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Numerical Modeling and Simulation of Bread Dough Mixing using concept of Computational Fluid Dynamics (CFD)

M. Luchian[1], I. Litovchenko[2], S. Stefanov[3], C. Csatlos[1]

[1]*Faculty of Food and Tourism, University Transilvania from Braşov, România*

[2]*National University of Food Technology, Kyiv, Ukraine*

[3]*University of Food Technology, Plovdiv, Bulgaria*

Abstract

Mixing theory is important for its relevance in understanding some of 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 modeling and simulation of bread dough mixing process, in order to provide a predictive capability of optimum design parameters of dough mixers using Computational Fluid Dynamics.

Key words: mixing, bread dough, numerical modeling, simulation.

INTRODUCTION

Mixing is a fundamental unit operation in the food process industry. Mixing increases the homogeneity of a system by reducing non-uniformity or gradients in composition, properties or temperature.

Beside the primary objective of homogeneity, secondary objectives of mixing include control of heat and mass transfer rates and structural changes [4]

In food processing applications, additional mixing challenges include sanitary design, complex rheology, desire for continuous processing and the effects of mixing on final product texture and sensory profiles.

The bread industry must continually to improve the process design to increase efficiency and facilitate the development of new products.

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

Many modeling studies have focused on bread baking stage in order to predict heat flow and expansion of dough during thermal accumulation. 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 [7].

METHOD AND COMPUTER SIMULATION

Computational Fluid Dynamics (CFD) is a simulation tool that can be used to model and simulate bread dough mixing process, which involves the use of powerful computers and applied mathematics

This study approach 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 process, in order to provide a predictive capability of optimum design parameters of dough mixers.

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

Fig. 1. *Spiral Mixer SL 50*

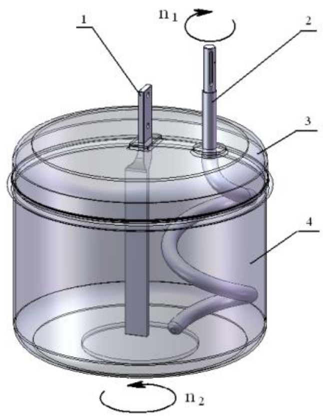

Fig. 2. *3D - model of mixer*
1- opposite spiral;2- spiral mixing;3-lid;
4- batter bowl

The spiral mixing arm 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.

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 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 elements [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 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:

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

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

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

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

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

The equation used for energy calculation is:

The simulation of the process of flowing of bread dough comprises the steps from figure 3.

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, it has been choose a suitable discretization method; a method of approximating the differential equations by a system of algebraic equations for the variables at some set of discrete locations in space and time. [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 of the complexity of the mixing problem and used the differential equations. [2]

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

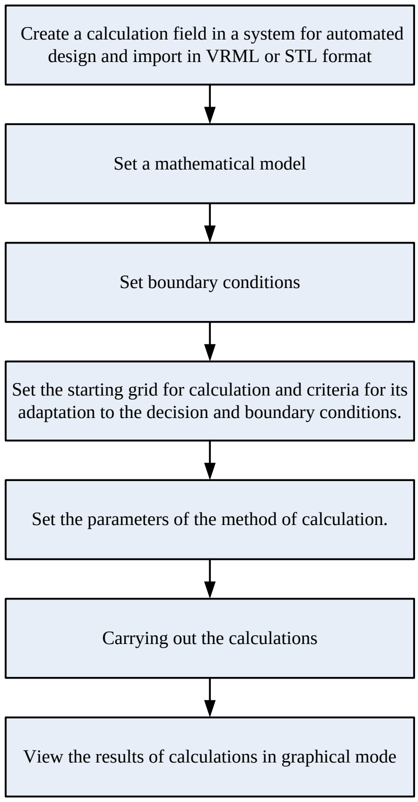

Fig. 3. *Steps for simulation of mixing bread dough process*

RESULTS AND DISCUSSION

The object of the investigation is mixing bread dough (with 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:

- distribution of velocity vectors in vertical and horizontal direction of the mixer;
- 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 4 and 5 are presented distribution of the velocity vectors of the bread dough flow in the vertical direction at 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 velocity 1,5 m/s.

In the Figures 6 and 7 we can see 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 maximum value of the scale of the velocity 1,5 m/s.

The last Figures 8 and 9 contain the representation of 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.

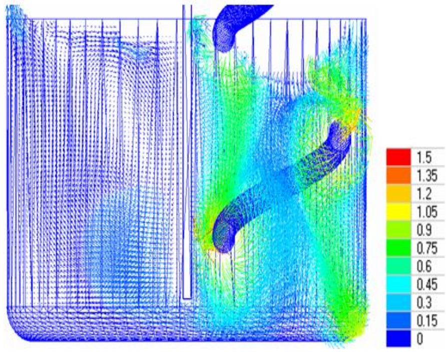

Fig. 4. *Vectors of the flow velocity in vertical direction at a density of the bread dough 1100 kg/m^3*

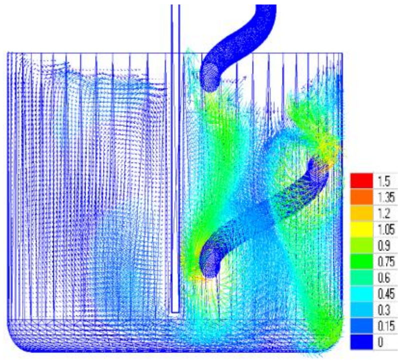

Fig. 5. *Vectors of the flow velocity in vertical direction at a density of the bread dough 1200 kg/m^3*

The analysis of the distribution of the flow velocity vectors of bread dough in vertical direction of the mixer (Figures 4 and 5) 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 with high elastic properties of the bread dough.

From the distribution of the velocity vectors in 3D horizontal sections of the mixer (Figures 6 and 7) 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; it is 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.

The dissipation of the kinetic energy (Figures 8 and 9) is proportional to the gradient of the 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 density (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.

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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.

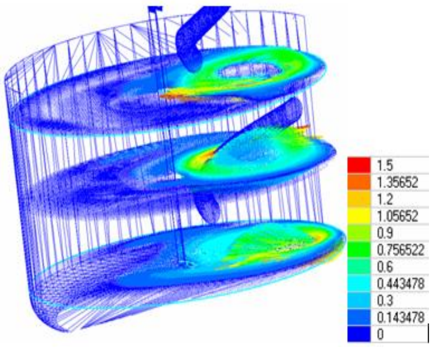

Fig. 6. *Vectors of the flow velocity in horizontal direction at a density of the bread dough 1100 kg/m³*

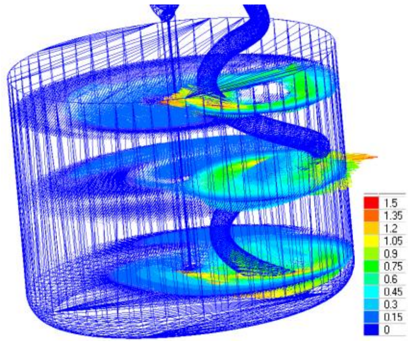

Fig. 7. *Vectors of the flow velocity in horizontal direction at a density of the bread dough 1200 kg/m³*

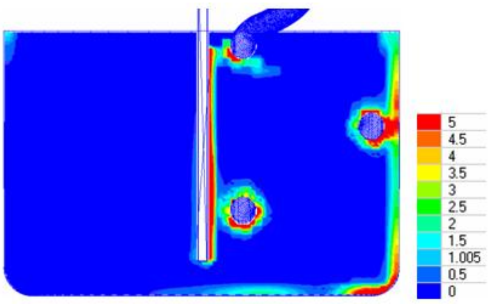

Fig. 8. *Dissipation of the kinetic energy in the mixer at a density of bread dough 1100 kg/m³*

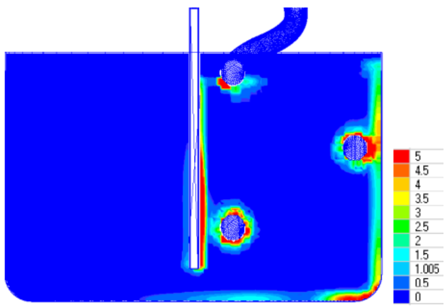

Fig. 9. *Dissipation of the kinetic energy in the mixer at a density of bread dough 1200 kg/m³*

CONCLUSION

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 of its optimum shape and geometrical parameters; determination of the optimum frequency of rotating of the working organ and the batter bowl.

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Corresponding author:

PhD Student Mihaela Ionela LUCHIAN, Faculty of Food and Tourism, Transilvania University of Brasov, Romania, Street Castelului, No. 148, tel: 0040742.903.221, email: m_luchian@yahoo.com.