

Е. А. Тимановский [E. A. Timanovsky]

УДК 004.94

**МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССА ПЕРЕМЕШИВАНИЯ МНОГОКОМПОНЕНТНЫХ ПИЩЕВЫХ СМЕСЕЙ В ПРОГРАММЕ VISIMIX****MATHEMATICAL MODELING OF THE MIXING PROCESS OF MULTI-COMPONENT FOOD MIXTURES IN THE VISIMIX PROGRAM**Филиал ФГБОУ ВО «НИУ «МЭИ» в г. Смоленске  
e-mail: eugene.tim@mail.ru

**Аннотация.** Процесс перемешивания применяется во многих сферах промышленности, таких как пищевая, химическая и нефтеперерабатывающая, и его изучение является одной из важнейших задач, при моделировании новых перемешивающих устройств, а также при усовершенствовании уже существующих технологий и техники.

**Материалы и методы.** Рассмотрено разложение ускорения по отсутствующему базису, также наглядно представлен процесс перемешивания, при котором происходит полное взаимное распределение компонентов. Представлен обзор математических программ по моделированию процесса перемешивания. Подробно описана программа VisiMix, в которой произведено моделирование процесса перемешивания жидкой фазы, широко распространённой в технологии производства пищевых продуктов.

**Результаты и обсуждения.** Проведена визуализация гидродинамического моделирования. По заданным значениям параметров ёмкости, рабочего органа и жидкой фазы математически рассчитан показатель числа Рейнольдса. Смоделирован график зависимости тангенциальной скорости от радиуса мешалки и представлены значения параметров тангенциальной скорости. Представлен график зависимости рассеиваемой энергии  $W/kg$  от радиуса мешалки.

**Заключение.** В связи с ростом технологического прогресса, пакеты программ, способные моделировать разнообразные процессы играют ключевую роль в создании инновационных технических решений в различных сферах промышленности. В результате анализа возможностей программы VisiMix представляется перспективным дальнейшее её использование при усовершенствовании оборудования и создании новых технологических схем.

**Ключевые слова:** перемешивание, моделирование, пищевые смеси, VisiMix.

**Abstract.** The mixing process is used in many areas of industry, such as food, chemical and oil refining, and its study is one of the most important tasks when modeling new mixing devices, as well as improving existing technologies.

**Materials and methods.** The decomposition of the acceleration of the ends of the mixer is considered, the mixing process is also clearly presented, under the action of which the complete mutual distribution of the components occurs. A review of mathematical programs for modeling the mixing process is presented. The VisiMix program was studied in detail, in which the simulation of the mixing process of the liquid phase, widely used in food production technology, was performed.

**Results and discussions.** The hydrodynamic modeling was visualized. Based on the given values of the parameters of the capacity, working body and liquid phase, the Reynolds number indicator is mathematically calculated. A graph of the dependence of the tangential velocity on the radius of the mixer is simulated and the values of the tangential velocity parameters are presented. A plot of the dissipated energy  $W/kg$  versus the radius of the mixer is presented.

**Conclusion.** In connection with the growth of technological progress, programs capable of simulating a variety of processes play a key role in creating innovative technical solutions in various industries. As a result of the analysis of the capabilities of the VisiMix program, it seems promising to further use it in the production of new technological schemes for production.

**Key words:** mixing, modeling, food mixes, VisiMix.

**Introduction.** Recently, in the food industry, the most common mixing method is mechanical, used for dry fine mixtures and viscous liquids. The presented type of mixing is used in the manufacture of high quality gels and food products. The demand for installations using this type of mixing in the production of consumer products is also growing. With the growing demand for these installations, the requirements for the equipment in question also grow, due to their widespread use.

It should be noted that hydrodynamic technologies in mixing machines occupy a special place, since they combine simplicity, reliability and high efficiency. An important role is also played by the design of the impellers used for intensive and high-speed mixing, which is also a necessary condition for the creation of high-tech equipment. To solve these problems, when designing new or modernizing existing equipment, high-precision methods of calculating and modeling physical processes are used using CFD libraries and CAE programs [1].

With all its wide industrial distribution, mixing technology has not been fully studied, due to the complex physical processes that occur during mixing. Thus, the creation of new, as well as the improvement of existing devices is relevant. For this reason, much attention is paid to the search for existing and the creation of completely new methods for analyzing complex physical processes that occur during mixing, which determine the technological process of the mixing device.

**Materials and methods.** Mixing is used to create emulsions, bulk products and in the implementation of processes such as mass transfer and heat transfer. In this regard, there are several types of mixing process. The equipment is also divided into types, used depending on the state of aggregation of the mixing components. Depending on the envi-

ronment in which the process takes place, mixing is isolated in a liquid, in a solid, in a granular, and also in a homogeneous medium [2].

It should be noted that in many industries mixing of components is used, which are in different states of aggregation. This mixing process is carried out to obtain homogeneous and heterogeneous emulsions, as well as suspensions and bulk materials.

It is in the complex movement of particles and their movement relative to each other that the mixing process lies. The presented motion of the particles is formed by the addition of three directions that arise due to the rotation of the mixer. Figure 1 shows the rotation curve of the agitator ends, which characterizes centripetal and tangential acceleration [3].

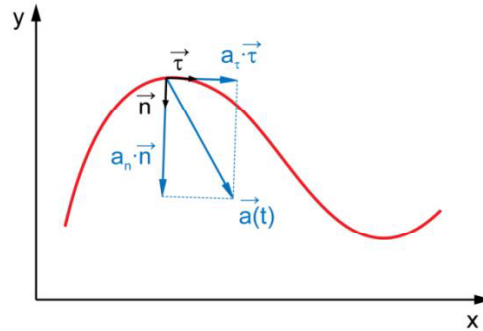


Fig. 1. Decomposition of acceleration  $a(t)$  to tangential  $\alpha_t$  and normal  $\alpha_n$

Tangential acceleration in vector form can be represented as:

$$\alpha_t = \frac{dv}{dt} = \frac{d|\vec{v}|}{dt} \quad (1)$$

The centripetal acceleration modulus is:

$$|\alpha_n| = \omega^2 \cdot r = \frac{v^2}{r} \quad (2)$$

The third direction of rotation of the mixer is axial  $u_o$ , which has a direction along the axis of the shaft.

However, when mixing the two components, we get a mixture in which these components are evenly distributed throughout the entire volume of the resulting mixture. At the same time, at the beginning of mixing, the components are slightly distributed over each other's volume, and pronounced areas of mixing components are observed. In turn, the result of a long mixing process is a complete mutual distribution of components. Figure 2 illustrates the mixing process of the two components [4].

As a result of mixing, a variety of mixtures are obtained, which can be divided into two groups, these are homogeneous and heterogeneous mixtures. A characteristic feature of homogeneous mixtures is the complete decomposition of components into elementary particles, such as atoms and molecules of miscible substances, which in turn are completely distributed in each other. Homogeneous mixtures include saline solutions, mixtures of gaseous compounds, and true solutions [5].

A characteristic main feature for heterogeneous mixtures is the presence of chemical-integral components, which are evenly distributed in each other in the form of drops or powder. The mixtures under consideration include powders, emulsions, suspensions, and aerosols.

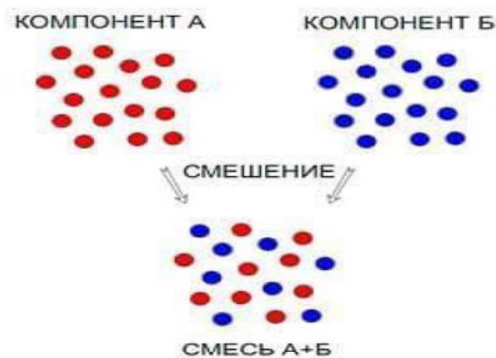


Fig. 2. Mixing process

Thus, it is possible to single out the main goals of mixing, which include the acceleration or deceleration of chemical reactions, ensuring the full distribution of both solid particles in a liquid and a liquid in a liquid, and one of the goals is to intensify the heating and cooling processes.

When choosing a mixing device, as well as the mixing method itself, the following categories should be followed:

- the degree of mixing or the indicator of homogeneity, characterized by the distribution of the components as a result of the end of mixing. This indicator is determined empirically to determine the quality of mixing
- the intensity of mixing, an indicator expressed in the frequency of rotation of the working body of the mixing device. In industrial applications, the intensity of mixing is characterized by the time it takes to obtain a certain technological result.
- mixing efficiency, characterized by the ability to obtain the required mixing quality for a certain period of time with the lowest energy costs.

Having considered the above indicators, it should be noted that at the moment there is no specific method or criterion by determining which you can choose the necessary mixer for the process under consideration. Since each mixing device has both positive and negative aspects of its use. Thus, for a more rational choice of a mixer, it is required to be guided by existing experiments and results that were carried out in laboratory conditions [6].

Computer-aided design methods for a variety of processes are being developed and implemented, thus, the traditional methods of modeling are gradually being replaced by newer ones using CAD / CAM / CAE packages on personal computers. One of the programs under consideration is ANSYS, which, according to many experts, is the most powerful tool, the main task of which is the calculation and simulation of programmed processes. This program allows to accelerate the development technology, as well as the efficiency of the designed machines and devices.

Another program under consideration is VisiMix Turbulent, which is a unique tool for mathematical modeling. This program allows you to simulate mixing processes in which one of the components is a liquid. The program under consideration contains the parameters of the mixing process, which are required for the analysis and optimization of mixing plants with various types of working bodies. This program provides the ability to use Newtonian and non-Newtonian media, it also has a wide range of used sizes, both tanks and working bodies. One of the main features of VisiMix is the modeling of emulsions, determination of the achievement of the final stage of emulsification. Also, the program has the ability to calculate the drop size, mixing time of components and many other indicators of processes that play an important role in the mixing process. The main area of application of the program is to simulate the mixing process in cylindrical tanks using mixing devices [7].

Within the framework of this work, we will simulate the mixing process in a tank with a conventional heat jacket and an elliptical bottom. The total volume of the designed tank should be 5000 liters with a diameter of 1600 mm. Also, the projected tank must have a reflector, the upper part of which does not protrude beyond the upper level of the mixing mixture. The thermal jacket should be designed in such a way that it covers the entire surface area of the tank. It is also necessary to place a turbine mixer in the tank, the rotation speed of which will be 125 rpm.

A tank with these characteristics is necessary for mixing both liquid mixtures and mixtures with the addition of a solid phase. A simulated reservoir will also allow studying the formation of stagnant zones, which will give an idea of the required degree of mixing. The simulated impeller will allow you to study the change in tangential velocity over the entire volume of the considered vessel. This will allow evaluating the effectiveness of the decisions made.

Creating a project in VisiMix begins by opening Project, which is on the home page in the menu bar. Figure 3 clearly demonstrates the above menu.

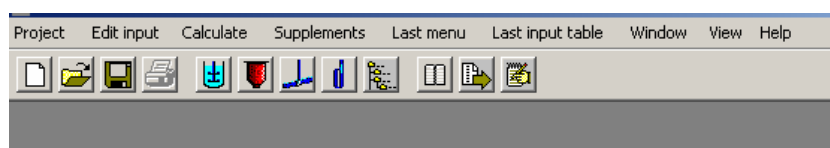


Fig. 3. Main menu of the program

After selecting Project, a menu appears, which is shown in Figure 4. In this window, select New ...

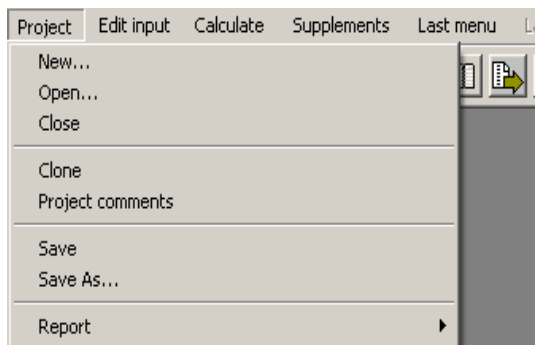


Fig. 4. Project Submenu

After selecting the New ... menu, a window for saving a new project opens, in which we specify the name of the Project-1 file and save it. This window is shown in Figure 5.

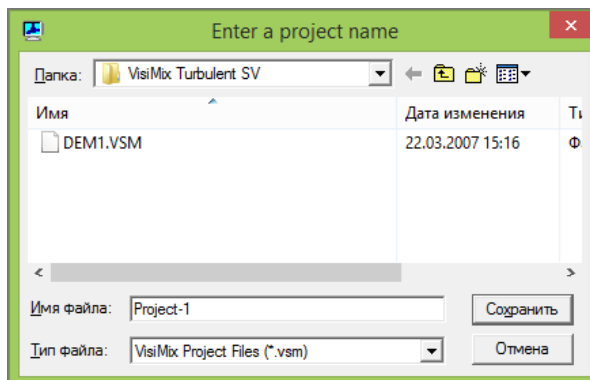


Fig. 5. Dialog box for saving a new project

After saving the project, the program provides a window for selecting different types of tankers, shown in Figure 6. All tankers are divided into four groups, namely, an insulated tank without a jacket, a tank with a conventional thermal jacket, a tank with a half-tube thermal jacket and tanks with embossed / dimpled thermal shirt. Also in each group are tanks with different types of bottom, such as flat bottom, elliptical and conical.

In the corresponding window, select a tank with a conventional heat jacket and an elliptical bottom. When you select this tank, it will be displayed in a small window on the right, in which you should confirm your choice by clicking on the Ok button.

When the required tank is selected, a window for entering its dimensions will open. This window is shown in Figure 7.

In this window, you must enter the inner diameter, enter 1600 mm, the volume of the tank, which is 5000 liters, while the program will calculate the height of the tank, the value found is 2620 mm. Also in this window, the volume of liquid is entered, in this case 4000 liters, the height of the column is 2123 mm. After entering the necessary data, the entered data will be reflected in the right area of this window. To confirm them, click OK, after which the window will change.

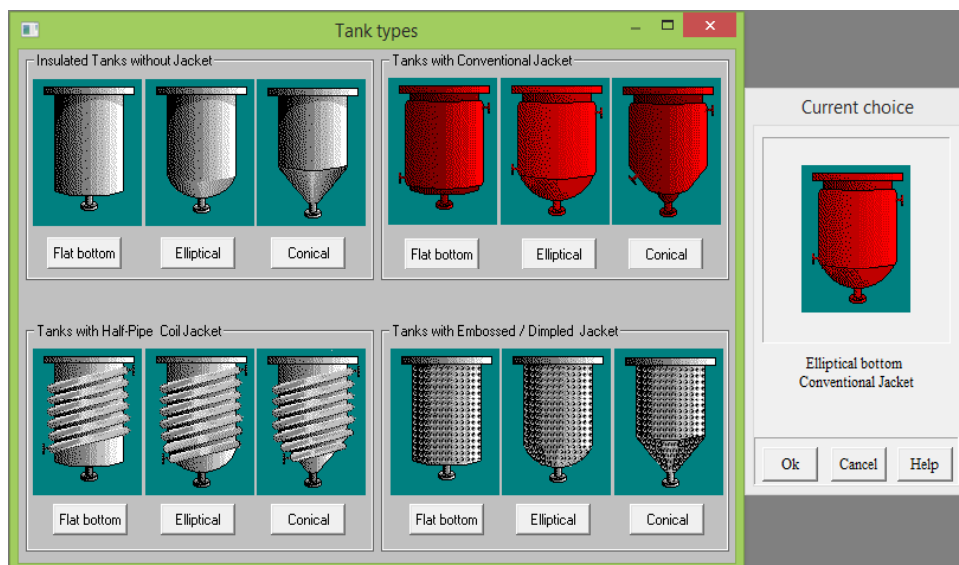


Fig. 6. Window for selecting the type of tank

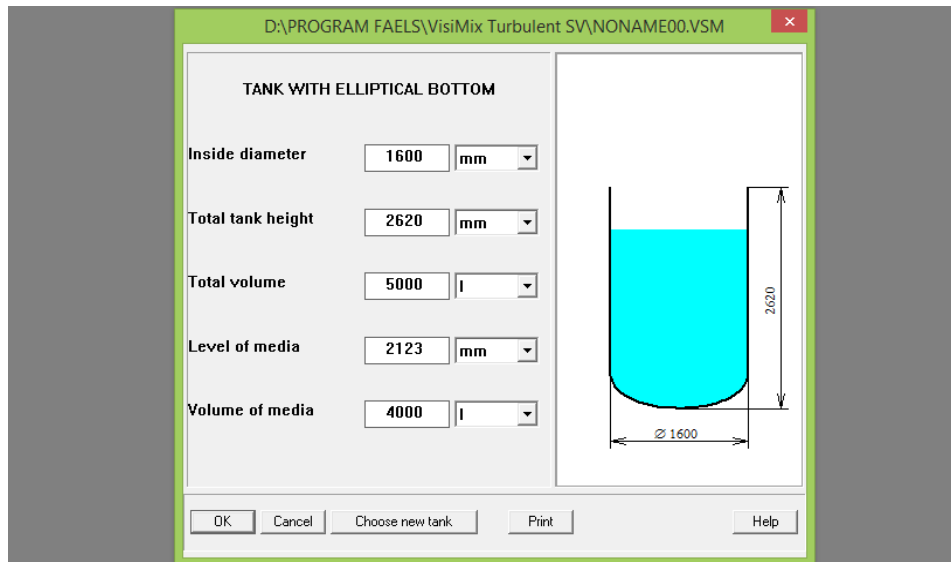


Fig. 7. Window for entering tank dimensions

Next, a window for selecting the type of reflectors appears. This window is shown in Figure 8. There are two types of flat reflectors, namely flat reflector 1 (placed on the wall) and flat reflector 2 (located at a distance from the wall). There are also two types of tubular reflectors of different designs. In this window, you can also select a defocused reflector and a container in which there will be no reflective partition.

Select the flat reflector 2 (located at a distance from the wall) and confirm the selection in the secondary window on the right. Next, the window for entering the dimensions of the reflective partition will be presented. Let's enter the number of partitions located along the perimeter of the container equal to 4. We also enter the width and height of the partitions, which are equal to 160 mm and 1700 mm, respectively. Next, you should enter the distance at which the partition will be from the bottom of the tank, which is 450 mm. The distance from the wall is 50 mm. The tilt angle of the partition is 0°. All entered data will be reflected in the right part of the selection window, which is shown in Figure 9.

After entering all the values for the dimensions of the partition, you should confirm your choice by clicking on the OK button. Then a window for selecting a working body will appear. The non-commercial version of this program provides only two types of mixing body to choose from, such as turbine and propeller. Choosing a turbine mixer. The mixer selection window is shown in Figure 10.

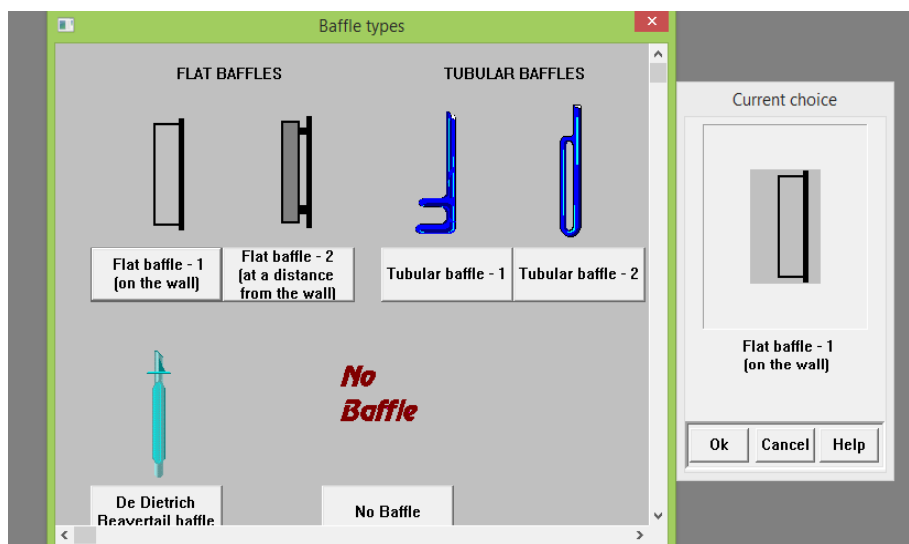


Fig. 8. Selection of the type of baffle plate

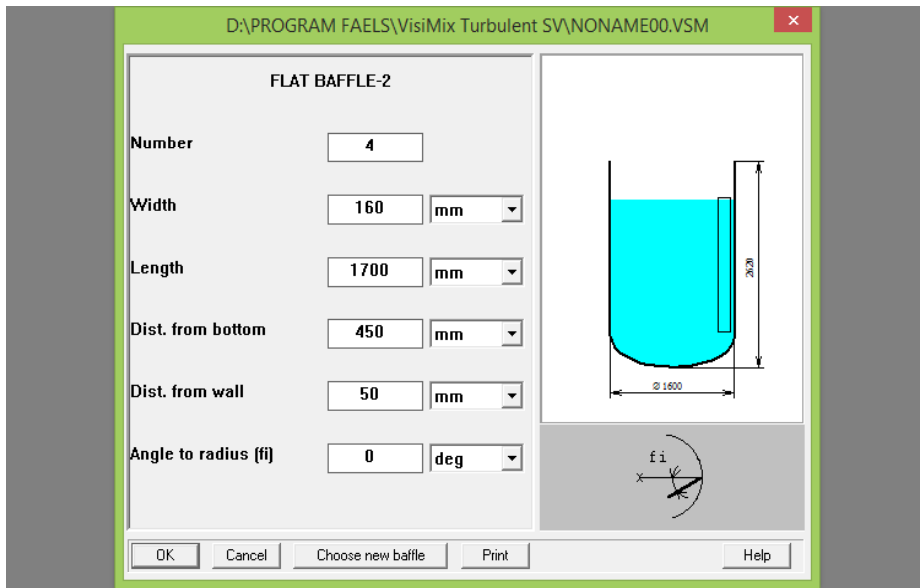


Fig. 9. Window for entering the dimensions of the reflector

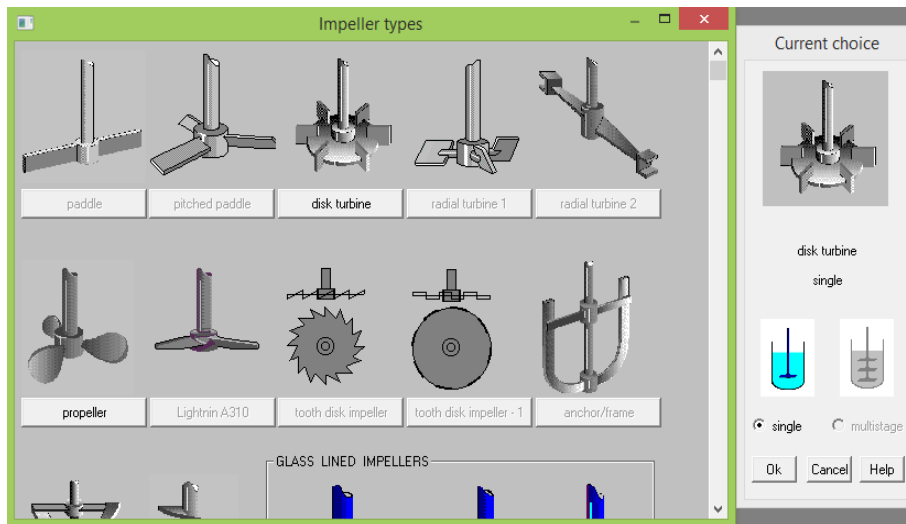


Fig. 10. Impeller selection window

After confirming the selection by pressing the OK button, the following window for entering the mixer dimensions will appear. This window is shown in Figure 11.

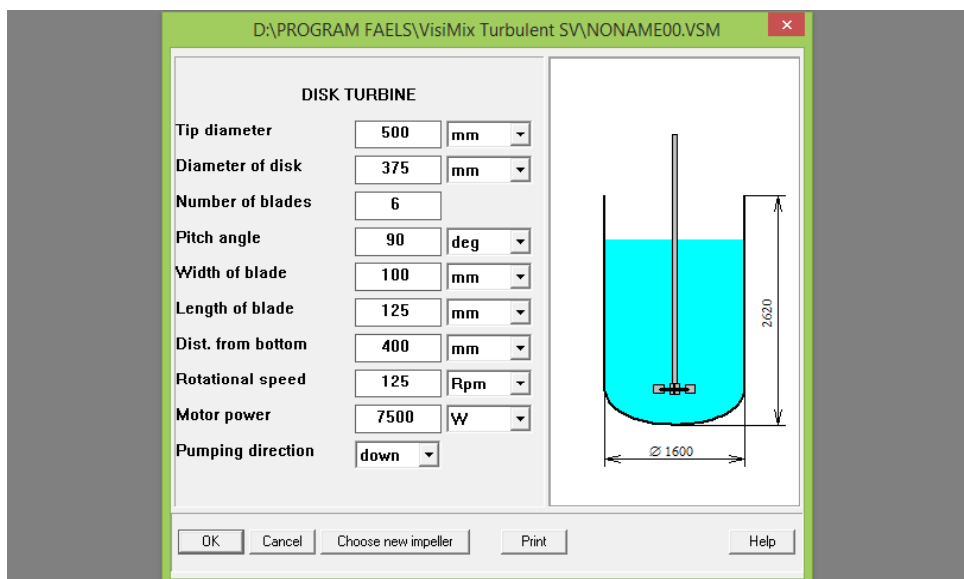


Fig. 11. Window for entering mixer parameters

In this window, enter the following values:

- blade diameter  $T_d = 500$  mm;
- disc diameter  $D_d = 375$  mm;
- the number of blades  $N_b = 6$ ;
- the angle of inclination of the blades  $P_a = 90$ ;
- blade width  $W_b = 100$ ;
- blade length  $L_b = 125$ ;
- distance from the bottom  $D_b = 400$  mm;
- rotation speed  $R_s = 125$  rpm;
- motor power  $M_p = 7500$  Watts.

After entering the data, click on the OK button, as a result of which the following window appears. Figure 12 shows the window for entering the characteristics of the casing.

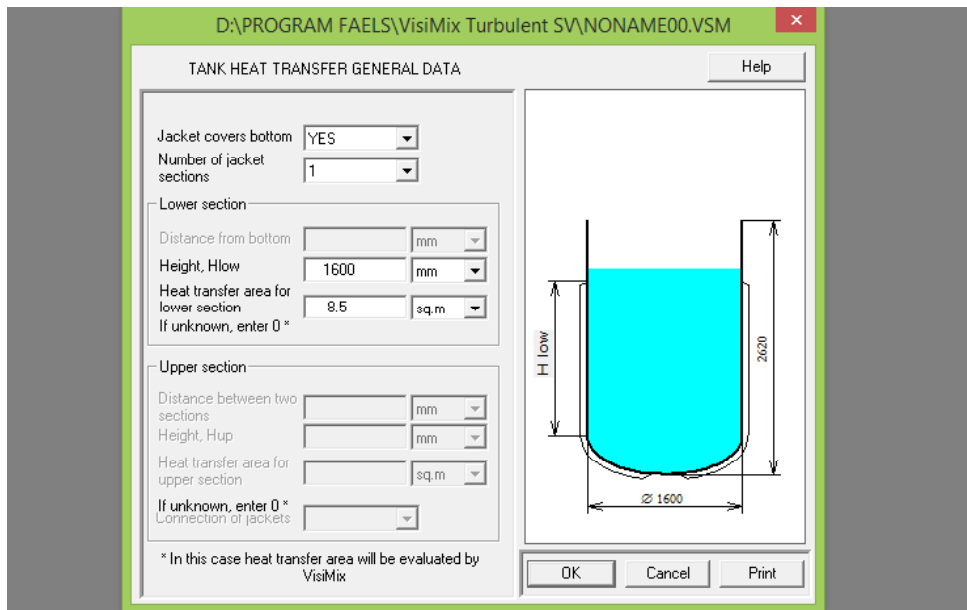


Fig. 12. Window for input of casing values

In this window, select the YES value, which means that the casing will cover the bottom of the container. Next, let's choose 1, the value of the number of sections. The section height is 1600 mm. The heat transfer area of the lower section is 8.5 m<sup>2</sup>.

Further, after confirming the entered values, you must enter the average properties of the environment. The main indicators are the average density, the value of which is equal to 1050 kg / m<sup>3</sup>. This data entry window is shown in Figure 13.

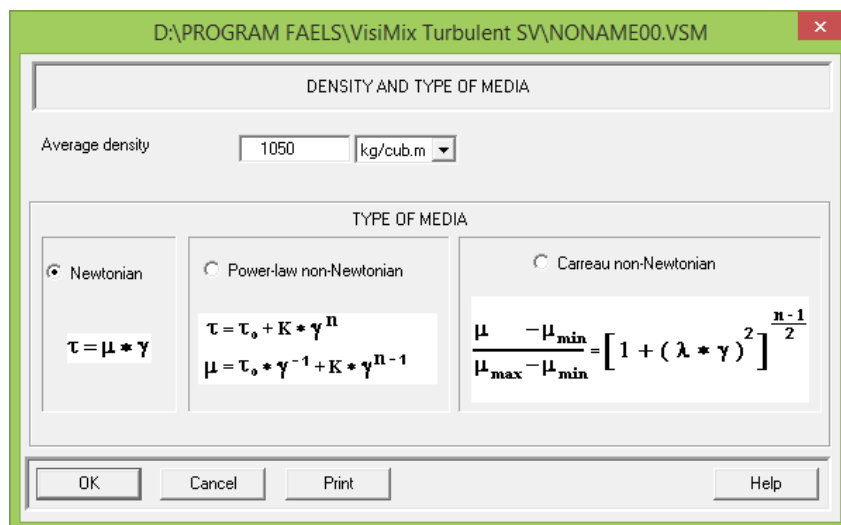


Fig. 13. Window for entering the density of the medium

The next input box is responsible for dynamic and kinematic viscosity. This window is shown in Figure 14. Here you need to enter the value of the dynamic viscosity, which is equal to 2 cP, and the kinematic viscosity will be calculated by the program automatically.

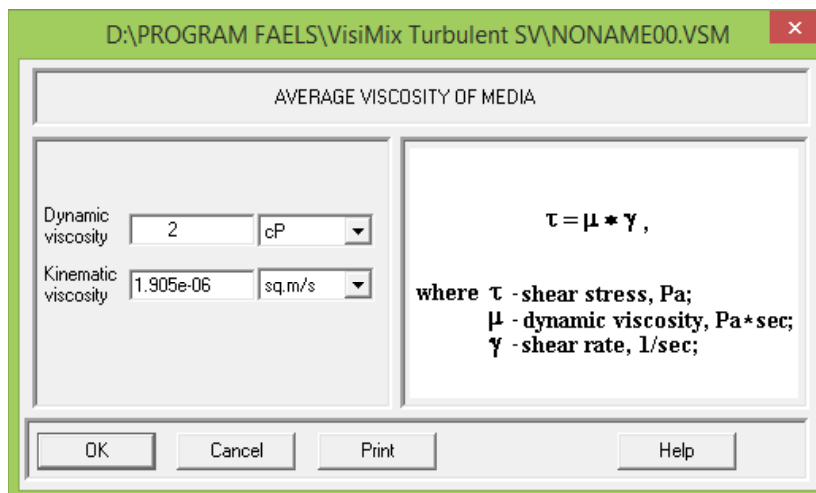


Fig. 14. Window for entering the medium viscosity

After entering all the above data, a schematic drawing of a tank with an agitator will appear. This means that the entered data is sufficient for mathematical modeling of the main hydrodynamic processes. This drawing is shown in Figure 15.

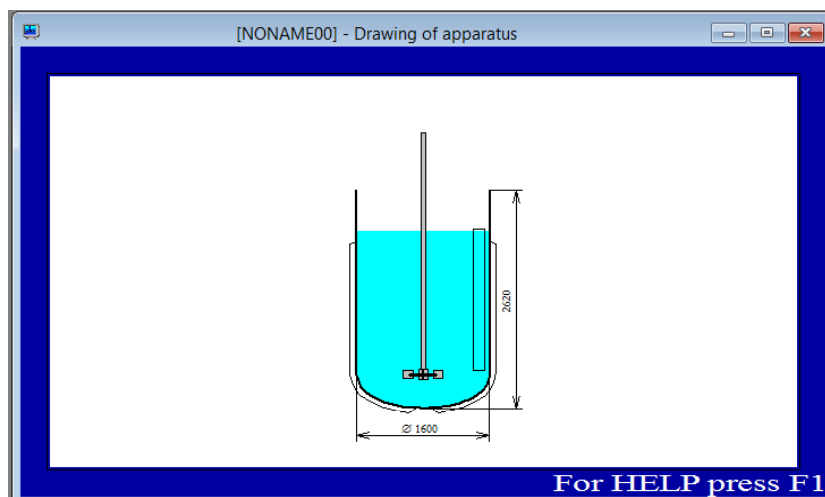


Fig. 15. Schematic drawing of the tank

**Results and discussion.** One of the main modeling processes is hydrodynamic modeling. The visualization of the process is based on the results of an approximate flow simulation with stabilized hydrodynamics. The mixing process simulates the movement of tracer particles that are introduced into the tank. Figure 16 shows a general diagram of the fluid flow at different times.

This process can be done by clicking on the following menu sequence: Calculate - Hydrodynamics - General Flow Pattern (Approximate).



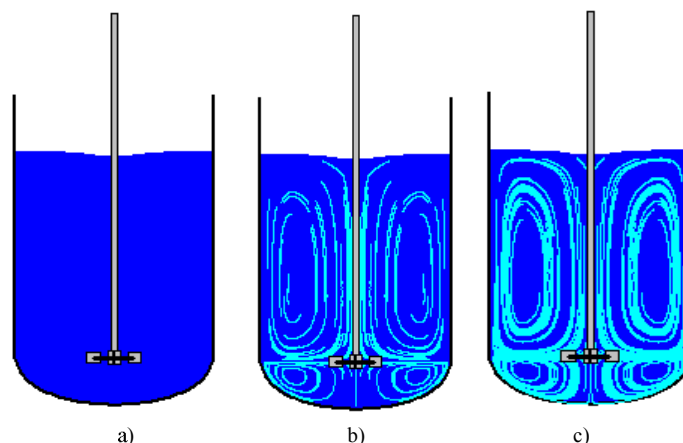


Fig. 16. General flow diagram a) start of the process 0 s; b) after 3 s; c) after 8 s

Analyzing the data presented, it is possible to identify several areas in the reservoir in which stagnant zones are formed. Thus, at the design stage or selection of the required working body, amendments can be made that will not allow the appearance of technical and technological errors in the future [8].

Also, one of the most important criteria for mixing the liquid phase is the Reynolds number. This value is based on average flow rate and tank radius. Called as follows: Calculate - Hydrodynamics - Reynolds number for flow. Figure 17 shows the result of calculating the Reynolds number.

**REYNOLDS NUMBER FOR FLOW**

Parameter name	Units	Value
Reynolds number for flow		1.79e+05

Fig. 17. Reynolds number

Using the software capabilities, a plot of tangential velocity versus stirrer radius has been modeled. Thus, in a well-developed turbulent flow, the profile of the tangential velocity is close to the average, practically over the entire volume of the tank, except for the area of action of the working body, which is 250 mm.

Figure 18 shows a graph of the radial distribution of the tangential velocity.

**RADIAL DISTRIBUTION OF TANGENTIAL VELOCITY**

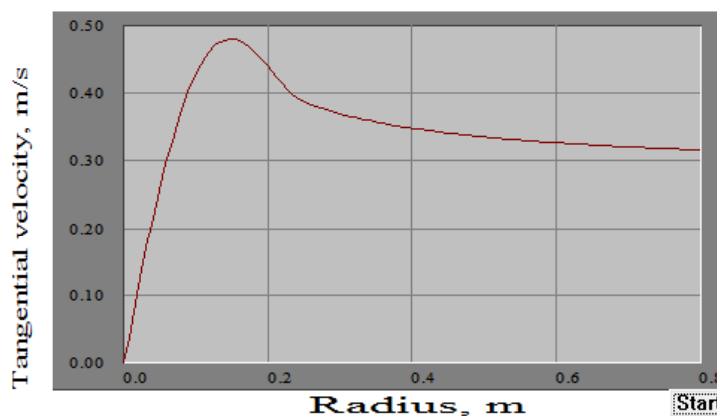


Fig. 18. Radial distribution of tangential velocity

Also, according to the results of the analysis of the graph, a table should be presented, which includes the following parameters:

- the average value of the tangential velocity;
- the maximum value of the tangential velocity;
- tangential velocity at the wall. This is the tangential velocity near the wall, outside the boundary layer;
- is the speed of the end of the impeller. This parameter represents the speed of the outer edge of the tool blade.

It is used to compare blade speed and fluid flow rate.

Figure 19 shows the tangential flow characteristics.

CHARACTERISTICS OF TANGENTIAL FLOW

Parameter name	Units	Value
Average value of tangential velocity	m/s	0.347
Maximum value of tangential velocity	m/s	0.479
Tangential velocity near the wall	m/s	0.317
Impeller tip velocity	m/s	3.27

Fig. 19. Tangential flow characteristics

Figure 20 shows a graph of the dissipated energy  $W / kg$  versus the stirrer radius. The disc diameter together with the blade length is 500 mm. Thus, the greatest dissipated energy is observed in the center of rotation of the mixer within a radius of 250 mm and is 25  $W / kg$ .

As a result of the analysis of the graph, it can be concluded that the vortex, formed due to the movement of the blades of the working element, has maximum values in the center of rotation. It is also worth noting that a significant part of the energy is dissipated within a radius of 150 mm and amounts to 3.8  $W / kg$ . Thus, the average value of the dissipated energy over the entire volume of the container is 0.377  $W / kg$ , and the dissipated energy near the reflectors is 0.146  $W / kg$ . Based on these data, it can be concluded that the power of the electric motor is sufficient.

DISSIPATION OF ENERGY AROUND THE IMPELLER

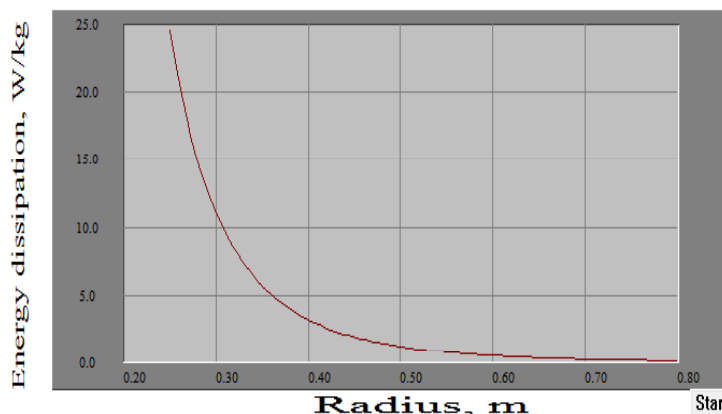


Fig. 20. Dissipated energy around the working body

**Conclusion.** Based on the results of the work, the rotation curve of the accompanying basis was established, which characterizes the centripetal and tangential acceleration. The visualization of the mixing process of two components is presented. Considered packages CAD / CAM / CAE in such modeling programs as Ansys and VisiMix.

As a result of computational and mathematical modeling of the experiment, using the CAD / CAM / CAE packages of the VisiMix Turbulent program, such indicators as the required motor power, Reynolds number were determined. The values of the tangential velocity are found at different points of the tank, the graph of the dependence of the tangential velocity on the radius of the mixer is modeled. Also presented is a graph of the dependence of energy loss when moving away from the mixing device.

Thus, the work done allows us to minimize technical and technological errors in the improvement of equipment and the creation of new technological schemes.

#### ЛИТЕРАТУРА

1. Борисов Г.С. Основные процессы и аппараты химической технологии // М.: – 1963. – С. 75-81.
2. Винников В.В., Ганиев К. О. Дипольный метод моделирования процессов перемешивания // Вестник Московского авиационного института. 2009. №2. С. 15.
3. Куликова М.Г., Аксенова О.И. Математическое моделирование пищевых многокомпонентных продуктов с учётом взаимодействий рецептурных составляющих // Информатика, математическое моделирование, экономика. 2014. №1. С. 100-104.
4. Куликова М.Г., Кончина Л.В., Моделирование технологического оборудования в пищевой промышленности // Естественные и технические науки. 2017. № 5. С. 126-127.

5. Орлов П.В. Моделирование перемешивания жидких пищевых сред с малым содержанием твердой фазы // Процессы и аппараты пищевых производств. 2006. №2. С. 33-35.
6. Стаценко В.П. Прямое трёхмерное численное моделирование турбулентного перемешивания в плавучей струе // Вопросы атомной науки и техники: Математическое моделирование физических процессов. 2006. №1. С. 39-49.
7. Стренк Ф. Перемешивание и аппараты с мешалками // Польша. Пер. с польск. под ред. Щупляка И. А., 1971. – С. 45-63.
8. Andree. W. Modelling for design of industrial equipment and processes // Modeling for Electromagnetic Processing: Proceedings of the International Scientific Colloquium, Hannover, Marh 24-26, 2003. – P. 13-18.
9. Bao I., Huang X. Mexanism of off-bottom suspension of solid particles in a mechanism stirred tank // Chin. I. Ckem. Eng., vol. 10, № 4, 2002. – P. 476 – 479.
10. Jie W., Jongang Z. The effect of impeller pumpind and fluid vheology on solids suspension in a stirred vessel // Can. J. Chem. Eng., vol. 79, №2, 2001. – P. 177-186.
11. Mersman A.B., Werner F. Theoretical approach to minimum stirrer speld in suspensions // 8th Eur. Conf. Mixing, Cambridge, 21-23 sept., 1994. – Rugby, 1994. – P. 33- 40.
12. Shamlou A.P. Mechanism of suspension of coarse particles in liquids in stirred vessels // I. Chem. E. Sym. Ser., № 121, 1992. – P. 397- 412.

#### REFERENCES

1. Borisov G.S. Osnovnye protsessy i apparaty khimicheskoy tekhnologii // М.: – 1963. – s. 75-81.
2. Vinnikov V.V., Ganiev K. O. Dipolnyy metod modelirovaniya protsessov peremeshivaniya // Vestnik Moskovskogo aviatcionnogo instituta. 2009. №2. S 15.
3. Kulikova M.G., Aksenova O.I. Matematicheskoe modelirovanie pishchevykh mnogokoponentnykh produktov s uchedom vzaimodeystviy retsepturnykh sostavlyayushchikh // Informatika, matematicheskoe modelirovanie, ekonomika. 2014. №1. S. 100-104.
4. Kulikova M.G., Konchina L.V., Modelirovanie tekhnologicheskogo oborudovaniya v pishchevoy promyshlennosti // Yestestvennye i tekhnicheskie nauki. 2017. № 5. S. 126-127.
5. Orlov P.V. Modelirovanie peremeshivaniya zhidkikh pishchevykh sred s malym sodержaniem tverdoy fazy // Protsessy i apparaty pishchevykh proizvodstv. 2006. №2. S 33-35.
6. Statsenko V.P. Pryamoe irekhmernoє chislennoє modelirovanie turbulentnogo peremeshivaniya v plavuchey strue // Vo-prosy atomnoy nauki i tekhniki: Matematicheskoe modelirovanie fizicheskikh protsessov. 2006. №1. S. 39-49.
7. Strenk F. Peremeshivanie i apparaty s meshalkami // Polsha. Per. s polsk. pod red. Shchuplyaka I. A., 1971. – s. 45-63.
8. Andree. W. Modelling for design of industrial equipment and processes // Modeling for Electromagnetic Processing: Proceedings of the International Scientific Colloquium, Hannover, Marh 24-26, 2003. – P. 13-18.
9. Bao I., Huang X. Mexanism of off-bottom suspension of solid particles in a mechanism stirred tank // Chin. I. Ckem. Eng., vol. 10, № 4, 2002. – P. 476 – 479.
10. Jie W., Jongang Z. The effect of impeller pumpind and fluid vheology on solids suspension in a stirred vessel // Can. J. Chem. Eng., vol. 79, №2, 2001. – P. 177-186.
11. Mersman A.B., Werner F. Theoretical approach to minimum stirrer speld in suspensions // 8th Eur. Conf. Mixing, Cambridge, 21-23 sept., 1994. – Rugby, 1994. – P. 33- 40.
12. Shamlou A.P. Mechanism of suspension of coarse particles in liquids in stirred vessels // I. Chem. E. Sym. Ser., № 121, 1992. – P. 397- 412.

#### ОБ АВТОРЕ | ABOUT AUTHOR

**Тимановский Евгений Алексеевич**, студент магистратуры кафедры «Машины и агрегаты пищевых производств», Филиал ФГБОУ ВО «НИУ «МЭИ» в г. Смоленске.

**Timanovsky Evgeny Alekseevich**, Master's student of the Department of Machines and Units of Food Production, Branch of the Federal State Budgetary Educational Institution of Higher Education "NRU" MPEI "in Smolensk.

Дата поступления в редакцию: 11.03.2019

После рецензирования: 23.08.2019

Дата принятия к публикации: 11.11.2019