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EFFECT OF TRITICALE MOISTURE CONTENT AND SLENDERNESS RATIO OF A SILO ON PRESSURE DISTRIBUTION

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A b s t r a c t. Results of stand studies on the vertical and horizontal pressure of triticale grains with different moisture content ($u_1 = 0.212$ and $u_2 = 0.245$ kg kg^{-1} d.b.) in silos of $H/D_1 = 15$ and $H/D_2 = 8$ slenderness are presented in this study. Duration of each experiment was 10 days. It was found out that an increase of moisture content caused higher pressure both on the sides and bottom of the silo. Slenderness affected pressure values as well. Pressures were higher in a thickset silo than in slim one. Pressures exerted by triticale to the silo bottom were significantly higher than those exerted to the sides. The highest increase of the parameters under study was found during the first five days of triticale storage. Triticale was bridged only in thickset silo (in its upper part) during storage with the grain of moisture content $u_2 = 0.245$ kg kg^{-1} d.b. between the 6th and the 10th day.

K e y w o r d s: triticale, moisture content, slenderness of a silo, pressure, bridging

INTRODUCTION

Grain bridging in a silo is a very unfavourable process. It can result in total or partial disturbance of the material flow in a silo, difficulties in stock-taking and many other problems. This phenomenon leads to long-term silo shut-down, often silo damage or sometimes to an explosion. Problems connected with material storage in silos were described by Kobielak and Klimek [5]. Bridging is caused by an increase in the pressure on the silo walls. According to Kamiński [4], pressure value is significantly affected not only by the parameters related to the features of a loose material and factors related to the construction and exploitation of a silo but also by chamber slenderness, shape of the walls and bottom as well as roughness of internal surfaces [2,3,10]. Estimation of the effect of chamber slenderness on the horizontal pressure distribution during studies carried out in a natural scale is very difficult, because tests are often carried out under different conditions. The influence of slenderness estimated on the basis of the model studies in which identical conditions can be applied, such as the shape of chamber and bottom as well as their porosity is more evident. The initial tests using models with the same capacity and different slenderness (H/D= 5 and H/D=5/3) were made by Pankratova and Nagajcev [11]. They found out that increase of sand horizontal pressure when emptying the silo were higher for a model with bigger slenderness than when it is low.

Kamiński [4] estimated pressure values for sugar and wheat during filling and symmetrical emptying of silo models with 3.95, 2.75 and 1.95 slenderness. He proved that slenderness of the chamber significantly affected the value and distribution of horizontal pressure and global loads on the bottom and sides. Horizontal pressure values were lower for sugar than for wheat. An increase of chamber slenderness influenced the pressure value during emptying for both raw materials. In addition, Thompson *et al*. [12,13] found large differences between pressure values calculated on the basis of standards and experimental values which pointed to the need for carrying out experimental studies.

Most of the authors do not present physical properties of materials used for their studies. Only density is given. There are no data referring to moisture content that directly affects the 1000-grain weight, porosity, density, size, repose angle etc. for grains. It also affects development of microorganisms and respiration processes, to which grain temperature is directly related [14]. Investigations by Kusińska [6-9] and Grochowicz *et al.* [1] proved that during grain storage in the silo, its moisture content increased which caused temperature increase, enlargement of grain size and significant increase of pressure to the silo side. From the above studies, it results that apart from the physical properties of raw material, time and conditions of storage should be taken into account, because most of the cited results of side pressures refer to the conditions just after filling of a silo or after short time of storage.

MATERIAL AND METHODS

The above mentioned drawbacks in the studies carried out so-far and in the estimation of grain bridging conditions in a silo, created the need to investigate relation between silo slenderness and moisture content of grain, and side and bottom pressures, as well as the ability for bridging of material in a silo. Investigations were carried out on a laboratory scale to maintain the required moisture content of grain, outer temperature and silo wall roughness. They covered triticale grain pressure to the side and bottom of a silo with 15 and 8 slenderness values. Moisture content in triticale amounted to $u_1 = 0.212$ kg kg^{-1} d.b. and $u_2 = 0.245$ kg kg^{-1} d.b. Duration of each experiment was 10 days; ambient temperature 18 °C. The experiment was performed with three replications of each variant.

Tests were carried out on a measuring stand presented in Fig. 1. The basic element of the stand was a removable cylindrical silo (1) placed on a stand (5) and fixed to the frame (2) with a regulation screw (4), spacing elements (7) and a block (3). Such a construction allowed for a quick silo removal. The silos of the same height (H = 2350 mm) and different inner diameters (D_1 = 153 mm and D_2 = 284 mm) were used in the tests. Slenderness of the silos amounted to: $H/D_1 = 15$ and $H/D_2 = 8$, respectively. The silo bottom (6) was supported by brackets. It had a hole in the middle for the measurement of vertical grain pressure with an extensometrical sensor (8). The cylindrical surface had also eight holes for horizontal pressure measurement using extensometrical sensors (9). The first sensor was placed 40 cm above the bottom and the next ones 195 mm from one another. After filling with grain, silo was hermetically closed with a cover (10) and grain pressure to the bottom and sides was measured once a day at the same hour. After 10 days, the sensor below the bottom was gently removed and grain was spilled while observations on grain bridging were made.

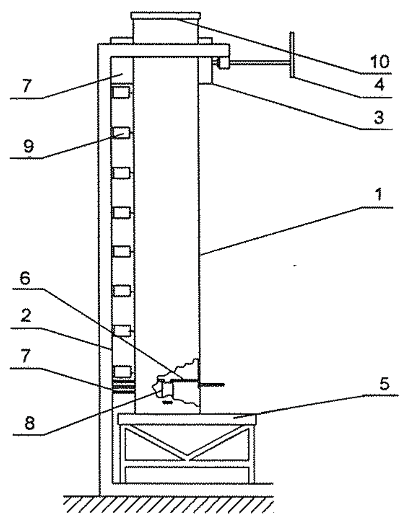

Fig. 1. A lay-out of a measuring stand: 1 - cylindrical silo; 2 - frame; 3 - block; 4 - regulation screw; 5 - stand; 6 - bottom; 7 - spacing elements; 8, 9 - extensometrical sensors; 10 - cover.

RESULTS AND DISCUSSION

It was found that in all the studied cases, an increase of horizontal and vertical pressure of triticale occurred. The maximum horizontal pressure values were noted always on the 430 mm level. They were presented in Fig. 2

a

b

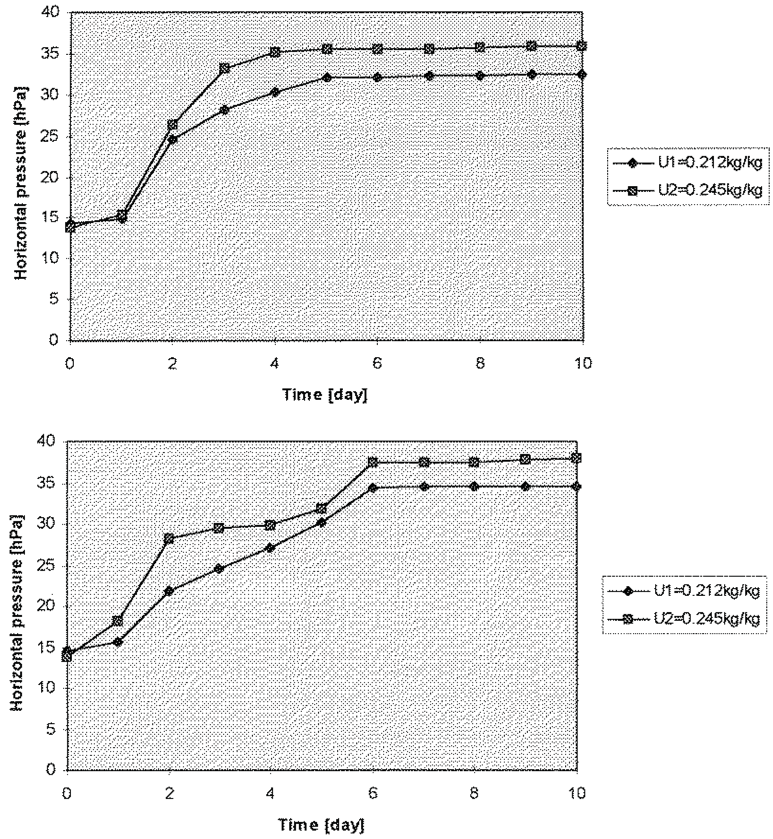

Fig. 2. Plot of horizontal pressure in the silo with the slenderness of H/D_1 = 15 (a) and H/D_2=8 (b) (430 mm above bottom) depending on storage time and moisture content.

relative to storage time and grain moisture content separately for both silos.

Horizontal pressure in both silos, measured after silo filling (day "0") had lower values for triticale with higher moisture content (u_2). It resulted from its lower bulk density (ρ_1 = 0.665 kg dm^{-3}, ρ_2 = 0.641 kg dm^{-3}). Even after one day of storage, the side pressure value increased. For grain with u_1 moisture content, pressure value in the silo with the slenderness of 15 increased from 14.3 to 14.8 hPa and for u_2 - from 13.8 to 15.5 hPa. In the silo with the slenderness of 8, a more sudden increase of horizontal pressure occurred after 1 day (up to 15.6 and 18.2 hPa, respectively). In both chambers, the initial horizontal pressure values were very close. A high increase in this parameter was observed during the first several days. It was observed up to the 5th day in the silo with the slenderness of 15, and to the 6th day when the slenderness was 8. The increase was very small in the following days of the measurement cycle. After 10 days of the experiment, it was found that in the silo with the slenderness of 15, the horizontal pressure value reached 32.4 hPa for triticale with u_1 moisture content and 35.9 hPa for u_2. In the silo with the slenderness of 8, the increase of horizontal pressure was higher. The measured values of the parameter amounted to 34.6 and 38.0 hPa, respectively for both moisture contents.

In the upper parts of the silo with the slenderness of 15, the measured changes in the horizontal pressure were slight during the whole experiment for both moisture contents. Different relations were observed for the silo with the slenderness of 8 (Fig. 3). At the level of 1210 mm for triticale with u_1 moisture content, a uniform increase of horizontal pressure from 7.0 to 10.8 hPa during the measuring period was found. For the triticale with u_2 moisture content, a higher pressure increase from the 4th day was observed. After 10 days, in this case, horizontal pressure amounted to 18.5 hPa. However, it was lower than the value obtained at the level of 430 mm. That was the only case when grain bridging occurred in the silo with 1210 mm height. It can be accounted for the water release during biological respiration of triticale grain. Water diffused as vapour from the silo bottom towards its upper part and caused grain swelling which was the reason for pressure increase. The largest amounts of water were produced and absorbed in the silo with the slenderness of 8 at the initial u_2 moisture content. In the lower part of the silo, the moisture decreased by 2.3%, while in the upper part it increased by 3.6% (which was accompanied by the processes of moulding). In that case, the average moisture content increased from 0.245 to 0.249 kg kg^{-1}.

This phenomenon is also the reason for vertical pressure. The values of the maximum vertical pressure (in the middle of the bottom) depending on the moisture content of grain and storage time for both silos are presented in Fig. 4. The value of this parameter also changed. Vertical pressure was increasing with time up to the 6th day in uniform way, but they were slight

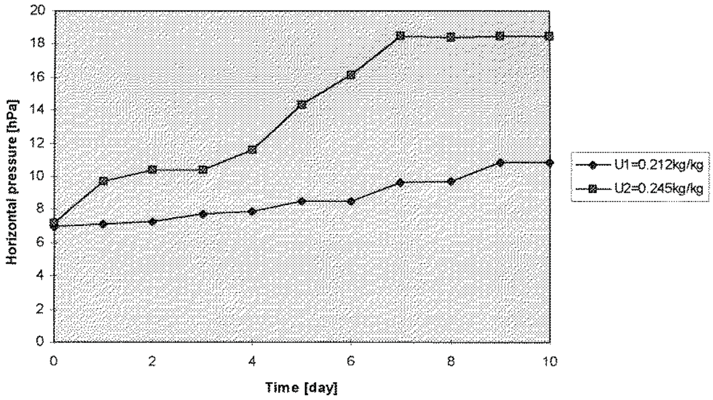

Fig. 3. Plot of horizontal pressure in the silo with the slenderness of H/D_2=8 (1210 mm above bottom) depending on storage time and moisture content.

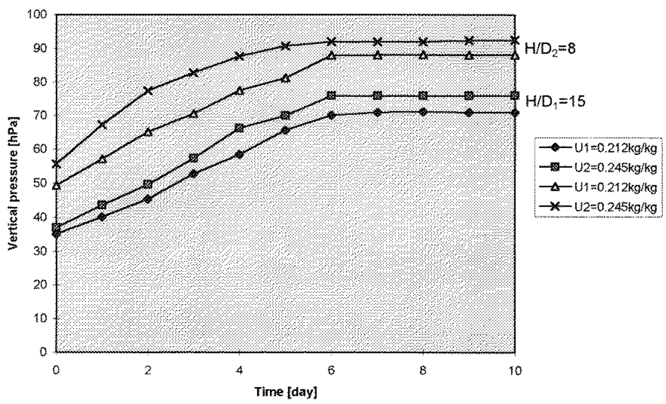

Fig. 4. Plot of the maximum vertical pressure related to storage time and moisture content of grain for the silos with the slenderness of 15 and 8.

to the 10th day. Probably, the water produced was mostly absorbed by the layers of the upper part of the silo. The highest values of axial pressure were observed for the silo with the slenderness of 8 and triticale with u_2 moisture content (92.5 hPa), slightly lower (88.1 hPa) for u_1. For the silo with the slenderness of 15, those values amounted to 76.1 and 71.0 hPa, respectively. The vertical pressures were significantly higher than the horizontal ones.

The present results were subjected to variance analysis. It revealed that moisture content, storage time and silo slenderness had a significant influence ($\alpha = 0.05$) on the horizontal and vertical pressure values.

Equations expressing horizontal (P_h) and vertical (P_n) pressures in relation to storage time t (days), measuring level h (mm), moisture content u (kg kg^{-1} d.b.), and silo diameter D (mm) were constructed according to regression analysis:

$$P_h = -31.489122 - 0.845327\,t + 0.035874\,h + 0.024298\,u + 0.035421\,D, \text{ (hPa)},$$
$$R^2 = 87.45\%,$$

$$P_n = -33.275956 + 42.870034\,t + 0.024823\,u - 3.657778\,t^2 + 0.000237\,D^2, \text{ (hPa)},$$
$$R^2 = 82.39\%.$$

CONCLUSIONS

1. Horizontal and vertical pressures increased during storage time of triticale in a silo. Pressure values were higher for triticale with higher moisture content (u_2 = 0.245 kg kg^{-1} d.b.).

2. An increase of the horizontal and vertical pressure was higher in the silo with lower slenderness ($H/D_2 = 8$).

3. The highest changes in the tested parameters occurred up to the 5th day of storage.

4. A decrease in the silo slenderness and increase in the moisture content of grain favoured bridging of the material in the silo.

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