of up to 550 m^{-1} [4] were measured in plunging jet flows (CHANSON 1997, CHANSON and TOOMBES 2000). These examples illustrate the potential for aeration enhancement in the presence of white-water.

CHANSON and TOOMBES (2000) combined Equations (7A-1) and (7-A-2) with measured air-water interfacial areas. They deduced aeration efficiency, in terms of dissolved oxygen , of about 30 to 40% for a 24 m long stepped cascade with a 1.4 m total drop. The result was verified with dissolved oxygen measurements.

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[4]That is, nearly twice the surface area of two basketball courts in one cubic metre of air and water.