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SIMULATION OF THE MIXING BREAD DOUGH PROCESS USING COMPUTATIONAL TECHNIQUES

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Abstract: *Mixing theory is important for its relevance in understanding some of the most fundamental problems involving bread dough flows, and for its practical impact in connection with bakery industry and other food industries. Mixing is a crucial operation in the bakery industry. The bread dough is a very complex material, considered viscoelastic whose behavior depends on moisture content and temperature. The aim of this article is to develop advanced technology for modeling bread dough mixing, in order to provide a predictive capability of optimum design parameters of dough mixers using computational techniques.*

Key words: *bread dough, flow vision, mixing, modeling, simulation.*

1. Introduction

Computational techniques used for studying the mixing process is a powerful tool that is used to mathematically model fluid flows of different mixing arm designs in mixing tanks [4], [5].

Mixing bread dough is a common operation in bread making industries. Understanding the bread dough motion in these tanks is critical for equipment design, scale-up, process control and economic factors.

Computational techniques used for studying the mixing process allow us to see what is taking place in the mixing vessel.

The results enable an engineer to select the best mixing arm design to obtain the desired process performance. The movements of bread dough in mixing tanks are complex, which makes computational techniques used for mixing a time-consuming process. A long time may be needed to define all the equations and run the program.

2. Computer simulation

Many modeling studies have focused on the bread baking stage in order to predict heat flow and the expansion of dough during thermal accumulation. Mixing parameters are external factors for the mixing operation that may adapt to the requirements of mixing in correlation with the physical and chemical composition of wheat flour dough.

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The dimensions of the mixing space and the amounts of mixed materials play an important role in dough formation and influence its properties. Much research has been done in order to study the flow of material by numerical simulation and the mixing mechanism in conventional mixers or extruders [7].

This study's approach is a three-dimensional numerical simulation of dough mixing that occurs very often in the bread processing industry. The motivation of this study is to develop advanced technology for modeling dough mixing, in order to provide a predictive capability of optimum design parameters of dough mixers.

Subjected to investigation was a dough mixer with a rotating mixing spiral arm Model SL 50 (Figure 1), placed eccentrically from the batter bowl.

Fig. 1. *Spiral Mixer SL 50*

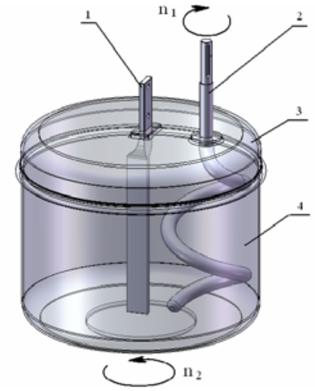

Fig. 2. *3D - model of mixer*
1 - opposite spiral; 2 - spiral mixing; 3 - lid;
4 - batter bowl

The spiral mixing arm rotates around a vertical axis in the batter bowl, considered in a vertical orientation (x, y, z), as can be seen in Figure 2.

In this study, a CFD package (Computational Fluid Dynamics) called Flow Vision was applied to build the model calculation and the calculation results. First, a parameterized three-dimensional geometric model of the mixer with spiral arm was designed. For this purpose a CAD software (called Solid Works), used in the design of objects with very complex geometry was applied. Geometry from Solid Works transferred to CFD Flow Vision preprocessor package is more flexible and precise than in the case in which it would have been conducted with the preprocessor itself.

The results of the simulation flow in the mixer using Flow Vision, e.g. contour lines of the component of the vector velocity and speed, are presented in the following figures.

For the study of the processes occurring in the mixer during its operation, computer simulations are made by means of the program system Flow Vision. For the purpose simulation of the mixing bread dough process using computational techniques of the simulations, the method of the finite elements is used [6].

The given model describes the flowing of viscose fluid on small numbers of Max ($M < 0.3$), small and big (turbulent) numbers of Reynolds. In this model are included the equations of Navier-Stokes and the energy equations.

The model of turbulent incompressible fluid is based on using turbulent viscosity μ_t. The determination of μ_t depends on the chosen model of turbulence.

In the model the Navier-Stokes equations are used:

$$\frac{\partial V}{\partial t} + \nabla(V \otimes V) = -\frac{\nabla P}{\rho} + \frac{1}{\rho}\nabla\left((\mu + \mu_t)\left(\nabla V + (\nabla V)^T\right)\right) + S \tag{1}$$

$$\nabla V = 0 \tag{2}$$

where the S is equal to:

$$S = \left(1 - \frac{\rho_{hyd}}{\rho}\right)g + B + \frac{R}{\rho} \tag{3}$$

At rotating coordinate system, the force of rotation (Koriolis and centrifugal) looks like the equation (4):

$$B = -2\omega V - \omega^2 r \tag{4}$$

The equation used for energy calculation is:

$$\frac{\partial h}{\partial t} + \nabla(Vh) = \frac{1}{\rho}\nabla\left(\left(\frac{\lambda}{C_p} + \frac{\mu_t}{\Pr_t}\right)\nabla h\right) + \frac{Q}{p} \tag{5}$$

The simulation of the process of flowing of bread dough comprises the following steps:

- creating a calculation field in CAD and importing through the format VRML or STL;
- setting the mathematical models;
- setting the boundary conditions;
- setting the starting computing grid and criterion for its adaptation to the decision and the boundary conditions;
- setting the parameters of the method of calculation;
- carrying out the calculation;
- presenting the results in graphical form.

The starting point of any numerical method is the mathematical model, i.e. the set of differential equations and boundary conditions [1].

After selecting the mathematical model, a suitable discretization method was chosen; a method of approximating the differential equations by means of a system of algebraic equations for the variables at some set of discrete locations in space and time. There are many approaches, but the most important of them are: finite difference (FD), finite volume (FV) and finite element (FE) methods [6].

The discrete locations at which the variables are to be calculated are defined by the numerical grid which is essentially a discrete representation of the geometric domain on which the mixing problem will be solved. It divides the solution domain into a finite number of subdomains (elements, control volumes etc.) [3] [8].

The method of calculation depends on the complexity of the mixing problem and uses differential equations [2].

3. Results and Discussions

The object of investigation is mixing bread dough (Mixer SL 50) with the geometric and force characteristics. Simulation studies of the processes in the mixer during its work with bread dough have been carried out.

The conditions of the simulated experiment are: density of the bread dough: ρ_1=1100 kg/m3 and ρ_2=1200 kg/m^3; viscosity: μ=2.61 Pa·s; frequency of rotation of the spiral mixing: n_1=180 rev/min and frequency of rotation of the batter bowl: n_2=30 rev/min.

The following indexes of the regime of the mixer are investigated:

- distribution of velocity vectors in vertical and horizontal direction of the mixer. Velocity vectors are determined for two densities of the bread dough ρ_1=1100 kg/m^3 and ρ_2=1200 kg/ m^3;
- dissipation of the kinetic energy in the mixer at a density of bread dough ρ_1=1100 kg/m^3 and ρ_2=1200 kg/ m^3.

The Figures 3 and 4 present the distribution of the velocity vectors of the bread dough flow in the vertical direction at a density of the product: ρ_1=1100 kg/m^3 and ρ_2=1200 kg/m^3, at a maximum value on the scale of velocity 1.5 m/s.

In the Figures 5 and 6 we can see the distribution of the velocity vectors of the bread dough flow in 3D horizontal sections of the mixer at a density of the product ρ_1=1100 kg/m^3 and ρ_2=1200 kg/m^3, at a maximum value on the scale of velocity 1.5 m/s.

The last Figures 7 and 8 contain the representation of the dissipation of kinetic energy in the mixer at a density of the bread dough ρ_1=1100 kg/m^3 and ρ_2=1200 kg/ m^3.

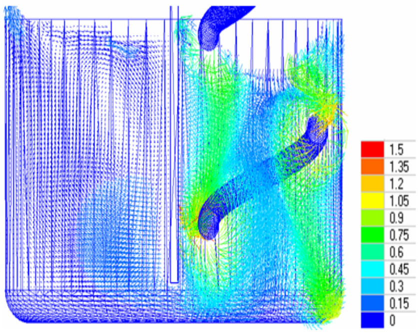

Fig. 3. *Vectors of the flow velocity in vertical direction at a density of the bread dough 1100 kg/m^3*

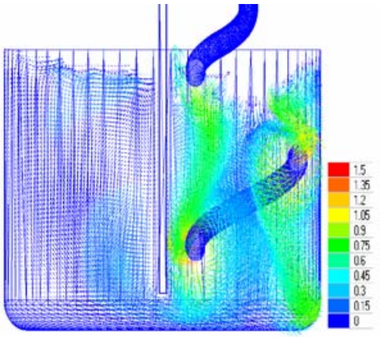

Fig. 4. *Vectors of the flow velocity in vertical direction at a density of the bread dough 1200 kg/m^3*

The analysis of the distribution of flow velocity vectors of bread dough in vertical direction of the mixer (Figures 3 and 4) reveals the existence of vertical cylindrical zones of increased pressure (0.75…1.2 m/s). This boundary layer retains higher velocity even after overshooting the mixing spiral, explaining the phenomenon by the high elastic properties of the bread dough.

From the distribution of velocity vectors in three horizontal sections of the mixer (Figures 5 and 6) it can be concluded that the prevailing speed of the dough is 0.5…0.8 m/s. The highest values of the dough speed are observed on the surface of the spiral 1.35 m/s, equal to the peripheral speed of the loops. Intensive movement (mixing) of the dough takes place only in the range of the spiral.

In the rest of the batter bowl the dough is put in motion by the rotation of the batter bowl due to its adhesion properties.

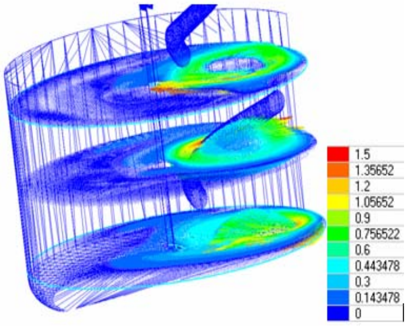

Fig. 5. *Vectors of the flow velocity in horizontal direction at a density of the bread dough 1100 kg/m*^{3}

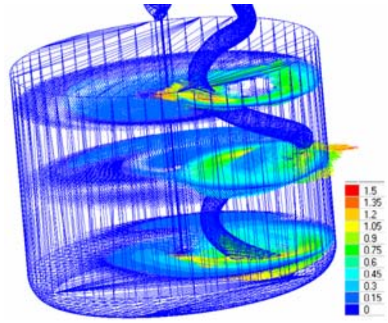

Fig. 6. *Vectors of the flow velocity in horizontal direction at a density of the bread dough 1200 kg/m*^{3}

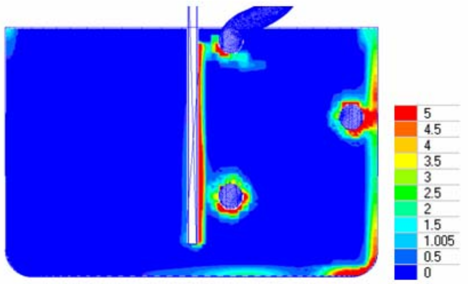

Fig. 7. *Dissipation of kinetic energy in the mixer at a density of bread dough 1100 kg/m*^{3}

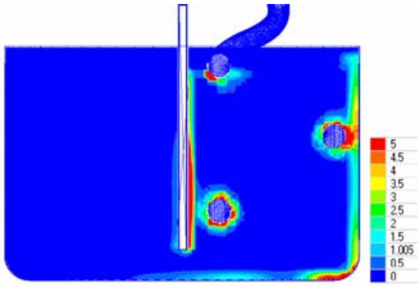

Fig. 8. *Dissipation of kinetic energy in the mixer at a density of bread dough 1200 kg/m*^{3}

The dissipation of kinetic energy (Figures 7 and 8) is proportional to the gradient of velocity. The highest values have been observed in areas adjacent to the surface of the spiral, the opposite spiral and the walls of the batter bowl.

In the carried out simulation experiments with bread dough with different densities (1100 kg/m^3 and 1200 kg/m^3) results are not significantly different, since the change in viscosity is not significant (important) to change the picture.

The obtained results provide a possibility for optimization of this type of dough mixing machines in reference to the size and proportions of the batter bowl and the working organs.

4. Conclusions

The obtained results allow:

- assessing the effectiveness of the mixing process;
- removal of the areas in the batter bowl, where the working organ insufficiently treats (processes) the dough;
- assessing the size of the boundary layer; i.e. determining the minimum distance between the working organ and the batter bowl wall;
- determining the driving force of the working organ and improving its optimum shape and geometrical parameters;

- determination of the optimum frequency of rotation of the working organ and the batter bowl.

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