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DEVICE FOR CONTINUOUS MEASUREMENT OF STRAW BRIQUETTE EXPANSION*

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A b s t r a c t. A device was developed for the continuous monitoring of the expansion of straw or hay briquettes after removal from the die. The instrument was tested within a trial of briquetting of various straws submitted for mechanical and chemical pre-treatments. The developed device proved to be easy to use, while allowing measurement sensitivity better than 0.5 mm over a long period of time. It was possible to record even slight briquette expansion and to determine different trends of expansion for wheat and rice straw and for straws that had undergone different treatment.

K e y w o r d s: straw briquette, expansion over time, measurement device

INTRODUCTION

Wide-scale use of rough fodder and other agricultural by products, for example cereal straws, is economically feasible if these are compressed into packages having high density and stability for easy mechanical handling.

Briquettes, which can be produced by extruding fibrous vegetal material through a tapered die or by compressing it in a closed die fulfill the condition [5,9]. Moreover in-depth knowledge of the mechanical characteristics of the vegetal material, and of its behaviour during compression and after removal from the die, is required to optimise the briquette forming process [8].

Many different studies and also experiments we have carried out [6,7] have revealed that the briquette formation process is a material deformation phenomenon, which depends to a considerable extent on histological characteristics that vary with the species and variety of cereal, and with its stage of maturity. Three operating parameters that have a major effect on formation of the briquettes have also been identified. These are as follows: the die dimensions; the mode of compression; the material characteristics and preparation [10]. From a practical point of view, bulk density after storage, and durability, (ability to withstand mechanical handling) are the most important characteristics of straw and hay briquettes.

On ejection from the die the briquette elongates rapidly and the diameter increases, to a lesser extent. There is then a delayed expansion over a specific period of time, after which the briquette attains its stable density, called relaxed density.

According to Faborode [4], total strain of the vegetal material during compression consists of five components, some of them are irrecoverable and depend on load application time (holding time) while others are independent of this and are only temporary (recoverable strain).

Several researchers have determined the reduction of density over time after ejection of the briquette from the die, but their results vary

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widely, partly because of the different vegetal material and operational conditions used.

Some works on hay have indicated that the expansion occurs mainly in the first 15 min and that after 30 min it is slight [3]. O'Dogherty and Wheeler [10] working on straw, found briquette relaxation almost complete 1 h after removal from the die, and the total density reduction was 64-75% of that under compression. Moshenin and Zaske [8], reported no further appreciable expansion in length after 5 h, and found radial expansion to be negligible; other workers have detected a continuous decrease in density, over a period of 1,000 h, but after 10 h the decrease was small [2].

The change in density after compression of the briquette, and the duration of its expansion until it reaches stable relaxed density, determinant for bulk density of the briquettes, require further study.

Within a programme of research into the behaviour of various straws during compression and after ejection from the die, a device to measure briquette expansion was developed and tested. The aim of this study was to monitor the briquette expansion after removal from the die precisely and continuously until stable density was reached and to define the trend and duration of the expansion.

A secondary aim was to ascertain whether physical and mechanical pretreatments are a suitable method to increase the compressibility of straw.

MATERIALS AND METHODS

Experimental equipment and straw treatments

Compression tests of barley, wheat and rice straws were carried out with an experimental press with which a maximum pressure of 110 MPa could be exerted on the material in the die. Instrumentation, fitted to the press enables the force applied, the one at the base of the die, the friction forces at the walls and piston displacement to be measured [6].

Our current experiments concern the effect of the mechanical treatment - chopping to 40 mm, or opening up (cutting along) and chopping of the stems - and of chemical treatment, using anhydrous ammonia (NH_3) in doses ranging from 0 to 50 g kg^{-1} of dry matter (DM).

For the chemical treatment, the chopped (CHP), or opened and chopped straw (CHPO) was placed in micro-silos into which gas was injected; they were sealed for 40 days.

A number of compression tests were carried out comparing two pressure values, 42 and 60 MPa, applied to the straw for 8 s. A cylindrical die, 220 mm high, 45 mm in diameter was used. For each test a sample of 40 g of straw was used.

After ejection from the die, the briquettes were weighed, measured with a high precision gauge and then placed in the device, for the measurement of expansion over time. At the end of the monitoring, they were measured again with the same technique. The device was located in controlled climate at 20 °C and with 70% of relative humidity, representing typical climatic conditions.

On some of the briquettes, after three or eight days, the durability was determined according to the ASAE S 269.2 Standard [1].

Longitudinal expansion (*EL*), of the briquette was calculated on the basis of the sample length after ejection from the die (l_i,) and of the length after expansion (l_f) as follows:

$$EL = \frac{l_f - l_i}{l_i}.$$

Description of the continuous measurement device for briquette expansion

The device makes it possible to take four concurrent measurements; each measurement unit has a precision potentiometer, with a resistance of 5 kΩ±30%, with a grooved pulley with a diameter of 23 mm, inserted on the shaft (Fig. 1). A thread of low .creep material is wound around the spiral of the pulley. Two weights 2.45 and 3.33 daN are attached to the ends. These are selected, as ascertained previously, so that the lower one (G of Fig. 1) can be moved by a force of 0.39 daN in such a way that it has no noticeable effect on elastic recovery of the

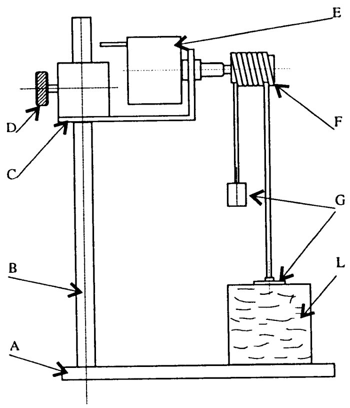

Fig. 1. Device for continuous measurement of straw briquette longitudinal expansion: A-base, B-shaft, C-adjustable holder, D-fixing screw, E-precision potentiometer, F-pulley, G-dead weights, L-wafers.

briquette. The measurement range is 70 mm; the potentiometer, has a full scale value of 1.6 V. The signal is sent by the power supply and amplification unit to a recorder and data logger.

The linear movement of the upper part of the briquette lifts the plate and is transformed into rotary motion of the potentiometer axis and then into a Volt signal that is recorded in time.

Even if the briquettes are obtained at high pressures, their height is not less than 30 mm. Thus a 30 mm high metal cylinder is placed under the smaller weight so that the signal corresponds to zero, and a 100-mm high cylinder is used to find the signal of the full scale value.

As soon as the briquette is removed from the die it is placed under the lower mass plate. The effective value of the height at time t, h_t is obtained, from the value h_i read as follow:

$$h_t = \frac{h_i}{k} + 30$$

where k varies according to amplification of the signal.

RESULTS

Table 1 gives the results of the tests carried out with CHP and CHPO wheat and rice straw, treated with 25 and 50 g NH_3 kg^{-1} DM, and compressed at 42 MPa. The length of wheat straw briquettes was in all cases significantly higher, already after 1 h, than that of rice straw. Durability, measured 3 days after production, was higher for rice straw briquettes, smaller differences being detected at the higher dose of NH_3. The ammonia seemed to have a smaller effect on this characteristic than on volume rebound.

Operating with a pressure of 42 MPa, most of the expansion in the briquette occurred within the first two hours after removal from the die, in a much wider frame than that (30 min) indicated by other researchers [3].

After 36 or 48 h, depending on the pressure applied (42 or 60 MPa) the expansion became negligible. On average, after a week, a further expansion ranging from 1.5 to 2.8 % of the initial length was detected, which again depended on both type of straw and ammonia treatment.

The expansion trend differed according to the varieties of straw and was greatly affected

Table 1. Increases of length (%) measured* after ejection from the die and variations in time of rice straw briquettes given different mechanical and chemical treatments, compressed in a die, at 60 MPa

Treatment		Lenght (mm)	Time (min)								
			1	5	10	20	30	60	120	180	600
NH_3	0 g kg^{-1} DM										
	- chopped	35	32	72	85	115	140	165	176	186	201
	- opened+chopped	37	28	66	79	98	108	119	140	154	176
NH_3	50 g kg^{-1} DM										
	- chopped	32	29	38	44	50	54	78	98	104	110
	- opened+chopped	33	20	49	52	56	59	64	71	86	97

*Averages of four replicates.

by the physical and chemical treatments (Fig. 2). The ammonia seemed to be more effective for restraining the briquette rebound, when applied on opened straw.

The course of experimental data suggested an exponential function as a model of the process. The non-linear least squares fitting procedure was applied to measurement data of longitudinal expansion as function of time. A function of the form:

$$y = a+b\ [1\text{-exp}\ (-t/c)]$$

was adopted. Parameters *a, b* and *c* are empirical constants. Their physical meanings are: *a*, the briquette length when measurement started; *b*, asymptotic increase in briquette length; *c*, the time required by the briquette to expand in length by a value of (1-1/e), approximately equal to 63% of total linear expansion.

Their values, determined for the expansion curves of briquettes from rice straw compressed at 42 MPa, as shown in Fig. 2, are given in Table 2.

The derivatives of the curves fitting the data points of briquettes from opened and chopped wheat straw, WCPHO, and rice straw, RCHPO, (Fig. 3), were determined in order to calculate the instantaneous velocity of expansion, at the times: $t = 0$; $t = c$; $t = 2\,c$; $t = 3c$.

At these times, the velocity has decreased to 37%, 15%, 5% of the initial value.

Wheat straw was found to have a higher initial expansion velocity than rice straw: 0.25 and 0.22 mm min^{-1}, respectively. Still at time $t = 3c$, the velocity for wheat was higher, though the difference was less.

For untreated chopped rice straw, the increase in length of the briquettes, 10 h after production, was more than double, i.e., 201% against 97% for straw treated with 50 g NH3 kg^{-1} DM (Table 3).

This confirms that alkali treatment acting on the structure of lignin-cellulose components, and on the wax and cutin of the surface cells of straw may improve its compressibility [11], and moreover might confirm that the yielding effect, and therefore also the binding action, of ammonia is greater for rice straw. This behaviour also leads

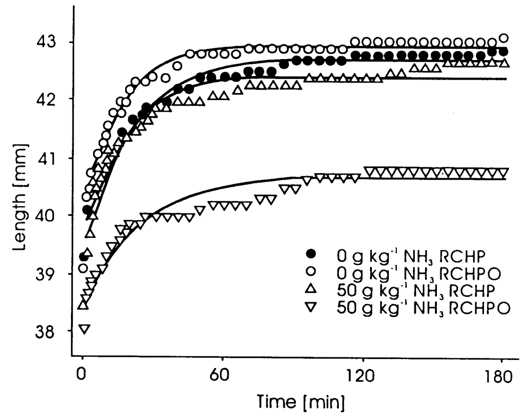

Fig. 2. Curves of the expansion over two hours after ejection from the die of chopped (CHP) or chopped and opened up (CHPO) rice straw briquettes obtained at 42 MPa.

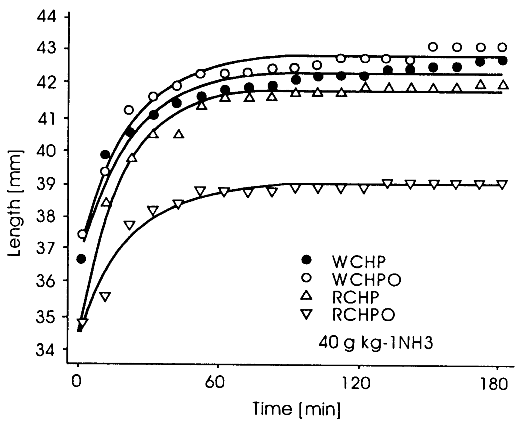

Fig. 3. Longitudinal expansion in time of briquettes from wheat (W) and rice (R) straw chopped (CHP) or chopped and opened up (CHPO), treated with 40 g/kg DM of anhydrous ammonia and compressed at 60 MPa.

Table 2. Values of empirical constants of the exponential curves of expansion in time for rice straw briquettes produced at 42 MPa

Treatment	Constans		
	a (mm)	b (mm)	c (s)
NH3 0 g kg-1DM			
- chopped	40.02	2.71	23.71
- opened+chopped	39.84	3.08	14.76
NH3 50 g kg-1DM	39.40	2.99	15.97
- chopped	38.54	2.16	25.70
- opened+chopped	38.54	2.16	25.70

Table 3. Variation in length (mm) over time and durability of briquettes produced with straws given different mechanical and chemical treatment, compressed in a die, at 42 MPa

Straw and treatment		Time (h) 0	1	3	24	Durability° (%)
		*				
Wheat						
NH_3 25 g kg^{-1}DM	- chopped	44^a	59^a	62^a	66^a	87^b
	- opened+chopped	45^a	57^{ab}	63^a	68^a	83^c
NH_3 50 g kg^{-1}DM	- chopped	41^a	57^a	61^a	64^a	88^{ab}
	- opened+chopped	39^a	46^b	48^b	52^b	91^a
Rice						
NH_3 25 g kg^{-1}DM	- chopped	37^b	44^b	47^b	51^b	89^{ab}
	- opened+chopped	39^a	46^b	48^b	52^b	91^a
NH_3 50g kg^{-1}DM	- chopped	35^b	40^c	45^c	49^{bc}	93^a
	- opened+chopped	37^b	43^{bc}	46^{bc}	48^c	94^a

*at ejection ° three days after ejection from the die; a, b, c: means in the same column with different superscripts, differ significantly ($P<0.05$).

to the conclusion that the irreversible component of the total deformation of the rice straw briquettes is higher than for those made from wheat straw.

A marked correlation was found between the final and the extruded length of the briquettes produced at 42 MPa, but it was not so close for the 60 MPa pressure (Fig. 4). This level of pressure would appear to be sufficient to alter the mechanical structure of the fibres, producing important irrecoverable strain in the briquetted rice straw.

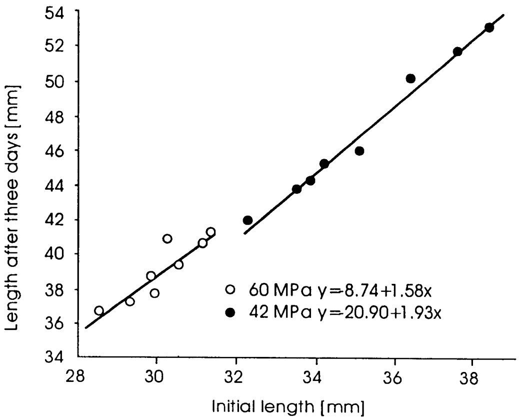

Fig. 4. Relationship between the final length and the length after ejection from the die of briquettes made from rice straw, compressed at 42 or 60 MPa.

CONCLUSIONS

The apparatus developed proved to be easy to use, and permitted continuous concurrent measurements of extension along the lengthwise axis of four wafers even for a week.

The difference in weight, 0.39 daN, between the contrast plate and the mass of the counterweight, supported by the shaft of the potentiometer, had no noticeable effect on the expansion of the briquettes. The difference in weight however allowed us to determine the average shift, in relation to the plane of the upper base of the wafer, and not in relation to the single stem fractions which, in some cases, tended to become detached.

Measurement sensitivity was better than 0.5 mm; it was therefore possible to record even very low expansion values, as highlighted by the data presented, and to follow the expansion of the straw or hay compressed to high density, characterised by limited elastic recovery.

The apparatus could, therefore, be used for a more in-depth study of the effect of the physical-chemical treatment of the straw to be compressed, both on elastic recovery and on stress relaxation which determine the final density of the briquette after storage.

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