Physical Properties of Alfalfa Hay:

(1) Specific Weight of Chopped Hay Fragments
(2) Porosity of Alfalfa Hay Masses

BY

C. L. DAY AND H. H. PANDA

CONTENTS

Physical Properties of Alfalfa Hay:
(1) Specific Weight of Chopped Hay Fragments
(2) Porosity of Alfalfa Hay Masses

BY

C. L. Day and H. H. Panda

INTRODUCTION

Better methods for harvesting, handling, drying and storing forages can be developed more rapidly if the basic physical properties of the forage are known. Previous publications reported information on the bulk densities of chopped alfalfa hay and the resistance of hay to air flow. (1) (2)* Two properties—the specific weight of individual pieces or fragments of hay and the porosity of hay masses—relating to the baling, pelleting and drying of hay are discussed.

A porous medium may consist of solids, liquids, pore spaces enclosed by the solids and interstitial spaces between the solids. Hay can be considered to be made up of solids, liquid and air. The solids consist chiefly of cellulose, protein, starch, sugar, pectin, lignin, fats, organic acids and metallic ions. Liquid, in the form of water, fills a part of the space within and between cells, tissues and fibers. Air occupies the remaining space.

The specific weight of a hay stem or leaf can be determined by measuring its volume and dividing by its weight. This value differs from the bulk density of a hay mass in that the latter is generally defined as the weight of bulk stored material per unit volume. The bulk density of dry hay is affected by the amount of pressure applied by baling or pelleting. When stored more than two feet deep, the weight of the hay causes an increase in the bulk density at the bottom of the mass. (1) The specific weight of an individual fragment, however, is not likely to be affected by pressures encountered in the bulk storage of hay. Both specific weight and bulk density may be expressed in pounds per cubic foot.

Since the specific weight of a hay fragment has been defined as its weight per unit volume, it cannot necessarily be determined from the specific weight of its liquids and solids as it may contain some pore spaces enclosed by the solids. A change in composition or in the volume of a fragment might cause a change in the specific weight of the fragment. The most common change in the composition of hay is loss of moisture. At the time of cutting, alfalfa hay usually has a moisture content of between 60 and 75 percent (wet basis). It is generally considered safe for bulk storage when dried to a moisture content of 20 percent or less.

* Numbers in parenthesis refer to appended references.

SPECIFIC WEIGHT OF CHOPPED ALFALFA HAY FRAGMENTS

One method of determining the specific weight of chopped alfalfa fragments is to submerge the fragments in a liquid that will fill all the interstitial spaces and the pores which are not enclosed. The desirable characteristics of the liquid are:

1. Low viscosity at room temperature.

2. Non-wetting.

3. Chemically inert to organic matter and metals.

4. Stable specific weight, i.e., specific weight remains constant over the range of usual room temperatures and does not differ if obtained from different sources.

5. Not easily evaporated at room temperature.

6. Low density.

7. Neither harmful to work with nor hazardous.

Though mercury is preferred to determine porosity of materials due to its non-wetting property, it was not considered to be suitable as there is no practical way to submerge the hay sample in it. Two other liquids, water and diesel fuel, were tested for suitability. The measured values of specific weight of alfalfa fragments were lower when water was used to submerge the hay than when diesel fuel was used. In each case, the weight of the sample submerged in the liquid gradually increased as the liquid filled more of the pores, but the weight in diesel fuel increased more rapidly than the weight in water. Moreover, after a few hours of submersion in water, the hay started to decompose. For these reasons water was not considered suitable. No sign of decomposition was noted when hay was submerged in diesel fuel for periods up to 48 hours. Hence, the experiment was conducted with diesel fuel.

A balance-type scale with a least division of one gram was used for weighing the samples. Four metal cans, 10 inches in diameter and 13½ inches deep, were used to contain the diesel fuel. Cans, 4 inches in diameter and 6½ inches deep with small openings at the bottom, were used as containers for the hay while submerged in the diesel fuel.

The specific gravity of the diesel fuel used was determined by a precision specific gravity balance with an accuracy of 0.0001 and found to be 0.828. The weight of each can and accessories (such as wire mesh and weight) in diesel fuel was obtained using a Toledo balance scale.

Freshly cut alfalfa hay was spread for uniform, gradual drying. At intervals of time sufficient to change the moisture content by 10 to 15 percent, approximately two pounds of hay was chopped manually for testing. A sample weighing 100 to 200 grams was packed into each can after determining the exact

weight of the sample. Two other samples collected from the remaining chopped hay were dried in an electric oven to determine moisture content of the hay when it was placed in the cans. It was found that after 48 hours of submersion in diesel fuel very little change occurred in the weight of the submerged sample. Therefore, the cans and their contents were weighed while submerged after 48 hours of submersion in diesel fuel.

The specific weight of the hay fragments was calculated from its weight and its true volume. The volume of diesel fuel displaced when the hay was submerged in it is determined by dividing the buoyant forces by the specific weight of the diesel fuel.

$$\text{volume displaced} = \frac{W_a - W_d}{S_d} \qquad \text{Equation 1}$$

where W_a is the weight of a sample of hay in air, W_d is the weight of the sample of hay when submersed in diesel fuel, and S_d is the specific weight of diesel fuel. The specific weight of the hay fragments (S_h) then becomes

$$S_h = \frac{W_a \times S_d}{W_a - W_d} \qquad \text{Equation 2}$$

Buoyant forces in air were assumed to be negligible.

The results of the tests conducted for determination of the specific weight of chopped alfalfa hay fragments are given in Table I. The same data along with

TABLE I--ORIGINAL DATA FOR MOISTURE CONTENT AND SPECIFIC WEIGHT OF HAY FRAGMENTS

Moisture Content (percent)	Specific Gravity of Hay			Specific Weight* of Hay Fragments (lbs/ft^3)
	Trial 1	Trial 2	Mean	
0	0.826	0.854	0.845	52.64
5.87	0.828	0.821	0.825	51.40
11.15	0.900	0.890	0.895	55.82
16.95	0.974	0.985	0.980	61.05
17.56	0.862	0.872	0.867	54.01
25.72	0.986	0.980	0.983	61.24
26.51	0.963	0.946	0.955	59.50
33.03	0.986	0.974	0.980	61.05
35.69	1.010	0.994	1.002	62.42
40.72	1.040	1.028	1.034	64.42
43.75	1.052	1.056	1.054	65.66
57.25	1.048	1.049	1.049	65.35
59.73	1.035	1.022	1.029	64.11
63.04	1.033	1.063	1.048	65.29
70.13	1.041	1.016	1.029	64.11

*Specific weight of water was taken to be 62.3 pounds per cubic foot.

the value for the density of water are presented graphically in Figure 1. A digital computer was used to determine the best polynomial curve to fit the experiment data.

The following second degree polynomial was found to best fit the experimental data:

$$S_h = 51 + 47M - 39\ M^2 \hspace{4em} \text{Equation 3}$$

where S_h is the specific weight of the hay fragments and M is the moisture content (wet basis) expressed as a decimal fraction. By differentiating this equation and setting the derivative equal to zero, the maximum specific weight was found to occur when the moisture content was about 60 percent.

As stated previously, the moisture content of alfalfa hay rarely exceeds 75 percent. If we can assume that the hay plant is saturated at 75 percent moisture, then higher moisture contents could be achieved only by adding water external to the plant. The material then becomes a mixture of hay and free water. Thus, a discontinuity would be expected to occur in the curve at the point where the hay becomes saturated. Each point in Figure 1 represents the mean value of two replications of the tests. Though there is some scattering of points, the experimentally determined values of specific weight of hay fragments increased with moisture content from zero up to 60 percent and then leveled off or dropped slightly.
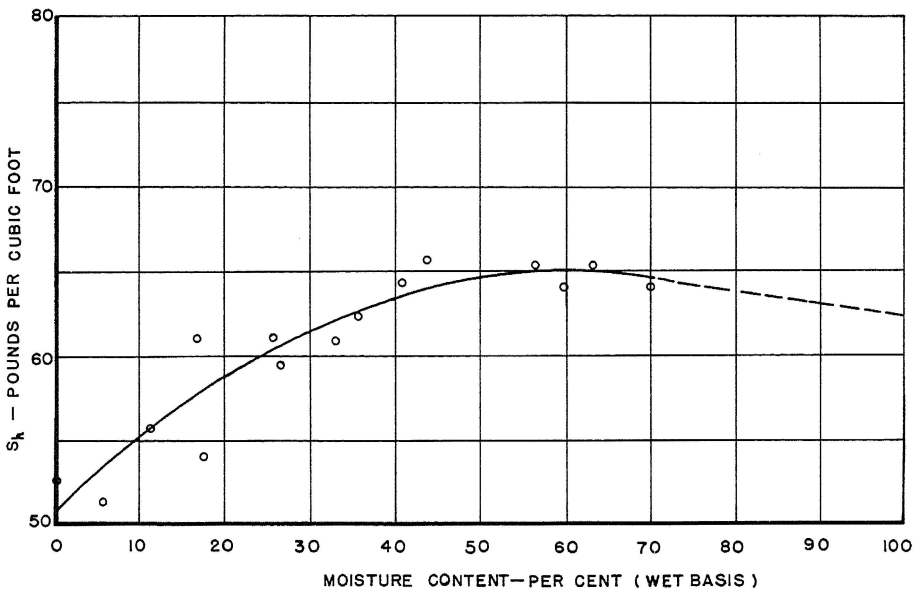

Fig. 1—*Relationship between the specific weight of hay fragments and moisture content of the hay.*

The specific weight of individual pieces of hay changes as a result of exchange of air and moisture. Obviously the maximum specific weight occurs when the maximum amount of air is replaced by water. In the case of alfalfa hay, it appears that the particles become saturated between 60 and 75 percent. Any further increase in moisture content must be accompanied by an increase in volume and, assuming that the specific weight of the fiber is higher than that of water a decrease in specific weight must result. This finding is consistent with results obtained by Day (2) relating to the resistance of hay to air flow. He found that the resistance increased sharply at moisture contents above 60 percent if the dry matter bulk density was held constant.

If it can be assumed that the maximum specific weight as indicated by Figure 1 occurs at a point where all of the air is excluded from the plant and an individual piece consists only of solids with a specific weight S_s and liquid with a density of 62.3 pounds per cubic foot, S_s may be determined as follows. At 60 percent moisture, the composition of individual pieces of hay is W_1 pounds of water and W_2 pounds of solids occupying the entire space (no air). If enough pieces are considered to constitute one cubic foot and if their specific weights are 65.0 pounds per cubic foot, the maximum shown in Figure 1, then

$$W_1 = 65.0 \times 0.60 = 39.0 \text{ pounds of water}$$

$$W_2 = 65.0 \times 0.40 = 26.0 \text{ pounds of solids}$$

and

$$\frac{W_1}{62.3} + \frac{W_2}{S_s} = 1 \text{ cubic foot}$$

or

$$S_s = \frac{(26.0) \ (62.3)}{62.3 - 39.0} = 69.5 \text{ pounds per cubic foot}$$

Although this value may not be precise, it is, at least, reasonable. The initial specific weight of hay pellets ranges up to 50 pounds per cubic foot and such pellets would undoubtedly contain some interstitial air spaces. A laboratory determination of the specific weight of commercially available pressed wood (masonite) was made by weighing samples in air and in water. A value of 71.3 pounds per cubic foot was found for a sample which had been submerged in water for about 20 minutes. It can be assumed that the specific weight of hay fibers would be near that of wood fibers.

If the hay fragments at all moisture levels consisted only of solids and water (no enclosed air spaces), the specific weight (S) of the individual fragments could be determined by the following relationship:

$$S = 62.3 M + (1-M) S_s \qquad \text{Equation 4}$$

where M is the moisture content expressed as a decimal fraction, 62.3 is the specific weight of water at 70°F (pounds per cubic foot) and S_s is the specific

weight of the solids. If the specific weight of the solids is the same as that of water, then the specific weight of the hay would be independent of moisture content. If, however, the specific weight of the solids is higher than that of water, the specific weight of an individual fragment with no enclosed air spaces depends upon the proportion of water and solids. Under such conditions, the specific weight of the individual fragments at any moisture content could be determined from the straight line relationship shown in Figure 2.

If Figure 1 is superimposed on Figure 2 (see Figure 3), the two curves are seen to coincide for moisture contents above about 60 percent. For moisture contents less than 60 percent, there apparently were enclosed pore spaces which were not penetrated by the diesel fuel during the 48 hours that the hay was submerged in it. It is possible that some of these enclosed spaces could be penetrated by air or other fluids.

POROSITY OF ALFALFA HAY

The porosity of alfalfa hay is defined as that fractional space made up of the interstitial spaces between hay fragments and of the pore spaces in the hay which are not enclosed. The remaining space occupied by the solids, liquids and enclosed pores was used in defining the specific weight of the hay fragments.
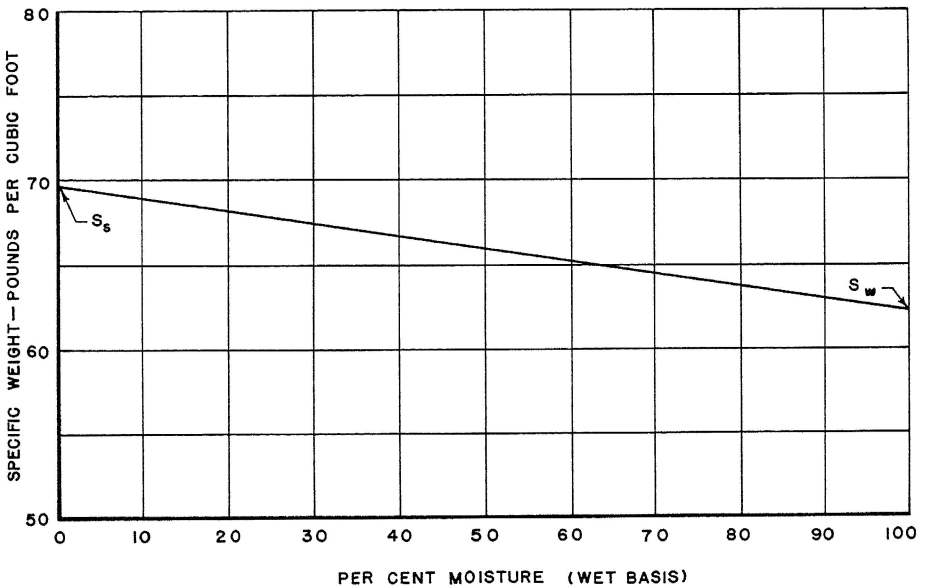

Fig. 2—Relationship between specific weight and moisture content for a material with no enclosed pore spaces.
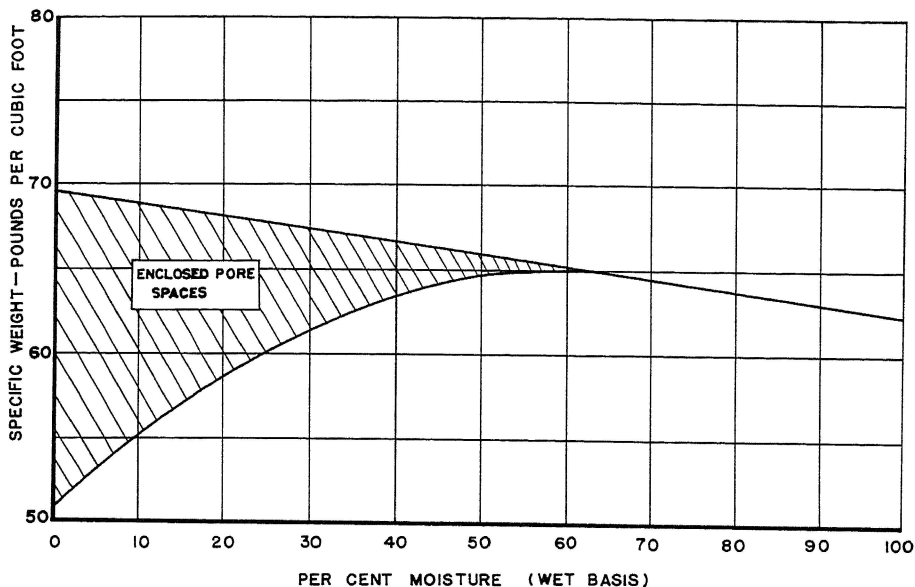
Fig. 3—Relationship between specific weight and moisture content for hay frag-ments with and without enclosed pore spaces.

The porosity of a hay mass can be calculated if the specific weight of the individual fragments making up the mass is known and the bulk density of the mass is known. The relationship is

$$f = 1 - \frac{S_a}{S_h} \qquad \text{Equation 5}$$

where f is the porosity expressed as a decimal fraction, S_a is the bulk density of the mass and S_h is the specific weight of the fragments making up the mass.

A number of determinations of porosity of alfalfa hay have been made using the apparatus described by Day (3). The method which he used was based on the general gas law and the void spaces were filled with air rather than liquid. The results of some of his measurements along with values calculated from Equation 5 (using values of S_h from Figure 1) are shown in Table II. It will be noted that the measured and calculated values for porosity are in fairly good agreement for hay with a high moisture content. However, the calculated values are consistently lower than the measured values in the case of the dry hay. This indicates that air was able to penetrate some of the pores which were not filled by the diesel fuel in the case of the hay with 12 percent moisture. Hay with 67

percent moisture was essentially saturated, i.e., all the enclosed pores were filled with water and therefore, were not available for penetration by either air or diesel fuel.

TABLE II--COMPARISON OF MEASURED VALUES OF POROSITY WITH VALUES
CALCULATED FROM EQUATION 5

	Bulk Density	Percent	
	lbs/ft^3	Measured	Calculated
Dry Hay	2	97.1	96.4
(approximately 12 percent moisture)	2	96.5	96.4
	3	96.1	94.6
	4	94.7	92.8
	5	92.2	91.1
	5	94.3	91.1
	6	91.6	89.3
Fresh Cut Hay			
(approximately 67 percent moisture)	5	93.5	92.3
	6	92.1	90.7
	7	89.9	89.2
	8	87.5	87.6
	8	89.1	87.6
	9	84.5	86.1
	9	86.8	86.1
	9	86.0	86.1
	10	83.9	84.6
	10	82.3	84.6

SUMMARY AND CONCLUSIONS

The specific weight of individual fragments of alfalfa hay was determined by submerging samples in diesel fuel and weighing while submerged. Results of the specific weight measurements were used as a basis for calculating porosities of hay masses.

The following conclusions relative to alfalfa hay were drawn from the study:

1. The specific weight of the fibers is approximately 69 pounds per cubic foot.

2. The specific weight of individual fragments varies with moisture content.

3. The maximum specific weight of individual fragments is about 65 pounds per cubic foot and occurs when the moisture content is approximately 60 percent.

4. The specific weight of individual fragments at 20 percent moisture (a common storage moisture) is approximately 58 pounds per cubic foot.

5. The specific weight of individual fragments decreases slightly at moisture contents above 60 percent.

REFERENCES

1. Day, C. L. and Panda, H. H., "Bulk Density of Chopped Alfalfa Hay," University of Missouri, Agricultural Experiment Station Research Bulletin 891. August, 1965.

2. Day, C. L., "Resistance of Hay to Air Flow," University of Missouri Agricultural Experiment Station Research Bulletin 864. June, 1965.

3. Day, C. L., "A Device for Measuring Voids in Porous Materials," *Agricultural Engineering,* 45:36, 37. 1964.