Pumping of Mercury Drops by a Travelling Electrical Potential Wave

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The fact that a dielectric fluid can be pumped by a travelling potential wave has been demonstrated in past studies (*1*, *2*). That drops of liquid metal can also be pumped by this mechanism is a lesser explored phenomenon and is the subject of this article. The electrical forces involved in these two cases have different sources but are ultimately involved with the motion of surface charges in an electric field. Experiments were performed in which beads of mercury were pumped up a slightly inclined insulating surface by a travelling potential wave.

The pumping of drops of a conducting liquid can have many uses. For example, drops could be pumped from a condensing surface of a heat exchanger, thereby enhancing the condensation rate and heat transfer. Also, a travelling wave pump can be used as a particle size discriminator. For example, when pumping up an inclined plane, metal beads over a critical size (determined by the system parameters) would not be pumped while all those under this size would be pumped away.

EXPERIMENTAL APPARATUS

Figure 1 is a sketch of the experimental arrangement. Segmented electrodes were embedded in a 6-in. sq. Plexiglas slab, ⅛ in. below the slab surface. The slab was tilted slightly of the order of 1° from the horizontal, so that true pumping could be distinguished from the somewhat random motion of mercury beads on a plane. The electrode segments were spaced 0.375 in. apart. To obtain a travelling wave, a switching circuit was constructed of two remodelled automobile distributors adjusted 180° out of phase and driven by a common shaft. The center terminal of one distributor was connected to a 30-kv. power supply, with the center terminal of the other distributor held at ground. Each of the external distributor terminals (eight per distributor) was connected to the corresponding terminal on the other distributor and to every eighth segment of the segmented electrode in the test section. Accordingly, at any point in time during an experiment every fourth electrode segment was alternately at power supply voltage and ground, giving a wavelength of 3 in. As the distributors rotated, the potential wave moved continuously along the test section at a velocity of 6 in./sec. Motion pictures were taken of mercury drops introduced near the lower end of the slab and typical drop motions were analyzed from the film. A film speed of 16 frames/sec. was used for the study.

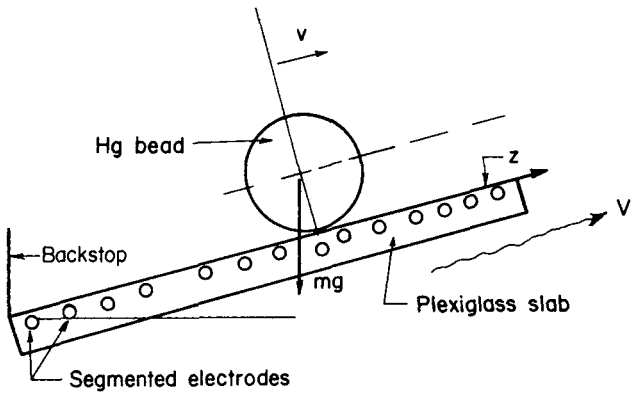

Fig. 1. Schematic of mercury drop as it is pumped up an inclined plate.

EXPERIMENTAL RESULTS AND DISCUSSION

Before applying voltage, it was verified that mercury drops introduced onto the plexiglass plane in general moved to the lower end to form pools of mercury. The plane was then cleared of mercury and the 30-kv. travelling wave applied. A number of drops were observed and from these a few were selected for quantitative observation. In particular both a small drop and a large drop were selected which travelled most of their path perpendicular to the electrodes (which had a velocity component in the z direction only).

The motion of the small drop, which had an equivalent spherical diameter estimated to be about 0.2 in., is shown graphically by the data points in Figure 2. Also shown in this graph is the line on which the points would fall if the drop velocity was always equal to the wave velocity. The average particle velocity was approximately equal to the wave velocity.

Figure 3 shows graphically the motion of the large drop, which was estimated to be about 6 times as massive as the small one. This drop deformed greatly from spherical and changed shape as it moved up the inclined plane. The

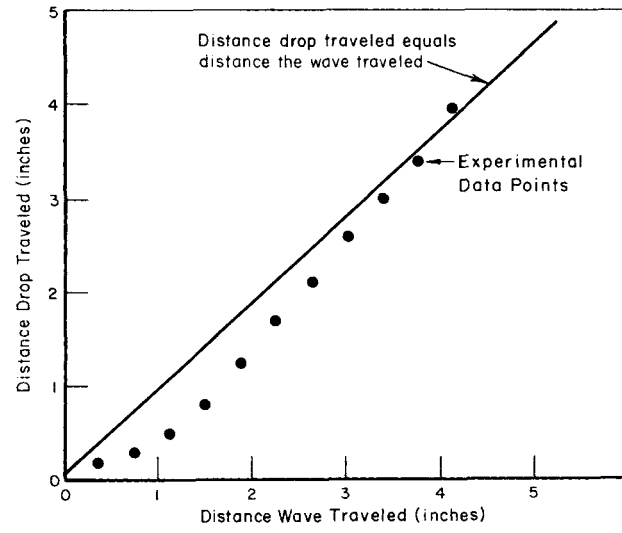

Fig. 2. Distance a drop of mercury with 0.2-in. diam. has travelled as a function of the distance the potential wave travelled. (The potential wave velocity is 6 in./sec.).

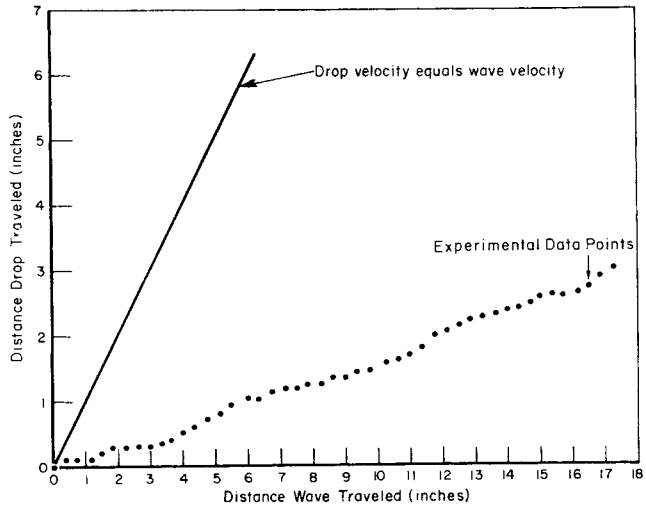

Fig. 3. Distance a drop of mercury with approximately 0.5-in. diam. has travelled as a function of the distance the potential wave has travelled. (The wave velocity is 6 in./sec.).

particle travelled at only about one-fourth the wave velocity. The apparent scatter in the experimental data is believed to be a real reflection of the particle motion. When viewed as a motion picture, the drop indeed appeared to stutter in its climb up the plane.

SUMMARY

It has been demonstrated that drops of a conducting liquid can be pumped by a travelling electrical potential wave. For drop below some critical size the drops travel at approximately the potential wave velocity. As the size of the drop is increased the drops no longer travel at the potential wave velocity but are pumped along by the wave at a slower velocity. It is anticipated that for a particular gravitational field opposing the motion and for a given strength potential wave, drops above a certain size would not be pumped but would roll down the inclined plane.

ACKNOWLEDGMENT

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Boundary Layer Effects on Catalytic Reactions with Volume Change

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The asymptotic solution proposed by Petersen (*1, 9*) for catalytic effectiveness under conditions of large diffusional limitation has proved very useful. Aris (*10*) and Bischoff (*11, 12*) have developed the technique to include fairly complex reaction rate forms. Recently, the method has been used (*2* to *4*) to explore the importance of uniform boundary layers in systems of relatively simple kinetics. The purpose here is to detail a class of solutions which may be obtained for reactions with volume change in the presence of uniform boundary layers.

We consider the reaction $A \rightarrow (m+1)B$. In general the rate will be a function of y, the mole fraction of A and the temperature T. It is assumed that the reaction is carried out in a porous catalyst in the presence of uniform thermal and concentration boundary layers. To a first approximation of the flux of A in such a system may be written as

$$N_A = -\frac{DP}{RT}\frac{\nabla y}{(1+my)} = -\frac{DP}{RT}\nabla\left[\frac{\ln(1+my)}{m}\right] \quad (1)$$

so that the mass and energy conservation equations in dimensionless form are

$$\frac{d^2}{dz^2}\left[\frac{\ln(1+my_0c)}{my_0}\right] = \phi^2 r^*(c,\theta) \quad (2)$$

$$\frac{d^2\theta}{dz^2} = -\beta\phi^2 r^*(c,\theta) \quad (3)$$

with the normal symmetry conditions

$$\frac{dc}{dz} = 0, \quad \frac{d\theta}{dz} = 0 \text{ at } z = 0$$

and with surface conditions specified by external transport rates

$$\left(\frac{1}{my_0}\right)\frac{d}{dz}[\ln(1+my_0c)] = N_{Sh}(1-c_s)$$

$$\frac{d\theta}{dz} = N_{Nu}(1-\theta_s) \quad (5)$$

Weekman (*5*) has shown how temperature may be eliminated in terms of concentration for the solution of the pair of Equations (2) and (3), using the procedure of Prater (*6*) in equating the generation terms of the two equations. The result is

$$\theta = \left[\theta_s^{2-a} + \left(\frac{2-a}{my_0}\right)\beta\ln\left(\frac{1+my_0c_s}{1+my_0c}\right)\right]^{1/(2-a)} \quad (6)$$

in which it is assumed that the temperature dependence of transport coefficients is given by

$$\frac{D}{K} = \left(\frac{D_0}{K_0}\right)\left(\frac{T}{T_0}\right)^a \quad (7)$$