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Wind/Wave-Tunnel Measurements of Chemical Enhancement of the Carbon Dioxide Gas Exchange Rate

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From previous experimental and theoretical studies it is obvious that chemical reaction in the aqueous mass boundary layer at the ocean surface could enhance CO_2 air-sea exchange at low wind speed conditions (Hoover and Berkshire, 1969; Wanninkhof and Knox, 1996). However, all previous experimental studies were only performed in small stirred tanks (Wanninkhof and Knox, 1996, Kuss and Schneider, 2004).

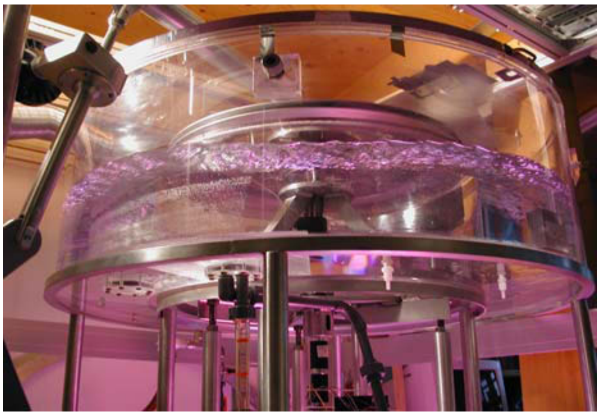

Figure 1: *Small annular wind-wave facility (construction Erik Bock) used for the experiments.*

For the first time, wind/wave tunnel experiments were performed using the small circular wind wave facility at Heidelberg University (Fig. 1) to study chemical enhancement of CO_2 gas exchange and its dependency on turbulence and pH. A series of evasion experiments were carried out at different pH values from 6 - 8.9 with reactive CO_2 and inert N_2O at stepwise increased wind speeds between 0.6 and 8 m/s. Because of the very similar physical properties of the two species, especially the same diffusion coefficient, differences in gas transport are due to chemical enhancement only. Fresh and salt water was used in the experiments. The corresponding gas fluxes were then calculated from monitored temporal changes of the gas concentrations in the headspace by using the "controlled-leakage technique" (Degreif 2006). The measurements show chemical enhancement of up to a factor of three and increase with pH and decreasing turbulence at the air-water interface (Fig. 2). With a smooth, surface film covered water surface, the effect of chemical enhancement extends to higher wind speeds. The measured enhancement agrees very well with the simple linear model of Hoover & Berkshire (1969) under all conditions (Fig. 3).
We also extended this model by replacing the simple film model to describe the turbulence

with surface renewal and turbulent diffusion models and found maximum deviations of about 8% so that the simplest model (surface renewal) is sufficient to describe the chemically enhanced CO_2 gas transfer under all kind of turbulence conditions with sufficient accuracy.

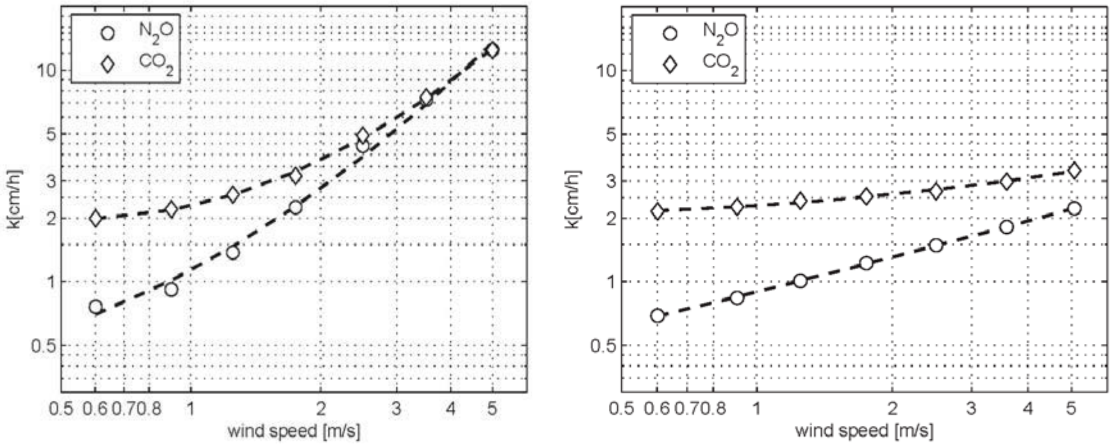

Figure 2: *Enhancement of the CO_2 transfer velocity versus the N_2O transfer velocity at a clean water surface and pH 8 (left) and a surface-film covered surface without waves and pH 7.7 (right) as a function of the reference wind speed in the annular facility (The corresponding wind speed at a 10 m height in the field would be about twice as high).*

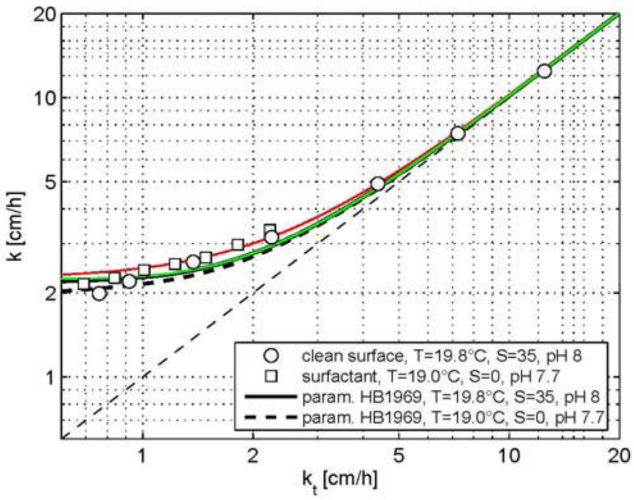

Figure 3: *Comparison of the measured enhancement with the model of Hoover & Berkshire (1969).*

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