Previously, we reported on laboratory results from a wind-wave tunnel comparing transfer velocities of heat and gas measured at a wavy air-water interface using an active infrared technique and two gas tracers, respectively [Atmane et al., 2004]. Surface renewal model formalisms [Danckwerts, 1951] indicate that the transfer velocity of heat, $k_H$, will be related to the transfer velocity of a sparingly soluble non-reactive gas, $k_L$, by the ratio of their Schmidt numbers raised to the $\frac{1}{2}$ power. However, in our previous data when $k_H$ and $k_L$ were referenced to $Sc = 660$ using relationships derived from surface renewal, $k_H$ was found to be several times higher than $k_L$. Potential origins of such a discrepancy such as lateral patch dispersion were not found to be able to account for the observations.

Surface renewal theory relates $k_H$ or $k_L$ to the timescales of renewal events in the thermal or concentration boundary layers, respectively, near the air-water interface. However, there are other conceptual models describing how aqueous-phase turbulence affects heat and gas transfer. For example, in surface penetration theory eddies that impinge upon the air-water interface do not necessarily renew the entire surface layer. In the random eddy modification to the surface penetration framework, $k_H$ or $k_L$ depend on both a timescale for the renewal event and the depth in the boundary layer at which this renewal event occurs [Harriott, 1962]. An important consequence of including eddy approach distances into the calculation of the transfer velocity is that heuristic arguments based on diffusive length scales can be used to explain how heat and gas might not scale with diffusivity as predicted by a pure surface renewal model.

Numerical simulations performed by Atmane et al. [2004] using the random eddy model of Harriott demonstrated that in the general case one would not expect $k_H$ and $k_L$ to scale as the square root of the ratio of their diffusivities. Furthermore, these simulations showed that the scale factors observed in the wind-tunnel data sets could be explained in terms of a surface penetration conceptual framework. These results suggested that both the timescales and depths of surface renewal events are required in order to unambiguously calculate heat and gas transfer rates at air-water interfaces. However, it was not possible to directly test surface penetration models using the wind tunnel data set because measurements of eddy approach distances were not available.

Asher and Pankow [1986] measured $k_L$ for carbon dioxide (CO$_2$) as a function of aqueous-phase turbulence in a grid-stirred tank. They also measured surface renewal timescales [Asher and Pankow, 1991b] and eddy approach distances [Asher and Pankow, 1991a] under the same turbulence conditions. Here, we use these data to calculate the air-water flux of carbon dioxide using the random eddy surface penetration model of Harriott [1962]. These fluxes are compared to carbon dioxide fluxes measured directly by Asher and Pankow [1986] in order to provide further evidence that surface penetration provides a more complete conceptual picture of air-water transfer processes than surface renewal theory.


