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19 August 1969

Evaporation Retardation by Monolayers

MacRitchie (*1*) presented data for the evaporation of water from a liquid surface and also studied the retardation of evaporation by monolayers of hexadecanol. Using laminar boundary layer theory, he analyzed both systems. We reexamined MacRitchie's data and found that the mass of water vapor transferred in the absence of hexadecanol is proportional to $U_0{}^{0.8}$ (where U_0 is the air velocity), which would indicate a turbulent boundary layer (*2*). MacRitchie justified his application of laminar boundary theory, which would yield a $U_0{}^{0.5}$ dependence (*2*), by noting that the maximum value of the Reynolds number ($\mathrm{Re} = LU_0/\nu$, where L is length and ν, kinematic viscosity) is only 28,800. However, the use of a fan in these experiments may introduce a complicated rotational motion, with vortices starting from the ends of the blades, unless shrouds, straighteners, and appropriate entry sections are provided; there is no mention of these. It is therefore not surprising that one obtains experimental data for this system which is consistent with results obtained for turbulent flows.

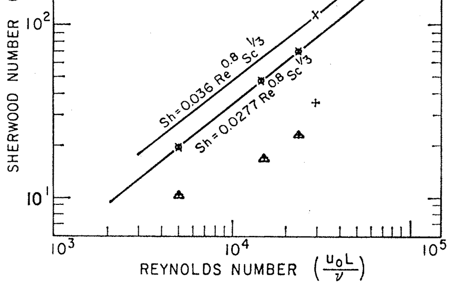

Fig. 1. Variation in Sherwood number with Reynolds number.

Data from previous experiments on turbulent flow have been correlated by the relation

$$\mathrm{Sh} = C\,\mathrm{Re}^{0.8}\,\mathrm{Sc}^{1/3} \tag{1}$$

where Sh, the Sherwood number, is defined by $mRTL/D\Delta P$, with m being the mass transferred; R, the universal gas constant; T, temperature; D, diffusivity; and ΔP, partial pressure difference (*2*); the Schmidt number Sc is defined by ν/D; C is equal to 0.036 although there is significant scatter in the data. The experimental results for the velocities and relative humidities reported (*1*) are in good agreement with Eq. 1 with C equal to 0.0277 (Fig. 1).

MacRitchie's experiments with hexadecanol monolayers showed that the "evaporation retardation ratio" $\dot{m}_{\mathrm{II}}/\dot{m}_{\mathrm{I}}$ is independent of the relative humidity at a given Reynolds number where $\dot{m}_{\mathrm{II}}$ and $\dot{m}_{\mathrm{I}}$ are the evaporation rates with and without hexadecanol, respectively. From this result he concluded that the hexadecanol produces no barrier to the vaporization step (the migration of water molecules from the liquid water phase into the vapor phase) but exerts its sole effect by altering the hydrodynamic boundary layer. However, the presence of a vaporization step with hexadecanol does yield results which are consistent with the above experimental observation. In detail, the presence of two resistances in series, that is, both in the vaporization step and in the hydrodynamic boundary layer, yields the relation

$$\frac{\dot{m}_{\mathrm{II}}(x)}{\dot{m}_{\mathrm{I}}(x)} = \frac{h_{V,\mathrm{II}}\,h_{H,\mathrm{II}}}{h_{V,\mathrm{II}} + h_{H,\mathrm{II}}} \cdot \frac{1}{h_{H,\mathrm{I}}} \tag{2}$$

which is also independent of the relative humidity, where $h_{V,\mathrm{II}}$ and $h_{H,\mathrm{II}}$ are the vaporization and hydrodynamic conductances, respectively, with hexadecanol present, and $h_{H,\mathrm{I}}$ is the hydrodynamic conductance without hexadecanol. Equation 2 is a local relation, so that the (total) retardation ratio is obtained by integrating it over the length of the plate. The integrated result would also be independent of the relative humidity at a given Reynolds number.

To obtain the total retardation ratio we assume that the hydrodynamic conductances $h_{H,\mathrm{I}}$ and $h_{H,\mathrm{II}}$ are equal and given by the turbulent boundary layer results $Ax^{-0.2}$ where $A = D(C/0.8)(U_0/\nu)^{0.8}/\mathrm{Sc}^{1/3}$ (*2*) with $C = 0.0277$.

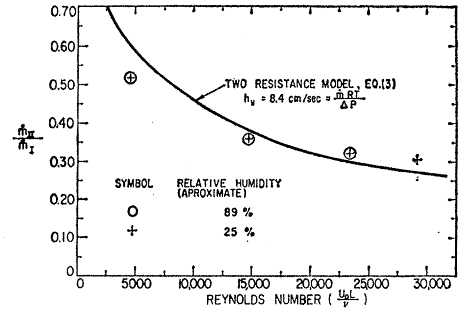

Fig. 2. Evaporation retardation ratio as a function of Reynolds number.

This relation is consistent with Eq. 1. We also take the vaporization step conductance

$$h_V = \dot{m}RT/\Delta P$$

to be constant; upon integrating Eq. 2, we obtain

$$\frac{\dot{m}_{\mathrm{II}}}{\dot{m}_{\mathrm{I}}} = \int_0^1 \frac{d(x/L)}{1 + (A/h_V L^{0.2})(x/L)^{-0.2}} \tag{3}$$

Based on the experimental results of MacRitchie (*1*) a value of h_V equal to 8.4 cm/sec has been chosen and the results are shown in Fig. 2.

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9 May 1969

Ecological Succession

E. P. Odum (*1*) asserts the need of an understanding of ecological succession. He offers three parameters of succession, one being that, "It results from modification of the physical environment by the community; that is, succession is community-controlled even though the physical environment determines the pattern, the rate of change, and often sets limits as to how far development can go." Succession is certainly one of the key principles of ecology and requires examination, but the parameter quoted needs clarification. Odum asserts that succession "results from modification of the physical environment by the community" and "refers to changes which are brought about by biological processes *within* the ecosystem in question." These statements define the conventional concept of autogenic succession and exclude changes brought about in the community by changes in the physical environment, allogenic succession in the usual terminology. In his discussion of lake succession "progressing in time" from the less productive (oligotrophic) lakes to more productive (eutrophic) lakes, Odum attributes this trend to the addition of nutrients from outside of the lake from the surrounding watershed. Erosion or leaching as a geological process is not a biological process, although organisms may modify the rate and kind of nutrient flow. In this sense, succession (eutrophication) caused by ordinary nutrient flow into a lake would not fit into Odum's definition of succession.

After commenting that nutrient import into a lake produces a successional change from oligotrophy to eutrophy, Odum states that adding nutrients to an experimental ecosystem is its equivalent, and the system (lake) is "pushed back" to a "younger" or bloom state. This implies a retrogressive succession in the common terminology, as younger is clearly an earlier or pioneer state or, one infers from the earlier statement, an oligotrophic state.

The apparent confusion may arise from a confounding of lake succession in the sense of oligotrophic to eutrophic with what Odum terms "seasonal successions which follow the same pattern." These might better be regarded as annual periodicities. In any event, the "bloom" or younger state referred to results, according to Odum, from an addition of nutrients and is thus parallel to eutrophy, the later stage in the ordinary lake succession, rather than earlier or oligotrophic state of lake succession, which contradicts his assumption of equivalence.

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8 May 1969

Lake eutrophication as a successional process can be interpreted in several ways, as McIntosh has pointed out. I chose to limit "ecosystem development" to what he has called "autogenic succession" because the biotic processes of community development are quite different in nature and often in end result from the geochemical forces (erosion, glaciation, mountain building, and so on) or climatic changes that bring about "allogenic succession." The latter, in my view, is not really "succession" in terms of a unidirectional strategy, which is why I prefer the phrase "ecosystem development" to "ecological succession." Physical forces can cause changes in biological systems in all kinds of directions (such forces can both create and destroy lakes, for example). The history of a lake is, of course, the resultant of the interaction of biotic processes and physical factors, but I feel that a conceptual distinction between the autogenic and the allogenic process is of great practical importance, because it is man the "mighty" geological agent, rather than man the animal, who is causing the greatest disruption of those biogeochemical cycles which have been biologically controlled under near steady-state condition for long periods of time.

Perhaps the well-documented story of Lake Washington in Seattle (*1*) will illustrate my position. Studies on diatom remains in the sediments in this lake (*2*) indicated a "near steady state condition" (the investigators' words) for many years preceding the period when sewage enrichment caused a progressive decline in water quality (decreased transparency, nuisance algal blooms, oxygen depletion, species change, and so on). When the citizens of Seattle and its suburbs finally passed a "metro" bond issue that resulted in complete diversion of treated sewage from the lake during 1964 to 1967, reversal of eutrophication was dramatic. Edmondson (*3*) thinks that the lake, if now left to its own devices, will return to its former less eutrophic condition despite the fact that a large supply of phosphorus and other nutrients introduced during the sewage era remain in the sediment. He points out that since exchange between sediments and water involves mostly the surface layers of the former, the excess nutrients will soon be buried and out of circulation. Studies of sediment cores of Italian lakes show that intense road building and other cultural activities of the Romans caused marked eutrophication which reversed when these activities declined (*4*).

Enrichment or eutrophication is a natural process during the early stages of ecosystem development. However, continued enrichment to the point of producing cancerous overgrowth and the ultimate destruction of the system is not part of life-system strategy, but is usually caused by some vast outside disturbance that produces inputs of materials or energy at rates that cannot be assimilated.

As I already said, "it is the entire drainage or catchment basin, not just the lake or stream, that must be considered the ecosystem unit if we are to deal successfully with our water pollution problems" (*5*). Much of the money now allocated by federal bureaus for water pollution study and abatement is being wasted in nearsighted mission orientation. The cause of and the solutions for water pollution are not to be found by looking into the water; it is bad management on the watershed by terrestrial man that causes lakes and streams to sicken and die.

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25 July 1969

Caribbean Cores P6304-8 and P6304-9: New Analysis of Absolute Chronology

Taken at face value, the new Pa^{231}/Th^{230} ages obtained by Rona and Emiliani (*1*) provide strong support for the absolute time scale previously obtained for Caribbean cores (*2*). Moreover, these authors conclude that the ages they obtained have greater precision (*3*) than the previously published results and provide a more accurate time scale for the past 170,000 years. We question the reliability of the data from which these new dates were calculated. Shown in Table 1 are comparisons between the data published by Rona and Emiliani (*1*) and those we have obtained on the same cores. In three of the four pairs the samples are separated by sufficiently small depth intervals to permit direct comparison. Differences greatly exceeding the experimental uncertainties are present.