BEHAVIOR OF A LIQUID FILM ON A ROTATING SPHERE

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The present study will offer results of an experimental investigation of instability of a liquid film on the surface of a rotating sphere.

The experiments employed apparatus a block diagram of which is shown in Fig. 1. It consists of equipment for magnetically suspending and applying torsion to the sphere 1-6, a support generator 9, a rotating magnetic field generator 10, regulated power supplies 11, 12, and instrumentation for determination of the rotational velocity of the sphere. Upon sphere 3, which carries a black target, the light from incandescent lamp 7 is focused, and the light reflected from the sphere falls on the photocathode of photomultiplier 8. When the sphere rotates an ac electrical signal develops across the photomultiplier, which is amplified by amplifier 13 and applied to the vertical input of oscilloscope 14. The reference signal generator 15 drives the horizontal plates. Measurement of rotational velocity is done by observing the Lissajous patterns on the oscilloscope screen, or a frequency meter may be employed.

In the experiments described below a steel sphere was magnetically suspended. A drop of liquid capable of wetting the sphere was placed on the lower portion of the latter, and the sphere was then rotated about its own axis by a rotating magnetic field until the liquid was torn from the sphere.

Free suspension of the steel spheres was accomplished with the magnetic suspension generator 9, described in [1]. Sphere suspension at the desired height is achieved by regulating the current of solenoid 1 with a tracking system, the sensor of which is coil 5.

Sphere rotation is accomplished by a rotating magnetic field at a frequency of 500 Hz, created by coils 4, supplied by generator 10. The sphere rotates like the armature of a nonsynchronous motor with a high slip relative to the magnetic field. Acceleration is ~ 3 rev/sec^2.

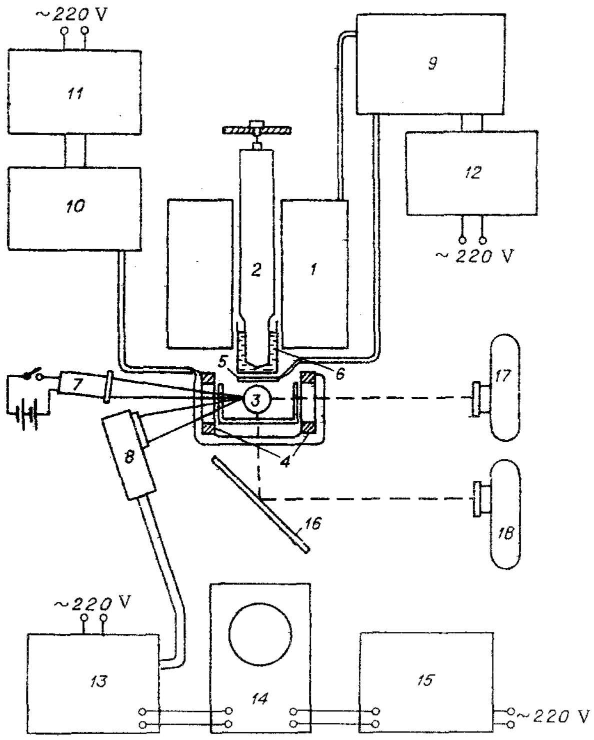

Fig. 1

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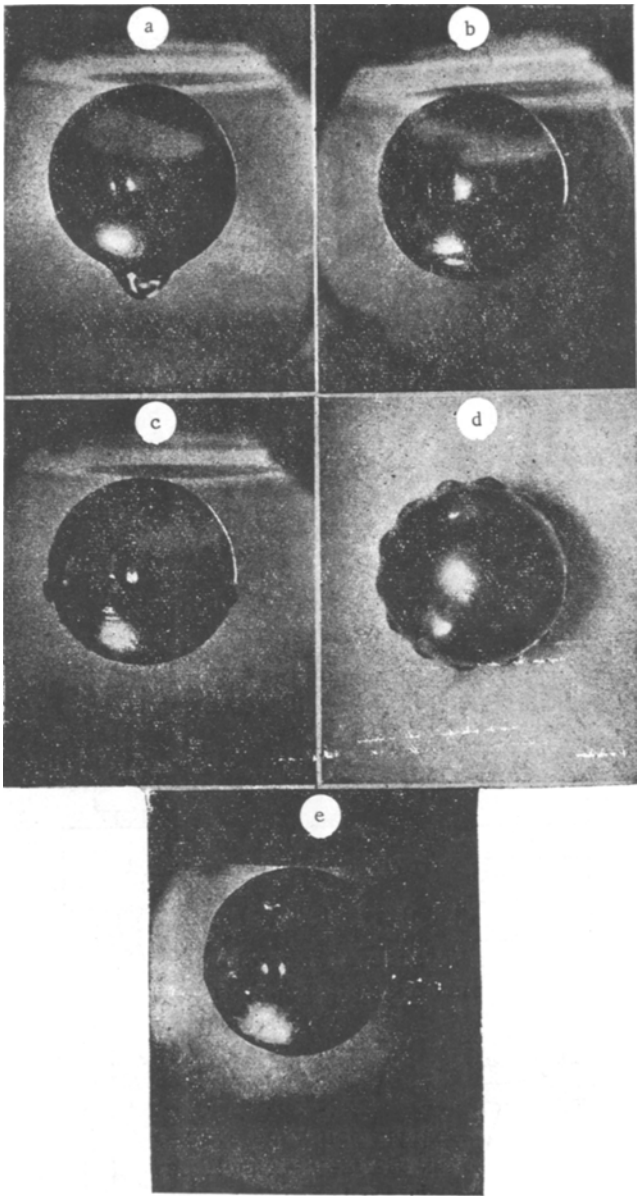

Fig. 2

Preliminary experiments revealed that upon rotation the spatial position of the axis of rotation becomes unstable and it is necessary to introduce force to damp out horizontal displacements of the axis.

Precession of the axis of rotation was eliminated by the technique employed in [2]. To do this the core 2 of the solenoid was suspended on a short steel wire, and its lower end was placed in a thin-walled nonmetallic container 6, filled with oil. Since the sphere is connected to the core by the common magnetic flux, as the core is steadied, the sphere is also.

Experiments on liquid breakoff were performed with spheres 17.5, 19.0, and 22.2 mm in diameter. The wetting liquids used were water, glycerine, and transformer oil. Water and glycerine proved undesirable in these experiments, since they broke off from the sphere surface before the drop reached the sphere equator. The most suitable liquid was transformer oil with a viscosity of 142 $N \cdot sec/m^2$, with which all experiments were performed. To protect the equipment from flying liquid the sphere was surrounded by a glass vessel. The experiments revealed that the first droplets of liquid broke off the equator of the various diameter spheres at approximately one and the same peripheral velocity, ~ 1.1 m/sec.

To determine the behavior of the liquid on the sphere surface at various rotational velocities high speed photographs were made perpendicular to and along the axis of rotation from the bottom, using mirror 16, attached below the bottom of the container at an angle of 45°. Photographs were taken in total darkness with the shutters of the cameras 17, 18 open, using a photoflash tube with a duration of $1.1 \cdot 10^{-5}$ sec.

Figure 2 shows the behavior of the liquid on a 19 mm diameter sphere at various stages of the rotation, up to liquid breakoff. The photographs of Fig. 2a-c, e were taken perpendicular to the axis of rotation, and Fig. 2d along the axis. The photographs represent different times (i.e., different rotation velocities). In all the experiments an attempt was made to keep the size of the suspended droplet constant, at a volume of ~ 0.03 cm^3.

With the sphere immobile, the liquid hangs suspended in the form of a droplet below the sphere, under the influence of gravity (Fig. 2a). At the commencement of rotation the liquid flows over the sphere and rises toward the equator (Fig. 2b). Then a "rope" begins to form at the equator, upon which perturbations develop immediately, in the form of periodically spaced droplets (Fig. 2c, d). Depending on the size of the suspended drop, from 7 to 14 droplets are formed, with 11 being most frequent. With increase in the speed of rotation the droplets grow large and extend outward perpendicular to the axis of rotation, after which they break off in the form of cords with thickened ends (Fig. 2e). After breakoff the cords contract into droplets.

Analysis of the experiments performed reveals that the final stage of liquid breakoff from the rotating sphere differs from the conclusions of [4], where stability conditions for the cord developed at the equator were not considered. Moreover, that study did not consider gravitation and treated only axisymmetric configurations. The experiments performed reveal that the liquid does not wet the upper portion of the sphere above the equator, because the centrifugal force produced at the equator is larger than the adhesion force between liquid and sphere.

Further, according to the theory of [4], a ring of liquid should be formed on the equator. With increase in speed of rotation a gradually narrowing isthmus should appear between ring and sphere, after which the ring breaks off from the sphere and the ring then breaks into individual droplets.

The experiments have shown that liquid under the action of the centrifugal force of a rotating sphere is drawn to the equator, but even in the process of cord formation the liquid begins to collect into individual droplets. It is possible that the droplet formation may be explained by the theory of liquid column instability of [5]. In forming the ring at the equator the liquid is in turbulent motion, which develops because of small perturbations created by liquid friction against the sphere and surrounding air, leading to instability and formation of individual droplets.

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STRUCTURE OF COMPLETELY DISPERSED SHOCK WAVES IN RELAXING MIXTURES

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Shock waves in chemically active gas mixtures with an arbitrary number of reactions are discussed. It is assumed that the difference between the frozen and equilibrium sound velocities calculated from the unperturbed state of the material is a small quantity relative to one of these velocities. The flow rate at infinity is assumed to lie within the range between the frozen and equilibrium sound velocities; the shock wave does not then contain discontinuities, i.e., it possesses complete dispersion. Different cases which may be encountered upon increasing the velocity of the advancing flow are successively investigated. The method of splicing exterior and interior asymptotic expansions is used to construct a solution.

1. Formulation of the Problem. Let us apply to the investigation of the structure of weak shock waves in multicomponent relaxing media the system of equations which describes one-dimensional steady flow in the transonic velocity range

$$2\left(\varepsilon m_\infty v' + \varepsilon_a^2\gamma_f\right)\frac{dv'}{dx'} = \delta_a^2 \mathbf{e}_2' \frac{d\mathbf{q}_2'}{dx'},\quad \delta_a^2 = \frac{p_\infty}{\rho_\infty v_\infty^2}\varepsilon_a^2, \qquad (1.1)$$

$$\frac{d\mathbf{q}_2'}{dx'} = -\mathbf{E}\boldsymbol{\omega}_2',\quad \boldsymbol{\omega}_2' = \mathbf{D}\mathbf{q}_2' + \mathbf{e}_2' v'.$$

Both the length along the coordinate x' and the velocity v' of the perturbed motion of particles together with the components of the vectors $\mathbf{q}_2' = (q_{21}', \ldots, q_{2N}')$ and $\boldsymbol{\omega}_2' = (\omega_{21}', \ldots, \omega_{2N}')$ of the completeness and affinity of the chemical reactions are taken here in a special dimensionless system of units. The density, pressure, and dimensionless thermodynamic coefficient, which is proportional to the curvature of the Poisson adiabat for a mixture with constant composition, are denoted by the letters ρ, p, and m, respectively. The subscript ∞ refers to the state of the material in the advancing uniform flow. The small parameter ε is proportional to the amplitude of the perturbations, and the appearance of the other small parameter ε_a^2 is dictated by the conditions for providing closeness of the frozen $a_{f\infty}$ and the equilibrium $a_{e\infty}$ sound velocities in the unperturbed state. It is assumed in the derivation of Eqs. (1.1) that the velocity v_∞ of the advancing flow deviates slightly from both the frozen and equilibrium sound velocities; the number γ_f is used to specify this deviation, to wit,

$$v_\infty - a_{f\infty} = \varepsilon_a^2\gamma_f v_\infty. \qquad (1.2)$$

Any two positive-definite and symmetrical matrices can appear in the original Euler equations as the kinetic matrix and the stability matrix of the system. Linear transformations of the completeness and affinity vectors of the chemical reactions permit reducing these matrices to the unit E and diagonal D matrices, respectively. This transformation is assumed to be carried out in the system of Eqs. (1.1). The components of the constant dimensionless vector $\mathbf{e}_2' = (e_{21}', \ldots, e_{2N}')$, which are proportional to the adiabatic derivatives of the specific internal energy of the system with respect to the specific volume and one of the components of the completeness vector of the reactions, are also assumed to be subject to the indicated linear transformations.

Since the advancing flow is uniform and is in a state of complete thermodynamic equilibrium,

$$v' \to 0,\ \mathbf{q}_2' \to 0,\ \frac{dv'}{dx'} \to 0,\ \frac{d\mathbf{q}_2}{dx'} \to 0 \quad \text{as} \quad x' \to -\infty. \qquad (1.3)$$

The gas mixture reaches a new equilibrium state as a result of compression within the shock wave; therefore,

$$v' \to v_0',\ \frac{dv'}{dx'} \to 0,\ \frac{d\mathbf{q}_2'}{dx'} \to 0 \quad \text{as} \quad x' \to +\infty. \qquad (1.4)$$

The boundary conditions (1.3) and (1.4) determine the solution with an accuracy to an insignificant shift in x'.

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