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A Study on Densification of Timoty (*Phleum pratense*) Hay at Different Moisture Content

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Abstract: In this study wilted Timothy plants with different levels of moisture content were compressed using a laboratory hydraulic press. The moisture content of hay varied from 7.0 to 20.0% wet basis (wb) and applied pressure varied from 0.0 to 21.0 MPa. During each compressing interval, the thickness of compressed hay was measured and the density of the resulting laboratory scale bales was calculated. In general, the density of the bales increased and their thicknesses decreased with the applied pressure, however the trends were not linear. The maximum density of the resulting bales was about 1163.0 kg m^{-3} which occurred at 21.0 MPa pressure for 16.0 and 20.0% moisture levels. After reaching equilibrium moisture content with the environment, the bales prepared from the hay with 7% moisture attained the lowest density while the bales made from hay with 16% moisture content had the highest density.

Key words: Compression, timothy hay, moisture content, thickness, density

INTRODUCTION

Hay stalks, after being harvested and field dried, are baled using various bale making machines. The main objective of baling are ease and less cost of handling, storage and transportation. The field bales are produced in different sizes and weights. In the area where the production is high, the large square balers are used to make bales with a weight of up to 900.0 kg and a density of about 150.0 kg m^{-3}. For export purposes, the large square bales are usually further processed at the baling operating plants where they are highly compressed to a density of about 500.0 kg m^{-3}.

In Canada the dominant cultivar of hay is timothy (*Phleum pratense*). Considerable amount of highly compressed timothy is regularly exported to Japan. Possible infestation of hay by Hessian fly, *Mayetiola destructor* (Say), is a concern of Japanese quarantine regulators. The current established quarantine security protocol between Canada and Japan requires the inspection of the hay for Hessian host plants (Tabil *et al*., 1999).

In Canada visual inspection is still the only current method for detecting the Hessian fly host plants in exporting hay. Development of a procedure that ensures the destruction of the Hessian fly puparia in the baled hay is to the interest of both importing and exporting countries. Alternative economical, safe and environmentally friendly methods for deinfestation of hay bales have been the subject of research efforts for the past two decades. Yokoyama *et al*. (1993) developed a multiple-quarantine treatment of compression and fumigation of bales which ensured 100% mortality of Hessian fly puparia. Yokoyama *et al*. (1994) indicated direct pressure of 20.6 kPa was sufficient to rupture the pupa of Hessian fly. Sokhansanj *et al*. (1992) and Opoku *et al*. (2001 and 2002) studied on thermal destruction of Hessian fly pupa and during field and laboratory studies. In general pupa is destroyed at temperatures above 55.0 EC, however the uniform transfer of heat through the hay bales was indicated to be the prevailing problem.

Laboratory studies by Shaw *et al*. (2004) revealed that compressing the bales is an effective way to deinfest the exporting hay. In their experiments the seedling containing pupa placed in the bales and compressed at 10.0 or 12.0 MPa pressure. In their laboratory experiments they achieved 100% mortality of the pupa. Tabil *et al*. (2006) conducted experiments for disinfestations of timothy hay bales from Hessian fly. They indicated that a pressure around 10.5 MPa was needed for killing 100% of the fly puparia.

High compression of bales has both potential of a suitable means of size reduction and an effective means for deinfesting the bales. With advances in compression equipment and development of double-compression

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presses, there is a more promising opportunity for disinfestations of hay bales using high compression process. Currently the hay for export is compressed at about 10.0 MPa. With increase in compression technology it is becoming more possible to compress hay to above 15.0 MPa. Knowledge of the changes in density and volume of the timothy hay under with various moisture content and increased pressures will be useful for efficient storage, handling and transportation of the bales. Thus, the objectives of this study were: a) to investigate the change in density and volume of bales under increased pressures ranging from 0.0 to above 20.0 MPa and b) to determine an optimum moisture content for maximum density of bales.

MATERIALS AND METHODS

The timothy hay stalks for use in this project were acquired from Elcan Forage Inc., Broderick, Saskatchewan. The initial moisture content of the hay was about 11.0% wet basis (wb). For the experiments, the moisture content was adjusted to 7.0, 12.0, 16.0 and 20.0% wb. For 7.0% moisture, the hays were left for a period of 10 days at room temperature until reaching equilibrium moisture content. For the moisture of 12.0% and above, a calculated amount of distilled water was evenly sprayed on the hays in plastic bags and the bags were kept at 5.0 EC for minimum 7 days.

The compression of the hays was performed using a hydraulic press (Fig. 1). The press consisted of a two-way

Fig. 1: The hydraulic press and the chamber used for the experiments

hydraulic cylinder which was driven by a 30.0 kW electric motor. The press was capable of developing up to 30.0 MPa pressure. A 288 125 125 mm compression chamber was used for placing the hays inside it. The cross sectional area of the compression chamber was designed in such a way that the resulting pressure on the top surface of hay was the same as the gauge pressure of the hydraulics cylinder.

For density studies, 200.0 g of hay stalks was placed in the compression chamber and the pressure was increased in a stepwise manner with 3.5 MPa intervals to a maximum pressure of 21.0 MPa. At the end of each stage, the applied load was recorded and the stroke length of the piston was measured. The same test procedure was performed for different levels of moisture content. Each test was repeated three times and the average of the three replicates was used for analysis of the results and discussions.

After compressing, the laboratory scale bales were kept at room environment (about 25.0°C and 40.0% RH) and they were allowed to loose moisture until equilibrate with the surrounding. Then the weight of each bale was determined and the changes in the density of bales were calculated.

RESULTS AND DISCUSSION

The results of decrease in the thickness of the hay during are presented in Table 1. The last row of the table indicates that the lower moisture content hays resulted in larger bale thickness. This is generally to the friction of the hay stalks which is a higher when moisture content is lower. Within the limit of the tests, the thickness reaches the same amount when moisture content reaches 16.0% and above.

The graph of bale thickness versus the applied pressure is shown in Fig. 2. The graph indicates a sharp decrease in the height of the bales by applying 3.5 MPa pressure. Then the size of the bales become close to each other. To get a better under standing of the changes in the thickness of the bales at different level of pressure and moisture content, the same data but for the pressure

Table 1: The thickness changes of the hay as applied pressure is increased

	Moisture contents (%)			
Pressure (MPa)	7	12	16	20
0.0	284.0	284.0	284.0	284.0
3.5	28.5	29.0	21.0	18.0
7.0	24.5	23.0	16.5	14.5
10.5	21.0	18.0	14.0	14.0
14.0	19.0	15.0	12.5	12.5
17.5	17.0	13.0	11.5	11.5
21.0	16.0	12.0	11.0	11.0

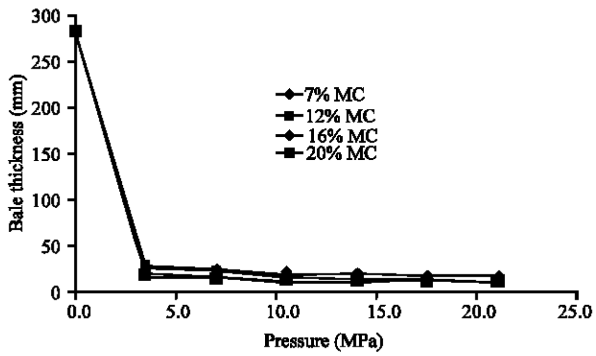

Fig. 2: The general trends of decrease in bale thickness with increase in the applied load

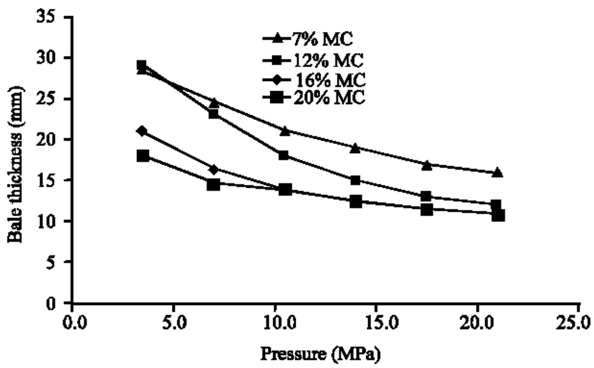

Fig. 3: The detail trend of changes in thickness of the bales between 3.5 and 21.0 MPa pressure

range of 3.5 to 21.0 MPa are plotted in Fig. 3. As it can be seen from the graph, at 3.5 MPa, the 7.0 and 12.0% moisture content hays are compressed almost to the same thickness, while the 16.0 and 20.0% moisture content hays are, respectively compressed more. The thickness is decreased almost exponentially as pressure is increased for all levels of moisture content. But for the 16.0 and 20.0% levels their thicknesses merged at 10.5 MPa and remain the same after that point. Data in Table 1 indicates that about 97.5% of decrease in thicknesses of the bales is obtained when the applied pressure is about 7.0 MPa and only about 2.5% of the decrease is attributed to pressures above this level.

The data for changes in density of the bales under different pressure and moisture content are presented in Table 2. The plot of variations in the densities of the bales is presented in Fig. 4. It is clear that the density of the bales increases with the applied pressure and the bales with higher moisture content initially have higher density. However, the 16 and 20% moisture content hays reach the same density at 10.5 MPa. This is due to their original equal weights and their final equal thicknesses, as

Table 2: Density of the bales at different pressure and moisture contents

	Moisture content (%)			
Pressure (MPa)	7	12	16	20
0.0	45.1	45.1	45.1	45.1
3.5	449.1	441.4	609.5	711.1
7.0	522.4	556.5	775.8	882.8
10.5	609.5	711.1	914.3	914.3
14.0	673.7	853.3	1024.0	1024.0
17.5	752.9	984.6	1113.0	1113.0
21.0	800.0	1066.7	1163.6	1163.6

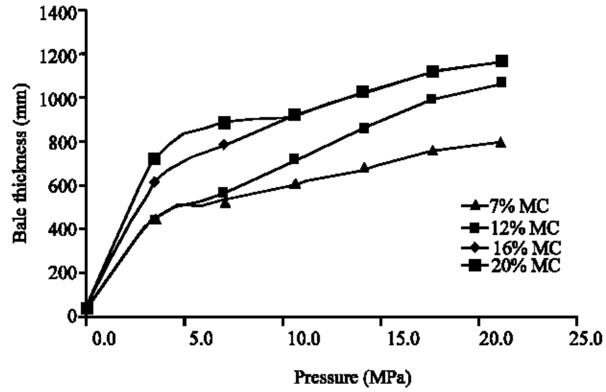

Fig. 4: The change in densities of the bales as pressure is increased

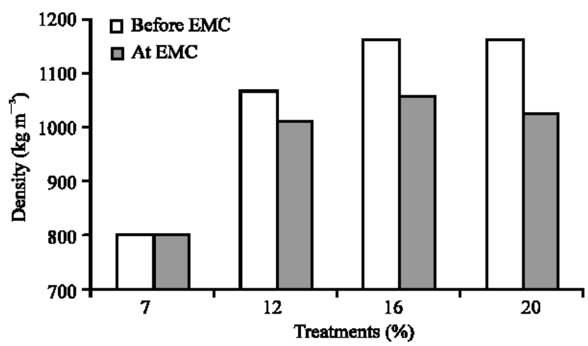

Fig. 5: Density of the bales before and after reaching equilibrium moisture content (EMC)

indicated in Table I. It is interesting to notice that the 12% moisture content hay, after about 7.0 MPa, exhibits an increase in its density. The densities follow the same trends as the thickness of the bales, but in opposite manner.

After leaving the bales to equilibrate with the surrounding moisture for about 15 days, all the bales reached a moisture content of 7%. Since the volume of the individual bales is unchanged (strapped bales), the loss of moisture causes their densities to decrease. The calculated changes in the bale densities immediately after baling and after reaching their equilibrium moisture content are plotted in Fig. 5. The graph shows that with increase in moisture content, the density initially rises and then it levels off at 16% moisture content. However, after giving off their moisture, the density of the bales for 7% moisture level was unchanged, but for the other three treatments they decreased. But, again at EMC, the densities of the bales increases as their original moisture content increases. This is true for baling hays up to 16% moisture level. However, at EMC, the density of the bales prepared from 20% moisture level was lower than the bales made from 16% moisture content. Thus, baling hays at 16% moisture content resulted in higher final bale density and consequently lower volumes.

CONCLUSIONS

Samples of Timothy hay were conditioned to attain moisture contents of 7.0, 12.0, 16.0 and 20%. The samples were compressed to laboratory size bales using a hydraulic press. The exerted pressure was up to 21.0 MPa and the changes in the thickness and density of the bales were recorded at 3.5 MPa intervals. The analysis of data showed that 97.5% of the drop in the thickness of the bales was obtained when the applied pressure was about 7.0 MPa. The highest density occurred for 16 and 20% at the maximum applied pressure. At EMC, the lowest density was for the bales prepared from hay with 7% moisture and the maximum density was for the bales made from hay with 16% (wb) moisture content.

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