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HYDRAULIC RESISTANCE OF AIR FLOW THROUGH WHEAT GRAIN IN BULK

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Summary. The paper presents the results of a study on the resistance of air flow through wheat grain in bulk. The value of resistance is affected primarily by the air flow velocity and material density that is dependent on external load and its duration. An increase of wheat grain density from 0.787 to 1.063 kg·dm^{-3} and an increase of air velocity from 0.15 to 0,5 m·s^{-1} caused an increase in flow resistance from 0.73 t 9.24 hPa·dm^{-1}. Changes in grain density and hydraulic resistance were described with mathematical equations.

Key words: airflow resistance, grain, wheat, density.

INTRODUCTION

Ensuring high quality of cereal grain bulk in storage is assuming an increasingly great importance. There are various methods of cereal grain preservation, but the most frequently applied is the method of active aeration. In the course of that process, knowledge of air flow resistance through grain deposit is highly significant for practical purposes [Kizun, Kusińska 2004]. Airflow resistance depends on the air velocity, grain deposit thickness, and on the properties of the grain material (i.e. kind of grain, its bulk density, porosity, content of contamination, and moisture content) [Siebenmorgen *et al.* 1987, Sokhansanj *et al*. 1990, Jayas and Muir 1991, Dairo and Ajibola 1994, Giner and Dienisienia 1996, Waszkiewicz 1999, Nimkar *et al*. 2002, Ray *et al.* 2002, Kusińska 2005]. The value of airflow resistance can be also strongly affected by the pouring density of grain that may depend on its moisture content or on the method of silo charging [Molenda *et al*. 2005a, Molenda *et al.* 2005b]. Airflow resistance is not a constant feature and depends on the duration and conditions of grain storage [Szwed 2000]. Any particulate or granular material in storage undergoes compaction under the effect of its own weight, which results in deformation of grains and has a detrimental effect on the grain quality features [Szwed, Kusińska 2005]. That process may cause an increase in airflow resistance in grain bedding, which is not taken into consideration in research works. In the literature there is a notable lack of results of research on airflow resistance in grain deposits compacted under the effect of high pressures. In metal silos it is frequent for the grain filling height to be close to twenty metres, which causes its compaction and an occurrence of high load pressures in the lower layers of grain. Air flow through grain and seed beddings is most frequently described by means of equations of Ergun [1952], Shedd [1953], and Hukill and Ives [1955].

OBJECTIVE

The objective of the study presented herein was to determine airflow resistance in wheat grain bedding with relation to air velocity, and grain density. The density of wheat grain of different levels of moisture content varied under the effect of external loads of variable duration.

METHOD OF RESEARCH

The study was performed on wheat grain cv. "Elena" with moisture content of 16% d.b. Measurement of airflow resistance in grain bedding was performed on a test station (Fig. 1), the basic element of which was a replaceable cylindrical container 1 with inner diameter of 76 mm and height of from 280 to 560 mm (capable of holding grain samples with thickness of 120 – 400 mm). The container was filled with grain to the maximum charge height (400 mm). Measurements of air flow resistance were made at apparent air flow velocities of 0.15, 0.3, 0.4 and 0.5 $m \cdot s^{-1}$. Passage of air flow through the grain sample was enforced by a suction-pressure fan 2 with adjustable output controlled by means of autotransformer 3. Airflow intensity was measured by means of a gas rotameter 4. Static pressure drop of the air flow passing through grain samples was measured by means of a differential liquid micro-manometer 5.

Successive samples of wheat grain were subjected to vertical external loads of 17.5 kPa, 35 kPa, 52.5 kPa and 70 kPa. The maximum load value was equivalent to ca. 10-metre height of silo filling with the grain material. The duration of load application was 2, 4, 12 and 24 hours. Prior to each air flow resistance measurement, the grain sample was weighed and its height was determined for density determination. All measurements were made in triplicate.

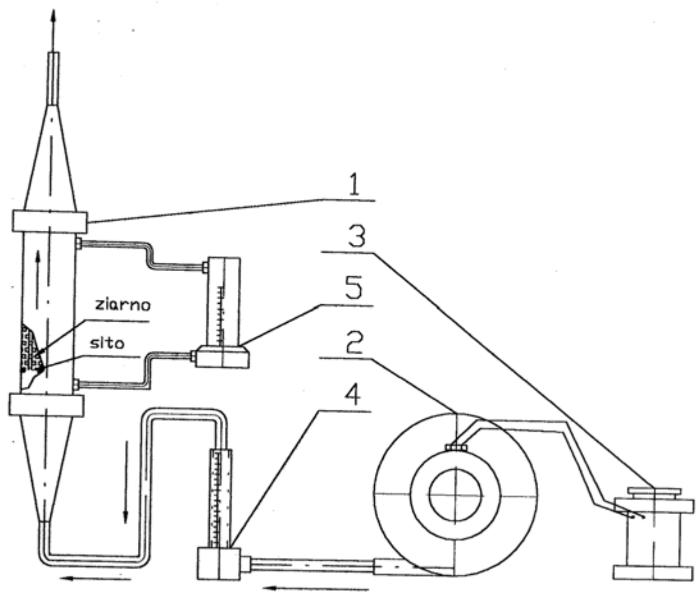

Fig. 1. Diagram of the test station: 1 – cylindrical container (silo), 2 – suction-pressure fan, 3 – autotransformer, 4 – gas rotameter, 5 – liquid micro-manometer

The design of the test station precluded an occurrence of air turbulence before and after passage through the tested sample, thanks to the application of narrow-angle (12^o) cones controlling air supply and exhaustion. Uniform distribution of air flow velocity was tested by measuring dynamic air pressure at specified points at the inlet and outlet of the measurement column.

RESULTS AND ANALYSIS

The results of wheat grain density ρ in relation to the value of load P and its duration time τ are presented in Fig. 2. The lowest value of grain density was obtained for grain not subjected to the effect of any external load (0.787 kg·dm^{-3}). Sample loading for two hours at external load values from 17.5 to 70 kPa caused an increase of wheat grain density to 0.888 and 1.001 kg·dm^{-3}, respectively.

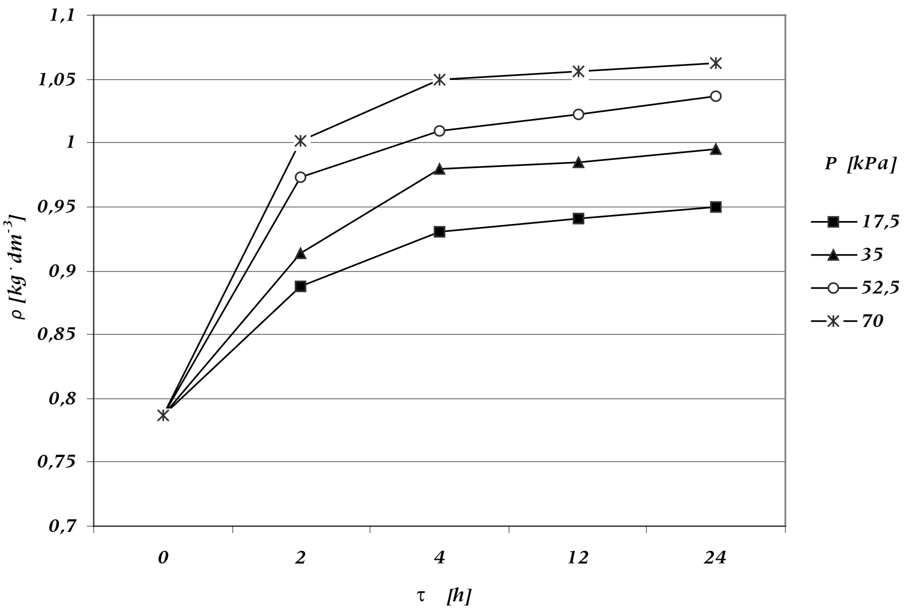

Fig. 2. Relation of wheat grain density to external load and its duration

The highest increases in density were observed during the initial four hours of load application. After that time the values of grain density corresponding to load values of 17.5 and 70 kPa were 0.931 and 1.049 kg·dm^{-3}, respectively. The highest values of grain density were obtained after 24 hours of load application. In this case the load of 70 kPa caused an increase of grain density to the level of 1.063 kg·dm^{-3}. Extension of the duration of load application from 4 to 24 hours had a small effect on the density increase. An analysis of variance did not reveal any significant differences between the obtained results.

The relation of wheat grain density to the value and duration of external loading can be described by means of the following multiple regression equation (R^2=0,928 and $\alpha \leq 0,01$):

$$\rho = 0{,}844 + 0{,}0022P + 0{,}0239\ln\tau, \quad (1)$$

where:
ρ – density of grain [kg· dm^{-3}],
P – load applied to grain bedding [kPa],
τ – duration of load application [h].

There is a high level of correlation between the dependent variable ρ and the independent variables. The coefficient of correlation between density ρ and load P has the value of 0.95, and between density and lnτ its value is 0.88.

The relation of unit air flow resistance in wheat grain bedding subjected to the effect of external load from 0 to 70 kPa, lasting for 2, 4, 12 and 24 hours, is presented in Fig. 3.

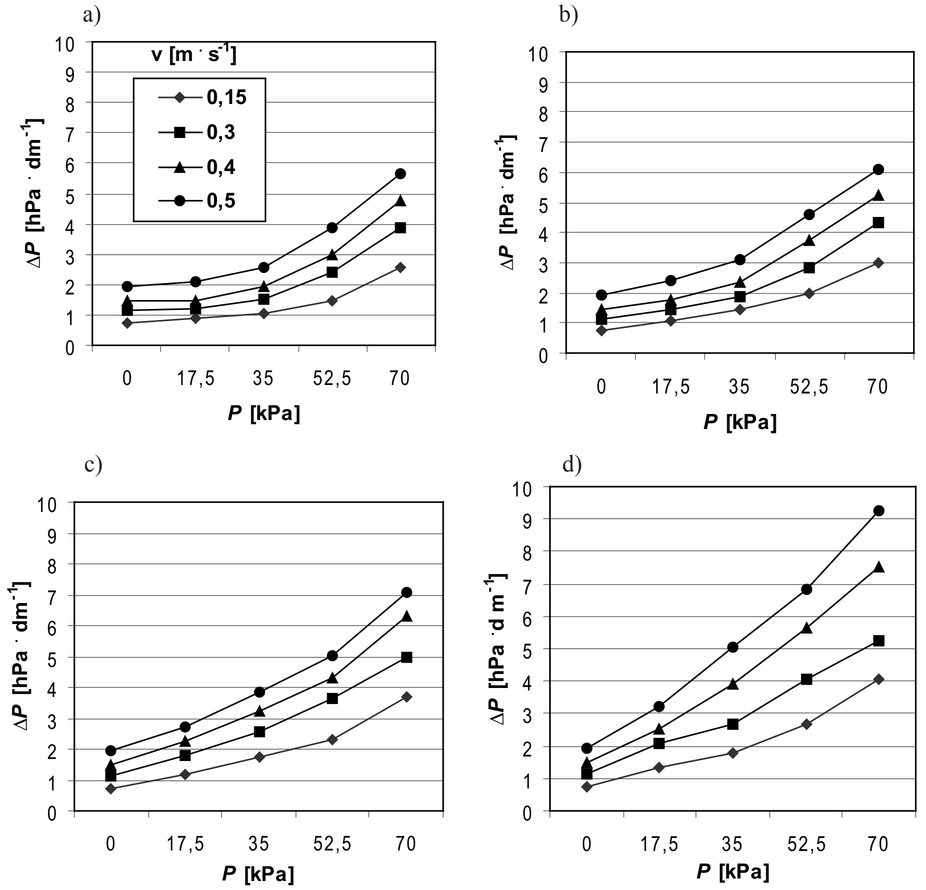

Fig. 3. Unit air flow resistance in wheat grain as a function of grain loading and air flow velocity. External load duration: a) 2 h, b) 4 h, c) 12 h, d) 14 h

The increase of air flow resistance was caused by the increase of the air flow velocity, value of the applied external load, and extension of the duration of load application. At the air flow velocity increase from 0.15 do 0.5 $m \cdot s^{-1}$, grain not subjected to external load was characterised by unit air flow resistance values from 0.73 to 1.93 $hPa \cdot dm^{-1}$. Air flow resistance of grain loaded for 2 hours with load value of 70 kPa, for the air flow velocity increase from 0.15 do 0.5 $m \cdot s^{-1}$, increased already from 2.59 to 5.63 $hPa \cdot dm^{-1}$ (Fig. 2a). Four-hour duration of loading under the same conditions resulted in unit air flow resistance increase from 2.98 to 6.12 $hPa \cdot dm^{-1}$ (Fig. 3b), twelve-hour – from 3.67 to 7,07 $hPa \cdot dm^{-1}$ (Fig. 3c), and 24-hour – from 4.04 to 9.24 $hPa \cdot dm^{-1}$ (Fig. 3d).

Fig. 4 illustrates the relation of unit air flow resistance in wheat grain bedding to the grain density and the air flow velocity. Both independent variables cause an increase in air flow resistance.

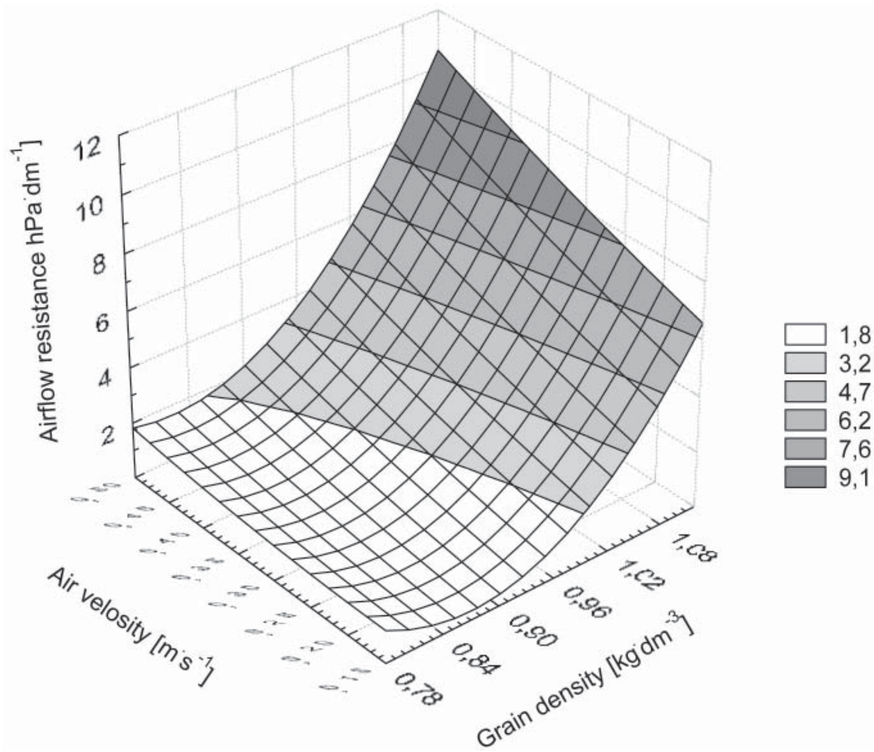

Fig. 4. Unit airflow resistance as a function of air velocity and wheat grain density

For the description of unit airflow resistance the Ergun [1952] equation was applied:

$$\Delta P = av + bv^2, \tag{2}$$

where:
ΔP – unit airflow resistance [$hPa \cdot dm^{-1}$],
v – air velocity [$m \cdot s^{-1}$],
a, b – empirical coefficients.

Following the inclusion in the equation of changes in grain density, the following relation was obtained, for which the participation of substantiated variance is 0.95 at $\alpha \leq 0{,}01$:

$$\Delta P = 7{,}43\rho^{7,5} \cdot (1{,}8v + 1{,}03v^2), \tag{3}$$

where:
ρ – grain density [kg·dm^{-3}].

Airflow resistance in wheat grain bedding not subjected to external load, at air velocities applied in the experiment, is comparable to the results obtained by other authors [Molenda et al. 2005b, Yayas et al. 1989]. The value of airflow resistance is dependent on the physical and aerodynamic properties of grain and seed. In the experiment presented here, greater values of unit air flowresistance were obtained for wheat grain than for rye under similar experimental conditions [Kusińska 2006] and higher than for oat grain [Kusińska, Kizun 2006].

An increase in density from 0.787 to 1.001 kg·dm^{-3} after two-hour application of loads of 0 and 70 kPa resulted, at air velocity of 0.15 m·s^{-1}, in an increase of airflow resistance from 0.73 to 2,59 hPa·dm^{-1}, and when air velocity of 0.5 m·s^{-1} and 24-hur load duration were applied, the increase in airflow resistance was from 1.794 to 9,24 hPa·dm^{-1}. Those values of airflow resistance were notably greater than the corresponding values for raw materials compacted with various methods of silo charging [Molenda *et al.* 2005a, Molenda *et al.* 2005b, Sokhansanj *et al.* 1990] and than resistance values of contaminated grain material [Siebenmorgen *et al.* 1987]. The obtained high values of unit airflow resistance were caused by grain deformation due to high pressure and by reduction in grain bulk porosity (from 34 to 11%). In the studies conducted by other authors the change in porosity was usually 2 – 3%, which was due mainly to the application of material with various moisture levels and not to an increase in the material's compaction.

CONCLUSIONS

1. External loads of 0 to 70 kPa applied to wheat grain bedding during times from 0 to 24 h caused an increase of grain density from 0.787 to 1.063 kg·dm^{-3}.
2. The highest increase in density occurs during wheat grain loading for up to four hours, for all the applied load values. Changes in density are statistically significant. Further extension of load duration does not cause significant changes in the parameter in question.
3. An increase of wheat grain density from 0.787 to 1.063 kg·dm^{-3} and of air velocity from 0.15 to 0.5 m·s^{-1} cause an increase of airflow resistance from 0.73 to 9.24 hPa·dm^{-1}.
4. A high increase of unit air flow resistance is caused by grain deformation under the effect of exerted pressure and notable decrease in porosity.
5. The effect of wheat grain density and air velocity on the unit airflow resistance can be described with high accuracy by means of a modified form of the Ergun equation.

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