INFLUENCE OF MOISTURE AND VERTICAL PRESSURE ON AIRFLOW RESISTANCE THROUGH OAT GRAIN*

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Abstract. The article presents the results of research on the airflow resistance through oat grain. The measurements were performed using raw material with the moisture ranging from 14% to 22% with variable load of its layer from 0 to 70 kPa over a period of seven days from the time the tank was filled. The airflow velocity was changed within the range from 0.1 to 1.0 m·s^{-1}. Key importance of the influence of the airflow velocity and mutual interactions between the storage time, vertical pressure and the moisture of the material on the value of hydraulic resistance has been determined.

Key words: airflow resistance, moisture, vertical pressure, oats

List of symbols:

ΔP	– airflow resistance [kPa·m^{-1}],
w	– raw material moisture [%],
t	– load duration [day],
v	– airflow velocity [m·s^{-1}],
a, b	– empirical coefficients.

Introduction

Poland is the leader in oats production in the European Union. At present it is grown on approx. 550 thousand ha in Poland, which makes up 6% of the area occupied by cereals [Sułek 2005]. Oats is valued for both its agrotechnical properties and nutritional value. It has quite low requirements as far as its growing conditions are concerned. It yields well in both dry and damp areas, in lowlands and mountainous areas as well as on nutrient-poor soils [Jasińska&Kotecki 1999]. The importance of oats in human and animal nutrition results from its chemical composition. Oat grain contains large amounts of protein, dietary fibre, unsaturated fatty acids, vitamins, mineral salts and antioxidants [Gibiński 2005].

Maintaining high quality of oats after combine harvesting requires fulfilling appropriate conditions during storage. Oats stored in silos is exposed to temperature fluctuations connected with changing times of day and seasons which cause moisture migration.

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As a result, layers which considerably exceed allowable moisture levels appear even in initially dry and uniform batches of grain.

Active airing of the grain silo is one method of preventing the occurrence of such phenomena. Mechanical ventilation requires familiarity with airflow resistance through a layer of grain [Kusińska 2007]. Airflow resistance depends on numerous factors, including the airflow velocity, grain layer thickness, physical properties of the deposit (type of grain, density, porosity, impurity content) and storage time [Sokhansanj et al. 1990, Jayas & Muir 1991, Giner & Dienisienia 1996]. Grain moisture also plays a significant role. An increase in moisture, especially in silos of considerable height, significantly changes both the character and the value of airflow resistance [Kobus et al. 2011].

No comprehensive study taking into account the combined influence of the moisture content and the height of the deposit on airflow resistance through oat grain is available in the literature.

Aim of the study

The aim of the study was to examine the influence of moisture and vertical pressure (resulting from the height of the deposit) on airflow resistance through oat grain.

Research methodology

The research was conducted using oats of the Sławko cultivar with the initial moisture of 14% and grain with added moisture reaching 18% and 22%.

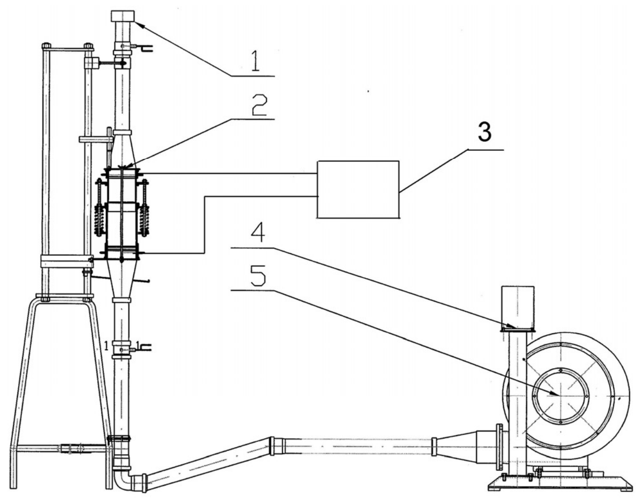


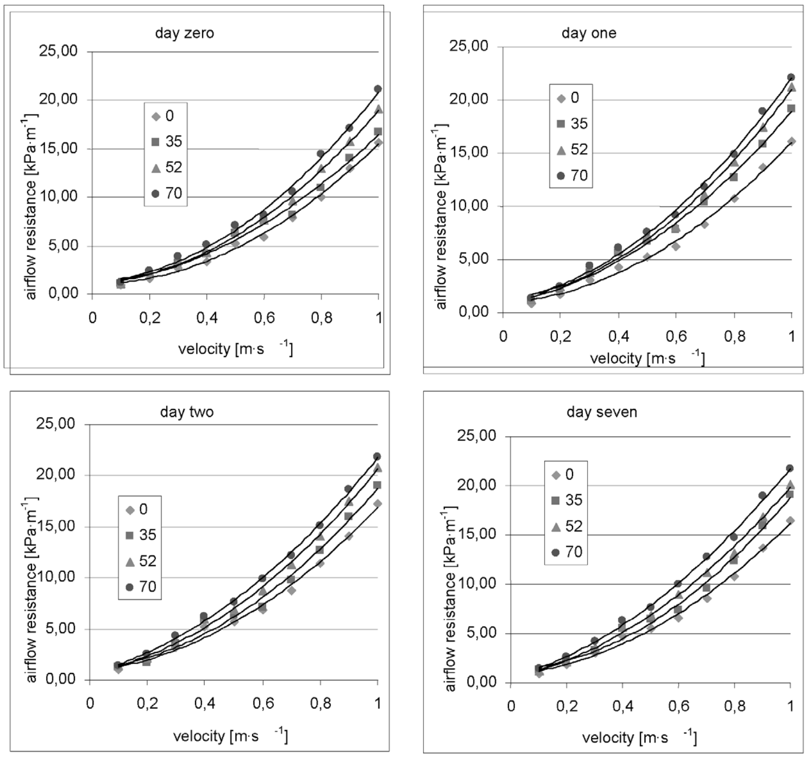
Fig. 1. Research station plan: 1 – aerometer 2 – cylindrical tank, 3 – micromanometer, 4 – inverter, 5 – fan with a suction and pumping system

Airflow resistance values were measured at the airflow velocity ranging from 0.1 to 1 m·s^{-1}. Airflow resistance through and empty tank was used to assess airflow resistance. The measurements were performed for grain stored at a temperature of 22°C. The experiment was performed in 7-day cycles and the measurements were made directly after filling the tank with grain and next 24 hours (1 day), 48 hours (2 days) and 168 hours (7 days) after filling. The airflow was induced using a centrifugal fan with a suction and pumping system connected to an autotransformer (Fig. 1). The airflow velocity was measured using a digital aerometer and a decrease in the static pressure using a digital micromanometer.

Four levels of vertical load were used during the experiment: 0 (control test) 35; 52.5 and 70 kPa. The last value corresponds to an approx. 10-metre height of the material in the silo. All measurements were repeated three times.

Results and discussion

The values of airflow resistance through oat grain with a 14% moisture level subjected to external load ranging from 0 to 70 kPa, lasting from 0 to 7 days are presented in Fig. 2.



Source: authors' own research

Fig. 2. The influence of the airflow velocity and vertical pressure on the value of hydraulic resistance in a layer of oats with a 14% moisture content

The increase in airflow resistance was caused by an increase in the airflow velocity and an increase in the load values. The extension of the load period also resulted in higher airflow resistance. Grain which was not exposed to external load was characterized by the airflow resistance ranging from 0.95 to 15.63 kPa·m^{-1} within the airflow velocities under analysis (from 0.1 to 1.0 m·s^{-1}). The airflow resistance increased together with the grain storage time and reached the value of 0.99-17.89 kPa·m^{-1} 7 days after the tank was filled. An increase in the external load caused higher airflow resistance through oat grain. The load on the layer of grain of 35 kPa caused an increase in airflow resistance directly after filling the tank to a value within the range 1.07-16.72 kPa·m^{-1}, the pressure of 52.5 kPa within the range of 1.12-19.09 kPa·m^{-1} and the pressure of 70 kPa within the range of 1.22 to 21.11 kPa·m^{-1}. The influence of the load duration on the airflow resistance value revealed a similar tendency as a deposit without load.

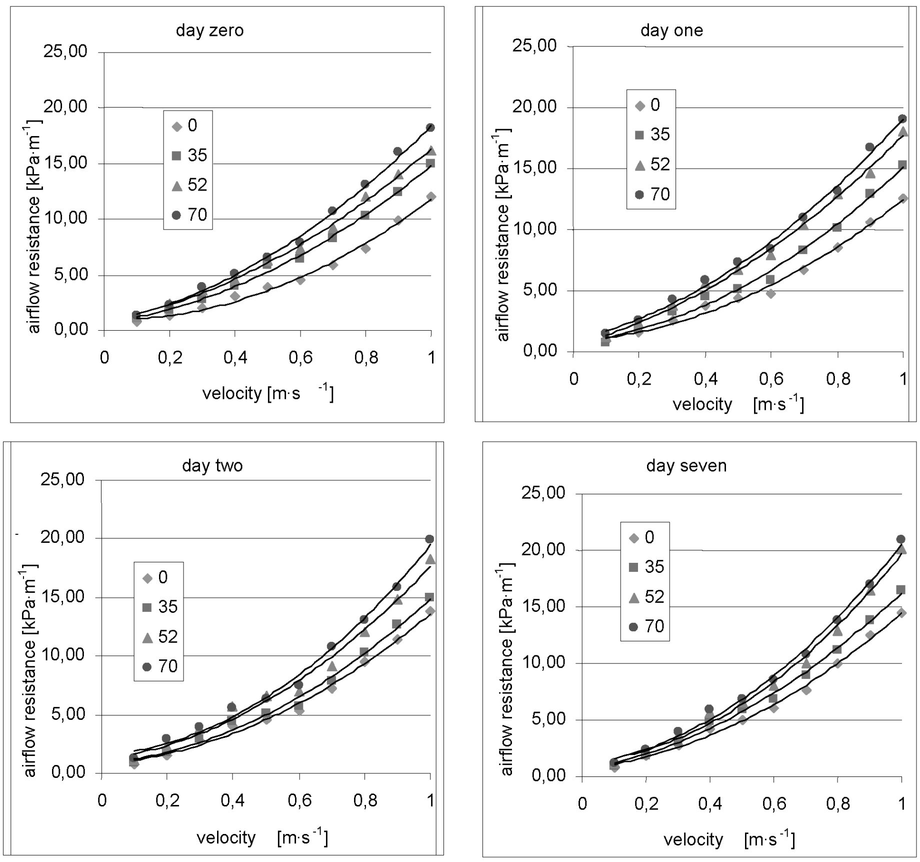


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Fig. 3. The influence of the airflow velocity and vertical pressure on the value of hydraulic resistance in a layer of oats with an 18% moisture content

Fig. 3 shows the values of airflow resistance through oat grain with an 18% moisture level subjected to external load ranging from 0 to 70 kPa, lasting from 0 to 7 days. An increase in the moisture of the material resulted in an insignificant decrease of airflow resistance (ranging from 0.84-12.00 kPa·m^{-1}) for grain which was not subjected to external load.

An increase in the external load caused higher airflow resistance through oat grain. Subjecting the layer of grain to a load of 70 kPa caused an increase in airflow resistance to the values of 1.31-18.12 kPa·m^{-1} directly after filling the tank and to the values of 1.41-20.95 kPa·m^{-1} on the seventh measurement day.

Fig. 4 shows the airflow resistance through oat grain with a 22% moisture content. A further increase in the moisture of the grain resulted in a decrease of airflow resistance to the values of 0.69-11.26 kPa·m^{-1}. External load on the grain, in turn, resulted in a very rapid increase in the airflow resistance. Increasing the load to the value of 70 kPa causes an over two-fold increase in airflow resistance (values within the range of 1.76-25.42 kPa·m^{-1}). Significant differences between the curves describing hydraulic resistance values occurred.

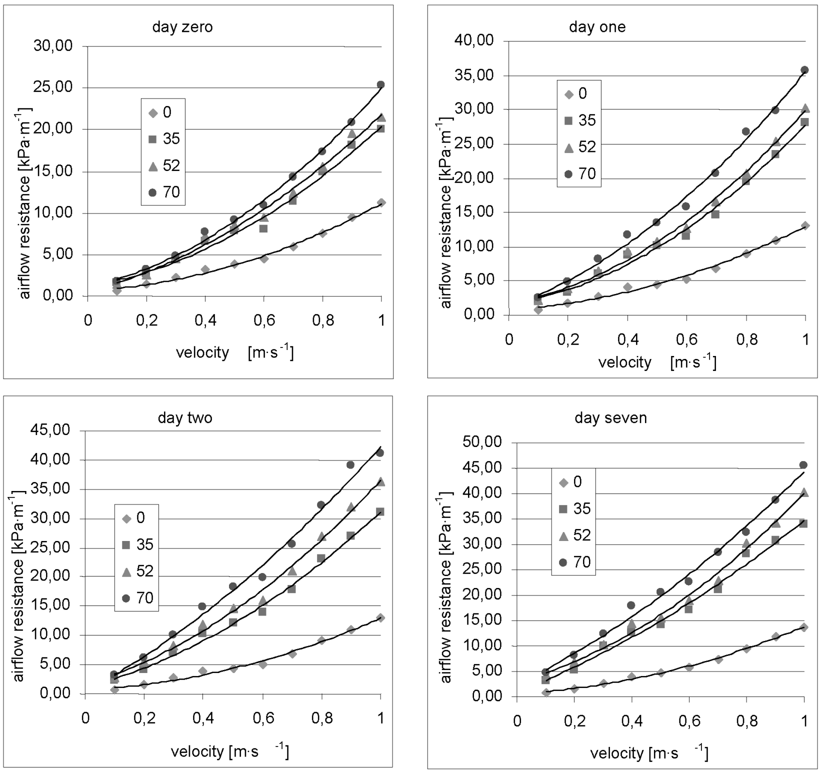

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Fig. 4. The influence of the airflow velocity and vertical pressure on the value of hydraulic resistance in a layer of oats with a 22% moisture content

The Ergun equation was used to describe individual flow resistance [1952]:

$$\Delta P = av + bv^2 \tag{1}$$

After taking into account the influence of moisture and storage time, the following equations were obtained for the individual vertical pressures (Table 1).

Table 1. Equations describing the influence of the airflow velocity, moisture and the storage time on the value of hydraulic resistance in a layer of oats

Vertical pressure [kPa]	Equation	Share of explained variation R^2 at $\alpha \le 0.05$
0	$\Delta P = -0.04w + 0.157t + 6.19v + 7.82v^2$	0.95
35	$\Delta P = 0.23w + 0.29t + 25v^2$	0.76
52.5	$\Delta P = 0.26w + 0.33t + 28.55v^2$	0.75
70	$\Delta P = 0.34w + 0.36t + 32.67v^2$	0.71

Source: authors' own calculations

The equations presented in Table 1 show the variable influence of moisture on the values of hydraulic resistance depending on the vertical pressure value. Moisture has a negative influence on the values of airflow resistance for a deposit which is not subjected to pressure (0 kPa), while it is positively correlated with airflow resistance for a deposit subjected to pressure and the strength of this correlation grows together with the increase in the vertical pressure value.

This phenomenon can be accounted for in the following way: An increase of the moisture content to 22% causes an increase in the porosity of the deposit and, at the same time, a decrease in the resistance. On the other hand, a high moisture content increases the grain susceptibility to densification to a significantly higher degree than for the moisture of 14% and 18%. The process of porosity reduction resulting from the higher susceptibility of the grain to densification significantly outweighs the change in porosity achieved as a result of increasing the linear dimensions of the material. This leads to a significant increase in the hydraulic resistance of the deposit.

Conclusions

1. Airflow resistance through oat grain depends on moisture and external load. If there is no load (0 kPa), an increase in the moisture from 14% to 22% results in lower airflow resistance from 0.95-15.63 kPa m^{-1} to 0.69-11.26 $kPa \cdot m^{-1}$, depending on the airflow velocity. As the load on the oat deposit increases, an increase in the moisture results in higher airflow resistance. At a load of 70 kPa, an increase in the moisture from 14% to 22% results in higher airflow resistance from 1.22-21.11 $kPa \cdot m^{-1}$ to 1.76-25.42 $kPa \cdot m^{-1}$, depending on the airflow velocity.
2. The influence of the storage time on the airflow resistance through a layer of grain grows together with an increase in the oat moisture. For 14% moisture content, the increase in the airflow resistance through a layer of oats ranges from 3% to 10%, and for 22% moisture content, the increase in the resistance ranges from 14% to 21% depending on the airflow velocity.

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WPŁYW WILGOTNOŚCI I NACISKU PIONOWEGO NA OPORY PRZEPŁYWU POWIETRZA PRZEZ ZIARNO OWSA

Streszczenie. W artykule przedstawiono wyniki badań dotyczące oporu przepływu powietrza powietrza przez ziarno owsa. Pomiary przeprowadzono na surowcu o wilgotności od 14 do 22%, przy zmiennym obciążeniu jego warstwy od 0 do 70 kPa w okresie siedmiu dni od momentu napełnienia zbiornika. Prędkość przepływu powietrza zmieniano w zakresie od 0,1 do 1,0 $m \cdot s^{-1}$. Wykazano kluczowe znaczenie wpływu prędkości przepływu powietrza i wzajemnych interakcji pomiędzy czasem składowania, naciskiem pionowym i wilgotnością surowca na wartość oporu hydraulicznego.

Słowa kluczowe: opór przepływu powietrza, wilgotność, napór pionowy, owies

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