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ERRORS IN FUEL-MOISTURE MEASUREMENT RESULTING FROM GRINDING IN A WILEY MILL

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ABSTRACT

The effect of reducing the particle size of fuel components with the Wiley mill in preparation for determining the moisture content of forest fuels was tested. The results of tests on three types of simulated fuel, logs, twigs, and needles showed a strong direct relation between the loss of moisture during the grinding phase and the initial moisture content of the sample and a strong inverse relation between moisture loss and final particle size. The tests conclusively showed the use of the Wiley mill for reducing fuel particle size in preparation for moisture determination to be incompatible with the level of accuracy required for forest fire research.

EXTRAIT

Mesure de l'humidité contenue dans les combustibles forestiers après avoir réduit les dimensions des particules les composant au moyen du moulin Wiley. Après vérifications avec trois types de combustibles, - en l'occurrence des billes, des rameaux et des feuilles - les auteurs se sont aperçus qu'il existait une relation directe très nette entre, d'un côté, la perte d'humidité durant la réduction et le broyage et, d'autre côté, le contenu initial en humidité. Qu'il y avait une relation inverse très accusée entre la perte d'humidité et les dimensions finales des particules. On doit conclure que l'usage du moulin Wiley entraîne de fortes erreurs de calcul et est incompatible avec des recherches valables sur les incendies de forêt.

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INTRODUCTION

The weight of absorbed and adsorbed water, expressed as a percentage of the dry weight of fuel, is the most important factor influencing the flammability of wildland fuels. Moisture content is thus one of the more commonly measured variables in the discipline of forest fire research. In the area of fire-danger rating, the predicted moisture contents of at least two fuel components are the basis of most rating systems. In the field of prescribed fire, moisture contents of the various fuel components of a heterogenous fuel complex must be ascertained in order to predict fire behavior and the effect of treatment.

Research in these fields of study requires that fuel moisture content be determined to at least ± 5% of the actual per cent moisture content, although practical applications of the results may be less accurate.

There are several techniques for determining the moisture content of cellulose, the most common being oven drying with or without vacuum assistance, freeze drying, various distillation processes, and titration. Although various distillation techniques have attracted early interest (Buck and Hughes, 1939), foresters in general, and particularly those in fire research, have conventionally used oven drying. More recently Van Wagner (1963) tested a distillation method using xylene and concluded that it offered no advantage over oven drying.

Oven drying involves the lowest equipment cost and is uncomplicated, and the number of samples that can be processed is dependent only on sample and oven size. A further important advantage is that most forest fuels can be processed without prior treatment to standardize particle size. The main disadvantages of the technique that are especially pertinent to field operations are the power requirements and the time lapse that occurs before results are available. It is generally accepted that oven drying requires at least 24 hours' drying time at 105 C to determine the moisture content of

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most forest fuels unless the particle size is reduced. In mobile field installations, where generator power supplies are used, continuous generator operation is impractical because of the constant surveillance required and the operating costs. Variations in indicated moisture content due to changing ambient relative humidity were reported by Buck and Hughes (1939) but are probably not unique to the oven-drying method.

All the other commonly used moisture-determination techniques share common disadvantages of high initial cost, long periods of power consumption, or limited sampling capacity. In all techniques, reduction of fuel-particle size by grinding or mastication results in reduced treatment time, but in some techniques - for example, titration - particle reduction is required.

The Karl Fischer titrimetry method of determining moisture content was selected as the most applicable technique for use in a recently constructed mobile prescribed-fire laboratory acquired by the British Columbia Region. Briefly, this technique involves extraction of water from a known sample weight by a known volume of methyl hydrate (CH_3 OH). Karl Fischer reagent, a solution of iodine, sulfur dioxide, pyridine and methanol (SO-K-3), having a known titer, is added until a transient electronically indicated end point is attained. The main points in favor of the Karl Fischer titration method were its adaptability to a variable number of samples, the rapid rate of sample treatment, and the short periods of power consumption. The main disadvantage of this method was the need for reduction of particle size to reduce treatment time and to ensure maximum absorption of water by the titrant. The Wiley mill is the most readily available apparatus for producing the required particle size of the various fuels treated.

PURPOSE

Because the reduction of particle size is also required for other techniques, it was decided to test the limitations of the Wiley mill for particle-size reduction and to estimate the moisture lost from the sample during the various phases of the task.

Of primary concern was the change in the moisture content of various types of fuel during reduction to maximum particle size of 40 mesh and 10 mesh as a function of the initial moisture content of the fuel sample. Living vegetation or fuels having a high moisture content tend to compact and clog the Wiley mill; for this reason an estimate of the highest fuel moisture content that could be conveniently treated in the mill was also desirable.

OBJECTIVES

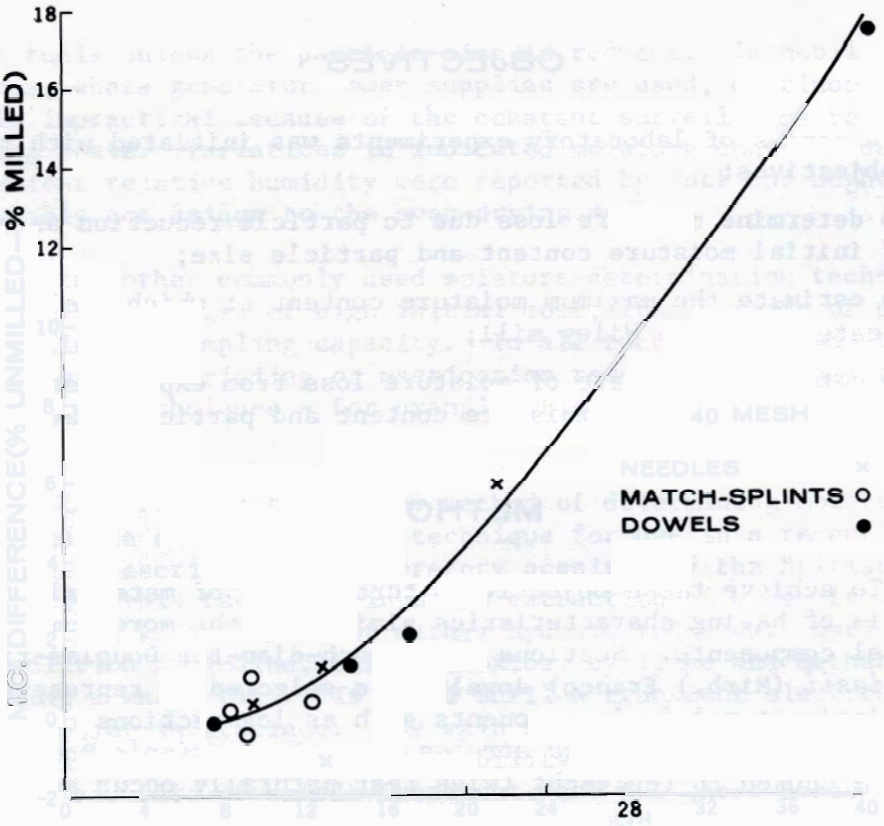
A series of laboratory experiments was initiated with three specific objectives:

1. To determine moisture loss due to particle reduction as a function of initial moisture content and particle size;
2. To estimate the maximum moisture content at which fuels may be treated with the Wiley mill;
3. To determine the rate of moisture loss from exposed samples as a function of initial moisture content and particle size.

METHODS

To achieve these objectives, three types of material were selected, on the basis of having characteristics similar to the more commonly sampled natural fuel components. Sections of .5-inch-diameter Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) dowels were selected to represent samples of large-sized natural fuel components such as log sections or cores and large limbs. White pine (*Pinus strobus* L. or *P. monticola* Dougl.) matchsplints were chosen to represent twigs that naturally occur as litter on the forest floor and the flash-fuel components common to a slash-fuel complex. Two-year-old ponderosa pine (*Pinus ponderosa* Laws.) needles were selected to represent foliar fuel components in the litter of natural fuel complexes. A quantity of each material was saturated in tap water for a minimum period of 24 hours, then spread on a screen and allowed to dry. Periodically, samples were subjected to milling to determine if the milled sample would pass through the screen. When the moisture content was reduced to the point where compacting and subsequent clogging of the screen did not occur, the test to determine moisture loss due to milling was initiated. For this test, four portions of each fuel type, each weighing approximately 10 grams, were separated from the drying material. Approximately half of each portion was milled in the Wiley mill and weighed in preweighed petri dishes, while the remaining half portion was weighed only before oven drying. After drying for a period of 24 hours at a temperature of 105 C in a circulating oven, the eight samples were removed and weighed. The average per cent moisture content (oven-dry basis) was determined for the milled and the unmilled samples, and the difference (Unmilled M.C.% - Milled M.C.%) was plotted against the moisture content of the unmilled sample (Figures 1 and 2). Each fuel type was treated in a similar manner at progressively lower moisture contents and for two maximum particle sizes, 40 mesh and 10 mesh. Ambient conditions during the test remained essentially constant, temperature 70-75 F and RH 30-35%.

To determine the rate of moisture loss from exposed samples of the milled fuel, a single portion of each fuel weighing about 6 grams was milled and placed in a preweighed dish on the weighing platform of an electric



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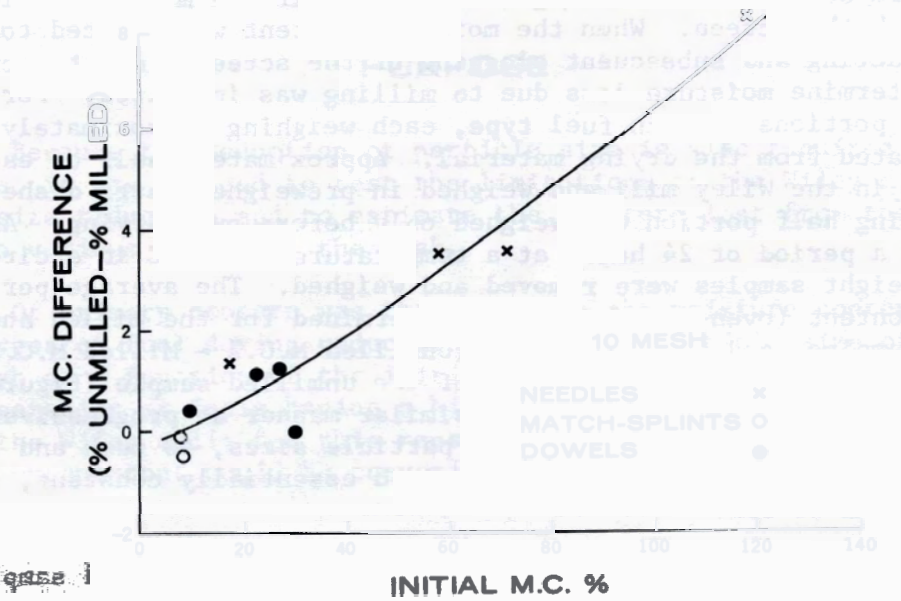

Figure 2. Effect of initial moisture content on the apparent per cent moisture content of unmilled fuels and fuels milled to a maximum particle size of 10 mesh.

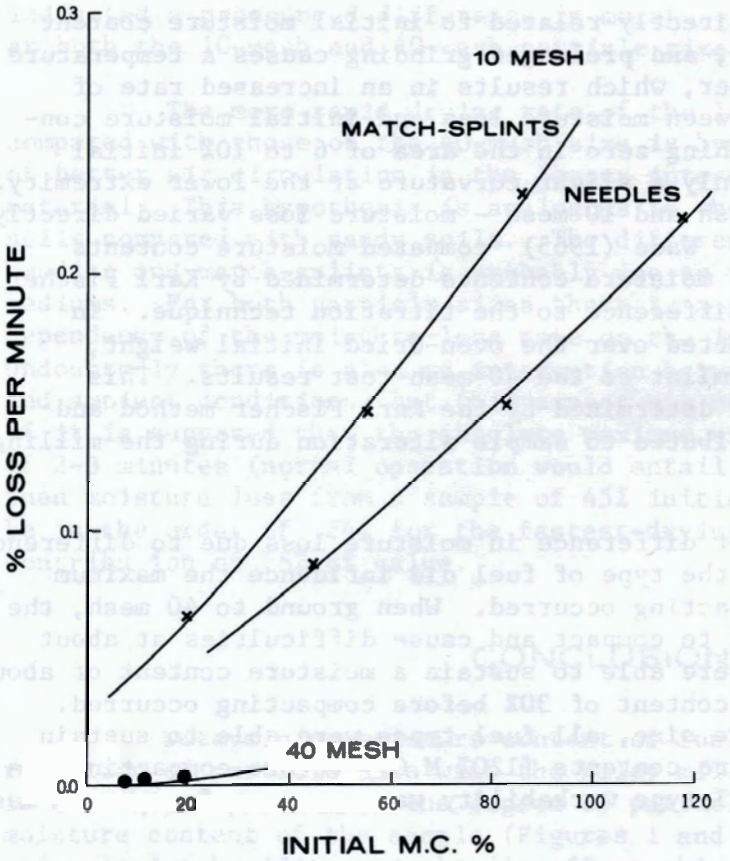

Figure 3. Per cent moisture loss per minute as a function of particle size and fuel type.

balance. The weight of the exposed sample was recorded at one-minute intervals for a period of 30 minutes, after which the sample was oven-dried and the initial and periodic moisture contents were calculated and plotted as in Figure 3.

RESULTS AND DISCUSSION

Figure 1 shows the differences (M.C.% of unmilled - M.C.% of milled) that result in the per cent moisture content of three fuel types when these types are milled to a maximum particle size of 40 mesh as a function of initial moisture content. Figure 2 shows the same relation for a maximum particle size of 10 mesh. In each case the difference in moisture content was apparently independent of fuel type - i.e. needles, dowels or match-splints - but, within the limits of this study, was dependent on the initial moisture content of the material being treated and the particle size. A comparison of Figures 1 and 2 indicates that moisture loss during treatment is inversely related to particle size. Both conclusions are obvious results of the two tests. The wetter the sample, the greater the opportunity of the grinder interior to adsorb free water. Also, as the particle size is reduced, a greater surface area is exposed to evaporation.

Compacting is also directly related to initial moisture content and inversely to particle size, and prolonged grinding causes a temperature increase in the grinding chamber, which results in an increased rate of evaporation. The relation between moisture loss and initial moisture content is nearly linear, approaching zero in the area of 6 to 10% initial moisture content and showing only a slight curvature at the lower extremity. In both cases - i.e. for 40 mesh and 10 mesh - moisture loss varied directly with initial moisture content. Wade (1965) compared moisture contents determined by oven drying with moisture contents determined by Karl Fischer titration and attributed the difference to the titration technique. In fact the differences, when plotted over the oven-dried initial weight, resulted in a relation very similar to the 40-mesh-test results. This indicates that the differences determined by the Karl Fischer method and oven drying may be wholly attributed to sample alteration during the milling phase of the process.

There was no apparent difference in moisture loss due to differences in the type of fuel; however, the type of fuel did influence the maximum moisture content at which compacting occurred. When ground to 40 mesh, the fibrous needle material tended to compact and cause difficulties at about 20%, while the match-splints were able to sustain a moisture content of about 25% and the dowels a moisture content of 30% before compacting occurred. When ground to 10-mesh particle size, all fuel types were able to sustain grinding at much higher moisture contents (120% M.C.) before compacting was evident. No difference in fuel-type workability was apparent for the 10-mesh treatment.

The results of the test to determine moisture loss during exposure from the 40-mesh and 10-mesh treated samples are shown in Figure 3. Ambient conditions were 30-35% RH in all cases and 70-75 F in still air. This test

TABLE 1. ERROR IN MEASUREMENT OF PER CENT MOISTURE CONTENT RESULTING FROM GRINDING TO 40 AND 10 MESH AND RESULTS OF WADE'S TESTS (GROUND TO 40 MESH)

(all in per cent)

INITIAL M.C.% OVEN DRY	VICTORIA TEST		WADE'S TEST
	10 MESH	40 MESH	40 MESH
8	0.	-.2	0
15	.2	1.7	3
20	.7	4.2	5
30	1.2	10.6	10.5
40	1.9	17.7	16
60	3.3		38
80	4.8		42

indicated a pronounced difference in moisture loss between both fuel types at both the 10-mesh and 40-mesh particle size.

The more rapid drying rate of the larger 10-mesh particles compared with those of the 40-mesh size is hypothesized to be a function of better air circulation in the larger interspaces of the coarser material. This hypothesis is analogous to the slower drying rate of clay soils compared with sandy soils. The difference in drying rates of the needles and match-splints is probably due to inherent differences of these mediums. **For both particle sizes there is a strong, nearly linear** dependency of the moisture-loss rate on the initial moisture content. Undoubtedly there is also an interaction between the moisture-loss rate and ambient conditions, but this aspect was not investigated. In any event, if it is supposed that the absolute maximum exposure time is in the order of 2-3 minutes (normal operation would entail a period of 5-10 seconds), then moisture loss from a sample of 45% initial moisture content would only be in the order of .24% for the fastest-drying 10-mesh sample, an error contribution of .5% of value.

CONCLUSION

Determining moisture content of fuels by any technique requiring reduction of particle size with the Wiley mill is subject to error which is strongly dependent on the degree of particle reduction and the initial moisture content of the sample (Figures 1 and 2). Ambient temperature and relative humidity undoubtedly affect this phase, but these effects were not investigated. **Use of 10-mesh particle size rather than 40 mesh improves** the accuracy to a barely tolerable level for only the crudest requirements (4-5% rather than 6-40% error).

Fuels having a maximum initial moisture content of approximately 20, 25 and 40% for needles, match-splints and dowels, respectively, could be reduced to 40-mesh size with some difficulty. **For trouble-free** operation, moisture contents of less than 20% would be desirable. Initial moisture contents up to 120% were tolerated with no difficulty with the 10-mesh treatment.

Moisture-loss rates due to exposure during the period of treatment depended directly on initial moisture content and inversely on particle size; in the most extreme cases, however, losses during these periods would make a negligible contribution to error.

The results of these tests have shown that techniques for determining moisture content involving fuel-size reduction with the Wiley mill are subject to errors that are incompatible with the level of accuracy required for forest fire research. Unless more suitable techniques of reducing the fuel-particle size are applied, the Karl Fischer method of determining moisture content should not be used.

Investigations of techniques that circumvent the requirement of size reduction and of other techniques for encapsulated size reduction are continuing.

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