NUMERICAL SIMULATION OF ENERGY DISSIPATION IN MIXING PROCESS OF BREAD DOUGH

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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. The aim of this article is to develop advanced technology for numerical simulation of bread dough mixing process, in order to provide a predictive capability of optimum design parameters of dough mixers using Computational Fluid Dynamics code named Flow Vision.*

Keywords: *mixing, bread dough, numerical simulation, CFD, Flow Vision.*

1. Introduction

Computational Fluid Dynamics (CFD) is the division of Fluid Mechanics focused on numerical simulation of the heat and mass transfer in different technical industry, including bread making process. The main problem of CFD is numerical integration of the Navier-Stokes equations describing the fluid dynamics. Additional equations are needed to describe turbulence, porosity and other physical and chemical phenomena and processes. [2]; [6]

Commercial code Flow Vision is intended for modeling of three-dimensional fluid (bread dough) flow in technical object with subsequent visualization of the results using different methods of computer graphics.

The modeled flows may be steady or unsteady, laminar or turbulent, compressible, weakly compressible, or incompressible.

Flow Vision is based on the finite-volume approach to the integration of the fluid dynamics equations. It uses a hexahedral adaptive grid with local refinement. Sub-grid resolution technology is implemented for accurate approximation of curvilinear geometry. The technology enables to import geometries from CAD systems and to interact with finite-element systems. The technology implies automatic grid generation, only several parameters are to be specified in order to build the grid for a computational domain of arbitrary complexity. [7]

Access to the model parameters and possibility to local adapt computational grid allow simulation of bread dough flow with strong swirl, free surfaces, etc.

2. Working steps

Calculation of a bread dough mixing flow implies the following steps: [5]

- creation of the mixer geometry of computational domain in a CAD system and import of the geometry to Flow Vision from the VRML;
- specifying mathematical model;
- setting boundary conditions;
- specifying primary grid and criteria for its adaptation to the solution and boundaries;
- specifying parameters of the numerical methods used for integration of different equation;
- calculation, witch are carried out without user interference;
- visualization of the obtained results, saving the needed characteristics in files;
- repetition of calculations on a finer grid in order to estimate the accuracy of the results.

The goal of the flow of bread dough mixing simulation is to obtain the fields of energy, pressure, and other quantities in the computational domain. The calculations require specifying the laws governing the flow. The set

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of the laws constitute the mathematical model of the flow. [1]; [4]

In general, the mathematical model is a set of partial differential equations describing conservation of mass, momentum, and energy; corresponding boundary conditions, and appropriate state equations.

3. Computer numerical simulation

Mixing parameters are external factors for mixing operation that may adapt to the requirements of mixing in correlation with physical and chemical composition of wheat flour dough.

The dimensions of the mixing space and the amounts of mixed materials play important role in dough formation and influence its properties. Many researches have been done and studied the flow of material by numerical simulation and mixing mechanism in conventional mixers or extruders. [5]

This study approach 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. [3]

It was investigated a dough mixer with rotating mixing spiral arm Model SL 50 (Figure 1), placed eccentric from batter bowl.

The spiral mixing arm is rotating 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 was designed a parameterized three-dimensional geometric model of the mixer with spiral arm. For this purpose was applied a CAD software (called Solid Works), used in the design of objects with very complex geometry. Geometry from Solid Works transferred to CFD Flow Vision preprocessor package is more flexible and precise than in the case that be realized with the preprocessor itself.

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Fig. 1. *Spiral Mixer SL 50*

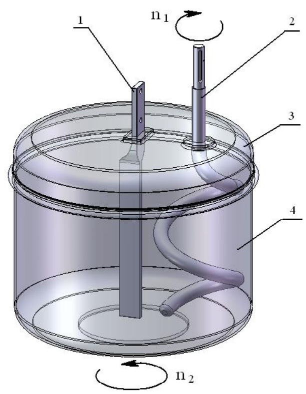

Fig. 2. *3D - model of mixer*
1- opposite spiral;2- spiral mixing;3-lid;
4- batter bowl

The results of the simulation flow in the mixer using Flow Vision, e.g. dissipation of pressure and kinetic energy, are presented in next figures.

For study of the processes passing in the mixer at the time of its work, there are made computer simulations in medium of the program system Flow Vision. For the purposes of the simulations it is used the method of the finite volume. [4]

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 the using turbulent viscosity μ_t. The determination of μ_t depends on the chosen model of turbulence.

In the model are used the Navier-Stokes equations:

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

$$\nabla V=0 \quad (2)$$

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

At rotating coordinate system, the force of rotating looks like in equation (4):

$$B=-2\omega V-\omega^2 r \quad (4)$$

The equation used for energy calculation is (5):

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

4. Results and discussion

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

The conditions of the simulated experiment are: density of the bread dough: ρ_1=1100 kg/m^3 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.

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

- Figures 3 and 4 - change of the pressure of bread dough into 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 maximum value of the scale of the pressure – 400Pa;
- Figures 5 and 6 present the dissipation of the 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.

High pressure values of the bread dough (Figures 3 and 4) are observed in two areas: in areas between the mixing spiral and the batter bowl walls (360÷400 Pa) as a result of volume reduction between the working organ and the walls of the batter bowl in the process of work, and in a layer near the walls of the batter bowl (200 ÷ 280 Pa), which is explained by the centrifugal forces and the hydrostatic pressure.

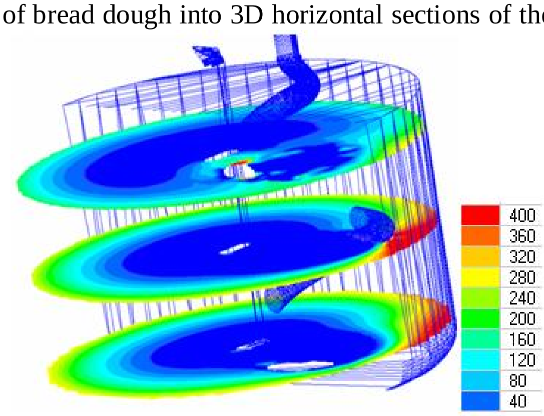

Fig. 3 Pressure of the bread dough in horizontal sections of the mixer at a density 1100 kg/m^3

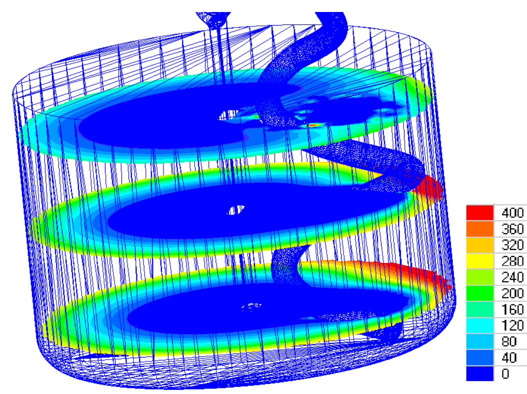

Fig. 4 Pressure of the bread dough in horizontal sections of the mixer at a density 1200 kg/m^3

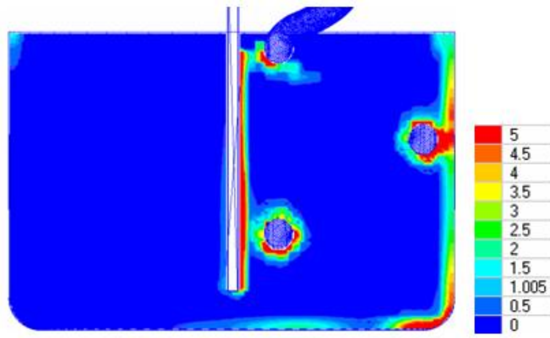

Fig. 5 Dissipation of the kinetic energy in the mixer at a density of bread dough 1100 kg/m^3

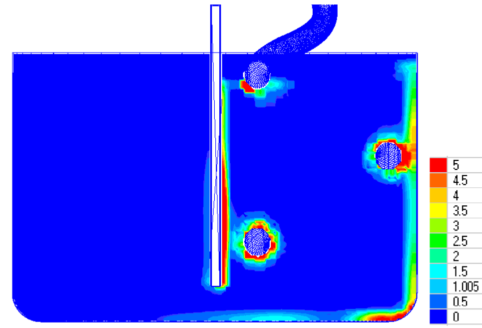

Fig. 6 Dissipation of the kinetic energy in the mixer at a density of bread dough 1200 kg/m^3

The dissipation of the kinetic energy (Figures 5 and 6) is proportional to the gradient of the velocity. The highest values are 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 density (1100 kg/m^3 and 1200 kg/m^3) results are not significantly different, since the change in viscosity is not significant (important) like we can see from results of simulation.

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

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