We conducted laboratory (fig. 3) experiments for four different nozzles. We compared and found through observation that CLN and CShN have the largest spray angle than CLNH and CShNH, due to the high velocity in the tangentially directed channels. The decrease in the angle may be due to the fact that the main liquid flow passes through the central hole and reduces the swirl of the liquid by reducing the flow rate in the tangential channels of the nozzles. The experimental results partially coincide with the simulation results.

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DESIGN AND ANALYSIS OF SPHERICAL PACKING WITH HEMISPHERICAL DEPRESSIONS FOR ENHANCED MASS TRANSFER

Mass transfer apparatuses with moving packing are an important class of equipment widely used in various industries such as chemical, petrochemical and food. These apparatuses are designed to perform mass transfer processes, including rectification, absorption, desorption and extraction. They play an important role in the effective separation and purification of substances [1].

In such apparatuses, the mass transfer process occurs between two phases (gas-liquid, liquid-liquid) with a developed interphase surface. The main feature is the presence of a moving packing, which helps to intensify mass transfer processes by increasing flow turbulence and updating the interphase surface. Uniform distribution of points on the surface of the ball is a critical aspect in the design of a moving packing, as this allows achieving maximum efficiency of phase interaction. Optimization of the shape and size of the packing particles, as well as their location inside the apparatus, contribute to this [2]. There are several main types of mass transfer devices with moving packing, which differ in the type of packing movement (rotary, reciprocating, oscillatory), frame design (column, plate, contact type) and other parameters [3, 4].

The purpose of this work is to consider in detail the design features, operating principle and areas of application of these devices with an emphasis on the importance of uniform distribution of points on the surface of the ball.

The packing for mass transfer processes is a solid sphere, on the surface of which hemispherical depressions are located. The number of depressions depends on the diameter of the ball, measured in millimeters. The depth of these depressions varies from 0.08 to 0.095 of the ball diameter, also in millimeters, and the distance between them is from 0.3 to 0.7 diameters of the depressions [5].

Studies have shown that the proposed packing demonstrates lower hydraulic resistance compared to a smooth ball of the same diameter. In this design, balls with depressions of a patented design [5] were used to increase the contact area of the liquid phase with the gas. An image of this element of the packing is shown in Figure 1.

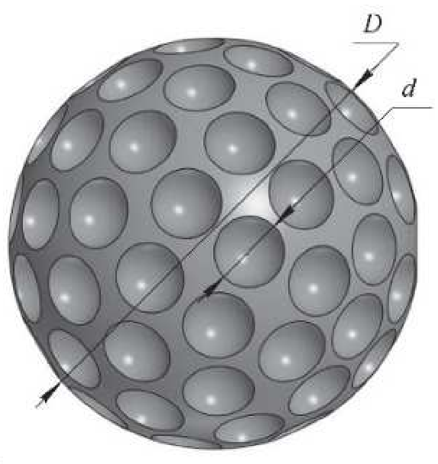

Figure 1 – Ball with dimples

One of the key objectives of the study was to determine a method for uniformly distributing depressions on the surface of a spherical packing. A spherical coordinate system was used for this purpose. The use of this system allowed us to develop a technique that ensures uniform distribution of depressions on the surface of the spherical element of the packing, which is important for optimally increasing the effective surface area available for mass transfer processes.

To distribute depressions on the surface of the ball, 9 layers were selected, located at equal angles equal to π / 8 radians. This division of layers ensures uniform distribution of depressions vertically and avoids their accumulation in one area. At layer I, the coordinates on which the depressions are located will be written as follows:

$$r = R \quad \theta = 0 \quad \varphi = 0 \tag{1}$$

At layer II and later:

$$r = R \quad \theta = \frac{\pi}{8} \quad \varphi = \frac{\pi}{6} \cdot k, \quad k = 0,...5 \tag{2}$$

$$r = R \quad \theta = \frac{\pi}{4} \quad \varphi = \frac{\pi}{11} \cdot k, \quad k = 0,...10 \tag{3}$$

$$r = R \quad \theta = \frac{3 \cdot \pi}{8} \quad \varphi = \frac{\pi}{14} \cdot k, \quad k = 0,...13 \tag{4}$$

$$r = R \quad \theta = \frac{\pi}{2} \quad \varphi = \frac{\pi}{15} \cdot k, \quad k = 0,...14 \tag{5}$$

$$r = R \quad \theta = \frac{5 \cdot \pi}{8} \quad \varphi = \frac{\pi}{14} \cdot k, \quad k = 0,...13 \tag{6}$$

$$r = R \quad \theta = \frac{3 \cdot \pi}{4} \quad \varphi = \frac{\pi}{11} \cdot k, \quad k = 0,...10 \tag{7}$$

$$r = R \quad \theta = \frac{7 \cdot \pi}{8} \quad \varphi = \frac{\pi}{6} \cdot k, \quad k = 0,...5 \tag{8}$$

$$r = R \quad \theta = \pi \quad \varphi = 0 \tag{9}$$

The analysis in the Cartesian coordinate system showed that the special arrangement of the hollows on the surface of the spherical packing increases the total surface area compared to the smooth sphere. This is due to the fact that the hollows create an additional area available for interaction between phases in such mass exchangers as absorption, rectification and extraction.

Mathematical modeling in the Cartesian coordinate system made it possible to quantify the increase in the effective surface area, achieved thanks to the proposed design of the nozzle with a special location of the hollows. This increase in surface area is an important factor that contributes to an increase in the intensity and efficiency of mass exchange processes in industrial devices using this type of packing.

Dependence for determining the area of the hollows on the surface of the spherical element of the nozzle is as follows:

$$S_O = \pi r^2 \left(1 - \frac{r}{R}\right) \cdot n \tag{10}$$

The total area of the surface of the ball will be determined by equation:

$$S_{tot} = 4\pi R^2 + \pi r^2 \left(1 - \frac{r}{R}\right) \cdot n \tag{11}$$

This dependence will be taken into account in the future in the study of the processes of mass exchange. The ball with these parameters was developed and printed on a 3D printer. With its help, experiments were conducted to determine the thickness of the water film on a single element, which is important for mass sharing processes. The experiment consisted in weighing the ball before and after it dives into the liquid.

During a series of tests, the average difference in the mass of the ball before and after immersion was 2.89 grams. Using this mass and knowing the density of water (ρ = 1000 kg/m^3), we can calculate the volume of the fluid remaining on the surface of the ball (the so -called film).

The thickness of the film δ was calculated as follows: by applying equation (10), we determined the total area of the surface of the ball, which was S_{tot} = 7530.96 mm^2. Using the volume of the fluid and the surface area of the ball, we calculated the thickness of the water film δ_c, which remained on the ball after diving into the liquid. For a ball with a diameter of 40 mm, the film thickness was δ_c = 385 microns.

This study has explored mass transfer apparatuses with moving packing, which play a crucial role in various industries, including chemical, petrochemical, and food processing. The developed packing in the form of a sphere with hemispherical depressions demonstrated advantages in reducing hydraulic resistance compared to a smooth surface, thereby enhancing the efficiency of mass transfer processes.

The use of a spherical coordinate system for the uniform distribution of depressions on the surface of the sphere facilitated the optimization of the contact area between phases. This research confirmed that the proper arrangement of depressions contributes to an increase in the effective surface area, which in turn intensifies mass transfer processes such as absorption, rectification, and extraction.

Experimental data on the thickness of the water film left on the sphere after immersion in liquid underscored the importance of studying this parameter for mass transfer processes. The obtained film thickness of 385 microns for a sphere with a diameter of 40 mm highlights the significance of gas-liquid interaction, which should be considered when designing more efficient absorption units.

Overall, the findings of this research open new avenues for optimizing packing designs and can be applied to further investigations in the field of mass transfer, ultimately leading to improvements in the purification and separation processes within industrial applications.

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INFLUENCE OF MOVABLE PACKING ON FLOW DYNAMICS IN ABSORPTION SYSTEMS

This paper investigates the influence of movable packing on flow dynamics in absorption systems. With the increasing demand for efficient gas-liquid contact in various industrial applications, movable packing technologies have emerged as a significant enhancement over traditional static packing [1]. This study explores the effects on mass transfer rates, flow uniformity, pressure drop, and liquid hold-up.

Absorption processes are integral to numerous industries, including chemical manufacturing, environmental engineering, and petrochemicals. The efficiency of these processes heavily relies on effective mass transfer between gas and liquid phases [4]. Traditional absorbers typically employ static packing, which can lead to uneven flow distribution and reduced efficiency. In contrast, absorbers with movable packing offer dynamic interactions that enhance performance [2].