The Effect of Vibration Upon Rate of Sublimation

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Lemlich and Levy (*3*) studied the effect of vibration upon the rate of mass transfer by sublimation from small horizontal cylinders of naphthalene and camphor to air at room temperature. Their results, partly shown on Figure 1, are presented in the form of the ratio of mass transfer coefficients k/k' vs. the *stretched-film* vibrational Reynolds number, defined as

$$N_{ReS} = \frac{(D + H)\,\overline{V}\rho}{\mu} \quad (1)$$

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The stretched-film, with total length $D + H$, derives from a physical picture described previously by Lemlich (*2*), who contends that the film is not carried back and forth with the vibrating cylinder, but rather is stretched along, and surrounds, the entire vibrating path between the extremes through which the cylinder moves (see Figure 2).

Goh (*1*) employed an apparatus in which cylinders of naphthalene were vibrated in sinusoidal motion from a sample cradle at the end of a steel rule, obtained results which are presented in the coordinates of Figure 1. These results, while similar in form to

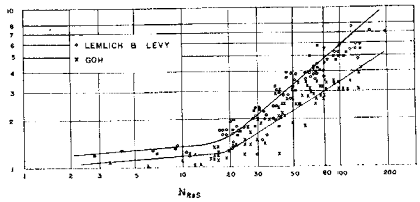

Fig. 1. Ratio of mass transfer coefficients vs. stretched-film Reynolds number.

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Use of a Radio Frequency Plasma Jet in Chemical Synthesis

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Production of acetylene and hydrogen cyanide in a d.c. plasma jet with either an inert or a reactive plasma gas made interesting the use of a radio frequency plasma jet for the production of nitrogen oxides, acetylene, and hydrogen cyanide. The radio frequency plasma jet utilizes the energy of a high-frequency electromagnetic field to dissociate and ionize gas molecules (*4*). When these ions recombine, the absorbed energy is given off in the form of heat.

APPARATUS

Two radio frequency plasma jet units were used for the experiments: a 0.3-kw. unit for low-pressure operation for nitrogen oxides and a 1.5-kw. unit for atmospheric-pressure operation for acetylene and hydrogen cyanide operation.

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The 0.3-kw. unit is a 27.5-mc. power oscillator of approximately 350 watts (power input to plate), with a special water-cooled coil for the output resonance tank. The output power can be varied by either grid detuning or plate voltage.

The high-voltage end of the resonance-tank coil is attached to a water-cooled brass tube ¼-in. in diameter and 7 in. long, with a conical molybdenum tip that runs through the center of the coil.

A water-cooled glass tube surrounds the top half section of the tank-coil tube. The plasma gas enters through a glass side tube approximately 1 in. below the tip of the tank-coil tube.

The 1.5-kw. unit is basically a transmitter that operates between 24 and 28 mc. The output-tank coil is suspended vertically on the side of the generator cabinet. The center tank coil electrode is adjustable for various load impedances. Both the center electrode and the tank coil are water-cooled. The plasma gas is injected into the top of a Vycor tube that extends down through the center of the tank coil.

PREPARATION OF OXIDES OF NITROGEN

Since the oxides of nitrogen were successfully prepared using a d.c. plasma jet, (*5*) their preparation under reduced pressure was investigated using the 0.3-kw. radio frequency

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TABLE 1. NITROGEN-OXYGEN EXPERIMENTS AT REDUCED PRESSURE

Gas used	1:2; nitrogen:oxygen	1:1; nitrogen:oxygen	Air
Total gas flow, st. cc./sec.	6	5	6
Total power to jet, watts	375	394	375
Running time, hours	4.5	1	2.5
Run pressure, mm. Hg abs.	117.5	75	110
Amount of material collected			
Dry ice trap, cc.	nil	nil	nil
Liquid nitrogen trap, cc.	0.5	0.2	0.4
% conversion (based on conversion to nitrogen dioxide	1	1¼	2
Average molecular weight of product	58	51.2	56
Identification by infrared spectrum	Nitric oxide, nitrogen dioxide	—	Nitric oxide, nitrogen dioxide

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The friction factor-Reynolds number relation for the steady flow of pseudoplastic fluids through rectangular ducts: Part I. Theory, Wheeler, John A., and Eugene H. Wissler, **A.I.Ch.E. Journal, 11,** No. 2, p. 207 (March, 1965).

Key Words: A. Fluid Flow-8, Pseudoplastic-0, Sodium Carboxymethyl Cellulose-9, Ducts-9, Pipes-9, Rectangular-0, Square-0, Rheology-8, Non-Newtonian-0, Calculation-8, 10, Velocity Profile-9, 8, Shear Stress-9, 8, Viscosity-9, Friction Factor-9, 8, Reynolds Number-9, 8, Power Law Model-10, Plot-8, Digital Computer-10, Equations-8, Finite Difference Scheme-10, Ethers-9, Theoretical-0.

Abstract: The flow through rectangular ducts of pseudoplastic fluids, such as aqueous solutions of sodium carboxymethylcellulose (CMC), is considered in this paper. The velocity profile, shear stress and the friction factor-Reynolds number product are calculated from the finite difference technique. A Control Data Corporation 1604 computer was used for the calculations. Velocity and viscosity contour plots are included.

The friction factor-Reynolds number relation for the steady flow of pseudoplastic fluids through rectangular ducts: Part II. Experimental results, Wheeler, John A., and Eugene H. Wissler, **A.I.Ch.E. Journal, 11** No. 2, p. 212 (March, 1965).

Key Words: A. Measurement-8, 9, Friction, Friction Factor-9, 8, Reynolds Number-9, Ducts-9, Pipes-9, Rectangular-0, Sodium Carboxymethyl Cellulose-9, Comparison-8, Calculation-9, 8, Experimental-0, Fluids-9, Pseudoplastic-0, Rheology-8, Viscosity-8, 9, Power Law Model-10, Fluid Flow-8, Ethers-9.

Abstract. The friction factor and Reynolds number were measured for sodium carboxymethylcellulose flowing through a rectangular duct. These measured values were compared with the values calculated using a power law model in Part I of this paper.

Mixing of viscous non-Newtonian fluids in packed beds, Hassell, H. L., and Arnold Bondi, **A.I.Ch.E. Journal, 11,** No. 2, p. 217 (March, 1965).

Key Words: Mixing-8, Viscosity-7, Non-Newtonian-9, Reynolds Number-6, Peclet Number-7, Friction Factor-7, Polymer Solution-9, Fluid Flow-8, Diffusion-7, Packed Beds-10.

Abstract: Radial mixing of concentrated solutions of rubber dissolved in a light aliphatic hydrocarbon was studied in beds packed with glass spheres or York mats. The degree of mixing in the bed of spheres was significantly better, that is the Peclet number much smaller, than predicted from Wilhelm's correlation.

Pressure drop associated with the flow of rubber cement through packed beds is well represented by existing correlations, provided the effective viscosity is obtained from a shear rate vs. shear diagram for the fluid.

Mixing and chemical reaction in turbulent flow reactors, Keeler, R. Norris, E. E. Petersen, and J. M. Prausnitz, **A.I.Ch.E. Journal, 11,** No. 2, p. 221 (March, 1965).

Key Words: Mixing-8, Chemical Reaction-8, Turbulent Flow Reactor-10, Electrical Conductivity Probe-10, Theory of Toor-10, Yield Prediction-8, Reactant Concentrations-6.

Abstract: Mixing and a chemical reaction were studied in a turbulent flow reactor. Concentrations were measured with a very small electrical conductivity probe. The theory of Toor was used to predict reaction yield. Varying reactant concentration was found to have a strong effect on reaction yield.

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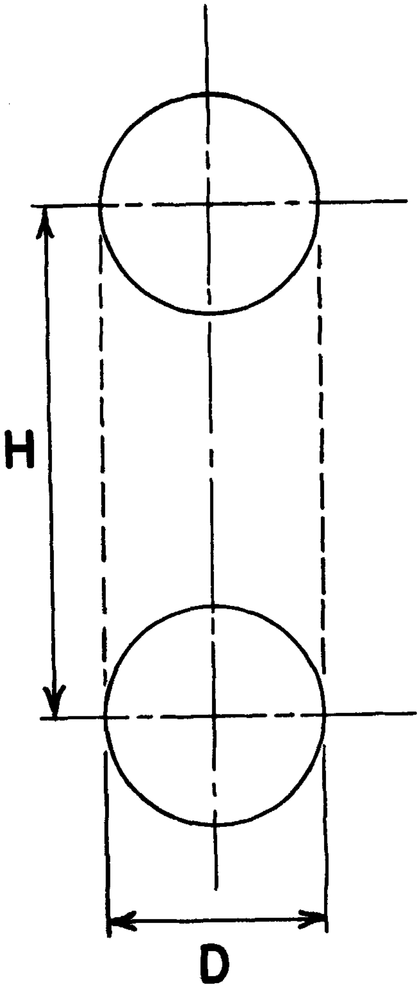

Fig. 2. End view showing vibrating cylinder in the extreme positions of its motion.

those of Lemlich and Levy (3), and showing the same characteristic break at a stretched-film Reynolds number of about 20, are nevertheless clearly lower, differing almost by a factor of 2 at the higher N_{ReS}.

Lemlich and Levy (3) suggested that the break at $N_{ReS} = 20$ could possibly be attributed to a change in the vibration-induced streaming currents about the sample, a fact which had been observed by West (4) when vibrating a wire through air. However, when one applies West's results to the data of Lemlich and Levy (3) and also of Goh (1), it is seen that the change in streaming pattern should occur at a value of N_{ReS} much greater than that at which the break is observed. Allowing for the fact that the mass transfer convection currents, produced by sublimation, may alter the streaming pattern, there is still no independent evidence that a change in streaming pattern should occur at $N_{ReS} = 20$.

It appears that the stretched-film concept can be utilized in a different way. Making reference to Figure 2, it is seen that the effect of the stretched-film can be to increase the effective surface area over which sublimation can occur. If it is assumed that everywhere throughout the film envelope the vapor pressure is that of the pure solid, then one can deduce that the ratio of the effective surface area of the stretched-film to the surface area of the cylinder itself (nonvibrating case), neglecting end effects, is

$$\frac{A}{A'} = 1 + \frac{2H}{\pi D} \qquad (2)$$

Using this area ratio, and the vibrational Reynolds number used by Lemlich (2), defined as follows

$$N_{Re} = \frac{D\overline{V}\rho}{\mu} \qquad (3)$$

with the average velocity $\overline{V} = 2HF$, it is possible to establish a correlation using both the data of Lemlich and Levy (3) and Goh (1) in which A/A' appears to the second power and N_{Re} to the first power.

The final relationship,

$$\frac{k}{k'} - 1 = 0.021\, N_{Re} \left(\frac{A}{A'}\right)^2 \qquad (4)$$

is shown in Figure 3. The mass transfer coefficient k is based upon A', so that the left-hand side of Equation (4) gives directly the fractional increase in the rate of mass transfer due to the effect of vibration, all other conditions being identical. Basing k upon A' rather than the effective mass transfer area A results in an enhancement of the exponent upon the area ratio term. No explanation can be offered at the present time, though, as to why the area ratio appears to the second power.

The form of Equation (4) satisfies the boundary condition that $k \rightarrow k'$ as $N_{Re} \rightarrow 0$. Except at very low values of k/k' in the work of Goh (1), where the experimental precision is lowest, and for values of $A/A' > 4.0$ ($H/D >$

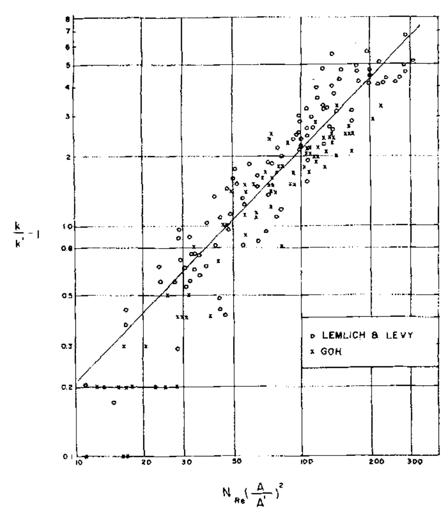

Fig. 3. $k/k' - 1$ vs. $N_{Re}\,(A/A')^2$ using data of Lemlich and Levy (3) and Goh (1).

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Pseudocritical constants Reid, R. C., and T. W. Leland, Jr., **A.I.Ch.E. Journal, 11,** No. 2, p. 228 (March, 1965).

Key Words: A. Calculation-8, 10, Pseudocritical Constants-2, 8, Kay's Rule-10, Comparison-8, Rules-9, Force Constants-1, Distribution Function-1, Interaction Force Constants-1, Mixtures-9, Critical Properties-2, 8. B. Calculation-8, Equilibrium Properties-2, Mixtures-9, Transport Properties-2, Law of Corresponding States-1.

Abstract: This paper shows that all of the common pseudocritical rules can be obtained from a common base. In certain limiting cases all rules reduce to Kay's rule. These pseudocritical rules provide a means to determine reduced properties for mixtures so that pure component corresponding states correlations may be used to estimate mixture properties.

Feedback control of an overdetermined storage system, Wilde, Douglass J., **A.I.Ch.E. Journal, 11,** No. 2, p. 237 (March, 1965).

Key Words: A. Control-8, Inventory-2, Feedback-10, Tank-9, Overdetermined-0, Stability-8, Linear Controller-9, Random-1.

Abstract: Two schemes are analyzed for feedback control of inventory systems with more tanks than controllers. Such systems are shown to be inherently stable and to have appropriate asymptotic properties for linear controllers. The results suggest that automatic inventory control may soon be practical.

Analysis of phase boundary motion in diffusion-controlled processes: Part III. Penetration of metal ions into cellulose xanthate fibers and growth of sulfuric acid droplets in humid air, Griffin, J. R., and D. R. Coughanowr, **A.I.Ch.E. Journal, 11,** No. 2, p. 246 (March, 1965).

Key Words: Moving Boundary Problem-8, Diffusional Process-8, Copper Ions-1, Cellulose Xanthate-1, Swelling of Polymer Fiber-8, Penetration of Fibers-8, Growth of Droplet-8, Sulfuric Acid-9, Differential Analyzer-10, Analogue Computer-10.

Abstract: The general methods of Part I for solving moving boundary problems are applied to two challenging problems. In the first problem on the penetration of copper ions into cylindrical cellulose xanthate fibers, a mathematical model was developed which gives results that agree with experimental data reported in the literature on the rate of motion of the reaction front toward the center of the fiber. In the second problem on the rate of growth of sulfuric acid droplets in humid air, the results of the mathematical model agreed with experimental data for droplets containing 15 to 62 wt. % sulfuric acid and having diameters in the range of 500 to 1,000 μ. This model was solved by means of an analogue computer.

Effect of the equilibrium relationship on the dynamic characteristics of distillation column sections, Mohr, C. Michael, **A.I.Ch.E. Journal, 11,** No. 2, p. 253 (March, 1965).

Key Words: Equilibrium Curve-6, 8, Equilibrium-6, 8, Time Constants-7, Distillation-9, 7, 8, Response-7, 8, 9, Dynamic-0, Binary Mixture-9, Distillation Column-9, 7, 8, Material Balance-8, Linear-0, Nonlinear-0, Vapor-Liquid Equilibria-6, 8, Concave-0, Convex-0, S Shape-0, Size-6, Calculation-8, Digital Computer-10, Distillation Trays-9, Steady State-0, Computer-10, Mathematical Machines-10, Separation-9, 7, 8.

Abstract: The dependence of the dynamic characteristics of distillation column sections on the shape of the equilibrium relationship and the number of plates comprising the section is discussed. Dynamic characteristics, valid near the steady state operating condition, were obtained for single-column sections separating binary mixtures by a calculation with a digital computer.

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4.72) in the work of Lemlich and Levy (*3*), the fit is of the same precision as the original fit of the latter authors using the stretched-film Reynolds number. The additional feature is that the apparent break in the correlation has been eliminated.

When the ratio of amplitude to diameter becomes very large, the stretched-film envelope can be expected to break down, resulting in a reduced effective surface area A' for mass transfer and hence smaller values of k/k'. For $A/A' > 4.0$, the experimental values of k/k' were smaller than those given by Equation (4) and these data were not used to establish the correlation and are not shown in Figure 3. This diminution of k/k' for high H/D is also observed in the correlation of Lemlich and Levy (3) using N_{Res}.

The data of Goh (*1*) on Figure 3 have the general tendency to be slightly lower than those of Lemlich and Levy (*3*), but this is only of the order of a few percent, compared to almost 100% in the alternative correlation. Allowing for the difference in the apparatus employed, and the fact that the physical picture presented is a greatly simplified one, the agreement between the different investigations is quite good.

The proposed correlation is based upon the substances naphthalene and camphor, both of which have Schmidt numbers of the order 2.6. Hence, Equation (4) should not be applied for substances whose Schmidt numbers differ greatly from this in order of magnitude. The upper limit of the frequency range is approximately 100 cycles/sec. and the upper limit of the range of double amplitude H is approximately 8 mm., provided that H/D does not exceed 4.7.

There is some evidence that the suggested relationship may apply to the increase in natural convective heat transfer due to vibration, provided that the temperature difference, and hence the thermal convection currents, are kept relatively small. If we restrict ourselves to $\Delta t < 10°F.$, then the heat transfer data presented by Lemlich [(2), Figures 2 and 3] fit Equation (4) quite well, if $h/h' - 1$ is substituted for $k/k' - 1$. This may suggest that when density differences, induced either by concentration differences or temperature differences, are kept small, then the two phenomena of vibration-enhanced mass transfer and heat transfer may be represented by similar equations.

NOTATION

A = surface area per unit length of film in stretched position, $\pi D + 2H$

A' = surface area per unit length of stationary (nonvibrating) cylinder, πD
D = diameter of cylindrical sample
F = frequency of vibration, cycles per unit time
h = heat transfer coefficient, based upon area A'
h' = heat transfer coefficient for no vibration, based upon area A'
H = amplitude of vibration (sometimes also known as double amplitude)
k = mass transfer coefficient, based upon area A'
k' = mass transfer coefficient for no vibration, based upon area A'
N_{Re} = vibrational Reynolds number, given by Equation (3)
N_{ReS} = stretched-film vibrational Reynolds number, given by Equation (1)
Δt = temperature driving force for heat transfer
$\overline{V}$ = $2HF$, average velocity under vibration

Greek Letters

ρ = density of fluid (air)
μ = fluid viscosity

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plasma unit. The tank-coil tube was enclosed in a water-cooled glass tube that was attached to two glass traps, one cooled with dry ice-acetone and the other with liquid nitrogen. The entire system was attached to a vacuum pump with an appropriate manometer and valve.

The plasma jet was started by introducing helium at a pressure of about 0.5 atm. and then changing to a nitrogen-oxygen mixture of air. The results of three experimental runs are tabulated in Table 1.

The conversions are low. However, the power level is also low and higher conversions can be expected from higher power inputs. The material collected in the liquid nitrogen trap was blue and yielded a red-brown gas upon evaporation. This indicates the presence of nitric oxide (3). Infrared spectrum and a molecular weight determination showed this product to be a mixture of nitric oxide and nitrogen dioxide. A mixture of 50% nitric oxide—40% nitrogen