https://doi.org/10.26160/2474-5901-2023-34-86-91

RATIONALE FOR THE OPERATION OF A PNEUMOHYDRAULIC SPRAYER IN CAVITATION MODE

Gorobey V.P.
All-Russian National Research Institute of Viticulture and Winemaking "Magarach" RAS, Yalta, Russia

Keywords: pneumohydraulic atomizer, channel, diameter, mixing chamber, pressure, injection, cavitation, speed, coefficient.
Abstract. The purpose of the study of the design and technological features of the pneumohydraulic atomizer, the supply of air for aeration of the liquid in which can be carried out both forcibly and by ejection, was to substantiate its operation in the cavitation mode. Collision of compressed jets of air and liquid phases is carried out in the expansion zone of the mixing chamber in a state of supersaturation, due to the release of latent heat of vaporization during condensation.

ОБОСНОВАНИЕ РАБОТЫ ПНЕВМОГИДРАВЛИЧЕСКОГО РАСПЫЛИТЕЛЯ В РЕЖИМЕ КАВИТАЦИИ

Горобей В.П.
Всероссийский национальный научно-исследовательский институт виноградарства и виноделия «Магарач» РАН, Ялта, Россия

Ключевые слова: пневмогидравлический распылитель, канал, диаметр, камера смешения, давление, инжекция, кавитация, скорость, коэффициент.
Аннотация. Целью исследований конструктивно-технологических особенностей пневмогидравлического распылителя, подача воздуха для аэрации жидкости в котором может осуществляться как принудительно, так и эжекцией, являлось обоснование его работы в кавитационном режиме. Соударение сжатых струй воздушной и жидкой фаз осуществляется в зоне расширения камеры смешения в состоянии перенасыщения, обусловленного выделением скрытой теплоты парообразования при конденсации.

The process of drop formation during the supply of irrigation water with the help of sprinkling machines has been studied quite deeply [1]. The sizes of drops of natural and artificial rains vary widely: the first – from 0.1 to 7 mm, and the second – from 0.4 to 4.0 mm. Researchers noted the negative impact of increasing the diameter of droplets on the topsoil, and the impact force of drops with a diameter of 3-5 mm is 4-5 times greater than drops with a diameter of 1 mm [2]. Analyzing the characteristics of existing sprinkling machines, we can conclude that further development of sprinkling machines with good performance in terms of material consumption and equipment cost should be carried out in the direction of reducing energy costs. Re-equipment of irrigation equipment with low-pressure nozzles makes it possible to reduce the energy intensity of sprinkling from 16 to 50%, while significantly increasing the efficiency of using water resources [3]. From the point of view of expanding the range of regulation of the size of water droplets sprayed by a sprinkler, it is promising to use aerators with an ejection effect in their design. Such devices, with a simple design, make it possible to obtain a water-air mixture that easily breaks up into drops when it exits the sprinkler nozzle into the air, without additional expenditure of mechanical energy [4]. The ingress of air into a liquid is always possible, due to the high speed of its molecules, which penetrate not only the surface energy barrier of the liquid, but also actively penetrate into its intermolecular space [5]. The concept of cavitation is explained as the formation of fluid breaks as a result of a local decrease in pressure in it. Cavitation can also occur when, for some reason, sections appear in the liquid in which the speed of its movement is different [6]. At a pressure not much higher than the cavitation threshold, a lot of cavitation bubbles immediately appear, occupying a certain part of the space, which is called the cavitation region [7]. Under pulsed tensile stresses in a liquid, cavitation nuclei begin to grow, forming a cavitation cluster, the shape and length of which are determined by the initial size spectrum of cavitation nuclei, the nature of the applied stress, and boundary conditions [8].

It follows from theoretical assumptions that an increase in hydrostatic pressure leads to a decrease in the time of bubble collapse and an increase in the intensity of shock waves. As the temperature rises, the pressure inside the bubble, determined by the pressure of vapor and gas, increases and the shock wave weakens, but this also leads to an increase in the cavitation region [9].

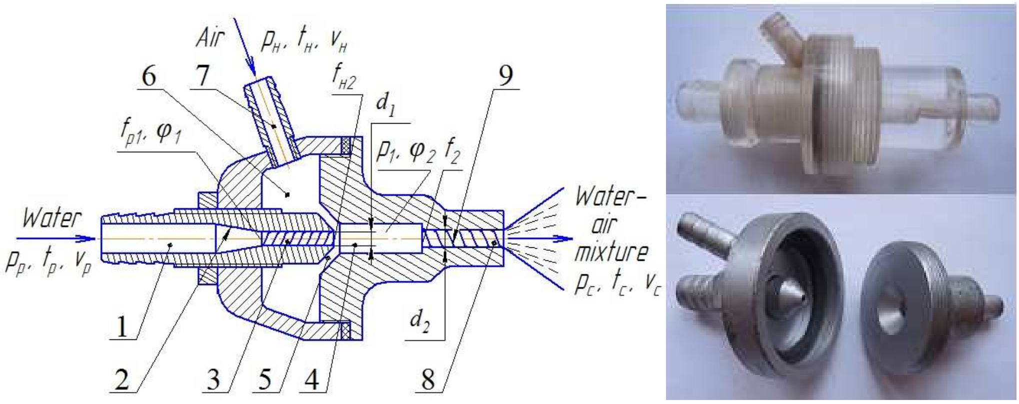
An innovative pneumohydraulic device of a pneumohydraulic type sprinkler has been developed [10] and the geometry parameters of the structural device have been partially determined [11]. In connection with the need to develop irrigation technologies and sprinkler equipment designs that, at an economically feasible level of productivity, save water, energy, material and technical and labor resources without negative impact on the soil and the environment, it is relevant to justify the design and technological features of the sprayer in a cavitation mode. The essence of the technical solution of the device is illustrated by graphic material in fig. 1, where: on 1*a* – structural and technological equivalent diagram is shown, on 1*b* – pneumohydraulic sprinkler device pneumohydraulic type.

During the operation of the device, water under pressure enters through the channel 1 of the fitting, receives acceleration in the cone-shaped constriction 2 and enters the nozzle 3 and is ejected into the mixing chamber 4 in which a vacuum is created for the air under pressure entering partly with a swirl through the cone-shaped annular gap 5 with the converted part of the kinetic air energy from the diffuser 6, and into the diffuser through the channel 7 of the tangentially installed fitting from the compressor. Collision of compressed jets of air and liquid phases is carried out in the expansion zone of the mixing chamber in a state of supersaturation, due to the release of latent heat of vaporization during condensation. The water atomized by air is directed to the outlet nozzle 8, where it is partially driven into a rotational movement along the helical recesses 9 and is additionally swirled out of the device in the form of artificial rain.

The minimum pressure p_1 of the injected or mixed flow takes place in the inlet section of the cylindrical mixing chamber (see fig. 1*a*). This is the minimum pressure

$$p_1 = p_н – \Delta p_к, \qquad (1)$$

where: $p_н$ – air pressure; $\Delta p_к$ – pressure drop at the inlet conical section of the mixing chamber.



a b

Fig.1. Structural and technological equivalent diagram – *a* and appearance of prototype samples – *b* pneumohydraulic sprinkler device pneumohydraulic type

At a pressure p_2 equal to the boiling pressure p^* of the mixed flow passing through the mixing chamber, a cavitation regime occurs in the atomizer. The pressure p^* depends on the temperature of the mixed flows t_p and $t_н$ and the injection coefficient u.

With an increase in the injection coefficient u of the atomizer, $\Delta p_к$, changes, as does the pressure p^* in accordance with the boiling point t_c. When the pressure p_1 decreases to the value p^*, the cavitation mode of operation of the atomizer occurs.

According to [4], the dependence for calculating the cavitation coefficient injection u_*, at which the cavitation regime occurs in the atomizer, has the form:

$$u_* = \frac{\varphi_2}{\varphi_1}\left(\frac{f_2}{f_{p1}} - \frac{1}{\sqrt{1+\dfrac{p_н - p_*}{\Delta p_p}}}\right)\sqrt{\frac{p_н - p_*}{\Delta p_p}}, \qquad (2)$$

where: φ_1, φ_2 are the velocity coefficients of the nozzle of the water nozzle and the mixing chamber, taking into account the loss of momentum in the atomizer due to friction;

f_2 – cross-sectional area of the mixing chamber;

f_{p1} – cross-sectional area of the water nozzle,

$$f_{p1} = \frac{\pi d_1^2}{4}, \qquad (3)$$

$$f_2 = \frac{\pi d_2^2}{4}, \qquad (4)$$

where $d1$ is the diameter of the cylindrical nozzle of the water fitting; where $d2$ is the diameter of the cylindrical mixing chamber. In a cylindrical mixing chamber

$$f_2 = f_{p1} + f_{н2}, \qquad (5)$$

where: $f_{н2}$ is the area of the annular gap at the inlet to the cylindrical mixing chamber.

As can be seen from equation (2), the cavitation injection coefficient u* is greater in apparatuses with a large cross section ratio f_2/f_{pl}. In addition, u^* increases with an increase in the pressure of the injected medium p_H and a decrease in the temperature of the mixed flow t_c, the pressure p* corresponding to it, and the pressure drop of the working medium Δp_p in the atomizer nozzle. At given temperatures of the working flow t_p and injected flow $t_и$ each temperature of the mixed flow t_c corresponds to a certain injection coefficient u^*.

Cavitation in the atomizer occurs at $u = u^*$. If the temperatures of the working and injected flows are the same ($t_p = t_n = t_c$), the cavitation pressure $p^* = f(t_c)$ is a constant value. Therefore, for an atomizer with given dimensions (f_2/f_{pl} = const) at constant parameters of water and air flows (p_p = const and p_H = const), as can be seen from equation (2), the cavitation injection coefficient u^* depends only on the temperature of the medium $t_p = t_н = t_c$.

According to [4], the injection coefficient and is determined from the dependence:

$$u = \frac{K_1 \dfrac{a_{p*}}{a_{c*}} \lambda_{pн} - K_3 \lambda_{c3}}{K_4 \lambda_{c3} - K_2 \dfrac{a_{н*}}{a_{c*}} \lambda_{н2}}, \qquad (6)$$

where: K_1 –working flow rate coefficient; K_2 – rate coefficient of the injected flow;

$a_{р*}$, $a_{н*}$, $a_{с*}$ – critical velocities of the working, injected and mixed flows, respectively, m/s [4];

$\lambda_{p2} = \lambda_{pн}$, $\lambda_{н2}$, λ_{c3} – are the reduced isentropic velocities of the working, injected and mixed flows, respectively [4],

$$a_{p*} = \sqrt{2 \frac{k_p}{k_p + 1} p_p v_p},$$
$$a_{н*} = \sqrt{2 \frac{k_н}{k_н + 1} p_н v_н}, \qquad (7)$$
$$a_{c*} = \sqrt{2 \frac{k_c}{k_c + 1} p_c v_c},$$

where: k_p, $k_н$, k_c are the adiabatic indices of the working, injected and mixed flows, respectively [4];

p_p, p_h, p_c are the pressures of the working, injected and mixed flows, respectively;

v_p, $v_н$, v_c are the specific volumes of the working, injected and mixed flows, respectively.

Based on experimental studies [4], it is recommended to take φ_1= 0.95; φ_2 = 0.925, K_1 = 0.925 and K_2 = 0.9.

Let's check the possibility of a cavitation regime at the inlet section of the mixing chamber. To do this, let us set a number of values for the injection coefficient and then determine the boiling pressure of water p^* at each temperature t_c of the mixed flow.

Based on the found values of p^* and the given values of Δp_p, we find by formula (2) the cavitation coefficients u^*. The cavitation regime at the inlet section of the mixing chamber occurs at $u = u^*$.

Based on the results of calculating the parameters in the WPS spreadsheet processor using formulas (1)-(7), plots of dependence u, $u^* = f(t_c)$ were plotted fig. 2.

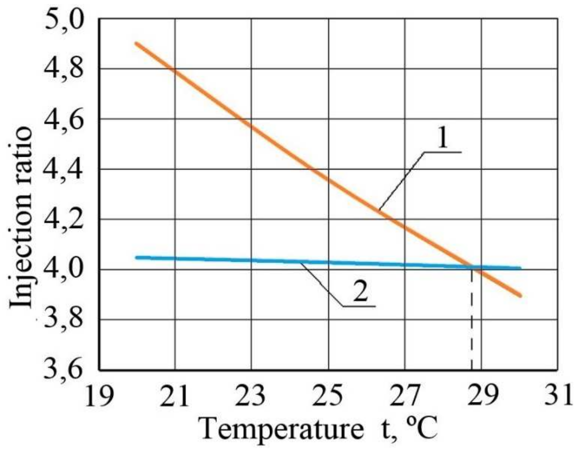


Fig. 2. Graphs of dependence: 1 – injection coefficient, u ; 2 – cavitation injection coefficient , u_* on the temperature of the water-air mixture

As can be seen from these graphs, the cavitation regime in the inlet section of the mixing chamber will occur at t_c = 28.2°C, when $u = u^* = 4$. This mode will occur at values of the injection coefficient corresponding to the cavitation coefficient or greater than it ($u \geq u^*$), that is, at a temperature $t_c \leq$ 28.2°C.

A theoretical model for the operation of a promising pneumohydraulic sprayer in the cavitation mode is proposed, graphical dependencies are obtained that can be used to optimize technological and geometric parameters, as well as design solutions when improving technology for producing artificial rain.

References

1. Pospelov A.M. The structure of rain during artificial sprinklingof agricultural crops // Sprinkling: Proc. of the VNIIGiM. 1940, vol. 3, pp. 117-186.
2. Shepelev A.E. Research on the characteristics of artificial rain of wide-spread multi-support sprinkling equipment // Ways to improve the efficiency of irrigated agriculturem. 2017, no. 4 (68), pp. 36-42.
3. Droplet size distribution the water application with now. – Plessure Splinklers, 1985. – 243 p.
4. Sokolov E.Y., Singer N.M. Inkjet devices. – M.: Energoatomizdat,1989. – 352 p.
5. Efremova K.D., Pilgunov V.N. Cavitation properties of liquids // Science and education. Electronic Journal of the MSTU n.a. N.E. Bauman. 2016, no. 3, p. 20.

6. Geguzin Ya.E. Bubbles. – M.: Science, 1985. – P.154-157.
7. Rosenberg L.D. Cavitation region // Powerful ultrasonic fields / Ed. L.D. Rosenberg. – M.: Science, 1968. – Part 6. – P. 221-266.
8. Novitsky B.G. Application of acoustic oscillations in chemical-technological processes. – M.: Chemistry, 1983. – 192 p.
9. Sirotyuk M.G. Experimental studies of ultrasonic cavitation // Powerful ultrasonic fields / Ed. L.D. Rosenberg. – M.: Science, 1968. – Part 5. – P. 168-220.
10. Patent No. 2704175 RU. Pneumohydraulic sprinkler / V.P. Gorobey. – Appl. No. 2019107468 from 03/15/19; publ. 10/24/19, Bull. No. 30.
11. Gorobey V.P., Moskalevich V.Y., Godzhaev Z.A. Substantiation of the device for generating drops of artificial rain by pneumohydraulic spraying of liquid // Agricultural machines and technologies. 2021, vol.15, no. 2, pp. 53-61. DOI: 10.22314/2073-7599-2021-15-2-53-60.

Список литературы

1. Поспелов А.М. Структура дождя при искусственном дождевании сельскохозяйственных культур // Дождевание: Сб. науч. тр. ВНИИГиМ. – 1940. – Т. 3. – С.117-186.
2. Шепелев А.Е. Исследования характеристик искусственного дождя широкозахватной многоопорной дождевальной техники // Пути повышения эффективности орошаемого земледелия. – 2017. – №4(68) – С. 36-42.
3. Droplet size distribution the water application with now. – Plessure Splinklers, 1985. – 243 p.
4. Соколов Е.Я., Зингер Н.М. Струйные аппараты. – М.: Энергоатомиздат, 1989. – 352 с.
5. Ефремова К.Д., Пильгунов В.Н. Кавитационные свойства жидкостей // Наука и образование. Электронный журнал МГТУ им. Н.Э. Баумана. – 2016. – №3. – С. 20.
6. Гегузин Я.Е. Пузыри. – М.: Наука, 1985. – С.154-157.
7. Розенберг Л.Д. Кавитационная область // Мощные ультразвуковые поля. – М.: Наука, 1968. – Ч. 6. – С. 221-266.
8. Новицкий Б.Г. Применение акустических колебаний в химико-технологических процессах. – М.: Химия, 1983. – 192 с.
9. Сиротюк М.Г. Экспериментальные исследования ультразвуковой кавитации // Мощные ультразвуковые поля / Под ред. Л.Д. Розенберга. – М.: Наука, 1968. – Ч. 5. – С. 168 – 220.
10. Патент № 2704175 РФ. Пневмогидравлический дождеватель / В.П. Горобей.– Заявка № 2019107468 от15.03.19; опубл. 24.10.19, Бюл. № 30.
11. Горобей В.П., Москалевич В.Ю., Годжаев З.А. Обоснование устройства генерации капель искусственного дождя пневмогидравлическим распылением жидкости // Сельскохозяйственные машины и технологии. – 2021. – Т. 15, № 2. – С. 53-61. – DOI: 10.22314/2073-7599-2021-15-2-53-60.

Gorobey Vasily Petrovich – doctor of technical sciences, senior researcher	**Горобей Василий Петрович** – доктор технических наук, старший научный сотрудник
trial237@rambler.ru	

Received 16.02.2023