

BREAD DOUGH KNEADING PROCESS OPTIMIZATION IN INDUSTRIAL ENVIRONMENT, USING A DEVICE FOR DOUGH CONSISTENCY CONTROL

Gheorghe MUSCALU¹, Gheorghe VOICU², Adriana ISTUDOR³

Bread dough kneading control is the key step in achieving high performance in bread making industry. This paper emphasizes the necessity of dough kneading process control and optimization in industrial field, using three main parameters: the mixing characteristics of the flour used in the process, the amount of added water (reported to flour) and the cumulated specific energy introduced into the dough. Optimal dough consistency and corresponding cumulated specific energy introduced into the dough were established through a series of nine tests, using a device which can control the consistency of dough for each batch.

Keywords: kneading process control; dough consistency; kneading control device; specific energy; added water.

1. Introduction

The kneading process is the crucial operation in bread making industry, by which flour, water and other ingredients, under the action of mechanical work, are transformed into coherent dough [1, 2, 3]. Work input and mixing intensity are two critical factors for optimal dough development [4, 5]. Work input can be defined as the energy required to mix the dough until the highest peak in the development curve is reached. The mixing intensity is the rate at which the dough is mixed. Both should be above a minimum critical value and vary with the flour properties and with the type of mixer used [6, 7].

The dynamic process of dough development causes low correlations between the dough rheological parameters (development time, dough stability, softness) obtained from different mixers. The empirical dough mixers like farinograph or mixograph have been developed to control the testing conditions at laboratory scale but these do not exert identical mixing actions not only between them but also in comparison with industrial mixers [8]. Even so, farinograph stability is well correlated to the mixing requirements of dough [9], while the mixograph development time is well correlated to the bakery mixing time [10]. Due

¹ PhD student, Faculty of Biotechnical Systems Engineering, University POLITEHNICA of Bucharest, email: gheorghe.muscalu@yahoo.com

² Prof., Faculty of Biotechnical Systems Engineering, University POLITEHNICA of Bucharest, email: ghvoicu_2005@yahoo.com

³ PhD student, Faculty of Biotechnical Systems Engineering, University POLITEHNICA of Bucharest, email: istudor.adriana@yahoo.com

to the dissimilarities between laboratory analysis and industrial application, the flour's profile and its behavior has to be validated through tests in the industrial bread making process with a closer inspection of the real behavior of dough and the characteristics of the end product. Using specific energy introduced into the dough for kneading control is a worldwide known fact. But creating a good functional kneading system between the quality of the flour, its hydration (which depends on the properties of flour and on the technological possibilities of the bread making plant) and the right amount of specific energy introduced in the bread making dough, represents a complex phenomenon that can't be controlled by only one parameter. Also, creating a real time image of the kneading process can bring huge advantages for industrial bread making, where control at a large scale is as necessary as it is difficult.

The paper approaches this problem through a series of tests for kneading process optimization in the bread making plant Panifcom, located in Iasi.

Our goal was the analysis and optimization of the kneading process, using a device which can be attached to any conventional mixer. The device uses the cumulated specific energy introduced into the dough as the control mechanism for dough consistency.

The specific objectives of this study were to 1) evaluate wheat dough mixing characteristics using the conventional mixer and the attached device; 2) establish the optimal quantity of added water into the dough for the specific industrial bread line in comparison to the one recommended by the farinograph; 3) evaluate the influence of different quantities of cumulated specific energy introduced into the dough by comparing the volumes obtained for the finished product; 4) analyze the recorded data in order to establish the optimal kneading process for the bread making plant where the tests were performed.

2. Materials and methods

Flour

For the experiments, it was used Romanian wheat flour provided by 7 Spice mill, Iasi, 2016 production (fig.1a). Laboratory analysis showed 61% water absorption, 1.9 minutes, development time and 3.1 minutes stability time (fig.1a), using a Brabender farinograph (AACC 54-21).

Compared to an Italian wheat flour for example as shown in fig. 1b), the one used in the experiments is considered to be of medium to lower quality, as are most Romanian wheats.

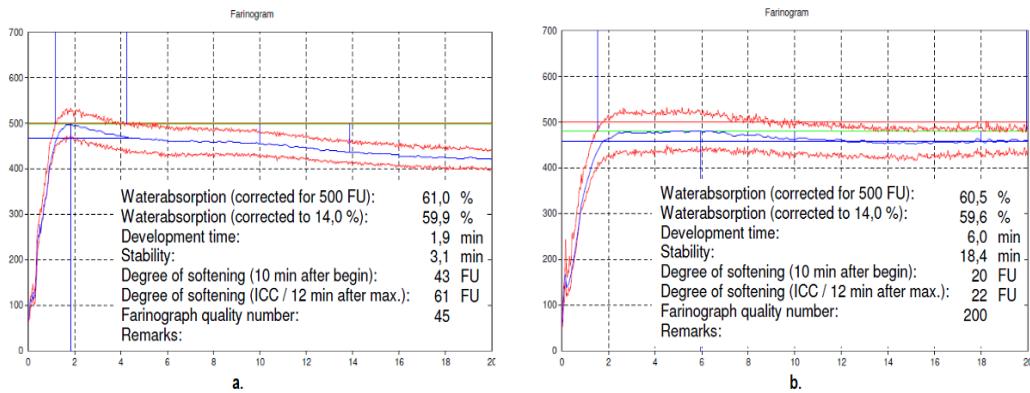


Fig.1 Wheat flour analysis: a) flour from 7Spice mill, medium quality (used in experiments),
b) high quality flour, Manitoba mill, Italy

Equipment

For the kneading process the following equipment was used: industrial kneader, developed by San Cassiano Italy, type GDA 340, Hydra, with double kneading arm and variable speed (0-150 rpm), at which was connected the system for kneading process optimization called SOPF, developed by BioTecnologiCreativ company, an electrical current intensity transducer and two flaps for ingredients discharge control. For the volume measurements of the bread samples, it was used a bread analyzer, type BVM – 6630 at the plant's laboratory. The equipment can be seen in Fig. 2.



Fig. 2 Equipment used in the experiments

In Fig. 3 it is presented the logical diagram of SOPF system which has an integrated acquisition and data processing unit (11) and measures current through a tension translator (10), consumed by the engine which powers the kneading arm (4) and the engine which powers the kneader's vat, in order to control the kneading process by stopping the kneader using two electrical relays (9). The device

determines the optimal consistency (energy set point) and shows it on tactile screen (12) as a kneading diagram and stops the kneader when usable input energy, cumulated in every second of kneading, reaches a previously established value (considered optimal). Through the screen (12), the operator can set the work recipe which is composed of batch kilograms, energy set point, minimal time of kneading and a safety value line (3), under which the kneading process is faulty and the dough can't be used correctly in the process.

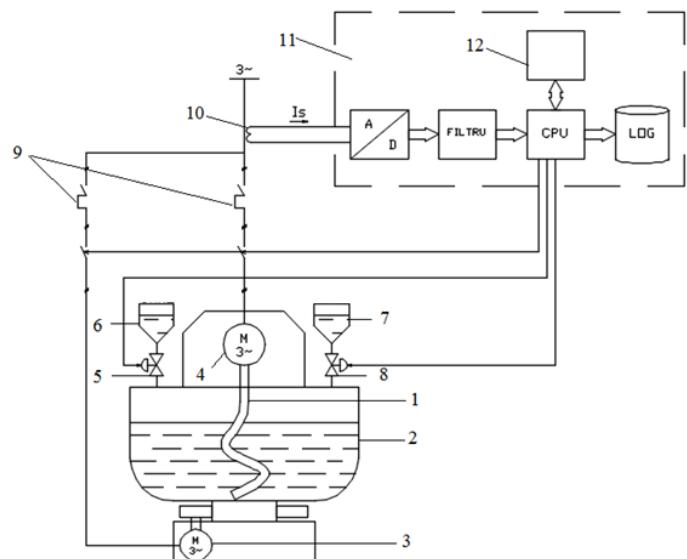


Fig.3 Phase diagram of SOPF system, connected to the industrial kneader

Because Romanian flour has little stability time and a greater softening degree than other European flour, dough development curve decreases rapidly after the peak (see fig.4, left). Figure 4 presents the way the specific energy is transferred to the dough for both types of flour (Romanian, left and Italian, right, see also fig.1).

The available systems on the market control the kneading process using a time step of one second for specific energy input. The kneading process is stopped when the specific energy input is reached, regardless of time and dough development. In many situations, the kneading process would be stopped before obtaining the proper development of dough (as is the case with Romanian flours).

It is possible to control the kneading process by calculating the surface under the kneading curve, described by the specific energy monitored and registered in each second. The kneading process is stopped when the dough is optimally developed and reaches a cumulated specific energy input.

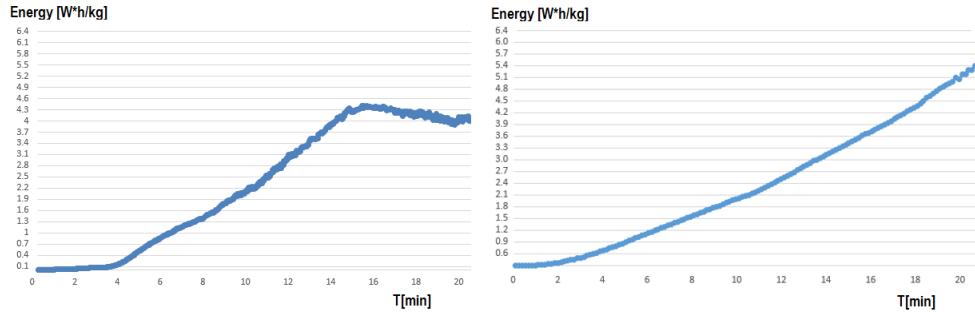


Fig.4 Energy transferred to the dough for: left - Romanian flour, right – Italian flour

Figure 5 shows a kneading diagram developed by SOPF system, which also allows the operator to take instant captions: 1 is the curve obtained with the maximal values for energy couple, 4 portrays the minimal values, 2 is the curve developed with medium values, 3 represents the safety line (the minimal consistency accepted by the bread making process where the tests are performed) and 5 represents a table of values like: the maximum value for the energy couple, dough extensibility (the distance between maximal, minimum and medium curve at the end of kneading time) and also the value for instant energy input and total energy input at the end of kneading, which has to be the same with set point.

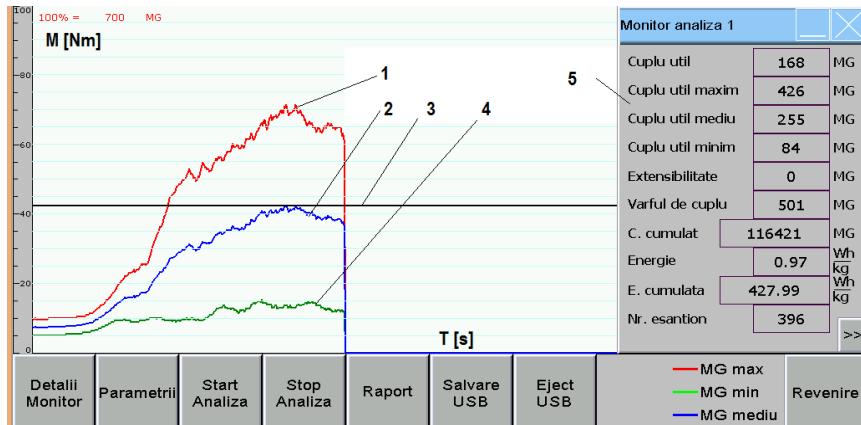


Fig. 5 Diagram for kneading process developed by SOPF system

Algorithm

For graphical diagram of the kneading process, dynamic development and interpretation of data, the device uses a mathematical algorithm.

Considering the general relation for calculating the necessary driving power on the working arm and at a given rotation, n (rpm), it can be written:

$$P = M_m \frac{\pi n}{30} \quad (1),$$

where: M_m is the opposing moment at the kneading arm, and P is the corresponding power of this moment [3].

The SOPF system measures the electrical current intensity consumed by the kneading arm's engine. The following parameters are considered constant: electrical tension, $U = 400$ V, the power factor, $\cos \Phi = 0.8$ and the rotations of the kneading arms are measured using a rotational transducer. Before calculating the opposing moment at the kneading arm, working without load current consumption at the kneading arm's engine is measured and eliminated.

$$M = M_t - M_g \quad (2),$$

where: M_t – total opposing moment at the kneading arm calculated using the measurements of electrical current intensity consumed by the kneading arm's engine during the kneading process; M_g – the opposing moment at the kneading arm when working without load.

A calculus example for a 35 ampere (A) consumption at a kneading arm's rotation of 80 rpm/min is presented below.

$$M = \frac{P}{\omega} = \frac{\frac{\sqrt{3} \cdot U \cdot I \cdot \cos \varphi}{\frac{\pi \cdot n}{30}}}{\frac{3,14 \cdot 80}{30}} = \frac{1,73 \cdot 400 \cdot 35 \cdot 0,8}{3,14 \cdot 80} = 2314.93 \text{ [Nm]} \quad (3)$$

The SOPF system uses conventional units called MG ; an MG unit equals 3 N·m. The opposing moment at the kneading arm becomes:

$$M = \frac{2314.93}{3} = 771.64 \text{ [MG]} \quad (4)$$

The energy consumed in the kneading process (E) is obtained using the following formula:

$$E = P_m t_f = M_m \frac{\pi n}{30} t_f = \frac{S_n}{9,55} \quad (5)$$

At a constant rotation ($n=\text{constant}$), the consumed energy is dependent only on the surface area under the kneading curve, S : $E = f(S)$.

The specific kneading energy ε can be determined using the report between the consumed energy E and the mass of the dough, Al_c .

$$\varepsilon = \frac{E}{Al_c} \quad [\text{J/Kg}] \quad (6)$$

For energy input measurement in each second, the following formula was used:

$$E = \frac{M \cdot \omega \cdot t}{Md} \quad [\text{J} \cdot \text{h/Kg}] \quad (7),$$

where: M is the opposing torque at the kneading arm (Newton meter), ω is the angular speed (radians/second), t is the kneading time (seconds) and Md , dough mass (Kg).

Previous research showed that dough control using instantaneous specific energy introduced into the dough, using just the formula presented above, does not satisfy every kneading process, especially when lower quality flour is being used, as are the majority of Romanian flours. The SOPF system controls the moment when the kneading is stopped, using the cumulated specific energy introduced into the dough.

The sum of energy input measured every second of kneading is equivalent to the integrated sum of areas under the curve.

$$\sum_{k=1}^n E = E_1 + E_2 + E_3 + \dots + E_n \quad (8)$$

Using as a reference value the surface under the kneading curve described by the cumulated specific energy input, the SOPF system introduces the same amount of total energy into the dough, kneading stronger flours for a longer time than the weaker ones.

Method

The dough recipe used in all tests was: flour type 650 – 112 Kg, salt – 2.1 kg, leavening agent – 3,6 Kg, improver – 1 Kg, and added water (reported to flour quantity) ranging between 52% and 56%. Kneading time was established 3 minutes for first speed (80 rpm) and second speed (150 rpm), 5 minutes for the tests in the first part, and variable for the tests in the second part.

Five kneading tests were performed with different amounts of added water (flour weight basis), adding successively 1% at each batch. Dough's behavior and its acceptability in the next steps of bread making process were analyzed in order to establish a permanent kneading time, the optimal quantity of added water to suit the process and obtain a good finished product. The percentage of added water, reported to flour was established as being optimal at 54%.

The recorded data using the SOPF system was introduced in the Excel program for comparison with the standard analytical equations (linear, power, logarithmic, and exponential) in order to find which trend line best describes the influence the amount of added water has over the consistency of dough.

After establishing the working parameters described above, we performed four kneading tests, at different set levels of total specific energy input (280, 330, 380 and 450 [W·h/Kg]), in order to evaluate the influence it has over the volume of the finished products and establish which level of specific energy introduced into the dough is best suited for the technological process where the tests were performed. From each batch, 10 samples of bread pieces were randomly selected for volume comparison.

The tests results were introduced in an ANOVA analysis, provided by EXCEL program.

3. Results and discussions

Figure 6 presents the 5 kneading batches using different quantities of added water, but keeping all the other working parameters constant, for data accuracy.

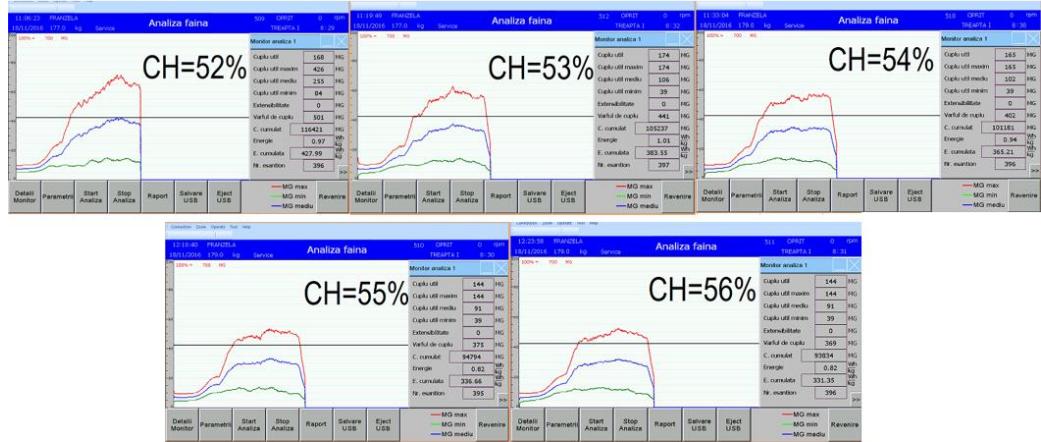


Fig.6 Kneading curves with different amounts of water, from 52% to 56%

The peak registered for every batch has decreasing values for the opposing moment at the kneading arm, which pinpoints the progressive decrease in consistency. This is better shown in figure 7, where the values for each peak were introduced in a trend line, using the Excel program.

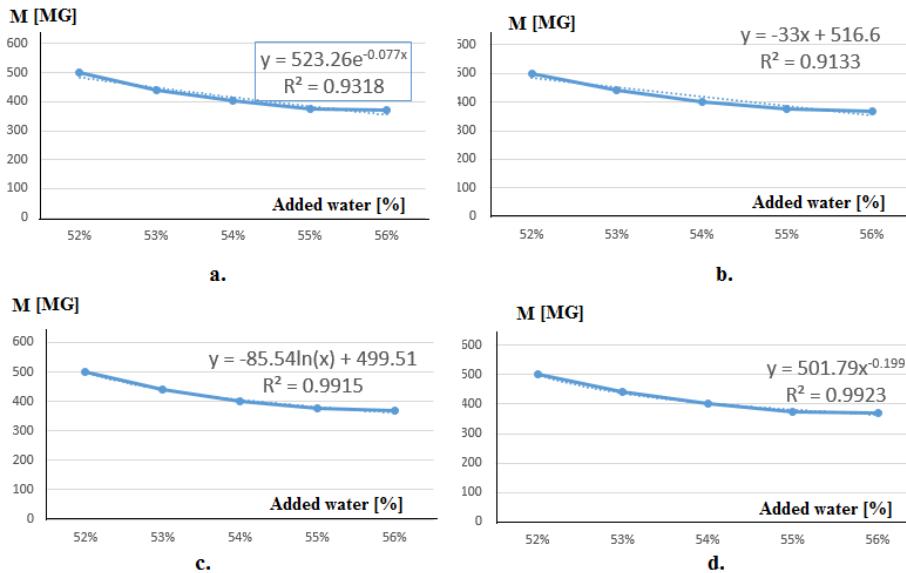


Fig. 7 Analytical equations which describe the change in consistency for each percent of added water: a) exponential, b) line, c) logarithmic, d) power

Analyzing the values obtained for the peak moments in each batch with different quantities of water, it can be said that for the type of kneader used, the best trend line that suits is the power one, with an R^2 value of 0.99, function which does not express a direct proportion between the quantity of added water and dough's consistency.

Because the most important element in the bread making process is the final product, the ones obtained using different amounts of cumulated specific energy introduced into the dough were compared in terms of volume. The values obtained for the volume of the bread samples can be seen in Table 1. In Table 2 results for the ANOVA analysis can be observed.

Table 1
Bread volume variation at different levels of cumulated specific energy introduced into the dough

Bread volume/Specific total energy	280 [W·h/Kg]	330[W·h/Kg]	380[W·h/Kg]	450[W·h/Kg]
[Cm ³ /100g]	532	550	586	542
	530	535	566	544
	545	569	570	539
	530	567	581	545
	542	560	570	550
	538	563	570	538
	540	560	570	539
	542	562	552	543
	535	550	585	544
	540	558	570	545

Table 2
Summary of ANOVA with a single factor analysis

Anova: Single factor

SUMMARY

Groups	Count	Sum	Average	Stdv	Variance
280 [W·h/Kg]	10.00	5374.00	537.40	5.36	28.71
330[W·h/Kg]	10.00	5574.00	557.40	10.02	100.49
380[W·h/Kg]	10.00	5720.00	572.00	10.01	100.22
450[W·h/Kg]	10.00	5429.00	542.90	3.60	12.99

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7244.08	3.00	2414.69	39.84	1.57E-11	2.87
Within Groups	2181.70	36.00	60.60			
Total	9425.78	39.00				

The ANOVA analysis shows significant differences between the bread volumes obtained at different levels of cumulated energy introduced into the dough. The differences between the bread volumes of the same batch can be attributed to random errors in the bread making system which can be neglected as their influence is too small to affect significantly the quality of the experiments being performed.

The collected data shows that the best result was obtained for the cumulated specific energy introduced into the dough of 380 [W·h/Kg]. The values of 280 and 330 [W·h/Kg] weren't enough for a proper gluten development which caused improper fermentation, while the specific energy of 450 [W·h/Kg] was too large; dough registered a high degree of softening which caused improper working with the dough in the next steps of the bread making process. It can be said that 380 [W·h/Kg] represents the critical energy level, after which, dough enters in an accelerated process of softening. Figure 8 presents a graph for the bread volume obtained at each specific energy introduced into the dough and figure 9 presents photos with the slices of bread corresponding to each of the four values.

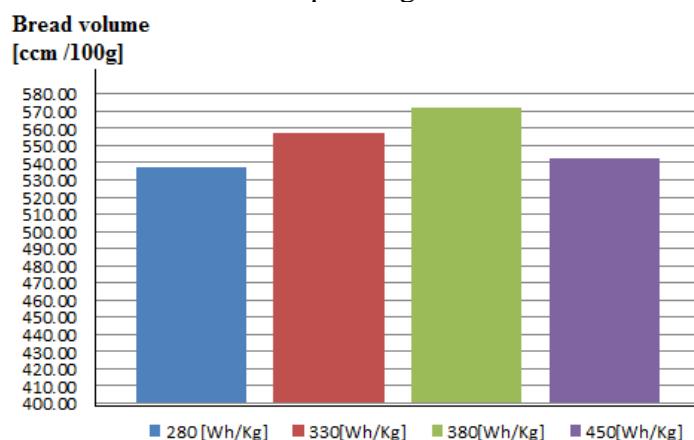


Fig. 8 Bread volume variation with cumulated specific energy introduced into the dough

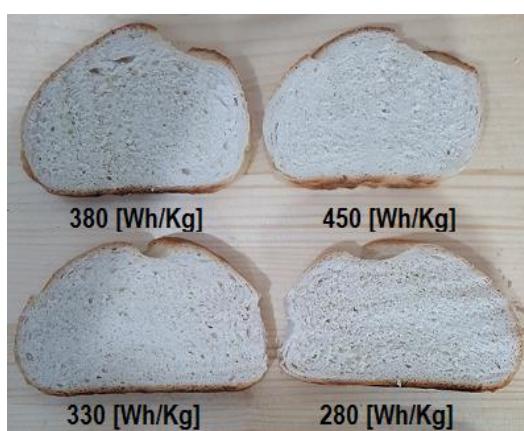


Fig. 9 Bread slices samples for different specific energies introduced into the dough

4. Conclusions

Kneading is a complex phenomenon which can be controlled by creating a symbiosis between flour properties, the optimal quantity of specific energy introduced into the dough and the technological limitations of the line where bread is being processed. For Romanian flour and mainly for medium and low quality flour the cumulated specific energy introduced into the dough is an essential element for proper dough development due to its little stability and greater softening degree. Controlling the kneading process after this parameter versus instantaneous energy input is more reliable because powerful flour has a different behavior than medium or weak flour.

For an optimal dough development, it is important to know the right amount of water which can be added to the flour being processed and the optimal quantity of specific energy introduced into the dough during the kneading process, at which the dough registers a peak in gluten development. The cumulated specific energy introduced into the dough decreases with each percent of added water but in a nonlinear way, the best trend line describing this process being the power analytical expression. The results obtained with water quantity variation in dough (reported to flour) showed a clear image over the influence it has over the kneading process. The values of consistency obtained at different levels of hydration can be used for creating a scale in the kneading process for future flour processing.

The visible variation in bread volume for dough kneaded at different levels of cumulated specific energy introduced into the dough shows the clear necessity to control this parameter, which can give the possibility to stabilize an industrial process and obtain higher quality end products.

For the bread making process where the tests were performed, the optimal water absorption was established at 54% reported to flour. The dough was considered fully developed after kneading to a cumulated specific energy set point of 380 W h/kg, for a fixed 3 minutes on first speed (80 rpm) and variable kneading time on second speed at 150 rpm.

By mounting the system for dough control, it is possible to monitor and control the final consistency of dough, stopping the kneading process after the cumulated specific energy (previously determined to be optimal) for that individual bread making process. The entire bread making process increases in stability which results in better quality of the end products and smaller fabrication costs. By visualizing every kneading curve, the operator can choose the optimal kneading regime, in order to obtain the best results in dough development, replacing the usual organoleptic analysis performed at the end of kneading.

SOPF system is now permanently implemented at plant Panifcom, Iasi. It is developed by the BioTehnologiCreativ Company and is in the process of patenting [12].

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