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On the possibility of thermodynamic equilibrium in the cavitation bubbles

M.G. Rudenko[a]

Doctor of Technical Sciences, Irkutsk Agricultural Academy, Irkutsk, Russia

Hydrodynamic cavitation is an effective means to ensure the intensification of various processes carried out in liquid media.

Analysis of the results of existing and specially designed experiments to elucidate the mechanisms of the effect of cavitation on the properties of the liquid, let V.M. Ivčenko and E.D. Malimon allocate following hydrodynamic phenomena by which may be obtained by technological effects: [1]

- The formation of intense pressure fields and expansion waves - the compression arising from the pulsations of cavities or in the initial stage of coalescence;
- The formation of cumulative jets accompanying asymmetrical compression of the cavity;
- The occurrence of oscillations of the bubble surface in the initial stage of collapse.

All these phenomena are seen as a consequence of two factors [2]:

- The presence of surface tension at the interface and
- The curvature of the surface.

For the case of cavitation, these factors may be considered necessary, but at the same time, insufficient.

We consider the mechanical equilibrium of the two identical in size and shape of the surface, but of compositionally different of bubbles (cavitation and gas) in a liquid.

In both cases there is surface curvature and surface tension, but the gas bubble is stable enough, whereas cavitation bubble collapses. The differences can be explained by the intensity of the processes of mass transfer of the bubble with the surrounding fluid.

Parameters of the phase transition of gas is significantly different from the parameters of the phase transition the surrounding liquid. State of aggregation of the contents of the bubble, which is determined taking into account the Laplace equation ($\Delta p = \frac{2\cdot\sigma}{r}$) does not change with changes in pressure (see Fig. 1). As a result, a gas bubble can be in power and thermodynamic equilibrium with the surrounding fluid, and the intensity of a possible process of mass transfer is small and is determined by the intensity of the dissolution of gas in liquid.

Parameters of the phase transition the content of the cavitation cavity and its surrounding fluid are almost identical. With increasing pressure and compression of the bubble, the surrounding liquid is in a state of thermodynamic equilibrium. Vapor pressure inside the bubble, which is able to balance the effect

[a] Corresponding author: mg-rud@mail.ru

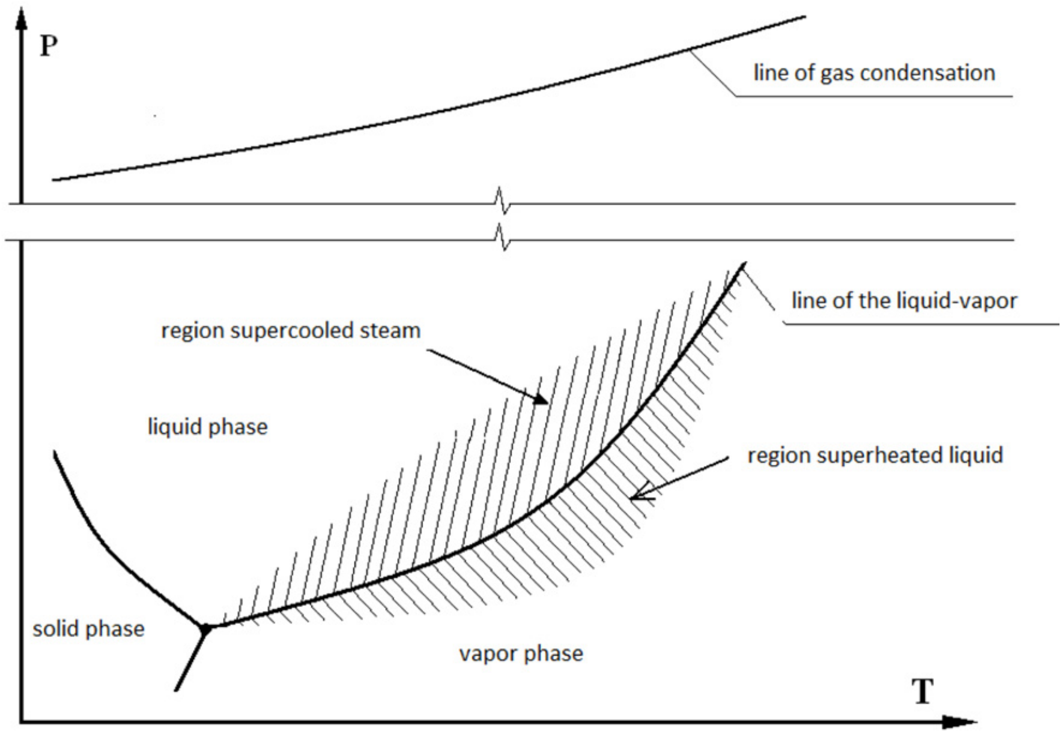


Figure 1. Comparison of the lines of the phase transition of liquid and gas.

of surface tension is determined by the Laplace equation, does not corresponds as of thermodynamic equilibrium vapor. As a result, the bubble is not may have an equilibrium with the surrounding fluid, and collapses.

Experimental data on the collapse of the cavitation bubble and the solution of the problem of the collapse of the Rayleigh empty cavity in a liquid have qualitative agreement [3]. This confirms the assumption, that during collapse, the steam has no thermodynamic equilibrium and do not prevents a decrease in the radius of the bubble.

Thus, for the generation of hydrodynamic processes that accompany the lifecycle of the cavity, you need the following three conditions:

- The presence of surface tension;
- The presence of the curvature of the interface;
- The lack of thermodynamic equilibrium of a compressible phase.

Note that the thermodynamic equilibrium of the gas bubble is possible only if the parameters of the fluid is disposed between the line of the liquid – vapor and condensation of the gas line (see Fig. 1). Above the line of gas condensation, the latter has no equilibrium and cannot prevent the collapse of the bubble

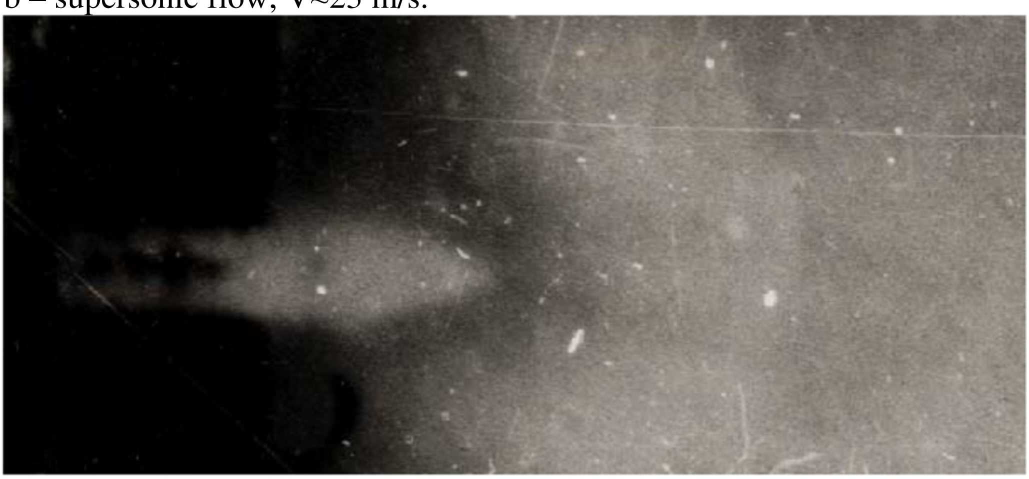
Similar phenomena are observed when the excitation of cavitation in a heterogeneous liquid consisting of two mutually insoluble components (emulsion), wherein the dispersed phase is a liquid having a relatively high vapor pressure of saturation [4].

The experiment was conducted on a hydrodynamic booth closed type.

On entering the working area of 70 mm diameter was installed Laval nozzle with critical a diameter of 50 mm. At the outlet from the working portion, in a diametral plane, was fixed the plate about 5 mm

a – wedge in a stationary medium

b – supersonic flow, V≈23 m/s.



c – supersonic flow, V≈30 m/s.

Figure 2. Wedge in the flow of environment.

thick. The front edge of the plate facing towards the flow have been formed as a wedge with an angle of forward (Fig. 2a). The distance from the nozzle to the front edge of the plate, was approximately 0.4 m.

As the dispersion medium used the water, the dispersed phase – unleaded petrol.

When passing through the Laval nozzle formed two-phase flow consisting of water vapor and gasoline. At supersonic a speed, in the front part of plate, was formed a shock wave. At the top of the wedge, the thickness of the shock wave was about 12 mm (see Fig. 2b). With increasing flow velocity, the thickness of the shock wave decreases to about 5–6 mm (Fig. 2c).

During movement of the environments from the nozzle to the front edge of the shock wave was approximately 0.017 seconds for observation which shown in Fig. 2.1 (b) and respectively, 0.014 to (c).

It should be noted changes in properties of the incident flow before and after the shock wave. It testifies that up to the front of the shock wave, we have a sufficiently stable flow of fluid.

Stable can be only a thermodynamically the equilibrium state. Then it can be concluded that, during the working portion the vapor phase have thermodynamic equilibrium.

In the shock front is increased in pressure of the fluid. As a result, the vapor phase is condensed on the surface of the bubble. The bubble is surrounded by liquid having the same composition, and this creates the conditions for the nonequilibrium condensation of the vapor phase and leads to the collapse of bubbles.

Ehereby

1. The thermodynamic nonequilibrium of compressible of the phase is a key factor of the emergence of hydrodynamic processes of high intensity – on an equal basis with the action of surface tension and surface curvature.
2. When excited by cavitation in the emulsion environments, thermodynamic phase equilibrium can be reached in case of a complete vaporization of the liquid forming the dispersed phase.

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