FRICTION COEFFICIENTS OF ALFALFA AT HIGH PRESSURES

D.R. Menzies

Research Station, Agriculture Canada, Box 185, Vineland Station, Ontario L0R 2E0

Received 20 June 1975

When alfalfa was compressed in a closed-end chamber at applied pressures up to 11,200 kilo-Pascals, the coefficient of sliding friction was found to be independent of contact pressure for moisture contents up to 14% wet basis, but decreased with increased pressure for moisture contents between 18 and 23.7%.

INTRODUCTION

The cost of handling, shipping, and storing bulk material such as alfalfa is inversely related to the material's bulk density. Because of the severe regional droughts that periodically occur in Australia, and the concomitant need for storage and transhipment of fodder for feeding livestock, a study of the compression of alfalfa to high bulk densities was instituted.

Compression can be done by stationary or mobile balers, wafering and pelleting machines. However, in all these compression processes, the frictional forces of the material on the chamber or die walls can cause a sizable energy loss. Several workers have studied the energy requirements for hay compression and how various parameters affect the density and durability of high density packages (Ashcroft 1968; Bellinger and McColly 1961a,b; Bruhn et al. 1959; Butler and McColly 1959; Mewes 1958; Reece 1966; Richter 1954; Stewart 1969; Yang 1968; Rehkugler and Buchele 1969). In all cases, the friction effects of the material on the chamber walls were either minimized, or not evaluated. Mewes (1958) studies both interlaced and parallel straw samples during and after compression and noted that wall friction retarded relaxation of the compressed sample. Richter (1954) determined the friction coefficients of straw, hay, grass silage, and corn silage at low normal pressures. He observed a reduction in the coefficients with increased pressure for high moisture content silage (>70%) when tested at pressures of from 268 Pa to 3,352 Pa. The effect of low pressure on the friction coefficient of chopped hay and straw was considered insignificant.

This paper reports the effect of moisture content (4.4 − 23.7% w.b.) and high contact pressure normal to the chamber walls (698 kPa − 4,400 kPa) on the sliding coefficient of friction of alfalfa when compressed in a closed-end rectangular chamber (Menzies 1976) at applied pressures of up to 11,200 kPa.

TEST PROCEDURE

Thirty samples of material were randomly taken from previously baled, medium-to-late-bud, first-cut alfalfa. Samples to be compressed at elevated moisture contents were moistened by a fine water mist and allowed to stabilize for 24 h prior to compression. Samples to be tested at low moisture contents were sun-dried prior to compression.

The chamber (Menzies 1976) was firmly packed by hand with enough material to fill it. The load was then applied to a maximum of 11,200 kPa at a rate of 190 kPa/sec. Following compression, the samples were removed from the chamber and oven-dried at 74°C for 48 h to determine their moisture contents.

RESULTS

The 30 tests were grouped into 10 classes according to moisture content and a linear regression analysis of friction coefficient versus contact pressure was done on each class for lateral pressures greater than 698 kPa (Table I). The contact pressure of 698 kPa was the point above which the relationship became linear for all samples tested. At lower contact pressures, the friction coefficient was observed to be higher than the linear relationships would indicate. Therefore, friction coefficients calculated from the data in Table I are applicable in the contact pressure range of 698 kPa − 4,400 kPa.

The friction coefficient of alfalfa was independent of pressure for moisture contents up to 13.9% w.b. ($P > 0.05$) but decreased with increased lateral pressure for moisture contents from 18.0 to 23.7% w.b. ($P < 0.05$) (Fig. 1). Free moisture was observed on the chamber walls and base following compression of samples at 18.0 − 23.7% moisture content, but not for the drier samples. This observation would support the conclusion that expressed moisture lubricated the chamber walls at the higher pressures, thereby reducing the frictional forces on the walls.

Published data relating the sliding friction coefficient of chopped forage on stainless steel to moisture content show values of 0.25 at 20% and a rapid increase to 0.60 at 40%, followed by a levelling off to a maximum coefficient of 0.65 at 74% moisture content (Agricultural Engineers Yearbook 1974; Richter 1954). Richter indicated that for chopped grass at 74%, the friction coefficient on galvanized steel dropped from 0.80 to 0.64 when the pressure increased from 268 Pa to 3,352 Pa. It would appear that at high moisture content, liquid is expressed at the relatively low applied pressures of 0.3 kPa − 3.3 kPa, whereas

TABLE I. TEST GROUPINGS AND REGRESSION ANALYSES OF FRICTION COEFFICIENT VS. PRESSURE FOR ALFALFA ON STEEL FOR PRESSURES FROM 698 TO 4,400 kPa

Group	Moisture content range (% w.b.)	No. of tests	Intercept	Slope	Std. error of estimate
1	4.4 − 4.6	4	0.145	0.6×10^{-5}a	0.006
2	6.2	1	0.166	-2.9×10^{-5}a	0.003
3	7.2	1	0.180	0.0×10^{-5}a	0.000
4	10.7 − 11.4	5	0.226	4.6×10^{-5}a	0.029
5	12.2 − 12.8	5	0.233	2.2×10^{-5}a	0.025
6	13.0 − 13.2	3	0.291	-0.8×10^{-5}a	0.024
7	13.5 − 13.9	5	0.298	1.8×10^{-5}a	0.017
8	18.0 − 18.8	2	0.367	-20.4×10^{-5}bc	0.035
9	20.7 − 21.3	3	0.390	-28.6×10^{-5}c	0.015
10	23.7	1	0.337	-20.2×10^{-5}b	0.006

a Not significantly different from zero ($P > 0.05$).
a-c No significant difference between slopes with same letters ($P > 0.05$).
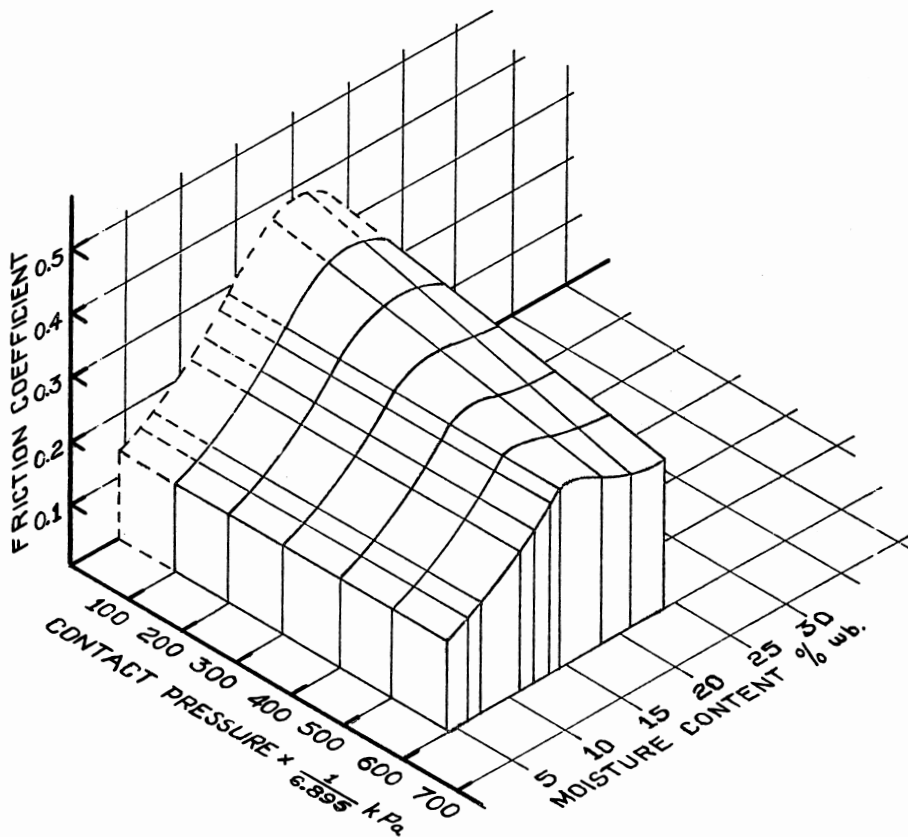
Figure 1. Relationship of friction coefficient versus moisture content and contact pressure for alfalfa on hot-rolled steel plate.

at moisture contents of ca.20%, this occurs at applied pressures in the 690-kPa to 11,200-kPa range.

When compressing alfalfa, it is possible that the upper useful limit of compaction would occur at the point where moisture is expressed, as any further reduction of bulk density would be dependent on moisture loss. This would result in nutrient loss.

As stated, the alfalfa used in this study had been field-baled prior to compression in the chamber. To elevate the moisture content of some samples, water was added. Both these factors could influence the results as compared to values obtained from compressing fresh dehydrated alfalfa. However, the pressures experienced in field balers (138 − 200 kPa) are not likely to cause a significant difference in the results because little physical damage is done to the stems of the plant where the greatest reduction in volume takes place during compression. Field crushing or crimping would likely cause a greater discrepancy. The differ-

AGRICULTURAL ENGINEERS YEARBOOK. 1974. Amer. Soc. Agric. Eng. p. 439.

ASHCROFT, D.A. 1968. The compression creep properties of reduced forage. Unpublished MSc. Thesis, Pennsylvania State Univ.

BELLINGER, P.L. and H.F. McCOLLY. 1961a. Energy requirements for forming hay pellets. I. Agric. Eng. 42(4): 180-181.

BELLINGER, P.L. and H.F. McCOLLY. 1961b. Energy requirements for forming hay pellets. II. Agric. Eng. 42(5): 244-247, 250.

BRUHN, H.D., A. ZIMMERMAN, and R. NIEDERMEIER. 1959. Developments in pelleting forage crops. Agric. Eng. 40(4): 204-207.

BUTLER, J.L. and H.F. McCOLLY. 1959. Factors affecting the pelleting of hay. Agric. Eng. 40(8): 442-446.

CHANCELLOR, W.J. 1962. Formation of hay wafers with impact loads. Agric. Eng. 43: 136-139, 149.

MENZIES, D.R. 1976. An instrumented chamber to compact fodder at high pressure. Can. Agric. Eng. 18: 18-20.

MEWES, E. 1958. Zum verhalten von pressgutern in presstopfan. Lantech. Forsch. 8(H6): 158-164.

REECE, F.N. 1966. Temperature, pressure and time relationships in forming dense hay wafers. Amer. Soc. Agric. Eng. Trans. 9(6): 749-751.

REHKUGLER, G.E. and W.F. BUCHELE. 1969. Biomechanics of forage wafering. Amer. Soc. Agric. Eng. Trans. 12(1): 1-8, 12.

RICHTER, D.W. 1954. Friction coefficients of some agricultural materials. Agric. Eng. 35(6): 411-413.

STEWART, W.O. 1969. Creep and relaxation properties of compressed alfalfa forage. Unpublished MSc. Thesis, Pennsylvania State Univ.

YANG, YANN-MO. 1968. A rheological approach to compressibility of alfalfa forage. Unpublished MSc. Thesis, Pennsylvania State Univ.