NUMERICAL MODELING OF CONDENSATION RELAXATION OF SUPERSATURATED VAPOR UNDER STATIC AND DYNAMIC CONDITIONS

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Let us consider a mixture of vapor and a noncondensing gas in an adiabatically isolated cylinder with a movable piston. When the piston is moved, its velocity determines the rate of attainment of a supersaturated state of the vapor. In turn, the piston displacement determines the degree of vapor supersaturation.

We consider the modeling of the bulk condensation process of a vapor from a vapor-gas mixture using two modes of attaining a supersaturated state. In one of these modes, condensation relaxation occurs during continuous vapor expansion (dynamic mode). In the other, a vapor expands from the initial to a given volume of the mixture with the subsequent keeping until the completion of condensation relaxation (static mode). By analyzing the results of numerical modeling, the approximate expressions are obtained for the characteristics of condensation relaxation (relaxation time, attained degree of supersaturation) as functions of expansion rate. These expressions can be used to solve two problems:

(1) from a given expansion time, it is necessary to determine the degree of expansion at which the degree of supersaturation during dynamic relaxation attains a maximum;
(2) for a given degree of expansion, it is necessary to determine the expansion rate at which the maximum of the degree of supersaturation during dynamic relaxation is attained at a given degree of expansion.

The second problem is necessary to solve, in particular, for analyzing condensation relaxation in the static mode. Let us choose a certain value $\left(V/V_0\right)_1$ of the expansion ratio and, by the above method, determine the corresponding expansion rate $\dot{V}_1$. It is clear that for the found combination of the expansion ratio and the expansion rate, consideration of condensation relaxation in both the dynamic and the static modes gives the same results (Fig.1a, 1b solid and dashed curves *1*). The difference between the relaxation modes is exhibited with an increase in the expansion rate (Fig. 1. solid and dashed curves *2*, *3*). In the dynamic mode an increase in the expansion rate leads to attaining a higher maximal supersaturation ratio, which corresponds to a higher expansion ratio. However, the qualitative shape of the relaxation curves with an increase in the expansion rate in the dynamic mode remains unchanged (Fig. 1a, solid curves *2*, *3*). Conversely, an increase in the expansion rate at a constant expansion ratio (the static mode) changes the qualitative shape of the relaxation curves: in them, a characteristic plateau emerges, which corresponds to the induction period in condensation relaxation (Fig. 1a, dashed curves *2, 3*).

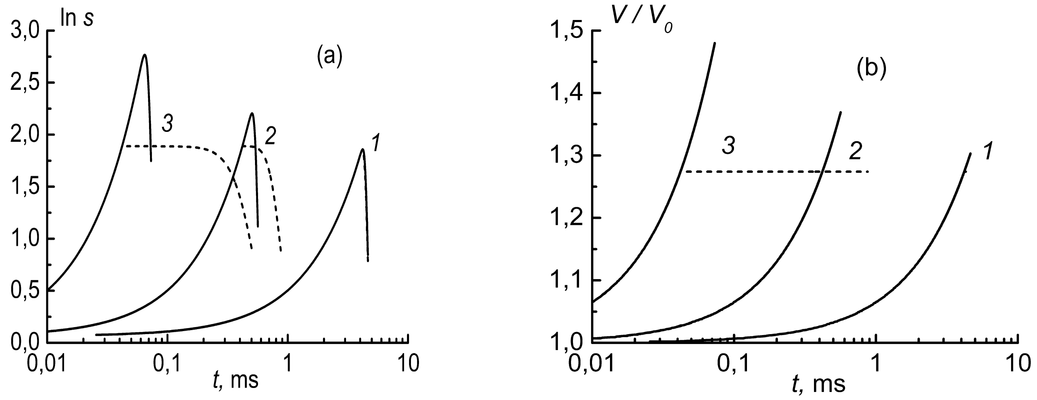

Fig. 1. (a) Supersaturation ratio and (b) expansion ratio versus time in the dynamic (solid lines) and static (dashed lines) modes of condensation relaxation at various expansion rates: $\dot{V}_2 = 10\dot{V}_1$, $\dot{V}_3 = 100\dot{V}_1$

The relaxation portions of the curves, which describe the behavior of the supersaturation ratio, temperature, the number density of drops, and the nucleation rate in the static mode, are presented in Figs. 2 and 3 as functions of relative time t - t_m . Here, t_m is the moment of time (depending on the expansion rate) at which the maximal supersaturation ratio is attained. It is seen that with an increase in the expansion rate from the value corresponding to the dynamic mode, the induction period duration increases from zero to the limiting value, which is characteristic of a given expansion rate. It is to this value of the induction period duration that the results of our previous paper [1] correspond. Thus, one can state that the increase in the induction period duration with an increase in the expansion rate at a given expansion ratio is indicative of a transition from the dynamic to the static mode of condensation relaxation.

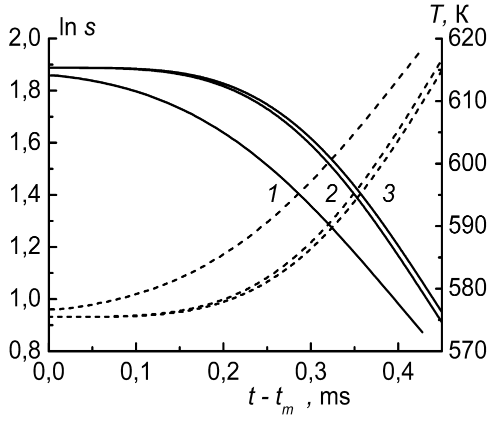

Fig. 2. Supersaturation ratio (solid lines) and temperature (dashed lines) versus time in the static mode of condensation relaxation at various expansion rates: $\dot{V}_2 = 10\dot{V}_1$, $\dot{V}_3 = 100\dot{V}_1$

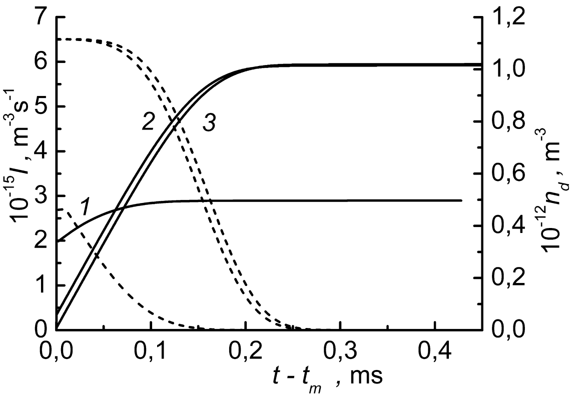

Fig. 3 Number density of drops (solid lines) and nucleation rate (dashed lines) versus time in the static mode of condensation relaxation at various expansion rates: $\dot{V}_2 = 10\dot{V}_1$, $\dot{V}_3 = 100\dot{V}_1$

The minimal expansion rate at which the relaxation mode can be considered static was determined as follows. Variant calculations at different expansion ratio gave the expansion rates at which, in the expansion time by the beginning of the relaxation step ($0 < t < t_\mathrm{m}$), the number density of drops had reached no more than 1% of the final value of this quantity. It turned out that throughout the considered ranges of the parameters being varied (which for the expansion rate was as wide as six orders of magnitude), the condition imposed is satisfied by the expansion rates obeying the relation

$$\dot{V}_{st} \geq 50\dot{V}_d ,$$

where $\dot{V}_d$ is the expansion rate found by the above method (problem 2) in the dynamic mode for a chosen degree of expansion and $\dot{V}_{st}$ is the expansion rate in the static mode for the same expansion rate.

Acknowledgment

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References

[1] Kortsenshtein, N.M., Samuilov, E.V., Dokl. Akad. Nauk, 2003, vol. 392, no. 3, pp. 365—369.