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Simulation of mixing and crushing of liquid at the initial site by a high-temperature gas flow

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Abstract. A mathematical model of mixing and crushing of a liquid at the initial site of a device for supplying a solution with a high-temperature gas flow has been developed. The process of mixing and crushing using the energy of hot water vapor, cotton oil misc when it is fed to the final distillation process is considered. An analytical method for calculating the actual size of the initial section of the nozzle for the supply of solution has been developed. Based on the initial data of the process of final distillation of cotton oil misc in production, by methods of mathematical modeling of the hydrodynamics of phases, the radii of the nozzle nozzle for hot steam and liquid, the location of the location of the liquid input into the steam stream are theoretically determined. The dimensions of the mixing chamber and the length of the initial section are determined. The initial parameters of the main and passive flows are proposed based on the conditions of liquid crushing by the Weber and Reynolds criteria.

1 Introduction

In the production of vegetable oil during the final distillation, the main factor of intensification is the contact surface of the phases, which provides an increase in the mass transfer coefficient between phases.

To solve the problem of spraying the total flow of the miscella into droplets using the energy of acute steam, it is necessary to study the hydrodynamics of deformation and crushing of the droplet in a two-phase flow, since the cotton oil miscella has its own characteristics and the pressure of acute water vapor fluctuates in the range of 5-6 atm.

The regularities of deformation and crushing of liquid droplets in a two-phase flow belong to the fundamental problems of hydrodynamics and are of interest in solving many applied problems. Bearing in mind the significant application of such processes, extensive scientific research works of scientists are devoted to them [1,2]. Such tasks include the tasks of crushing a liquid with a gas flow.

Scientific research has developed designs of mixers forming droplets from liquids using gas energy and investigated various ways of supplying phases.

In [3], a method of design calculation of a two-component jet gas-liquid nozzle with internal mixing is proposed, where the nozzle consists of external and internal contours. The

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sequence of calculation of such a jet nozzle is given. In this case, the diameter of the passage section is selected first. To determine the length of the nozzle, the thickness of the middle and fire bottoms, the distance between them and the size of the nozzle protrusions above the middle and fire bottoms are taken into account. The optimal size of the nozzle is in iterative mode.

The paper [4] presents a mathematical model and the results of calculations of crushing and evaporation of liquid droplets in subsonic and supersonic flows with a high braking temperature. It is noted that the most powerful influence on the process of gas-dynamic crushing of a drop is its relative velocity. A modified equation is proposed for calculating the coefficient of aerodynamic drag of the droplet, taking into account the influence of both the deformation of the droplet and its flow regime. The extent of the regions of gas-dynamic crushing and evaporation of droplets in flow paths with variable distribution of parameters is estimated. In [5], the deformation and fragmentation of single liquid droplets injected into a continuous air jet were experimentally investigated. High-speed shadow photos were used in combination with image contour recognition. All experiments are repeated many times to determine the behavior of the droplet based on statistical methods. The changes in the shape and mass of the droplet in different initial data are investigated.

In the studies of the authors [6], it was found that with an increase in pressure, the crushing of droplets proceeded less efficiently. Under the influence of increased pressure, the free surface area of the fragments is restrained, i.e. their transformation relative to the spherical shape is limited and the area of expansion relative to the collision zone becomes quite small.

From the review of literary sources it can be seen that there are almost no works devoted to the comprehensive study of the dimensions of the mixing device of steam and liquid. In addition, the pressure ratio of the active flow to the passive is very large.

When a high-temperature vapor stream collides, droplets of various sizes form in the liquid, such processes in industrial apparatuses are formed using separate devices called nozzles, liquid flows to them in various directions.

To increase the efficiency of the final distillation process of the cotton oil miscell, it is necessary to reduce the residence time of the miscell in the apparatus, the temperature of the miscell should not be exceeded from 105^0C, the residual content of extraction gasoline should provide the required norm, the consumption of hot steam should be minimal, it is necessary to reduce stagnant zones in the designs of final distillers, etc.

To ensure maximum efficiency of the process of final distillation of cotton oil misc, we propose a new design of the apparatus operating in two stages of the introduction of the process- spraying and layer.

In the proposed new device, the spraying of the total flow of the miscella entering the final distillation is carried out using the energy of acute water vapor.

Many mixers are based on the principle of ejectors when using a high-speed jet of liquid coming out of the nozzle into the receiving chamber to involve a passive medium in motion, which may be a liquid, gas or hydro mixture containing solid particles [7].

But in the process we are considering, the liquid does not have solid particles. Also, in such ejectors, the question arises of the completeness of the coverage of the ejection material by the carrier fluid.

In a gas-liquid jet device, this condition can be achieved by installing a nozzle device directly in front of the mixing chamber at the end of the initial section of the gas phase.

The study of the outflow of water vapor to the cotton oil miscell in the food industry has its own characteristics. For example, when mixing water vapor and cotton oil micelles, it is necessary to adhere to the time of the technological regime. The residence time of the mixture in the mixing device should be small, the temperature of the mixture should strictly be within 100-105 C in order to meet technological requirements. At the same time, when liquid is introduced into the device, its mixing by the gas flow should be on a small stretch.

2 Methodology

The objective of our research is to develop a methodology for analytical calculation of the basic geometric parameters of a mixer for mixing hot water vapor with a cotton oil miscell. On the proposed mixing device, the gas phase of the acute water vapor is fed along the center of the mixing pipe, and the liquid phase-the cotton oil misc comes from the upper part perpendicular to the movement of steam. In this case, the acute water vapor should be divided into drops of the total flow of the miscella. The dimensions of the mixer, such as the diameter, length of the mixer, as well as the dimensions of the droplets formed, must be determined based on flow rates and flow pressures.

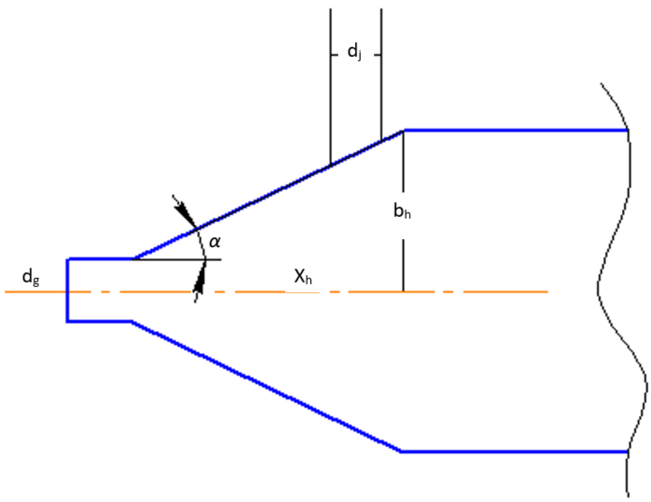

Fig.1. Diagram of the gas-liquid mixing device.

Crushing of a high-density liquid in a gas stream having a lower density has a number of factors. One of the main ones is the appearance of a liquid in a gaseous medium, so that there are pressure disturbances around the droplet. In our opinion, it is better to inject the liquid across the gas stream (Figure 1). In such cases, the crushing of parts of the liquid in the form of droplets is preceded by their significant deformation. With an increase in the velocity of the main stream, this particle (drop) first takes the form of an ellipsoid, then flattens, acquires a domed shape, and then splits. Crushing is determined by the size of the droplet, the viscosities of the gas, the substance (liquid) of which the droplet consists, surface tension, velocity and other parameters, from which a number of dimensionless criteria can be compiled. The most important of them is the Weber number, which is equal to the ratio of the products of the velocity pressure by twice the diameter of the drop to the surface tension. The critical number is called the Weber number corresponding to the crushing of the drop. To calculate the Weber number, you need to enter some notation.

Let the radius of the liquid nozzle, the density of the liquid, the mass flow rate of the liquid, σ_ be the surface tension of the misc drop. The density of the liquid is selected based on the temperature of the liquid entering the mixing chamber.

Accordingly, the radius of the water vapor pipe, the density of the liquid, the mass flow rate of the liquid. The density of water vapor is also determined based on the temperature of the steam entering the mixing chamber.

The loss of mass by a drop of liquid during collisions will occur as a result of gas-dynamic crushing and evaporation. The intensity of these processes depends on many factors, in general it can be described by the criteria of Weber: $We = \rho_g \cdot \left(u_g - u_j\right)^2 \cdot d / \sigma$, Reynolds: $\mathrm{Re} = \rho_g \cdot \left(u_g - u_j\right)^2 \cdot d / \mu$, Laplace: $Lp = \rho_j \cdot \sigma \cdot d / \mu_j^2$, and Nusselt: $Nu = a_j \cdot d / \lambda$. Here d is the diameter of the drop in the undeformed state (equivalent), $u_g - u_j$ the relative velocity of the drop, u_g is the velocity of the gas, u_j - the velocity of the drop, ρ_g is the density of the gas, ρ_j - the density of the liquid, σ is the surface tension coefficient of the liquid of the drop, μ is the dynamic viscosity coefficient of the gas, μ_j - the dynamic viscosity coefficient of the liquid, λ is the thermal conductivity of the gas, a_j - the coefficient of heat transfer from the gas to the drop. In this case, the initial diameter and mass of the drop are respectively equal to d_0 and m_0 .

In the literature [8], the following characteristic values of the Weber criterion are established: At We < 10.7, the drop in the flow is deformed, but does not yet disintegrate; at We = 10.7, the lower limit of crushing is reached – the drop is destroyed into two parts, while 10-20% of the total number of drops disintegrates. As the Weber criterion increases in the range of 10.7 ≤ We < 14, the drop is divided into 3, 4, 5, etc. droplets and the number of fragmented droplets increases. At We = 14, the upper limit of crushing is reached – all 100% of the droplets are crushed into many small particles (droplet spraying mode), then at all We > We = 14, the droplet crushing mode is preserved. The resulting droplets will be the smaller the greater the value of We.

During the technological mode of operation of enterprises, the expenses of the parameters of water vapor and cotton micelle in mass expenses are set, i.e. the mass expenses of water vapor q_g and cotton micelle q_j are set.

It is known [9] that when the liquid is overheated and the pressure is within 10-15 atmospheres, an intense disintegration of the jet into droplets occurs. In our case, the water vapor has a temperature, so everything coming out of the nozzle is a vapor-gas-liquid mixture.

To determine the initial velocity, we proceed to the volumetric flow rate according to the formula:

$$q_{ob} = \frac{q_{mas}}{\rho}, \tag{1}$$

Using the volumetric flow rate, we find the initial velocity

$$u_0 = \frac{q_{ob}}{s}, \tag{2}$$

Where is the cross-sectional area of the nozzle at the outlet.

The jet formed when the gas flows into the droplet liquid, destroying it when it collides, forms a gas-liquid jet. In such cases, the gas interacts with the liquid, resulting in a jet of homogeneous liquid [1]. In these cases, from a hydrodynamic point of view, we are dealing with a gas jet containing liquid droplets. While the flow has an initial section, its parameters can be found by considering it as the old one, we believe that at the transition section the boundary of the boundary layer reaches the boundary of the mixing zone (Figure 1).

It should also be noted that the high speeds used in such devices make it possible to neglect gravity.

To determine the gas-dynamic characteristics of a gas-liquid jet, we introduce the concept of "weight concentration of gas in a mixture" [1]:

$$x_g = \frac{G_g}{G_g + G_j} \tag{3}$$

G_v - the second flow rate of the gas part of the mixture, G_j - the second flow rate of the liquid part of the mixture. From here

$$\frac{G_j}{G_g + G_j} = 1 - x_g \tag{4}$$

The volume of such a two-phase mixture is equal to the sum of the volumes filled with gas and liquid, respectively:

$$V = V_g + V_j \tag{5}$$

And

$$\frac{G}{\rho} = \frac{G_g}{\rho_g} + \frac{G_j}{\rho_j}$$

Thus, modifying this formula, given that, we find the density of the mixture

$$\rho = \frac{G_g + G_j}{\frac{G_g}{\rho_g} + \frac{G_j}{\rho_j}} = \frac{\rho_g}{x_g + (1 - x_g)\frac{\rho_g}{\rho_j}} \tag{6}$$

After the steam exits the nozzle, a turbulent layer is formed due to intensive mixing with the liquid [10].

The movement of liquid droplets in the jet basically obeys the laws of air movement, and it can be considered an air jet.

If air vapor flows out of the nozzle, after which a heavy mixture is mixed that does not have an initial velocity, or has a low velocity, then the characteristic initial velocity is determined from the condition of preserving the amount of motion [1]

$$\frac{G_g}{g} u_g = \frac{G_j + G_g}{g} u_0 \tag{7}$$

From here

$$u_0 = \frac{u_{g0}}{1 + x_0} \tag{8}$$

Where $x_0 = \frac{G_j}{G_g + G_j}$ is the initial volume concentration of the mixture, u_{g0} -is the initial velocity of water vapor.

A feature of a flooded gas-liquid jet is a relatively rapid increase in its thickness than a jet of one liquid [1,10].

At the end of the initial section, within the transition section of such a jet, it can be assumed that a gas-liquid mixture has been formed, calculating the length of the initial section and the thickness of the jet in this area, it is possible to determine the parameters of the mixing zone.

The length and width of the chamber is chosen so that the mixing process of the flows has practically finished in it, as short as possible, so as not to increase hydraulic losses and reduce the overall dimensions of the mixing device.

It is better to place the liquid flow entry points at the end of the initial section of the gas flow, since in this section it becomes possible to cover it with an expanded gas flow.

The length of the initial section of such a gas-liquid jet is determined based on the density ratios [1]

$$\overline{x}_h = \frac{x_h}{r_0} = 3.7\frac{(1+x_0)^2}{(1+0.5x_0)(0,416+0.309x_0)} \quad (9)$$

Where $x_0 = G_g / G_j$ -is the ratio of expenses.

When the gas flows into the liquid, when the potential core of the jet is still gas, the increase in the width of the boundary layer can be determined by the formula [1]

$$\frac{b_{st}}{x} = 0.135\cdot\ln\frac{\rho_j}{\rho_v} = 0.31\cdot\lg\frac{\rho_j}{\rho_v} \quad (10)$$

In the boundary layer at the end of the initial section of the transverse velocity profile can be expressed by the expression [1]

$$\frac{u}{u_m} = 2\cdot y^{1.5} - y^3 \quad (11)$$

Thus, we can determine the parameters of the initial section of the mixing chamber of the water vapor flow and the missella flow, the further passage of the mixture is carried out through a pipe of constant cross-section, where hydrodynamic equations can be used to determine the parameters of the mixture flow. With the help of these data, it is possible to determine the hydrodynamic fragmentation into droplets of the total flow of the micelle.

3 Results and discussion

In the production of steam, the mixing chamber is fed within a temperature of 150-2000C, for these limits, the vapor density can be taken approximately $\rho_g = 8\,kg/m^3$, and the mass flow rate of steam through $q_{gm} = 0.063\,kg/sek$,the nozzle is kept based on the capabilities of the enterprise. The diameter of the nozzle $d_g = 0,005m.$ Then the cross-sectional area of the nozzle will be equal to

$$s_g = \pi\cdot\left(\frac{d}{2}\right)^2 = 3.14\cdot\left(\frac{0,01}{2}\right)^2 = 0.000079\,m^2$$

Using the formula (1) we find the volume flow of steam:

$$q_{go} = \frac{q_{gm}}{\rho_1} = \frac{0.063kg/sek}{8\,kg/m^3} = 0.00788\,m^3/sek$$

Now, using the formula (2), we find the initial steam velocity:

$$u_0 = \frac{q_{go}}{s_g} = \frac{0.00788}{0.000079} = 100.7\,m/s$$

The miscella is fed into the final distillation apparatus within a temperature of 100C. Then the density of the liquid corresponding to this temperature $\rho_j = 850\,kg/m^3$, and the mass flow rate of the liquid through the nozzle to keep $q_{jm} = 0.063\,kg/sek$, also based on the capabilities of the enterprise $d_j = 0.01m.$. The diameter of the incoming misc pipe is equal to

$$s_j = \pi \cdot \left(\frac{d}{2}\right)^2 = 3.14 \cdot \left(\frac{0.01}{2}\right)^2 = 0.000079\, m^2$$

Using the formula (1) we find the volumetric flow rate of the liquid:

$$q_{jo} = \frac{q_{jm}}{\rho_2} = \frac{0.167 kg / sek}{850\, kg / m^3} = 0.00025\, m^3 / sek$$

Now, using the formula (2), we find the initial velocity of the missella:

$$u_{j\_nach} = \frac{q_{jo}}{s_j} = \frac{0.00025}{0.000079} = 0.9\, m / s$$

Let's determine the relative speed

$$\mathrm{V} = \left|\mathrm{u}_0 - \mathrm{u}_{2\_\mathrm{nach}}\right| = 100.7 - 0.9 = 99.8 \frac{\mathrm{m}}{\mathrm{cek}}$$

To calculate the Weber Number, we determine the primary radius of a liquid drop.

First, we determine the primary radius of the drop by the formula [11]

$$d_k = 2 \cdot \left(\frac{\sigma}{0.3 \cdot \rho_j}\right)^{3/5} \cdot \left(\frac{d_g \cdot \rho_g}{\rho_j}\right)^{2/5} \cdot V^{-6/5} \tag{12}$$

Inserting the data into (12) we get

$$d_k = 0.000023m$$

Let's express this in micrometers d_k=0.000023 m=0.000023 mm=23 µm.

Let 's calculate the Weber number

$$We = \frac{\rho_g \cdot V \cdot V \cdot d_k}{\sigma_ж} = \frac{0.5 \cdot 154.2 \cdot 99.8 \cdot 0.000023}{0.05} = 36.7$$

Here We>14, so in our case the initial crushing will take place.

Knowing the value of the Weber number, it is possible to determine the diameter of the droplets formed as a result of the collision of a liquid with a gas stream:

$$d_{max} = \frac{2 \cdot We \cdot \sigma}{\rho_g \cdot V^2}$$

Setting the initial data gives

$$d_{max} = 0.000024$$

Thus, the diameter of the formed droplets is almost the same.

When designing installations, the initial section of the jet is also important, which retains the initial velocity.

The initial section of the gas phase jet is determined by the formula:

$$L_g = \frac{12.4 \cdot r_g}{\sqrt{1 + 0.56 \cdot \frac{q_ж}{q_g}}} \tag{13}$$

Setting the initial data gives

$$L_g = \frac{12.4 * 0.005}{\sqrt{1 + 0.56 \cdot \frac{0.00096}{0.0079}}} = 0.197m = 197mm.$$

At the end of the initial section, the velocity profile of the gas-liquid flow can be taken as [1]

$$\frac{u}{u_m} = 2 \cdot y^{1.5} - y^3$$

The speed profile in this case will look like

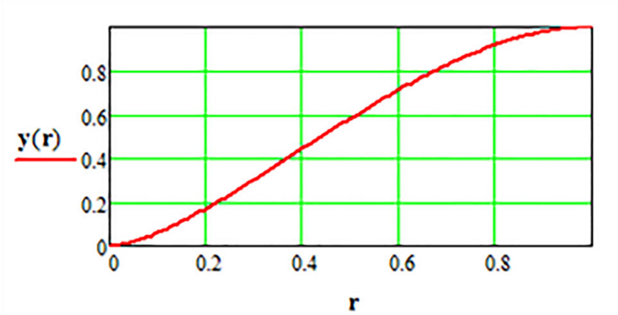

Fig. 2. Velocity profile at the end of the initial section.

According to [1], when gas flows into a liquid, when the potential core of the jet is gas, the increase in its thickness is determined by

$$\frac{b(x)}{x} = 0.135 \cdot ln\left(\frac{\rho_j}{\rho_g}\right)$$

Setting the initial data gives

$$b(x) = 0.628x$$

This corresponds to about 32 degrees.

Now that the length of the initial section is known, the growth of the jet, it is possible to determine the half-width of the mixing chamber. Inserting the length of the initial section into the last equation we get

$$b_h = b(0.197) = 0.628 \cdot 0.197 = 0.123m = 123\ mm$$

Thus, the width of the mixing chamber can be approximately taken as 250-300 mm, or about 25 centimeters.

4 Conclusion

Thus, given the initial parameters of the flow rates of gas (acute water vapor) and liquid (miscells), the geometric dimensions of the nozzles were determined, which gives the necessary crushing of the total flow of liquid (miscells) on the droplets, creating a contact surface of the phases. Determining the length of the initial section of 123 mm gives the location where the liquid nozzle can be installed. Determination of the expansion of the carrier jet gives a choice of the mixing chamber width of 300 mm. Determining the length of the mixing chamber requires further investigation.

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