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INFLUENCE OF MOISTURE CONTENT ON TEMPERATURE DISTRIBUTION IN TRITICALE GRAIN DURING LAYER FILLING OF A SILO

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Summary. Results of model studies on temperature distribution in „Maja" triticale grain at longitudinal section of a silo filled with two grain layers of different moisture contents were presented. Four experiments were carried out, diffeing with upper and lower grain layers moisture contents as follows: 16% w.b. and 12% w.b., 12% w.b. and 16% w.b., 20% w.b. and 12% w.b., 12% and 20% w.b. Grain was stored at constant outer temperature of 15°C for 21 days under oxygen respiration conditions. Grain temperature was recorded every day at 40 measurement points. Higher grain temperatures were achieved in cases when higher-humidity grain was at the top part of the silo. Study results were subjected to regression analysis, which resulted in formulation of the equations determining the grain temperature at subsequent experiments depending on process duration and localization of measurement points. Variance analysis revealed that all experimental variables exerted significant influence on temperature increase of triticale grain.

Key words: grain storage, silo, temperature

INTRODUCTION

Storage time depends on water content in grain and the temperature. Respiration processes occur during storage. Oxygen respiration leads to the emission of great amounts of heat and water. If these products are not quickly carried away, secondary grain moisturizing occurs, which causes further increase of respiration intensity. Self-heating of bulk grain is a result of grain and microorganism respiration. It can be of focal character. Low thermal conduction of bulk grain is a physical basis of self-heating phenomenon. Processes of temperature and water content increase take place at the same time. Arising differences between temperature and water content invoke their diffusion [Khankari *et al.* 1994, Kusińska 1999].

Seasonal and daily temperature oscillations are a serious reason for water migration and changes of its distribution inside stored material. Precise prediction of water content and temperature of stored grain is necessary for control of ventilation process [Grzesiuk *et al.* 1994]. Free water migration depends on several factors: type and quality of stored grain, grain size and shape, temperature, initial water content, weather conditions, storage duration, sorption and diffusion properties. Due to these factors, water migration process is unstable [Hellevang 1988, Kusińska 2005].

Khankari *et al.* [1992, 1994] found that water migration increased along with the grain temperature increase. Their studies revealed that water migration occurs at all silo dimensions, and it begins earlier in smaller silos.

Kusińska [1998, 2001, 2002, 2002a, 2006, 2006a] performing the simulation tests using cereal grain observed very high correlation between results of water content and temperature measurement and their strong influence on values of horizontal pressure, which in turn is of great practical importance in silo designing. Measurements of temperature, that is directly associated with water content in grain, are usually made during grain storage. Knowledge on the grain temperature distribution in a silo is necessary for evaluation of stored material quality.

MATERIAL AND METHODS

Purchased triticale grain „Maja" was characterized with diverse water content in particular unit packages. Water content ranged from 10,5–11,5% w.b. Before the experiment began, 250 kg of grain was poured out on a sheet made from canvas paulin, thoroughly mixed using shovel, then it was poured into plastic barrels with hermetic cover and stored for a day. After that, grain was poured out again and twenty samples were taken randomly for water content determination. Necessary water weight that should be added to the grain in order to achieve required water content was calculated on the basis of water balance after mean water content determination. Water amount was calculated using the following formula:

$$M_w = M_g \frac{w_2 - w_1}{100 - w_2} \tag{1}$$

where:

M_w – volume of needed water addition to achieve moisture content of w_2, kg,
M_g – mass of watered grain, kg,
w_1 – initial grain moisture content, % w.b.,
w_2 – required grain moisture content, % w.b.

Grain was moisturized using distilled water by means of spraying, then mixed and poured into barrels that were hermetically sealed with covers. Barrels were half filled to facilitate the grain's mixing during turning. Grain was mixed every 6–12 hours. It was stored at 15°C for two days. Then, triticale was poured out onto the sheet, shoveled, mixed partially in a drum mixer, shoveled again and checked for water content. Principle to maintain 15°C of grain was kept during all these procedures. Therefore, grain was moisturized till achieving the material with required water content. Experimental material prepared in the above way was applied for stand measurements.

Measurement stands of own design for measurements of cereal temperature with possibility to maintain outer temperature at the constant level during grain storage were applied during tests.

The scheme of measurement stand is presented in Fig. 1. Its general element is a silo consisting of cylindrical part (1) of 600 mm inner diameter and 1200 mm height, conical part with bolt and cover with isolation material (foamed polystyrene) lining. Cylindrical and conical parts is equipped with thermostatic jacket, to which water of constant temperature is delivered from ultrathermostat (4) of UH-16 type. In cylindrical part, along the generatrix, there are holes of 38 mm diameter each at the following distances from cylinder edge: 175, 275, 375, 475, 575, 675, 775 and 875 mm. Holes were for temperature measurements at five distances from reservoir's symmetry axe (0, 75, 150, 225 and 300 mm).

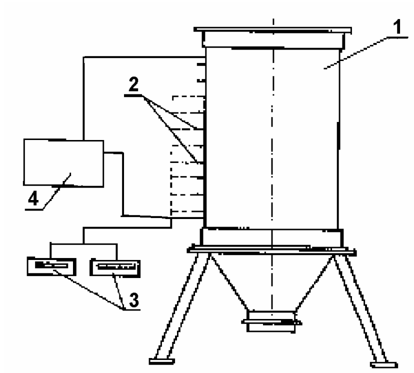

Fig. 1. Schematic diagram of the test station:
1 – silo, 2 – thermocouples, 3 – temperature gauges, 4 – thermostat

Fe-CuNi thermoelements (2) of I-TP 11 type, signal from which was transmitted to digital measuring instruments (3) of AR 592 type, were applied for temperature measurement. Temperature values were read with 0.1°C accuracy.

Before the study began, silo cleanness, efficiency of controlling and measuring device had to be checked and proper water temperature in thermostatic jacket adjusted. Then the silo was filled with the prepared material, hermetically shut with the cover and experiment lasting 21 days began. Grain temperature measurements were made in forty points of the silo at the same time every day.

Four experiments were conducted. The silo was filled with grain layers of different moisture contents. The first experiment consisted in filling the lower part of the silo (up to 525 mm height) with grains of w_l = 12% w.b. moisture content, and upper (to 1100 mm) with w_u = 16% w.b. moisture content. Inverse order of layers was applied in the second experiment. The third and fourth experiments following moisture contents of grain were applied: w_u = 20% w.b. and w_l = 12% w.b. as well as w_u = 12% w.b. and w_l = 20% w.b. Temperature of water in thermostatic jacket was maintained at constant level of 15°C. All measurements were carried out in three replications.

RESULTS

Temperature changes were soon recorded during „Maja” triticale storage in the model silo. The temperature increased faster in higher-humidity layers (16 or 20% w.b.).

Higher moisture contents caused faster temperature rise. In the layer of 12% w.b. initial moisture content, grain temperature increased slowly for the first days. Increasing temperature of medium (16% w.b.) and high (20% w.b.) grain moisture content resulted in the diffusion of water to layers with its lower concentrations. Such phenomenon accelerated the temperature increase also in drier grain layer (12% w.b.).

Figure 2a presents grain temperature distribution in the silo after 21 days of storage and filled with two layers: lower – grain of w_l = 16% w.b. and upper w_u = 12% w.b.

In this case, due to parallel processes of respiration and water diffusion, the lowest grain temperature was found in upper layer (17°C), which was only by 2°C higher; grain near silo's axis (r = 0–150 mm) at the level of 0–575 mm gained the highest temperature (25°C). At reversed layer arrangement (Fig. 2b), much higher triticale temperature was recorded at the upper part of silo near its axis (32.5°C), and only 17°C in lower layer.

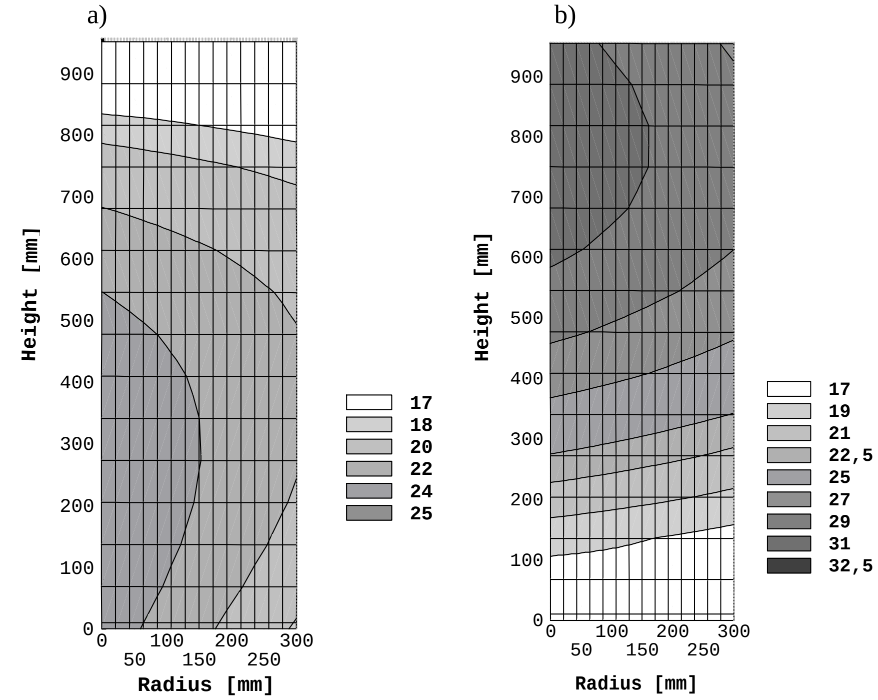

Fig. 2. Temperature distribution in silo after 21 days of storing the triticale grain of different moisture contents:
a) lower layer – w_l = 16% w.b. and upper layer w_u = 12% w.b.;
b) lower layer – w_l = 12% w.b. and upper layer w_u = 16% w.b.

Filling the silo with grain layers of higher moisture content differences resulted in higher grain temperatures. At moisture content of lower layer w_l = 20% w.b. and upper layer w_u = 12% w.b. (Fig. 3a), temperature reached 21.5°C in upper and 33°C in lower grain layer. At reversed layers order, after 21 days of storage, at constant outer temperature of 15°C, grain's temperature in lower part of silo was 19°C, and in upper section 37°C (at the level above 775 mm around silo's axis).

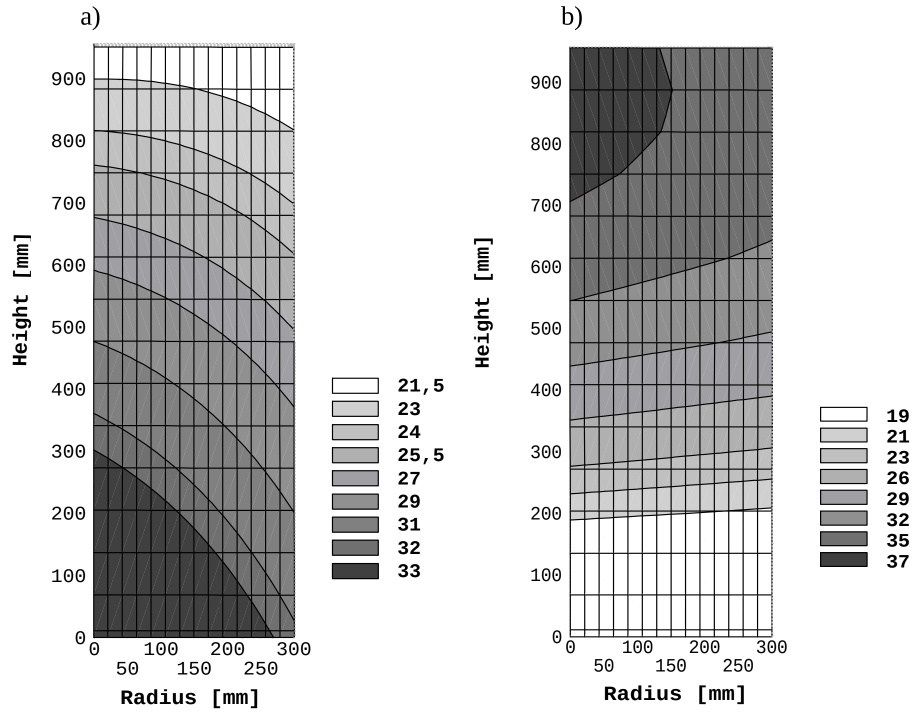

Fig. 3. Temperature distribution in silo after 21 days of storing the triticale grain of different moisture contents:
a) lower layer – w_l = 20% w.b. and upper layer w_u = 12% w.b.;
b) lower layer – w_l = 12% w.b. and upper layer w_u = 20% w.b.

Figures 4 and 5 present mean values of triticale temperature at 40 measurement points. After filling the silo with grain layers of different moisture contents (w_l = 12% w.b. in lower and w_u = 16% w.b. in upper layer) (Fig. 4), mean grain temperature increase was of linear shape till the 11th day of storage with peak value of 23.8°C. On the following days, the temperature increases were smaller and finally after 21 days of storage, mean temperature was 25.7°C. Final mean temperature of grains was lower (20.1°C) after 21 days of storage at reversed arrangement of layers.

Higher temperature increase was observed at larger difference of layers moisture contents (Fig. 5). Applying lower layer humidity of w_l = 12% w.b. and upper layer moisture content of w_u = 16% w.b. also caused the linear temperature increase till the 11th day of storage but faster. It reached to 26.6°C, i.e. by 2.8°C higher than in previous experiment. Finally, its value was 28.8°C.

In the fourth experiment at grain moisture content in lower layer w_l = 20% w.b. and upper layer w_u = 12% w.b., temperature was 26.7 ° in 21st day of storage; its linear increase was recorded only till the 6th day of the process.

Apparent worsening of grain quality was observed in the 3rd and 4th experiments. Processes of grain lodging and rotting were noticed in points with the highest temperatures. It can be supposed that for all cases, faster self-heating of grains occurred when higher-humidity grain was in the upper layer. Variance analysis confirmed that fact; in addition, it indicated that triticale grain temperature in silo was affected by initial moisture contents of layers and the order of their arrangement.

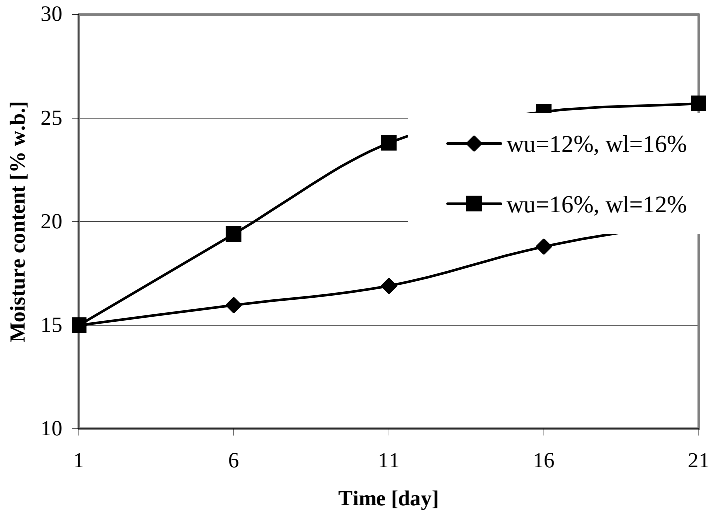

Fig. 4. Mean temperature of triticale during storage of grain of w_l = 16% w.b. in lower layer and w_u = 12% w.b. in upper layer as well as w_l = 12% w.b. in lower layer and w_u = 16% w.b. in upper layer

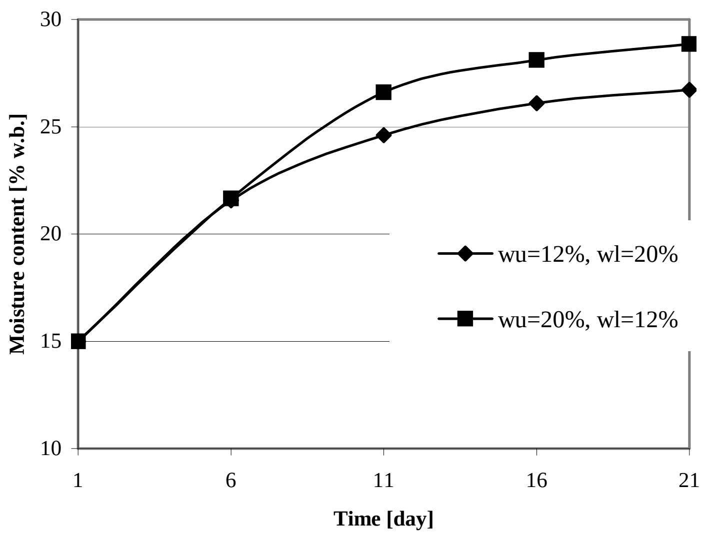

Fig. 5. Mean temperature of triticale during storage of grain of w_l = 16% w.b. in lower layer and w_u = 12% w.b. in upper layer as well as w_l = 12% w.b. in lower layer and w_u = 16% w.b. in upper layer

Achieved study results were subjected to multiple regression analysis, which resulted in equations describing dependencies between temperature values depending on measurement point location and triticale grain storage time. Regression analysis results are presented in Table 1.

Table 1. Multiple regression equations describing the dependencies of triticale temperatures in considered cases

Initial grain moisture content in layers, w, % w.b.		Temperature t, °C	R^2
w_l	w_u		
19	13,6	$29{,}071-0{,}004r+0{,}098\tau^2-2{,}08\ln h$	0,78
13,6	19	$6{,}94-0{,}012h+0{,}01\tau^2+2{,}94\ln h-0{,}67\ln r$	0,86
25	13,6	$4{,}31-0{,}011h-0{,}0041r+0{,}01\tau^2+2{,}94\ln h$	0,84
13,6	25	$-45{,}05+5{,}04\ln\tau+9{,}58\ln h$	0,88

where:

h – measurement level, mm,
r – distance from the silo axis, mm,
τ – storage time, days.

CONCLUSIONS

1. The triticale temperature in model silo filled with grain layers was significantly affected by: grain layer moisture content, their arrangement, localization of measurement points, and storage time.
2. Grain was self-heated in whole silo.
3. Grain was faster heated when higher-humidity grain was in upper part of silo (16 or 20%). At 20% of moisture content, grain temperature was higher (reached 37°C) than at 16%.
4. The highest mean grain temperatures in silo (28.8°C) was achieved after 21 days of triticale storage with lower layer of w_l = 12% w.b. and upper layer of w_u = 20% w.b. of moisture content.

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