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EFFECT OF VACUUM IMPREGNATION AND INFRARED RADIATION TREATMENT ON ENERGY REQUIREMENTS IN WHEAT GRAIN MILLING

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Summary. The paper presents the results of a study on the energy requirements of the process of wheat grain milling. The grain was prepared for the milling through the application of combined treatments of vacuum impregnation at pressures of 5 and 100 kPa and IR treatment at temperatures of 150 and 180°C during 90 and 150 s in various variants. It was found that the method of grain preparation for milling affected the energy consumption. The consecutive application of the processes of impregnation and micronisation caused an increase in the energy requirements of the grain milling process. That energy requirement was higher in the case of grain impregnation at 5 kPa.

Key words: energy consumption, vacuum impregnation, infrared radiation treatment, milling, wheat.

INTRODUCTION

In cereal processing grain is frequently subjected to various processes related with a change in its moisture content. Grain moistening causes a number of various changes. The inner structure of kernels changes. The forces binding proteins and starch are reduced, and the kernel structure gets damaged through the appearance of strains caused by the various levels of swelling of the particular components [Obuchowski et al. 1981].

Increase in the moisture of maize grains by as little as 1.5% already causes the appearance of internal damage. The extent of the damage increases with increasing moisture and attains its maximum after 8 hours of grain contact with water [Wu et al. 1988]. The cause of the damage to grain structure is excessively fast imbibition of water due to the low initial moisture level [Sivritepe et al. 1995].

In the course of soaking of wheat grain there takes place intensive lateral cracking of the parenchyma. The appearance of such cracks leads, in consequence, to a reduction in the kernel hardness index [Grundas et al. 1998]. Among other strength properties of grain that are affected by the process of moistening we should also mention the decrease, by half, of the value of the modulus of elasticity [Singh et al. 2001].

Moistening reduces the mechanical strength of cereal grain. That decrease is observed at moisture levels above 11% [Obuchowski et al. 1985]. Whereas, there takes place an increase in the energy requirements for grain fragmentation. In the case of wheat kernels, that parameter doubles in value within the moisture range of 10 – 18% for soft wheat cultivars, and for durum wheat cultivars – increases 1.5-fold [Jurga 1997, Dziki et al. 2004, Opielak et al. 2004, Dziki et al. 2005, Grochowicz et al. 2006].

In the cereal industry a variety of equipment is used for the realisation of the process of grain moistening. Their operation consists is sprinkling a grain deposit with a specific amount of water which is then distributed on the surface of the kernels by means of various methods (e.g. the Bühler or the Vibronet systems). In such an approach to the process the uniformity of grain moistening is far from perfect. However, the approach is highly convenient from the technological point of view, as it permits relatively easy determination of the final moisture level at the end of the process. It does, however, present a number of difficulties, which is evident in the fact that at large processing plants the technological process provides even for triple moistening of the same grain material prior to the milling. Such a philosophy of realisation of the process of grain moistening enforces, moreover, long periods of grain tempering. In the case of durum wheat the duration of grain tempering may be even 36 hours.

In the study presented here the grain material was moistened using the vacuum impregnation technique, one of the new techniques in food processing, permitting notable intensification of the process of mass exchange in the solid-liquid system, which causes uniform moistening of kernels in their outer layers, without wetting the parenchyma [del Valle et al. 1998, Betoret et al. 2003, Chiralt et al. 2001, Guamis et al. 1997, Gonzalez et al. 1999, Chafer et al. 2003, Fito et al. 1996, Fito et al. 2001]. However, grain subjected to vacuum impregnation is characterised by too high moisture levels, in some cases even exceeding 20%, to be directly subjected to milling. Hence the proposal to apply the technique of infrared radiation treatment (micronisation) that guarantees the possibility of obtainment of virtually any desired grain moisture level prior to the milling and ensures favourable changes in the structure of the kernels. Another advantage of the process is the fact that the times of grain exposure to infrared radiation are very short (up to 3 min), which minimises the energy consumption.

The objective of the study was to determine the effect of vacuum impregnation and IR radiation treatment on the energy consumption in the process of milling.

PURPOSE AND METHODS

The experimental material was wheat grain cv. Koksa and Sukces. The grain was moistened to several levels of initial moisture content. The milling of the grain was performed on a laboratory mill Quadrumat Junior presented in Fig. 1.

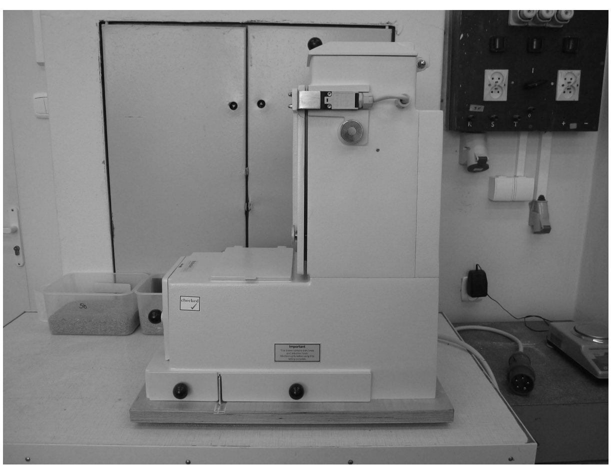


Fig. 1. Laboratory mill Quadrumat Junior

It is a four-roller laboratory mill with an aspiration system and a drum sifter. The milling of a grain sample using this mill corresponds to the milling parameters obtained in industrial mills. Determinations of grain material moisture prior to and after the moistening, and of the flour and bran obtained as a result of the milling, were made with the over-dry method in accordance with the standard PN-86/A-74011. Grain moistening was conducted in sealed containers. A laboratory balance with an accuracy of 10^{-2}g was used to weigh portions of 500 g of each kind of grain, the portions were placed in the containers, and then water was added in such amounts as to obtain the required levels of grain moisture. Then the containers with the grain material were sealed, shaken and placed in a refrigerator for a period of 72 hours.

During the milling, the energy consumption of the process of fragmentation of wheat grain in the laboratory mill Quadrumat Junior was measured with the help of a Lumel PP83 transducer.

Impregnation of wheat grain

The process of grain impregnation was conducted in a chamber with a volume of ca. 2 dm^3, coupled to a vacuum pump permitting the regulation of pressure win the chamber within the range of 5-100 kPa. The chamber was immersed in the water bath of an ultra-thermostat which permitted the process to be conducted under various temperature conditions. To ensure complete immersion of all kernels, they were placed in a container made of wire mesh. The level of pressure in the chamber was recorded by means of a vacuum gauge. The cover of the camber was additionally equipped with a system of valves connecting the chamber with the vacuum pump and a water reservoir. The tight sealing at the interface between the chamber and the cover was achieved by means of a gasket greased with vaseline.

After placing the vacuum chamber in the ultra-thermostat, the temperature of the process of grain moistening was set. The temperature of 15°C was applied. The water wetting the grain was at a temperature similar to that of the temperature in the chamber. The differences between those temperatures were within ±2°C. After the temperature in the chamber stabilised, a container with a weighed portion of grain material, with a weight of ca. 40 grams, was placed in it.

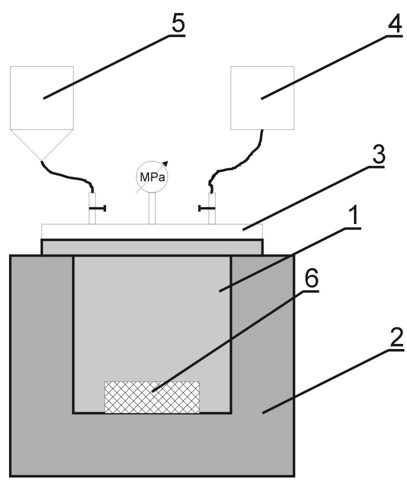


Fig. 2. Schematic of the measurement system for the study of the process of vacuum impregnation of grain: 1 – vacuum chamber, 2 – ultra-thermostat, 3 - cover, 4 – vacuum pump, 5 – water reservoir, 6 – container with grain material

Next, when the hydraulic hoses were filled with water, the chamber was closed and, after opening the valve connecting with the vacuum pump, the pressure in the chamber was set. The pressure levels applied in the study were 5 kPa and 100 kPa – atmospheric pressure (control treatment). When the pressure stabilised, the valve connecting with the water reservoir was closed. Each time the grain sample was flooded with a portion of water with volume of ca. 0.2 dm^3. In the course of flooding the grain sample with water, a slight increase of the pressure in the chamber was observed as the chamber filled with the water. The control sample was moistened following a similar procedure, but under the conditions of atmospheric pressure.

When the grain sample was fully flooded, the pressure was rapidly brought up to the atmospheric pressure. Grain samples were taken immediately after the impregnation (after about 30 seconds of contact with water).

The measurement system is presented in Fig. 2.

Grain heating with IR radiation

The process of grain heating with IR radiation was conducted with the help of a device designed and constructed by Andrejko [2004]. The main elements of the system (Fig. 3) are frame 1, belt conveyor and a heating system with stepless temperature adjustment. The grain material is pursed into chute 3, equipped with a shutter, and then it is fed onto the belt of the conveyor (single layer). The material on the conveyor belt is moved to the heating zone 8, where it is subjected to treatment with infrared radiation. The conveyor is powered by a DC electric motor with a voltage regulator permitting smooth adjustment of the belt speed within the range from $5\times10^{-3} m\times s^{-1}$ to $7\times10^{-2} m\times s^{-1}$ (the material remains in the heating zone for 15 to 200 s, respectively). The conveyor belt material is characterised by considerable resistance to high temperatures (up to 250°C) and low IR transmittance (ca. 10%). The device is equipped with two heating heads 2 (each with 4 IR radiators); the upper head, positioned above the belt, and the lower head, located beneath the belt.

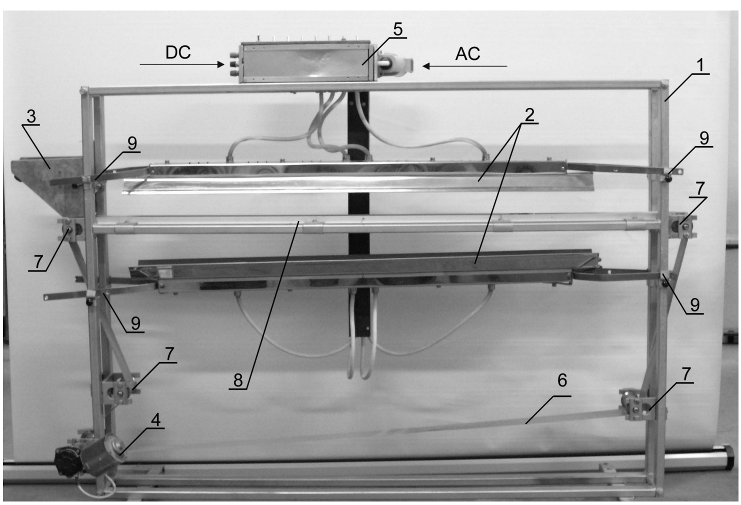
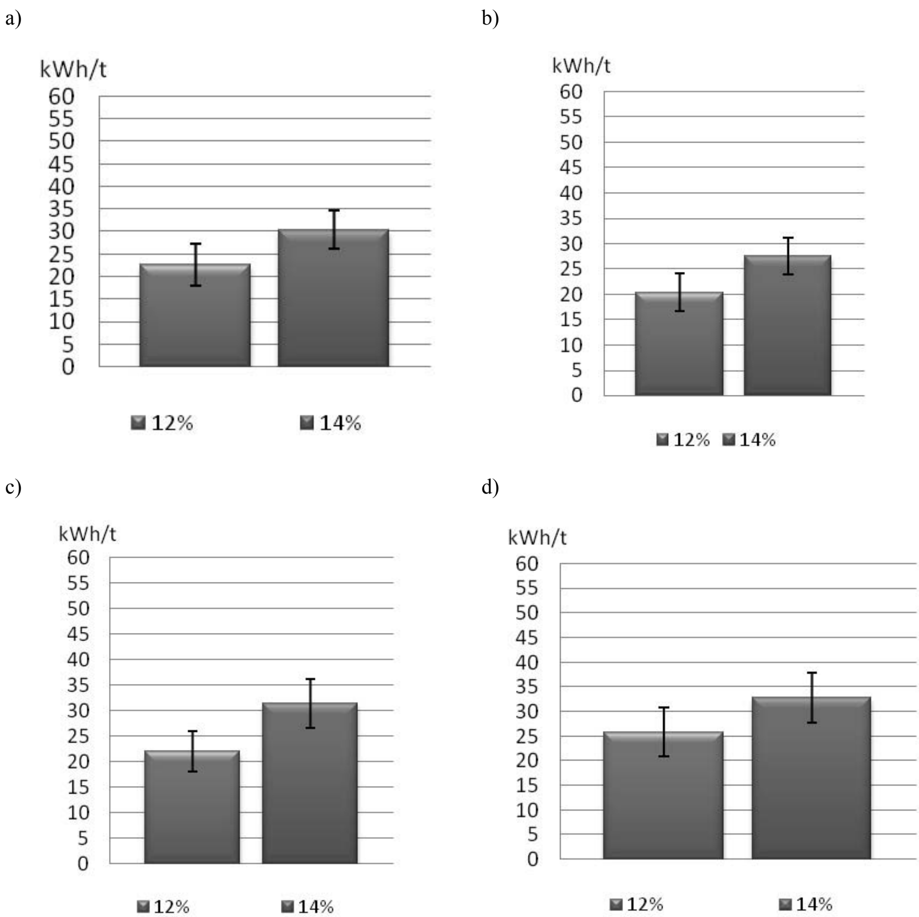


Fig. 3. Laboratory device for IR treatment of granular plant materials; 1 – frame, 2 – heating head with 4 IR radiators with individual power supply, 3 – filling chute, 4 – DC motor, 5 – control module, 6 – conveyor belt, 7 – rollers, 8 – heating zone, 9 – adjustment of heating head position

For heat treatment of small grains it is sufficient to use only the upper head. When heating large seeds, e.g. those of white lupine, it is recommended that the lower head is also switched on. In such a case the belt of the conveyor should be replaced with a belt of φ = 0.1 mm copper wire, with square mesh of 1 mm side. Such a wire mesh has IR transmittance of over 90%.

IR radiation is emitted by 8 individually supplied radiators (4 in each section). Those are temperature radiators, built of ceramic material, supplied with mains power (230V), and their power rating is 400W. In their spectrum the share of visible radiation is at a level of a fraction of one percent (dark emitters). Due to their design (flat panel emitters) they provide uniform heating at all points of the surface of the conveyor belt within the heating zone. Mean temperature of the emitter surface is ca. 500°C, and the emitted wavelength is λ = 2.5-3.0 µm.

RESULTS AND DISCUSSION



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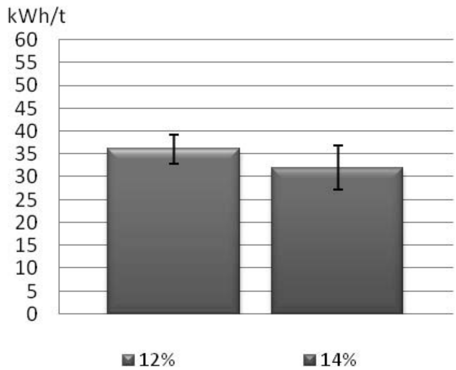
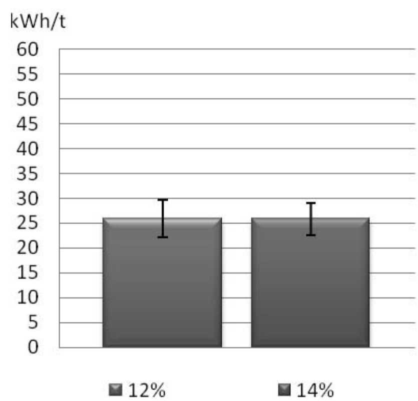


Fig. 4. Effect of consecutive processes of impregnation and micronisation on energy requirements of the process of milling of wheat grain cv. Koksa. Initial moisture of the grain samples - 12%,14%:

a) Zero sample, grain not subjected to any treatment,
b) Impregnation of grain at atmospheric pressure, micronisation for 90 s,
c) Impregnation of grain at atmospheric pressure, micronisation for 150 s,
d) Vacuum impregnation of grain at 5 kPa, micronisation for 90 s,
e) Vacuum impregnation of grain at 5 kPa, micronisation for 150 s.

Figure 4 presents the effect of the consecutive processes of impregnation and micronisation on the energy requirements for the milling of wheat grain cv. Koksa, with initial moisture content of 12% and 14%. Grain subjected to impregnation and micronisation showed a slight increase in energy requirements, only the sample with initial moisture of 12%, subjected to impregnation at 5 kPa and micronised for 150 seconds displayed a significant increase in milling energy requirements. Measurement for grain with initial moisture of 16% was impossible due to the high plasticity of the material, which precluded the operation of the laboratory mill.

a)



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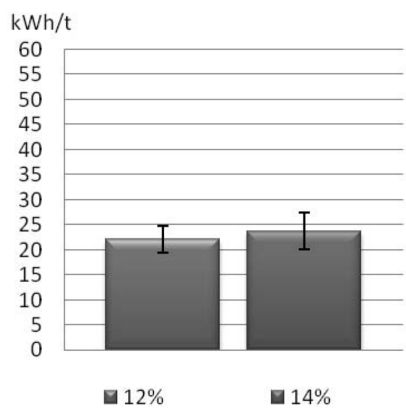

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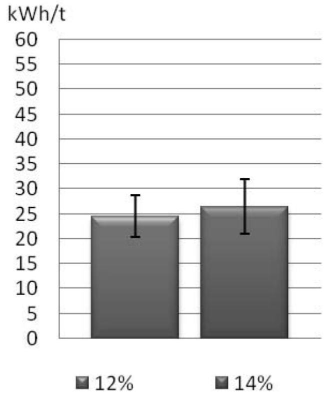

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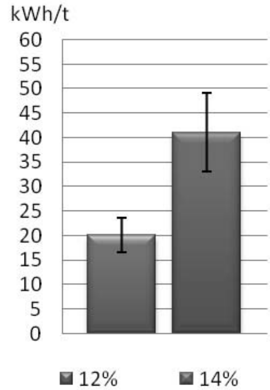

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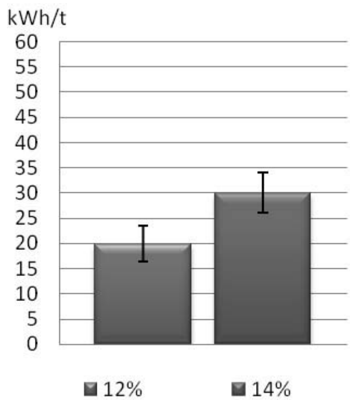

Fig. 5. Effect of the process of micronisation and of the consecutive processes of impregnation and micronisation on energy requirements of the process of milling of wheat grain cv. Sukces. Initial moisture of the grain samples - 12%,14%:

a) Zero sample, grain not subjected to any treatment,
b) Impregnation of grain at atmospheric pressure, micronisation for 90 s,
c) Impregnation of grain at atmospheric pressure, micronisation for 150 s,
d) Vacuum impregnation of grain at 5 kPa, micronisation for 90 s,
e) Vacuum impregnation of grain at 5 kPa, micronisation for 150 s.

Figure 5 presents the results of measurements of energy requirements of the process of milling of samples of wheat grain cv. Sukces. Grain samples with initial moisture content of 12% and 14% could be tested, while the experiment with grain sample with initial moisture of 16% was impossible due to the high plasticity of the material, which caused the laboratory mill to block. In all the cases an increase was observed in the energy requirements for the milling process, the highest after the application of vacuum impregnation at 5 kPa.

CONCLUSIONS

The results obtained permitted the formulation of the following conclusions:

1. Preliminary treatment of wheat and rye grain consisting in micronisation at 150°C for 90 and 150 s caused a slight increase in the amount of energy required for the milling of 1 ton of the material.
2. Consecutive application of the processes of impregnation and micronisation caused an increase in the energy requirements for the process of milling. That requirement was greater in the case of the application of vacuum impregnation.
3. Impregnation of grain with initial moisture content of 16% resulted in an excessive level of moisture of the material, with resultant increase in its plasticity, which made it impossible to conduct the milling of the grain.

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WPŁYW IMPREGNACJI PRÓŻNIOWEJ I OBRÓBKI PROMIENIOWANIEM PODCZERWONYM NA ENERGOCHŁONNOŚĆ PRZEMIAŁU ZIARNA PSZENICY

Streszczenie. W pracy zaprezentowano wyniki badań energochłonności procesu przemiału ziarna pszenicy. Ziarno przygotowano do przemiału przez zastosowanie połączonych zabiegów impregnacji próżniowej w ciśnieniu 5 i 100 kPa oraz obróbki promieniowaniem podczerwonym w temperaturze 150 i 180 ^{o}C i czasie 90 i 150 s w różnych wariantach. Stwierdzono, że sposób przygotowania ziarna do przemiału ma wpływ na energochłonność. Zastosowanie kolejno po sobie następujących procesów impregnacji i mikronizacji powodowało wzrost zapotrzebowania energii na proces przemiału. Zapotrzebowanie to było większe w przypadku zastosowania impregnacji w ciśnieniu 5 kPa.

Słowa kluczowe: energochłonność, impregnacja próżniowa, obróbka promieniowaniem podczerwonym, przemiał, pszenica.