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The working process of mixing Newtonian fluids in the channel of the multi-unit mixer diffuser-confusor type

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Abstract The article presents the results of mathematical modeling of mixing the components of Newtonian fluids in the tubular channel of the mixer in the three-dimensional formulation. The mixing of components occurs under turbulent conditions, without taking into account the influence of mass forces and chemical interaction. The flow of the mixture is modeled in a tubular multi-channel diffuser-confuser type using the package "Fluent". The input of mixing components into the channel is made through jet nozzles. The quality of the resulting mixture is estimated by the mixing ratio. Using results of three-dimensional model the analysis of the mutual influence of the character of the current of the mixing components from the way of their giving in the channel is made: quantity and an arrangement on a channel rim of jet nozzles.

Keywords: Newtonian fluids, multi-channel diffuser-confuser, jet nozzles, three-dimensional model.

1. Introduction.

By the end of the 20th century, specialists and engineers in the design of tubular channels in mixer machines, widely used in chemical, petrochemical, food and other industries accumulated considerable experience in using these devices in different forms and types of tubular channels [1,4],



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Fig. 1. It is known that the greatest practical efficiency in mixing the turbulent flows of liquids is represented by diffuser-confusor type channels [5,8].

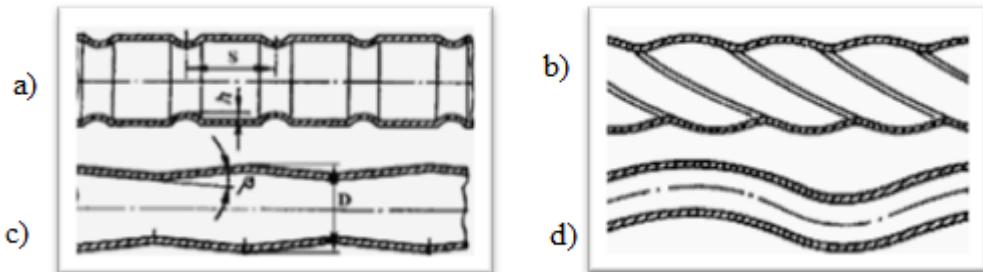


Figure 1: Different types of tubular channels: a) Channel with an annular projection, b) Pipe or a channel of the diffuser-confusor type, C) Spiral profiled channel, d) channel with a wave axis.

The hydrodynamics of the process in a multi-link channel of the diffuser-confusor type when mixing Newtonian fluids has been well studied by scientists such as Mukhametzyanova A. G., Takhavutdinov G. S., Danilov Yu. M., Garanin S. F., Petrov A. G., and so on. [6-11]. The tasks in these works were set as axisymmetric, however, with such a formulation of tasks it is impossible to simulate the input of components into the channel through jet nozzles, if in a real apparatus-mixer the supply of mixing components into the channel is carried out through a system of jet nozzles or nozzle heads. That is, the model in the axisymmetric formulation will not fully reflect the real picture of what is happening. The introduction of the mixture components into the channel in this simulation can be done only through the annular section. Therefore, the problem of mixing the components of liquids in a tubular multi-channel diffuser-confusor type with the input of components through the nozzles should be simulated only in a three-dimensional formulation [12], which will most adequately reflect the real mixing process.

2. Theoretical equations.

The aim of this work was to model a three-dimensional formulation for the problem of mixing two components of Newtonian fluids in a tubular multi-link channel of diffuser-confusor type with the introduction of the second component into the channel through jet nozzles. The mixing coefficient [13] (formula-1) was used for qualitative evaluation of the mixing process of components.

$$\gamma_a = 1 - \frac{1}{V} \iiint_V |C(x, y, z) - C_0| dV, \quad (1)$$

where γ_a - the average volume mixing coefficient; C_0 - the desired(specified) concentration; C - the resulting concentration; V - the specified volume; x, y, z - axis of the Cartesian coordinate system.

The mixing coefficient is associated with the rate of dissipation of the kinetic energy of turbulence, depending on the length of the confusor and diffusor part of the channel, the length of the entire tubular channel, the ratio of the cross-sectional diameter of the tubular channel and the diameter of the

inlet nozzles, the opening angle between the diffusor and confusor parts, the ratio between the thickness of the channel pipe in its widest and narrowest parts, as well as the properties and modes of mixing components.

A mathematical model based on the system of the Reynolds equations for turbulent mass transfer [14-16] (formula 2) was constructed for this problem. The channel of confuser - diffuser type (length $L_k=1\text{m.} - 5\text{m.}$) was used in the simulation. The opening angle of the diffuser was chosen so that the resulting unsteady micro separation of the flow of the resulting mixture from the wall did not cause a sharp increase in hydraulic resistances. The nozzles are located at right angles to the longitudinal axis of the channel section, the diameter of the nozzles $d\phi=0,004 - 0,01 \text{ m.}$ with respect to the diameter of the channel section 1: 10, $dTp. = 0.04 \text{ m} - 0.1 \text{ m.}$ The flow rate of the mixture in the range from $U_1= 0,3\text{m/s} - 1\text{m/s,}$ the speed of entering the components through the nozzles $U_2= 1\text{m/s-3M/s,}$

$$\begin{cases} \bar{\rho} \left[\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} \right] = - \frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j} \left(\mu \frac{\partial \bar{u}_i}{\partial x_j} \right) - \bar{\rho} u'_j \frac{\partial u'_i}{\partial x_j} \\ \frac{\partial \bar{u}_j}{\partial x_j} = 0, \frac{\partial u'_j}{\partial x_j} = 0 \\ \frac{\partial C}{\partial t} + \bar{u}_j \frac{\partial C}{\partial x_j} = D \frac{\partial^2 C}{\partial x_j^2} \end{cases} \quad (2)$$

where D is the coefficient of mutual diffusion , \bar{p} is the averaged pressure. \bar{u} - Averaging-Favre velocities [17] (formula 3).

$$\bar{u} = \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} u dt. \quad (3)$$

It is assumed that the mixing occurs without thermal interaction and without chemical reactions; the components of the mixture have no interfaces-free interpenetration; the mixture is considered to be a continuous medium with average, depending on local values, concentrations $C(x,y,z),$ density and molecular viscosity (formula 4)[18]:

$$\rho = \frac{\rho_1 \rho_2}{C \rho_1 + (1-C) \rho_2}, \quad \mu = \frac{\mu_1 \mu_2}{C \mu_1 + (1-C) \mu_2}. \quad (4)$$

The following turbulence model was used to close the system of equations (2): SST is a two - layer model proposed [14].

According to the boundary conditions for the tubular channel shown in Fig. 2 it is assumed that the velocity profiles, initial turbulence parameters and volume fractions of the components used are set in the input channel sections. $\varphi(x, y, z):$

$$\text{Input 1: } (u_1, \mu_1, C_1, k_1, \varepsilon_1) = \varphi(x, z)_1, \quad \text{Input2: } (u_2, \mu_2, C_2, k_2, \varepsilon_2) = \varphi(x, z)_2$$

In the output section, “soft” boundary conditions of the steady flow are set:

$$\left(\frac{\partial \phi}{\partial y} \right) = 0.$$

In the area of the walls, a "non - equilibrium" function was used-Non-Equilibrium Wall Functions-NEW F. on the walls themselves, the condition of "adhesion" - all components of the velocity are zero [19-21].

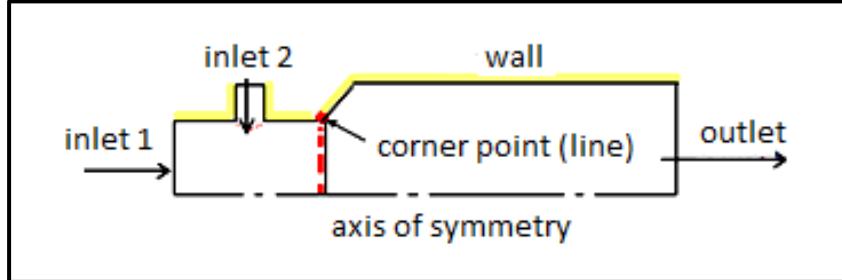


Figure 2: Initial section of the channel.

The task was solved with the help of the package "Fluent". The model of hydrodynamic mixing process is three-dimensional, the grid is adapted. A preliminary preparation of the grid area was carried out. In the area of the symmetry axis of the channel, the grid is sparse – "rough". Closer to the periphery, condensation was set, in the area of angular points, series decomposition was used to exclude non-physicality. The procedure of mirroring the grid area was also used to eliminate possible asymmetry of the flow [22]. The most detailed description of the adaptation and preparation of the grid to the problem is given in the article [23,24]. The number of nodes used was at least $N = 150,000$. The stability of the method was tested by the Courant condition. The convergence of the scheme was analyzed on thickening grids (by the mixing coefficient).

| The number of nodes in the grid | The mixing coefficient γ_a |
|---------------------------------|-----------------------------------|
| 50000 | 0.865 |
| 60000 | 0.843 |
| 70000 | 0.878 |
| 80000 | 0.905 |
| 90000 | 0.892 |
| 100000 | 0.928 |
| 110000 | 0.937 |
| 120000 | 0.944 |
| 130000 | 0.948 |
| 140000 | 0.949 |
| 150000 | 0.949 |

Table 1. The dependence of the coefficient - γ_a on the number of nodes in the grid.

3. Simulation Results

For Figure.3 based on the simulation results, the concentration field of the component in the tubular channel of the diffuser-confuser type, designed for mixing three components of liquids that do not enter into a chemical reaction with each other, is shown. The length of the diffuser-confusor tubular channel was equal to five transverse length scales. It is obtained that in this case the output mixing coefficient is equal to $\gamma_a = 0.949$.

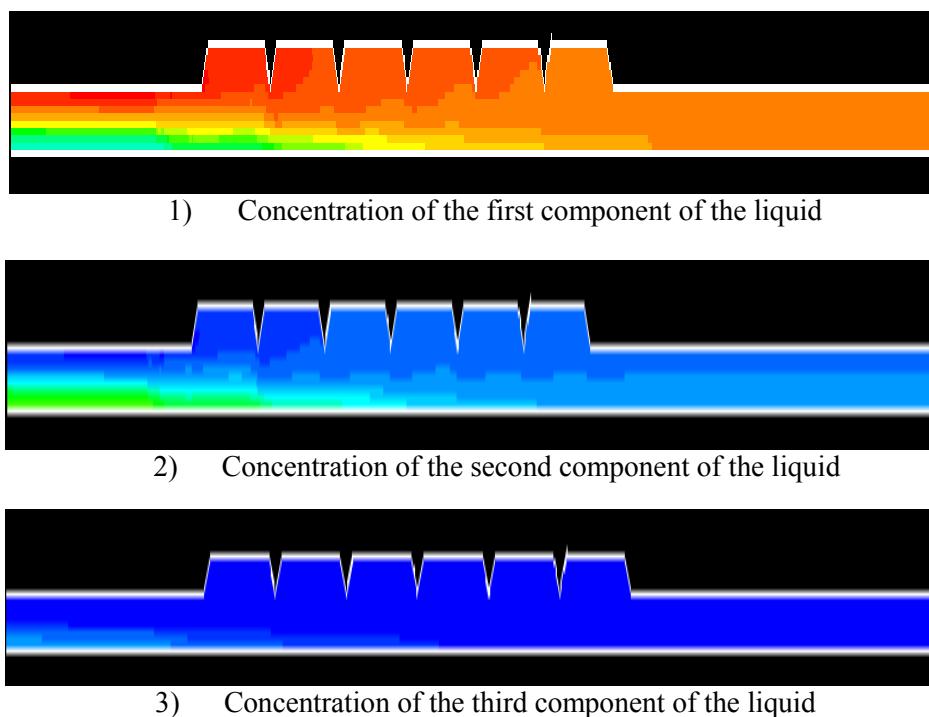


Figure 3: The distribution of the concentration of the liquid component.

When the relative length of the channel is up to 20 (the number of nodes is not less than $N = 400\ 000$), the mixing coefficient at the output increased to $\gamma_a = 0.975$, which indicates an increase in the quality of mixing Figure 4.

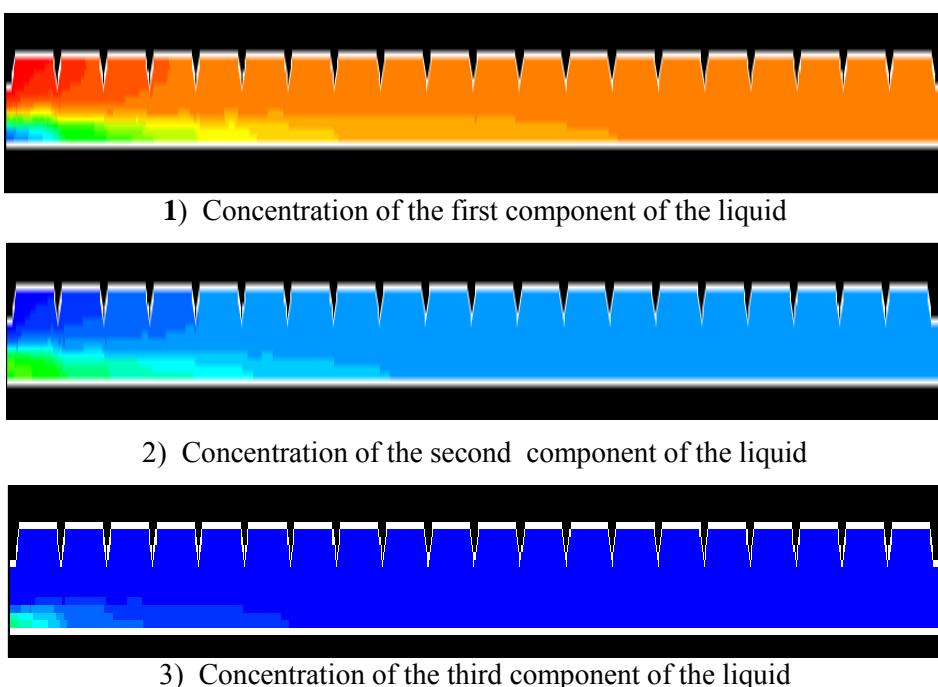
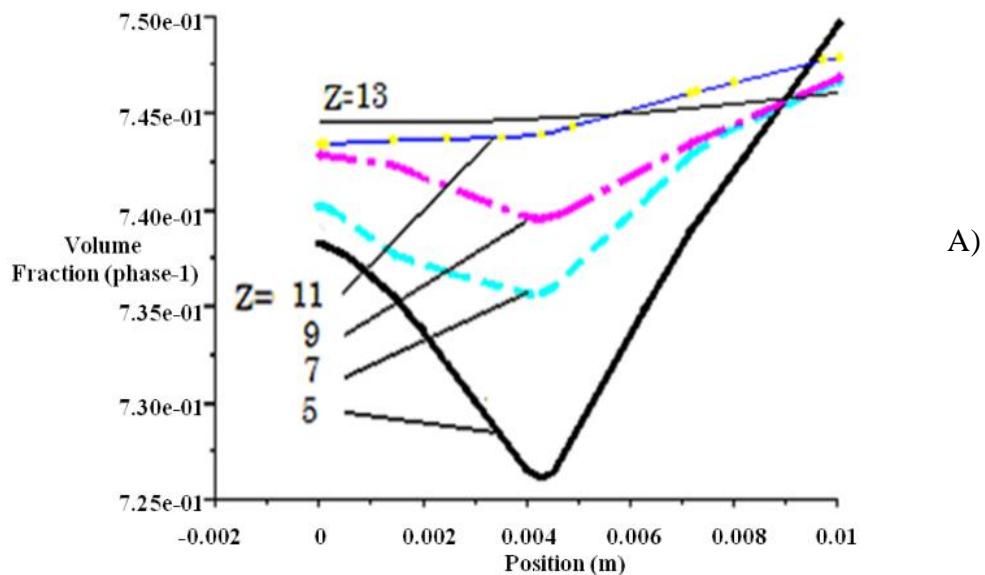


Figure 4: The distribution of the concentration of the liquid component.

| The number of nodes in the grid | The mixing coefficient y |
|---------------------------------|----------------------------|
| 50000 | 0.675 |
| 70000 | 0.789 |
| 90000 | 0.826 |
| 110000 | 0.837 |
| 130000 | 0.849 |
| 150000 | 0.856 |
| 170000 | 0.875 |
| 190000 | 0.886 |
| 210000 | 0.893 |
| 230000 | 0.907 |
| 250000 | 0.918 |
| 270000 | 0.926 |
| 290000 | 0.934 |
| 310000 | 0.946 |
| 330000 | 0.955 |
| 350000 | 0.968 |
| 370000 | 0.974 |
| 390000 | 0.975 |
| 410000 | 0.975 |

Table 2. The dependence of the coefficient - y_a on the number of nodes in the grid.

Figure.5 shows the concentration profiles in a tubular apparatus when mixing water (the first component) and ethyl alcohol (the second component) on the cross-section of the channel, where $z=L/r$ - is the number of the ratio of the scale of the length of the channel to the cross-section of its radius.



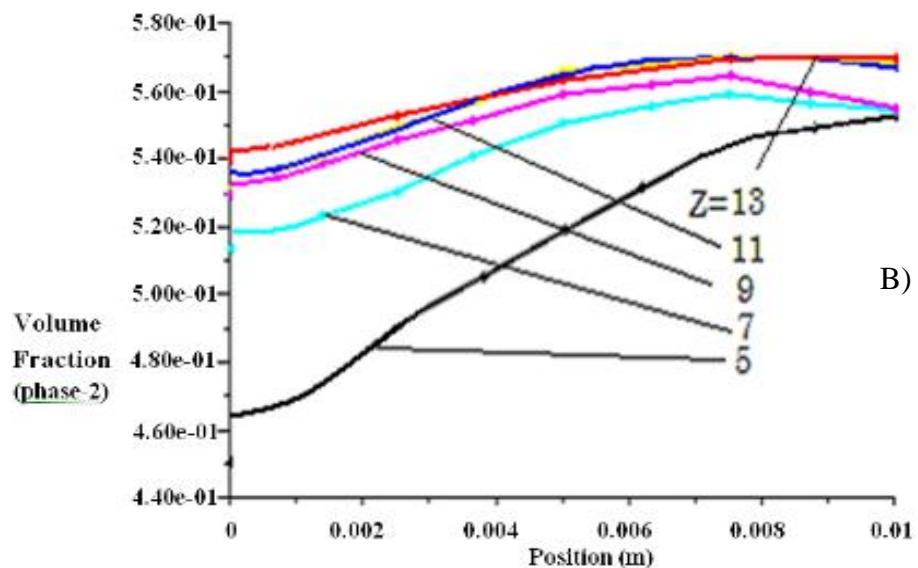


Figure 5: A) - Distribution of concentrations of the 1st component across the channel sections,

B) - Distribution of concentrations of the 2nd component across the channel sections

4. Conclusion.

As a result of the simulation, it is obtained that starting from approximately $L/r=18$, the concentration profiles in cylindrical apparatuses become almost identical regardless of the method of organization of the components supply. A similar pattern is observed with respect to the distribution of other hydrodynamic parameters.

As a rule, for tubular multi - link channels, the relative lengths $z = 25-60$ and in some cases even more are characteristic. Therefore, the flow in a larger area of the channel will not depend on the method of organization of the input of liquid components into it. Nevertheless, the main output variables affecting the efficiency of the channel (turbulence energy and its dissipation rate) will be strongly determined by the parameters of the injected fluid flows in the nozzle region, and it is possible to simulate the flow of mixing components through the nozzles into the channel only by a three-dimensional formulation of the problem [25]. That is, only in this case the obtained approximating expressions for the basic hydrodynamic parameters depending on the design and control variables should be used in the design of tubular channels, including the confuser-diffuser type. It can also be noted that before starting the process of modeling mixing in a tubular multi-channel diffuser-confusor type should first be analyzed: prepared and adapted to the flow area of the grid, to find out the mutual influence of the flow pattern of the mixture flow in the channel from the feed part of the nozzles of the channel, to calculate and analyze the provision of the necessary residence time of the components in the mixture for better mixing.

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