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Summary of PhD Thesis

RESEARCHES ON IMPROVING THE WORKING REGIME PARAMETERS OF A PRETZEL PRODUCTION LINE MACHINES

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CONTENT

FOREWORD

The bakery industry is one of the essential sub-branches of the food industry, and lately, it has had a significant increase in automation, but with this increase, not all the factors that can affect the technological process of obtaining bakery products have been analyzed. Thus, knowing the factors which can affect the technological process of obtaining bakery products is of real importance for those in the field, specialists, construction planners, and operators.

Doctoral thesis "*Research on improving the working regime parameters of the machines of a pretzel production line*" presents a synthesis of theoretical and experimental research carried out by the author regarding the possibility of improving the operating regime parameters of the equipment on the technological flow specific to these bakery products.

The doctoral thesis is structured in 7 chapters, developed in several 192 pages, and contains 120 figures and graphs, 18 tables, 107 mathematical relations, and a bibliography of 214 sources. The paper also contains a list of notations and symbols (3 pages) and, in the end, a series of annexes (31 pages) regarding the studies and research presented in the thesis.

The general objective of the doctoral thesis was the identification and optimization of factors affecting the working mode parameters of machines specific to a small-capacity pretzel production line, in order to improve, as much as possible, the quality of the pretzels obtained, through research, both theoretical and experimental, carried out and filling out the database in the field.

Thus, **chapter 1**, entitled "*Technological manufacturing process of bakery products with hard texture*" are presented some general aspects of the baking process, the pretzels classification, recipes, the production process stages of pretzels and bakery products, the role and importance of operations, material balances within the technological flow, description of the technological process and pretzels production operations, indicators for assessing the operations and the finished product.

Chapter 2, "*Physico-mechanical and technological properties of the raw materials used in the pretzels manufacturing*" analyzes the main physico-mechanical, physico-chemical and technological characteristics of the components of the recipe for pretzels production and the obtained dough, characteristics that influence the technological process operations and requires certain specific characteristics for the machines on the technological flow.

In **chapter 3**, "*Constructive solutions of technological lines for hard-textured bakery products manufacturing*" are presented some constructive variants regarding the most essential used equipment on the technological flow of pretzel manufacturing, in the order of flow operations, such as kneaders, modeling machines, kettle and ovens for pretzels baking. Also, there are presented the main trends in modeling and wire-cut dough machines and ovens used in pretzel baking.

Chapter 4, entitled "*Synthesis of theoretical and experimental research regarding the technological process of pretzels manufacturing*", presents, first, some quantities and rheological models for characterizing bakery doughs, and then are presented briefly, synthetically and analytically, the results of theoretical and experimental research conducted worldwide, by synthesizing technical articles in the field. The factors that influence the doughs' rheological properties (the quality and characteristics of the flour, water, salt, yeast, sugar, but also the parameters of the dough kneaders) are analyzed, in order of importance. Furthermore, the research results on energy consumption in pretzels manufacturing or modeling and simulation of the technological process are also taken into account.

The chapter's conclusions return to the importance of knowing the physico-mechanical and rheological properties of doughs and the factors that influence them.

Chapter 5, entitled *"Theoretical aspects and contributions"*, is developed a mathematical model regarding the pretzel dough sheeting process parameters by using the dimensional analysis and the theorem taking into account seven basic parameters that influence the process. This chapter also simulates the process of wire-cut dough for pretzels by using the finite element method to determine the mechanical stresses in the profiled rolls of the wire-cut machine, the safety factor, and the power required to wire-cut the dough.

Moreover, in this chapter is made the analysis of the airflow in the baking chamber of the Zanolly Synthesis 06/40 VE pretzel electric oven using the Flow Simulation module from Solid Works, all these in order to identify the possibilities to optimize the pretzel manufacturing process and the operating regime parameters of the equipment on the technological flow, as well as reducing material and energy losses in the process.

Chapter 6, entitled "*Experimental research on the technological process of pretzels manufacturing*", presents the synthesis of own experimental research carried out, mainly on the technological line of pretzel manufacturing, existing in the laboratory of the Faculty of Biotechnical Systems Engineering. The experimental research objectives, the apparatus and equipment used in the experimental research, and the applied working method are specified at the beginning.

Further, are presented, in turn, but enough, experimental research and their results regarding some characteristics of raw materials and doughs used in the pretzels manufacturing, as well as energy consumption specific to dough modeling and baking operations and pretzels production from several types of flour, with different contents of water and other additions, as well as the materials balance in the baking process.

The experimental research and the results obtained regarding the mechanical behavior of the manufactured pretzels, subjected to the shear cutting operation with straight or inclined knives, are also presented.

The chapter's conclusions refer to each of the aspects mentioned above, specifying the main elements that arise from the performed analyzes.

In **chapter 7**, "*General conclusions. Personal contributions. Recommendations and future research perspectives*" there are presented in synthesis, both the conclusions resulting from the documentary research, as well as the main conclusions of the theoretical contributions chapter and the experimental research chapter, highlighting both the importance of knowing the analyzed factors with significant influences on the process and the quality indices of pretzels and the main contributions of the author on the technological process of manufacturing these products.

Furthermore, some recommendations are addressed to specialists in the field of baking processes and some future research directions for people interested in the field.

THE TOPIC IMPORTANCE AND OBJECTIVES OF THE DOCTORAL THESIS

The doctoral thesis's general objective aims to conduct theoretical and experimental research on the pretzel manufacturing process and improve the working regime parameters of the equipment of a pretzel manufacturing line.

The **specific objectives** of the doctoral thesis include:

- ❖ Theoretical and experimental notions on the rheological behavior of the dough;
- ❖ Analysis of the current state of kneaders constructive solutions used to make pretzel dough;
- ❖ Analysis of the current state of constructive solutions of pretzel modeling machines;
- ❖ Analysis of the current state of constructive solutions of kettle used in the manufacturing pretzels technological process;
- ❖ Analysis of the current state of constructive solutions of pretzel dough baking ovens;
- ❖ Synthesis of research regarding determining the energy consumption of equipment on the technological flow of pretzels manufacturing;
- ❖ Synthesis of research regarding the use of modeling and simulation in the technological process of manufacturing pretzels;
- ❖ Mathematical modeling of the sheeting process;
- ❖ Using simulation in the process of drawing pretzel dough;
- ❖ Analysis of air flow in the baking chamber of an electric oven;
- ❖ Characteristics evaluation of raw materials and doughs;
- ❖ Evaluation of energy consumption in modeling and baking doughs;
- ❖ Determining the mechanical characteristics of pretzels manufactured on the technological line;
- ❖ Evaluation of material losses in the process of baking pretzels.

LIST OF NOTATIONS AND SYMBOLS

CHAPTER 1

m_F– total weight of flour in the recipe, [kg]
m_A– total weight of water in the recipe, [kg]
m_D – total weight of yeast in the recipe, [kg]
m_S – total weight of salt in the recipe, [kg]
m_I – total weight of finishing materials in the recipe, [kg]

CHAPTER 4

σ, τ – tension, [Pa]
ε, γ – strain, [mm]
$\dot{\varepsilon}, \dot{\gamma}$ – deformation speed, [s^{-1}]
E – longitudinal modulus of elasticity, [MPa]
G – transverse modulus of elasticity, [$N/m^2 \cdot s$]
η – viscosity, [Pa·s]

CHAPTER 5

h_1 – thickness of the sheeting dough, [m]
v – peripheral sheeting speed, [m/s]
u – dough moisture, [%]
p – dough pressure at sheeting, [DaN]

CHAPTER 6

$P_{h\,1-2}$ – hydraulic losses between points 1 and 2, [%]
L_0 - length of the wick before breaking, [m]
A_0 – the initial area of the wick section, [m^2]
σ_{al} – dough resistance to stretching, [Pa]

CHAPTER 1 - TECHNOLOGICAL MANUFACTURING PROCESS OF BAKERY PRODUCTS WITH HARD TEXTURE

1.1. GENERAL ASPECTS REGARDING THE BAKING PROCESS

1.1.1. Generalities. Pretzels: Classification, characteristics, recipes

Pretzels are food products, ring-shaped, with a dense texture and easy to chew, being prepared from various types of flour and boiled before being baked, boiling being done to result in finished products with a brown and glossy shell. Before baking, the pretzel is sprinkled with various salty or sweet spices, [8, 194].

Pretzels can be produced with different flavors, shapes, and sizes, resulting in a wide variety of assortments: salt pretzels, simple pretzels, beer pretzels, vanilla pretzels, cheese pretzels, dessert pretzels, syrupy pretzels, etc.

1.1.2. The production process stages of hard-textured pretzels and bakery products

Obtaining the pretzel dough is done by adding the main ingredients (flour, water, salt, and yeast) to the kneader bowl and mix them. In obtaining pretzels, the fermentation step may be missing, as this can lead to a problematic shaping of the dough wick. Modeling pretzels in different shapes is done using automatic or manual machines, [8,183]. Boiling is done in boiling vessels or fryers, and it is recommended that the water temperature is below boiling point; thus, energy wasted is avoided, [8]. Baking the dough pieces is the last step and is done in tunnel ovens, at temperatures between 230 - 290 °C, for 4 - 12 minutes. Baking is done without steam because the outer surface of the pretzels is already gelatinized when boiled. Cooling pretzels is a mandatory operation because it is impossible to pack if their temperature does not reach ambient temperature. Pretzels should be stored and stored in a clean, dry place, away from moisture and foreign odors.

1.2. OBTAINING AND PROCESSING THE BAKERY DOUGH

1.2.1. The role and importance of operations

The main purpose of kneading is to obtain a homogeneous mixture of raw and auxiliary materials. During kneading, the dough is subjected to uni- and biaxial deformations, and from a rheological point of view, it has a viscoelastic behavior, , [118].

After the kneading operation, the dough is subjected to the dividing operation into approximately constant mass pieces, which are modeled into different shapes to uniformly develop the product during baking and give it a uniform structure by eliminating gaps, [117, 143].

After shaping, the dough wicks are passed to the boiling operation. The boiling operation is done to gelatinize the starch on the pretzel's surface to give it its specific luster and maintain its shape during baking, [8].

Baking is done in order to transform the dough into a core and form a brown crust. During the baking process, there are also increased volume, starch gelling, yeast inactivation, and the Mayllard reaction. An essential role in this stage is the baking time and temperature, [40, 64].

1.2.2. Material balances within the technological flow

The dough is a moist and homogeneous mass developed after mechanical mixing of wheat flour, water and other ingredients.

$$m_F + m_A + m_D + m_S + m_{MI} = m_{Al} + P \quad (1.1)$$

where: m_F total mass of flour; m_A total mass of water; m_D total mass of yeast; m_S total mass of salt; m_I total mass of added finishing materials; m_{Al} total mass of dough; P losses due to mechanical losses or moisture loss or dry matter, [143].

1.2.3. Description of the technological process and pretzels manufacturing operations

At the beginning of the kneading process, the order in which the ingredients are added to the mixer bowl must be taken into account because the flour's hydration depends on it, but especially on the protein in the flour, [25]. The time required for the dough development is between 2 and 25 minutes, [143].With the continuation of kneading, the dough structure can change, becoming soft, less elastic, very extensible and sticky, [143].

Dividing the dough into pieces can be done either by cutting a dough strip into equal pieces or cutting a dough cylinder, or compressing it into a closed volume, [143].

The dough piece obtained by division is shaped in the first phase in the form of a sphere; subsequently, this sphere is elongated with the help of the palms until it is transformed into a wick (string) of suitable diameter and length so that it can be braided in the shape of a pretzel.

The dough pieces' boiling is done to obtain finished products with a glossy surface and specific color.

After placing the dough pieces in the oven baking chamber, they begin to increase in volume due to the carbon dioxide resulting from fermentation, and the water from the composition of the dough evaporates, [143].

1.2.4. Indicators for assessing the operations and the finished product

The assessment of the kneading end is done with the help of consistometers or sensory. The dough should be homogeneous, consistent, elastic, and easily detached from the kneader's arm and bowl [140, 141, 143].

The assessment of the end of fermentation is established organoleptically, based on the volume change and by determining the acidity [143].

In the division operation, the dough pieces' weight is as accurate as possible, and when determining their weight, the losses that occur during baking are also taken into consideration, [94].

The modeling is done to obtain dough pieces with a smooth surface and a correctly made wrist, [94].

Floating the dough pieces on the surface of the sugar solution is the end of the boiling process. The end of the baking process is done organoleptically. The shell must be brown and the core elastic and determine the core temperature. The core temperature must be in the range of 93-97 °C.

The resulting pretzels must fulfill the assessment indicators' admissibility conditions and the physical and chemical characteristics specific to the pretzels.

1.3. CONCLUSIONS

The pretzels and pastries manufacturing process includes kneading, division, modeling, boiling, baking, interdependent, and forming a whole technological flow.

The quality of the finished products is determined by the balance of the raw materials, working parameters, and equipment on the technological flow, so it is recommended that the entire technological process be monitored and controlled from start to finish.

CHAPTER 2 - PHYSICO-MECHANICAL AND TECHNOLOGICAL PROPERTIES OF THE RAW MATERIALS USED IN THE PRETZELS PRODUCTION

2.1. PHYSICO-MECHANICAL AND TECHNOLOGICAL PROPERTIES OF THE FLOUR

Different varieties of flour are used in the bakery industry, and their quality is established primarily by the sensory, physical, chemical, and rheological properties, [94, 143].

The doctoral thesis presents flour properties, such as color, smell, taste, acidity, moisture, fineness, carbohydrates, protein substances, fatty substances, vitamins and enzymes, hydration capacity, quantity and quality of gluten, ability to form and to retain the fermentation gases.

2.2. PHYSICO-CHEMICAL PROPERTIES OF THE WATER

Water is used to prepare the baking dough to hydrate the flour particles and form the dough. The absence of water in the technological baking process leads to the impossibility of obtaining the dough. Drinking water must fulfill the conditions of admissibility for temperature, hardness, color, taste, smell, Etc.

2.3. PHYSICO-CHEMICAL PROPERTIES OF THE BAKERY YEAST

In the technological process of baking, compressed or liquid yeast can be used. The yeast must fulfill the admissibility conditions from an organoleptic perspective, humidity, to be used in the baking process.

2.4. PHYSICO-CHEMICAL PROPERTIES OF THE SALT

The salt used for the bakery products manufacturing is used in a ground state or salt solution and has the role of flavoring bakery products, improving the dough's qualities by increasing the forming time and reducing the softening time the dough, [9, 94]. The salt used must fulfill the admissibility conditions from an organoleptic perspective, sodium chloride content and granulation, [9, 142].

2.5. PHYSICO-CHEMICAL PROPERTIES OF OTHER INGREDIENTS

In addition to the raw ingredients used in the preparation of doughs, auxiliary materials are also used to improve the taste and increase its nutritional value, [9]. Sugars and fats are part of the auxiliary materials for the preparation of pretzel dough.

The quality of sugars and fats is checked according to the organoleptic properties, which must fulfill the admissibility conditions.

2.6. GENERAL PROPERTIES OF BAKERY DOUGHS

The consistency of the dough results from the combination of viscosity, plasticity and elasticity. They depend on the moisture of the dough, the temperature and the biochemical composition of the flour and the materials added for the preparation of the dough.

By adding water over the amount of flour and mixing them, the process of formation and development of the glute takes place, and with the kneading it intensifies. Gluten is a protein network found in all wheat flour-based products. Even if the flour is hydrated quickly after the addition of water, gluten needs more time to develop, and the network formed has two properties: elasticity and extensibility, [56].

The amounts of air introduced into the dough during kneading indicate the density of the dough, and the higher the lipid content of the flour, the higher the amount of air introduced into the dough [36, 114].

2.7. CONCLUSIONS

Ingredients from the recipe for obtaining bakery and pastry products can more or less influence the doughs' rheological properties and their behavior in the stages of the manufacture technological flow. To be able to be used in the baking process, they must meet the admissibility conditions.

CHAPTER 3 - CONSTRUCTIVE SOLUTIONS OF TECHNOLOGICAL LINES FOR HARD-TEXTURED BAKERY PRODUCTS MANUFACTURING

This chapter presents a series of equipment used in the manufacture of pretzels. These include: kneaders, molding machines, kettles and ovens.

3.1. CONSTRUCTIVE SOLUTIONS OF KNEADERS

The kneading of various models must ensure optimal kneading of the dough, even if these machines are differentiated by: the geometry of the kneading arms and the bowl, the working capacity, the variation in the number of rotations of the kneading arm and, where appropriate, the bowl.

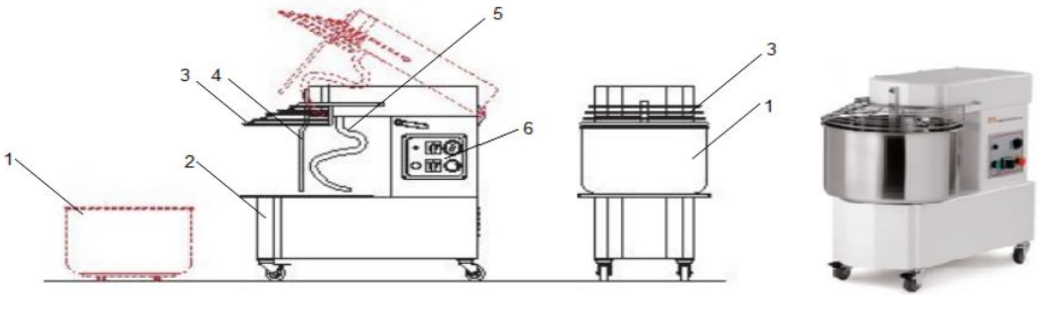


Fig. 3.1. Vertical kneader, model MCS-IM25DS, [201]

1. bowl; 2. housing; 3. protection grid; 4.rod; 5. spiral arm; 6. control panel

Fig. 3.2. Kneader Salva with fork arm, [195, 197]

1. bowl; 2. fork arm; 3. protective cap, 4, 5. transmission; 6. electric motor; 7. control panel

3.2. CONSTRUCTIVE SOLUTIONS OF MODELING MACHINES

The pretzel dough modeling can be done either manually or with the help of machines intended to process the dough in the form of a wick, ring or pretzel.

The most advantageous machine for modeling pretzel dough is the pretzel maker model CO.FO 63/47. Its use does not require an operator's additional presence to catch the ends of the dough wicks after drawing.

The outer diameter of the resulting pretzel is 63 mm, and the inner one is 47 mm. Both external and internal dimensions can be adjusted by +/- 4 mm. The weight of the pretzels can vary from 4 g to 80 g. The productivity of the machine is between 35 and 50 and depending on the diameter buc./min pretzels.

Fig.3.3. Pretzel shaper, model CO.FO 63/47, [192]

1. frame; 2. electric motor; 3. conveyor belt; 4. fixed plate; 5. divisor; 6. control panel; 7. steel tube

3.3. CONSTRUCTIVE SOLUTIONS OF KETTLE

The characteristic taste of pretzels, the color, and luster of the shell, is obtained by boiling the dough wicks in a sugar solution in water or sodium hydroxide (NaOH) in water. The boiling operation is done before inserting the pretzels into the oven's baking chamber, [200].

The kettle with the most significant advantage in terms of operation, continuous or discontinuous, is the pretzel kettle with the constant function. The boiling procedure can be performed without the close supervision of the process. The advantage that the other constructive types of kettle do not have is that the introduction and removal of the pretzels after they have risen to the water's surface is done manually. Thus, the process must be followed closely.

Fig. 3.4. Pretzel kettle - continuous, [11]

1. housing; 2. conveyor belt; 3. additional conveyor belt; 4. cover; 5. control panel

3.4. CONSTRUCTIVE SOLUTIONS OF OVENS FOR PRETZELS BAKING

Pretzels sell best when they are warm, and for this reason, baking ovens have been made that have the possibility of programming so that the heating of the baking chamber starts 40 minutes before the start of the work program, [187].

Many manufacturers offer constructive solutions and improvement of ovens by the possibility of thawing and fast baking of doughs using infrared technology, the use of granite conveyor belts on which the product is placed directly, offering the benefit of penetrating the temperature from the bottom up, so that the heat transfer is done in bulk, and the dough can be baked in depth.

Fig. 3.6. Pretzel oven with infrared, [211]

1. digital control panel; 2. shaft; 3. conveyor belt; 4. system for adding seeds; 5. seed tank; 6. insulated housing

Fig. 3.5. Tunnel oven PICARD’S LP-200, [190]

1. stainless steel hood; 2. control panel; 3. stainless steel isolated door adjustable in height; 4. stainless steel panelling; 5. two direct-fired burners with slotted stainless steel covers; 6. electric motor; 7. mechanical access door; 8. Electrical push buttons to run granite stone conveyor belt when the safety top cover is removed; 9. Emergency electrical red button to stop the granite stone conveyor belt; 10. heavy duty stainless steel legs adjustable in height; 11. Stainless steel sliding crumb pan; 12. Removable stainless steel panels for cleaning;13. Stainless steel hinged doors for oiling main drive chain; 14. granite stone conveyor belt; 15. Steel conveyor belt; 16. stainless steel sliding crumb pan; 17. removable stainless steel panel for cleaning; 18. stainless steel insulated door adjustable in height to save on heat; 19. space for storage

3.5. CONCLUSIONS

The finished product's qualities dictate machines' choice on the technological flow of manufacturing hard-textured bakery products.

The dough's quality obtained with the help of the kneaders is of particular importance for the bakery technology. For this reason, the emphasis is constantly on improving the equipment from a constructive point of view by the installation of speed controllers of the kneading arm, installation of cooling systems of the kneading chamber, construction of the kneading arm so as not to heat the dough during kneading.

The current trend is to improve the dough modeling process by producing fully automated installations without requiring an employee to catch the ends of the wicks.

The use of a continuously operating boiling can prevent the pretzels from being removed from the kettle before gelling the starch on the surface of the pretzel is completed, thus avoiding the preparation of pretzels with a matte surface.

The variety of ovens that meet the requirements for baking pretzels must also satisfy the possibility of storing baking programs, as it is desired to maintain a constant quality of the finished product.

CHAPTER 4 - SYNTHESIS OF THEORETICAL AND EXPERIMENTAL RESEARCH REGARDING THE TECHNOLOGICAL PROCESS OF PRETZELS MANUFACTURING

In recent years, significant progress has been made in automating pretzel production using high-speed mixers, pretzel dough cutting systems, automatic pretzel forming machines, and fully automated pretzel ovens. Several patents have been granted for new methods of making hard pretzels, including processing methods. Despite these advances in production technology, little research has been done to understand the process variables that influence pretzel quality, [156].

4.1 RESEARCH ON THE RHEOLOGICAL CHARACTERISTICS OF DOUGHS

Rheology can be defined as the study of how materials deform, flow, or fail when a force is applied [4,52].

For processed foods, the composition and addition of ingredients to achieve a particular food and product quality performance require a deep understanding of ingredients' rheology [4, 50].

Dough refers to a moist mass-developed after mixing wheat flour with water and other ingredients, and rheological properties of his, respectively structural mechanical properties, are the elasticity, viscosity, plasticity, and relaxation time. Their knowledge is essential because the product's volume and finite shape, the shell's elasticity, and the core depend on them, [79, 98].

4.1.1. General elements of dough rheology. Rheological quantities

The main rheological measurements mentioned in the thesis are: stress (σ, τ), deformation (ε, γ), deformation speed ($\dot{\varepsilon}, \dot{\gamma}$), elasticity, viscosity, relaxation, relaxation time, creep.

4.1.2. Rheological models

The simplest rheological model is a spring (Hooke's solid) and a dashpot (Newton's liquid), which can be mounted in series or in parallel. By mounting the spring and the dashpot in series, the Maxwell model is obtained, which is characteristic of liquids, and by mounting in parallel, the Kelvin - Voight model is obtained, characteristic of solids, [34, 57].

- ***Hooke rheological model***

If a force is applied to an ideal solid material, it will respond instantly by a deformation proportional to the force applied. Deformation disappears, and the body returns to its original shape when the effort disappears. This behavior is described by an elastic spring, [57, 128, 176].

$$\tau = G \cdot \gamma \tag{4.1}$$

where: σ - longitudinal tension; τ - transverse tension; γ - strain; E - longitudinal modulus of elasticity; G - transverse modulus of elasticity.

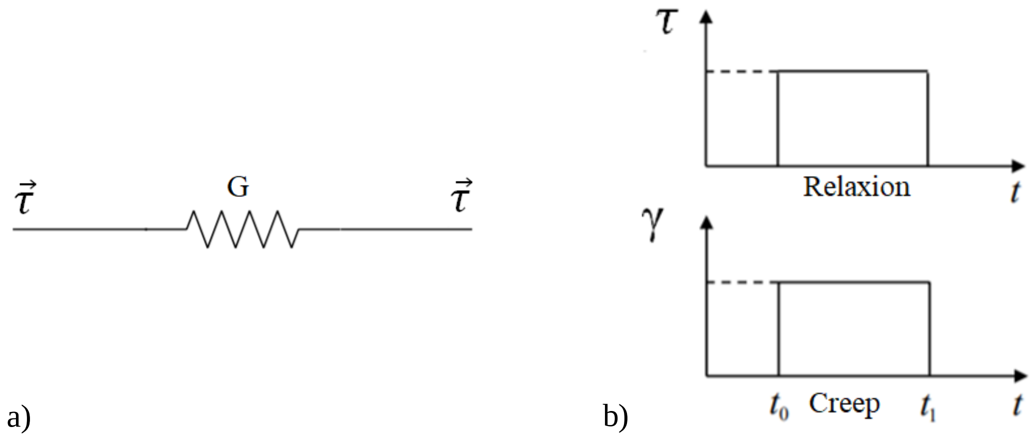


Fig.4.1. a) the model; b) stress and relaxation curves for the ideal solid, [57, 176]

❖ *Newton's rheological model*

An ideal fluid is deformed continuously from the moment the effort is applied. When the effort is removed, the deformation remains constant, and the material does not return to its original shape. Newton's law is the relationship between effort and deformation speed. This behavior is described by an ideal dashpot, [57, 128, 176].

$$\tau = \eta \cdot \dot{\gamma} = \eta \frac{d\gamma}{dt} \tag{4.2}$$

unde: τ represents the shear stress directly proportional to the deformation speed $\dot{\gamma}$; η represents the dynamic viscosity coefficient;

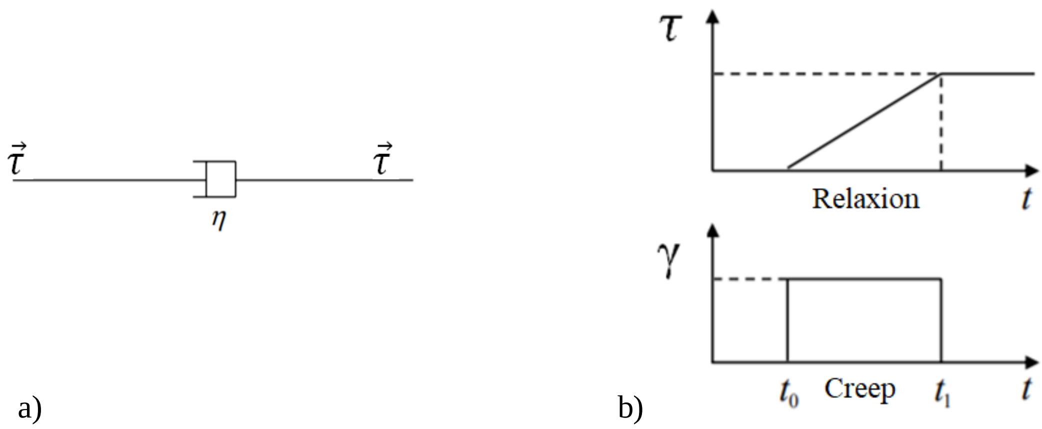


Fig.4.2. a) the model; b) stress and relaxation curves for Newtonian fluid, [57, 176]

❖ *Maxwell viscoelastic liquid model*

The Maxwell model contains a Hook spring and a Newtonian dashpot coupled in series. The model allows the interpretation of stress relaxation curves for both viscoelastic fluids and polymeric fluids, [34]. The effort is the same for both the spring and the dashpot, while the total deformation is the sum of the partial deformations specific to the spring and the dashpot, according to the equations, [36, 41, 57, 93 ,128]:

$$\gamma = \gamma_e + \gamma_v \tag{4.3}$$

$$\tau = \tau_e = \tau_v \tag{4.4}$$

where: γ_e , γ_v represents the elastic deformation, respectively viscous deformation; τ_e, τ_v, represents the effort applied to the spring, respectively to the dashpot.

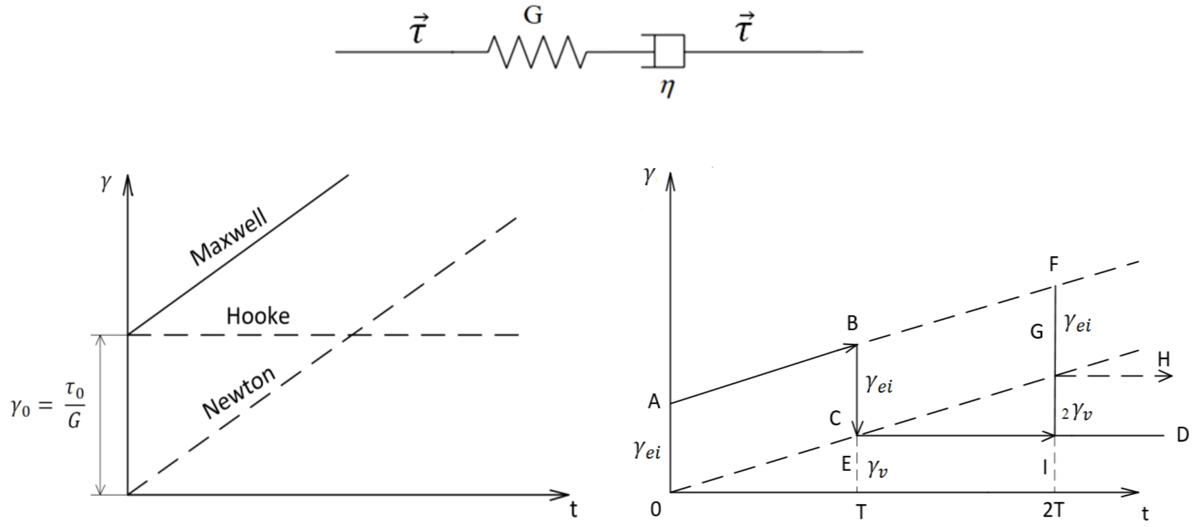


Fig.4.3. Maxwell model, [36, 57]

❖ ***Kelvin - Voigt solid viscoelastic model***

The Kelvin - Voigt model describes the behavior of a vascoelastic body through the mechanical model formed by the parallel mounting of a deshpot and a spring, [34]. The deformation is the same for both the spring and the shock absorber, while the total effort is the sum of the partial stresses applied to the spring and the dashpot, according to the equations, [34, 36, 57, 93]:

$$\gamma = \gamma_e + \gamma_v \quad (4.5)$$

$$\tau = \tau_e + \tau_v \quad (4.6)$$

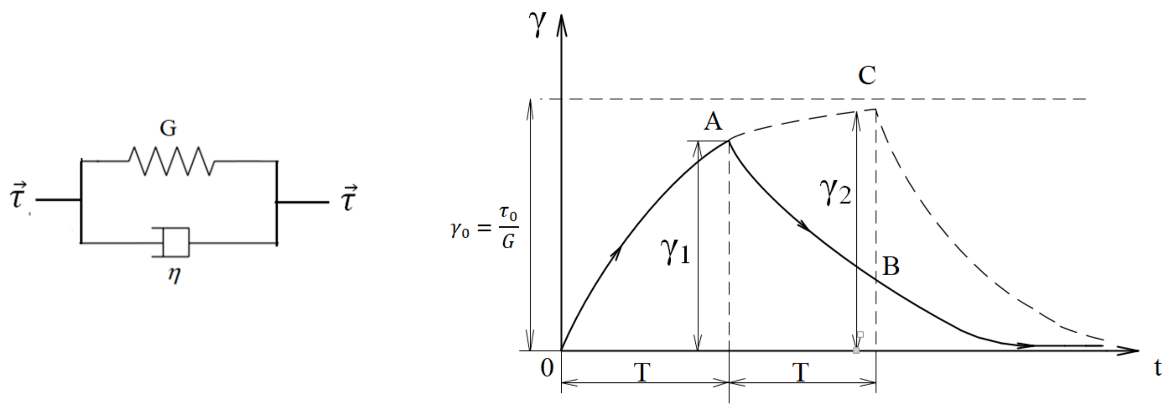


Fig.4.4. The Kelvin - Voigt model, [36, 57]

❖ ***Burgers model***

The Burgers model is used to represent only a part of the rheological properties of doughs. The model is obtained by serial mounting of a Maxwell model and a Kelvin Voigt model, [34].

$$\gamma = \gamma' = \gamma'' \quad (4.7)$$

$$\tau = \tau' + \tau'' \tag{4.8}$$

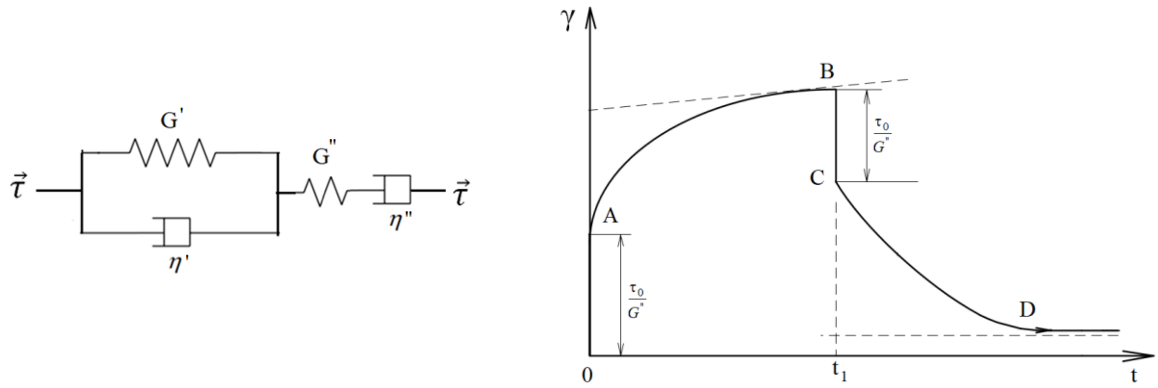


Fig.4.5. Burgers model, [36, 93, 128]

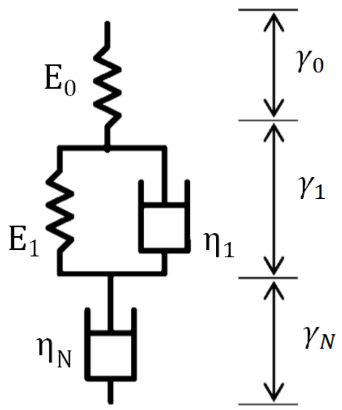


Fig.4.6. Burgers model with four-element, [36, 63]]

In the Burgers rheological model, E_0 represents instantaneous elasticity, and E_1 delayed elasticity, η_1 represents the viscosity delay coefficient, and η_N normal viscosity coefficient, [36, 63].

A theoretical solution for the relaxation tension is derived from the Burgers model, when it is assumed that the cross section of the dough and the compression speed are constant over time:

$$\sigma = (E_1 - \eta_1\lambda_1)A_1 e^{-\lambda_1 t} + (E_1 - \eta_1\lambda_2)A_2 e^{-\lambda_2 t}, \tag{4.9}$$

where:

$$A_1 \frac{\left(\sigma_{t_2} - \sigma_{t_1} e^{-\lambda_2 t_2}\right)}{(E_1 - \eta_1\lambda_1)(e^{-\lambda_1 t_2} - e^{-\lambda_2 t_2})}; \tag{4.10}$$

$$A_2 \frac{\left(\sigma_{t_2} - \sigma_{t_1} e^{-\lambda_1 t_2}\right)}{(E_1 - \eta_1\lambda_2)(e^{-\lambda_2 t_2} - e^{-\lambda_1 t_2})}, \tag{4.11}$$

where: σ_{t1}, σ_{t2} represents the strain value at $t = t_1$, respectively la $t = t_2$; λ_1, λ_2 represents the roots of the equation, [36, 63]:

$$\frac{\eta_1}{E_0}\lambda^2 - \frac{E_0\eta_1 + E_0\eta_N + E_1\eta_N}{E_0\eta_N}\lambda + \frac{E_1}{\eta} = 0 \tag{4.12}$$

❖ ***Lethersich model***

The Lethersich model is formed by inserting a Kelvin - Voigt model and a dashpot. This model describes the purely viscous flow and delayed elasticity, [34, 36].

$$\sigma = G\gamma_{el} + \eta_K\dot{\gamma_{el}} = \eta\dot{\gamma_v} \qquad (4.13)$$

where: γ_{el} , γ_v, represents the elastic deformation, respectively plastic deformation (irreversible); η, η_K represents the viscosity for γ_{el}, respectively γ_v.

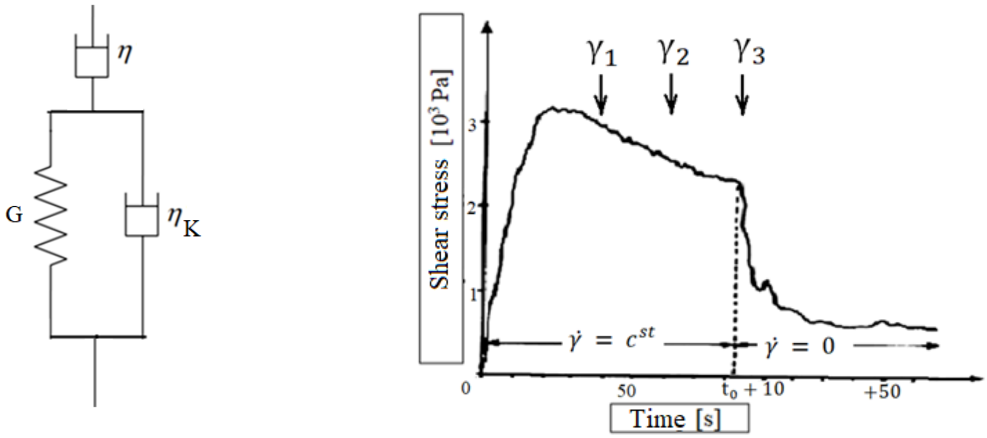


Fig.4.7. Lethersich model, [34]]

4.1.3. Factors influencing the rheological properties of doughs

According to studies by Sission M. (2008), [123] și Amjid M.R. și colb. (2013), [5], researchers are focusing on the composition of raw materials and how they affect the characteristics of dough and the quality of the final product. There are a wide variety of ingredients added to the dough mixture that could generally be classified as processing aids or that can have side effects for dough rheology.

a) The influence of the quality and quantity of flour

High protein flours tend to produce hard and hard textured pretzels, and low protein flours cause problems with rolling machines and create a weaker shape and size of the product.

Increasing the glutenin/gliadin ratio improves maximum shear viscosity and dough resistance.

Rye flour mixed with white wheat flour negatively influences the dough's farinographic characteristics, decreasing the development time and the stability time.

Small and large amounts of flour require longer mixing times than an average quantity of flour relative to the dough vat volume.

b) The influence of water addition and its quality

A more considerable amount of water entering the process leads to a decrease in kneading time and the amount of mechanical energy consumed in the dough's production. Simultaneously, increasing the amount of water increased the dough's viscosity and elasticity because the increase corresponds to the maximum swelling of the proteins.

The water's hardness affects the kneading power of the flour and the total energy consumption; the kneading time is greatly extended if the water's hardness increases.

c) The influence of the amount of salt

Salt or sodium chloride are widely used and can be considered a crucial ingredient because, without the addition of salt, most dishes or foods can have less flavor, become tasteless, and are not appetizing, [108].

The salt improves the rheological parameters for the low protein flour by hardening the dough, making the operations to be carried out in better conditions.

d) The influence of sugar and sugar substitutes on rheological properties

In the dough composition, small amounts of sugar are allowed (up to 3%) because they negatively influence the rheological properties of the doughs; instead, they can facilitate the start of the yeast activity.

e) The influence of the type of kneader on the rheological properties

Studies show that both models of kneading and kneading speed can affect the rheological properties of dough and physical properties of finished products.

f) The influence of boiling pretzel dough on its properties

The paper [157], analyzed the boiling solution's study on pretzels' physical properties, and the results showed that pretzels boiled in water have a higher mass compared to those boiled in alkaline solution. Although the boiling temperature with alkaline solution did not influence the color of the pretzels' surface, it greatly affected the handling properties of the dough through its effects on starch and proteins.

4.2 RESEARCH ON ENERGY CONSUMPTION IN THE PRETZELS MANUFACTURING

The energy consumed by kneading, (E), can be calculated starting from the power required for kneading the dough or the torque from the kneader shaft, which can be obtained as a curve M = f (t) (Figure 4.8), when it is measured during kneading:

$$E = P_m \times t_f = M_m \frac{\pi \times n}{30} t_f \text{ , (J)} \qquad (4.14)$$

where: n = constant for a constant speed.

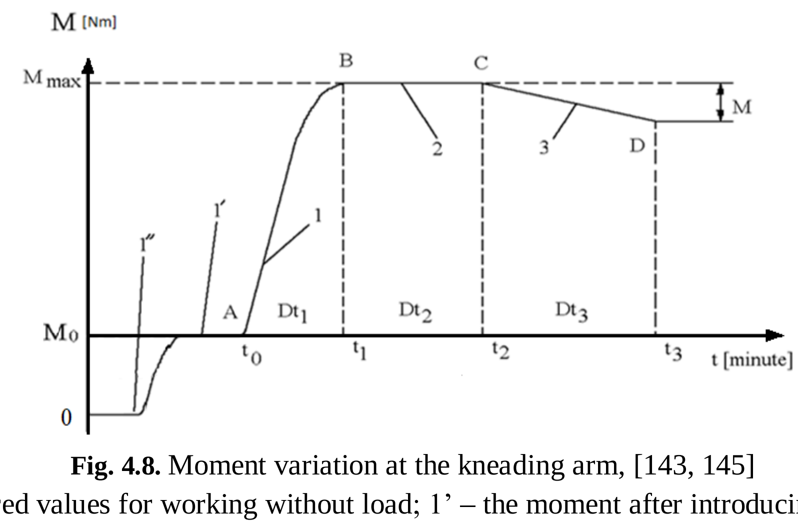


Fig. 4.8. Moment variation at the kneading arm, [143, 145]

1”– the registered values for working without load; 1’ – the moment after introducing the flour in the vat; AB – variation of the moment during the hydration of the flour, after the addition of water in the kneader bowl; BC – the moment during the dough kneading process; CD – softening phase when prolonged the kneading; Dt_1 – time for dough forming; Dt_2 – stability time; Dt_3 – softening period

The specific energy of the kneading (ε_{sp}), is determined by the ratio between the energy consumed and the weight of the kneaded dough:

$$\varepsilon_{sp} = \frac{E}{M_{al}}, \text{(Wh/kg)} \tag{4.15}$$

where: M_{al} – the weight of the dough.

In the literature, [145], the specific energy for kneading the dough is between 10-50 J/g, to point B of the diagram (Figure 4.8). It is assessed that, in practice, the kneading has ended when the dough is completely formed.

4.3. RESEARCH ON THE MODELING AND SIMULATION USE IN THE TECHNOLOGICAL PROCESS OF PRETZELS MANUFACTURING

4.3.1. The use of modeling and simulation in the technological process of kneading

Hosseinali Pour S. M., (2013) et al., [54], proposed *the Bird Carreau* model to describe the rheological behavior of wheat flour dough when kneading::

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty)(1 + \alpha^2\dot{\gamma}^2)^{(n-1)/2} \tag{4.16}$$

where: $\dot{\gamma}$ - is the shear rate and the values of the parameters for the infinite shear viscosity η_∞; η_0 - zero shear viscosity; α – material coefficient constant in time; n - flow behaviour index.

The purpose of the study of the authors Lunchian M.I et al., (2013), [80], was to develop advanced technology to shape bread dough kneading and provide a predictive capacity of optimal dough kneading parameters using computational techniques. The study results showed that intensive kneading of the dough takes place only within the radius of the kneading arm; the rest of the dough is set in motion by the rotation of the bowl. The highest kinetic energy values were observed in areas adjacent to the kneading arm's surface, the opposite spiral, and the walls of the bowl, [80].

4.3.2. The use of modeling and simulation in the technological process of baking

David A. P. et al. (2011), [39], followed a mathematical model to describe the evolution of temperature during the baking of bread and pastries and how this evolution affects the main qualitative characteristics of the finished product, such as the color of the shell, heating to a temperature of the product and weight loss.

$$x_i = p_{ts}T_s + p_{tl}T_1 + p_{ti}T_i \tag{4.17}$$

where: x_i represents the temperature in four baking areas of the oven; p_{ts} is the temperature of the higher part ; p_{tl} – the temperature of the sidewalls; p_{ti} - the temperature of the bottom; T_s - the temperature at the top; T_1 - side temperature; T_i - the temperature at the bottom of the oven.

Abraham J. P. et al. (2004), [2], developed a completely predictive, algebraic method for predicting the temperature variation at a given time of a thermal load located in an electrically heated oven. The model underlying the process considers both the natural convection inside the stove's baking chamber and the radiation between the thermal load and the oven walls. The model provides a complete description of the external heat transfer at thermal load. The first law of thermodynamics gives the starting point of the model development:

$$m c_p \frac{\mathrm{d}T_{LOAD}}{\mathrm{d}t} = \dot{Q} \tag{4.18}$$

where: m and c_p are the mass and specific heat of the thermal load.

A three-dimensional CFD model was developed by the authors Ciarmiello M. et al. (2016), for an electric oven for baking Neapolitan pizza, by simulating the heat transfer mechanism. This study is considered a basis for further research on furnace temperature control, as the power source can be more easily managed by automated control devices, [32].

4.4. CONCLUSIONS

The choice of a physical model for describing the rheological behavior of doughs must be made in correlation with the technological phase of laminar processing, wiring, modeling, and its components.

There is a wide variety of ingredients added to the dough mixture and could be generally classified as processing aids or which may have side effects for the dough's rheology (salt, fat, sugars).

By measuring the torque at the kneader shaft, the power required for kneading the dough can be calculated, respectively, the energy consumption for kneading.

CHAPTER 5 - THEORETICAL ASPECTS AND CONTRIBUTIONS

5.1. MATHEMATICAL MODELING OF THE DOUGH SHEETING PROCESS

The theory of dimensional analysis was applied to the theory Π, stated by Buckingham, [127], to determine a link between the sheeting process parameters. Sheeting dough pieces and other bakery products is an essential operation of the modeling process, through which dough thins and turns on the dough sheet. Sheeting is carried out, usually using a pair of sheeting rolls with rotation motion. Among others, the characteristics of the finished product depend on the way the operation is performed. These pull the dough piece between them, bringing it at a thickness given by the distance between them, in the form of a sheet approximately elliptical, asymmetric, [144].

From the theoretical and experimental researches of the sheeting process, a number of 7 main parameters that influence the sheeting process, were identified for the study: sheeting energy, E ($kg\cdot m^2/s^{-2}$); dough pressure at sheeting, p ($kg/m\cdot s^2$); the circumferential speed at sheeting, v (m/s); he weight of the dough subjected to sheeting, m (kg); dough density, ρ (kg/m^3); dough thickness, h_1 (m); dough moisture, u (%).

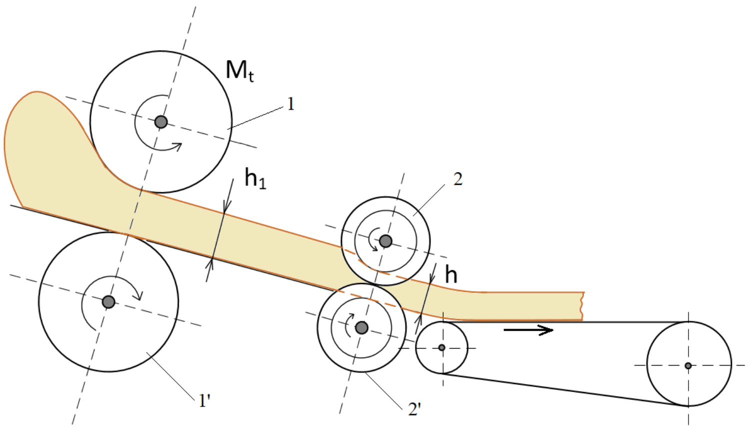


Fig. 5.1. Sheeting and drawing dough for pretzels
1,1'. sheeting rolls, 2,2'. drawing rollers

The lamination process is dimensionally described by the default function $f(p_i) = 0$, where all terms in relation to the fundamental quantities in SI (L, M, T) are homogeneous dimensions:

$$f(E, p, v, m, \rho, h_1, u) = 0 \tag{5.1}$$

The group is considered to determine sizes (*E*, *p*, *v*), based on the theorem Π, and dimensionless complexes (similarity criteria) of the sheeting process. Dimensional size u is entered directly into the criterion equation without being taken into account in the development of dimensionless complexes. For the physical quantities *E*, and h_1, corresponding dimensionless complexes will be elaborated:

$$\Pi_1 = \frac{m}{E^{x_1} \cdot p^{x_2} \cdot v^{x_3}} \quad , \quad \Pi_2 = \frac{\rho}{E^{x_1'} \cdot p^{x_2'} \cdot v^{x_3'}} \quad \text{și} \quad \Pi_3 = \frac{h_1}{E^{x_1''} \cdot p^{x_2''} \cdot v^{x_3''}} \tag{5.2}$$

in which the exponents x_1, x_2, x_3, x_1', x_2', x_3' și x_1'', x_2'', x_3'' can be determined from the conditions that Π_1, Π_2 and Π_3 are dimensionless, in relation to the fundamental quantities *L* (length), *M* (mass), *T* (time).

Write in the dimensional matrix the 6 quantities, which appear in relation, in relation to the fundamental quantities L, M and T:

	x_1	x_2	x_3			
	E	p	v	m	ρ	h_1
L	2	-1	1	0	-3	1
M	1	1	0	1	1	0
T	-2	-2	-1	0	0	0

The condition is that Π_1, Π_2, Π_3 be dimensionless in turn, in relation to the three fundamental quantities L, M, T, and systems of linear equations are obtained from the matrix and by solving them values were obtained for x_1, x_2, x_3, x_1', x_2', x_3' și x_1'', x_2'', x_3'', and the expressions of the complexes adminesionali are:

$$\Pi_1 = \frac{m \cdot v^2}{E} \qquad \Pi_2 = \frac{\rho \cdot v^2}{p} \qquad \Pi_3 = \frac{h_1 \cdot p^{1/3}}{E^{1/3}} \tag{5.3}$$

With the help of dimensionless quantities, it was possible to write the criterion equation in the implicit form:

$$\varphi\left(\frac{m\cdot v^2}{E},\frac{\rho\cdot v^2}{p},\frac{h_1\cdot p^{1/3}}{E^{1/3}},u\right)=0 \qquad (5.4)$$

To determine the expression of energy consumption in the sheeting, the term E was separated from the criterion equation:

$$\Pi_1 = f(\Pi_2, \Pi_3, \Pi_4) \qquad (5.5)$$

For a first approximation was proposed mathematical model of the product of others powers dimensionless quantities:

$$\frac{m\cdot v^2}{E} = k\cdot\left(\frac{\rho\cdot v^2}{p}\right)^{\alpha}\cdot\left(\frac{h_1\cdot p^{1/3}}{E^{1/3}}\right)^{\beta}\cdot u^{\xi} \qquad (5.6)$$

where: k, α, β, ξ are constant coefficients, respectively exponents that can be calculated by linear regression based on experimental data.

By performing the calculation was obtained:

$$E = k_1\cdot\rho^{\frac{\alpha}{1+\frac{\beta}{3}}}\cdot p^{\left(\frac{\beta}{3}-\alpha\right)\cdot\frac{1}{1+\frac{\beta}{3}}}\cdot v^{\frac{2\alpha-2}{1+\frac{\beta}{3}}}\cdot h^{\frac{\beta}{1+\frac{\beta}{3}}}\cdot u^{\frac{\xi}{1+\frac{\beta}{3}}}\cdot m^{-\frac{1}{1+\frac{\beta}{3}}} \qquad (5.7)$$

Noting:

$$a=\frac{\alpha}{1+\frac{\beta}{3}}\ ;b=\frac{\frac{\beta}{3}-\alpha}{1+\frac{\beta}{3}}\ ;c=\frac{2\alpha-2}{1+\frac{\beta}{3}}\ ;d=\frac{\beta}{1+\frac{\beta}{3}}\ ;e=\frac{\xi}{1+\frac{\beta}{3}}\ ;f=\frac{\xi}{1+\frac{\beta}{3}} \qquad (5.8)$$

It is obtained:

$$E = k_1\cdot\rho^a\cdot p^b\cdot v^c\cdot h^d\cdot u^e\cdot m^f \qquad (5.9)$$

The relationship can only be solved by giving values to some parameters and keeping only two variables, so that groups of variables can be obtained $E = f(\rho,l)$ or $E = f(h,\rho,)$ and graphs:

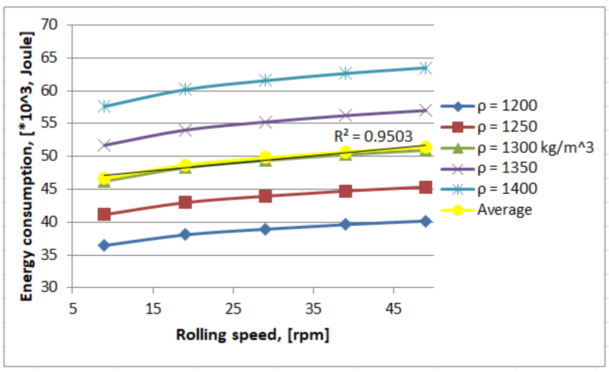


Fig. 5.2. Variation of energy consumption for five values of dough density depending on the speed of the sheeting roll

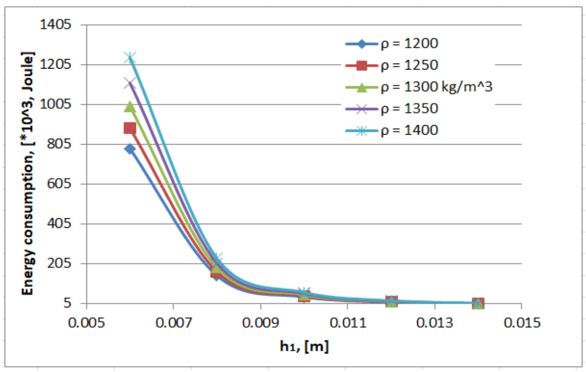


Fig. 5.3. Variation of energy consumption for five values of dough density depending on the thickness of the dough when sheeting

5.2. THE USE OF SIMULATION IN THE PRETZELS MANUFACTURING PROCESS

5.2.1. The use of simulation in the process of drawing pretzels dough

The purpose of this finite element 3D numerical simulation study was to simulate the behavior of the structure of a profiled tumbler of a GR 15 MINI dough modeling machine, manufactured by Italpan, Italy, used in pretzel modeling, [206].

In the first stage of this study, the simplified three-dimensional geometric model of a profiled tumbler and the simplified frame of the modeling machine were made. The 3D modeling was performed using the parameterized design program Solid Works Premium 2016 S.P. 0.0.

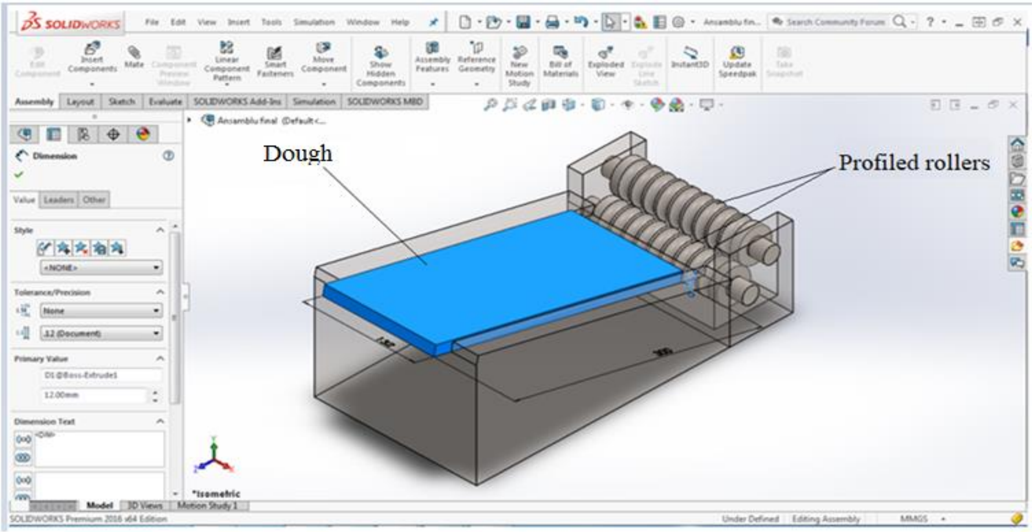


Fig. 5.4. The assembly and the interface software used

Before performing the actual dynamic simulation, each component of the assembly was assigned the material characteristics.

The dynamic simulation resulted in the profiled rollers' stress values, 2328 N for the maximum reaction force in the right bearing, and 2323 N for the maximum reaction force in the left approach. Also, the graph of the variation curve of the power required for drawing was obtained, and the maximum value was 51 W, well above the value of 144 W specified in the technical book of the drawing machine.

A finite element analysis of the profiled roller was also performed, resulting in the requests to which the profiled roller is subjected, together with their numeric values.

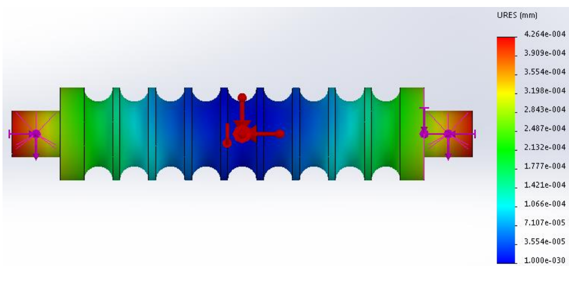


Fig. 5.5. Displacement values in the profiled roller

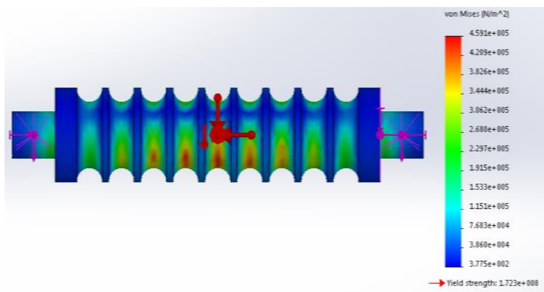


Fig.5.6. Equivalent stresses values according to the von Mises criterion

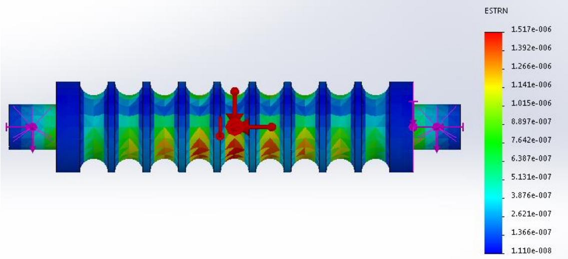


Fig. 5.7. The equivalent deformations in the profiled roller

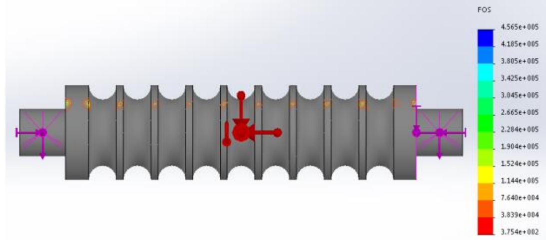


Fig. 5.8. The oscillation of the safety factor in the profiled roller

The minimum value of the safety coefficient is reached in the areas where the longitudinal cutting of the piece of dough is carried out. Since these areas are the most in demand, it can *be recommended that the cutting areas should no longer be executed with double edges but with a single edge*. *Thus it will increase pressure on dough to slitting, thereby reducing tensions in the roll profile.*

5.2.2 Analysis of air flow in the baking chamber of an electric oven

This study aimed to simulate the flow of hot air inside the baking chamber of the electric oven Zanolli 06 40V.

In the first stage, the three-dimensional geometric model of the electric oven model Zanolly SYNTHESIS 06/40V E. The 3D modeling was carried out with the design program set up Solid Works Premium 2016 S.P. 0.0.

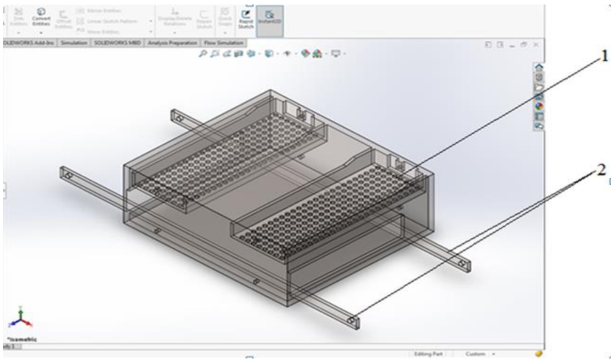


Fig. 5.9. Baking chamber
1. holes for air flow; 2. conveyor guides

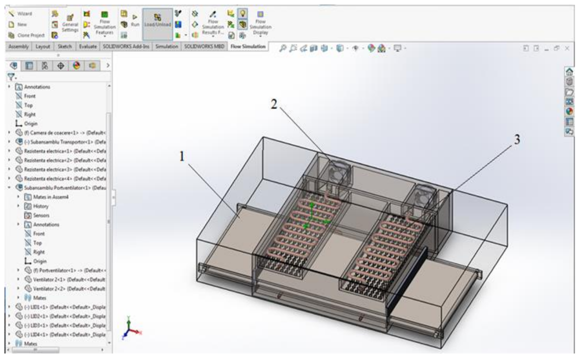


Fig. 5.10. The assembly used in the analysis of air flow
1. conveyor; 2. fan; 3. electrical resistance

After isolating the baking chamber's inner volume, were chosen type of analysis, the physical parameters, the type of fluid, the material from which the baking section is made, the thermal conditions of the process, and the initial thermodynamic parameters.

According to the program for the external conditions, was chosen as a heat transfer coefficient of 0,0369 W/m^{2}K, calculated with the relation, [167]:

$$\alpha_T = \alpha_0 \frac{273 + C}{T + C}\left(\frac{T}{C}\right)^{3/2} \quad (5.10)$$

where: α_T represents the coefficient of thermal conductivity at temperature T; α_0 - fluid conductivity at 273 K (for air α_0=0,0234 W/m^{2}K); T represents the absolute temperature (for the analysis performed it was considered that the temperature in the baking chamber is 230ºC); C - the characteristic constant of each gas (for air C=122 K), [167]:

Simultaneously, the conditions were set at the limits of the computational domain, the parameters of the fans were established, and the heat sources inside the baking chamber were set.

After carrying out the analysis, the program recorded air currents' circulation and their temperatures inside the baking chamber in its database.

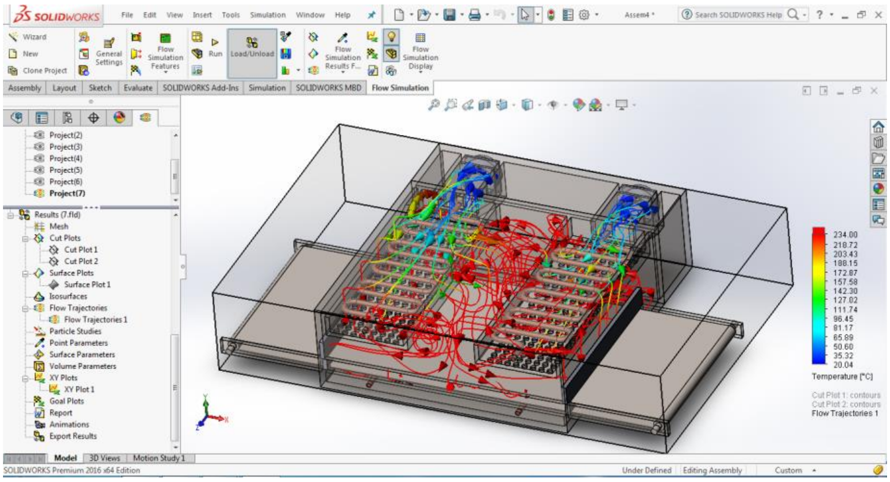
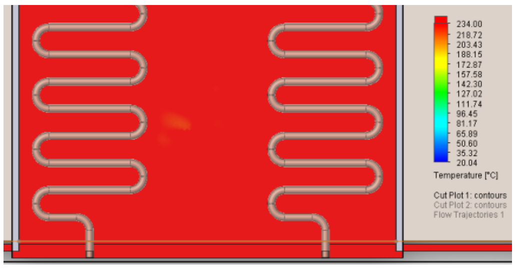
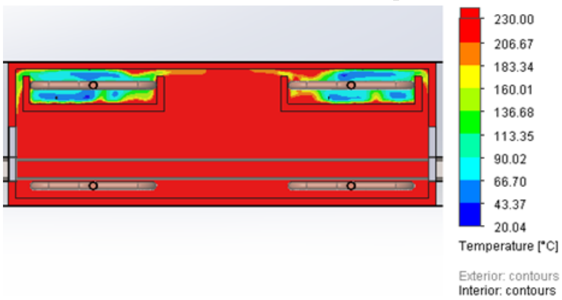


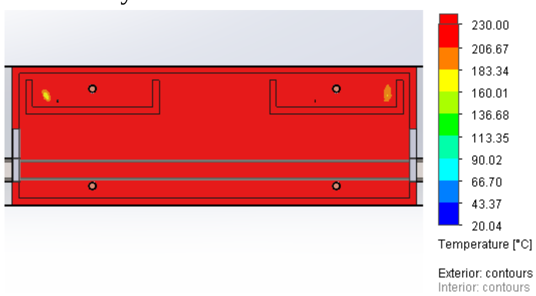
Fig. 5.11. The distribution of air flow inside the baking chamber



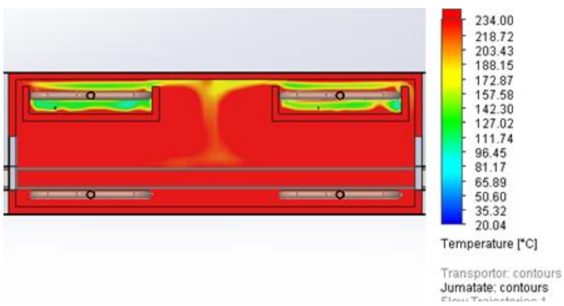
Temperature distribution at the conveyor belt



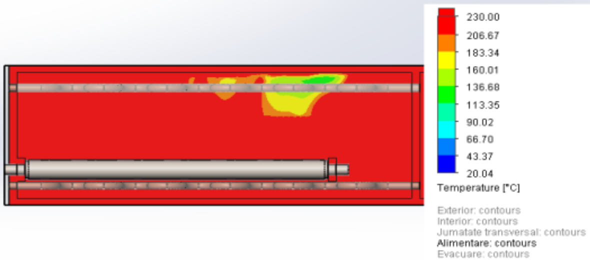
Temperature distribution in the air supply area in the baking chamber (longitudinal section)



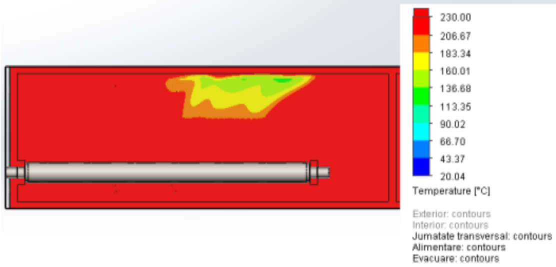
Temperature distribution in the area opposite the air supply in the baking chamber (longitudinal section)



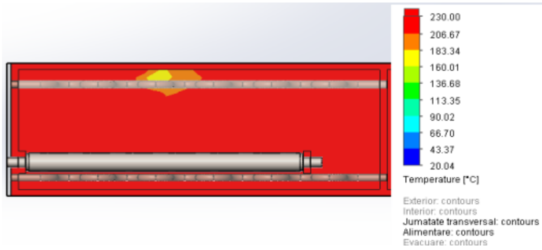
Temperature distribution in the median area of the conveyor (longitudinal section)



Temperature distribution in the feeding area in the baking chamber (cross section)

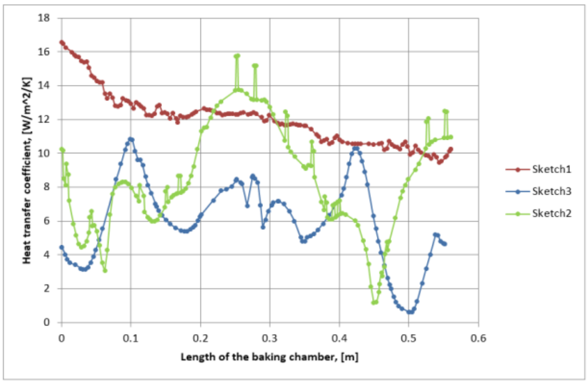


Temperature distribution in the outlet area of the baking chamber (cross section)

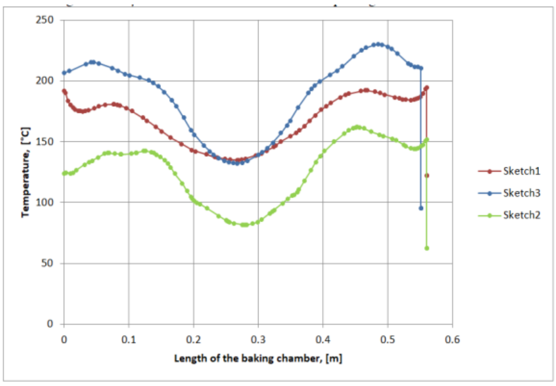


Temperature distribution in the middle area of the baking chamber (cross section)

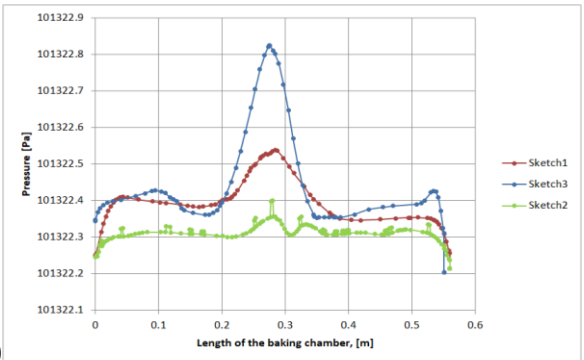
Fig. 5.12. Temperature distribution inside the baking chamber in several characteristic sections



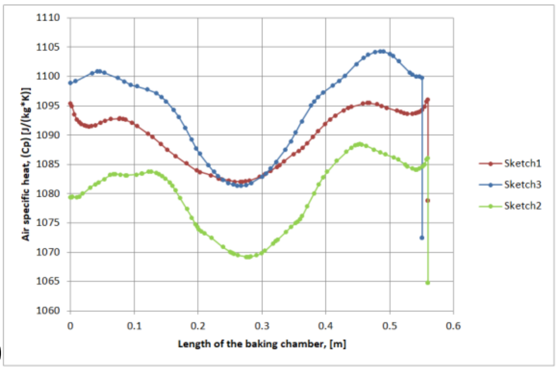
a)



b)



c)



d)

Fig.5.13. Variation of heat transfer coefficient (a), air temperature (b), air pressure (c) and specific heats (d) on the length of the baking chamber

In the electric oven, analyzed vorticity (the three areas above) is depicted in Figure 5.25. According to [103], vorticity is defined as a mathematical concept used in fluid mechanics and reflects the intensity of the circulation or rotation of a fluid and is often represented by rotation's angular speed.

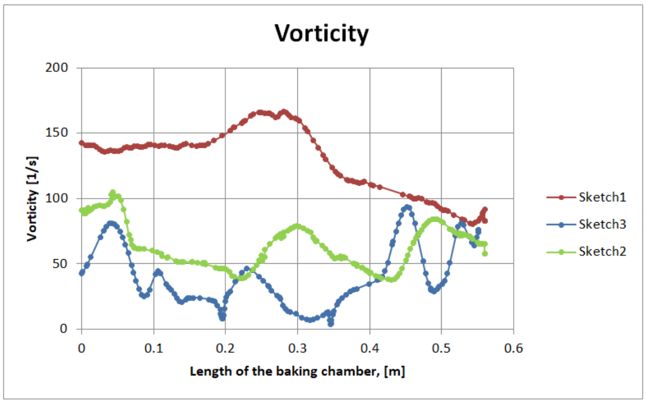


Fig. 5.14. Variation of vorticity in the length of the baking chamber

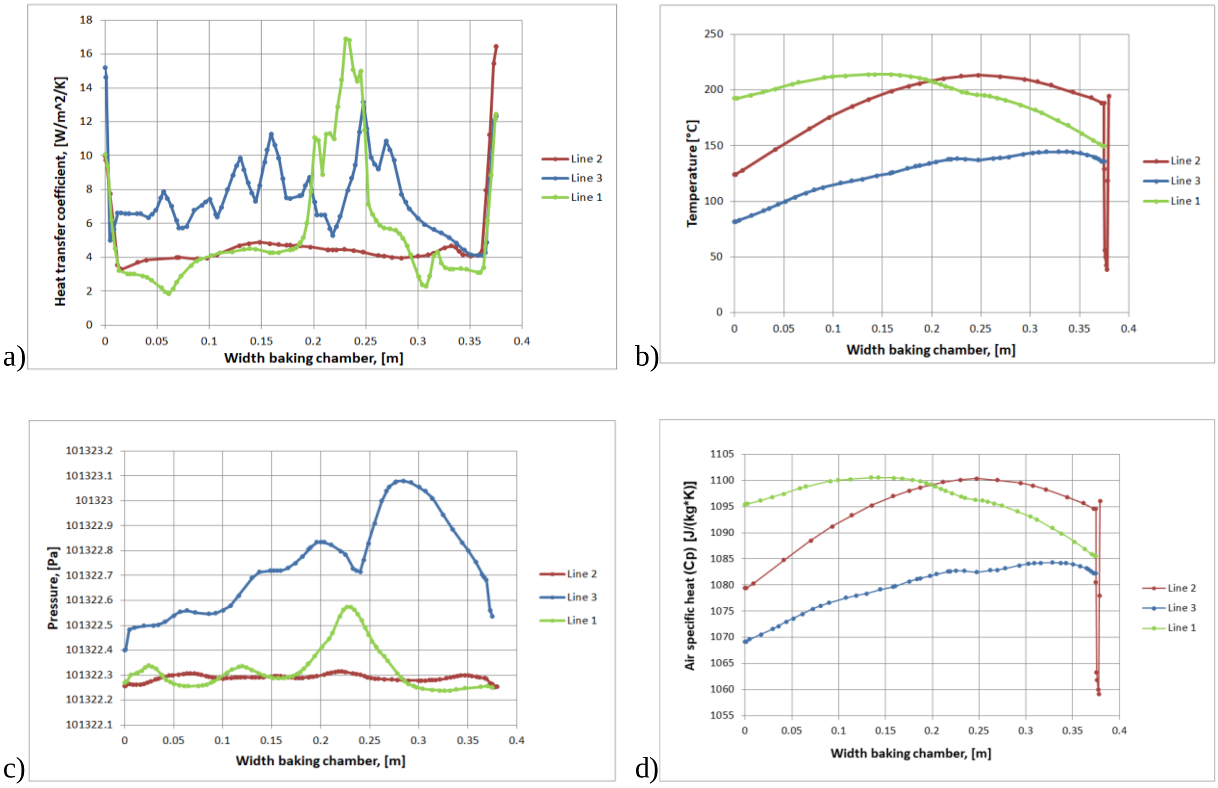


Fig. 5.15. Variation of heat transfer coefficient (a), air temperature (b), air pressure (c) and specific heats (d) on the width of the baking chamber

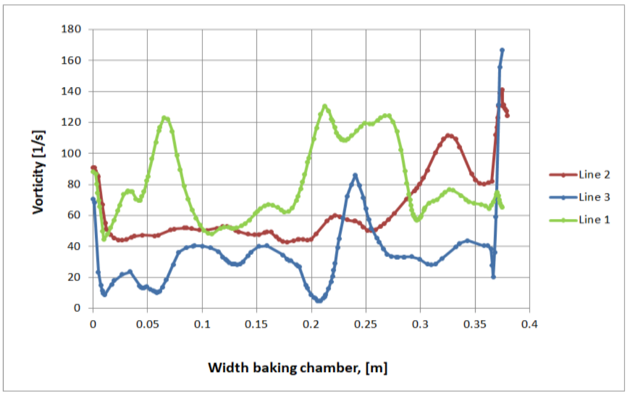


Fig.5.16. Variation of vorticity on the width of the baking chamber

This study was based on Navier Stokes' equations, which is the basis for almost all CFD (Computational Fluid Dynamics) flow models. Solving these equations predicts the fluid's speed and pressure in a specific enclosure geometry [3].

Continuity equation:

$$\frac{\partial p}{\partial t} + \nabla(\rho v) = 0 \tag{5.11}$$

Equation Navier-Stokes:

$$\rho \frac{\delta v}{\delta t} = -\nabla p + \rho g + \mu \nabla^2 v \tag{5.12}$$

where: ρ represents the density of the fluid (for air $\rho = 1{,}184$ kg/m^3); v - fluid speed (for analysis the air speed was determined v= 2,4 m/s); p - atmospheric pressure ($p = 1$ atm); μ - dynamic viscosity of the fluid (for air μ = 1,84·10^{-5} kg/ms), [170].

5.2.3 Validation of the air flow simulation inside the baking chamber of an electric oven

A series of measurements were made using the Extech MP530 MultiPro True RMS multimeter and a thermocouple to validate the temperature values obtained in the simulation of air flow inside the electric oven's baking chamber.

Fig. 5.17. Images from experimental determinations

Thus, were obtained the following values of temperature: for the lower zone the value of the temperature was 214°C, or the exit area on the lower median line, the temperature value was 226°C; for the middle higher zone the temperature value was 249°C, and for the lower middle zone the temperature value was 249°C.

5.3. CONCLUSIONS

Given the results, the structural analysis of profiled rollers of a machine modeling dough for pretzels can recommend cutting areas not to be executed double-edged but with one edge.

To reduce the energy consumption of such machines is recommendation engines no longer be oversized. Even if the dough's water content is reduced, thus increasing its rigidity, a 100 W electric motor is sufficient for the modeling machine to operate in good condition.

The program Solid Works module "Flow Simulation" was used to simulate the airflow in the baking chamber of an electric oven. The following values were obtained: the heat transfer coefficient, air temperature, air pressure, specific heat, vorticity, all parameters on the length and width of the baking chamber.

A series of recommendations are made to avoid heat loss in the middle area of the baking chamber. The air must be introduced into the cooking chamber to be preheated before feeding into it (but not before the fans' aspiration to protect them). Another idea could be to break those vortices formed in the baking section and draw the cold air fed into the baking chamber to the middle area and the surface of the conveyor. The breaking of these vortices can be done with deflector plates distributed in the areas of maximum intensity of the air currents' vortex.

CHAPTER 6 - EXPERIMENTAL RESEARCH ON THE TECHNOLOGICAL PROCESS OF PRETZELS MANUFACTURING

6.1. THE OBJECTIVES OF THE EXPERIMENTAL RESEARCH

The experimental research carried out had as the main objective the analysis of the dough's physical characteristics and the changes of its structure suffered during the entire technological flow of obtaining pretzels, but also the analysis of the working process of the machines on the technological flow.

6.2. APPARATUS AND EQUIPMENT USED IN THE EXPERIMENTAL RESEARCH OF PRETZELS MANUFACTURING

Experimental research was carried out between 2015-2019 in specialized laboratories of the Faculty of Biotechnical Systems Engineering - Department of Biotechnical Systems. Some of the equipment used to conduct the research are presented in the following figures:

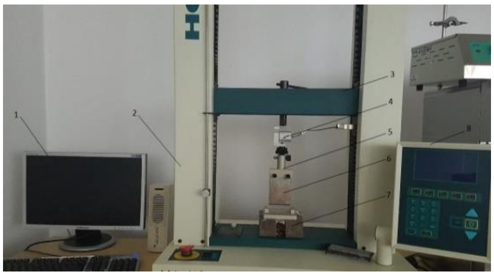


Fig.6.1. Mechanical testing apparatus Hounsfield H1KS

Fig.6.2. Pasta making machine motor IMPERIA Titania 675 6 Adjustments

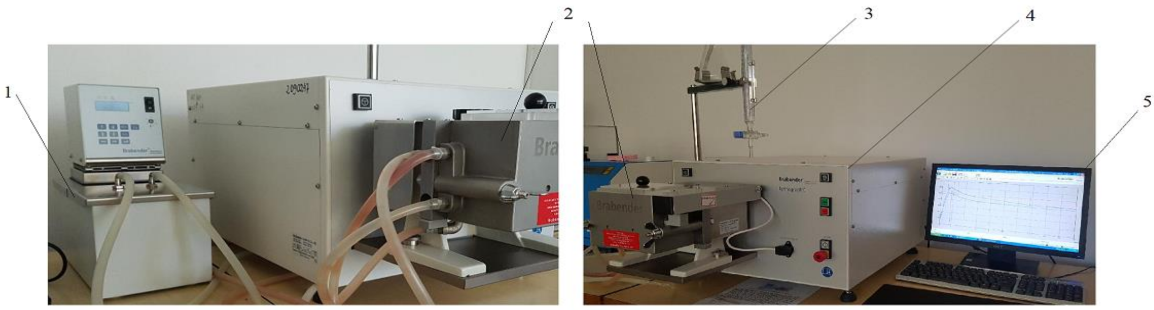
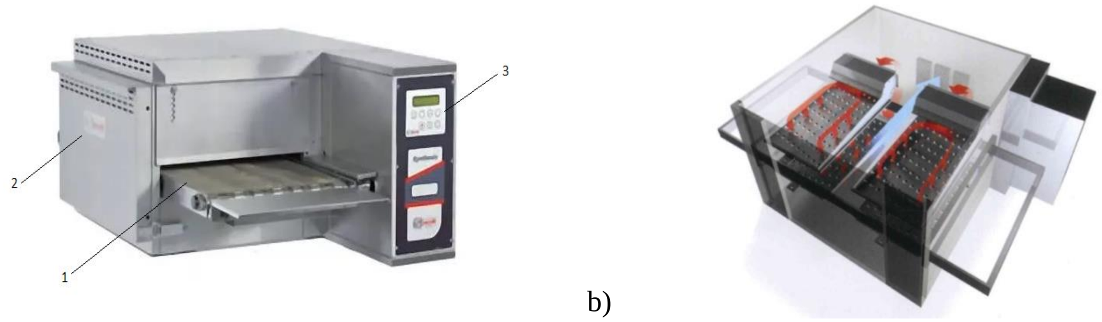


Fig. 6.3. Farinograf Brabender

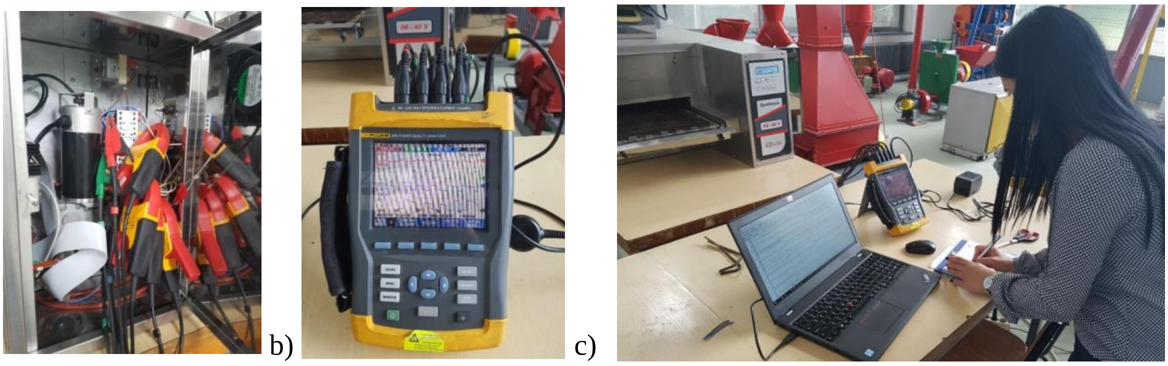


a) b)

Fig.6.4. Oven Zanolly SYNTHESIS 06/40V E

a) overview; b) how the hot air circulates in the baking chamber described in the technical book, [46]

1. conveyor; 2. housing; 3. control panel



a) b) c)

Fig.6.5. a) Gripping pliers ammeter; b) Data acquisition device; c) Data acquisition device connected to the computer

6.3 METHODOLOGY OF EXPERIMENTAL DETERMINATIONS

To achieve the objectives of this doctoral thesis, the following experimental research program was followed.

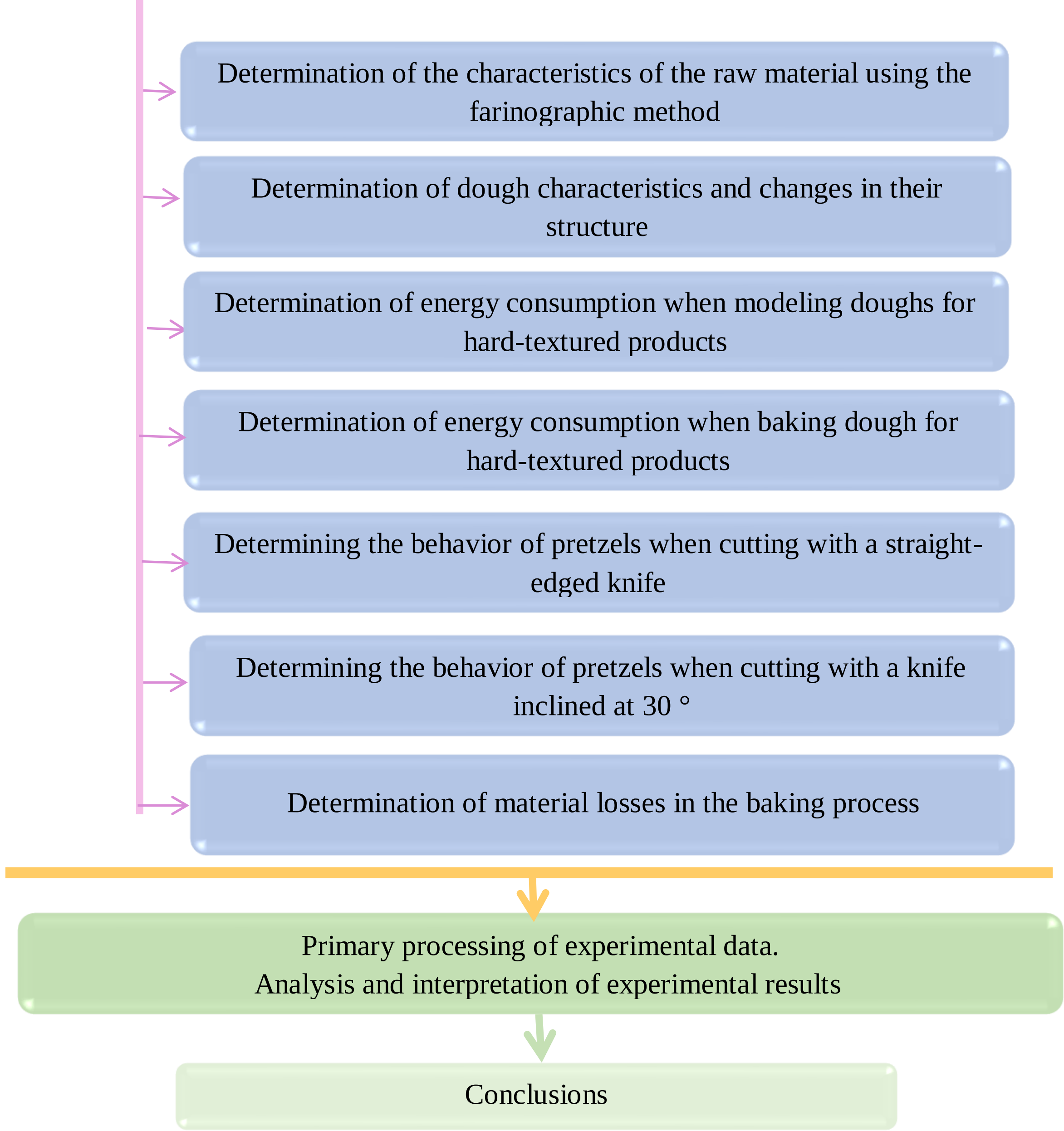
Procurement of raw materials used in experimental research

↓

Place of activity:
Faculty of Biotechnical Systems Engineering

↓

Instruments and apparatus used in experimental research:
Electronic balance Kern (precision 0,1g); thermobalance Kern RH 120-3; apparatus for determining water activity Rotronic; laboratory glassware; Brabender farinograph with electronic recording; device with cylinder, piston and flow hole for determining the flow of flour-water suspensions; Hounsfield H1KS mechanical testing machine; PC computer; DitoSima planetary spiral dough kneader; Dough kneader with spiral arm ITB ; Titania 675 pasta maker; kettle adjustable temperature; electric oven Zanolli SYNTHESIS 06 40V E; Fluke 434 clamp meter phase



6.4. FEEDSTOCK AND MATERIALS USED IN THE PRETZELS MANUFACTURING

For experimental research, I have used white flour and: drinking water from the city network, vegetable fats (sunflower oil), salt, fresh bakery yeast species *Saccharomyces Cerevisiae*, sugar crystals.

6.5. EXPERIMENTAL RESEARCH IN THE DOCTORAL THESIS

6.5.1. Experimental research on the raw materials and doughs characteristics used in the pretzels manufacturing

a) Research on the characteristics of flour-water suspensions when passing through flow channels

The study on the characteristics of flour - water suspensions, when passing through orifices, shows the flow through small diameter pipes of a fluid suspension based on flour, at several working temperatures, under the influence of pressure achieved by a piston pump. These tests simulate the flow of flour-based fluids through the holes in a mold (eg, the case of waffles, pancakes, cakes, muffins, etc.).

For the experiments, the FA 650 flour was purchased from the commerce and drinking water. The single sample composition was prepared from 100 ml of water and 14 g of wheat flour with a particle diameter of less than 100 µm.

The experimental determinations are presented in Table 1 and Figures 6.6 and processed using Excel.

Table 6.1 Variation of the resistant pressing force at different temperatures

Channel type	Force [N]	Temperature			
		27°C	40°C	50°C	65°C
l=10 mm ϕ =2 mm	Max.	1,5	2,8	3	5,1
	Min.	0,8	1,8	2,1	4,9
l=53 mm ϕ=0,838 mm	Max.	5,1	4,8	5,8	37,0
	Min.	3,2	4,4	5,1	33,5

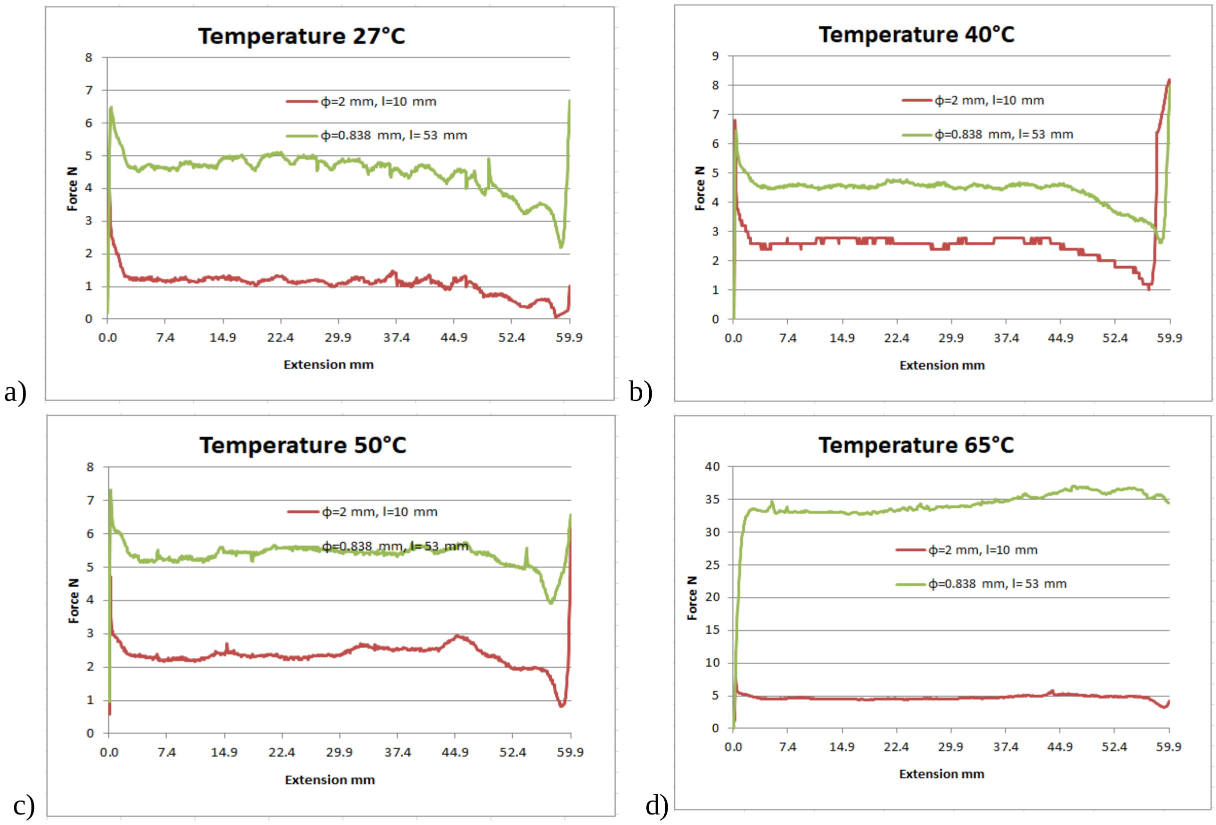


Fig. 6.6. The variation of the strength force of piston force for the four types of mixture that have undergone flow tests through channels of different size

It can be concluded that the gelling of starch granules significantly influences the flow through the channels (especially through narrow channels), and the extruded or injected machines must be adapted to the working temperatures (respectively, the driving power must be higher when working at higher temperatures greater than 60°C). This is much more sensitive to long narrow channels because the l/d ratio influences track losses.

b) Farinographic research on the characteristics of pretzel doughs

The study presents the analysis of the rheological properties of wheat flour used in research to determine the dough's extensibility, energy consumption when shaping and baking dough for hard-textured products, and the mechanical characteristics of the obtained pretzels.

The researches on farinograph characteristics are to determine the quality of the flour. They are of particular importance in both the technological process of obtaining bakery and pastry products, [101, 103].

Table 6.2 Farinograph curve characteristics obtained for the wheat flour FA4 650

Farinograph characteristics	Values
Hydration capacity [%] Correction for 500 U.F.	62,0 59,7
Dough development [min]	2,2
Dough stability [min]	3,7
Dough degree of softening [U.F]	46
Farinograph index	46

Table 6.3 Criteria for assessing the quality of flour

Flour	Farinograph characteristics				
	Hydration capacity [%]	Dezvoltare aluat [min]	Dough stability [min]	Dough degree of softening [U.F.]	Farinograph index
Very high	Peste 65	Peste 3	Peste 8	Sub 60	Peste 65
High	60 - 65	2 - 3	5 - 8	60 - 80	50 - 65
Satisfactory	55 - 60	1,5 - 2	3 - 5	80 - 100	40 - 50
Unsatisfactory	Sub 55	Sub 1,5	Sub 3	Peste 100	Sub 40

Table 6.4 Farinograph parameters for three commercial types of flour FA_1 650, FA_2 650, FA_3 650

Farinograph characteristics	Flour FA 650		
	FA_1 650	FA_2 650	FA_3 650
Hydration capacity [%] Correction for 500 U.F.	65,7 65,6	62,1 62,2	60,1 60,2
Dough development [min]	2	1,8	2,5
Dough stability [min]	4	2,2	4,2
Dough degree of softening [U.F.]	70	59	69
Farinograph index	49	33	56

c) Dough extensibility

The extensibility of the dough is its property of stretching without breaking [36, 205]. The results obtained help determine the dough's rheological properties, the quantities of ingredients for getting it, including the possibility of processing it and its baking, [28].

To make the extensibility test, the dough pieces were shaped in the form of wicks with a length of 400 mm and a diameter of approximately 18 mm. They were placed on the fixed crosspiece of the HOUNSFIELD H1KS mechanical test apparatus. During the experiments, the instrument was equipped with a hook, a 1000 N force cell, and a fastening system of the fixed crosspiece wicks. To record the maximum force applied for stretching until the dough flap was broken, I used a computer on which the Qmat software was installed. After gripping and centering the wick, the beam fixed hook means wick; the wick has been raised in the middle with a hook that has a vertical movement speed of 50 mm/min. Movement of the hook was done until the dough wound broke into one of the tear areas (a, b, c, d, e). From the moment the hook was lifted to breaking the batter dough into the Qmat software acquisition system, the maximum force was required to break each wick probe and the hook detonation on the vertical (figure 6.7).

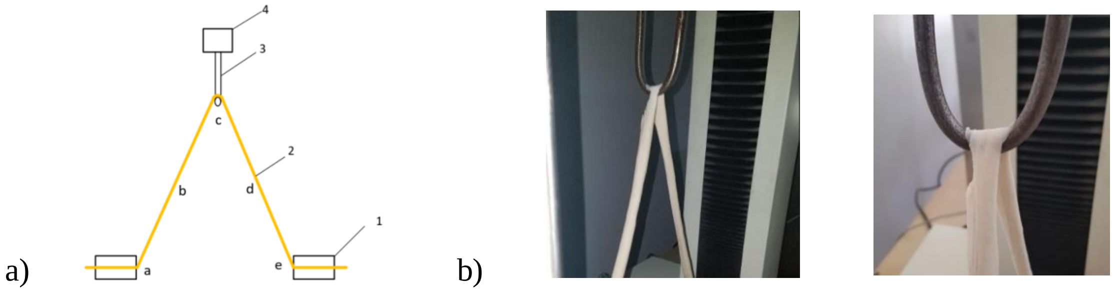


Fig. 6.7 a) Traction test who showing dough extensibility and breakage zones (a, b, c, d, e); 1 attaching the wick holder; 2. wick; 3. hook; 4. the force cell (1000 N);. b) an example

The experimental results recorded for the maximum force, respectively, the hook's displacement corresponding to the force's maximum value, are presented in table 6.5.

Table 6.5 Experimental results from determinations

		Dough with 45% water (type I)		Dough with 55% water (type II)	
		Maximum force [N]	Hook movement [mm]	Maximum force [N]	Hook movement [mm]
Sample	1	1,53	200	2,67	246
	2	1,90	182	2,7	278
	3	2,03	215,2	2,17	234
	4	1,87	193	3,17	248
Average		1,83	197,55	2,67	259,4

The values of the modulus of elasticity (E) determined by linear regression, values of the length after stretching the wick (L), deformation values (ε) and the resistance of the dough to stretching (σ_{al}) are presented in table 6.6.

Table 6.6 Physical characteristics and experimental data obtained for pretzel dough wicks

Dough type	Sample	$L_0 \cdot 10^{-3}$ [m]	$L \cdot 10^{-3}$ [m]	ε [%]	E [MPa]	σ_{al} [MPa]
Dough with 45% water	1	300	500	40	0,031	0,020
	2	300	470	36,17	0,041	0,023
	3	300	524	42,74	0,041	0,028
	4	300	488	38,52	0,039	0,024
Dough with 55% water	1	300	576	47,91	0,048	0,040
	2	300	630	52,38	0,052	0,045
	3	300	554	44,85	0,041	0,031
	4	300	578	48,09	0,062	0,048

In order to highlight the increase of the extensibility of the dough with the increase of the amount of water in the dough, the values of the modulus of elasticity and the length of the dough wick were stretched and are shown in Figures 6.8 and 6.9.

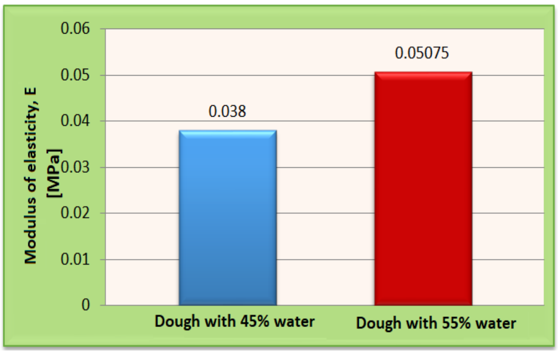


Fig. 6.8. Highlighting the difference of the average modulus of elasticity for the two types of dough

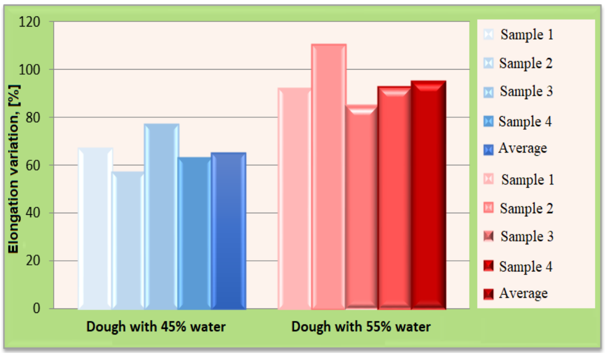


Fig. 6.9. Highlighting the variation of the elongation for the two types of dough

6.5.2 Experimental research on energy consumption in dough modeling and baking for hard-textured products

a) Research on sheeting and drawing of doughs

Sheeting and drawing dough between rolling and drawing rolls/cylinders, which rotate in opposite directions and with the same diameter or different diameters, are operations often used in the bakery industry as a dough forming process for a wide range of products: biscuits, pizza, noodles, pasta, bread, and other pastries, while also contributing to the development of its structure, [47, 75, 91, 115, 144].

The results obtained for the doughs prepared from the three types of white wheat flour are presented in Table 6.7.

Table 6.7 Dough parameters and energy consumption for sheeting and drawing

Flour sample	Moisture content of flour (%)	Hydration capacity, (ch %)	Energy consumption at drawing, ($\cdot 10^3$ J)	Specific energy consumption at drawing, ($\cdot 10^3$ J/kg)	Energy consumption at sheeting, ($\cdot 10^3$ J)	Specific energy consumption at sheeting, ($\cdot 10^3$ J/kg)
FA_1 650	9,56	65,6	9,00	5,39	11,52	6,91
FA_2 650	10,45	62,2	6,84	4,10	10,80	6,47
FA_3 650	11,59	60,2	6,48	3,88	9,72	5,83

Table 6.7 shows that the energy consumed for drawing, respectively lamination, the dough pieces prepared with the three types of flour are different and shows that they increase with the decrease of the value with moisture content, respectively with the increase of the hydration capacity of the flour.

Considering that the amounts of water in the recipe have been respected and did not take into account the hydration capacity or moisture content, it can be said that the difference in energy consumption is given by the small amounts of water and oil used in the preparation of the dough.

b) Research on baking pretzels

To do the experiments, an electric oven, Zanolli SYNTHESIS 06 40V E, was used for baking different types of bagels and pizza, and a Fluke 434 clamp meter phase.

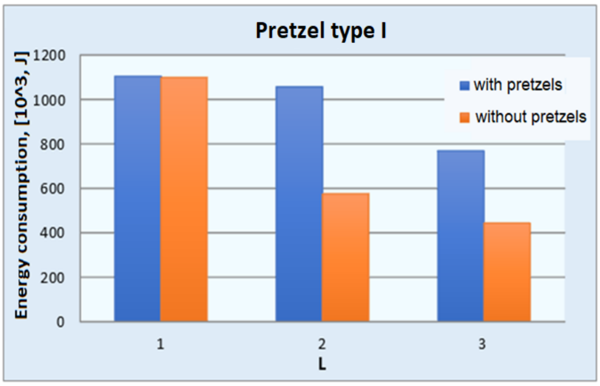
The data acquired by the device were 40 pieces for baking bagels/experiment, five rows by four committed. Before the oven was loaded, data was obtained for emptying the aggregate (no dough). I did the experiments for several types of bagels and several variations of the electric oven parameters.

To record the idle data, I kept the settings for each baking program for each pretzel assortment.

Following experimental measurements have obtained the results shown in Table 6.8 and graphs in Figures 6.10 - 6.11, processed using MS Office Excel.

Table. 6.8 Experimental data recorded with FLUKE 434

Electrical resistance	Energy consumption [$\cdot 10^3$ J]					
	Experiment 1		Experiment 2		Experiment 3	
	Pretzel type I	Without pretzel	Pretzel type II	Without pretzel	Pretzel type III	Without pretzel
L1	1104	1098	1104	1080	1104	1080
L2	1056	576	1056	576	1248	576
L3	768	444	720	384	816	384
Total	2928	2118	2880	2040	3168	2040



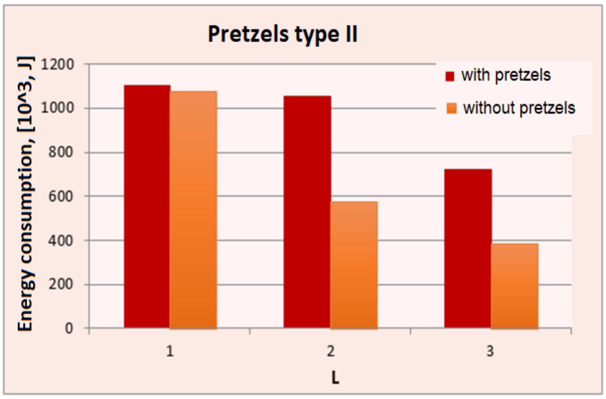


Fig.6.10. Energy consumption variation for baking pretzels and idling for the same baking program

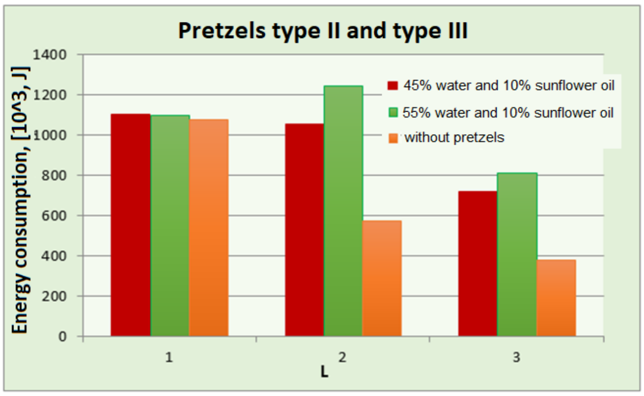


Fig.6.11. Variation of total energy consumption when baking pretzels and idleing, corresponding to the same baking program for type II and type III pretzels

From the analysis of the data in table 6.8 and the graphs in figures 6.10 and 6.11 it can be seen that if a dough with high moisture content is introduced inside the baking chamber of the electric strip oven, the value of the consumed electricity also increases. Thus, baking semi-manufactured products with 45% water and 10% oil consumption was $2880\cdot10^3$ J, baking the semi-manufactured products with 55% water and 10% oil consumption $3168\cdot10^3$ J. This increase is because the electric resistances are forced to produce more heat to assist in the evaporation of water in the dough pieces.

6.5.3. Research on the mechanical characteristics of pretzels manufactured on the low-capacity technological line

This study was proposed to investigate the effect of pretzels' way and storage time on their hardness.

The paper [61] mentions that the process of mastication has become an essential subject of research studies sensory and nutritional analysis. This process determines the release of flavor and the perception of texture but negatively influences the bioavailability of nutrients.

Tight between the structure of bakery products and their resistance to decomposition leads to finished products so that their digestion can be controlled from the mastication phase [61]. Their structure changes due to the different dough processing methods, but also depending on the way and time of storage.

To highlight the bagel mechanical behavior depending on storage, but also during the storage, pretzels types I, II and III, were divided into two groups. One group was left to store in the room's open-air, while the other sample was stored in paper packaging. Type IV of pretzels was kept only in paper packaging. Determinations for all samples were made at different time intervals after baking, 1h, 24h, and 48h. The storage of samples was carried out under conditions so that both humidity and physical and mechanical properties did not change significantly.

The determinations consisted of subjecting the pretzels to shearing, resulting from which the maximum cutting force was determined.

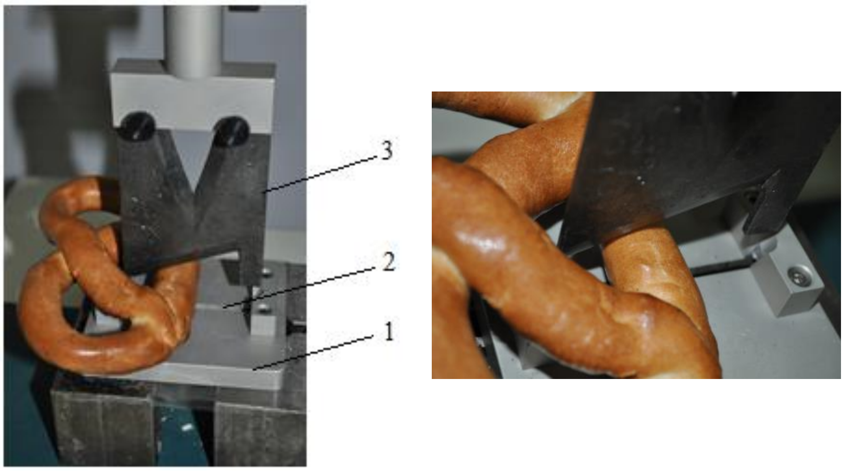


Fig.6.12. Images from experiments with the HOUNSFIELD H1KS
1. support plate; 2. slot; 3. cutting blade with inclined angle at 30 ° and sharpening angle of 20 °

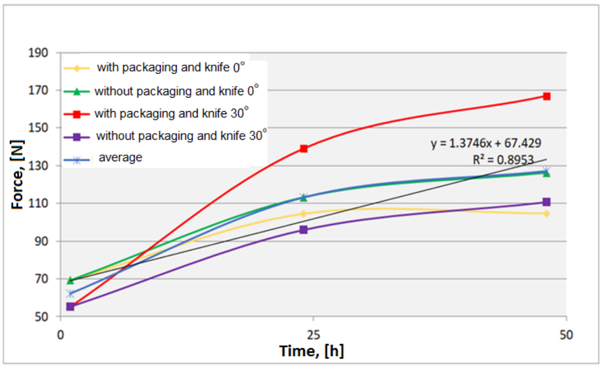


Fig. 6.13 Variation of the cutting force of type I pretzels depending on the angle of inclination of the knife blade, the way and time of storage

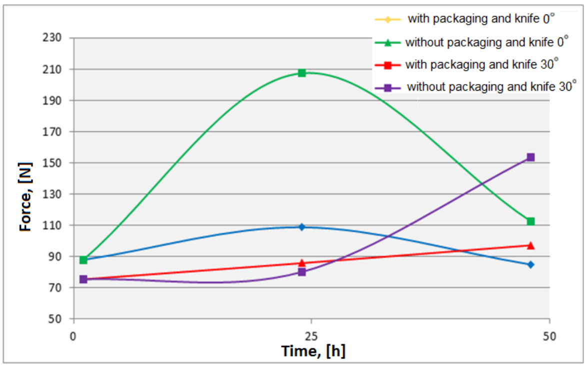


Fig. 6.14 Variation of the cutting force of type II pretzels depending on the angle of inclination of the knife blade, the way and time of storage

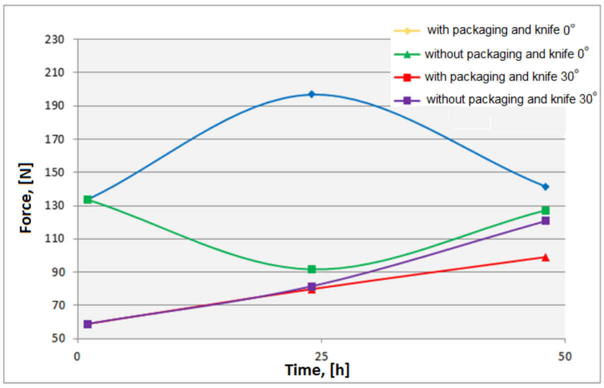


Fig. 6.15. Variation of the cutting force of type III pretzels depending on the angle of inclination of the knife blade, the way and time of storage

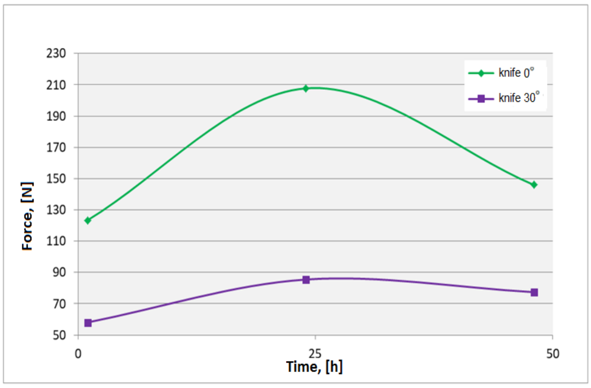


Fig. 6.16. Variation of the cutting force of type IV pretzels depending on the angle of inclination of the knife blade and time of storage

The curves of variation of cutting force remember the parameters are shown in Figures 6.13 - 6.16. To highlight the variation of the pretzels' cutting force according to their time and the way of keeping them, the value of the cutting force of the pretzels after 1 hour from their removal from the oven was taken into account for each curve on the graph.

The most considerable differences in the cutting forces recorded for the four types of pretzels were found between the pretzels' samples subjected to the cutting process 1 hour after their removal from the oven and those subjected to cutting 24 hours after removal from the oven storage or not in paper packaging. This difference can be explained by the fact that the samples recorded the highest cutting forces recorded the most significant hardness, hardness caused by loss of freshness. At the same time, by losing freshness, the pretzels became brittle, and when they were cut, the force applied led to the tearing of the samples and not their cutting, which is why some samples that were storage or not in the paper packaging had lower cutting forces compared to the forces recorded for cutting the samples 1 hour after removing them from the oven.

6.5.4 Research on the material losses in the pretzels baking process

Almost any loss of moisture in bakery products occurs during baking because of water evaporation. Variations in moisture loss are caused by the nature of the dough and the baking conditions. Due to the effect of heat during the baking process, the dough structure is changed into a continuous porous structure to allow water to move. Part of the water evaporates through the crust layer, while another is condensed at the dough center, [136].

Baking weight losses are calculated with the equation:

$$P_c\,(\%) = \frac{m_{Al} - m_C}{m_{Al}} 100, [\%] \tag{6.1}$$

where: m_{Al} – the weight of the dough placed in the oven; m_C – the weight of warm pretzels;

Cooling weight loss is calculated as follows:

$$P_r\,(\%) = \frac{m_c - m_{cr}}{m_c} 100, [\%] \tag{6.2}$$

where : m_{cr} − the weight of the pretzels 1 hour after removing them from the oven.

The experimental results on pretzel weights before baking, immediately after baking, and after cooling are presented in Table 6.10.

The dough used to determine the experiments on pretzel weights before baking, immediately after baking, and after cooling was prepared from 3 kg of white flour, 45% water, 10% oil, 100 g sugar, 36 g salt, 15 g yeast. The flour temperature was 22°C, the dough temperature 32°C, the atmosphere temperature 26°C.

Tabel 6.9 Pretzel weight

Shaped dough weight [g]	Boiled dough weight [g]	Hot pretzel weight [g]	p_c [%]	Cold pretzel weight [g]	p_r [%]
100	108,4	78,2	21,8	77,5	0,89
	109,0	78,7	21,3	77,7	1,27
	109,1	76,3	23,7	75,6	0,91
	110,1	79,4	20,6	78,6	1,00
	106,4	80,5	19,5	79,6	1,11
	107,8	80,7	19,3	79,6	1,36
	106,1	80,1	19,9	79,2	1,10
	107,1	80,4	19,6	79,6	0,99
	104,2	78,3	21,7	77,7	0,76
	107,2	80,5	19,5	79,9	0,74
	107,1	79,7	20,3	79,1	0,75
	104,3	78,5	21,5	77,9	0,76
	104,5	76,9	23,1	76,2	0,91
	105,3	76,7	23,3	75,9	1,04
	107,2	76,5	23,5	75,8	0,91
	105,5	77,9	22,1	77,2	0,89
	106,9	74,9	25,1	74,2	0,93
	108,9	76,6	23,4	76,0	0,78
	107,9	77,9	22,1	77,3	0,77
	107,6	77,8	22,2	77,3	0,64

6.6. CONCLUSIONS

From the analysis of experimental research, it can be affirmed that the temperature of flour-water suspensions, found in cookie products, is an essential parameter for their flow through narrow channels, the flow-resistant force being higher the temperature.

The geometry of the channel (diameter, length) influences the flow of flour-water suspensions, both the results of experiments and those in the literature, proving that the smaller the channel's diameter, the greater the resistance force, regardless of the temperature of the flour-water suspension.

The modulus of elasticity of the dough with 45% water and 10% oil, determined from the stretching curves, has much lower values compared to the modulus of elasticity of the dough with 55% water and 10% oil. It means that a more considerable amount of liquid in the dough produces an increase in the dough's extensibility, respectively easier handling of the dough wicks without them breaking or thinning during shaping.

A dough with less water will break faster than one with a higher water content; thus, the tensile strength values for the dough with 45% water and 10% oil vary in the limits 0.02 - 0.028 MPa, while for the dough with 55% water and 10% oil the tensile strength values range in the limits 0.031 - 0.048 MPa.

An increase in the moisture content and a lower value of the hydration capacity of the flour decreased the value of energy consumption in drawing from $11.52 \cdot 10^3$ J to $9.72 \cdot 10^3$ J, but also the energy consumption in sheeting from $9.00 \cdot 10^3$ J the $6.48 \cdot 10^3$ J.

If in the cooking chamber of the electrical tape oven is inserted a dough with high moisture content, then the amount of electricity consumed will increase.

The parameters that influenced the increase of the cutting force's values of the samples subjected to shear by cutting were: the angle of inclination of the knife blade and the storage time - keeping them.

CHAPTER 7 - GENERAL CONCLUSIONS. CONTRIBUTIONS. PERSPECTIVES

7.1. CONCLUSIONS ON TORETIC AND EXPERIMENTAL RESEARCH

- Knowledge of the physical-mechanical properties of wheat flour is important for choosing and optimizing the constructive and functional parameters, both of the pretzel production equipment and the bakery and pastry equipment in general.
- By applying rheological models that describe the viscoelastic behavior of materials can be obtained information about the dough's consistency, formation time, stability time, degree of softening, and flow mode.
- By measuring the torque at the shaft of a kneader, during the kneading process, a curve M = f (t) is obtained, which provides information about the dough properties, such as dough formation period, stability period, and softening period.
- The mathematical model developed in the thesis and obtained by dimensional analysis can estimate the energy consumption of sheeting the dough depending on its characteristics and those of the dough modeling machine.

- Simulation of the dough drawing process in the parameterized design program Solid Works Premium 2016 S.P. 0.0., led to obtaining the value of the power necessary for the wire drawing machine for pretzel dough for profiled rolls and dough with known characteristics. The study reveals that the value of power consumed is well below the modeling machine's installed power, and installing a lower power electric motor would reduce energy consumption.
- The results of the structural analysis of a profiled roller show that the movements in the simulation conditions are minimal, and the values of the equivalent stress according to the von Mises criterion are below the material's tensile strength. Regarding the minimum value of the safety factor, it is reached in the most requested areas, ie, in the areas where the dough sheet's longitudinal cutting is carried out. To reduce the tensile strength in the dough wire drawing machine's profiled roll and increase the pressure on the piece of dough, it is recommended that the cutting areas be made with a single edge and not with double edges (or at least a smaller width).
- Simulation performed using Solid Works Premium 2016 S.P. 0.0., the module "Flow Simulation", of the airflow in the baking chamber of the electric oven for pretzels, led to the obtaining of values both on the length and on the width of the baking chamber for the heat transfer coefficient, air temperature, pressure, specific heat. The air currents' vorticity in the baking chamber could also be determined for the known initial parameters. The temperature was the only parameter that could be validated experimentally, and the results obtained were satisfactory.
- To avoid heat loss in the middle area of the baking chamber of the analyzed oven, it is recommended that either the air introduced into the baking chamber be preheated before feeding into the baking chamber (but not before the suction fans, to protect them), or by breaking the vortices that form inside the baking section and which entrain the cold air fed into the baking chamber to the middle area and the surface of the conveyor.
- A larger amount of water in the dough leads to an increase in the dough's extensibility, respectively, to a more comfortable handling of the dough wicks without them breaking or thinning during shaping.
- If the mass of water added in the manufacturing recipe is not in correlation with the flour's hydration capacity, the energy consumption changes when modeling it.
- Following the experiments, it was shown that if a dough with a high moisture content is introduced inside the electric oven's baking chamber with an electric oven with a conveyor belt, the consumed electricity's value also increases. This increase is because the electric heaters need to produce more heat to help heat and evaporate the water in the dough pieces' composition during the baking process.
- Therefore, considering the recommendation of mounting the deflection plates inside the baking chamber and the results obtained for the study of material losses during baking, the flow of hot air inside should be adjusted accordingly to result in lower energy consumption.

7.2. PERSONAL CONTRIBUTIONS

1. By consulting a large number of technical papers published at the national and international level, an analysis was made of the dough's physical and rheological behavior during the manufacturing process of bakery products.
2. Development of a mathematical model to determine energy consumption when sheeting the dough depending on the sheeting rolls' speed and the thickness of the dough sheet.
3. Simulation of the mechanical behavior, by the finite element method, of the drawing rollers during obtaining the dough wicks for pretzels.
4. Simulation in the Solid Works CFD program of the airflow in the electric oven's baking chamber for pretzels and validation of the data with the measured results for the temperature in the baking section of the electric oven.
5. Carrying out experimental research to determine the flow resistance of flour-water fluid suspensions at different temperatures through channels with different geometries.
6. Carrying out farinographic research using the Brabender electronic farinograph to determine the characteristics of the flours used for pretzel dough.
7. Experimental determination of pretzel dough's extensibility using different amounts of water in relation to the amount of flour.
8. Experimental research on energy consumption in dough modeling for hard textured products.
9. Experimental research on energy consumption when baking doughs with different cooking recipes and other baking parameters.
10. Experimental determinations concerning pretzels' mechanical properties by performing shear cutting tests with the help of knife blades with a sharpening angle of 20°, straight and inclined at 30°.
11. Research on determining the loss of materials (water) in the process of baking pretzels.
12. Expressing a set of conclusions and recommendations for specialists in the bakery and pastry industry.
13. The results obtained in the studies and research carried out during the doctoral training were also capitalized by the elaboration and publication of a number of 17 scientific papers in specialized journals (4, of which 2 ISI and 2 BDI - 1 SCOPUS), in conference volumes. national and international (13, of which 3 listed ISI, 1 SCOPUS and 8 in other BDI), as author and co-author, according to the list of papers attached at the end of the thesis.

7.3. FUTURE RESEARCH RECOMMENDATIONS AND PERSPECTIVES

1. To make the scalding pretzels process more efficient, it is recommended to use continuous scalders and reduce the energy consumption during scalding; it is recommended that the temperature of the scalding solution does not reach the boiling point.

2. In order to reduce the sheeting power consumption, it is recommended that the equipment be equipped with motors suitable for the workload.

3. To reduce the tensions in the dough drawing machine's profiled roll and increase the pressure exerted on the piece of dough, manufacturers of pretzel dough drawing machines should make profiled drawing rolls with a single edge and not with double edges.

4. Electric oven manufacturers can improve the baking process and reduce energy consumption by avoiding heat loss in the middle area of the baking chamber, if the air supplied to the baking chamber is preheated or if deflector plates are installed in the baking chamber, where are the areas of maximum vorticity intensity.

Experimental research in this paper can be continued by:

1. Studying the behavior of doughs with different amounts of water, from other varieties of flour, at different storage periods to estimate their influence on the dough's processing and handling during the technological process of making pretzels.
2. Study and application of rheological models (Lethersich model, Burgers) on pretzel doughs, in which the flour, alveographic or extensographic characteristics were possibly determined.
3. Continuation of research on optimizing the electric oven's working process by performing tests in which to place deflector plates in the middle area of the baking chamber.
4. Continuation and extension of research on pretzel doughs' behavior in sheeting and drawing on doughs with different recipes.
5. Extending baking research and determining material losses for other types of bakery and pastry doughs.
6. Achieving the thermal balance of baking for pretzel ovens of different construction variants.

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(*) Nivelul Cadrului European Comun de Referinţă Pentru Limbi Străine

LIST OF SCIENTIFIC WORKS IN THE FIELD OF THESIS

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1. **Munteanu M.G.**, Voicu Gh., Ferdeș M., Ștefan E.M., Constantin G.A., Tudor P., *Dynamics Of Fermentation Process Of Bread Dough Prepared With Different Types Of Yeast,* Scientific Study & Research Chemistry & Chemical Engineering, Biotechnology, Food Industry, ISSN 1582-540X, 2019, 20(4), pp. 575 – 584, *WOS:000502846500007*

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