EFFECT OF EXTERNAL FIELDS ON THE MOTION AND GROWTH OF BUBBLES IN BOILING LIQUIDS

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It is noted that the growth of bubbles and boiling conditions of heated or saturated liquids can be controlled by employing external fields, which influence the bubble motion on which the thermodynamic growth conditions depend. The growth of bubbles in an accelerated bubble chamber can either be hindered or enhanced. Local inhomogeneous electric or magnetic fields which keep the bubbles near the vessel walls or repel them can be used to change the boundary conditions for boiling and heat exchange with the wall. The effects considered can be used, for example, to improve storage conditions of liquefied gases, heat exchange control, control of boiling, etc.

1. ACCELERATED BUBBLE CHAMBER

THE growth of a bubble in an effervescing liquid leads to local cooling of the liquid near the bubble. Consequently the translational motion of the bubble through new regions of the liquid can change appreciably the thermodynamic condition of the bubble growth. In particular, if there are no forces causing the bubble to float up, its growth can be appreciably hindered.

The bubbles can be kept from floating up in a "dropping" bubble chamber, which is allowed to fall freely during the time of bubble growth. It is much easier to make a "falling" bubble chamber than a "falling" cloud chamber [1] since the short bubble-growth time t makes it sufficient for the chamber to fall a short distance (let $s = gt^2/2$; usually $t \approx 10^{-3} - 10^{-2}$ sec, i.e., the path of the chamber need not exceed several millimeters). The start of chamber motion can be synchronized with the pressure drop. It is also possible to impart to the chamber an acceleration much greater than that of gravity, thus increasing sharply the Archimedean force that pushes the bubbles out of the liquid. All this allows us to study the influence of the motion of the bubble on its growth and to investigate, for example, the growth of the bubble under exceedingly simple thermodynamic conditions, which are amenable to simulation and to calculation (see, for example, [2,3]).

The compensation for the gravitational force in the falling bubble chamber can also eliminate convection in the working liquid and reduce distortion of the tracks.

2. EFFECT OF EXTERNAL INHOMOGENEOUS FIELDS ON THE MOTION OF BUBBLES IN LIQUIDS

In addition to the inertia forces and the gravity force $\mathbf{f}_g = \rho \mathbf{g}$, the liquid may be acted upon by inhomogeneous electric or magnetic fields (see, for example, [4,5]). The volume force acting on the liquid produces an additional Archimedean force acting on the bubble.

The total force acting on the bubble as a whole is

$$\mathbf{F} = \int_s \Big\{ \varepsilon \left[\mathbf{E}(\mathbf{E}\mathbf{n}) - \tfrac{1}{2} E^2 \mathbf{n} \right] + \mu \left[\mathbf{H}(\mathbf{H}\mathbf{n}) - \tfrac{1}{2} H^2 \mathbf{n} \right] \Big\} ds = \tfrac{4}{3} \pi a^3 \mathbf{f}_{\text{dip}} .$$

The condition for the equilibrium of the bubble in the liquid in the presence of gravitational force and electric or magnetic field is $-\mathbf{f}_g = \mathbf{f}_{\text{dip}}$, where $\mathbf{f}_{\text{dip}}$ is the force per unit bubble volume acting on the dipole moment of the bubble

$$\mathbf{f}_{\text{dip}} = -\frac{3}{4\pi} \left\{ \frac{\varepsilon - 1}{\varepsilon + 2} \nabla E^2_{\text{ext}} + \frac{\mu - 1}{\mu + 2} \nabla H^2_{\text{ext}} \right\} .$$

We consider here, for simplicity, bubbles with dimensions small compared with the characteristic dimensions of the field variation and for which the surface pressure is considerably greater than the pressure of the electromagnetic field on the surface of the bubble. In this case the principal role of the inhomogeneous electromagnetic field is to displace the bubble as a whole, and its deformation can be neglected. It is obvious that the equilibrium conditions and the force per unit volume tending to move the bubble are independent of its dimensions.

Let us estimate the necessary field gradients. The Archimedean force (due to gravity) becomes commensurate with the forces in the electric and magnetic field if $\chi_e \nabla E^2 \sim g$ and $\chi_m \nabla H^2 \sim g$, where χ_e and χ_m are the electric and magnetic polarizabilities per units mass of liquid. For typical values, $\chi_e \sim 0.3\ g^{-1}\ cm^3$ and $\chi_m \sim 10^{-6}\ g^{-1}\ cm^3$, we find that in a field with characteristic inhomogeneity dimension $l \sim 0.3$ cm the necessary field amplitudes are $E_0 \sim 10$ kv/cm and $H_0 \sim 10^4$ oe. Such fields can be readily realized in a thin layer near the chamber walls.

We note, for example, that the paramagnetic susceptibility of oxygen is hundreds of times greater, so that the fields can be decreased or their effective zone of action increased.

It is possible to control by means of inhomogeneous fields not only bubble growth but also the boiling conditions on the boundaries and the heat exchange at the walls; if the bubbles are kept at the walls by local fields, heat exchange between the liquids and the walls becomes difficult, and after the bubbles are removed heat exchange is facilitated. Inhomogeneous fields can be induced from the outside even in the case of a conducting wall (magnetic poles near the walls of a vessel containing a diamagnetic or paramagnetic liquid).

The foregoing possibilities of influencing the boiling and evaporation of liquids by using local inhomogeneous fields to retain or remove the bubbles near the walls can also be used to improve the conditions of storage of liquefied gases, to control evaporation, etc.

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