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# The effect of pipeline parameters of machines for applying liquid complex fertilizers on the drip-air mixture quality

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**Abstract.** The article is devoted to the study of a drip-air mixture flow through pipelines, namely, the determination of total pressure losses based on known values of the flow rates of the constituent phases or the loss coefficients of the constituent phases. The authors conclude that the conditions for introducing the drip-air mixture into the pipes do not affect the size of the flow structure stabilization area. It has been found that for small values of the air and liquid flow rates, the diameter and length of the pipeline, as well as its position, have a very significant effect on the flow structure of the two-phase mixture and on the average diameter of the droplets. For each pipeline length and diameter, there is a pulsation flow mode only at certain values of the air and liquid flow rates ($G_v/G_l$), moreover, the larger the diameter and length of the pipeline, the later the pulsation flow mode occurs. At high values $G_v/G_l$, the position, length, and diameter of the pipeline do not have a noticeable effect on the flow shape, the flow has a finely dispersed structure, pressure pulsation is practically absent.

## 1 Introduction

One of the main tasks of the Russian agro-industrial complex is to increase the crop production volume. Increasing the yield of agricultural products is impossible without the use of various types of fertilizers, which can be applied both in liquid and solid state using various technologies.

According to studies [1-3], the application of mineral fertilizers in liquid form is the most effective way because:

- useful substances are available to plants for a long time (prolonged action);
- high absorption percentage;
- uniform distribution in the soil;
- possibility of simultaneous application with LCF (liquid complex fertilizer) of various trace elements, biopreparations, and plant protection products;
- high level of mechanization in LCF application;
- LCF application has a more accurate dosage distribution over the area.

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LCFs can be applied locally in the form of an aerosol mixture, which are broken down by the air flow into small droplets and blown into the space between the soil particles**.** As a result of using this method of introducing fertilizers, microparticles of nutrients are formed in the zone of intensive activity of the root system of agricultural plants.

The introduction of LCF into the soil by this method increases the coefficient of their use up to one and a half times. At the same time, the guarantee of environmentally safe use of liquid fertilizers is significantly increased [4].

## 2 Materials and Methods

The working process of machines for applying fertilizers or pesticides to the soil in the form of a drip-air mixture includes its movement from the device preparing the mixture (spray mixer) to the nozzles of the working bodies. This process should proceed in such a way as to minimize undesirable and, at the same time, inevitable changes in the geometric structure of the two-phase medium during the mixture movement.

The movement of droplets in the air stream without a film reduces the resistance and provides a pulsation-free mode of mixture ejection from the working body.

As is known [5], the determining factor of the flow structure of the liquid-air mixture is the Froude criterion Fr= $\frac{\omega_{cm}^2}{d_p g}$, which can be written as follows:

$$\mathrm{Fr}=\frac{16G_{cm}^2}{g^3\rho_{cm}^2\pi^2 d_p^5}, \qquad (1)$$

where $\omega$ is the average flow rate of the mixture, m/s;
$d_p$ – pipeline diameter, m;
g – gravity acceleration, m/s$^2$;
$G_{cm}$ - weight second flow rate of the mixture, N/s;
$\rho_{cm}$ - mixture density, kg/m$^3$.

A review of experimental studies [5,6] showed that for pipes with a diameter of 25-30 mm and a mixture concentration 4.0>$G_a/G_l$>0.11 ($G_a/G_l$=X is the amount of sprayed liquid per 1 kg of air), a strongly dispersed (film-free) flow is observed at 14 $\omega_{cm}$ ≥m/s. Therefore, such a flow of the mixture as a continuous two-component medium with a constant concentration X for pipes $d_p$<25 mm and at the specified concentration values from (1) will be at values Fr≥1000.

Based on these conditions and some assumptions, the equations of gas-hydrodynamics of the mixture take on a form similar to the equations of a single-phase liquid.

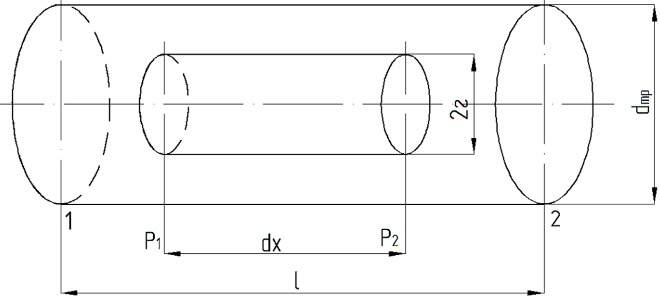

**Fig. 1.** To calculate the resistance of the drip-air mixture in a pipeline element.

Then:

1) the equation of the momentum constancy:

$$G_{cm}F_p \cdot \rho_{cm_p} \cdot \omega_{cm_p} \tag{2}$$

2) the equation of the momentum change:

$$\omega_{cm_p}\frac{\omega_{cm_p}}{dx} - \frac{1}{\rho_{cm_{\text{ир}}}} \cdot \frac{dP_{cm_p}}{dx} - \mu_p\frac{\omega_{cm_p}}{2d_p} \tag{3}$$

3) the equations of the flow energy constancy:

$$\frac{\omega^2_{cm_p}}{2} + \frac{KX_0}{KX_0-1} \cdot \frac{P_{cm_p}}{\rho_{cm_p}} = \frac{a^2_{*cm}}{2} \cdot \frac{KX_0+1}{KX_0-1}. \tag{4}$$

where $F_p$ - the cross-sectional area of the pipeline;

K is the indicator of the isentropic process, valid only for sound velocity calculation [7];

$a_{*cm}$ - the critical velocity of the mixture, m/s;

$\mu_p$ - the coefficient of pipe resistance;

$dx$ – the pipe element along the length ℓ in diameter fractions (Fig.1);

$X_0 = 1 - \frac{1}{X+1}$ – the reduced concentration;

$P_{cm_p}$ – the pressure of the mixture in the pipeline, Pa.

In smooth pipes, $\mu_p$ does not depend on $\lambda_p = \frac{\omega}{a_{*p}}$ [8,9]. This circumstance greatly facilitates their calculation. Indeed, from (2):

$$\rho_{cm} = \frac{G_{cm}}{F_p\omega_{cm_p}} = \frac{G_{cm}}{F_p a_{*cm}} \cdot \frac{1}{\lambda_p}, \tag{5}$$

From (4), considering (5), we obtain:

$$P_{cm_p} = \frac{KX_0+1}{KX_0} \cdot \frac{a_{*p}G_{cm}}{F_p} \cdot \frac{1-\frac{KX_0-1}{KX_0+1}\lambda_p^2}{\lambda_p}, \tag{6}$$

Substituting (6) into (3):

$$\frac{KX_0+1}{KX_0}\left(\frac{1}{\lambda_p} - 1\right)\frac{d\lambda_p}{\lambda_p} = \mu_p\frac{\mathrm{dx}}{d_p}, \tag{7}$$

We integrate equation (7), assuming X=const along the pipe and replacing the dimensional coordinate X with a dimensionless value ℓ, expressing the pipe length in diameter fractions.

$$\frac{KX_0+1}{KX_0}\int_{\lambda_2}^{\lambda_3}\left(\frac{1}{\lambda_p} - 1\right)\frac{d\lambda_p}{\lambda_p} = \int_0^{\ell}\mu_p(Re)d\ell, \tag{8}$$

Where from

$$\frac{KX_0+1}{KX_0}\left[\left(\frac{1}{\lambda_2^2} + 2\ln\lambda_2\right) - \left(\frac{1}{\lambda_3^2}2\ln\ell_3\right)\right] = \int_0^{\ell}\mu_p(Re)d\ell, \tag{9}$$

where: $\lambda_2$ - the reduced speed at the end of the mixing chamber;

$\lambda_3$ - the reduced speed at the end of the pipe;

Re is the Reynolds number.

To determine the mixture flow in the pipeline, it is necessary that the main parameters characterizing the mixture state are known at the entrance to the pipe (at the outlet of the mixer).

Equation (9) is solved only by a sequential approximation, since $\mu_p$ is a function $Re_{cm}$ depending on many variables (velocity, temperature, viscosity, etc.).

Determining $Re_{cm}$ at the beginning of the pipeline by the formula:

$$\text{Re}= \frac{\rho_{cm}\omega_{cm}d_p}{\eta_{cm}} = \frac{4G_{cm}}{\pi d_p g \eta_{cm}}, \tag{10}$$

and considering it to be constant in the first approximation along the pipe length, we find $\lambda_3$ by the known pipe cross section and length ($\eta_{cm}$ – mixture viscosity). To clarify, with the found value $\lambda_3$ it is possible to calculate $Re_{cm}$ and determine $\lambda_3$ again.

It is known from the literature [10] that at sufficiently high concentrations and high speeds of the mixture, it can be considered acceptable to determine friction losses $\mu_p$ based on the mixture flow density. At the same time, the maximum error does not exceed 5-10%. Therefore, it can be assumed that on an infinite small section of the pipe $\Delta\ell$, the resistance coefficient $\mu_p$ is a linear function from $\delta\ell/d_p$. Neglecting the phenomenon of heat transfer, we can write:

$$\frac{2\Delta P}{\rho_{cm}\omega_{cm_p}^2} = \mu_p\left(\frac{\Delta\ell}{\text{d}_\text{p}}; \text{Re}; \lambda_\text{p}; \text{K}\right);$$

or

$$\frac{\Delta P}{\Delta\ell} = \frac{\rho_{cm}\omega_{cm_p}}{2\text{d}_\text{p}}\mu_p(\text{Re}; \lambda_\text{p}; \text{K}) \tag{11}$$

If the length of the pipe is small and the pressure drop is relatively small, then the temperature changes are insignificant. In this case, $\mu_p$ does not depend on $\lambda_\text{p}$ and E [8]. Therefore, the velocity and density of the medium moving along the pipe will be constant. Then:

$$\frac{\Delta P}{\ell} = \frac{\rho_{cm}\omega_{cm_p}^2}{2\text{d}_\text{p}}\mu_p(\text{Re}) \tag{12}$$

Considering (1) of (12), we obtain:

$$P_{cm_{p(b)}} - P_{cm_{p(e)}} = \mu_p(Re)\frac{8\ell G_{cm}^2}{\pi^2 d_p^2 \rho_{cm}} \tag{13}$$

where $P_{cm_{p(b)}} or\ P_{cm_{p(e)}}$ – is the mixture pressure at the beginning and end of the pipeline.

From (13) after the transformation and considering that $\frac{\text{G}_\text{cm}}{\text{G}_\text{l}} = \text{X} + 1$, $\frac{\text{G}_\text{cm}}{\text{G}_\text{l}} = 1 + \frac{1}{X}$ and $\text{G}_\text{l} = \mu_\text{l} F_\text{l}\sqrt{2g\gamma_l P_l}$ it follows:

$$\left(\mu_\text{p}(\text{Re})\frac{\ell_\text{p}}{\text{d}_\text{p}}\right) = \mu_{\text{cm}_\text{p}} = \frac{\mu_{l_p} + \mu_{v_p}X}{1+X} = \frac{\text{G}_{cm_\text{p}}}{\text{G}_\text{cm}} = \frac{\text{G}_{l_\text{p}} + \text{G}_{a_\text{p}}}{\text{G}_{l_{\text{cm}+\text{G}_{a_\text{cm}}}}} \tag{14}$$

where $\text{G}_\text{cm}$, $\text{G}_\text{l}$, $\text{G}_a$ is the weight per second flow rate of the mixture, liquid, and air through the spray mixer.

## 3 Results and Discussion

Dependence (14) allows us to find the total loss coefficient $\mu_{\text{cm}_\text{p}}$ in the pipeline from the known values of the flow rates of the constituent phases (without pipeline and with pipeline) or the loss coefficients of the constituent phases (liquid $\mu_{l_p}$ and air $\mu_{a_p}$). It considers losses for the expansion of the gas component, losses from gravitational forces and coagulation in all forms and modes of the mixture flow.

At constant values of pipeline dimensions and mixer characteristics, the $A_{\mathrm{cm}}$ resistance coefficient $\mu_{\mathrm{cm_p}}$ depends on Re and, consequently, on the ratio of air and liquid flow rates $\mathrm{G_a/G_l}$; moreover, with increasing $\mathrm{G_a/G_l}$ (13) $\mu_p$ increases, reaching a maximum, and then decreases. For each $A_{\mathrm{cm}}$, $\ell_{\mathrm{p}}$, and d, there is the most advantageous mode of transportation of the droplet-air mixture, for which, $\mu_p \rightarrow \max$ with maximum torch polydispersity.

The conditions for introducing the drip-air mixture into the pipes do not affect the size of the flow structure stabilization area. In the study of two types of spray designs (Fig. 1) there are no changes in the nature of the mixture flow, therefore, the following characteristics of the mixer and liquid sprayer are used for research: $A_{\mathrm{cm}} = 0{,}879$; $A_{\mathrm{l}} = 2{,}09$.

The research results on the effect of the pipeline geometric dimensions on the quality of the drip-air mixture are presented in Fig. 2 in the form of a functional dependence of the average drop diameter $d_k^{(s)}$ on the ratio of air flow to liquid $\mathrm{G_a/G_l}$, length and diameter of the pipeline.

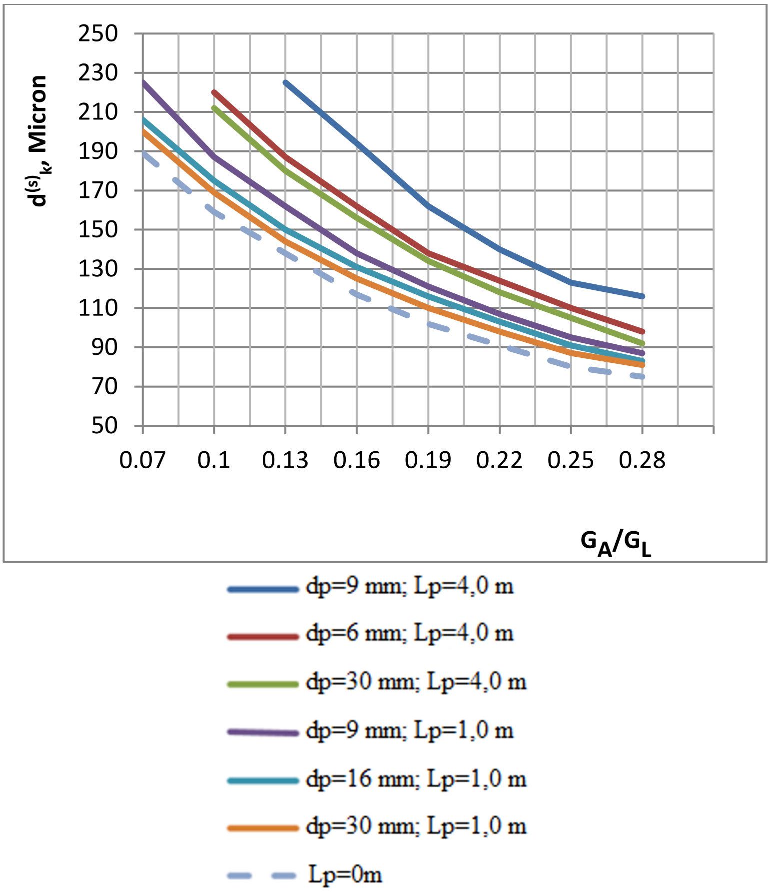

**Fig. 2.** The effect of the pipeline length and diameter on the drip-air mixture quality. Lines a, b, and c are the visible end of the pressure pulsation.

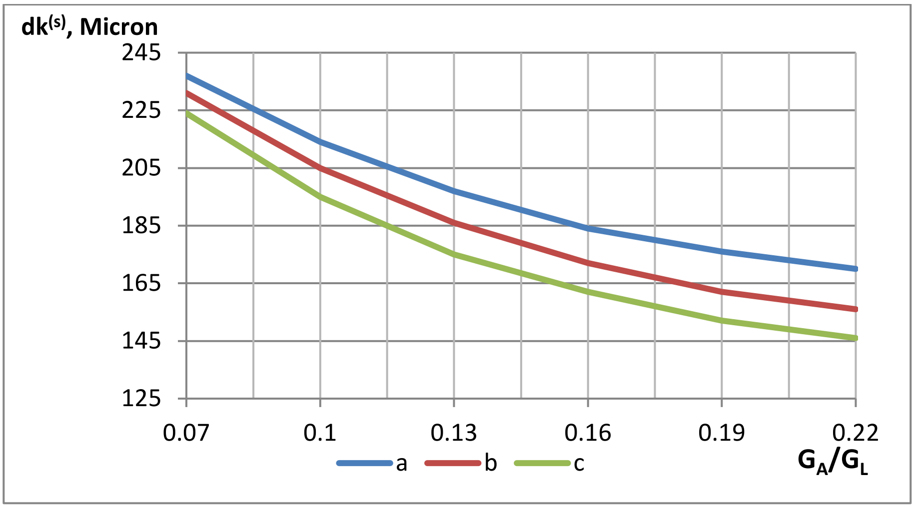

**Fig. 3.** Lines a, b, and c are the visible end of the pressure pulsation.

## 4 Conclusions

In conclusion, it can be noted that at small values of $G_a/G_l$ (≤0.08), the pipeline diameter and length, as well as its position, have a very significant effect on the flow structure of the two-phase mixture and on the average diameter of the droplets.

For each pipeline length and diameter, there is a pulsation (plug) flow mode only at certain values $G_a/G_l$,, moreover, the larger the pipeline diameter and length, the later (at higher values $G_a/G_l$) the pulsation mode of the flow begins.

With a small diameter of pipelines, the pulsation frequency increases much faster than with a large one. At $d_p \leq 9$ mm and a pipeline length of $L_p \geq 3$ m, the pulsation-free flow of the mixture is possible only in modes exceeding the optimal ones. This is due to the fact that liquid plugs form at the pipeline bending points and the larger the smaller $d_p$ and longer $L_p$. Periodic breakdown of liquid plugs leads to pressure pulsation. The amplitude of the pressure pulsation increases with increasing pipeline length in the range $G_a/G_l$ from 0.055 to 0.150.

At high values $G_a/G_l$, when the role of gravity becomes insignificant, the position, length, and diameter of the pipeline do not have a noticeable effect on the flow shape. The flow has a finely dispersed structure, there is practically no pressure pulsation. For pipelines with $25 > d_p \geq 16$ mm, the range of pulsation modes is shifted towards lower values $G_a/G_l$.

The boundaries of the pulsation modes of the drip-air mixture flow depending on the length and diameter of the pipeline and $G_a/G_l$ are shown in Fig. 2 by lines a, b, and c.

The strong dispersion of the flow is determined by the criteria $G_a/G_l$ and Weber We [11], which are related to the size of the initial droplets, but not to the pipe diameter. Therefore, the boundaries of transitions to stronger dispersion and improvement of the spray torch in the area of pulsation-free flow of the mixture move towards large pipeline diameters. The quality of spraying is improved with an increase in the diameter of the pipeline and the ratio $G_a/G_l$, and is worsened with an increase in the length of the pipeline.

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