Condition for the formation of mechanisms of increasing gas emission in the supply nozzle of a swirling chamber

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Abstract. In this paper, the degassing process in a swirling chamber as a function of the pressure drop, the diameter and length of the nozzle, and the mass flow velocity was considered. On the basis of the equations of the velocity of the pressure drop in the nozzle and the Rayleigh-Lamb equation describing the gas bubble growth, the dependence of the pressure change in the nozzle on time was obtained and the critical area was determined in which the formation of gas bubble nuclei occur. The condition of avalanche increase in gas emission in certain intervals of the nozzle length is obtained and its optimum value is determined. This condition makes it possible to realize the mechanism of heterogeneous and barrier-free gas evolution in a swirling chamber.

1. Introduction

One of the most important tasks of the oil and gas industry is the process of separation of multiphase (gas-liquid and liquid-gas) mixtures into separate phases, as well as physical processes which facilitate the separation of these mixtures.

2. Methodology

The analysis of the separation process in a swirling chamber is based on the assumption of the existence of the phase equilibrium in the system. However, in fact, dynamic processes are no less significant, since the gas phase formed in the liquid does not immediately separate from the liquid, due to the stretching of the process itself over time. We can expect the formation of bubbles at the stage of the introduction of the liquid phase into the swirling chamber. In this case, the formed gas bubbles in the nozzle, entering the swirling chamber, can become nuclei of heterogeneous nucleation. For a barrier-free, i.e. avalanche increase in gas emission within the swirling chamber, it is necessary to ensure a critical value of the degree of supersaturation.

The investigation of the gas bubbles formation with a rapid change in the pressure in the liquid must include the equations of conservation of mass, momentum, and energy for both liquid and gas bubbles. The equations for the formation of bubble nuclei describing their dynamics, considering the interphase energy transfer, can be obtained by following the results of the paper [1]. To consider the problem of the appearance of gas bubbles in a laminar liquid flow, the traditional approach (Lagrangian-Eulerian) to describing a two-phase medium [2] was used. It is assumed the phase equilibrium and the evolution of bubbles with the help of a model of test particles. On the basis of the equations of the pressure drop rate in the nozzle and the Rayleigh-Lamb equation describing the growth of a gas bubble, the dependence of the pressure change in the nozzle on the time can be obtained.

The equation of the gas mass conservation inside the bubble is:

$$\frac{\partial \mathrm{P}}{\partial t} \approx -\frac{3P}{R}\frac{dR}{dt} + \frac{\eta_a}{R}\sqrt{\frac{R_* T}{2\pi}}(|P_s - P|)\theta \ , \qquad (1)$$

where θ - dimension factor

The Rayleigh-Lamb equation:

$$R\frac{d^2R}{dt^2} + \frac{3}{2}\left(\frac{dR}{dt}\right)^2 = \frac{1}{\rho_l}\left(P - P_l - \frac{2\delta}{R} - \frac{4\mu}{R}\frac{dR}{dt}\right), \qquad (2)$$

where μ - fluid viscosity

At the initial instant of time, a homogeneous liquid which does not contain bubbles is at a set pressure and liquid temperature

$0\ t = 0$; $P_\ell = P_{\ell 0}$, $T_\ell = T_{\ell 0}$, $N_b = 0$, $U = 0$

In the section of the supply nozzle, a pressure drop is set

$P_\ell = P_{\ell 0} - V_p t$, where, υ_p - pressure drop rate.

Conditions change after the formation of bubbles: $R = R_{cp}$, $P = P_s$ A qualitative analysis of the solution is shown in Figure 1.

It is clearly seen that the pressure in the selected section of the nozzle drops to values less than P_s.

In this case, the liquid appears in the metastable state, which leads to a fluctuation formation of the nuclei followed by the intensive growth of the gas nuclei. As a result of the last process, the pressure stabilizes near the value P_s. The depth of the pressure undershoot $(\Delta P)^*$ determines the efficiency of the degassing process.

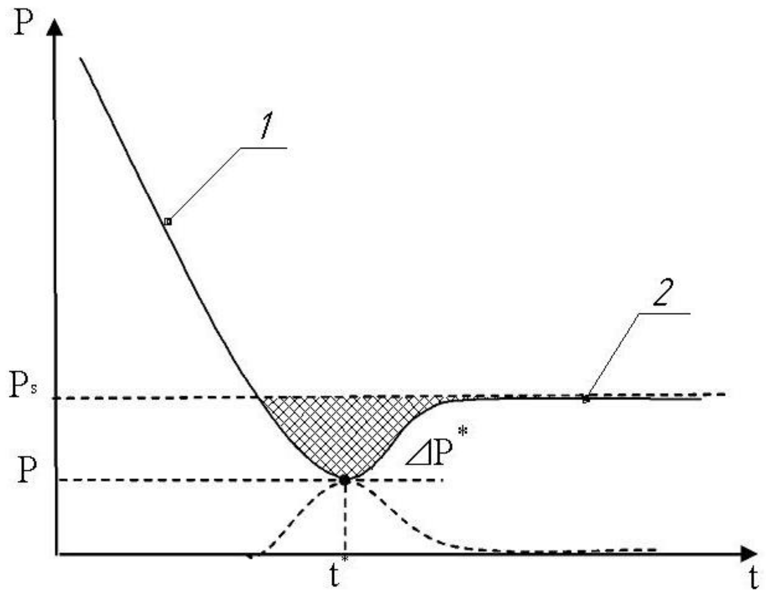

Figure 1. Dependence of the pressure change in the nozzle on time: 1 - pressure drop along the nozzle length, 2 - increase in pressure due to gas emission.

$(\Delta P)^* = (P_s - P)$ - The depth of the pressure drop required for the avalanche increase in gas emission. In fact, the depth of the pressure undershoot ΔP^* is the driving force which determines the degree of metastable state.

The results obtained make it possible to determine the limitations on the geometric dimensions of the supply nozzle. It is known that the velocity of the gas-liquid flow is related to the pressure drop by the relation:

$$U \approx \left[(1-0{,}8k)\exp\left(-0{,}06\Delta q \frac{\ell}{d}\right)\right]\tilde{\chi}\sqrt{\frac{2}{\rho_\ell}(\Delta P)}, \qquad (3)$$

where, U - gas-liquid flow rate; k – function of the ratio of the gas solubility in a given liquid and the solubility coefficient of carbon dioxide in water; Δq - the saturation degree of the liquid with gas; $\frac{\ell}{d}$ - the ratio of the nozzle length to its cylindrical diameter; $\tilde{\chi}$ - nozzle flow rate; ρ_ℓ - density of degassed liquid, kg/m^3; ΔP - differential pressure at the inlet and outlet of the nozzle, Pa.

The average residence time of the flow in the nozzle $\bar{t}$ can be determined by the expression

$$\bar{t} \approx \frac{\Delta P}{\left(\frac{dP}{dt}\right)} \qquad (4)$$

$\frac{dP}{dt} = \upsilon_\rho$ - the set pressure drop rate.

Then the length ℓ and the speed will be related by expression $\ell = U \cdot \bar{t}$.

Consequently, from expression (3), considering (4) and the results of calculating the pressure drop and (2), the condition for ΔP can be obtained at which the regime of avalanche increase of gas evolution in the nozzle is conducted.

$$\Delta P \approx \left(\frac{\ell}{\bar{t}}\right)^2 exp\left(-0{,}12\frac{\Delta q \ell}{d}\right)\frac{\rho_\ell}{\mu^2} > \Delta P^*, \qquad (5)$$

In Figure 2 the dependence $\Delta P(\ell)$ is shown from which it follows that there is an optimal size of the supply nozzle for each degree of supersaturation.

$$\left(\frac{\ell^*}{d}\right) = (0{,}06\Delta q)^{-1}, \qquad (6)$$

As follows from equation (5) for small values of the nozzle length, the determining value for the pressure drop is its quadratic dependence (curve 1) in Figure 2. With increase in the nozzle length, the second factor (curve 2) acquires an increasingly essence exponentially rapidly decreasing dependence $\Delta P(\ell)$.

As a result, a dome-shaped dependence is established, from which the existence of the minimum and maximum values of the nozzle size follows required for the realization of the heterogeneous degassing mechanism.

In Figure 2 it is shown that for a specific value ΔP^*, set by solutions (2) and (3), there is an interval of the geometric nozzle size for the effect realization.

$$\ell_{min} < \ell < \ell_{max}, \qquad (7)$$

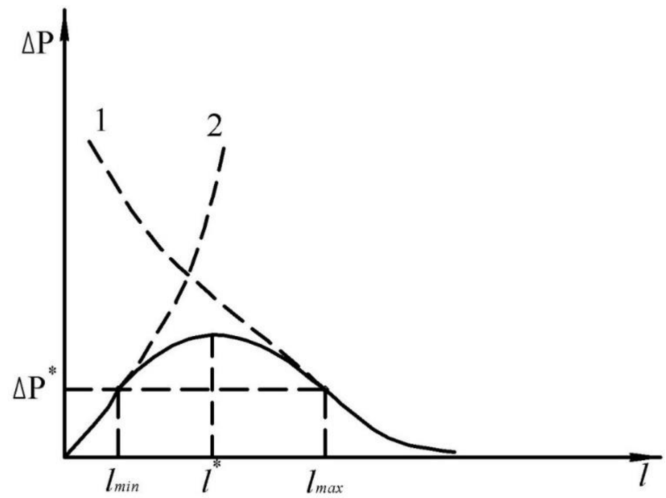

Figure 2. Graph of the dependence of the pressure drop in the nozzle as a function of its length: the curve which determines the quadratic dependence (the first factor in equation (5), 2 is the curve determined by the exponential factor in expression (5).

3 Conclusion

Thus, it was possible to identify the conditions under which the pressure drop wave propagates inside the supply nozzle below the pressure corresponding to the value at the spinodal, which determines the metastable state of the solution. As a result, in the nozzle, behind the front of the discharging wave, there will be an intensive process of gas evolution. Consequently, a solution containing gas bubbles will enter the swirling chamber, causing a hetero-phase character of the gas emission in the swirling chamber.

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