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RELATIONSHIPS AMONG PROCESSING AND RHEOLOGIC PARAMETERS DURING WHEAT DOUGH MIXING AND THEIR ASSETS FOR THE INDUSTRIAL PROCESSING

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ABSTRACT

The wheat dough mixing process today, is not perceived only as the blending process of the input materials. During the wheat dough mixing there are many factors which affect the final quality and processiblity of wheat doughs. This study describe the rheologic behaviour of doughs mixed on the Diosna SP12 kneader in particular stages of their development in dependecy from the mixing settings. The processing parameters as mixing energy, temperature increase and spiral rotation was monitored with the causal relationships to the evolving rheologic parameters of processed dough. The basic presumptions about interrealtions among rheologic and processing parameters during dough development for used flours and mixer were adumbrated. The relations among rheological and processing properties towards to product quality were determined by baking tests.

Keywords: rheology, wheat dough, mixing

INTRODUCTION

Wheat flour today, is the basic material for the production of modern bakery products in the world. The dough production is elemental condition for production in bakeries. From the sixties of last century, the wheat dough and the process of its creation and development were subjected to wide scientific research. **Kilborn and Tipples (1972)** formulated, that there are two basic conditions, which must be satisfied for the proper dough creation. The imparted mixing energy must be higher as the critical minimum for the dough and gluten development and the mixing intensity must be above the border for the dough creation. In the same work, they find out, that the amount of rotations of mixing element is different if the angular velocity of the element is different (if the amount of mixer work is constant). These results were confirmed by **Frazier et.al. (1975)** and proven by later authors. It is well known that dough properties can be affected by many features with different significance, therefore the dough development and processing optimization towards best quality bakery products is quite difficult problem. The quality and quantity of gluten macropolymers is the main factor, which determine the dough rheologic parameters, and therefore the products properties as well **(Gras et.al. 2000, Don et.al. 2005, Wang et.al. 2007)**. However, the starch influence on the dough rheology is not insignificant **(Hoseney et.al. 1995).** The way, by which the proteins are formed during dough mixing are not random, what is supported by depolymerisation process during mixing **(Aussenac et. al. 2001, Skerritt et.al. 1999)**. By depolymerisation**,** the **c**ontent of GMP decrease from the start to the end of mixing, however the extent of depolymerisation is dissimilar for each particular quality of flour **(Lefebvre et.al. 2003, Kuktaite et. al. 2004)**. The amount of GMP is well corelated with extensographic parameters, relaxation properties and loaf volume, but poor correlations are for dough consistency during dough development **(Gras et. al. 2000, Weegels et. al. 1997)**. **Belton (2005)** sceptically thinking about the interrelations between proteins extracted from the doughs and their importance as descriptors of the mixing process and argue, that these extracted proteins are only part from whole macromolecule, and furthermore it is chemically treated. Therefore their inner composition and properties are changed. Due to this, the extracted part is not same as the part of macromolecules which have major influence on the dough properties. The differences in quality of proteins extracts obtained from same flour sample is emphasized in work of **Kuktaite et.al. (2004)**. **Don et. al. (2003b)** presented, that the specific voluminosity of proteins might play key role in relation to changes in dough consistency during mixing. With the increase of GMP voluminosity, the amount of physically bonded watter in GMP gel increase. This is possible only if molecular weight of GMP and inner GMP bonds increase as well. These results are in concordance with the observations of **Alava et.al. (2001)** and **Wesley et.al. (1998),** where the water mobility measured by NIR and NMR during dough development, were minimal. Presumably, it is consequence of maximal aggregation of proteins at these stages of mixing. From this point, the proteins and other flour constituents react on the mechanical treatment during mixing and by evaluation of their reactions on these process is porbably possible to determine that ones, which have major influence on the mixing process. Mixing process can be affected by the parameters of mixer as mixer geometry and speed of mixing **(Haraszy et.al. 2008, Gras et.al. 2000),** which play a key role during creation of dough matrix and final quality of bakery products **(Aamodt et. al. 2003, Basaran a Göcmen 2003)**. By increasing of mixer speed (Farinograph), the dough consistency increasing too, while the stability decrease **(Olivier and Allen 1992)**. The mixer geometry play significant role during dough formation, what is highlited in the paper of **Mani et.al. (2002)**, where the comparable consistency of dough were achieved on three mixers independently with the same flour sample (Farinograph, Mixograph and Hobart mixer), but the time of mixing were different for each mixer. The wet gluten was washed from dough in different stages of mixing in work of **Abang Zaidel et.al. (2008)**, the results conform that the elasticity of gluten were higher in point of maximal development with higher values for stronger flours. The elasticity of gluten altered in dependency from the mixing stage (from which the gluten was washed). The elasticity of dough was higher as elasticity of gluten, what is contrary with findings of **Kuktaite et.al. (2005)**, which determine oposite trend in strong flours. For the determination of optimal consistency, the energy consumption profile of mixer could be utilizable. This aproach were applied by **Hwang and Gunasekaran (2001),** where the maximum of work input were evaluated as optimal consistency. The optimum was differ for strong and weak flours. Furthermore, the amount of energy per kg of dough was dependent from amount of mixed dough. The main problem in wheat dough mixing optimization is, that there are poor corelations between dough parameters evaluated from laboratory mixers in comparison to parameters of doughs prepared in industrial mixers **(Haraszi et. al. 2008, Don et al., 2005, Zounis a Qualil 1997)**. The consequences of mixer geometry lie in the complexity of mixing forces which are applied during mixing inside active mixing space. The different force vectors cause different changes and reactions in dough molecular structures **(Dobrasczyk and Morgenstern 2003)**. **Weegels et.al. (1996)** in their effort eliminated the differences in mixer geometries define the point of mixing action equality as the point in which the content of GMP is same for the same sample. The same content of GMP was determined for Mixigraph (3.5 min.), Farinograph 10 (7.0 min) and Farinograph 50 (12.0 min.).

Due to the complexity of the creation of dough during dough development and numerous factors which play role in these processes, it is needed to provide measurable relations for industrial usage, which must be derived from the industrial mixer. For this purpose, all measurement of mixing energy, templerature and rotation were evaluated with using of the model of industrial kneader - Diosna SP12, which possess same mixer geometry as industrial devices. The resulting rheologic parameters and bakery test were evaluated in relation to mixing parameters.

MATERIAL AND METHODOLOGY

For the determination of changes during mixing, the two samples of flour type T512 (Vitaflora Kolárovo, Slovakia) with defined properties were used. The samples of the flours were evaluated according to the described methods. The content of the ash (ICC standard 104/1, 1990), content of the nitrogenous components (STN ISO 1871, 1997), moisture content (ICC standard 110/1, 1976) content of the wet gluten (ICC standard No. 106/2, 1984), content of starch (STN EN ISO 10520, 2002), falling number (ICC standard 107/1, 1995), extensibility of the gluten (STN 46 101-9, 1997) and Zeleny index (ICC standard 115/1, 1994) have been determined. The characterization of the rheological properties was performed by the Farinograph-E (Brabender OhG, Duisburg, Germany) (ICC standard 115/1, 1997), Extensograph-E (Brabender OhG) (ICC standard 114/1, 1992), Amylograph-E (Brabender OhG) (ICC standard 126/1, 1992). Falling number characterization was determined by Falling number 1500 Perten (ICC standard 107/1, 1995).

The dough was prepared with addition of 2.23% NaCl (db), saccharose 1.0% (wb), yeast (4% wb) and with distilled water (Farinograph waterabsorption to 500 FU adjusted without yeast). Each flour sample were mixed according to the various regimes of mixing by Diosna SP12, where the following parameters were evaluated: temperature increase (with use of electronic thermal test probe Pt 100), the number of revolutions of mixing spiral, the mixing speed as revolution frequency per second at the constant rounds of the mixing bowl and energy consumption on the rotor (energy requirement). Finished dough was subsequently evaluated by the Farinograph and Extensograph modified methodologies according to **Zitny et. al. (2010)**. During baking test, the formed dough loaf were placed to the baking form and rise in the rise chamber (30°C/30 min.). The baking tests were performed in the MIWE condo oven, during 35 min., temperature/time of first baking step = 220°C/20 min, and for second step = 240°C/15 min. Doughs were mixed by DIOSNA SP12 with all recipe components at once. The penetration tests were performed on Extensograph-E, by using of penetration solid sphere made from lead (Pb) with diameter 7.0 mm, which was connected with the moving hook of Extensograph device by fibre (length 0.3 m / material - nylon). The volume of loafs were measured after 4 hour cooling (lab. Temperature 25°C) and measured by using of seeds. Setting of the Diosna SP 12 mixer during tests is shown in Table 1.

Table 1 Settings of the Diosna SP12 mixer

ω [Hz] / R [U] / ω_D [Hz]	**ω [Hz] / R [U] / ω_D [Hz]**
30 Hz/ 450 U /50 Hz	70 Hz/ 550U /50 Hz
30 Hz/ 750 U /50 Hz	70 Hz/ 1000U /50 Hz
50 Hz/ 500U /50 Hz	70 Hz/ 520U /30 Hz
50 Hz/ 880U /50 Hz	70 Hz/ 940U /30 Hz
50 Hz/ 1000U /50 Hz	70 Hz/ 1000U /30 Hz
60 Hz/ 580U /50 Hz	80 Hz/ 580U /50 Hz
60 Hz/ 880U /50 Hz	80 Hz/ 880U /50 Hz
60 Hz/ 1000U /50 Hz	80 Hz/ 1000U /50 Hz

ω [Hz] – speed of spiral, R [U] – number of revolutions of mixer spiral, ω_D [Hz] – speed of mixing bowl.

Table 2 The parameters evaluated for individual tests

G.5	viscoelastic index after 5 cm (resistance after 5 cm/ extensibility)
Gmax	viscoelastic index in maximum of extensographic curve (resistance in max / extensibility)
Fp	penetration force
ExE	extensographic energy
Vm	loaf density (volume per gram of crust)
dE/dU	the changes of mixinf energy over rotation of spiral
dT/dU	the changes of temperature progress during mixing over number of spiral rotation

RESULTS AND DISCUSION

The used flour samples are evaluated in Table 3. Both samples are suitable for bakery production and accomplish requests for bakery flours.

Table 3 Flour sample characteristics.

Flour properties	*Sample A*	*Sample B*
Ash [%]	0.55 ± 0.02	0.54 ±0.02
Falling number [s]	261 ± 9	298 ± 14
N x 5.25 [hm.%]	11.9 ±0.2	12.2 ± 0.1
Starch content [%]	71.5 ± 0.4	72.1 ± 0.3
Zeleny test [cm3]	35 ± 1	39 ± 1
Max. Consistency [FU]	504 ± 8	500 ± 5
Waterabsorption 500 FU [%]	54.8 ± 0.1	58.8 ± 0.1
Waterabsorption (14 %) [%]	54.2 ± 0.1	58.7 ± 0.1
Development time [min]	1.7 ± 0.1	2.5 ± 0.1
Stability [min]	9.4 ± 0.1	11.3 ± 0.1
Degree of softening [FU]	32 ± 6	20 ± 5
Degree of softening ICC [FU]	59 ± 5	33 ± 5
Farinograph quality number (FQN)	97 ± 18	131 ± 9
Begin of gelatinization [°C]	62.6 ± 0.1	59.3 ± 0.2
Gelatinization maximum [AU]	465 ± 12	798 ± 35
Temperature in maximum [°C]	82.0 ± 0.0	86.1 ± 0.2

During dough development, the energy requirements for spiral motion and temperature increase of dough wary in a wide range (Fig.1 and Fig.2). With the increasing of mixing speed, the energy demands for one spiral revolution is higher with some stages, which could be described as peaks of kneaders work input. These peaks are not in same interval of number of revolutions, and depends from angular velocity of mixing spiral. These claims are fundamentally consistent with results of **Zounies and Qualil** (1997) or other authors **(Haraszi et.al. 2008, Olievier and Allen 1992)**. **Zheng et.al. (2000)** determine the exact amount of mixing energy for strong and weak flour samples (as [Wh.kg^{-1}], strong flour 18 and weak flour 9.7) for double blade mixer. These results are inconsistent with our measurement, probably due to the different mixer geometry and dissimilar speeds of mixing elements. This have significant influence for dough development **(Mani et.al. 2002, Hwang a Gunasekaran, 2001)** and gluten structure **(Weegels et.al 1996)**.

The temperature progress during mixing is strictly connected to the processes which are play role during particular stages of mixing, from flour hydration through dough development to dough overmixing. The temperature flow on figure 2 are represented by temperature change in the same measuring intervals as the measuring intervals for energy consumption on figure 1. It is visible that initial hydration in interval around 200U caused dissipation of energy in form of heat, in interval from 300U to 400U, the temperature increase was low, probably due to the dough structure formation, during which the energy is used more for creation of inner bounds than for dissipation in form of heat. Further course of changes in temperature could be described in details only within limited accuracy. By comparison of fig.1 and fig.2 for each one mixing speed, there are some perceptible connections. The energy consumption during processing of dough with lower spiral speed at 30 Hz, is similar in peaks localisation. For 50 Hz and 60 Hz, the progress of curves for energy requirements and temperature flow show some rough tendentions. When the work input increase (behind of 400U) the temperature decrease or is almost constant and vice versa. When the work input is almost constant, the temperature start to rise. Over the border of 800U, the changes of temperature growth and work input have similar course (the ending of the curves is excluded due to the ending of process – turn off the mixer). There is only rough approximation, which could play role in mixing process optimization. The detailed study of these thermal processes is needed and it is theme for further work.

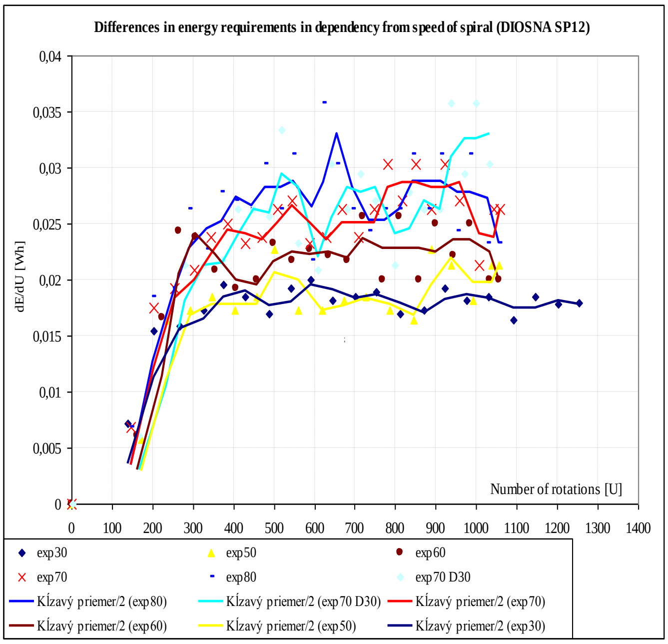

Fig.1 Energy consumption profiles of Diosna SP12 mixer during dough mixinig under differend speeds of spiral (the lines represent the moving average of measured work inputs)

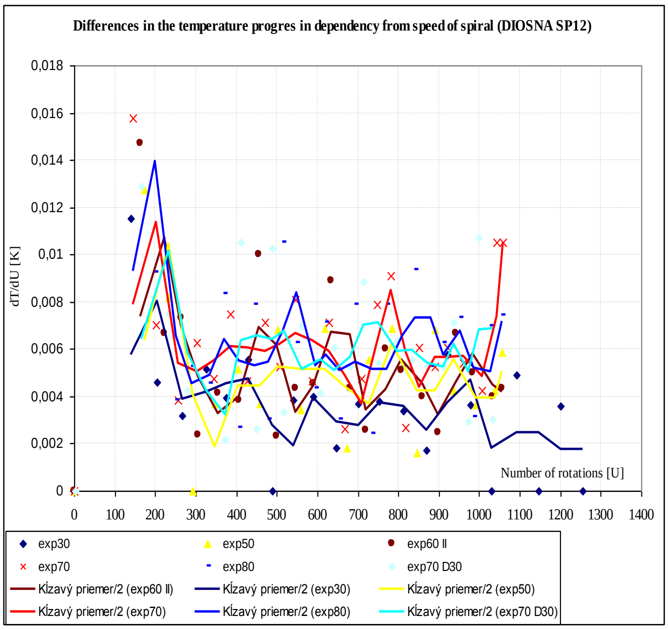

Fig.2 Temperature progress during mixing proces on Diosna SP12 mixer under differend speeds of spiral (the lines represent the moving average of points)

The maximal consistency of dough could be probably connected with maximal work input, but this is not necessary, if is taken to account, that the applied forces and therefore energy requirements in active mixing space can be affected not only by dough elasticity, but with forces arised from sticky dough behaviour after protein matrix degradation, as well. The extensographic evaluation (Ex. energy Fig. 3, and indexes of viscoelasticity G.5, Gmax – Fig. 4) shown, that extensographic energy increased with the speed of mixing, but only the maximal peak of extensographic energy (Ex.E) for each one speed regime is considered. The elasticity in these maximal peaks of Ex.E, is higher in comparison to other values, measured under same mixing conditions. Important is, that extensograph energy can rise up with increasing of both, elasticity and plasticity. Substantial is, if the ratio between elastic and plastic response of dough is in equilibium or not. This is presumably the reason, why Ex.E can rise up even if elasticity (Gmax, G.5) falling down at the end of the mixing spectra (Fig. 3 and 4). This is probably implication of depolymerisation effect, when the proteins molecular weight inside dough matrix decreased as consequence of imparted mixing energy behind the point of maximal consistency **(Don et.al. 2003 a,b,c, Gras et. al. 2000, Lefebvre et. al. 2003)**. This is rheologically accompanied with decreasing of consistency and elasticity of doughs. At the end of the mixing spectra (around 1000 U), the elasticity of all dough decreased, while Ex.E decreased slightly, but only for speeds over 70 Hz. During relaxation phase (Fig. 3 and Fig. 4) the doughs tested after 30 min. with previous extension showed higher elasticity (G.5.15+ and Gmax.15+) opposite to elasticity of doughs only rested 30 min (G5.30 and Gmax.30). Furthermore, their elasticity was higher in comparison to doughs tested after 15 min. of resting. This observation is valid for all mixing speeds, and probably relate with claims about reagregation of GMP during resting, where the partially rested doughs are more mobile inside dough matrix, therefore are able to create new crosslinks and entanglements among protein chains, which finally lead to the increasing of dough resistance and hence elasticity **(Li et al. 2003, Rao et.al. 2000)**. The trend of Ex.E values and values of loaf volume are very similar for mixing speeds up to 50 Hz, over this border, the course of loaf volume values are more close to Gmax values. With the increasing of volume per gram of loaf crust (Fig. 5), the penetration force (Fig. 6) decrease. According to **Don et. al. (2005)** and many other authors **(Haraszi et. al. 2008, Kuktaite et. al. 2005, Weegels et. al. 1996)** the volume of wheat loafs is well correlated to omount of GMP, and GMP are well correlated with results of extension test (extensibility, resistance to uniaxial extension). The optimally mixed dough must lead to bigger loaf volumes with elastic crumb. Crumb elasticity depend from cell wall elasticity, and is well known, that i tis function of cell gas volume (with the increasing of gas volume, the sell wall is more thinner and loss the elasticity). So, the consequence of this claim is, that the objective coparision of crumb elasticity (performed by penetration test) could be performed only on the loafs with same volume (under same processing conditions). Anyway, the course of changes in penetration force is fundamentally comparable with viscoelastic moduli G.5 and Gmax from extensographic tests. The loaf density trends is contrary well comparable with course of changes of Ex.E. Only the results from speed 60 Hz and 580U is out of this connection. For the further work, the mathematical reciprocal correlations for all properties and features will provide.

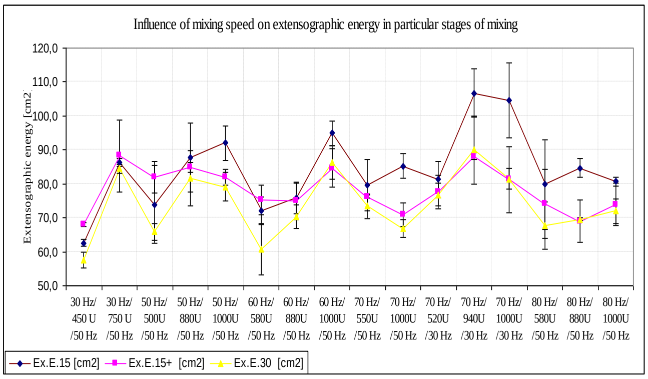

Fig. 3. The changes of extensographic energy in dependency from speed of mixing and number of spiral revolutions

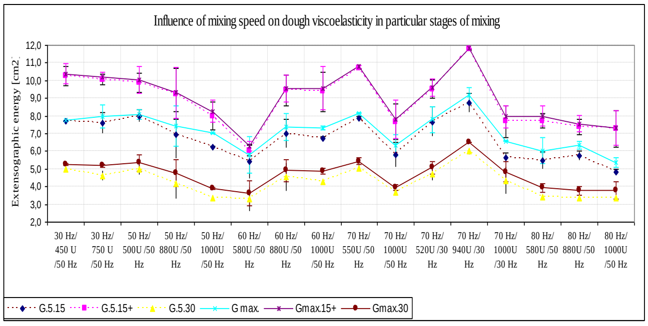

Fig. 4. The changes of dough viscoelastic properties - dependency from speed of mixing and number of spiral revolutions

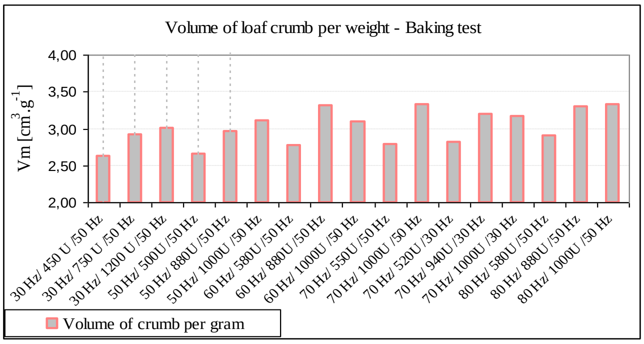

Fig. 5. The changes of loaf crumb density - dependency of loaf density from speed of mixing and number of spiral revolutions

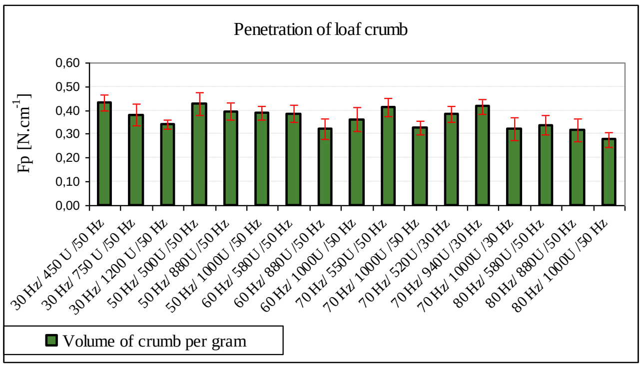

Fig. 6 The changes in penetration force in dependency from speed of mixing and number of spiral revolutions

CONCLUSION

This paper described the changes in energy requirements during dough development and mixing. With increasing of spiral speed, the work input for spiral rotation increase too. The progress of energy requirements among the particular speeds of mixer in different, furthermore, the the increase of work input is caused by different physical forces at the start and at the end of mixing. During first stage the dough is more elastic, while at the end of mixing period became more plastic, what contrary cause the increase of work input. The plastic and elastic response of dough had influence on the way of temperature progress behaviour. However these observations are only rough, there are fundamental perception about interrelations, which could be possible applied for optimization of mixing process. The penetration tests reveals its close relation to viscoelasticity of dough, while density of baked loafs are connected to extensographic energy. The crumb elasticity and density of crumb are inversely correlated. All results were connected only to used flour samples and laboratory equipment, therefore usability and versatility of results are limited.

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