Experiments on using "prismatic" nozzle in liquid-vapor system

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Abstract. The article is devoted to the research of the effect of the prismatic nozzle design on the large phase contact surface while steam nozzle is used to spray the mistella in the inner cavity of the final distiller. The appearance of the dispersed phase in spraying liquid in a prismatic four-nozzle sprayer was analyzed in the experimental equipment assembled for the study of heat and matter exchange processes using prismatic nozzles. For production conditions, the effectiveness of the use of vertical prismatic nozzles has been proven to accelerate the processes of heat and substance evaporation in the working volume of the device.

1 Introduction

The kinetics of the separation process of a solution consisting of vegetable oil and a low-boiling hydrocarbon solvent depends on the mass transfer between the mixture of solution, water and heated vapors of the solvent. Distillers of various designs are used in oil extraction enterprises. Important indicators of the efficiency of distillers are capital costs, energy costs, especially costs related to supplying steam to the final distiller for mistella processing, and the quality of the resulting oil. Distillation plant capital costs are proportional to its size and inversely proportional to its throughput. The mass transfer rate depends on the nature of the phase balance, is proportional to the mass transfer coefficient and the contact area between the phases. An increase in mass transfer occurs in conditions of high turbulence of one or both phases and at high speeds of their movement relative to each other [1,2].

When a steam nozzle is used to disperse the mist in the interior of the final still, the phase contact surface is large and the superheated water vapor co-flows near the nozzle orifice, creating a very high droplet flow velocity. The intensity of interphase transfer can be adjusted by changing the temperature and flow rate of the water vapor supplied to the nozzle, while the flow rate of the spray liquid remains constant. Heating the oil in the still for a long time has a negative effect on its quality, but to evaporate the solvent from the surface of the droplet, it must be heated to some degree relative to the temperature corresponding to the conditions of phase equilibrium.It depends on the pressure in the evaporation zone and the concentration of the solution on the droplet surface. [3,4].

The driving force of substance transfer from the droplet to the external vapor environment is the difference in the partial vapor pressures of the volatile component on the droplet surface and the one expelled from it. The larger the partial vapor pressure of the volatile component

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in the outer stream of vapor mixtures, the smaller the diffusion flux of the mass of the vaporizing component on the droplet surface. The higher the temperature and concentration of the evaporating component on the surface of the droplet, the greater its pressure near this surface. Process flows of steam mixtures from the distiller are required to be selected taking into account the above factors.

In order to correctly choose a nozzle when spraying liquids, based on the specific conditions of operation, it is first necessary to determine the type of spraying and choose the type of spray torch suitable for this situation. By knowing enough about this information, it will be possible to achieve the maximum effective results of spraying. These not only reduce production delays but also increase productivity.

- Spraying a certain amount of liquid;
- Scatter where needed;
- Spraying at a given time.

Liquid spraying with hydraulic nozzles occurs due to the fact that the liquid is fed to the nozzle under pressure using a pump. Narrowing the nozzle cross-section allows the flow rate to increase, as potential energy is converted to kinetic energy (velocity). A sudden decrease in pressure at the exit of the nozzle causes a laminar flow of the liquid to the surface, breaking it into droplets of different sizes and forming a specific spray flare.

2 Materials and methods

Due to the internal construction of the nozzle, it is possible to spray the liquid in different ways. The main types of spray torch are "empty cone", "full cone", "flat flow", "full flow". Each torch shown has its own characteristics and serves a specific purpose. Scatter torches can have different scattering angles - from 0 to 130 degrees.

"Full flow" nozzle covers the entire surface of the circle. This coating occurs very evenly, but the number of droplets is greater than in the "flat flow" type.

For liquids, the droplet sizes produced by different nozzles also vary, and the range of droplet sizes also depends on the pressure.

As a result of the increase in pressure, the droplet sizes become smaller. Table 1 shows the range of droplet sizes in different nozzles:

Table 1. Dependence of the droplet size change when the volume consumption in different nozzles changes.

Nozzle type	**Fluid pressure, bar**					
	1		**2**		**5**	
	Volume consumption, l/min	Droplet size, μm	Volume consumption, l/min	Droplet size, μm	Volume consumption, l/min	Droplet size, μm
"Empty Cone"	- 18	- 700	1 25	320 640	1.4 36	240 490
"Full Cone"	0.8 19	540 1300	1 25	400 1100	1.4 36	300 750
"Prismatic"	**0.7** **18**	**400** **1200**	**1** **25**	**360** **1000**	**1.6** **40**	**300** **690**

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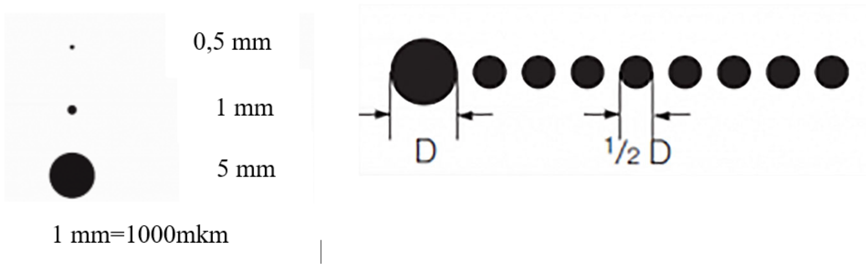

Fig. 1. Volumetric change in the breakdown of large droplets into small droplets.

The size of a large drop corresponds to the size of eight small drops with a diameter twice as small. The surface area of a large droplet is four times larger than the surface area of a small droplet (Figure 1).

Accordingly, the surface area of eight small droplets is twice as large as the surface area of one large droplet.

The phase contact surface is the sum of the surfaces of the dispersed phase elements in contact with the dispersed medium, i.e., $F = fn,$ here is f the surface of the dispersed phase element, n is the number of elements in the mixture.

In calculations, it is convenient to use the relative phase contact surface size a=F/V instead of F size, where V is the volume of vapor-liquid mixture.

In determining the contact surface of relative phases, it is assumed that the vapor-liquid mixture of volume V contains dispersed phase elements of spherical shape with diameter d. Accordingly

$$a = \frac{fn}{V} = \frac{\pi d_n^2 n}{V} \tag{1}$$

here

$$V = \frac{V_0 n}{\varphi_\text{г}} = \frac{\pi d_n^3 n}{6\varphi_\text{г}} \tag{2}$$

where V_0 is the volume of the dispersed phase element; φ_r is the volume fraction of the dispersed phase.

The following follows from the resulting equations

$$a = \frac{6\varphi_\text{г}}{d_n} \tag{3}$$

Thus, a decrease in the droplet diameter leads to an increase in the contact surface of the phases when φ_g =const.

The ratio (3) is important in the analysis of the operation of devices designed for the implementation of heat and matter exchange processes between phases.

In the case of the movement of liquid droplets in a gas stream, the vapor is the dispersed medium, and the liquid is the dispersed phase.

The main parameter characterizing the dispersed state of the two-phase system is the contact surface of the phases and depends on the values of φ_g and d_n.

In the case under consideration, φ_g =0.95÷0.99, that is, its value is close to one.

Therefore, the main effect on the rate of heat and matter exchange processes depends on the diameter of the formed droplets [5-8].

In existing final stills in oil extraction plants, a group of spray nozzles is used. The final distiller of the ND-1250 line has three nozzles located in one horizontal plane of the device and forming an equilateral triangle. When the mistella spraying process is carried out correctly, the nozzles create a dispersed phase. However, it is observed that the liquid sprayed using the nozzles located in one horizontal zone of the distiller does not completely occupy the working volume of the device, which leads to the formation of empty zones in the spray zone and the reduction of the device's performance [9-11].

3 Results and discussions

Experimental equipment was assembled to study heat and matter exchange processes using prismatic nozzles (Figure 2). Equipment cylindrical glass column 1, prismatic nozzles 2; bubbler 3; liquid collecting tank 4; pump 5; liquid consumption meter 6; compressor 7; consumption meter for gas (steam) 8; consists of separator 9 and control-measuring devices.

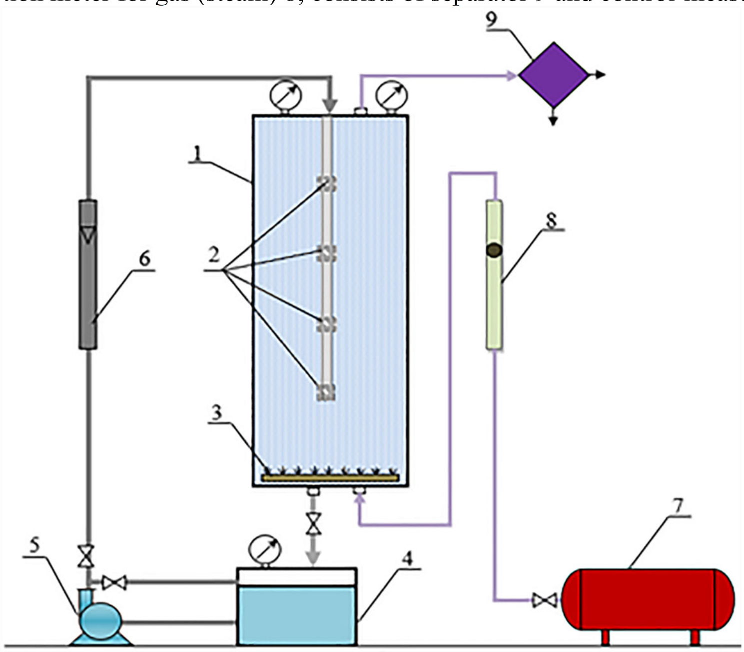

Fig. 2. Scheme of the experimental equipment for studying the process using the nozzle: 1- glass column; 2-prismatic nozzles; 3-barboter; 4- liquid collection tank; 5th-pump; 6-liquid consumption meter; 7th-compressor; 8-gas (steam) consumption meter; 9th-separator.

The distiller is made in the form of a cylindrical column. Four prismatic nozzles are placed at an angle of 90° to the vertical pipe cross-section in the working zone of the column. Prismatic nozzles are installed in four parts of the vertical pipe at the same distance in order to distribute liquid drops uniformly along the longitudinal section of the column.

A centrifugal pump is used to transfer the liquid phase through a vertical pipe, and a compressor is used to supply the vapor phase through a bubbler. At this time, the droplets that come out of the air flow are caught in the separator. The experimental device is equipped with measuring and control devices for determining temperature and pressure and valves for adjusting the consumption of material flows.

The experimental equipment works as follows: the liquid phase is sprayed from the top of the device using prismatic nozzles in a vertical pipe. Then, from the bottom of the column, sharp water vapor is supplied, which moves in the opposite direction with the liquid.

In this, the process of continuous chaotic movement of liquid droplets and vapor phase flows, which increases the turbulence and their contact surfaces, is observed.

An overview of the dispersed phase in each zone of the dispersed phase of the liquid sprayed with the help of nozzles located in one horizontal plane is presented (Figure 3).

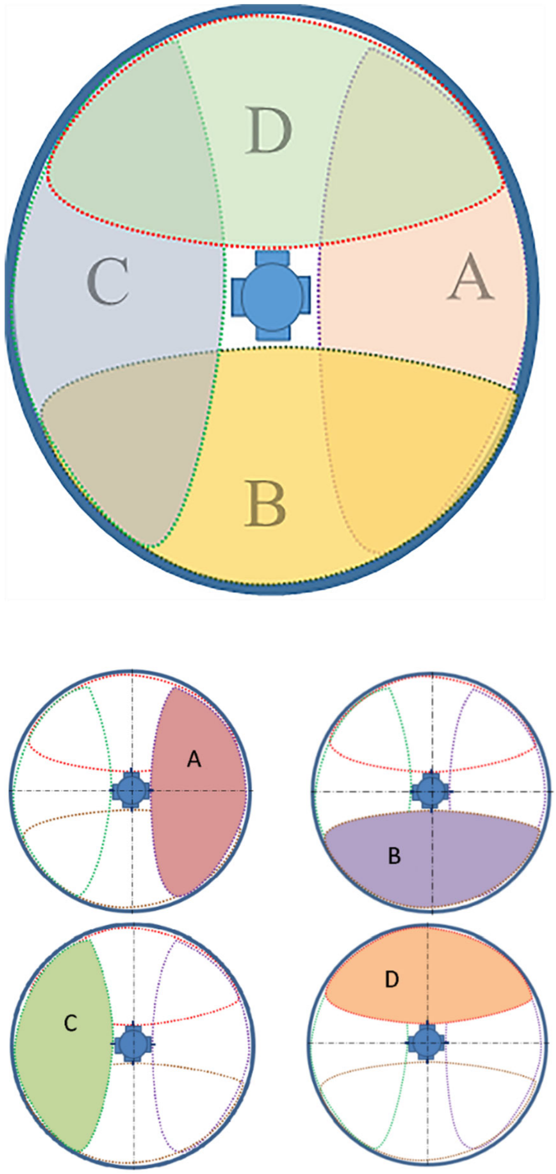

Fig. 3. Dispersed phase view of liquid spraying in a prismatic four-nozzle sprayer.

It can be seen from the graph that the cross-section of the field is almost completely occupied by the A-B-C-D zone with the dispersed phase. In this case, the nozzle shows that additional requirements for the character of the geometrical location are fulfilled: the distance of the flow in the lower section of the spray zone of the device is limited by the internal diameter of the device. In this case, the volume occupied by the dispersed phase is smaller than the volume in a single nozzle.

A random search method was used to determine the optimal geometric dimensions of the nozzle. The best nozzle design is determined by a series of experiments. For this purpose, the nozzle was prepared in different geometric dimensions (Table 2): $h_к$--nozzle channel height, mm; $l_к$--nozzle channel length, mm; nozzle equivalent diameter, mm; $d_т$.

Table 2. Dependence of the geometric dimensions of the nozzle on the liquid spray angle.

Nozzle channel height, mm; $h_к$	**Injector channel length, mm; $l_к$**	**Equivalent nozzle diameter,мм; $d_т$**	**Liquid scattering angle, ◦; $cos\varphi$**
0.1	10	1	30
0.1	13	1	30
1	10	1	45
1	12	2	45
1.5	10	4	60
1.5	12	4	60
2	10	4	100
2	13	4	100
3	10	4	140
3	13	4	160
4	10	4	160
4	13	4	160
5	10	6	160
5	13	8	160

In order to study the dependence of the geometric dimensions of the nozzle on the liquid splash angle, the experiments were conducted in the range of the height of the nozzle channel 0.1-5 mm, the length of the nozzle channel 10-13 mm, and the equivalent diameter of the nozzle 1-8 mm. Compared to other indicators, the effect of the change in the equivalent diameter of the nozzle on the angle of the liquid splash was shown to be the most significant. Based on the conducted experiments, it was determined that when the height of the nozzle channel is 4 mm, the length of the nozzle channel is 10 mm, and the equivalent diameter of the nozzle is 4 mm, the liquid scattering angle is $\cos\varphi=160°$ that is, it corresponds to the widest scattering angle.

4 Conclusion

The volume of the dispersed phase increases with the increase in the number of nozzles on the perimeter of the inner circle where four nozzles are located. At full filling of the maximum cross-sectional surface of the device with spray nozzles, the volume of the dispersed phase approaches the volume of the truncated cone formed by a single nozzle torch. Therefore, the use of a group of parallel injectors is not very effective. For production conditions, it is effective to use vertical prismatic nozzles to accelerate the processes of heat and substance evaporation in the working volume of the device.

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