

## Interfacial Concentration Observed during Dissolution

**Keyphrases** □ Dissolution of solids, descending column model – relationship to interfacial concentration □ Interfacial concentration – relationship to descending column dissolution □ Descending column dissolution – relationship to interfacial concentration

*Sir:*

In a recent series of papers, Kildsig and coworkers (1–4) investigated dissolution from compressed pellets in a static column of solvent, under conditions where the flat surface of the solid was either the lower or the upper boundary of the column (ascending and descending models, respectively). It was concluded that in the descending case an interfacial concentration,  $c_i$ , significantly lower than the saturation concentration,  $c_s$ , is operative and that  $c_i$  is related to energy parameters of the solid–liquid interface. The argument of the authors is not conclusive, however, and their experimental data can be interpreted in a more simple and convenient way which does not require the assumption of  $c_i < c_s$ .

When compared with the diffusion-controlled ascending case, the descending model represents a completely different hydrodynamic system which is usually described in terms of free convection; that is, whenever the dissolving surface is not at the bottom of the liquid, then inverse density gradients are generated within the liquid and these, in turn, induce macroscopic convective flow accompanied by a drastic increase of the rate of mass transfer. Systems similar to the descending column have been investigated with respect to flow pattern and mass transfer, e.g., laminar flow along a vertical flat surface (hanging pellet) (5, 6), laminar or turbulent flow around a single dissolving sphere (7), and convective flow along a horizontal circular surface (static disk) (8, 9). In the last case, the flow pattern may be visualized from the analogous process of heat-induced convection (10, 11).

The descending model of Kildsig and coworkers fits into this series of free convective dissolution systems, with one peculiarity: the solid surface extends over the entire cross section of the column. This complicates establishment of a typical, convective flow pattern. One might speculate that in the absence of any disturbances the system starts from a convection-free metastable state, which is identical with the ascending case where mass transfer is restricted to molecular diffusion. However, from Fig. 5 of Reference 1, it is evident that the system actually was in a convective state right from the beginning of the experiment. It must be left open what kind of flow pattern prevailed under the experimental conditions; some possibilities are gross laminar flow of the entire liquid column, a bundle of laminar flow cells distributed over the cross section, and

a random flow of liquid packets similar to those proposed by Danckwerts (12) for his surface renewal concept.

No attempt will be made to develop a complete mechanistic model which accounts for all of the experimental data reported by the authors. However, it is demonstrated with two examples that the concept of free convection is capable of treating the observations without any need for an abnormal interfacial concentration. Three additional points are made which show that the cited arguments are based on rather insecure premises.

For any free convective system, a distinct solute front is typical and represents the portion of the liquid that had first been in contact with the dissolving solid. The velocity of this front is governed by hydrodynamics (solubility, viscosity, and density as a function of concentration), and a constant velocity is not unexpected. Also, a correlation between front velocity and solubility, as shown in Tables III and IV of Reference 4, is consistent with such a concept and does not require explanation in terms of interfacial energy parameters.

When comparing dissolution rates of one solute in different solvents, an inverse correlation with solubility, such as the one shown in Fig. 2 of Reference 3, is not unusual and gives no verification that the descending dissolution is interfacially controlled. In the particular case, nearly a 10-fold increase in viscosity is found for the solvents (30°, viscosities in centipoises) (13): *n*-hexane, 0.29; *n*-heptane, 0.37; cyclohexane, 0.82; *trans*-decalin, 1.8; and *cis*-decalin, 2.7<sup>1</sup>. Since the viscosity is known to have a retarding effect on diffusion and, particularly, convection, and since the viscosity increase more than compensates for the increase in solubility, it is not surprising that the rate of dissolution decreases from hexane to decalin. Again, there is no need to rely on interface phenomena.

In Reference 1 (p. 216), the authors restrict diffusion to the upward direction in the gravitational field. This is not true since molecular diffusion by definition is independent of any external forces. In addition, all of the solutes are of low molecular weight, <200. Even in an associated or highly solvated state, these particles are far below the limit where directional flow under the influence of gravity (*i.e.*, sedimentation) is likely to be observable. Hence, it is hard to see how "solvated solute molecules flow through the stationary liquid solvent, the fluid elements or holes comprising the liquid solvent acting as a channeling or dispersion medium" (4, p. 1592). The only acceptable concept is that of macroscopic flow, *i.e.*, convection.

For all four examples shown in Figs. 8–11 of Reference 4, the agreement between experimental data points and the fitted telegraph equation is by no means perfect; rather, the examples disprove the applicability of this

<sup>1</sup> It is not clear from the Krause and Kildsig paper (3) whether the *cis*- or *trans*-isomer was used.

equation. Under these circumstances, any extrapolation to zero distance is arbitrary. The concentration profiles shown in Fig. 7 of *Reference 1* are speculative since the actual interfacial concentration and the initial concentration gradient cannot be assessed from the experimental data with sufficient accuracy. In addition, the assumption of a constant nonsaturated interfacial concentration independent of the initial concentration gradient (as shown in Fig. 7) is not consistent with a transport model involving two consecutive rate processes.

Since the telegraph equation is not applicable, it is meaningless to ask whether the random-walk model with autocorrelation is appropriate to the descending column. However, even if perfect agreement had been obtained with the equation, this would not be more than a formal quantitative description. The authors' attempt to establish a mechanistic analogy between their descending dissolution and the mutual displacement of two miscible phases in a porous medium would still be questionable.

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## Total Rate Equation for Decomposition of Prostaglandin E<sub>2</sub>

**Keyphrases** □ Prostaglandin E<sub>2</sub> decomposition log rate-pH profile, rate equation □ Dehydration, prostaglandin E<sub>2</sub>-log rate-pH profile, rate equation

Sir:

Monkhouse *et al.* (1) recently presented the 60° log rate-pH profile for the dehydration of prostaglandin E<sub>2</sub> (PGE<sub>2</sub>)<sup>1</sup> from pH 1 to 10. Between pH 4 and 10, the log of the rate data was correlated by a straight line with a slope of about 0.3. Our 60° rate data substantially agree

<sup>1</sup> PGE<sub>2</sub> is 11 $\alpha$ ,15(S)-dihydroxy-9-oxo-5-cis,13-trans-prostadienoic acid.

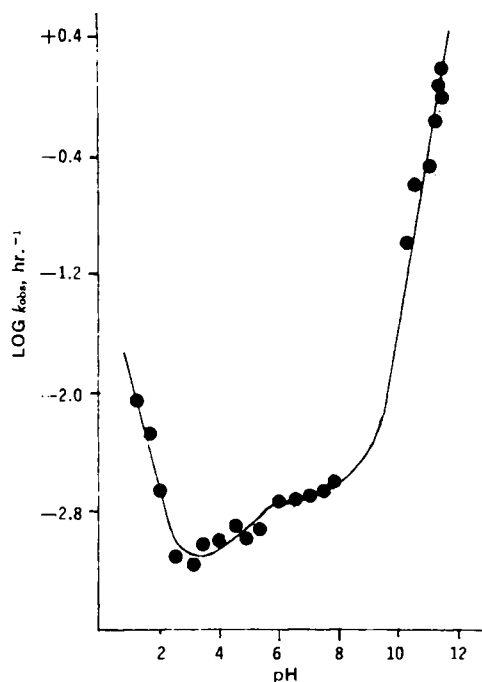


Figure 1 --Log rate-pH profile for decomposition of PGE<sub>2</sub> at 25.0°.

with the reported (1) 60° profile. However, we recently completed a 25° log rate-pH profile from pH 1 to 12 which appears to shed more light on the nature of the decomposition reaction between pH 4 and 10.

Figure 1 shows the log rate-pH profile for the decomposition of PGE<sub>2</sub> in water-methanol (95:5 v/v) at 25.00 ± 0.05°. The apparent first-order rates were determined in hydrochloric acid and formate, acetate, phosphate, carbonate, and sodium hydroxide buffers at a constant ionic strength of 0.10. The apparent first-order rate constants were determined by following the disappearance of the substrate by a TLC procedure specific for PGE<sub>2</sub>.

Although it may initially appear that the region between pH 4 and 9 is linear, the observed 25° rate constants ( $k_{obs}$  values) were best correlated by a rate equation depending upon the pK<sub>a</sub> of the prostaglandin<sup>2</sup>:

$$k_{obs} = k_H \cdot a_{H^+} (1 - \alpha) + k_{H_2O} (1 - \alpha) + k_{OH^-} a_{OH^-} (\alpha) + k_{H_2O}^{\dagger} (\alpha) + k^{11} (\alpha) \quad (\text{Eq. 1})$$

where  $k_H$  is the specific hydrogen-ion catalytic constant,  $k_{H_2O}$  is the catalytic constant for the water reaction of PGE<sub>2</sub>,  $k_{OH^-}$  is the specific hydroxide-ion catalytic constant,  $k_{H_2O}^{\dagger}$  is the catalytic constant for the water reaction of ionized PGE<sub>2</sub>, and  $k^{11}$  represents a catalytic constant for a reaction of PGE<sub>2</sub> in the ionized form. The hydrogen- and hydroxide-ion activities are represented by  $a_{H^+}$  and  $a_{OH^-}$ , respectively, and  $(1 - \alpha)$  and  $(\alpha)$  represent the fractions of PGE<sub>2</sub> in the unionized and ionized form, respectively.

The line in Fig. 1 was calculated from Eq. 1, and the points correspond to the experimentally observed apparent first-order rate constants. Buffer catalysis and isomerization at C<sub>8</sub> and C<sub>13</sub> (2) did not appear to contribute significantly to the overall rate expression.

<sup>2</sup> The pK<sub>a</sub> of PGE<sub>2</sub> under the conditions of the kinetic experiments was determined to be 5.00.