

THE GROWTH OF VAPOR LAYER AROUND THE DROPLET OF LIQUEFIED GAS IN A LIQUID

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Abstract: Vapor explosions, also called thermal detonations, occur when a liquefied gas comes into contact with water. During the contact of the two liquids with considerably different temperatures, intensive boiling of one of them takes place which is accompanied by an explosive increase in pressure. A similar phenomenon also arises in the cooling systems of nuclear-power stations, when, as a result of some accident, the heated particles of the nuclear fuel settle in the cold water. This leads to the explosive boiling of the liquid and to a rapid increase of the pressure. This paper presents asymptotic stage of the vapor bubble growth around the droplet of liquefied gas in the liquid. A simple estimate of vapor layer growth rate around the drop on asymptotic stage is obtained.

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Key Words: vapor bubble, droplet, heat and mass transfer, liquefied gas

1. Statement of the problem

Formulation of the problem of vapor explosion at the micro scale is done in [1]. Numerical simulation of the dynamics of two-phase bubble containing the droplets of liquefied gas is done in [2]. Let us consider analytically the asymptotic stage of the vapor bubble growth around the droplets of liquefied gas.

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We assume that the drop is spherical and processes of heat and mass transfer around the drop we will study in the frame of spherical symmetry. The origin of spherical system is located at the center of the drop. Estimates show that temperature inside the drop is uniform. Calculations [2] show that during considerably long intervals of time radius of the drop practically is not changing and the evaporation of the drop has quasi-steady character.

2. The basic equations

If we assume that heat conductivity of the vapor is constant then quasi-steady distribution of temperature at the asymptotic stage of vapor layer growth is described by formula:

$$T_\nu = (T_d - T_l) \frac{R_d}{R - R_d} \left(\frac{R}{r} - 1 \right) + T_l \quad (2.1)$$

where r is a spherical Eulerian coordinate, is radius R_d of the drop, R - radius of the vapor bubble, T - temperature. Subscripts d, v, l are corresponding to the parameters of drop, vapor and liquid. Calculations [3] show that for gas bubble without phase exchange temperature of the bubble surface is practically constant and equals to the temperature of the surrounding liquid. For this reason we assume $T_l = T_0 = \text{const}$. During quasi-state evaporation temperature at the drop surface is equal to saturation temperature corresponding to the pressure in the vapor layer: $T_d = T_s(P_v)$ where P is the pressure. Subscript s refers to the parameters along saturation curve. At the asymptotic stage of vapor layer growth the effects of inertia are not important. For this reason the pressure of vapor inside the vapor layer is constant. For this reason the temperature of the drop surface will be also constant: $T_s(P_v) = \text{const}$

In case of vapor bubble growth around heated particle [4] the process is going because of the evaporation of surrounding liquid. In case of the drop of liquefied gas evaporation takes place at the internal boundary of the vapor layer. Equation for the mass of vapor layer has form:

$$\frac{dm}{dt} = 4\pi R_d^2 j \quad (2.2)$$

where m is the mass of the vapor layer, j - evaporation rate which can be found from the boundary condition at the surface of the drop [3]

$$r = R_d : j l = \lambda_\nu \frac{\partial T_\nu}{\partial r} \quad (2.3)$$

Here l is latent heat of evaporation, λ - heat conductivity. Let us substitute to (3) temperature distribution given by formula (1). As a result we will get for asymptotic stage of bubble growth, when $R \gg R_d$:

$$j = \frac{\lambda_\nu}{l} \frac{T_0 - T_s}{R_d} \quad (2.4)$$

Let us estimate vapor layer growth at the asymptotic stage. For this we will use that

$$m = 4\pi \int_{R_d}^R \rho_\nu r^2 dr \quad (2.5)$$

$$\rho_\nu(r, t) = p_\nu \mu_\nu / BT_\nu \quad (2.6)$$

Here μ is the molecular mass, B - the gas constant. Taking into account (4), (5), (6) we will get from equation (2):

$$\frac{d}{dt} \int_{R_d}^R \frac{r^2 dr}{T_\nu(r)} = \frac{BR_d \lambda_\nu}{p_\nu \mu_\nu l} (T_0 - T_s) \quad (2.7)$$

Let us substitute formula (1) to equation (7). After integration we will get the dependence of bubble radius on time in implicit form:

$$\begin{aligned} \frac{BT_0^2 R_d \lambda_\nu}{p_\nu \mu_\nu l} t = & \frac{(R - R_d)^3}{3} + \frac{3}{2} R_d (R - R_d)^2 + 3R_d^2 (R - R_d) \\ & + R_d^3 \ln \left[1 + T_l \frac{R - R_d}{T_s R_d} \right] \end{aligned} \quad (2.8)$$

We use that $T_0 \gg T_s$. At the asymptotic stage of bubble growth $R \gg R_d$, and the first term on the right side of equation (8) is dominant. For this reason: $R \sim \sqrt[3]{t}$.

3. Conclusion

A simple estimate of vapor layer growth rate around the drop of liquefied gas in liquid on asymptotic stage is obtained.

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