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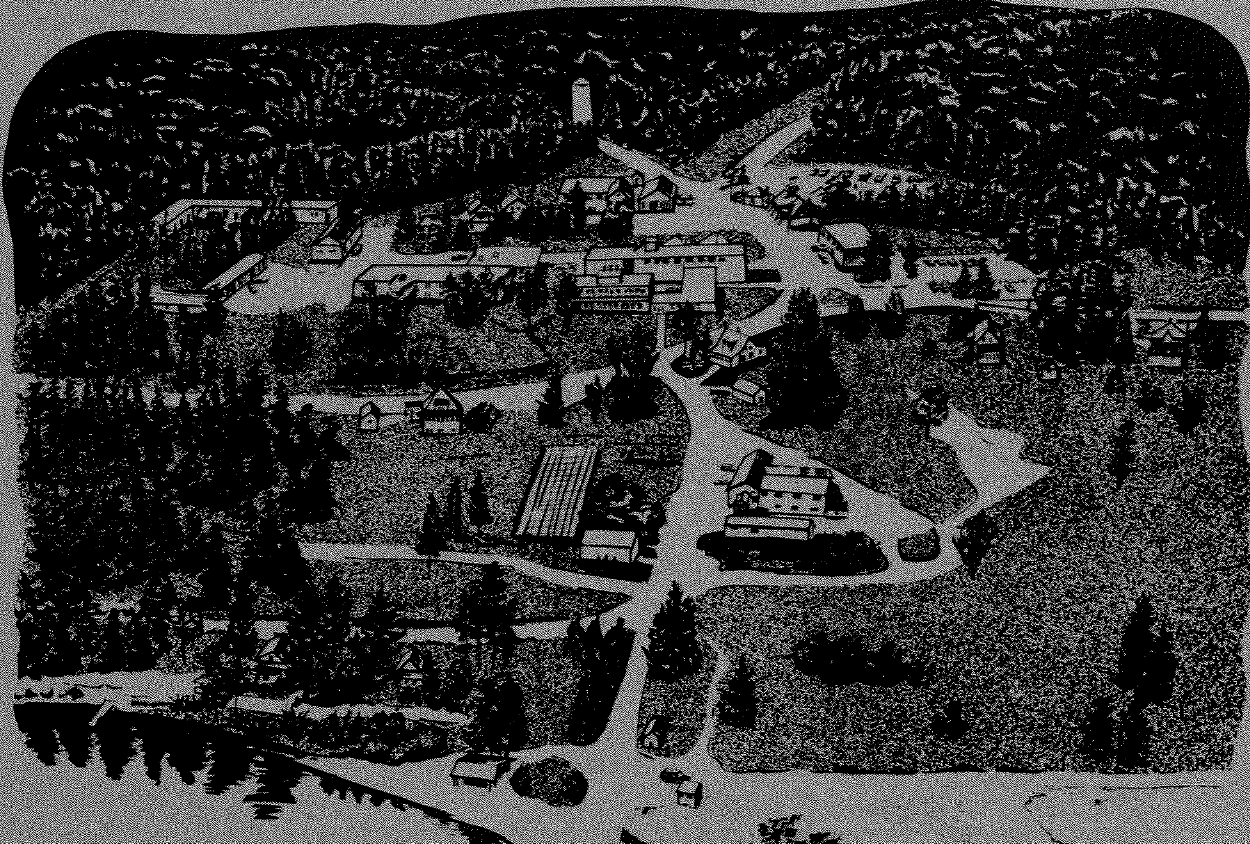
by C.E. Van Wagner



PETAWAWA FOREST EXPERIMENT STATION
CHALK RIVER, ONTARIO
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Introduction

If left indefinitely in a constant atmospheric environment, dead vegetative material tends toward a characteristic equilibrium moisture content. Since atmospheric conditions in nature usually vary appreciably on a scale of hours, it is only fast-drying materials that can occasionally approach true equilibrium. A knowledge of the equilibrium moisture content (EMC) is therefore of direct importance in estimating the moisture content of fast-drying fine forest fuels. It is also important for slow-drying fuels as well, because their drying rate depends on the amount of free moisture above EMC, not on the total moisture content.

The EMC of a particular fuel depends mainly on the relative humidity, and to a lesser degree on the temperature. Direct sunlight raises the temperature of the fuel and in turn the temperature of the adjacent air; assuming that the water vapour pressure remains constant, the relative humidity of the adjacent air will then be lowered by an amount that can be readily calculated. The effect of direct sunlight on surface temperature is complicated by wind, but wind has no effect on temperature or EMC in the absence of solar radiation. A good reference for the joint effect of sun and wind on surface litter temperature and moisture is Byram and Jemison (1943), and some laboratory work on the litter of Canadian species was done by Van Wagner (1969). This present paper deals with EMC and how it varies with relative humidity and temperature only.

Materials and Methods

During the years 1960 to 1968, the EMC's of several local species of tree litter were determined in a laboratory temperature-humidity cabinet. The results were used in other research but not considered of high enough quality to publish. Recently a new apparatus was acquired, enabling temperature to be controlled within 1 degree F and humidity within 1 to 2 percent. A further series of EMC determinations was then carried out on six kinds of leaf litter as well as match splints of aspen wood. The six species were white pine (Pinus strobus L.), red pine (P. resinosa Ait.), jack pine (P. banksiana Lamb.), trembling aspen (Populus tremuloides Michx.), sugar maple (Acer saccharum Marsh.), and grass (Calamagrostis sp.). Ten samples of each were collected, the litter species spread over the period May to October. The processed match splints were included because this material has been used often as a standard fine fuel in Canadian research on fire danger rating. The samples weighed 3 to 4 grams when oven-dry and were handled in cylindrical tins with covers.

During the experiment, the uncovered samples were held at 80 F for 48 hrs in succession at each of the following RH's: 97, 90, 80, 65, 50, 35, 22, 16, and 6 percent. This whole series was run through twice: first, starting all samples at a moisture level above EMC (desorption), and second, starting all samples from below EMC (adsorption). The same samples were used throughout. At the beginning of the desorption series the samples were dampened with liquid water and covered for 24 hrs to ensure an even high moisture content well above EMC at RH 97. Before each subsequent desorption setting the samples were conditioned for 24 hrs in the cabinet at RH 95. Before each adsorption setting the samples were conditioned for 16 hrs at 120 F and about RH 5.

After 48 hours at each setting, the samples were covered and weighed; then, at the end of the experiment, all samples were oven-dried for 24 hours at 212 F and the net dry weights determined. Weighing was precise enough to permit calculation of the EMC's to the nearest tenth of a percent.

Before this experiment, earlier runs in the old cabinet were carried out at temperatures of 60, 80, 100, and 120 F. These data were used to reinforce the present results and also in judging the effect of temperature on EMC.

Results

For each species the EMC's of the ten samples were averaged at each RH, and plotted as isotherms separately for desorption and adsorption. All curves were obviously sigmoid, rising with decreasing slope in the lower half of the RH range, and with increasing slope as RH increased toward 100 percent.

In judging the validity of these curves, the main question is about physical procedure rather than statistical treatment. The individual points were very reliable in the statistical sense, standard errors of the plotted points being:

Average for all RH up to 65%,		± 0.168	percent points
Average for RH 80 only	,	± 0.294	" "
" " RH 90 "	,	± 0.325	" "
" " RH 97 "	,	± 0.523	" "

Whenever a plotted point fell clearly off the obvious trend, the reason was most likely one of: insufficient pre-conditioning, a defective RH sensor, or imperfect control of RH during the run. Accordingly, rather than follow a purely statistical procedure, the curves were drawn freehand, using judgement about how much weight to give to plotted points apparently off the main trend. The curves were drawn as nearly as possible through the new data, referring to the old data when these seemed more logical. As examples of this procedure, Figures 1 and 2 show the desorption and adsorption data and curves for red pine litter.

When curves for the various materials were compared, the most obviously different from all the rest was aspen wood, whose curves lay about

3 points below the leaf species. Its isotherms appear in Figure 3. The three pines were generally within 1 point at mid-ranges and are shown as one composite result in Figure 4. Similarly, trembling aspen and sugar maple were similar enough to be combined in Figure 5. Grass, although not greatly different from hardwood litter, is shown separately in Figure 6. A composite pair of isotherms for all six leaf species appears in Figure 7. Finally, Figure 8 contains the EMC curves used in the Fine Fuel Moisture Code of the Canadian Forest Fire Weather Index (Anon., 1970); these are adjusted for a temperature of 80 F by lowering the standard 70 F curves 1 point along their whole length. Because comparisons among the various curves are difficult to make by eye, a list of the curve values (from the desorption isotherms only) appears in Table 1, for RH's 20, 60, 80, and 90. The isotherms are drawn between RH 5 and RH 95 only, on account of the great uncertainty in the EMC's at both ends of the range.

An effort was then made to render these curves as mathematical equations. Many theoretical treatments of this problem exist, but the most practical equation for present purposes was a semi-empirical one supplied by J.A. Turner[1/] for use in the Forest Fire Weather Index:

$$E = aH^b + ce^{(H-100)/d}$$

where E is EMC, H is RH, and a, b, c, and d are coefficients whose values change with species, temperature, and history of the sample; b is always less than 1. All curves were plotted on double log paper, and extended by eye to RH 100. As it turned out, these lines were all fairly straight up to about RH 60, above which the second term of the general equation became appreciable and produced the upswing at high RH. The coefficients for all individual species and species groups are given in Table 2. Again, the values for the EMC equations used in the Fire Weather Index are included, adjusted to 80 F.

The effect of temperature on EMC was then examined using data from older experiments carried out from 60 to 120 F. Desorption EMC's only were plotted against temperature at four levels of RH: 20, 60, 80, and 90. There was a definite trend to lower EMC at higher temperature showing, according to this limited treatment, a simple straight line relation. The slopes of the effect were fairly uniform over the RH range, averaging:

For the pines ,	-1.13%/10F
For aspen ,	-1.50%/10F
For wood splints,	-0.98%/10F

That is, for every increase in temperature of 10F, the desorption EMC drops about 1 point, and the adsorption EMC presumably behaves likewise. From this analysis, simple correction terms for the temperature effect on EMC, based on

1/ Research Scientist, Pacific Forest Research Centre, Victoria.

a normal 80F, could be designed for addition to the equation. These would be:

For the pines , 0.113 (80 - T)

For aspen , 0.150 (80 - T)

For wood splints, 0.098 (80 - T)

The vertical interval between desorption and adsorption isotherms, called hysteresis, is dependent on both RH and temperature. Judging from the plotted curves, the average hysteresis at 80 F rises from about 0.8 point at RH 10, through 2.5 points at RH 60 to about 4 points at RH 90. At medium RH, the hysteresis varies from about 1.5 points at 120 F to about 4 points at 60 F.

Discussion

A great many references exist on the theory of the sorption of gases on solids, including the particular case of water vapour on dry wood and cellulosic material. A reasonable review of the subject is given by Browning (1963), who lists many primary sources. According to him, all the features and effects observed in the present experiment can be justified on theoretical grounds, namely:

a) the sigmoid shape of the isotherms,

b) the decrease in EMC with rising temperature,

c) the presence of hysteresis between desorption and adsorption, and

d) the decrease in the magnitude of hysteresis with rising temperature.

For example, the sigmoid curve shape is the result of different modes of adsorption taking precedence in three separate ranges of RH:

1) monomolecular-layer adsorption up to about RH 20,

2) multimolecular-layer adsorption from about RH 20 to RH 60, and

3) condensation from RH 60 to RH 100.

The adsorption isotherm, approached always from a relatively dry state, should start at the origin (although the data do not show this well) and reach a fairly definite value at RH 100. The desorption isotherm is well-defined in the middle RH range, but whether it should meet the adsorption curve at the origin is not quite clear. Also, its position is somewhat vague at very high RH. For example, Browning mentions a spruce pulp whose EMC would not fall below 75.4 percent when dried from the wet state at RH 99.39.

The desorption and adsorption curves can only be obtained with material that has been either well wetted or well dried in some standard manner, so as to erase the "memory" of any previous moisture history. At the same time, the pre-treatment should not be too drastic. Too much soaking in water may dissolve out part of the dry matter; conversely, oven-drying at temperatures as high as 100 C permanently alters the sorption properties. Probably the equilibrium achieved by fine materials in nature falls usually within the hysteresis zone between the two bounding curves.

The leaf litter samples tested in this experiment were collected throughout the season. Inspection of the data suggests a possible slight seasonal trend, lowest in newly-fallen litter and increasing to a maximum throughout the following season. The maximum difference may be between 1 and 2 EMC points, but was judged of secondary importance in this experiment. The curves therefore represent seasonal averages.

A search for other published EMC's of natural forest litter yielded very few. King and Linton (1963) report some data, mainly for Australian eucalypts. Blackmarr (1971) gives EMC curves for some southern pines and hardwoods. These results are generally similar to those obtained here. The only comparable record of EMC determination on Canadian species is by Wright in 1932, whose curves for red and white pine needle litter agree fairly well with the present results. Several references for the EMC of various woods (e.g., Spalt, 1958) indicate that the curves for aspen wood splints are typical of light-weight woods in general.

The fine fuel isotherms of the Fire Weather Index result from a compromise between the EMC curves embedded in the original fine fuel Tracer Index from which the Fine Fuel Moisture Code was derived, and the present laboratory experimental values. As such, they rise more steeply in the range RH 50 to RH 80, and have distinctly less hysteresis. Only a field test would demonstrate whether these differences have an appreciable effect on the accuracy of prediction; probably they do not.

There are two main conclusions to be drawn from these data. First, all kinds of leaf litter have distinctly higher EMC's than the common woods, by an amount, about 3 percent, that is definitely important in fire danger rating. Second, while statistical differences between different kinds of leaf litter could probably be proved, these differences are not of much practical importance in the design of schemes for predicting fine fuel moisture content.

Acknowledgement

J.W. Bell collected the samples, performed the laboratory work, and processed most of the data for this report.

References

ANON. 1970. Canadian Forest Fire Weather Index. Can. Dep. Fish. Forest., Can. Forest. Serv.

BLACKMARR, W.H. 1971. Equilibrium moisture content of common fine fuels found in southeastern forests. U.S. Forest Serv., Southeast. Forest Exp. Sta., Res. Pap. SE-74.

BROWNING, B.L. 1963. The wood-water relationship. Chap. 9 in The chemistry of wood. Ed., B.L. Browning. New York, Wiley and Sons. 689 pp.

BYRAM, G.M., and JEMISON, G.M. 1943. Solar radiation and forest fuel moisture. J. Agric. Res. 67(4): 149-176.

KING, A.R. and LINTON, M. 1963. Moisture variation in forest fuels: equilibrium moisture content. C.S.I.R.O., Div. of Phys. Chem. Melbourne, Australia.

SPALT, H.A. 1958. The fundamentals of water vapor sorption by wood. Forest Prod. J. 8: 288-295.

VAN WAGNER, C.E. 1969. Combined effect of sun and wind on surface litter temperature. Can. Forest. Serv., Petawawa Forest Exp. Sta., Inform. Rep. PS-X-10.

WRIGHT, J.G. 1932. Forest-fire hazard research as developed and conducted at the Petawawa Forest Experiment Station. Reprinted in 1967 as Inform. Rep. FF-X-5 by Can. Forest. Serv., Forest Fire Res. Inst.

Table 1. Desorption EMC's for 80 F at four RH levels from the curves in Figures 3 to 8.

Material	Desorption EMC at			
	RH 20	RH 60	RH 80	RH 90
Aspen splints	6.0	11.1	16.2	22.1
Pine litter	7.8	13.7	18.8	24.9
Hardwood litter	8.7	14.5	20.0	25.2
Grass	8.0	14.3	19.5	24.0
All-leaf average	8.2	14.2	19.0	24.8
FWI fine fuel	6.0	14.3	19.0	23.3

Table 2. Coefficients in the EMC equation for 80 F isotherms of individual species and groups.

Material	Desorption				Adsorption			
	a	b	c	d	a	b	c	d
White pine litter	1.84	.480	20.7	10.5	1.76	.458	13.8	12.0
Red pine litter	1.86	.470	22.5	10.5	1.28	.492	14.1	12.0
Jack pine litter	1.86	.496	22.0	10.5	1.42	.500	16.0	12.0
Trembling aspen litter	2.38	.434	22.5	12.5	2.13	.415	15.5	14.5
Sugar maple litter	2.56	.398	21.0	12.5	2.26	.395	13.1	14.5
Grass	1.62	.532	13.7	13.0	1.42	.512	12.0	18.0
Pine litter average	1.85	.482	21.7	10.5	1.49	.483	14.6	12.0
Hardwood litter average	2.47	.416	21.8	12.5	2.20	.405	14.3	14.5
All-leaf average	2.02	.469	20.4	11.6	1.72	.462	14.1	13.9
Aspen wood splints	1.04	.580	16.0	12.0	1.04	.537	15.0	12.0

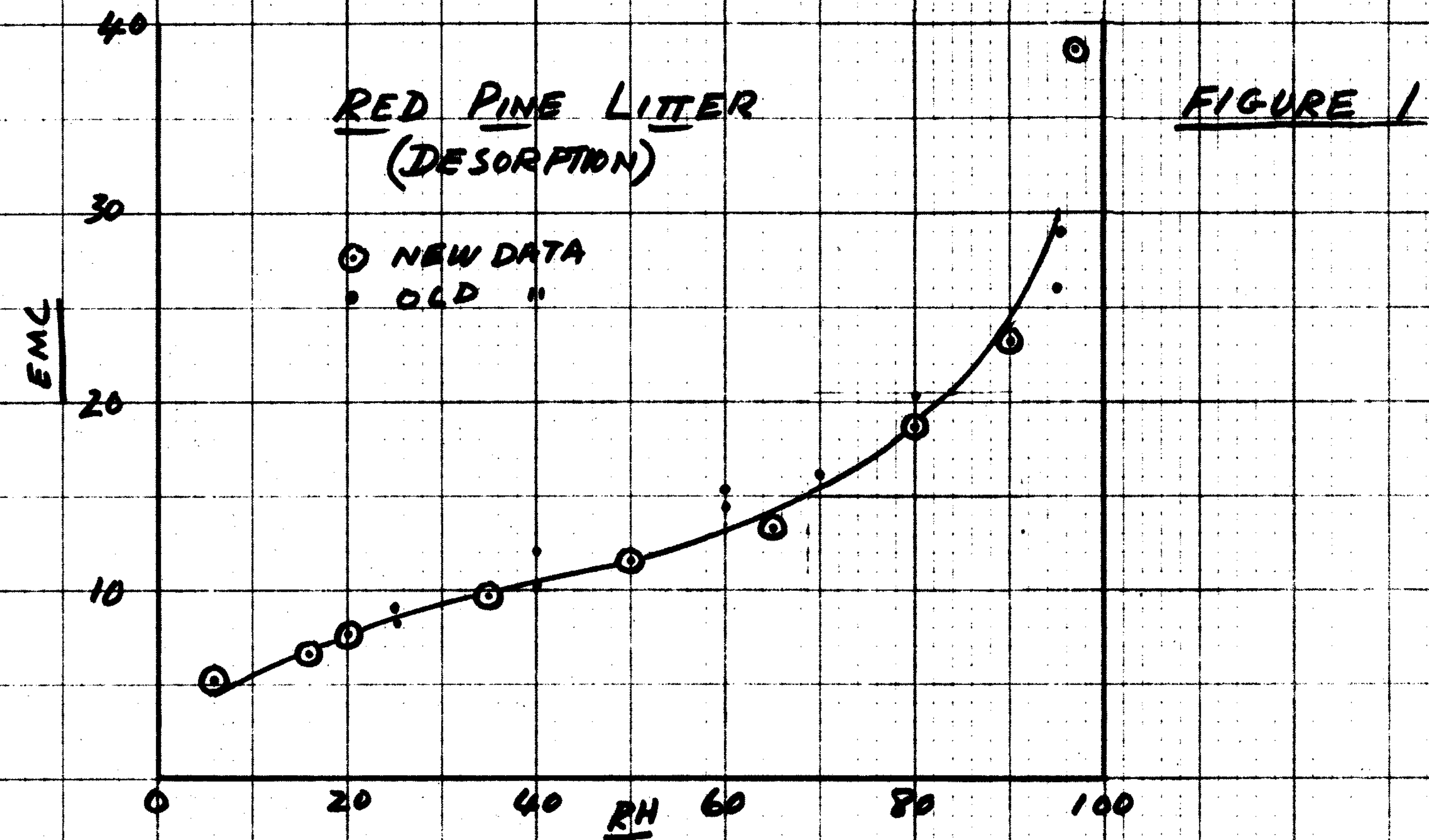

FIGURE 1

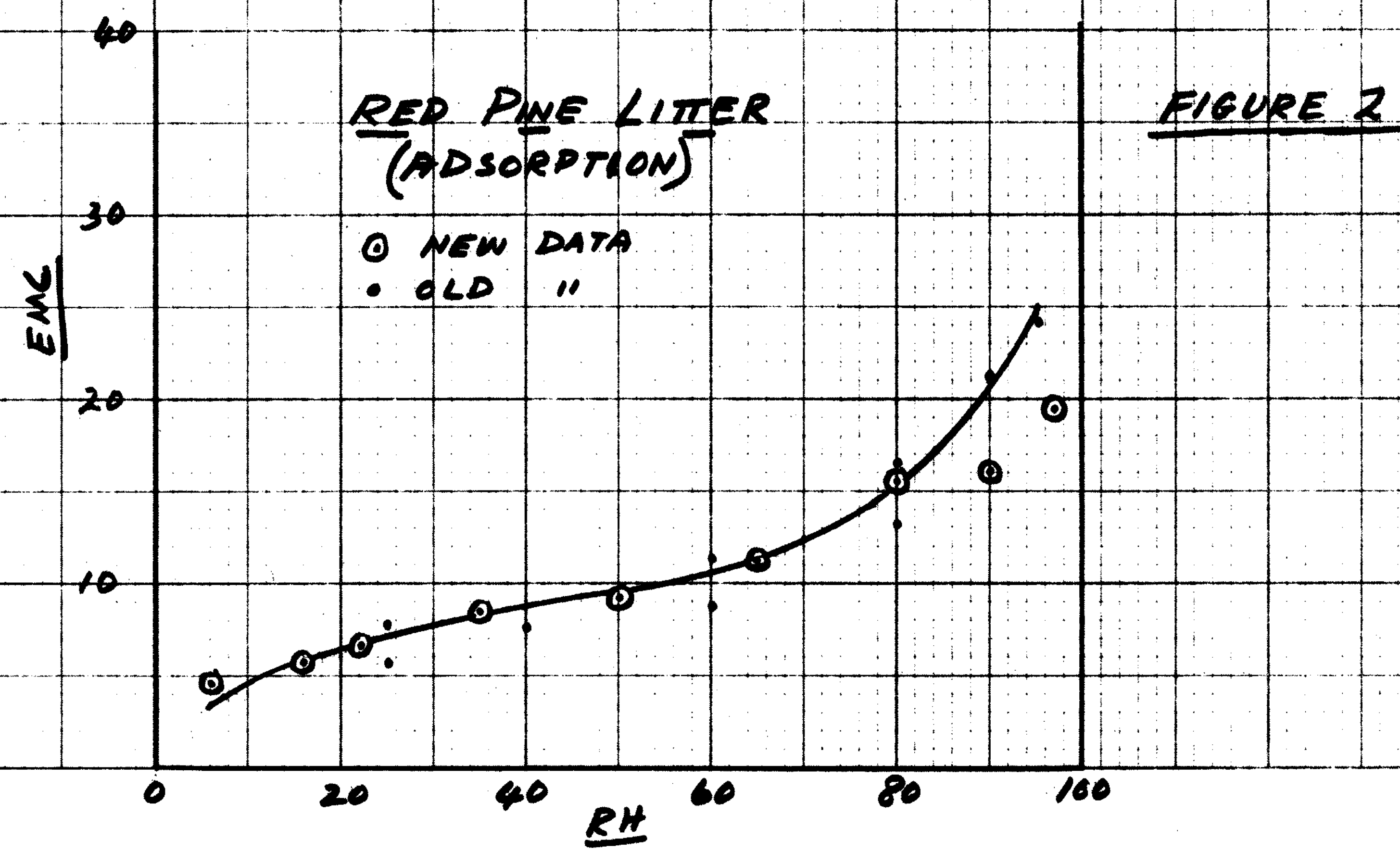

FIGURE 2

FIGURE 3

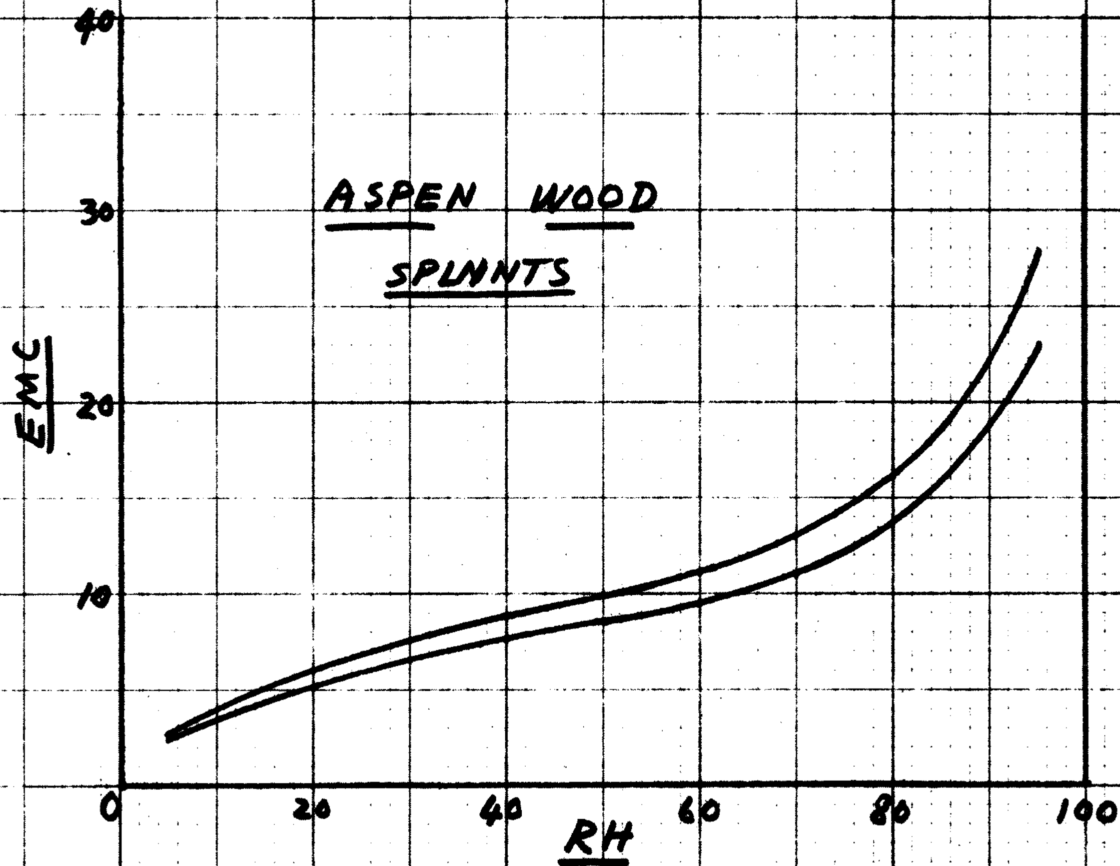

FIGURE 4

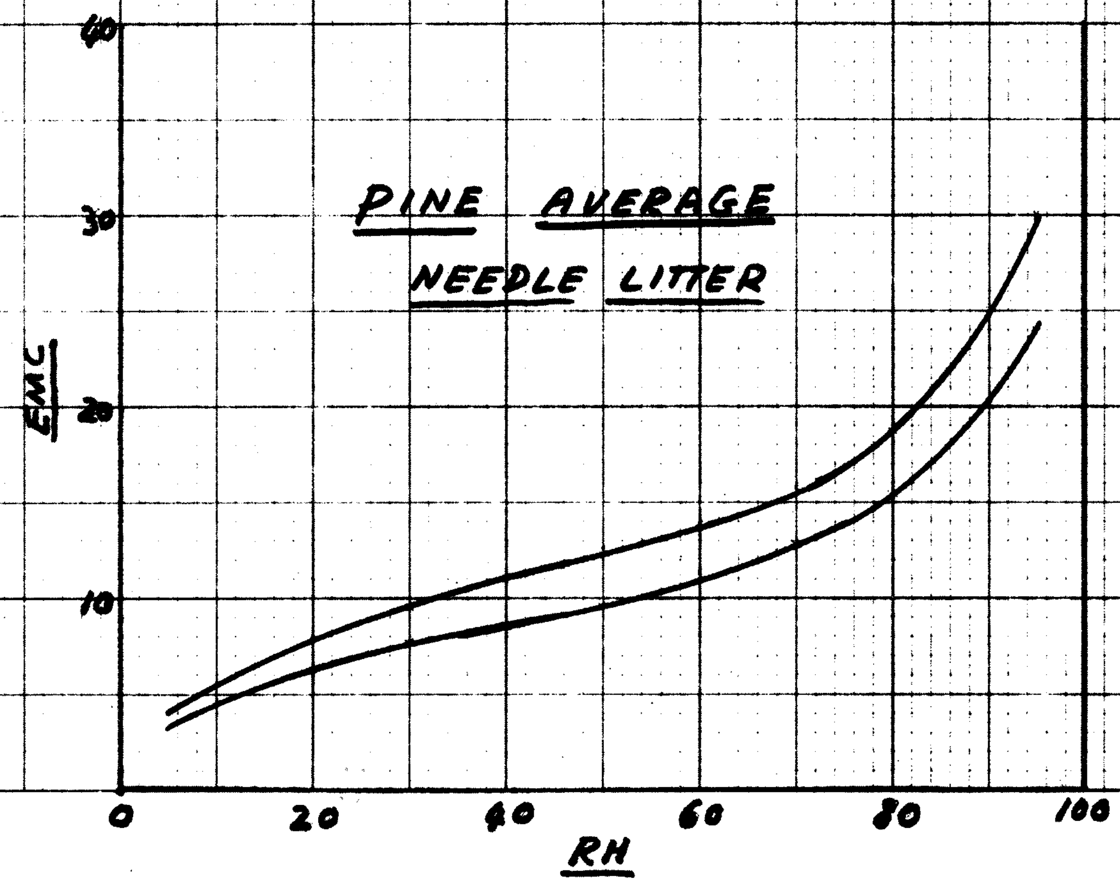

FIGURE 5

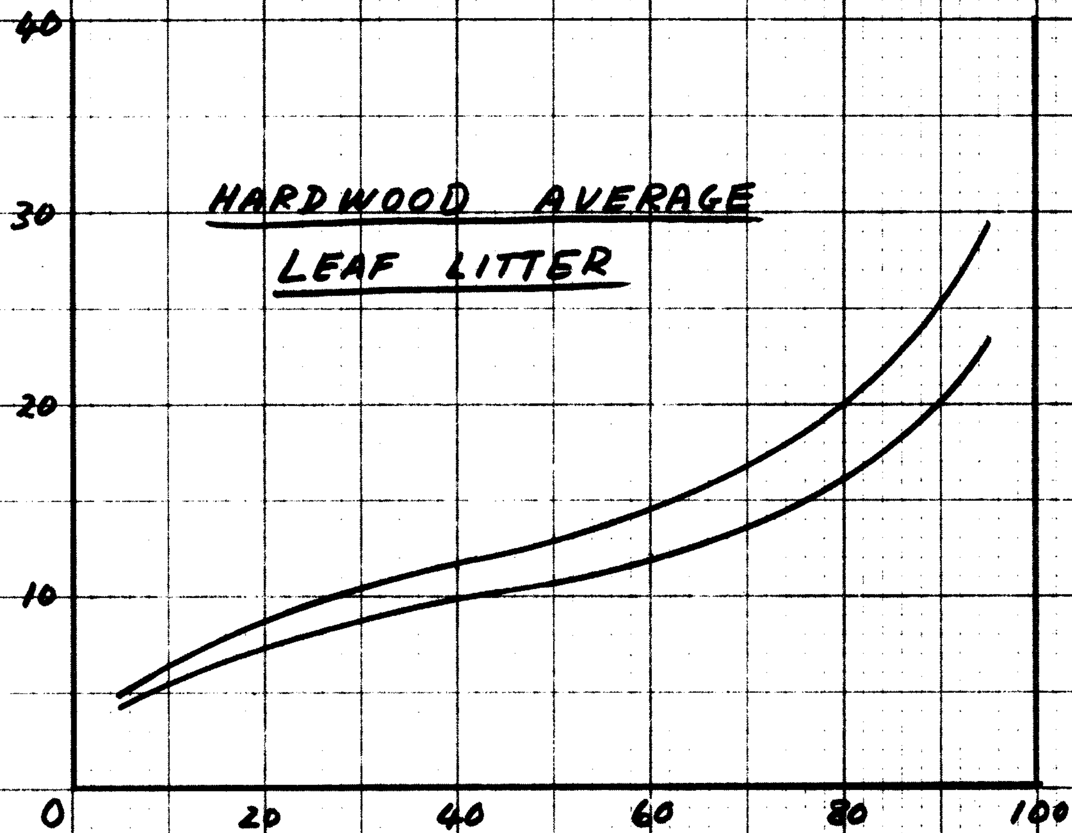

FIGURE 6

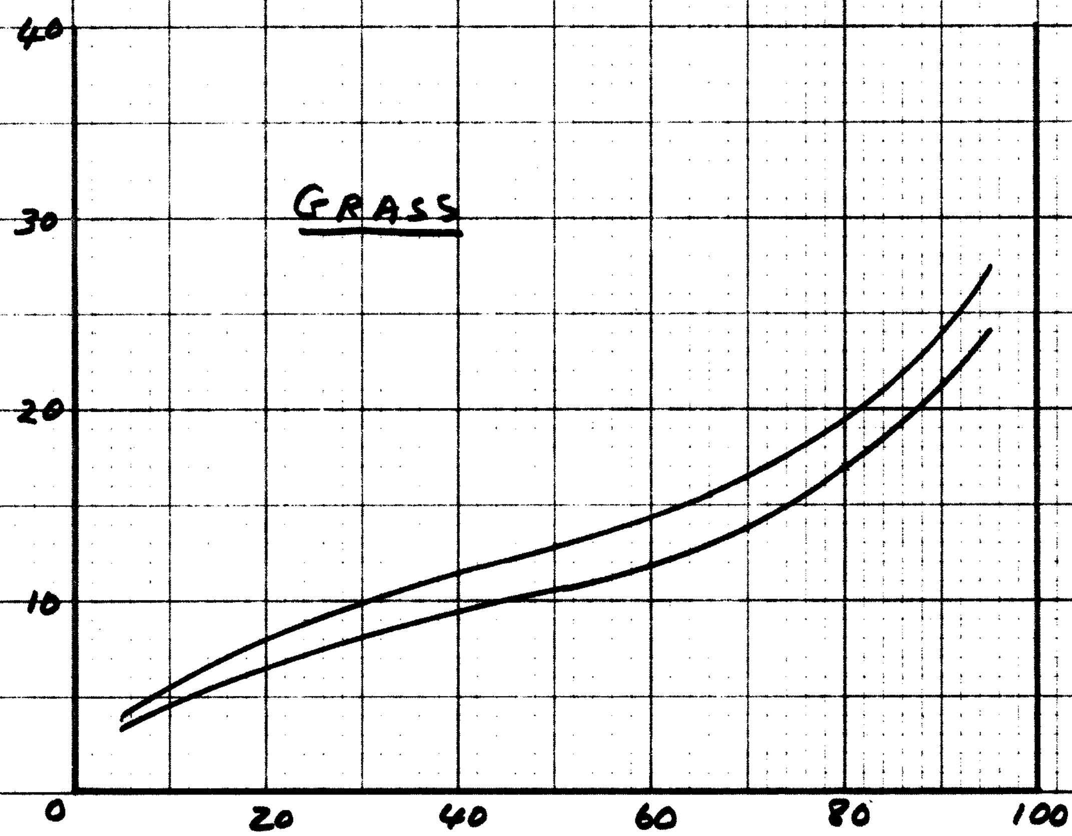

FIGURE 7

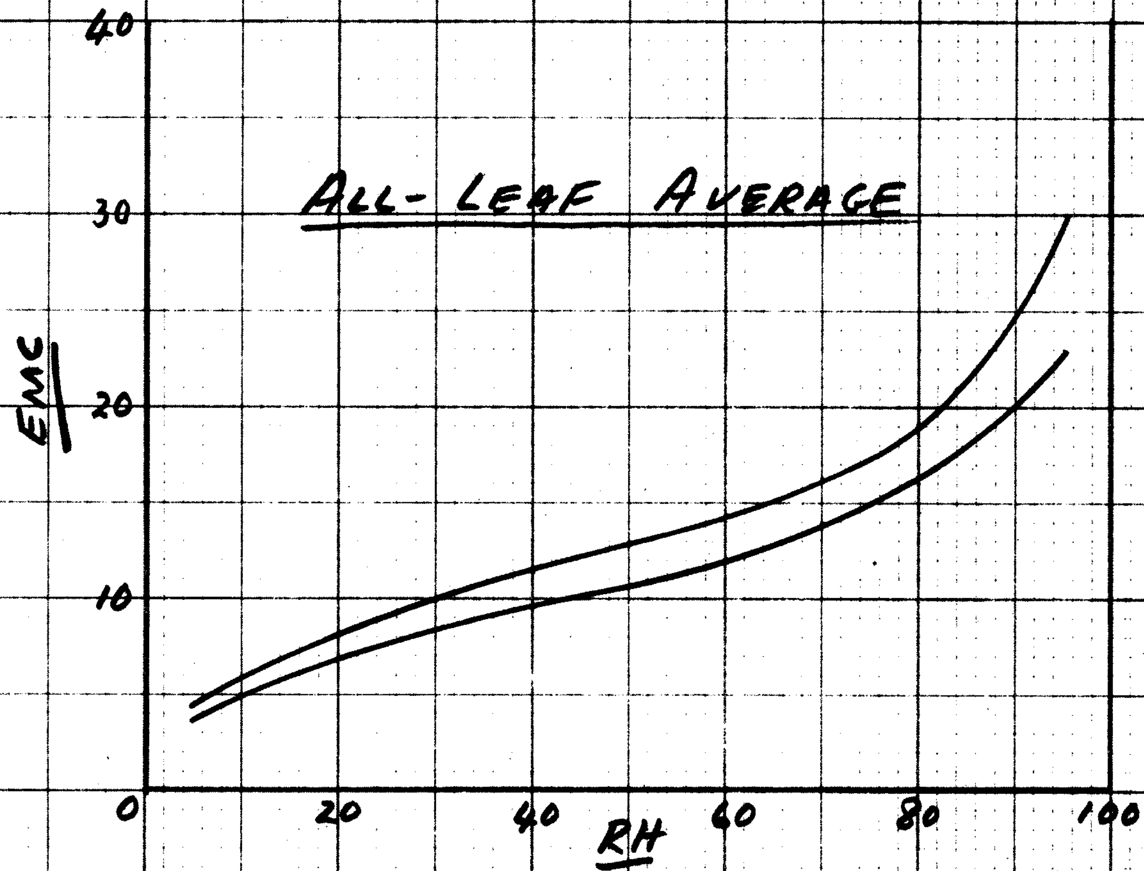

FIGURE 8