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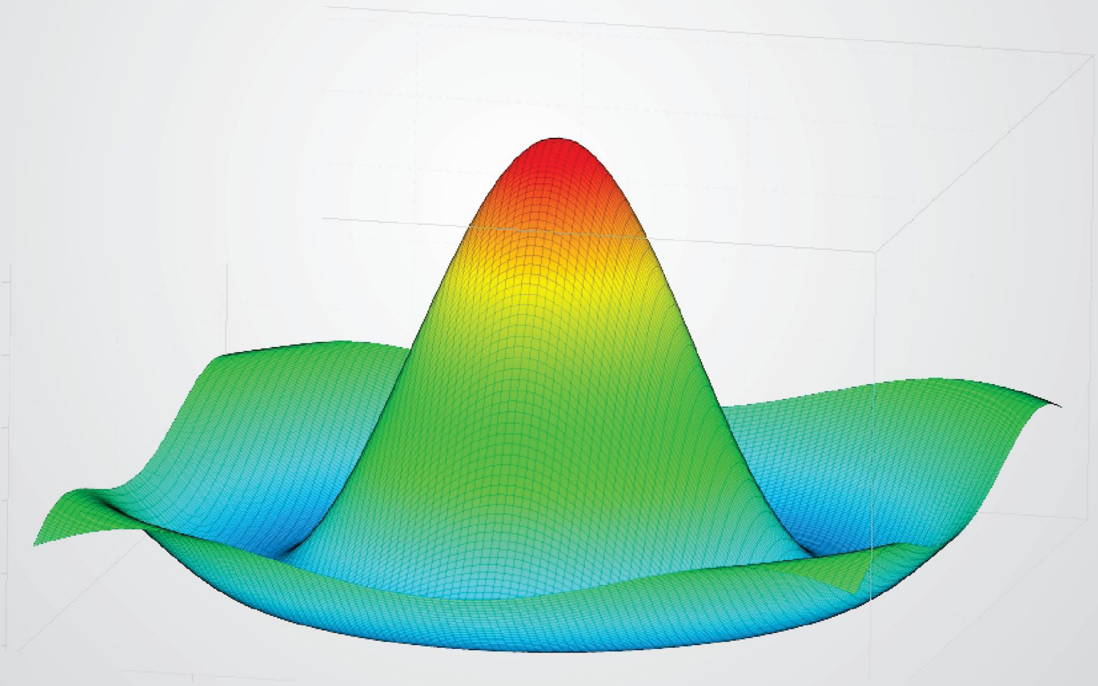

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SIMULATION OF FLUID DISPERSION IN EJECTION DEVICES

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Abstract. *This article describes how moisturizing of bulk components in the dryer-granulator and equipment for its implementation. An ejection device was proposed and by mathematical modeling its rational structure was proved. it was recommended to implement supply of liquid in the central tube and the air - in the peripheral holes.*

The use of ejecting spray devices which have a proposed design provides a homogeneous water-air mixture with a uniform velocity and sufficient pressure.

Key Words: dryer-granulator, ejection, modeling

I. Introduction

Hard drugs (pills) quality essentially depends on the realization of the granulation process of a tableting mixture. When using the modern pelletizer with fluidization layer the operations of mixing, granulating, drying and powdering combine in same device. At the granulation stage to moisturize dry components is necessary to disperse the liquid into a gas.

Devices that are used for this purpose, are similar to those operating in other industries – when drying liquid materials in spray dryers, moisturing of the air, spraying the surfaces of the dough half-finished products. Such devices can be divided into three main groups:

1) mechanical spray nozzles;
2) pneumatic nozzles running on compressed air or gas;
3) centrifugal spraying nozzles.

In the case of mechanical spraying, dispersed liquid enters the nozzle under considerable pressure and passes through a small diameter hole. When contacting a steady-state gas, under inertial force and surface tension force, the rapidly moving fluid jet breaks up into separate droplets, different in shape and size. The size of these droplets depends on many factors: the fluid pressure, diameter of the nozzle aperture and its design, physical constants of the liquid (especially viscosity). Nozzles can make the fluid jet rotate, which allows spraying the liquid through out the working chamber. One of the main problems associated with such spraying is the mechanical wear of individual components or parts of equipment [1].

The basic model of Huttlin HKC-100-DJ granulator-drier mechanically disperses fluid, which moistens the bulk components with the help of nozzles. However, as the moistening is not sufficiently uniform, granules of different sizes and shapes are formed in the granular drier, which leads to a rejection of a certain part of the output.

Ejectors are an alternative to conventional spraying devices used in the pharmaceutical industry.

Ejection happens when the operating medium captures the neutral one, both of them being under high pressure. When they get into a low-pressure medium, the mixture disperses.

Ejectors offer the following benefits:

- reliable construction and easy maintenance;
- stable mode of operation;
- allow pumping liquid and gaseous media without any additional pumping or compressor equipment.

Depending on the type of the media used in ejectors, they are divided into vapor-air and liquid-gas ejectors. The latter have good prospects for implementation in the pharmaceutical industry.

In liquid-gas ejectors the operating (liquid) and passive (gas) flows are in different states of aggregation, and are hardly mixed under ejection [2].

For a long time it was believed that gas was ejected (captured) by liquid primarily because of friction at the liquid-gas interface. Therefore it was assumed that the supply of gas by liquid jet ejectors was determined by the surface area of the working stream. However, the studies of G.I. Yefimochkin showed that the use of a crossed-shaped or ring-shaped section in the nozzle outlet instead of a circular section does not increase the ejector's suction coefficient.

L.D. Berman and G.I. Yefimochkin were the first to prove that the suction of air in liquid-gas ejectors essentially depends on the breaking up of the fluid jet into droplets, i.e. on the dispersion of the working fluid. And the main factors affecting the suction of gas into the fluid jet are the turbulence level of the mist flow on its surface and the total surface area of the droplets.

Total pressure $P0_2$ in a mixed flow is higher than the total pressure P01 in a low-pressure flow; relation $E = P0_2/P0_1$ is called a compression ratio, and it is one of the main characteristics of ejectors.

Ejecting devices are simple in design, can operate in a wide range of flow parameter variations, and allow easy adjustment of operating conditions. Therefore, these devices are widely used in various fields of technology: in aerodynamic tunnels, vacuum equipment, spraying systems etc. Gas-liquid ejectors are used most commonly. The use of ejection devices in the pharmaceutical industry to moisturize the bulk components in the granulator-drier allows obtaining high quality granulated material. Analyzing the ejection process to determine the rational design parameters of the equipment and its operation modes is appropriate to use the modern software [3].

II. Materials and methods

The research is aimed to show the rational construction of ejecting devices, which allows obtaining a fine-dispersed mixture with evenly distributed components and ensures its sufficient speed. The ejection process is simulated in the Flow Vision program.

The object of the research is the creation of fine-dispersed air-water mixture, and the subject of the research is the construction of an ejecting device and its operating parameters.

An ejection device includes components supply chambers, mixing chamber, convergent chamber and divergent chamber (Fig.1).

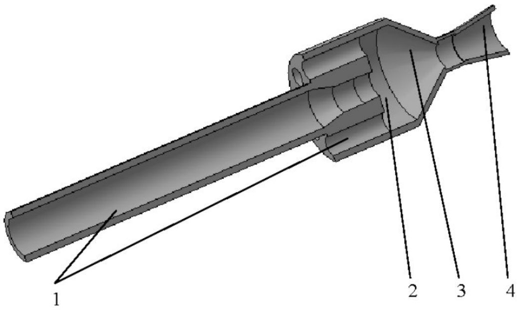


Figure1. *Ejector general view:*
1 – components supply chambers; 2 – mixing chamber; 3 - convergent chamber;
4 – divergent chamber

Two models of ejection devices, where in the supply chambers for liquid and gas medium were located in different places, were simulated with the help of the Flow Vision program. Since the properties of convergence of difference approximation are significantly affected by the size and number of elements in partition, in the course of the ejection process simulation the supply chambers for liquid and air, mixing, convergent and divergent chambers were examined separately (Fig.2).

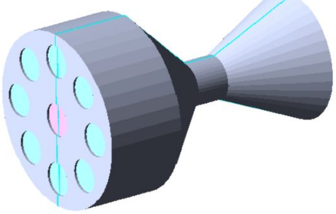


Figure 2. *3D model of the ejector's section, which was simulated*

This paper presents the results obtained in the course of the simulation of stages involving the mixing of components and output of a gas-liquid mixture from the ejector, namely the mixing chambers, convergent and divergent chambers. The components supply chamber was replaced with the corresponding boundary conditions - the feed rate for liquid and air. The "incompressible fluid" model, which describes the flow of a viscous liquid / gas at low Mach number (M <0.3), small and large (turbulent) Reynolds numbers, has been chosen for the simulation. There may be small changes in density, allowing to naturally take into account the elevating power. The model includes Navier-Stokes equations, energy and mixture concentration convection-diffusion transfer equations.

The turbulent incompressible fluid model is based on the use of k-ε turbulence model of first-level occluding. When it is used to occlude the system must obtain a formula for the turbulent viscosity coefficient μ_t. Currently, to achieve this goal often use the so-called two-parameter models. So they called because in these μ_t is defined through two parameters, for which the additional differential equations in partial derivatives are solved.

The model uses the following equations:

- Navier-Stokes equation

$$\frac{\partial V}{\partial t}+\nabla(V\otimes V)=-\frac{\nabla P}{\rho}+\frac{1}{\rho}\nabla(\mu+\mu_t)\left[\nabla V+(\nabla V)^T\right]+(1-\frac{\rho_{hyd}}{\rho})g$$

- The continuity equation of flow

$$\nabla\mathbf{V}=0,$$

where **V**– relative velocity vector, m/s; t – time, s; P – relative pressure, Pa; ρ – density, kg/m^3; μ – dynamic viscosity, Pa·s; μ_t – turbulent viscosity, Pa·s; ρ_{hyd} – hydrostatic density, kg/m^3; $\boldsymbol{g}$ – vector of gravity, m/s^2.

- The equation for the turbulent viscosity

$$\mu_t = C_\mu \rho \frac{k^2}{\varepsilon}.$$

In addition, the model includes equations for turbulent energy k and turbulent energy dissipation rate ε:

$$\frac{\partial(\rho k)}{\partial t}+\nabla(\rho V k)=\nabla\left[\left[\mu+\frac{\mu_t}{\sigma_k}\right]\nabla k\right]+\mu_t G-\rho\varepsilon$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\nabla(\rho V\varepsilon)=\nabla\left[\left[\mu+\frac{\mu_t}{\sigma_\varepsilon}\right]\nabla\varepsilon\right]+C_1\frac{\varepsilon}{k}\mu_t G-C_2\rho\frac{\varepsilon^2}{k},$$

where G is the expression:

$$G=D_{ij}\frac{\partial V_i}{\partial x_j}$$

$$D_{ij}=S_{ij}-\frac{2}{3}\left[\nabla\cdot V+\frac{\rho k}{\mu_t}\right]\delta_{ij}$$

$$S_{ij}=\frac{\partial V_i}{\partial x_j}+\frac{\partial V_j}{\partial x_i}$$

The parameter values are equal to:

$\sigma_k=1$; $\sigma_\varepsilon=1.3$; $C_\mu=0.09$; $C_1=1.44$; $C_2=1.92$

Transferring of components that are mixed, is solved by the equation of convective diffusion transfer:

$$\frac{\partial C}{\partial t}+\nabla(VC)=\frac{1}{\rho}\nabla\left[\left[\frac{\mu}{Sc}+\frac{\mu_t}{Sc_t}\right]\nabla C\right],$$

where C – substance concentration ; Sc – Schmidt number.

The geometric model shown in Fig. 2 consists of the mixing chambers, convergent chamber and divergent chamber. Boundary conditions (Fig. 3) describe the interaction between the initial components and gas-liquid mixture and elements of the equipment. In two versions of the ejection device operation, which have been researched, supply chambers for liquid and gas medium are located in different places.

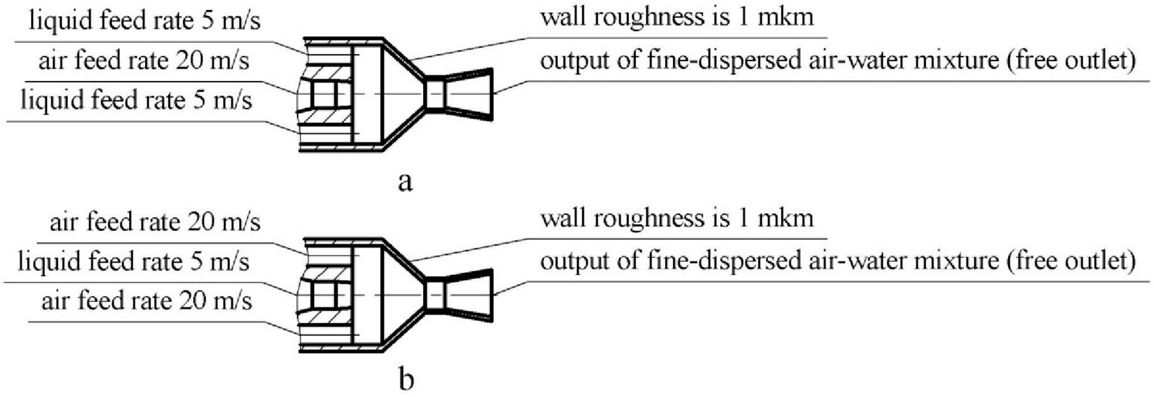


Figure 3. *Boundary conditions for the calculation of two ejection device versions: a) the supply of air into the inner tube; b) the supply of air into the peripheral air supply openings.*

To describe the rheological characteristics of the primary components, the Flow Vision package database has been used.

In order to obtain more accurate results in the area located between the convergent and divergent chambers, the computational grid has been adapted by increasing the number of cells taken into account in the calculations.

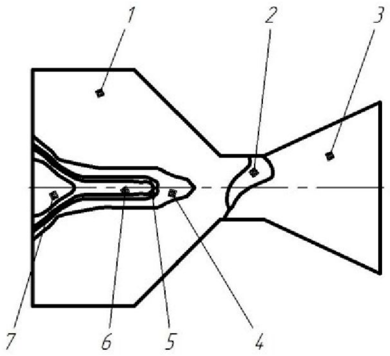
III. Results and discussion

The values of pressure, velocity and concentration in the longitudinal section of the ejection device and their changes in time have been analyzed in the course of the simulation.

Concentration is the main indicator of the quality of the resulting air-liquid mixture at the outlet of the ejector because it allows tracing the uniform distribution of component 1 (water) in component 0 (air). Only uniform distribution of both initial components in the resulting mixture will ensure high quality moistening of granulated material, formation of granules similar in shape and size.

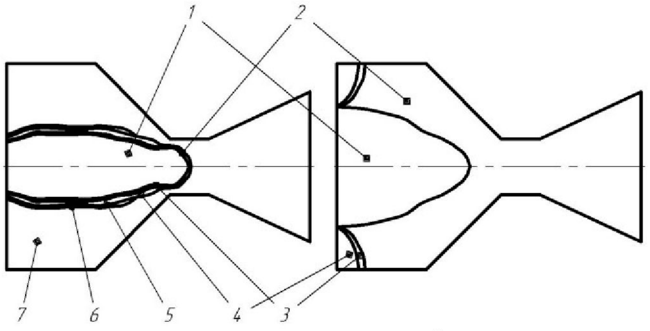
As shown in Fig. 4, the mixing of air and liquid begins at a distance of 1.5 mm from the entrance of the components into the ejector area in question. As water enters the ejector through eight holes, a mixture of uniformly distributed components (concentration 0.7 – 0.8) is formed at a distance of 11 mm from the place of supply of initial components.

The mixing of components in the second version of the ejection device (Fig. 5) differs from the previous one.



Position	Concentration
1	1
2	0.9
3	0.8
4	0.7
5	0.6
6	0.5
7	0

Figure 4. *Distribution of concentration for the first version of the ejection device*



a b

Position	Concentration
1	1
2	0.84
3	0.72
4	0.5
5	0.38
6	0.22
7	0

Figure 5. *Distribution of concentration for the second version of the ejection device: a – beginning of calculations, b – reaching the steady state*

Comparing the concentrations at the beginning of calculations and at steady state (see Fig.5), we can trace how the concentration becomes even and an instantaneous mixing of the initial components. Upon reaching the steady state, which is achieved 0.001 s after the ejector starts operating, the concentration of the outgoing mixture is 0.82 (Fig. 6).

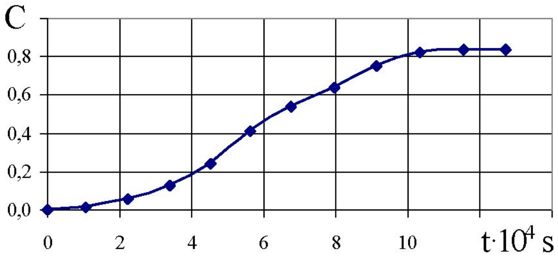
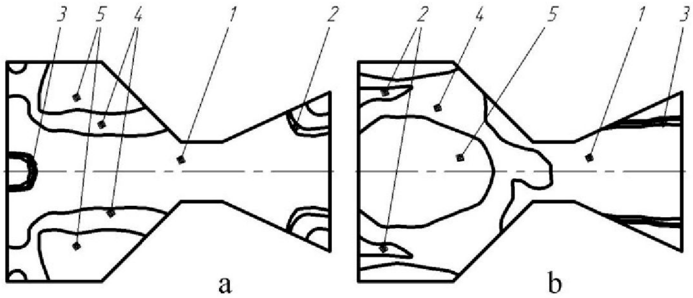


Figure 6. *Components concentration - time diagram*



a b

Position	Concentration
1	100
2	80
3	50
4	35
5	5

Figure 7. *Velocity field in the longitudinal section of the ejector: a - version 1 of the calculation, b – version 2 of the calculation.*

The water feed rate is 5 m/s, the air feed rate is 20 m/s. During standard operation of the ejecting device (Fig.7) the mixing of components results in the formation of the air-liquid mixture, its speed becomes constant and at the output in the central part reaches 200 m/s, which is less than the speed of sound and corresponds to empirical data obtained by other researchers. The areas where speed is different from that of the main flow are located on the periphery of the output (see Fig.7). The second option of the ejection device, where water is supplied into the central tube, shows a more even distribution of velocities.

At the entrance to the ejection device the pressure is 5.67 MPa. After the components are mixed in the convergent chamber, the pressure is reduced and at a distance of 13 mm from the components entrance point is 3.8 MPa. At the output of the ejection device the average pressure of the mixture is 3.2 MPa.

IV. Conclusions

Comparing the results of the simulation of the two above described models, which have different places for the supply of liquid and water, shows that a better mixing of the initial components is observed when liquid is supplied into the central tube and the air – in the peripheral holes. This is evidenced by even distribution of pressure, velocity and concentration in all parts of the ejector.

Thus, to ensure uniform moistening of the bulk components and to obtain high quality granulated material, it is necessary to install ejectors, in which liquid is supplied into the central tube, and air – into eight peripheral holes, in granulator-driers.

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