Experimental investigation and mathematical modeling of film thickness in channels of centrifugal sprayer

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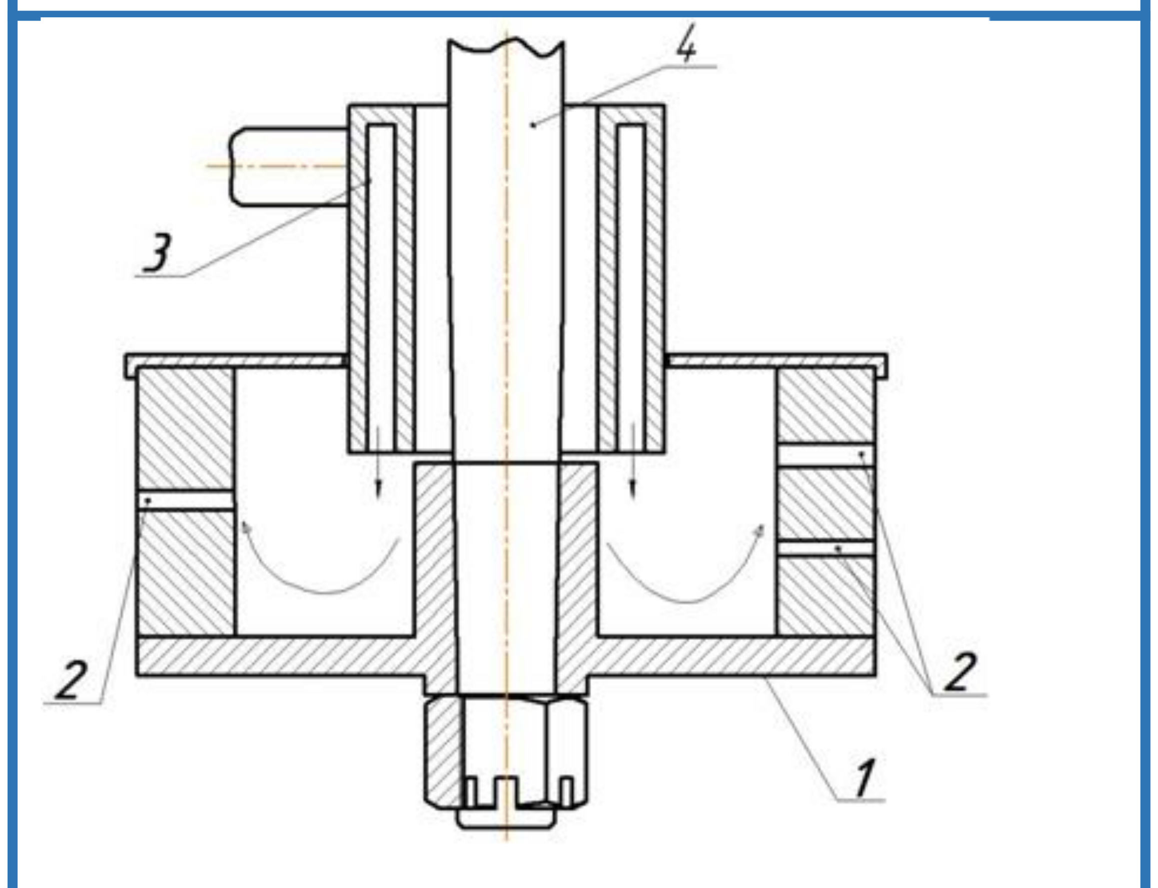
Abstract

The study of the behavior of liquid films on the surfaces of centrifugal atomizer is an important direction for many industrial and technological processes. The formation, distribution and transformation of liquid films play a key role in such industries as agriculture, the chemical industry, pharmaceutical production and materials science. In these areas, precise control of liquid atomizer parameters directly affects the efficiency of technological operations, the quality of the final product and the economic feasibility of the process. For example, in agriculture, centrifugal atomizers are used for uniform application of fertilizers and plant protection products, which helps to increase yield and reduce environmental load. At the same time, in the chemical and pharmaceutical industries, control of the dispersion of the liquid phase affects the processes of drying, emulsification, encapsulation of active substances and other critically important operations.

Centrifugal atomizer, which are widely used in industry, are designed to disperse liquids into small droplets using centrifugal forces. The basic principle of their operation is the formation of a thin liquid film on the surface of a rotating disk or other atomizing element. However, the distribution of the thickness of this film is uneven, which significantly affects the parameters of the final atomization: droplet size, their speed and homogeneity of the atomized mixture. The influence of the geometric parameters of the atomizer channels, rotation speed (from 1000 rpm to 6000 rpm), physicochemical properties of the liquid (density, viscosity, surface tension) and liquid flow rate is a critically important aspect that determines the efficiency of such devices. Previous studies have mostly focused either on purely theoretical approaches or on limited experimental observations that do not allow for a complete description of the mechanisms of interaction of the liquid with the atomizer surface. At the same time, modern methods of experimental analysis, such as optical interferometry, laser Doppler anemometry and high-speed video recording, allow obtaining more accurate data on the dynamics of the liquid film and the process of its disintegration on the droplet. An integrated approach that combines experimental data with theoretical modeling can provide a deeper understanding of the physical mechanisms that determine the behavior of the liquid film.

Problem statement

The most powerful dispersers of unit productivity on the liquid being sprayed, with a sufficiently finely dispersed composition of the spray - rotating atomizers. Let us consider the main schematic diagrams of rotating liquid atomizers and analyze, without going into technical details, their fundamental shortcomings, as well as possible directions for searching for ways to reduce energy consumption for dispersion and improve the dispersed composition of droplets of the sprayed liquid and, in particular, obtain a composition of droplets uniform in size.



Schematic diagram of a nozzle centrifugal atomizer

A nozzle centrifugal atomizer (nozzle disk) consists of a rotating housing 1 (for example, a cylindrical shell), located on a shaft 4, a nozzle (nozzle) 2, a device 3 for supplying and evenly distributing liquid inside the housing, which, under the action of centrifugal force, forms a ring on the inner surface of the shell walls.

In the case of a constant disk rotation frequency, the liquid flow rate is determined by the conditions of the liquid entering the disk, the thickness of the liquid annular layer, the number and diameter of the nozzles. To increase the productivity of the nozzle atomizer, it is made multi-row (consisting of several rows of nozzles). The liquid, entering the nozzle, is pressed against the rear wall in the direction of rotation of the atomizer, and therefore the peripheral velocities of the nozzle and the liquid are the same. When exiting into a gas (air) environment, the liquid velocity consists of the peripheral component of the velocity and the component of the relative motion of the liquid along the nozzle, which for low-viscosity liquids can be taken equal to the radial one.

Nozzle disks are simple in design, have high unit productivity and in many cases allow to obtain spray characteristics that satisfy industry. However, fine spray from a nozzle disk can be obtained only at significant peripheral speeds (120 m/s and above). From the analysis of the operation of nozzle disks, two features, two problems can be distinguished. For fine dispersion with nozzle atomizers, it is necessary to use high rotation speeds, due to the large thickness of the liquid jet emerging from the nozzle, and, therefore, to consume a significant amount of energy, and on the other hand, the liquid spray is fundamentally polydisperse. The main task - reducing the power consumed for dispersing a large amount of liquid with optimal droplet sizes, can be solved only by solving the issue of significantly reducing the thickness of the jets emerging into the gas medium at the time of their spraying.

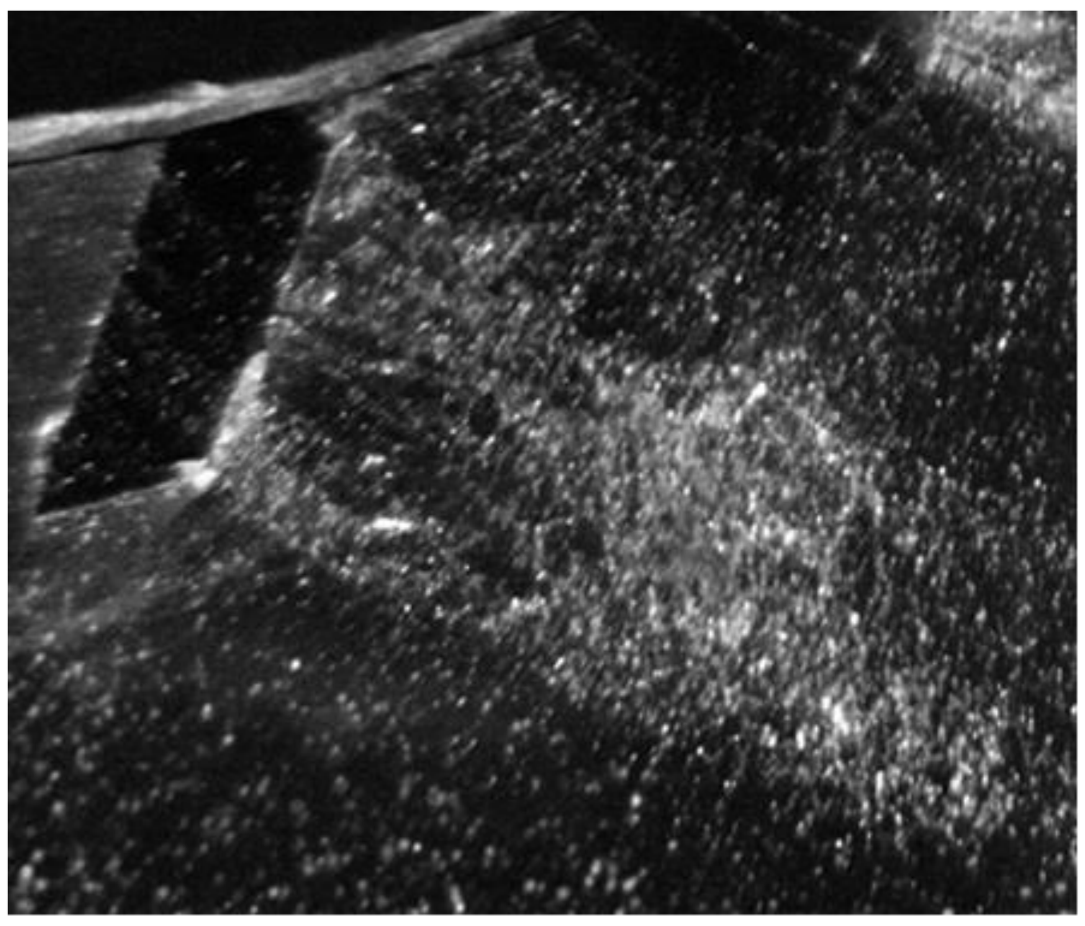
When solving the problem of low-energy obtaining a liquid homogeneous film on rotating atomizers, the second problem of centrifugal atomizers will be automatically solved: obtaining a high-quality spray, i.e. obtaining more monodisperse droplets. Let us discuss from this point of view more suitable designs of rotating atomizers for solving the problem - blade (slot) sprayers.

The main equations

In works it is shown that when the relative velocity of the shell and the liquid decreases, the coefficient e passes through a minimum, which means that the cross-sectional area of the jet emerging from the shell opening can be significantly smaller than the cross-section of the opening. Accordingly, the volumetric flow rate of the liquid Q under the listed conditions through a nozzle or other nozzle in the side opening of the shell can be significantly smaller than in the case of relative velocities tending to zero. And what is especially surprising: the relative decrease in flow rate is observed to a greater extent for large diameters of the outflow holes than for small ones.

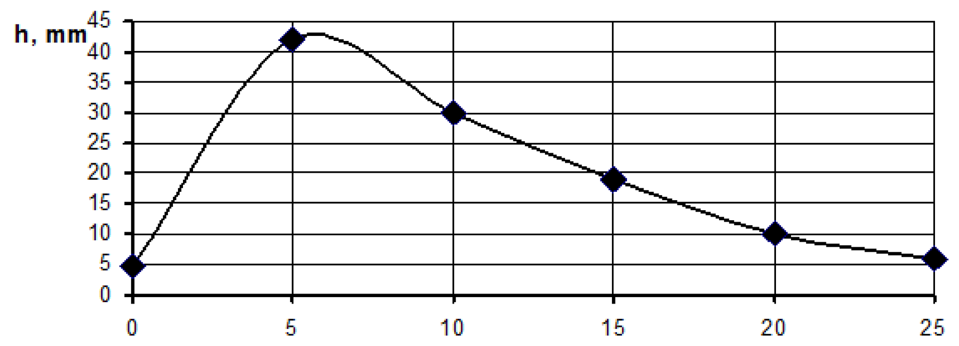
Such a theoretical conclusion is registered by direct observations .

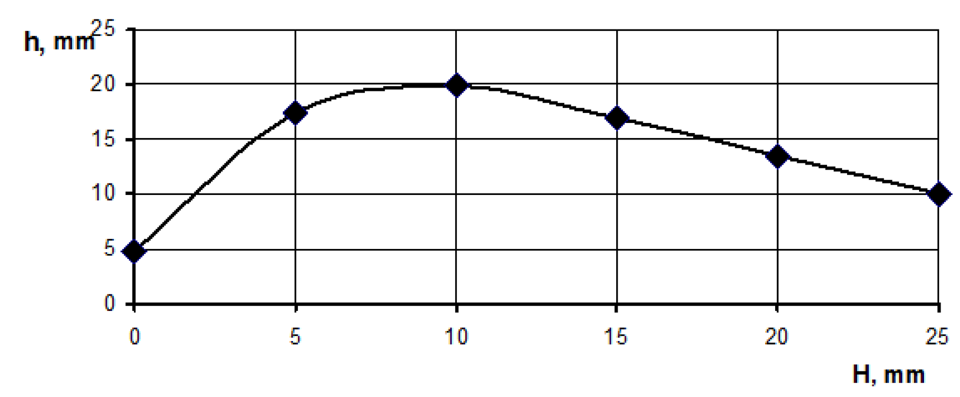
Figure shows the compression of a jet of liquid such as water emerging from a rotating cylindrical shell through blade channels onto a flat film former (disk with a diameter of 270 mm, disk speed 2800 rpm).

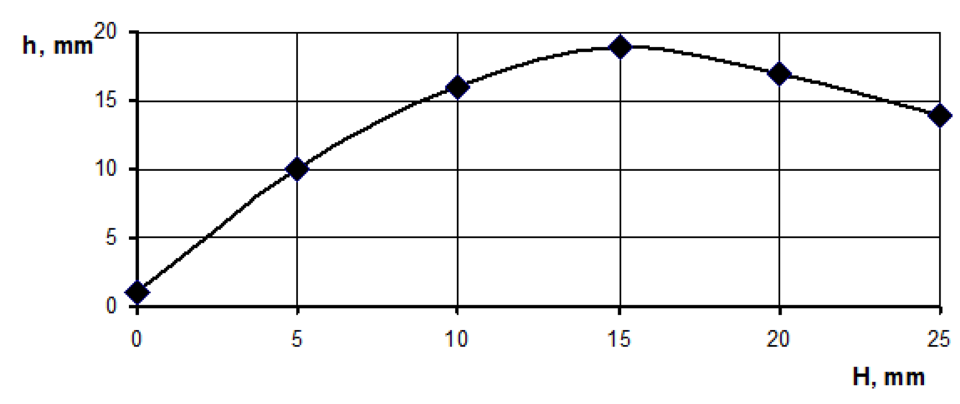


The photo shows that the liquid flowing out of the channel in the shell only partially fills it. This indicates that the compression coefficient e in this case is less than unity. The photos shown are experimental confirmation of the compression of the jet during the operation of any centrifugal sprayer. The real compression of liquid jets should be taken into account and used. It has found engineering application for the design of sprayers.

Shows the distribution of the average film thickness along the channel height at different disk rotation frequencies and constant liquid flow rate. The experiment was carried out with a disk with a diameter d = 270 mm, the number of channels n = 16, the height of the channels H = 25 mm, the width of the channels b = 25 mm. Characteristics of the sprayed liquid: technical water at room temperature, liquid flow rate – Q = 1 m3/h.







Conclusions

The conducted study of the distribution of the thickness of the liquid film in the channels of a centrifugal atomizer allowed to obtain a number of important results that have both theoretical and practical significance. The work used a specially developed method for experimental determination of film parameters using a local liquid receiver, which ensured high accuracy of the data obtained.

The experimental results showed that the distribution of film thickness along the height of the channel is uneven and depends on a number of factors, such as the geometric parameters of the channels, the frequency of rotation of the disk and the liquid flow rate. The greatest film thickness is observed in the middle of the channel and gradually decreases with height and to the base. It was also found that with increasing disk rotation speed, the film thickness changes nonlinearly, which can affect the quality of spraying and the stability of droplet formation.

Analysis of the influence of physical parameters of the liquid (density, viscosity, surface tension) and hydrodynamic forces (centrifugal and gravitational) allowed to identify the main patterns that determine the behavior of the liquid film. In particular, it was found that an increase in the viscosity of the liquid leads to an increase in the average thickness of the film, while an increase in the density has a less pronounced effect. This allows predicting the optimal parameters of the liquid for specific operating conditions of the sprayers.

The results obtained are of practical value for the development and optimization of centrifugal atomizer designs. The proposed models can be used to improve atomizer processes in agriculture, the chemical industry and pharmaceuticals, where control of liquid distribution is of crucial importance. In addition, the ability to accurately predict the characteristics of spraying allows to increase the efficiency of liquid use and reduce their costs, which is especially important in production processes with expensive or environmentally sensitive liquids.

The results obtained showed that the theoretical curve almost completely coincides with the practical curve, and if there is a deviation, it is insignificant. It is also possible to notice a tendency that with an increase in the disk rotation frequency, the maximum value of the film thickness shifts, and the distribution curve itself becomes uniform over the entire height of the channel. It is also noticeable that the practical value of the film thickness at the zero point shifts to zero. This is explained by the specifics of the design of the spraying disk, as well as an increase in the rotation frequency. Further analysis of these phenomena will allow improving the calculation models and increasing the accuracy of predicting the behavior of the film in real operating conditions.

An important aspect of the study is the determination of the boundary conditions under which the distribution of the liquid film becomes unstable. Such instability may lead to uneven droplet formation, deterioration of spray uniformity, and a significant decrease in the overall efficiency of the spraying process. In centrifugal spraying systems, the stability of thin liquid films directly affects the quality of atomization, droplet size distribution, and the operational characteristics of the equipment. Therefore, the investigation of critical parameters influencing film behavior is of considerable scientific and practical importance.

Special attention is paid to the influence of hydrodynamic factors, rotational velocity, liquid viscosity, surface tension, and external disturbances on the stability of the liquid film. The obtained experimental data make it possible to identify the characteristic modes of film deformation and breakup, which can be further used for the validation and improvement of mathematical models describing the dynamics of thin liquid films in centrifugal systems. Such models are essential for predicting the behavior of liquids under various operating conditions and for optimizing the parameters of spraying devices.

Thus, the conducted research combines detailed experimental analysis with theoretical modeling, providing a comprehensive approach to studying the dynamics and stability of thin liquid films in centrifugal systems. The obtained results not only contribute to a deeper understanding of the physical mechanisms governing liquid film behavior, but also create a reliable scientific basis for further investigations and engineering developments in this field. In addition, the proposed approach to the analysis of liquid films can be adapted for other types of spraying and dispersion systems, significantly expanding the potential scope of its application in industrial technologies, nanotechnology processes, chemical engineering, and scientific research related to liquid atomization and multiphase systems.