CANADA
DEPARTMENT OF FORESTRY
AND RURAL DEVELOPMENT

# FOREST - FIRE HAZARD RESEARCH

## AS DEVELOPED AND CONDUCTED AT THE PETAWAWA FOREST EXPERIMENT STATION

by

J. G. Wright

Forest Fire Hazard Paper No. 2

A Reprint of the 1932 Edition

FOREST FIRE RESEARCH INSTITUTE
OTTAWA, ONTARIO
INFORMATION REPORT FF-X-5

1867 1967

FORESTRY BRANCH
MARCH, 1967

Forest Service

Department of the Interior

Canada

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Division of Forest Protection

Ottawa 1932

Reprinted by
Forest Fire Research Institute
Forestry Branch
Department of Forestry and Rural Development
Sir Guy Carleton Building
161 Laurier Ave. West
Ottawa 4

O.D.C. 431.5 : 431.2

Information Report FF-X-5

March 1967

# FOREWORD

The original publication "Forest Fire Hazard Research as Developed and Conducted at the Petawawa Forest Experiment Station", Forest Fire Hazard Paper No. 2, was issued by the Forest Service, Department of the Interior, Canada, in 1932. It contains a wealth of information on the techniques of fire research and fire danger measurement. Unfortunately, this publication has been out of print for many years and has not been available to fire research personnel. The Forest Fire Research Institute has undertaken a program of reprinting some of the early publications on fire research in order to make this information more readily available.

The author of Forest Fire Hazard Paper No. 2, Mr. J.G. Wright, was one of the early fire research workers in Canada. The scope of his research work is well illustrated in this report. The forest fire danger rating system used throughout Canada today is based to a large degree on work accomplished by him.

James Godwin Wright was born at St. Louis de Gonzaque, Quebec, in 1892. He received his early education in Valleyfield and continued on to Queen's University, Kingston, Ontario, where he received his Bachelor of Science degree in Civil Engineering in 1917. In 1918 he entered the service of the Government of Canada in the Surveyor General's branch, Department of the Interior. In 1922, Mr. Wright transferred to the Dominion Forest Service as a Civil Engineer. He became interested in forestry problems and in forest fire control in particular. In 1929 he was given permission to organize and proceed with his proposed project of research into forest fire hazards. In the succeeding years, he developed what became widely known as the Wright System for the measurement of forest fire danger and for forecasting fire hazard. He was the author of many bulletins and articles dealing with fire research.

Mr. Wright was an early member of the Canadian Society of Forest Engineers and his many contributions to the public service were recognized in 1942 when he was elected president of the Professional Institute of the Public Service of Canada. In 1943 he was seconded to the Northwest Territories administration to coordinate the efforts of officers engaged in an economic survey of the Canadian Eastern Arctic. He was appointed an Executive Assistant in the National Parks Bureau in 1944. In 1946 he was appointed Superintendent, Eastern Arctic, and named Secretary of the Northwest Territories Council, a post he held until 1952.

In 1953 Mr. Wright left the Government service and moved to Sackville, New Brunswick, where he assumed the post of Assistant Professor of Engineering, in the Engineering Faculty of Mount Allison University. He continued in this post until his retirement in 1961. During this period, he became interested in municipal politics. He was elected an alderman on the Sackville Town Council in 1956 and elected Mayor in 1960, a post he still holds. During his term of office he was able to inaugurate many local improvements and achieved a high level of cooperation between the University and the town. He served a term as president of the Union of New Brunswick Towns.

The Forest Fire Research Institute is delighted to have the opportunity of republishing this report as the first in a series of reprints on forest fire research.

D. E. Williams,
Director.

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## Forest-Fire Hazard Research

The Forest Service of the Department of the Interior has long recognized forest protection as one of the important problems facing the people of this country. Scientific methods of increasing forest wealth can avail little unless the trees can be preserved from destruction. A satisfactory degree of protection must, therefore, be attained by any forest organization before skilled methods of forest management can be expected to have any material effect in arresting forest depletion. The Forest Service has always endeavoured to keep abreast of all progress in what may now safely be called the science of forest protection, and in 1929 an intensive study was begun at the Petawawa Forest Experiment Station with a view to arriving at a more complete understanding of the natural phenomena relating to forest fires. The following paper is a brief discussion of some of the conclusions reached and the methods used in carrying on this study.

The three leading causes of forest destruction are fire, insects, and disease. Entomologists and pathologists in many countries have for years been carrying on research work to discover the laws and means of control of the latter two causes. In the case of fire, however, the chief cause on this continent, no scientific attempt has been made until recent years to study the laws relating thereto. The reason for this anomaly is not hard to find, In European countries where the greatest progress in forestry has been made, fire does not assume the place of importance it does on this continent. Research has, therefore, been concentrated on insects and disease. Again, it is impossible to combat insects and disease without some knowledge of the natural laws governing them. With fire, however, the treatment is more immediately apparent and may be summed up as follows:

> Try to prevent fires from starting, but if they start, try to put them out as quickly as possible.

Following this policy we have carried on intensive campaigns to educate the public to the end that they be more careful with fire, and reduce in number the 87 per cent of forest fires which according to the latest 10-year statistics for all Canada, start from human agencies. We have required that persons secure permits before entering the forest, and before burning debris in forest areas, in order that their activities may be more closely controlled, and we have at times forbidden entry of the forest when fire conditions were deemed hazardous. This much we have done for prevention.

In the realm of direct control we have developed detection and communication, introduced improved fire-fighting equipment, and developed field organization to the point where the fire-fighting machinery of an up-to-date forest administration is nearly as efficient as that of the average city or town.

All this we have done, but until recently not a single attempt have we made to study in a scientific way the laws which govern the inflammability and combustion of the forest materials in which fires start and spread. We know in a rough sort of way that hardwoods are less inflammable than conifers, but we have no idea of the relative inflammability of different coniferous species, or of stands of different densities in the same species in various sites.

We know that rain reduces the inflammability of forest materials, but who can state in quantitative terms the effect of a half-inch or an inch of rain, or be definite as to how long it will render the forest safe from fire. Wind, temperature, and the degree of atmospheric moisture influence the rate at which the forest-fire fuels dry out, but we have never investigated their influence in units of time. We know wind aids the spread of fire, but to just what extent we have not known.

We have standards, or units of measurement for practically everything, but no unit for measuring fire hazard. Some say, what is the need of such a unit? You will know a hazard exists when fire breaks out, and you must be always ready to handle such an emergency. Quite true, and so in war-time must a commanding officer be always ready to handle an enemy attack, but who will say that officer will not be in a better position if he knows the strength of the enemy and when and where to expect the attack? So in forest protection there is great need of a unit for measuring cumulative fire-hazard or inflammability, which will enable forest authorities to know what to expect each day and be in a position to make their plans accordingly. This paper deals with the development of such a unit of measurement, and the preparation of curves or tables by means of which daily weather measurements may be converted into units of fire hazard.

## Definition of Terms*

In the discussion of any technical subject it is frequently necessary to employ words and terms to which special meanings are attached. A uniform terminology with proper definitions is essential to progress, otherwise different men may use the same term to express different ideas, or different terms to express the same idea, and great confusion results. When certain terms have been already accepted by a group of investigators, it is desirable for later investigators to adopt these terms, if reasonably satisfactory, for the sake of uniformity. In the present study, terms which are in accepted use by the United States Forest Service have been adopted. The definitions are as follows:

Duff - The layer of undecomposed and partly decomposed dead vegetable matter forming a mat covering the ground. In this layer the unit structures have not decayed to the stage where their original form cannot be recognized.

Top-layer Duff - The upper horizon of duff consisting of loosely compacted, undecayed leaves or needles. This is the layer which dries out first and in which fires start or spread.

Litter - The loose debris of dead sticks, branches, and twigs lying on top of the duff.

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* Some of the terms used here differ slightly in meaning from those adopted as standard by the Associate Committee on Forest Fire Protection, NRC, and published in the Glossary of Forest Fire Control Terms, 1963.

Humus - The layer of decomposed organic material found between the mineral soil and the duff. Owing to decomposition, unit structures cannot be readily recognized in this layer.

Fuel - Any material which supplies a medium to support combustion.

Hazard - The relative amount, character, arrangement, and moisture condition of the fuels.

Inflammability - The susceptibility of the fuels to ignition.

Risk - The relative chance or probability of fire starting, determined by the presence or absence of causative agencies. Risk refers only to the agencies which cause fires.

Danger - The sum of risk, inflammability, and hazard, together with damage probability and the degree of difficulty with which a fire can be put out.

## Combustion

The study of the composition and combustion of wood has been pretty thoroughly covered by different investigators. It is known that the chemical composition of the average bone-dry wood-substance reduced to the simplest form is approximately as follows:

| | |
|---|---|
| Carbon | 49 per cent |
| Hydrogen | 6 per cent |
| Nitrogen | small fraction |
| Oxygen | 44 per cent |
| Mineral matter | less than 1 per cent |

In the natural state these elements exist in wood in varied combinations, the principal one being cellulose, which together with lignin forms the body structure. Associated with the cellulose and lignin there is resinous material together with more or less water.

The moisture content of wood depends on a number of factors, viz., the kind of wood, time since cutting, and atmospheric conditions in the place of storage. In the living tree it depends upon the species, the site, the season of the year, and the portion of the tree from which the sample is taken.

The wood structure consists of a mass of small cells. In the living tree these cells contain water. As the wood is dried, these cells give up their water until the point is reached where the only water which remains in the wood is that contained in the cell-walls. This is called the fibre-saturation point. If the drying is continued further, the cell-walls give up their moisture and undergo shrinkage. which may give rise to distortion and checking of the wood if the drying is too rapid or too complete.

Once green wood has been dried, there is a balance maintained between the moisture content of the cell-walls and atmospheric moisture. Dry wood placed in damp air will take on moisture until the balance or equilibrium is reached. If the air becomes drier, the wood will lose moisture until equilibrium is again reached.

The moisture content of seasoned wood stored in the air may run from 5 to 25 per cent depending upon the kind of wood and the moisture content of the air.

The moisture content of growing redwood has been determined as follows:

Heartwood - from 160% at base of tree to 60% near the top
Sapwood - " 210% near the base to 260% " " "

A European investigator (A. Lullin) provides some interesting information on the combustion of wood. If wood is heated from 175°F to 230°F it loses its moisture and finally its resinous material. At 300°F carbon monoxide, carbon dioxide, and hydrocarbons are evolved. Around 450°F - 520°F pyrophoric "red charcoal" is formed and finally at about 570°F, black charcoal.

"Red charcoal" is said to be susceptible to spontaneous combustion, a slight current of warm air being sufficient to cause it to burst into flame. It is further stated that "red charcoal" may form at as low a temperature as 300°F if the heating is sustained long enough.

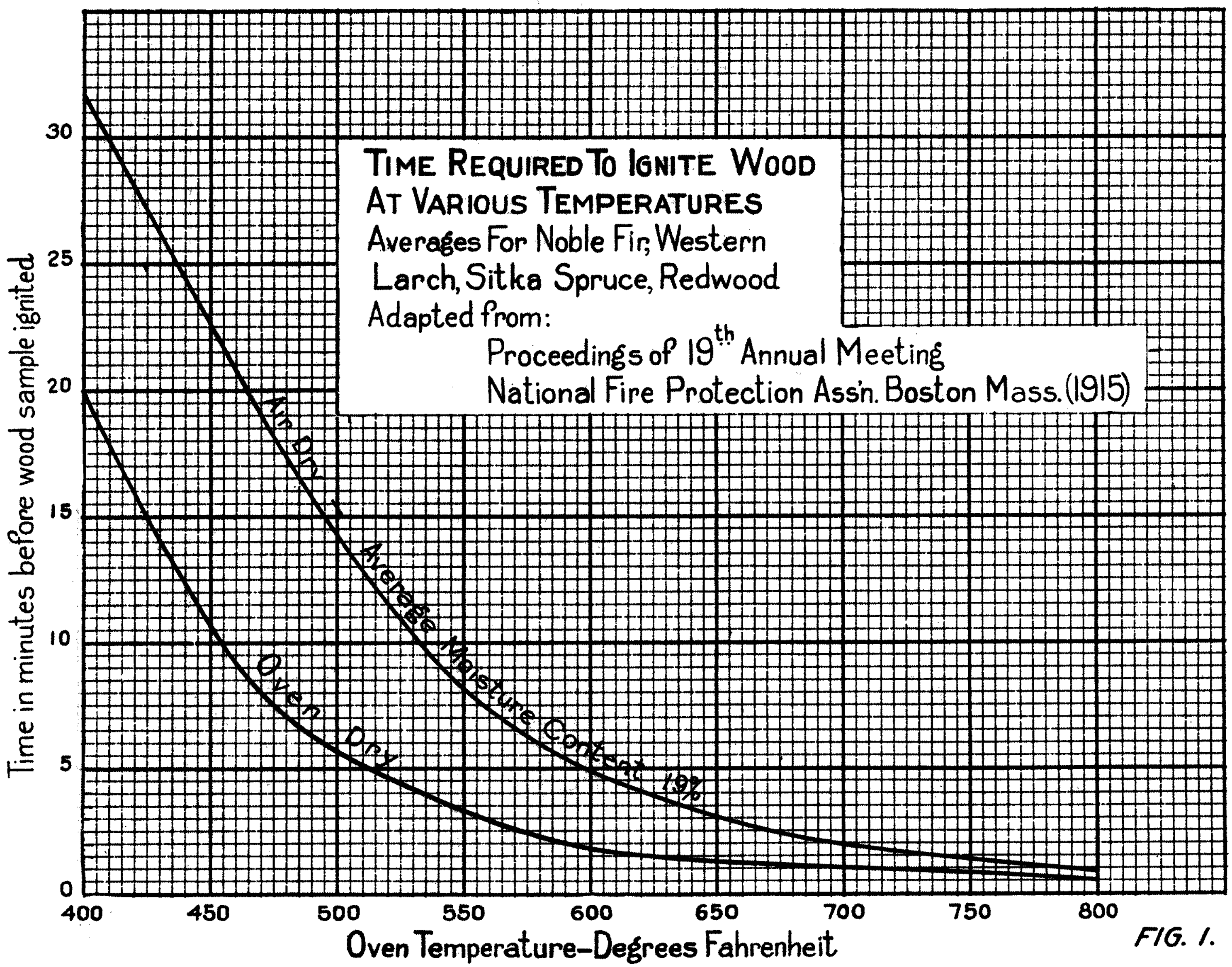
The reference to the formation of red charcoal is of interest in the consideration of the range in ignition temperature of any given wood.

The ignition temperature of wood ranges from about 400°F upwards, depending upon the kind of wood, its moisture content, and the length of time it is exposed to the heat. For a given species, at a given moisture content, the ignition temperature varies with the time of exposure.

Mr. R. E. Prince states that resinous material has a lower ignition temperature than the other volatile portions of wood, and in combustion the resinous material appears to use the wood substance as a wick.

For four western woods the average time taken for oven-dry material to ignite at 400°F was 20 minutes. At 19 per cent moisture content the time was about 32 minutes. At 600°F the time was 2 minutes for the dry material and 5 minutes for material at 19 per cent moisture content. At 650°F the times were 1 minute and 3 minutes, respectively. (Fig. 1)

It will be observed that the presence of moisture in the wood greatly increases the time taken to produce ignition. It would appear that at the lower temperatures the time is used up in driving off cell-moisture and forming "red charcoal" which will ignite at low temperatures.



TIME REQUIRED TO IGNITE WOOD
AT VARIOUS TEMPERATURES
Averages For Noble Fir, Western
Larch, Sitka Spruce, Redwood
Adapted from:
Proceedings of 19th Annual Meeting
National Fire Protection Ass'n. Boston Mass. (1915)
Air Dry - Average Moisture Content 19%
Oven Dry
Time in minutes before wood sample ignited
30
25
20
15
10
5
0
400
450
500
550
600
650
700
750
800
Oven Temperature-Degrees Fahrenheit


FIG. 1.

In the open, the heat from a fire passes off rapidly upwards by convection and radiation, and only in the case of a fire where there is a large concentrated volume of fuel would it be possible to maintain a temperature at a given point longer than about 5 minutes. In the case of a duff fire, the time would be much shorter than this, probably not over 3 minutes. It will be seen, therefore, that for a fire to start in the open, the condition of the fuel and the temperature of the ignition agent must be such as to allow practically instantaneous ignition. A temperature of not less than 600°F to 650°F would appear to be necessary to start a fire in the open.

## Combustion of Pine Duff

Certain tests have been made on pine duff at the Forest Products Laboratories of Canada. The calorific values of oven-dry duff were found to be as follows:

| | | |
|---|---|---|
| White pine duff | 10,000[x] | B.t.u. per pound |
| Red " " | 10,190 | " " " |

One pound of top-layer duff consisting of one-half to three-quarters of an inch of undecomposed material, in a mixed stand of red and white pine where the species are evenly divided, covers an area of approximately 10 square feet. The theoretical heat developed by the combustion of duff is therefore about 7 B.t.u. per square inch.

In this type, fire will not spread when the moisture content of the top-layer duff is 25 per cent or more. The amount of heat required to burn one pound, oven-dry weight, of duff at 70°F and an ignition temperature of 650°F, when it contains 25 per cent moisture is approximately as follows:

| | | | | |
|---|---|---|---|---|
| To dispose of ¼ lb. water | (sp.ht.steam 0.478) | 70°F - 650°F -- | 330 | B.t.u. |
| To heat 8 lb. air | (sp.ht.air 0.24) | " " | 1114 | " |
| To heat 1 lb. duff | (sp.ht.wood 0.326) | " " | 189 | " |
| | | | 1633 | B.t.u. |

Taking 10,000 B.t.u. as the calorific value of duff, it follows that only about 16 per cent of this amount of heat goes towards supporting combustion, the rest passing off upwards by convection and radiation.

In a series of laboratory tests it was found that when pine duff was heated to 270°F, a whitish gas began to come off. At 330°F this gas ignited with a blue flash when a flame was applied, but would not remain alight until a temperature of 350°F was reached. At 350°F the gas burned with a blue flame and rapidly ran the temperature of the duff up to 812°F. The gas could not be ignited unless a flame was applied.

[x]B.t.u. - British thermal unit.

In another test, disks of iron about one square inch in area, and weighing about 1/10 lb., were heated to known temperatures and dropped on natural duff samples of known moisture content. A disk at 1157°F caused the duff to smoke, but did not ignite at any moisture content.

A disk at 1337°F caused the duff to ignite even up to 26 per cent moisture content.

Taking the figure, previously derived, of 7 B.t.u. per square inch as the amount of heat necessary to support combustion in pine duff in the open, and the specific heat of iron as 0.13, the temperature of the 1157-degree disk after it had given off this amount of heat was computed as 619°F, i.e., too low to ignite the duff. The temperature of the 1337-degree disk, after giving off 7 B.t.u., was 798°F, i.e. well above the ignition point.

From the foregoing we may infer that the value of 650°F for the ignition temperature of pine duff is not far from correct.

The standard match used in ignition tests had a split white pine splint 2 1/8 inches long, of average weight 0.169 grams (.0003718 lb.). Taking the calorific value of white pine as 9150 B.t.u., a single match contains about 3.4 B.t.u.

The time for this match to burn, the average of a number of positions being taken, is 30 seconds. The temperature of the flame estimated from the colour of a fine iron wire held in the flame was about 1500°F. The highest contact temperature obtained was about 1000°F.

In field tests of duff inflammability it was found that a match was the most efficacious single fire-brand, camp-fires being the only agency which had a wider range of effectiveness. The reason for this is plain. Assuming the effective area heated by a match to be ½ square inch, its heating value is therefore 6.8 B.t.u. per square inch, -- nearly equal to that of the duff itself. This volume of heat is supplied at a temperature of 1000°F to 1500°F, which provides instantaneous ignition. For this reason a match will start a fire in pine duff almost up to the moisture point where the duff itself ceases to support combustion, because of the time taken to drive off the moisture.

The foregoing discussion relates only to a thinly spread out fuel like duff. If the fuel is concentrated, as in a slash pile, the materials will be heated to a much higher temperature for prolonged periods, and even green wood containing 200 per cent moisture may be induced to burn. Nevertheless, duff is the medium in which fires spread from pile to pile of large fuel, and if the duff will not burn there can be no serious fire danger.

The conclusions to be drawn are as follows:

(1) The effective ignition temperature of pine duff is about 650°F.

(2) Only about 16 per cent of the available heat in a duff fire goes to support combustion, the rest passing off upwards.

(3) The time taken to ignite duff increases with its moisture content, until a point is reached where the time is so great that the available head is lost into the air and combustion will not occur.

(4) The resinous material in the duff ignites first. This generates heat which evolves an inflammable gas which requires a flame (1000°F to 1500°F) to ignite it. This flame is, of course, provided by the burning resinous material.

## Inflammability Zones

It has been seen that the amount of moisture in a fuel largely determines its inflammability. The logical method, therefore, of establishing a unit for measuring fire hazard is to base it on percentage of moisture in the duff, which is the medium in which fires spread. Following this method, zones of inflammability have been established for the types studied at the Petawawa Forest Experiment Station.

The basis used for defining the boundaries of inflammability zones is still far from definite. Individual judgment plays a large part in determining the intensity of combustion and the personal error is thus inevitably introduced. There is great need for some standardized and scientifically accurate method of delimiting these zones which can be employed with uniform results by all investigators. In this connection the measurement of energy radiated from test fires offers a promising field of investigation.

The inflammability zones in the present study were established from test fires on the following basis:

| Duff Inflammability | Definition |
|---|---|
| Nil | Duff ignition will not take place even from a camp-fire one foot in diameter. |
| Low | Ignition frequently occurs from camp-fires but not from matches, and the rate of spread is slow. |
| Moderate | Ignition generally occurs from matches, but the rate of spread, height of flame, and depth of ash are such as to indicate that fires will not assume dangerous proportions for some time under existing conditions. |
| High | Ignition from matches is certain, and the characteristics of combustion indicate a dangerous conflagration, if the burning is allowed to continue. No difficulty is experienced in stamping out such test fires with the feet. |
| Extreme | Test fires are put out with the foot only with difficulty, or other means are necessary to extinguish them. |

Some investigators have based inflammability zones upon the effectiveness of certain fire-brands such as cigarette stubs, pipe "heels", etc. In the pine types investigated, however, it has not been possible to start a fire in the duff with these fire-brands except in the most extreme dry conditions.

A fire-test screen (Fig. 2) has been designed to render test fires safer, and at the same time establish a standard for measuring inflammability. It consists of a cylindrical frame $30\frac{1}{4}$ inches in diameter and 18 inches high covered, except for the bottom, with wire screening. The cylinder is set over the duff and worked down to mineral soil by means of a cutting edge. A lighted match is inserted through a small door in the top and placed in the duff at the centre of the circle. The area of the circle is 5 square feet. The time taken to burn over this area is noted, together with height of flame and depth of ash. With these data it is hoped to achieve greater standardization in the measurement of inflammability. The wire screen permits free circulation of air, but greatly reduces the risk of test fires spreading.

The zones of inflammability tentatively adopted for the pine types studied, based on a large number of test fires, are as follows:

| Degree of Inflammability | Moisture Content for Top-layer Duff | |
|---|---|---|
| | Mixed red and white pine type. Mixed jackpine, red and white pine type | Pure red pine type |
| Nil | 24 per cent and over | 35 per cent and over |
| Low | 19 to 23 per cent | 30 to 34 per cent |
| Moderate | 16 to 18 per cent | 19 to 29 per cent |
| High | 11 to 15 per cent | 13 to 18 per cent |
| Extreme | 10 per cent and under | 12 per cent and under |

It will be observed that the inflammability of pure red pine duff is very much greater than that of the other softwood types studied. The large heavy needles provide a thick loose mass of fuel through which the air circulates readily, producing rapid drying and high inflammability. The heating value of the needles is also greater than in the other species.

While no studies were made in pure white pine, owing to the absence of convenient stands, it would appear from tests made under groups of white pine trees that the boundaries of inflammability zones are at least 2 per cent lower than in the mixed pine types.

In the cut-over and other sites where there is a large variety of fuels, it is difficult to base the inflammability upon moisture-content measurements. The most promising method of studying these types appears to be to observe the inflammability each day with a fire-test screen and correlate it with one of the more easily measurable softwood sites.

While no intensive study has been attempted in other than the abovementioned softwood types, the following observations on other common types are of interest.

# Fire Test Screen

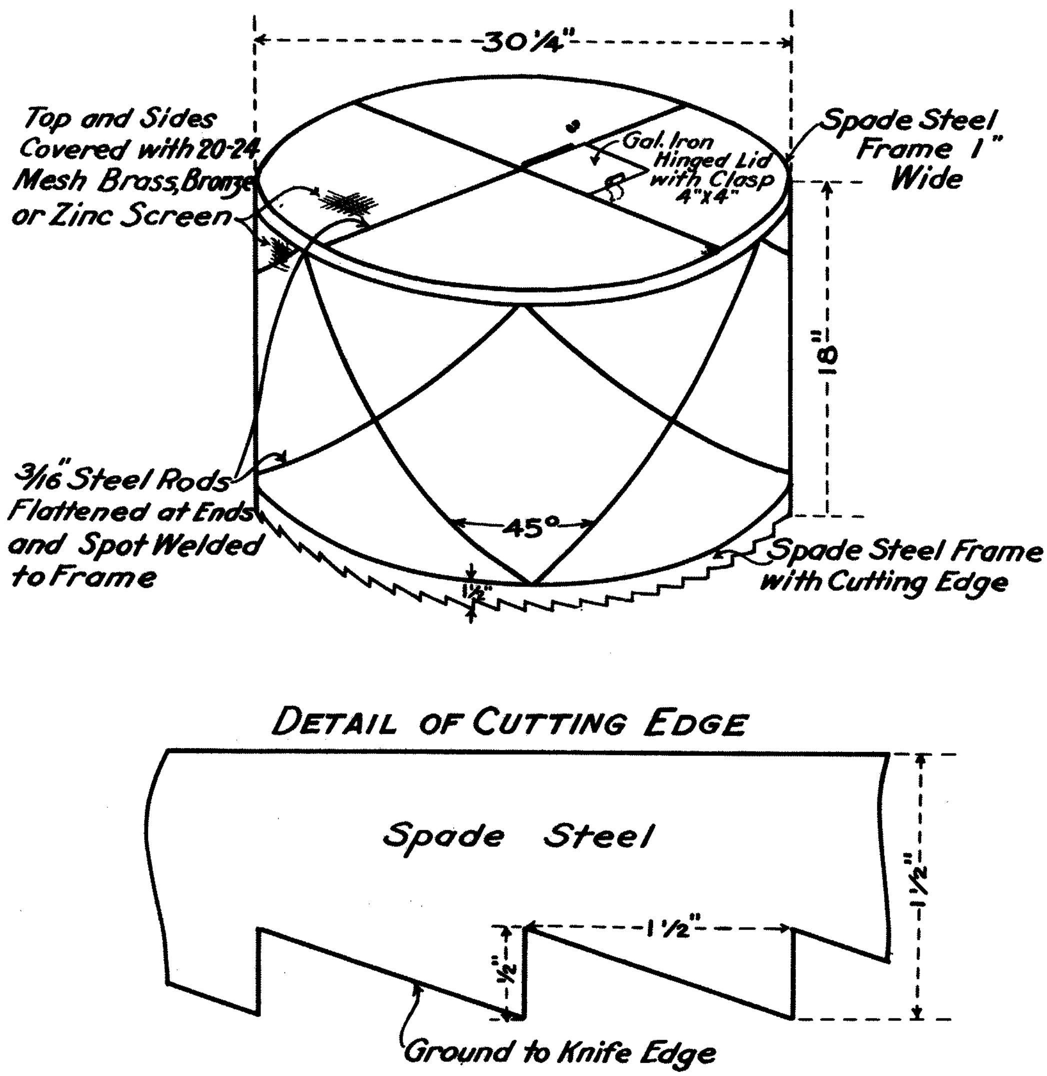



FIG. 2
C.S.M. Feb. 1932

In the hardwoods there is a much greater seasonal variation in fire hazard than in the softwoods. In hardwood stands sufficiently dense to prevent the growth of herbage on the forest floor, the only period when a serious hazard may develop is after the leaves have begun to fall. In a year of drought the fall of leaves may begin quite early and a considerable period of hazard may develop. As a rule, however, a few heavy rains will so pack down the newly fallen leaves that they form a compact mat which retains the moisture and offers little opportunity for a fire to start or spread. Oak leaves appear to remain loose and inflammable much longer than those of maple or large-toothed aspen.

In the spring the leaf litter in a hardwood stand is so well packed from the winter's snow that there is usually insufficient time before the new leaves come out for the material to become dry enough to constitute an appreciable hazard. With the advent of the new leaves the forest floor becomes well shaded, and an appreciable hazard can arise only after periods of most protracted drought.

In more open hardwood stands there is usually a growth of bracken, fern, grass, and other herbaceous plants. When this material dies, either from drought or from frost in the fall, it provides a splendid medium for the start and spread of fires, and, combined with the fallen leaves, affords sufficient fuel in dry periods for a very hot ground-fire. In the spring the grass and dead bracken may dry out quite rapidly in the period before new growth starts, and rapidly spreading spring fires may occur.

In open grassy spots a hazard may develop even a few hours after a heavy rain at any time when there is no snow on the ground. The period of least hazard in grassy areas is approximately from May 15 to July 15, when the new growth develops, reaches its maximum, and begins to die. Even during this period there is generally sufficient dead bottom-material among the green grass to carry fire well. Dry grass ignites extremely readily, and, as such areas are usually open and exposed to wind, the chief danger is that a fire may spread rapidly into more valuable material.

In areas which have been repeatedly burned over, there generally occurs a growth of Labrador tea, "scented fern", and blueberry bushes, together with more or less grass and bracken fern. In this type a fire once started in the grass may spread quite rapidly, even when the foregoing woody plants are green.

## Influence of Weather Factors on Inflammability

### Rainfall

Rainfall is the principal source from which the fuels receive moisture. The amount of moisture taken on from a given amount of rain depends on several factors:- the kind of fuel, its moisture content before the rain, the nature of the site, and the amount and duration of the rain.

Mixed pine duff will absorb moisture up to 270 per cent of its oven-dry weight before saturation, but this point is seldom reached in a single rain unless it is very prolonged. A series of intermittent showers of from 1/10 to 3/10 inch each are more effective in producing saturation than a single heavy rain, unless the heavy rain lasts over a period of a day or so.

In this study rainfall was divided into periods of under four hours' duration, and over four hours' duration. The effect of different amounts of rain in these periods in adding moisture to the duff has been observed and charts or tables made from the data. Figs. 3 and 3A.

## Relative Humidity of the Air

One pound of dry air at 70°F will hold 110 grains of moisture at saturation. When half saturated it holds 55 grains, or the relative humidity is said to be 50 per cent.

All dead forest materials are hydroscopic, that is, they take on or give off moisture until they come into equilibrium with the air. The rate of this exchange is fairly rapid in the finer fuels and much slower in the heavy material. The equilibrium moisture content of various fuels has been determined at the Forest Products Laboratories (Fig. 4). It may be observed that with air at saturation, or 100 per cent relative humidity, the materials will not take on more than 40 or 50 per cent of their oven-dry weight in moisture. Humidity at night usually rises to around 95 per cent, and this produces in the lighter materials a moisture content of 30 or 40 per cent if they are dry during the day. As the humidity begins to fall after sunrise, the materials lose moisture with a lag of about two hours behind the relative humidity and reach their their minimum moisture content late in the afternoon. (Fig. 5).

As a rule, no very serious hazard will develop if the humidity does not fall below 60 per cent, but this is by no means a safe rule, as wind velocity and temperature enter here as important factors.

Some of the early exponents of relative humidity as a criterion of fire hazard argued that, apart from its influence on the moisture content of the fuels, moist air retarded combustion and served as a wet blanket to protect nearby fuels. A glance at the following figures will show the fallacy of this theory:-

| | | |
|---|---|---|
| 1 cu.ft. dry air at 70°F and 29.5" pressure weighs | .07385 | lb. |
| 1 " " saturated air " " " " " | .07317 | " |
| Loss in weight due to water vapour | .00068 | " |

This reduces the weight of available oxygen in the air by 0.19 per cent, - a negligible amount.

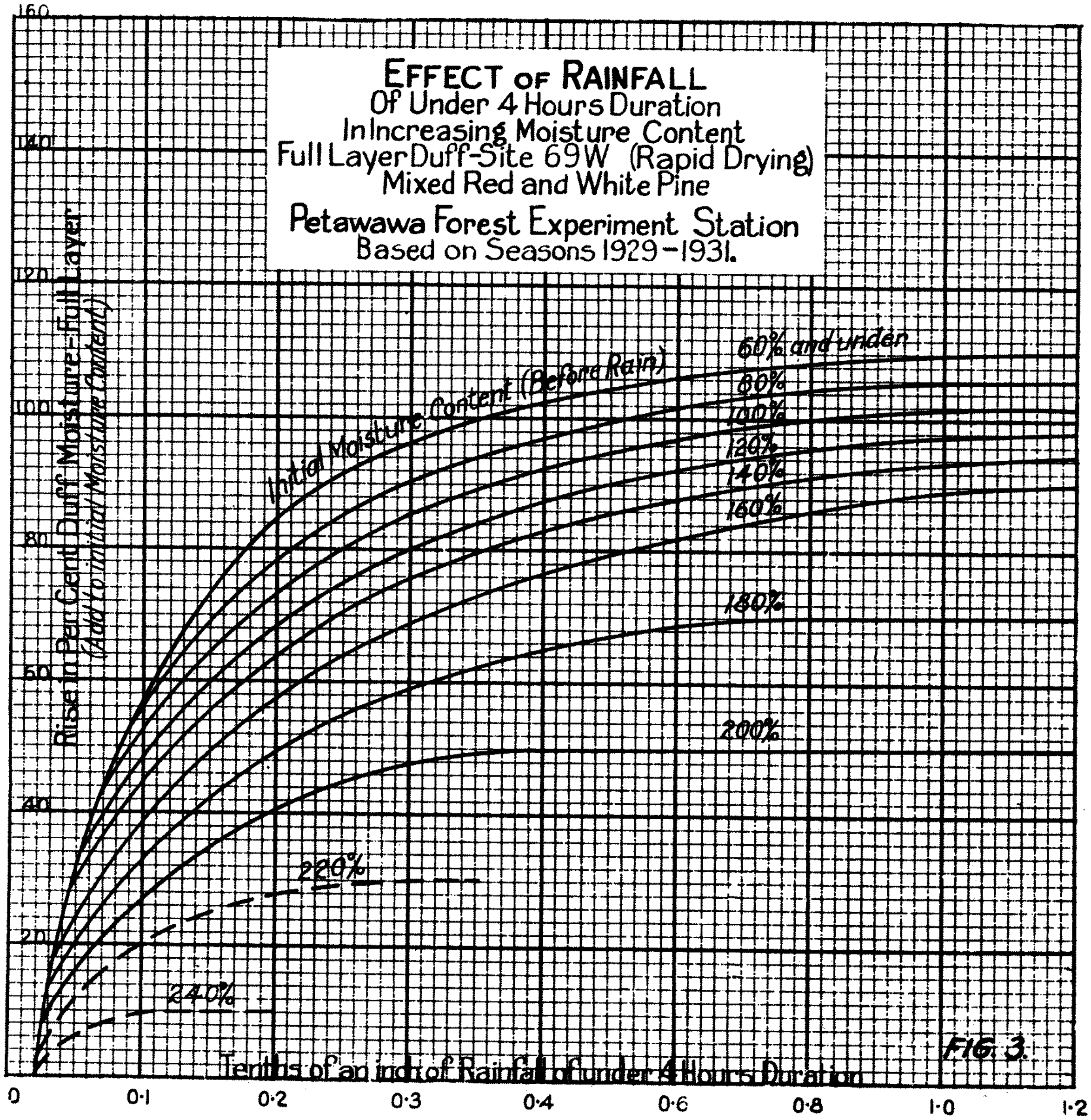
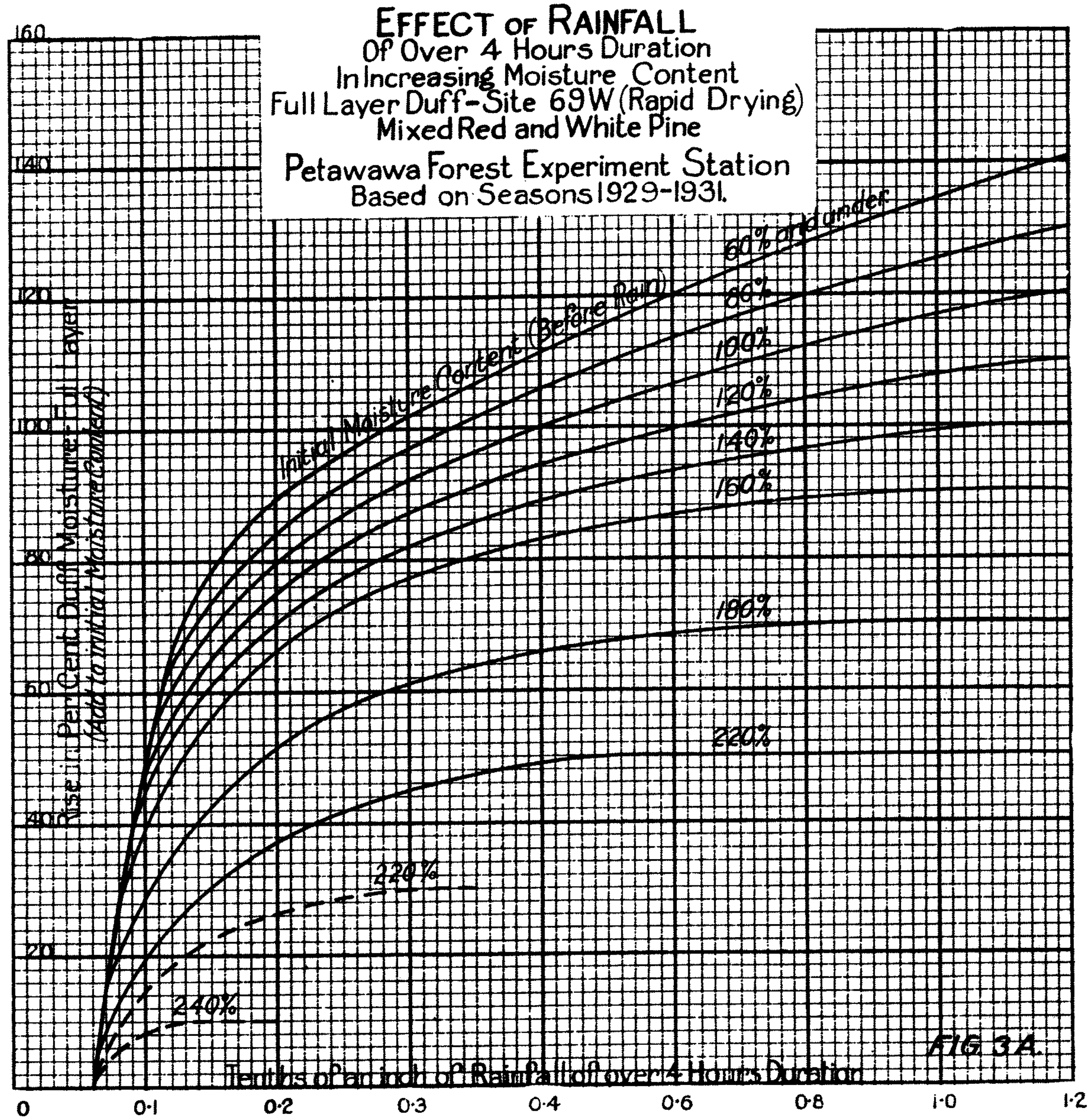
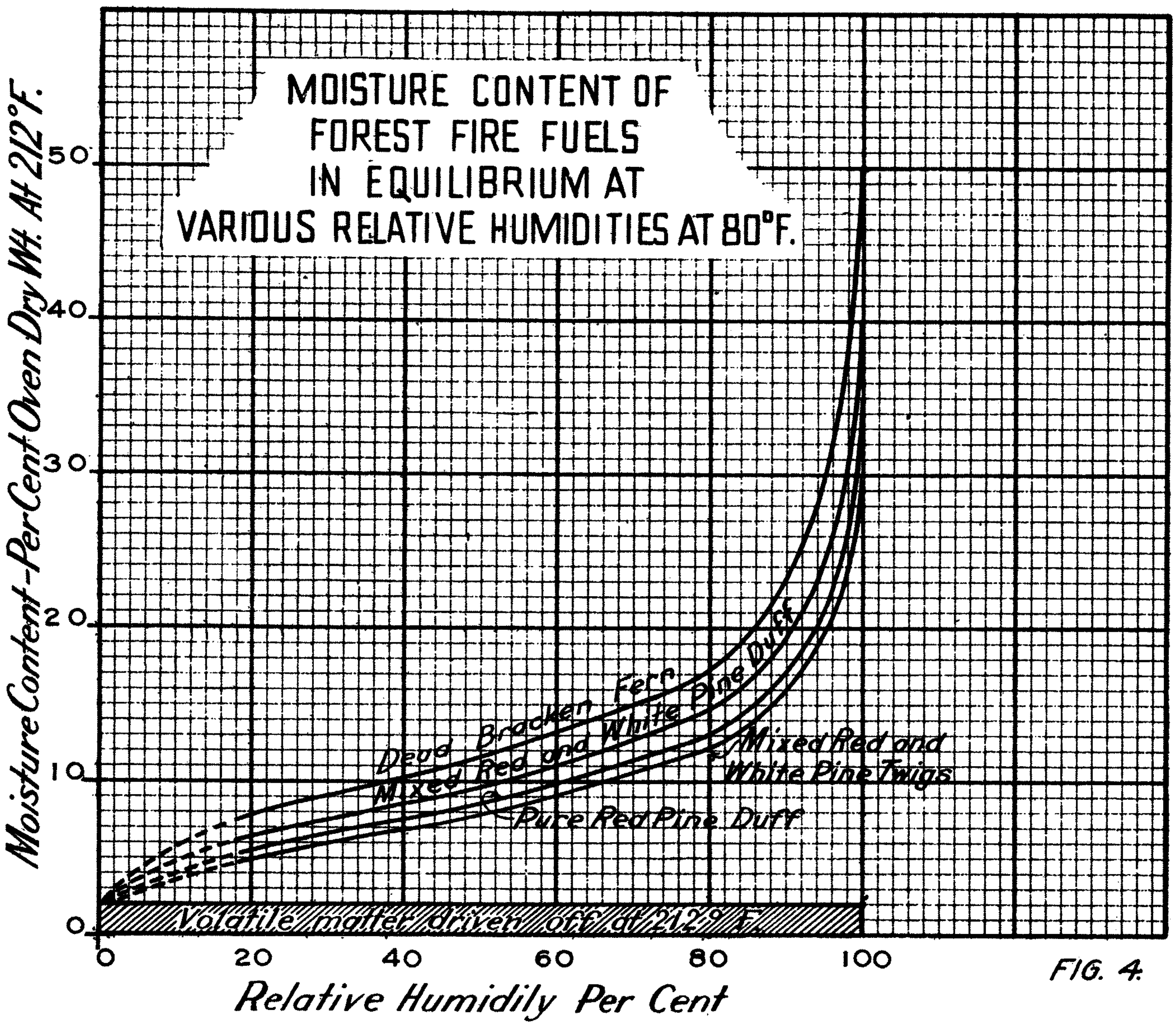

EFFECT OF RAINFALL
Of Under 4 Hours Duration
In Increasing Moisture Content
Full Layer Duff-Site 69W (Rapid Drying)
Mixed Red and White Pine
Petawawa Forest Experiment Station
Based on Seasons 1929-1931.
Rise in Per Cent Duff Moisture-Full Layer
(Add to Initial Moisture Content)
Initial Moisture Content (Before Rain)
60% and under
80%
100%
120%
140%
160%
180%
200%
220%
240%
Tenths of an inch of Rainfall of under 4 Hours Duration
160
140
120
100
80
60
40
20
0
0·1
0·2
0·3
0·4
0·6
0·8
1·0
1·2

FIG. 3.



EFFECT OF RAINFALL
Of Over 4 Hours Duration
In Increasing Moisture Content
Full Layer Duff-Site 69W (Rapid Drying)
Mixed Red and White Pine
Petawawa Forest Experiment Station
Based on Seasons 1929-1931.
Initial Moisture Content (Before Rain)
60% and under
80%
100%
120%
140%
160%
180%
220%
220%
240%
Rise in Per Cent Duff Moisture: Full Layer
(Add to initial Moisture Content)
Tenths of an inch of Rainfall of over 4 Hours Duration
160
140
120
100
80
60
40
20
0
0·1
0·2
0·3
0·4
0·6
0·8
1·0
1·2


FIG. 3A.



MOISTURE CONTENT OF
FOREST FIRE FUELS
IN EQUILIBRIUM AT
VARIOUS RELATIVE HUMIDITIES AT 80°F.
Moisture Content-Per Cent Oven Dry Wt. At 212°F.
50
40
30
20
10
0
Dead Bracken Fern
Mixed Red and White Pine Duff
Mixed Red and
White Pine Twigs
Pure Red Pine Duff
Volatile matter driven off at 212° F.
0
20
40
60
80
100
Relative Humidily Per Cent


FIG. 4.

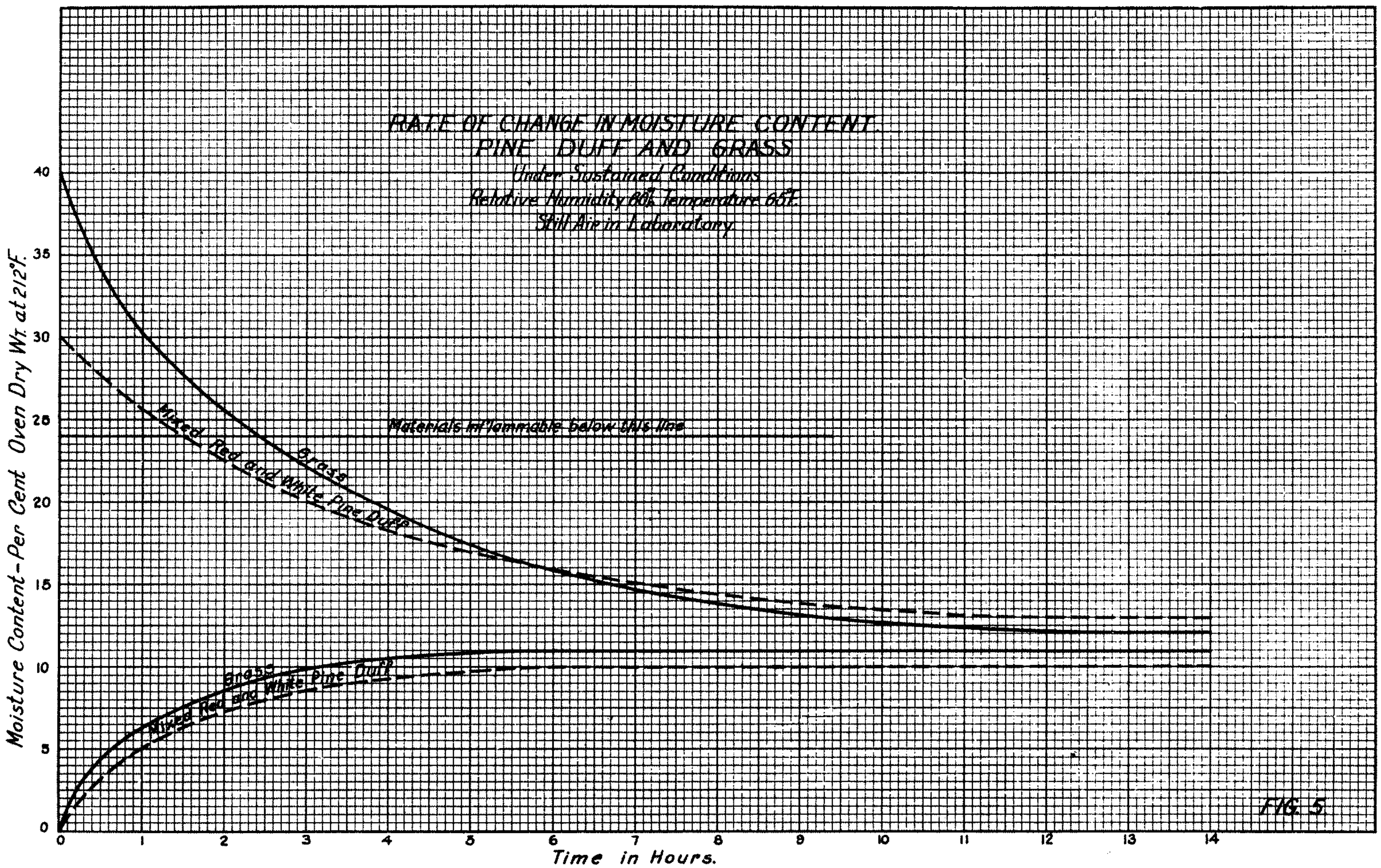

RATE OF CHANGE IN MOISTURE CONTENT.
PINE DUFF AND GRASS
Under Sustained Conditions
Relative Humidity 80% Temperature 65°F.
Still Air in Laboratory
Materials inflammable below this line
Grass
Mixed Red and White Pine Duff
Moisture Content - Per Cent Oven Dry Wt. at 212°F.
Time in Hours.
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

FIG. 5

Again

The specific heat of dry air at $70^{\circ}F$ = 0.2417
The " " saturated " " " = 0.2452

That is, the difference in specific heat is so small that the blanketing effect is negligible.

There is naturally a close correlation between relative humidity and cloudiness of the sky. On days with 40 per cent relative humidity, and under, the sky is usually clear. The cloudiness increases with increasing humidity until at 80 per cent the sky is usually completely overcast. (Fig. 6).

Air Temperature

Temperature is an important factor in rate of evaporation. The rate of evaporation is roughly proportional to the difference between the readings of the dry bulb and the wet bulb of a sling psychrometer. Thus the rate of evaporation at $60^{\circ}F$ and 40 per cent relative humidity will be approximately the same as at $94^{\circ}F$ and 60 per cent relative humidity. (Fig. 6A).

Duff Temperature

In shaded pine areas the duff temperature is usually several degrees below the air temperature when drying is going on, owing to cooling from evaporation. When the duff is taking on moisture, either from rain or atmospheric moisture, the reverse is usually the case, the duff temperature being slightly higher than the air temperature. At other times the duff temperature is about the same as the air temperature.

In areas exposed to the sun, duff temperatures may reach higher values. In a cut-over area (no shade), afternoon duff temperatures were frequently over $100^{\circ}F$ and on one occasion a temperature of $148^{\circ}F$ was recorded. These high temperatures rapidly drive off the moisture in the duff, and a high degree of inflammability is reached much more rapidly than in the shade.

In observing duff temperatures the thermometer must, of course, be completely shaded from the sun.

Solar Radiation

The intensity of solar radiation has a marked influence upon the rate of drying of fuels exposed to the sun's rays. It also has an influence on the rate of evaporation in general.

Rate of Evaporation

The rate of evaporation is the greatest single measurable factor controlling the rate of drying of forest fuels, combining, as it does, the effects of relative humidity, temperature, wind velocity, and solar radiation. Empirical curves have been prepared showing the average combined effect of the first three factors upon evaporation. (Fig. 7).

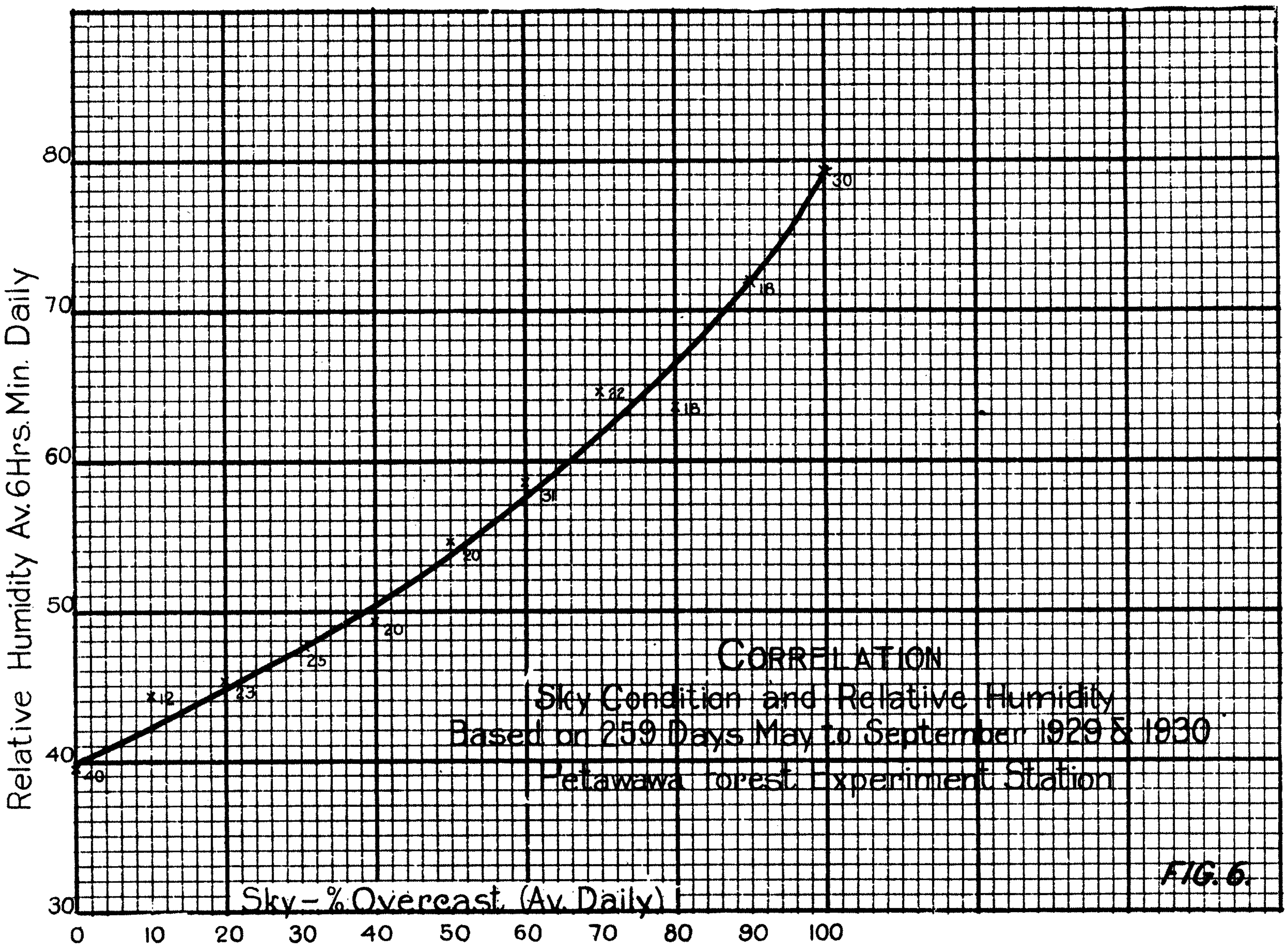

CORRELATION
Sky Condition and Relative Humidity
Based on 259 Days May to September 1929 & 1930
Petawawa Forest Experiment Station
Relative Humidity Av. 6Hrs. Min. Daily
Sky - % Overcast (Av. Daily)
30
40
50
60
70
80
0
10
20
30
40
50
60
70
80
90
100
40
12
23
25
20
20
31
22
18
18
30

FIG. 6.

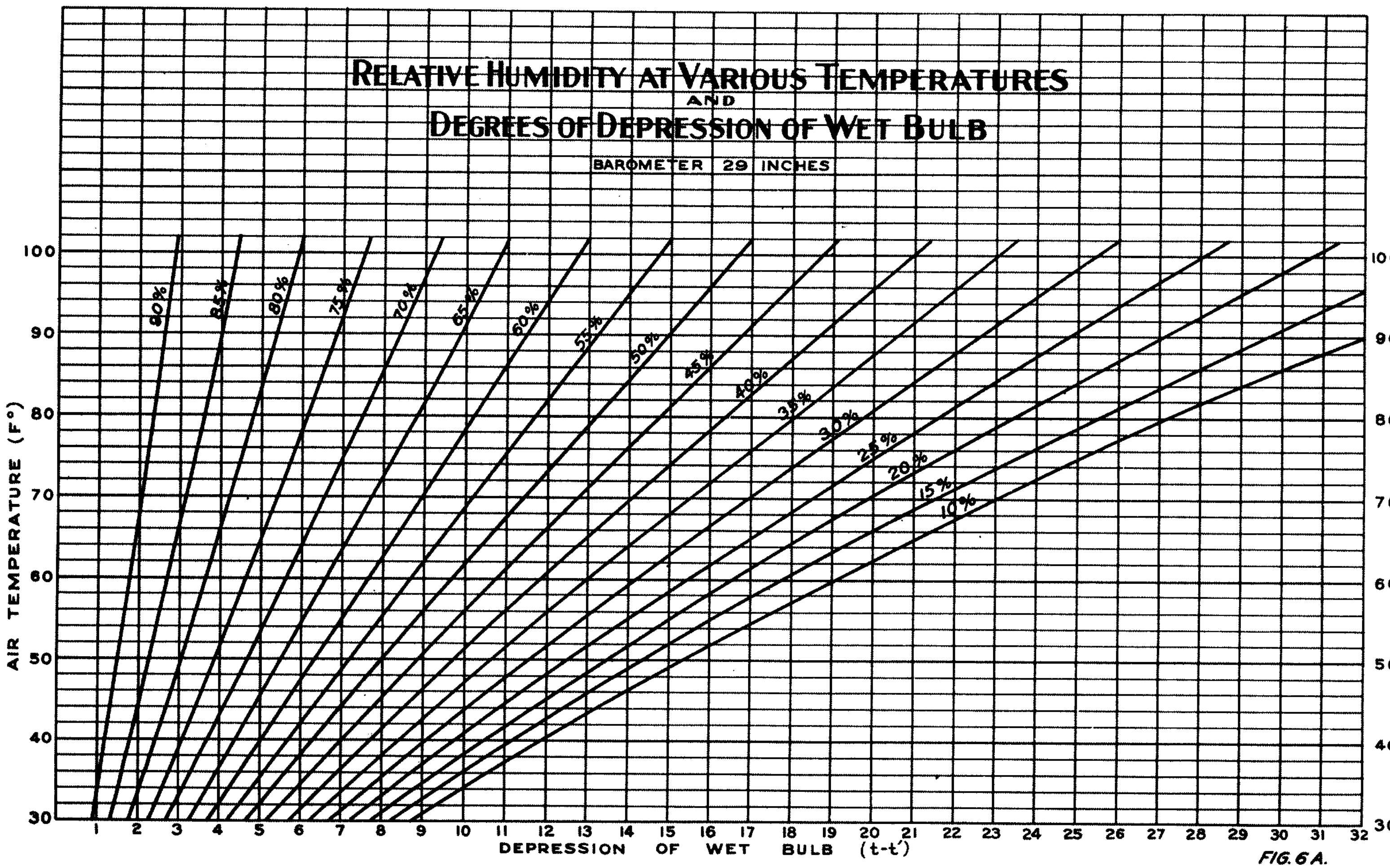

RELATIVE HUMIDITY AT VARIOUS TEMPERATURES
AND
DEGREES OF DEPRESSION OF WET BULB
BAROMETER 29 INCHES
AIR TEMPERATURE (F°)
DEPRESSION OF WET BULB (t-t′)
90% 85% 80% 75% 70% 65% 60% 55% 50% 45% 40% 35% 30% 25% 20% 15% 10%
30 40 50 60 70 80 90 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

FIG. 6A.

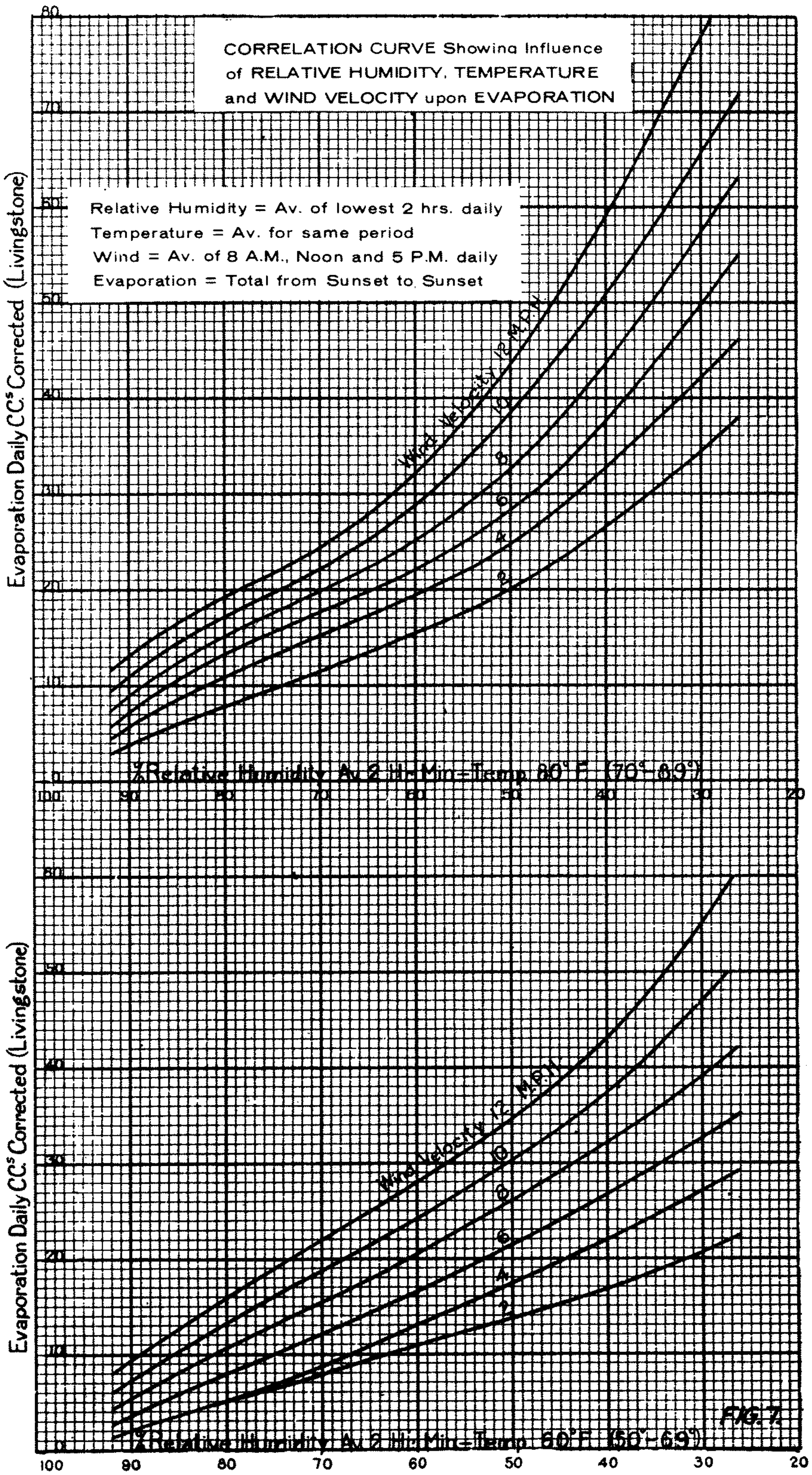

CORRELATION CURVE Showing Influence of RELATIVE HUMIDITY, TEMPERATURE and WIND VELOCITY upon EVAPORATION
Relative Humidity = Av. of lowest 2 hrs. daily
Temperature = Av. for same period
Wind = Av. of 8 A.M., Noon and 5 P.M. daily
Evaporation = Total from Sunset to Sunset
Evaporation Daily CC's Corrected (Livingstone)
Wind Velocity 12 M.P.H.
10
8
6
4
2
% Relative Humidity Av. 2 Hr. Min.-Temp. 80° F. (70°-89°)
100
90
80
70
60
50
40
30
20
Evaporation Daily CC's Corrected (Livingstone)
Wind Velocity 12 M.P.H.
10
8
6
4
2
% Relative Humidity Av. 2 Hr. Min.-Temp. 60° F. (50°-69°)
100
90
80
70
60
50
40
30
20

FIG. 7.

In these studies the rate of evaporation per day, together with relative humidity, has been found to give a reliable measure of the rate of drying. At the higher fuel moisture contents, rate of evaporation alone has to be considered. When the fuels reach the zones of inflammability, both rate of evaporation and relative humidity have to be used. By correlating measurements of these factors with measurements of duff moisture, it has been possible to prepare charts which show the rate of drying and change of moisture content in the duff. (Figs. 8 and 9).

<u>Wind velocity</u>

Wind velocity in addition to increasing the rate of evaporation, and therefore speeding up the rate of drying of forest fire fuels, has also a very marked effect on the behaviour of fires once started.

It has been shown (Page 7) that only about 16 per cent of the heat generated in a duff fire in practically still air goes towards supporting combustion, the rest passing off upwards. It will be readily seen that a horizontal current of wind will drive some of this escaping heat against adjacent fuels and so expedite combustion. As wind pressure varies as the square of the wind's velocity, some such relationship might be expected in the rate of spread.

From observations on 33 experimental fires in California, S.B. Show found that the rate of increase in the perimeter of a fire varied approximately as the square of the wind velocity.

In such studies it is very difficult to secure comparable conditions as to type of fuel and topography. However, several favourable occasions were found in the case of going fires in the present study, as follows:

| | | | |
|---|---|---|---|
| Wind velocity m.p.h. ........ | 5.5 | 8 | 12 |
| Wind velocity squared ........ | 30.25 | 64 | 144 |
| Advance in ft. per hr. ....... | 600 | 1200 | 2640 |

$1200 \div 600 = 2$ $\qquad$ $2640 \div 600 = 4.4$

$64 \div 30.25 = 2.1$ $\qquad$ $144 \div 30.25 = 4.7$

These figures bear out the finding of Show.

The relative humidity on all three occasions was 28 per cent, the ground was nearly level, and the forest cover consisted of dry grass, bracken, scented fern, and blueberry bushes.

On the average, in the three fires in question, fire was found to advance three to four times as fast with the wind as against it.

In nearly full-canopy pine stands on level ground, the wind velocity at a height of 4 feet is approximately 1/10 that above the trees.

Wind is also an important factor in the development of crown fires. Crown fires are not likely to occur unless there is a large volume of fuel under the trees. The heat from this fuel rises and is so intense that it ignites the green foliage. The combined heat from the ground fuel and the burning foliage, when levelled by a high wind, will cause the fire to run rapidly in the tree tops. An investigation of the amount of moisture in green foliage is of interest.

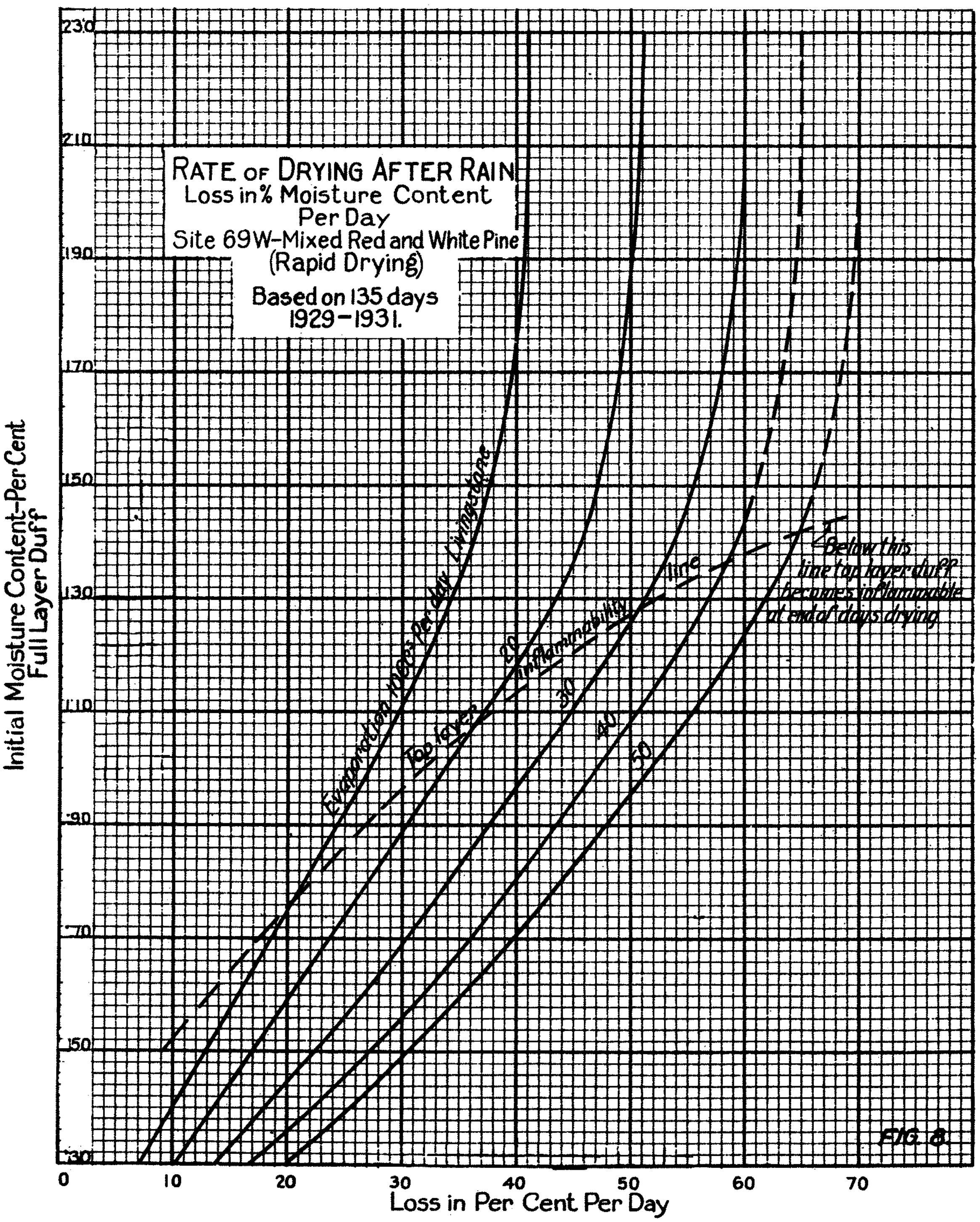

RATE OF DRYING AFTER RAIN
Loss in % Moisture Content
Per Day
Site 69W-Mixed Red and White Pine
(Rapid Drying)
Based on 135 days
1929-1931.
Evaporation 100% Per day Livingstone
Top layer inflammability line
20
30
40
50
Below this line top layer duff becomes inflammable at end of days drying
Initial Moisture Content-Per Cent
Full Layer Duff
230
210
190
170
150
130
110
90
70
50
30
0
10
20
30
40
50
60
70
Loss in Per Cent Per Day

FIG. 8

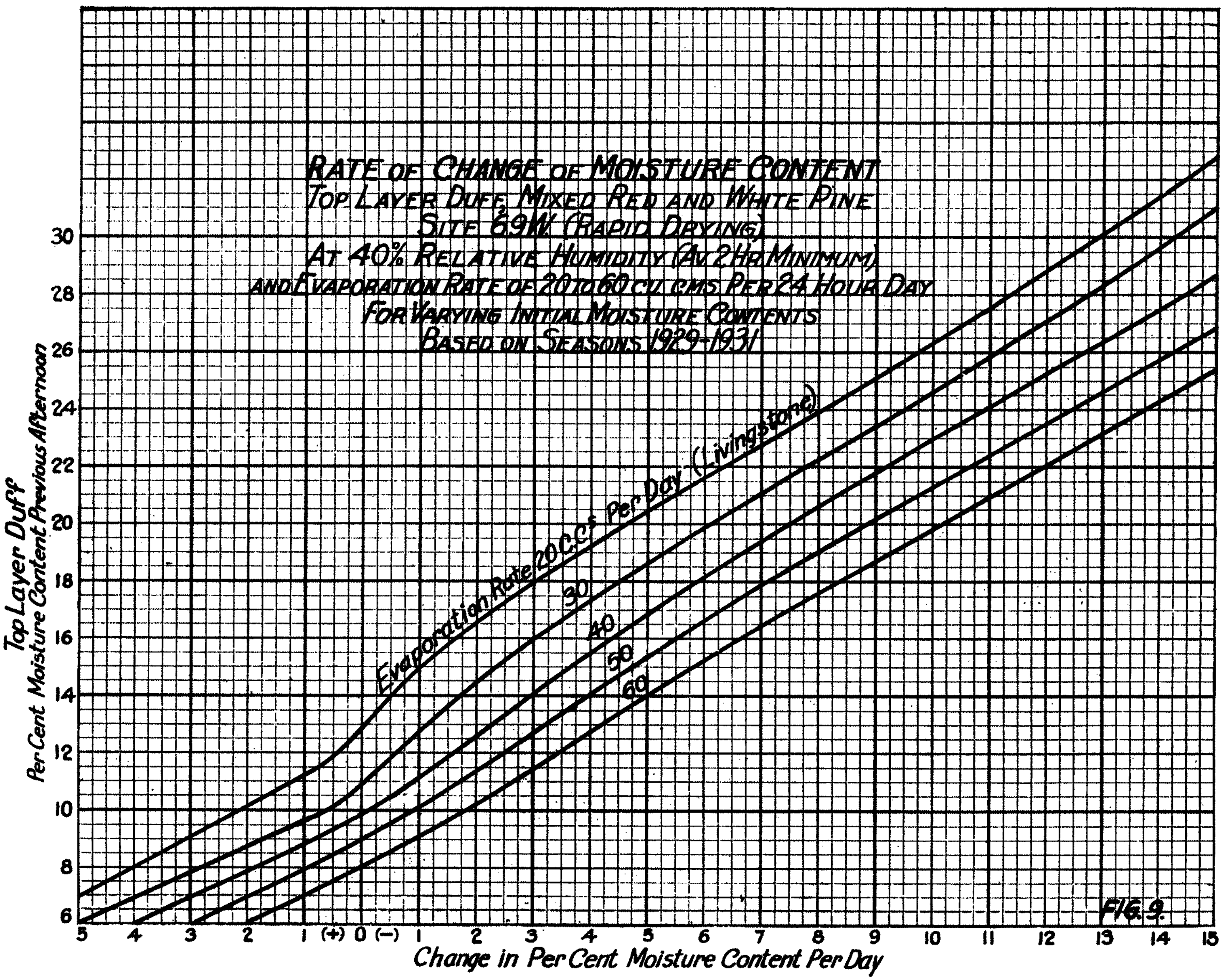

RATE OF CHANGE OF MOISTURE CONTENT
TOP LAYER DUFF, MIXED RED AND WHITE PINE
SITE 69W (RAPID DRYING)
AT 40% RELATIVE HUMIDITY (AV. 2 HR. MINIMUM)
AND EVAPORATION RATE OF 20 TO 60 CU. CMS. PER 24 HOUR DAY
FOR VARYING INITIAL MOISTURE CONTENTS
BASED ON SEASONS 1929-1931
Evaporation Rate 20 C.C.s Per Day (Livingstone)
30
40
50
60
Top Layer Duff
Per Cent Moisture Content Previous Afternoon
30
28
26
24
22
20
18
16
14
12
10
8
6
5
4
3
2
1 (+) 0 (−) 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Change in Per Cent Moisture Content Per Day

FIG. 9.

## Green-foliage Moisture

Samples of green foliage taken from standing softwood trees indicated a slow seasonal variation in moisture content. In the majority of species the greatest moisture content was found during the latter part of July and the beginning of August, particularly in the case of the pines. The range of moisture contents of samples in various species was as follows:

| | |
|---|---|
| White pine | 118 to 160 per cent |
| Red pine | 108 to 142 per cent |
| Jack pine | 110 to 135 per cent |
| Spruce | 109 to 131 per cent |
| Balsam fir | 101 to 140 per cent |

The aspens covered nearly the same moisture range as the white pine: red maple and white birch ran from 180 to 200 per cent.

In the case of red and white pine it was found that the foliage moisture-content in trees of 2-inch diameter was from 4 to 20 per cent greater than in larger trees around 8 inches in diameter.

## Influence of Soil Moisture on Duff Moisture

The effect of soil moisture upon the moisture content and consequently upon the inflammability of the overlying duff has been greatly overestimated in the past, at least in so far as the pine types are concerned. We have often heard statements to the effect that the hazard was lower than usual in a certain year because during the previous fall and winter there had been heavy precipitation which raised the water-table. In the same way the impression exists that a month of heavy precipitation will alleviate the hazard during a succeeding dry month. It will be shown that these assumptions are wrong in so far as pine forests are concerned, and lead to a false sense of security.

Experiments extending over two fire seasons were conducted to study this problem. Two pans 30 inches square and 10 inches deep were set into the forest floor, their tops level with the ground. In each of these pans was placed a block of soil with duff intact, of the same dimensions as the pan. The soil and duff were disturbed as little as possible, so that the natural structure would be preserved. The duff around the edges of the pans was carefully arranged in a natural manner so that it was impossible to observe where the pans lay.

To one pan, water was added through carefully prepared tubes each day until the water-table stood at two inches below the duff, where it was maintained. The other pan was kept dry for comparison. Both pans were covered during heavy rain. The moisture content of the duff over both pans was observed daily.

The moisture content of the upper two inches of mineral soil in the "dry" pan was about 5 per cent. In the "wet" pan it ran about 45 per cent, which in this type of soil (light sand) was complete saturation.

This extreme difference in soil moisture produced a difference of only 1 to 2 per cent in the moisture content of the top layer duff and from 3 to 12 per cent in the full layer duff.

Soil moisture was measured at a number of sites regularly, the upper two inches of mineral soil being used. The maximum soil-moisture variation observed in any site was in the neighbourhood of 20 per cent. It will be seen, therefore, in view of the foregoing experiment, that the most extreme variations in soil moisture found in nature in pine types can have little effect on the moisture content of the overlying top layer duff.

In hardwoods, where the duff forms a tight compact mat which acts as a mulch, the situation is probably quite different. Similarly in low-lying or swampy areas the effects of accumulated precipitation last a very long time.

## Weather Observations

In connection with the present study a complete weather observation station was established at the headquarters of the Petawawa Forest Experiment Station. The apparatus includes an automatic electric anemobiograph for recording wind direction and velocity, automatic recording rain-gauge, thermo-hygrograph for recording temperature and relative humidity, standard barometer, barograph, three types of evaporation-measuring devices, sunshine recorder, maximum and minimum thermometer, wet and dry bulb thermometer, and an Assman hygrometer for standardizing humidity-measuring apparatus. This station was established in co-operation with the Meteorological Service of Canada, and reports twice daily by code to Toronto. In return the station receives each morning a weather forecast covering the next sixty hours.

This station is situated in a clearing several acres in extent, on the south shore of Corry lake, and is particularly exposed to winds from west through north to northeast.

An auxiliary weather station was operated during the summer months in the valley of the Petawawa river near Racehorse rapids, about 9 miles south of headquarters. This station is situated in a clearing about one-half acre in extent on the south bank of the river.

Rainfall, relative humidity, and evaporation records were also taken at Highview and Montgomery lookout towers, at the east and west sides of the reserve respectively.

In addition, certain routine weather observations were made twice daily at the various sites where fuel moisture was being observed. As would be expected weather data from the sites under forest canopy differed materially from that taken at the standard weather station in the open, although a consistent relationship for each site is noted.

In working up the observed data to prepare curves showing the relation between weather and moisture content of duff, two courses were open. The changes in moisture content of the fuels might be correlated with weather factors observed at the site in question, or they might be correlated with the records of the main weather station situated in the open. The former method would yield no practical results, because to make use of them it would be necessary to take future weather observations at the site in question, and in this case it would be just as easy to actually measure the moisture content of the fuels.

As the weather measurements at each forest site bear a consistent relationship to the general weather over the area in the open, the most practical method is to correlate fuel moisture at each site with the standard weather readings at the main station. This method was adopted, the local-site weather data being used only as a check against local variations such as local showers.

It has been shown (Page 17) that the daily rate of evaporation is the most reliable measure of the rate of drying of forest fuels. This factor is much influenced by environment, and evaporation records, if they are to be standard for a large area, must be taken in the open at a point where there is good air circulation from all sides. The following comparison of evaporation records at six different sites with records at the standard headquarters station are of interest:-

| Site | Ratio Headquarters / Site | Ratio Site / Headquarters |
|---|---|---|
| Headquarters | 1. | 1. |
| Highview Tower (base) | 0.94 | 1.06 |
| Montgomery " " | 1.05 | 0.96 |
| Racehorse (small clearing) | 1.20 | 0.83 |
| Cut-over area (sheltered) | 1.35 | 0.74 |
| Red Pine .8 canopy (south exposure) | 1.43 | 0.70 |
| Mixed Pine, full canopy (level) | 2.22 | 0.45 |

It will be seen that the rate of evaporation at the two lookout towers is very nearly equal to that at headquarters, while in the other sites the rate decreases as the degree of shelter increases.

The Livingstone porous cup atmometer with rain-correcting mounting was used as the standard in this study, for measuring rate of evaporation. The instruments should be read in the evening, or preferably morning and evening.

## Practical Application of Fire-Hazard Measurements

The following are some of the uses to which a knowledge of the degree of fire hazard which exists each day may be put to good advantage:

(a) In detailing the work of forest employees so that they will be immediately available for fire duty if the inflammability warrants. If a forest officer has accurate knowledge that no fires will occur, he may leave men on productive work at outlying points with safety. At the same time, he is, on the other hand, in no danger of a fire unexpectedly developing while his men are scattered at remote points.

(b) In determining the number of men necessary to send to a fire. A glance at a forest-type map of the area of the fire, and at the fire-hazard chart for the types in this vicinity will indicate at once the fire danger involved. If there is no danger of rapid spread, fewer men need be sent.

(c) To know when it is safe to conduct slash or other burning operations. Slash piles will burn for a considerable period before fire will spread under forest cover. When danger of spread approaches, the burning should be stopped.

(d) To regulate the issuance or cancellation of burning permits issued to settlers.

(e) To regulate and control travel in the forest.

(f) To educate the public on the variation in fire hazard and warn them when a hazard exists.

(g) To know when to close forests to travel. In periods of extreme hazard the only sure way to prevent man-caused fires at present is to forbid entry of the forest. Ultimately it may be possible to educate the public to the extent that this will not be necessary.

(h) To know when to close down summer logging operations in cases where steam power units are not adequately equipped with fire-protective devices.

(i) To regulate the frequency of ground or air patrols and to know when it is safe to allow lookout-tower men off duty.

In the past, decisions on most of the above points have had to depend on the judgment of the individual forest officer, and many fires and much needless expense have occurred due to faulty judgment.

Fire-hazard measurements may also be used as a measure of the efficiency of an organization and of the effect of educational propaganda on the public. In the past, these factors have been judged on the basis of the number of fires which occurred, which is not a satisfactory criterion. Conditions may be favourable for a fire to start but owing to care on the part of the public, or vigilance on the part of protection forces, the necessary firebrand may not reach the fuels. This aspect is revealed only when years are compared by the number of days of hazard present in each.

Such a table is shown for the Petawawa area for 1929-30-31. The rapid-drying site represents an extreme condition. The slow-drying site more nearly represents conditions in the average pine forest. (Fig. 10).

During the period covered by the table, eight fires occurred in 1929, one in 1930, and one in 1931. It should be noted that while conditions in 1931 were nearly as serious as in 1929, only one fire occurred. There was no noticeable difference in the number of people entering the reserve in these two years, so it seems reasonable to assume that the public was more careful with fire in 1931.

At the principal entrance to the reserve from the highway, there is maintained a large notice-board with movable slides. Upon this notice-board is posted each morning the estimated hazard for the day in question, together with an appropriate warning to persons entering the reserve. The estimate is based upon the hazard measured at the rapid-drying mixed-pine site. This notice has attracted much attention and may be partly responsible for the reduced number of fires.

## Fire-Hazard Charts

As has been mentioned (Pages 12 and 17), curves have been prepared showing the effect of rainfall in reducing fire hazard and of relative humidity and evaporation in drying out the fuels in the types studied. Such curves have been completed for slow-drying and rapid-drying sites in mixed red and white pine forest. From these curves preliminary fire-hazard tables have been developed, by the aid of which an index of inflammability can be computed for each day if certain weather records are available. The tables will be published separately, together with explanations and directions for their use. The only weather measurements required are the amount, time and duration of rainfall each day, the relative humidity at 2.30 and 4.30 p.m., and the evaporation as read each evening covering the previous 24 hours. These data can be obtained at a number of outlying points and telephoned in to the central office where the degree of hazard can be computed for each area. A fire hazard chart computed from the tables is shown in Fig. 11.

Forest-fire hazard data and tables prepared for given forest types in one climatic area are not necessarily applicable in other areas where the types and climate are different. The present studies have been confined mostly to the pine types in the vicinity of the Petawawa Forest Experiment Station. The data obtained are no doubt applicable to the pine regions of eastern Ontario and western Quebec. Preliminary sets of the fire-hazard tables were tried out with good success in western Quebec during the fire season of 1931. It is, however, not to be expected that these tables would have given as good results had they been used in other types, say, in western Ontario or eastern Quebec.

In fire-hazard studies it is necessary to deal with each forest region and climatic area separately, if the most reliable results are to be obtained. A start has been made at the Petawawa Forest Experiment Station, certain standard methods which have been found productive of good results being used. The study should be extended to cover every forest type in each climatic area. Eventually, each forest officer should be as familiar with the effect of weather upon fire hazard in his territory as he is, or should be, with the rate of growth of the forest in his charge.

Petawawa Forest Experiment Station

NUMBER OF DAYS OF FIRE HAZARD

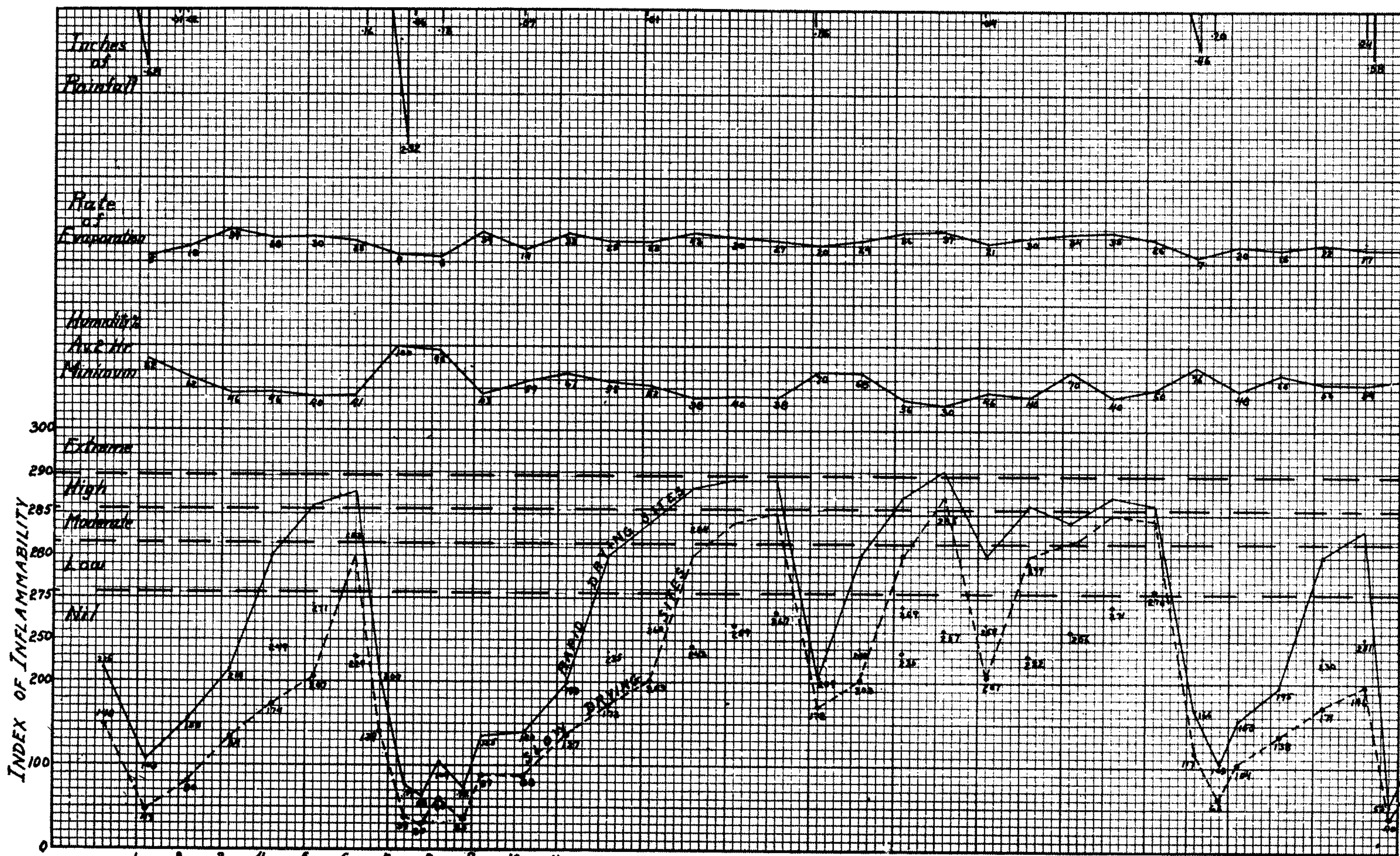
105 Day Period, June 8 - September 20, Years 1929-31

MIXED RED AND WHITE PINE FOREST

| Degree of Hazard | 8-30 June 1929 | 8-30 June 1930 | 8-30 June 1931 | July 1929 | July 1930 | July 1931 | August 1929 | August 1930 | August 1931 | 1-20 September 1929 | 1-20 September 1930 | 1-20 September 1931 | Total 1929 | Total 1930 | Total 1931 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RAPID DRYING SITE | | | | | | | | | | | | | | | |
| Low | 1 | 1 | 2 | 0 | 2 | 2 | 2 | 3 | 2 | 0 | 1 | 3 | 3 | 7 | 9 |
| Moderate | 2 | 6 | 5 | 1 | 7 | 1 | 0 | 6 | 0 | 1 | 0 | 1 | 4 | 19 | 7 |
| High | 5 | 3 | 5 | 5 | 8 | 4 | 11 | 8 | 13 | 5 | 0 | 4 | 26 | 19 | 26 |
| Extreme | 11 | 0 | 7 | 14 | 2 | 3 | 9 | 0 | 7 | 3 | 0 | 3 | 37 | 2 | 20 |
| Totals | 19 | 10 | 19 | 20 | 19 | 10 | 22 | 17 | 22 | 9 | 1 | 11 | 70 | 47 | 62 |
| Days of High or Extreme Hazard | | | | | | | | | | | | | | | |
| High or Extreme | 16 | 3 | 12 | 19 | 10 | 7 | 20 | 8 | 20 | 8 | 0 | 7 | 63 | 21 | 46 |
| SLOW DRYING SITE | | | | | | | | | | | | | | | |
| Low | 3 | 4 | 2 | 0 | 3 | 1 | 2 | 5 | 5 | 0 | 0 | 1 | 5 | 12 | 9 |
| Moderate | 3 | 3 | 2 | 2 | 3 | 0 | 4 | 1 | 2 | 0 | 0 | 1 | 9 | 7 | 5 |
| High | 6 | 0 | 6 | 10 | 2 | 5 | 8 | 0 | 8 | 2 | 0 | 5 | 26 | 2 | 24 |
| Extreme | 1 | 0 | 3 | 6 | 0 | 1 | 1 | 0 | 5 | 3 | 0 | 0 | 11 | 0 | 9 |
| Totals | 13 | 7 | 13 | 18 | 8 | 7 | 15 | 6 | 20 | 5 | 0 | 7 | 51 | 21 | 47 |
| Davs of High or Extreme Hazard | | | | | | | | | | | | | | | |
| High or Extreme | 7 | 0 | 9 | 16 | 2 | 6 | 9 | 0 | 13 | 5 | 0 | 5 | 37 | 2 | 33 |

FIG. 10.

FIRE HAZARD CHART




JULY 1932 PETAWAWA FOREST EXPERIMENT STATION FIG. 11

# DETAILS OF TECHNIQUE EMPLOYED IN FOREST-FIRE-HAZARD STUDIES

It has been shown that the inflammability of a forest-fire fuel depends very largely upon its moisture content, and that the latter may, therefore, be used as a reliable measure of the degree of fire hazard in a given site. Fire hazard, it should be remembered, relates to the amount, character, and arrangement of the fuels as well as to their moisture content. For a given site, however, the only variable is the moisture content, so that the latter, therefore, becomes a measure of the fire hazard in that site. Different sites in different species may have widely differing degrees of fire hazard under similar weather conditions, but if the relation between moisture content and fire hazard is known for each site, the moisture content of the duff in a given site becomes a measure of the fire hazard in that site.

## Selection of Sites

In entering upon a study of the fire hazard in a given region, the first step is to make a careful selection of a number of typical sites in the different forest species and types. It is a good plan, when possible, to investigate first pure stands in each species, and later proceed with mixed stands in various proportions. Two groups of sites should be selected for each species, one group representing what may be considered as rapid-drying sites, owing to exposure, degree of canopy, etc., and the other group representing the average or slower-drying sites.

When a site has been selected in a representative stand, a small plot should be laid out including all the trees which contribute the material which constitutes the duff in the central part of the plot. Usually an area 75 or 100 feet square will be sufficient. All trees in this area are carefully tallied by diameter and species.

A mechanical analysis, after careful sampling, should be made of the top-layer duff in the central part of the plot where the measurements are to be taken. This analysis should show, by percentage of the total, the number of leaves and the weight of leaves of each species.

This information should be included in a complete technical description of the site giving the location, nature of the stand, topography, exposure, degree of canopy, amount and nature of ground vegetation, nature of soil, and particulars of duff and litter. In this way the results obtained in different sites may be scientifically compared. While the description is mentioned first, it may be made at any convenient time during the season, but the points outlined should be kept in mind when selecting the sites.

## Critical Fuels

When a site has been selected, the next step is to determine the critical fuels, that is, those in which fire will start or spread. These may consist of duff, moss, or dead perennial vegetation, depending on the nature of the site. Attention should then be directed to measuring the moisture content of these fuels daily, and establishing zones of inflammability.

In the pine types investigated during the years 1929-31 it was found that the top-layer duff was the critical fuel. The inflammability zones established for these types, based upon the moisture content of the top-layer duff, have been described in a previous section.

It was found impossible to use the moisture content of full-layer duff as a criterion of fire hazard, as it was found that the top layer would become inflammable and carry fire at a wide range of moisture content of the full layer. For instance, in rapid-drying sites in mixed red and white pine the top layer of duff might become inflammable when the full layer contained 77 per cent of its oven-dry weight of moisture, if the rate of evaporation in the open was around 50 ccs. per day. When the rate of evaporation was around 10 ccs. per day, the moisture content of the full layer could drop to 55 per cent before the top layer would become inflammable. In slow-drying sites in the same type the range was even more pronounced. Low inflammability in the top layer occurred at 118 per cent moisture content in the full layer, if the rate of evaporation was around 60 ccs. per day. When the rate of evaporation was around 10 ccs. per day the top layer never became inflammable. It will thus be seen that top-layer duff may become inflammable when the full layer contains less than 120 per cent moisture and on the other hand <u>may not</u> become inflammable until the full-layer moisture has dropped to 50 per cent or less.

If the inflammability were to be actually measured in the field each day, it would only be necessary to measure the moisture content of the top-layer duff, neglecting the full-layer entirely. If, however, it is desired to prepare rate-of-drying curves from which to compute the inflammability from observed weather factors at a central weather station, it is necessary to study the behaviour of the full-layer duff, as the moisture content of the partially decomposed lower layers exerts a marked influence on the rate of drying of the top layer.

In pine sites it is, therefore, necessary to measure the moisture content of the top-layer duff and the moisture content of the full-layer duff independently. It is also desirable to measure the moisture content of the twigs and litter lying on top of the duff.

## Moisture Content of Top-layer Duff

That part of the duff in which fires start and spread is ordinarily the top layer, usually about one-half inch in depth. The underlying more compact and partially decomposed material does not burn readily, but continues to smoulder, if dry, long after the fire has passed through the top layer.

The moisture content of the top-layer duff is determined by means of a duff hygrometer. This instrument consists of a strip of rattan under slight tension in a perforated tube about 12 inches long. One end of the rattan is fixed and the other attached to a small chain which passes over a pulley and operates an indicator. The rattan strip changes in length as the moisture content varies. These changes in length cause the indicator to move across a scale graduated experimentally in percentages of moisture content. Each instrument must be calibrated in the duff in which it is to be used, and should be recalibrated each spring as the rattan undergoes progressive structural changes with the passage of time, and repeated wetting and drying. As a rule, however, a carefully calibrated duff hygrometer will remain in reasonably close adjustment during one fire season.

The placing of the duff hygrometer in position to give accurate results is a somewhat difficult operation and sometimes requires considerable patience. The hygrometer tube is inserted horizontally just barely under the surface of the duff. It is then covered with about one-half inch of top-layer duff raked up near by. This additional thickness of duff should extend about one foot on either side of the tube. If the tube is too low in the duff, the instrument will be influenced by the moisture contained in the lower partially decayed layers and give too high readings for the top-layer duff. On the other hand, if it is placed too near the surface, the atmospheric air will influence it and cause it to give too low readings.

When duff hygrometers are placed in mixed pine duff in the manner described in the preceding paragraph, they usually require no other adjustment than the addition or removal of a small amount of needles over the tube. This is done by experiment, with the aid of oven-dried samples of top-layer duff. After the instrument has been installed, small samples of the near-by top-layer duff are taken each afternoon for several days and placed in air-tight containers and their moisture content is determined in the field laboratory. All samples should be taken at least in duplicate. By comparing the moisture content thus determined with the readings of the duff hygrometer, the latter may be adjusted by adding or removing duff, so that the instrument will give correct readings within one or two per cent.

As the season progresses, the duff hygrometers have a tendency to settle down in the duff, owing partly to their weight and partly to the gradual decomposition of the duff. The readings of the instrument should, therefore, be checked at least once a week by oven-drying samples, and adjustments should be made when necessary.

Duff hygrometers will not read moisture contents above 50 per cent and their accuracy decreases rapidly above 30 per cent. This is because the instruments depend upon the relative humidity of the air in the spaces in the duff to produce changes in the length of the rattan strip. As the moisture content of the duff rises above 30 per cent, the humidity of the air in the duff rapidly approaches saturation, and the movements of the indicator decrease until they cease altogether.

High night humidities, dew, or rain cause the duff hygrometer to rise to high values or to cease to register. As the material begins to dry out, the readings of the duff hygrometer tend to lag behind the moisture content and give too high values. The most reliable time to take readings of the duff hygrometer is about 4.00 p.m., when the effects of the lag have disappeared. For this reason duff samples for checking the instrument should be taken in the afternoon.

A short strip of lath should be placed crosswise under the case of the instrument, in order to distribute the weight and prevent it settling at the heavy end. The case should be tapped gently with a pencil to bring the indicator to rest before reading. A protecting tripod of small poles should be erected over the instrument to prevent it being walked upon.

## Calibration Tube for Duff Hygrometer

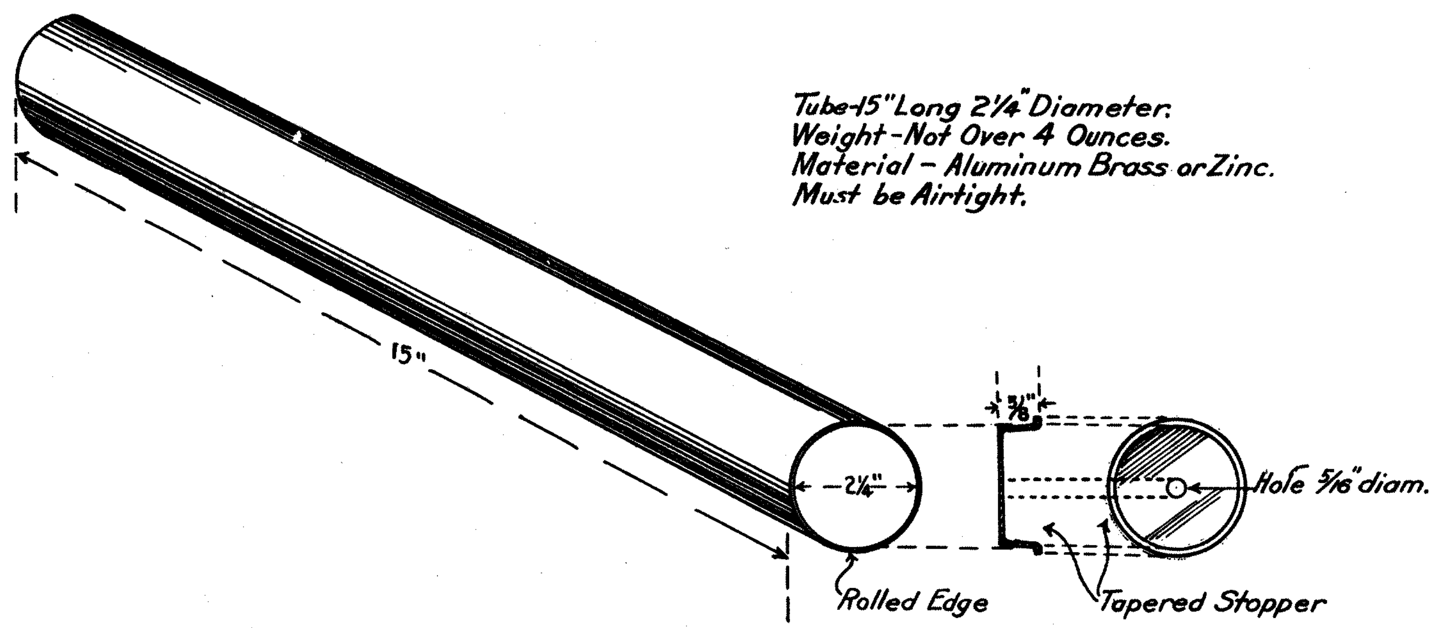



FIG. 12.

<u>Calibration of Duff Hygrometers</u>

Duff hygrometers before being put in use must be calibrated in the type of duff in which they are to be used. The calibration is carried out by placing the hygrometer in turn in each of a series of air-tight tubes containing duff at different moisture contents.

The calibration tube should be 15 inches long and 2¼ inches in diameter, made from light sheet brass, zinc or aluminum. (Fig. 12). It should be fitted with an air-tight stopper of the plug type, made from the same material. In the centre of the stopper a hole is cut the exact diameter of the hygrometer tube (usually 5/16 inch). This hole is fitted with a cork. Seven such tubes should be numbered as follows: 0, 5, 10, 15, 20, 30, 40, and the tare, or empty weight of each, including stopper and cork, marked thereon.

A quantity of top-layer duff at least sufficient to fill the seven calibration tubes is dried out to equilibrium (no further loss in weight) in a drying oven, at 212°F. Each tube is loosely packed with the dry duff as soon as it comes out of the oven, the stopper replaced, and the tube and contents weighed. The weight of oven-dry duff in each tube is thus obtained.

The weight of oven-dry duff in each tube being known, the weight of water necessary to produce a moisture content of 5, 10, 15, 20, 30, and 40 per cent in the different tubes can be computed. The amount of water necessary to produce the proper moisture content in each tube is inserted through the small hole in the stopper by means of a burette, and the cork replaced. All weights are recorded in grams, and the burette is graduated in cubic centimeters. One cubic centimeter of water weighs one gram.

After the water has been added, each tube is again carefully weighed. The weight of oven-dry duff which entered the tube and the weight of duff plus water being known, the exact weight of the water is found, and the percentage moisture content of the duff is obtained by dividing the weight of water by the weight of oven-dry duff. The tubes, stoppered air-tight, should be set aside for at least a day to allow the water to vaporize, diffuse throughout the tube, and be absorbed by the duff.

A uniform natural scale in degrees should be laid out with a protractor around the outer circumference of the dial of the duff hygrometer. The tube of the hygrometer is then carefully inserted its full length through the small hole in the stopper of calibration tube No. 0 after removing the cork. The indicator on the instrument is read at intervals after gently tapping and when its position ceases to change (usually in from four to eight hours), the reading of the natural scale is noted. The instrument is then withdrawn from tube No. 0 and inserted in tube No. 5. The operation is repeated for each of the seven tubes in ascending order and the scale readings noted. The instrument is then run through the tubes in reverse order from 40 to 0, the scale reading being noted in each case. The corks should, of course, be replaced in the holes in the stoppers as soon as the hygrometer is removed.

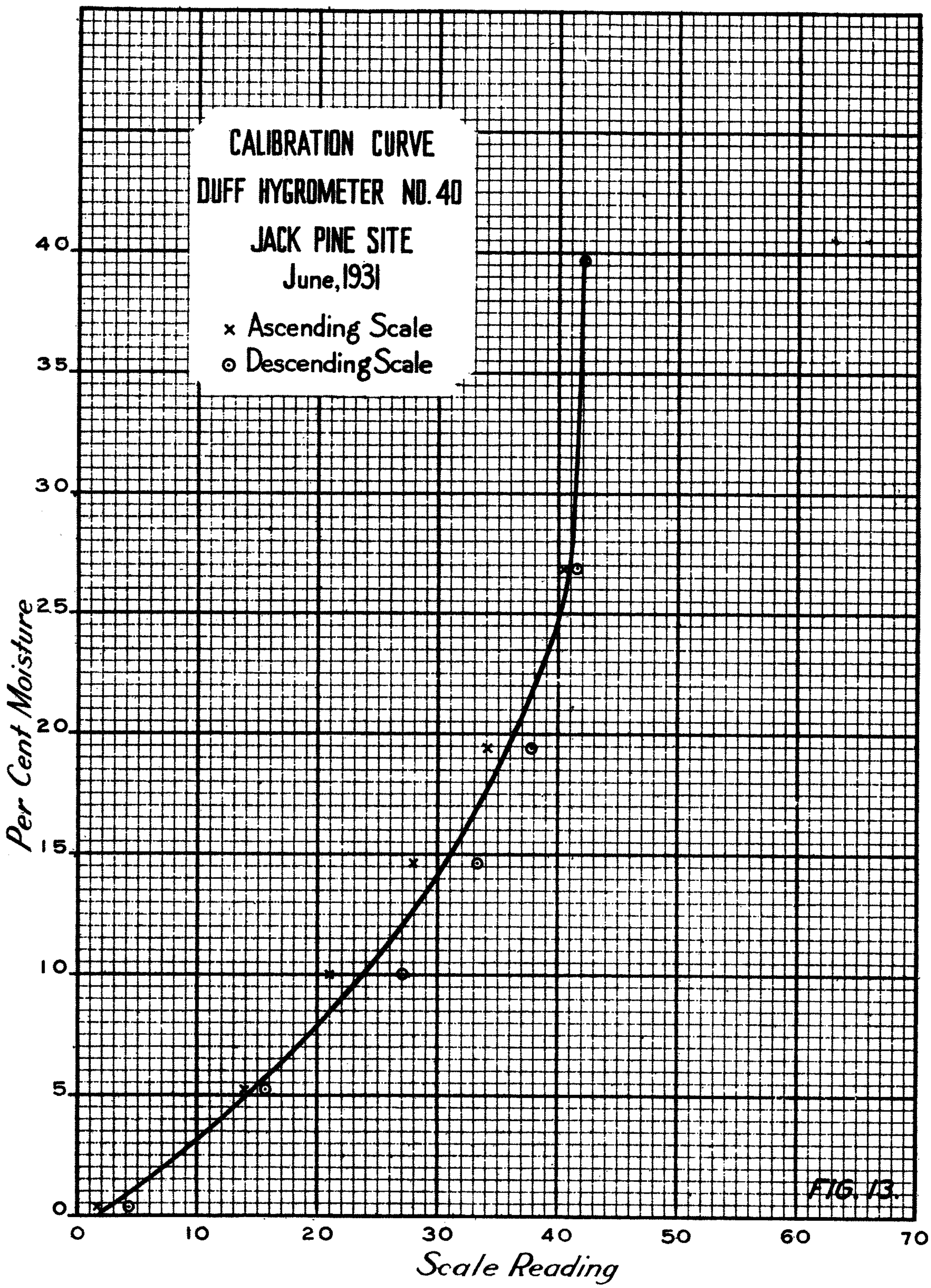

CALIBRATION CURVE
DUFF HYGROMETER NO. 40
JACK PINE SITE
June, 1931
× Ascending Scale
⊙ Descending Scale
Per Cent Moisture
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
Scale Reading

FIG. 13.

From the readings obtained it is possible to plot a curve of scale readings against moisture content. It will be found that the scale readings obtained when the hygrometer is going through the tubes in ascending order of moisture content are lower than the corresponding readings when it is going through in descending order (Fig. 13). This hysteresis, or lag, is no doubt due to disturbance in the physical structure in the fibres of the rattan strip. The same hysteresis was noted in determining the equilibrium moisture content of fuels at different relative humidities. (Figs. 4 and 5).

When the points have been plotted for the two sets of readings, an average curve is drawn through them. From this curve it is possible to obtain the natural scale reading for any moisture content from 0 to 40 per cent. A scale graduated in percentage moisture content may then be drawn on the dial. This completes the calibration of the duff hygrometer which is now ready to use. It is customary to use two instruments at each site, one serving as a check on the other. Two or more instruments may be calibrated almost as quickly as one, as they can follow one another through the calibration tubes. Each duff hygrometer should have a distinguishing number or letter printed on the dial for identification.

## Moisture Content of Full-layer Duff

It has been shown that the duff hygrometer will not measure moisture contents above 50 per cent. This, of course, is well above the range of inflammability, and the instrument will indicate with reasonable accuracy the point at which the fuels become inflammable and, at still lower moisture contents, the relative inflammability each day. Above 50 per cent moisture content of the duff or in most cases above 40 per cent the duff hygrometer gives no indication of the rate at which the forest materials are drying.

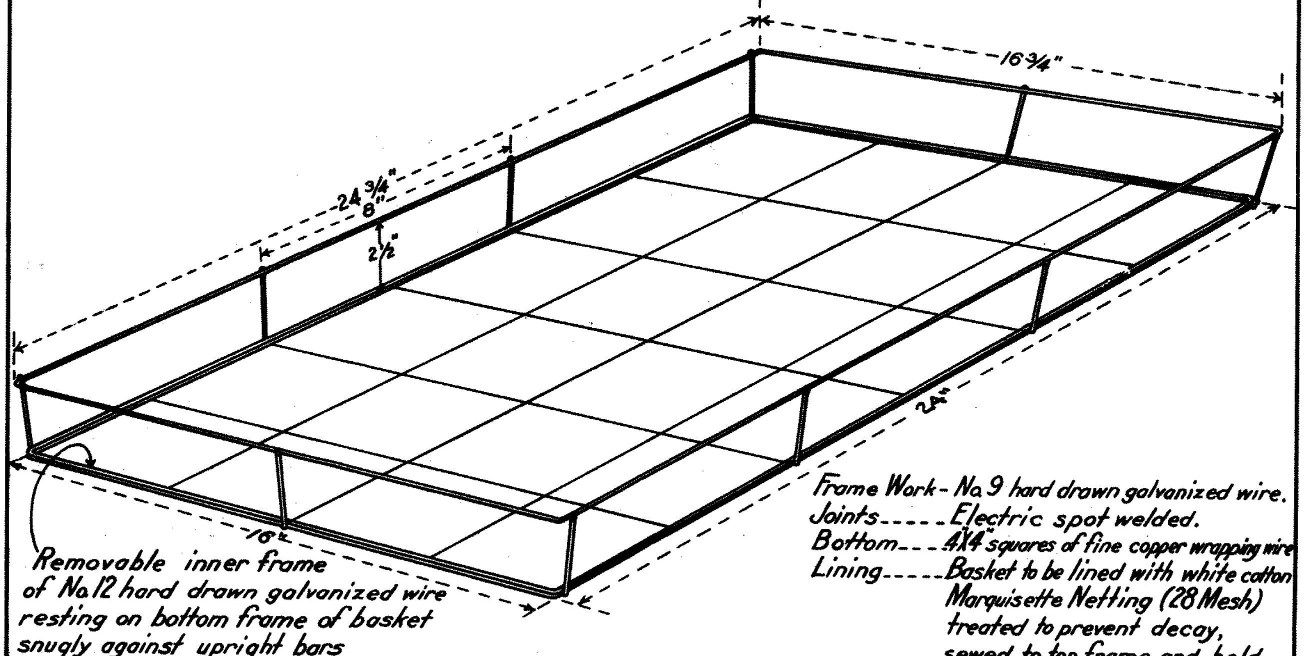
As full-layer duff in the pine types may absorb 250 per cent or more of its oven-dry weight in moisture, it is necessary to have some means of keeping track of these higher moisture contents. This is particularly necessary if it is desired to prepare rate-of-drying curves or tables based upon the weather factors, since it has been shown that the moisture in the lower levels of the duff influence the moisture content of the top layer in which fires start and spread.

After considerable experiment it was found that the most convenient way to measure the moisture content of full-layer duff was by the changes in weight of a standard tray or basket of the duff resting in natural position on the forest floor. This method, as will be shown later, is by no means free from objection, but, if used with proper allowance for its weak points, will give reasonably satisfactory results.

The standard tray, designed after considerable experiment, consists of a framework of No. 9, hard-drawn, galvanized wire. The bottom frame is 16 by 24 inches and the top frame is 16¾ by 24¾ inches. These frames are placed 2½ inches apart and uprights electric-spot-welded at each corner, 8 inches apart on the sides and ends, on the outside. The bottom is laced with fine copper wrapping wire to form 4 by 4 inch squares. A removable inner frame of No. 12, hard-drawn wire, the exact size of the bottom frame, rests upon the latter. The tray is

FIG. 14.

# Forest Litter Basket




Frame Work - No. 9 hard drawn galvanized wire.
Joints ----- Electric spot welded.
Bottom ---- 4X4" squares of fine copper wrapping wire
Lining ----- Basket to be lined with white cotton Marquisette Netting (28 Mesh) treated to prevent decay, sewed to top frame and held taut against bottom frame by removable inner frame which is sewed to bottom frame at intervals.

G.S.M. Feb. 1932

lined with cheesecloth or white cotton marquisette netting, which is sewed to the top frame and stretched taut by the removable inner frame which is sewed to the bottom frame at intervals. (Fig. 14). The netting should be soaked in creosote oil, allowed to dry in the air, and then heated for 5 hours in an oven at 212°F before the trays are used.

A section of duff the exact size of the bottom of the tray is carefully cut out of the forest floor, and deposited intact in the tray by the aid of a sheet of tin. The full-layer duff down to the level where the duff can be separated as a mat from the underlying humus is the section to be used. The tray containing the section of duff is placed in the space from which the duff was removed, and pegged down firmly at each corner by bent wire rods. The adjoining duff is carefully packed against the sides of the tray. When these precautions are taken, practically no unnatural drying occurs around the outer rim of the tray. The duff within the tray, having been restored to its original position in contact with the ground except for the intervening fine wire and netting, experiences practically the same variations in moisture content as the adjoining undisturbed duff.

The tray with its contents is weighed by lifting it carefully from its position by wires permanently attached to the four corners and suspending it from a spring scale attached to a tripod or other solid support placed immediately over the tray for protection. The daily weighings are performed as rapidly as possible, the tray immediately replaced in the duff, clamped down, and the adjacent duff packed against the sides.

The oven-dry weight of full-layer duff trays are determined as follows:-

Duplicate trays are established at each site, care being taken to see that the two duff sections are as nearly alike as possible in composition, thickness, and weight. After the sections have been placed in the two trays, both the latter are hung out in the sun and wind to dry, side by side, until they approximately reach equilibrium, or constant weight. At this point the moisture content of both trays will be approximately the same. The gross weight of both trays is then carefully noted. One tray (No. 1) is then installed in the place in the duff from which that particular section was removed. The other tray (no. 2) is taken to the field laboratory and dried out to equilibrium in a large oven at a temperature of 212°F without disturbing the contents. The weight at equilibrium will be the oven-dry weight of tray No. 2.

The net oven-dry weight of tray No. 1 may then be computed as follows:-

Let $x$ = Net oven-dry weight of tray No. 1
Let $a$ = grams of moisture in tray No. 1 at air-dry weight

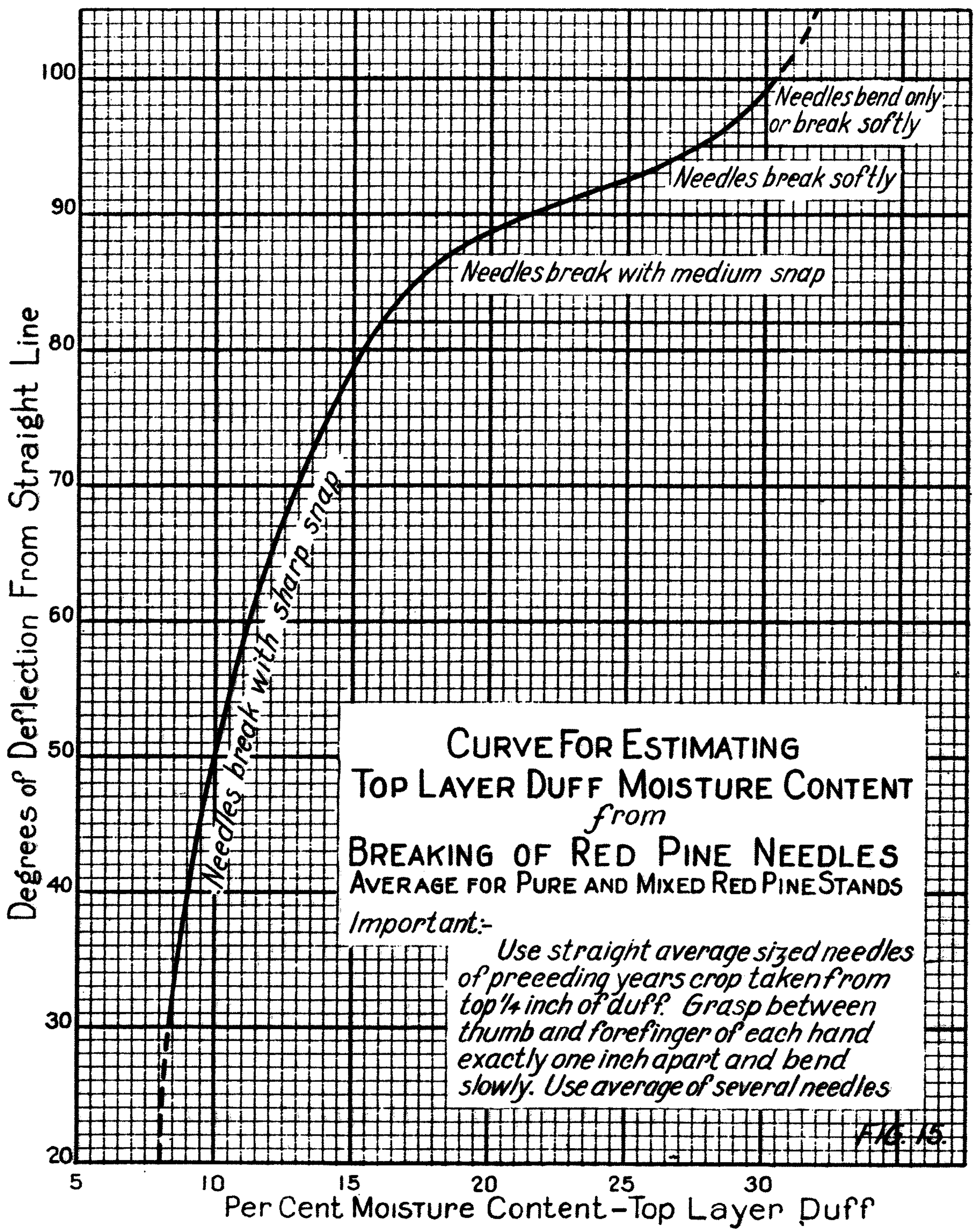
(1) then $x + a$ = net air-dry weight of tray No. 1

Let $y$ = net oven-dry weight of tray No. 2
Let $b$ = grams of moisture in tray No. 2 at air-dry weight

then $100a/x$ = % moisture content of tray No. 1 at air-dry weight

$100b/y$ = % " " " " No. 2 " " "

But $a/x = b/y$ and $a = bx/y$


Curve for Estimating
Top Layer Duff Moisture Content
from
Breaking of Red Pine Needles
Average for Pure and Mixed Red Pine Stands
Important:-
Use straight average sized needles of preeeding years crop taken from top 1/4 inch of duff. Grasp between thumb and forefinger of each hand exactly one inch apart and bend slowly. Use average of several needles
Needles bend only or break softly
Needles break softly
Needles break with medium snap
Needles break with sharp snap
Degrees of Deflection From Straight Line
100
90
80
70
60
50
40
30
20
5
10
15
20
25
30
Per Cent Moisture Content - Top Layer Duff
FIG. 15.

Substituting in (1) above we get

$$x = \frac{\text{Net air-dry weight tray No. 1 (known)}}{1 + b/y \quad \text{(known)}}$$

After oven-drying, tray No. 2 is installed in its place in the duff. When first set out both trays will require a good rain before they will give representative results. It will also be found that the oven-dried tray will not absorb moisture to quite the same extent as the tray whose oven-dry weight is computed. At the end of the season the oven-dry weight of both trays should again be determined by drying in the large oven.

The tare, or empty weight of all trays including netting and supporting wires, should be marked on an aluminium tag attached to each tray. The tag should also bear the distinguishing number of the tray.

Alongside each duff tray is placed an empty tray to catch the fall of fresh needles. This tray should be weighed from time to time and when the collection of fresh needles amounts to about 5 grams they should be removed and their oven-dry weight determined at the Laboratory. Careful record should be kept of the dates of removal and the weights, as these are required for adjusting the oven-dry weight of the duff tray at the end of the season.

All twigs which may fall upon the duff trays should be carefully removed each day before the trays are weighed.

## Estimating Moisture Content without Apparatus

A fair idea may be obtained of the moisture content of top-layer duff which contains red pine needles by the manner in which the latter break when bent. The red pine needle is grasped between the thumb and forefinger of each hand, spaced exactly one inch apart. The needle is then bent slowly and notes made of the angle at which it breaks, together with the manner of breaking. The angle of breaking is the estimated number of degrees the needle is deflected from a straight line. The relation between angle of breaking, manner of breaking, and top-layer duff moisture content, is shown in Fig. 15.

It is important that only straight needles from the preceding year's fall be used. These may be recognized by their slightly darker colour and should be taken from the top quarter-inch of duff. Freshly fallen needles are much too pliable, while very old needles are partially decayed and break too erratically.

This method is intended only as a guide to the probable moisture content of top-layer duff when no other means of measuring duff moisture are available.

## Time of Moisture-Content Observations

Routine observations of fuel moisture content should be made daily, centering on 8.00 a.m. and 4.00 p.m., except when rain is actually falling at those hours, in which event there is no object in taking readings. For the purpose of studying the effect of rainfall in adding moisture to the duff the best time to weigh the trays is about two hours after the rain. If the trays are weighed immediately after the rain stops, particularly in the case of brief rains in excess of one-tenth inch, the duff will contain considerable free water which has not had time to run off or be absorbed by the duff. Moisture-content readings taken at this time are likely to be too high. A certain amount of discretion should, therefore, be used in timing the readings. While 8.00 a.m. and 4.00 p.m. are mentioned as the hours for routine readings, it may be necessary to vary these slightly to allow one or two hours to follow the cessation of rain before the readings are taken.

As a rule, the 8.00 a.m. readings will be satisfactory for any rain which falls during the night and stops about 6.00 or 7.00 a.m. If the rain stops later than 7.00 a.m., it will be advisable to postpone the readings until about two hours after the rain stops. In the afternoon it may sometimes be necessary to take the readings at 3.00 p.m. or 5.00 p.m. to allow for about an hour after rain. When rain falls in the forenoon, followed by drying weather, it is advisable to take an auxiliary reading an hour or so after the rain stops to observe the effect of the rain before the duff starts to dry out. If drying conditions are good following the rain, as in the case of clear warm weather after a thunderstorm during the day, not more than an hour should elapse after the rain stops before the readings are taken. At other times, or in the early morning, an allowance of two hours is satisfactory.

The foregoing remarks apply to rainfall in excess of one-tenth inch. Below that amount practically none of the water will run off, and very little time need be allowed to lapse before the readings are taken.

## Analysis of Effect of Variation in Oven-dry Weight of Fuel-Moisture Trays

Change or variation from the initial oven-dry weight of sample trays of duff or litter in sites on the forest floor occurs owing to (a) progressive decomposition of the fuel which reduces the oven-dry weight and (b) the fall of new needles which becomes noticeable about the middle of August.

The effect of changing oven-dry weight upon the percentage of moisture content is shown as follows:-

Let o = the initial net oven-dry weight of duff
n = " new " " " " " after change
d = the loss in weight from decomposition
g = the gain " " " falling needles
m = the weight of moisture in the duff

Then, net field weight before change = $o + m$

$$m = (o + m) - o$$

Per cent moisture content before change = $\frac{m}{o}$

Net field weight after change = $o + g - d + m$

$$n = o + g - d$$

Per cent moisture content after change equals $\frac{m}{n} = \frac{m}{o + g - d}$

It will be observed that so long as d = g, the formula $\frac{(o + m) - o}{o}$ will give the correct moisture content in per cent of the oven-dry weight.

When, however, (g - d) differs much from zero, the records must be adjusted to compensate for the change in net oven-dry weight of the sample tray. Otherwise, the true percentage of moisture content at a given time based upon the oven-dry weight at that time will not be obtained.

Let us examine the average case of a mixed pine stand in 1930 where the average loss in weight of full-layer duff per day was .091 per cent of the initial oven-dry weight. At the end of 110 days the total loss would be .091 x 110 = 10 per cent of the initial oven-dry weight of, say, 250 grams or 25 grams less. The average gain from falling leaves at the end of the period is 15 per cent of 250, or 37 grams. Let us compute the moisture content arising from a net field weight of 450 grams at the beginning and then at the end of the period, assuming that none of the new needles have been picked off.

We have:

$$o = 250$$
$$g = 37$$
$$d = 25$$
$$n = 250 + 37 - 25 = 262$$
$$m = 450 - o, \text{ or } 450 - n$$

At the beginning the moisture content would be:-

$$\frac{450 - 250}{250} = 80 \text{ per cent}$$

At the end it would be:-

$$\frac{450 - 262}{262} = 72 \text{ per cent}$$

If the new needles had been picked off as they fell, or if no new needles had fallen up to the end of the period, we would have n = 250 - 25 = 225, and a field weight of 450 grams at the end of the period would mean a moisture content of $\frac{450 - 225}{225} = 100$ per cent.

It will thus be seen that field weighings of the same value may give radically different moisture contents depending on the time of the year, which largely governs the fall of new needles and, together with other factors, the amount of decomposition.

Let us consider this case another way. Assume that 200 grams of moisture are present in the duff sample from rain at the beginning and again at the end of the 110-day period.

At the beginning of the period

$$o = 250$$
$$m = 200$$
$$\text{moisture content} = \frac{200}{250} = 80 \text{ per cent of oven-dry weight}$$

At the end of the period

$$n = o + g - d = 250 + 37 - 25 = 262$$
$$m = 200$$
$$\text{Moisture content} = \frac{200}{262} = 76 \text{ per cent.}$$

If the new needles were picked off as they fell, or if no new needles fell, we would have at the end of the period:

$$n = o - d = 250 - 25 = 225$$
$$m = 200$$
$$\text{moisture content} = \frac{200}{225} = 89 \text{ per cent.}$$

It will be seen, therefore, that considerable care must be taken in order to secure reasonably accurate results from the basket or tray method of measuring the moisture content of duff or other fuels.

Two methods have been used to allow for the fall of the new needles:

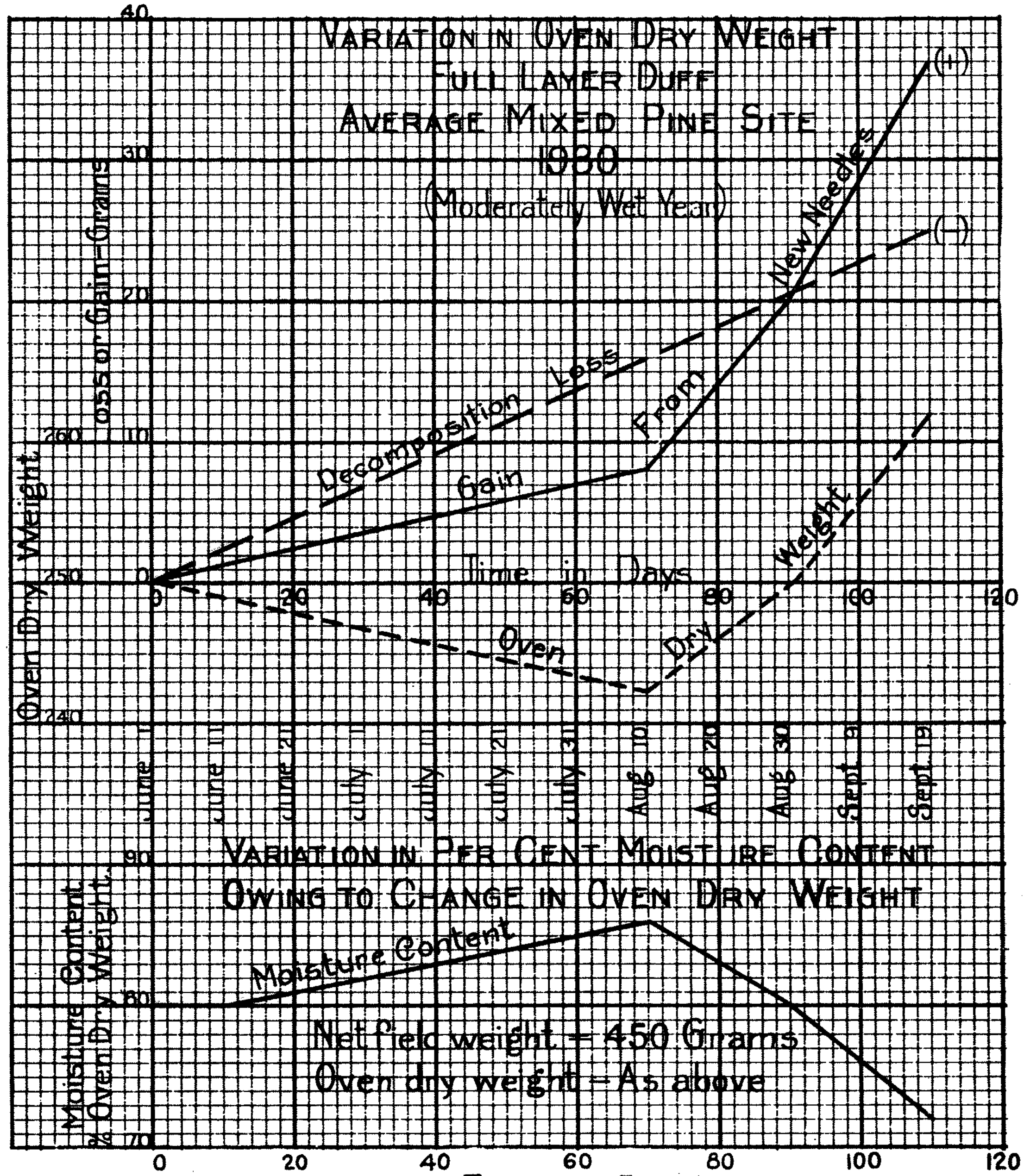
(1) The top of the duff basket or tray is laced with a two-inch mesh of fine thread. This intercepts the new needles as they fall, and they are easily removed from day to day. At the end of the season when the new oven-dry weight is determined and the loss from decomposition known, this loss is easily distributed proportionately throughout the whole season. This method is open to the objection that while it gives reasonably correct moisture contents for the sample tray, it does not fairly represent moisture conditions in the adjoining duff which received the fall of new needles.

(2) The litter tray is kept exposed to the fall of new needles, and a record of the rate of fall is obtained by removing and drying at intervals the new needles collected in one or more empty, standard trays exposed immediately adjacent to the duff tray. It is then possible to construct a graph of change of oven-dry weight against time from which it is possible to adjust the percentage of moisture content for each day during the period of the record.

A sample graph of this nature is shown in Figure 16. The initial net oven-dry weight of the duff is 250 grams. The net oven-dry weight at the end of 110 days is 262.

| | | |
|---|---|---|
| Between the beginning of the period and August 10th, | 8 | grams of needles fell. |
| Between August 10th and August 30th, | 12 | " " " " |
| Between August 30 and September 19th, | 17 | " " " " |

The total fall of needles during the period was thus 37 grams.



Variation in Oven Dry Weight
Full Layer Duff
Average Mixed Pine Site
1930
(Moderately Wet Year)
Loss or Gain-Grams
Oven Dry Weight
Decomposition Loss
Gain From New Needles
Oven Dry Weight
(+)
(−)
Time in Days
June 1
June 11
June 21
July 1
July 11
July 21
July 31
Aug 10
Aug 20
Aug 30
Sept 9
Sept 19
Variation in Per Cent Moisture Content
Owing to Change in Oven Dry Weight
Moisture Content
Net field weight = 450 Grams
Oven dry weight = As above
Moisture Content
% Oven Dry Weight
0
20
40
60
80
100
120
Time in Days


FIG. 16.

The loss from decomposition is, therefore, 250 - (262 - 37) = 25 grams, which is assumed to be distributed uniformly throughout the 110 days.

The correction to oven-dry weight for decomposition is minus, and that for fall of needles is plus. The net correction is, therefore, (needle fall minus decomposition loss), applied according to sign. This value can be obtained for any day of the period from the graphs of these two values by taking the intercept between the two curves. The corrected oven-dry weight for each day of the period is shown in Figure 16.

All field records of moisture content based on the daily weighing of a sample tray must be adjusted for variation in oven-dry weight before the results are used in the preparation of rate-of-drying curves or tables. Failure to make such adjustment may introduce very considerable errors into the results, as has been shown previously, and as is illustrated by the graph at the bottom of Figure 16. Here, with a given net field weight of 450 grams, the per-cent moisture content based on the oven-dry weight varies all the way from72 to 86. If no correction had been made, the reduction would show 80 per cent throughout the season. These values are for a moderately wet year. In a dry year the decomposition would be less and the fall of needles probably greater, so that towards the end of the season, if no adjustment were made, the per-cent moisture content readings would be very much too high.

Another source of error, which unfortunately cannot be readily corrected, arises from the unequal weight and varying absorptive power of the contents of standard litter trays. In pine types, a tray sample of full-layer duff is of the same horizontal dimensions as the standard tray, but the depth, of course, varies with the thickness of the mat of needles, it being impracticable to separate this mat at any other horizon than the one where it readily parts from the underlying humus. The net weights of standard trays of full-layer duff in the same type may thus differ by 50 grams or more, while the surface area is the same in each case. It, therefore, follows that when only the surface is wet, either from dew or small amounts of rain, the moisture content of a light tray will be greater than that shown by a heavier one.

While the foregoing adjustments do not fully compensate for all possible sources of error in this method of determining moisture content, it is felt that any further attempt at refinement would needlessly complicate matters and would be unjustified in view of the fact that it is difficult to make field weighings to within an accuracy of plus or minus 5 grams. The difference in absorptive power of duff samples in the same type also renders too great a refinement unnecessary, and, if the source of large cumulative errors is taken care of, the average of a number of sites will probably not be far from correct.

It will be seen from the foregoing that the permanent sample tray method of determining the moisture content of duff is by no means ideal. Nevertheless it is the only ready and practical method so far devised for keeping track of all ranges of moisture content in full-layer duff, and if used with a proper knowledge of its weak points will give reasonably accurate results.

Twig Samples

It will be observed from the accompanying loss-in-weight table (Page 48) that loss from decomposition in twigs is very much less than in duff. This loss is so small that as a rule no adjustment need be made. It is also possible to prepare samples of uniform oven-dry weight and if the tray is laced with thread it is also possible to remove any fresh leaves or twigs which may fall.

It has been found in a large number of sites that the twigs lying on top of the duff reach inflammability at about the same time as top-layer duff, and at about the same moisture content. A tray of twigs, therefore, provides a very practical means of obtaining an idea of when a particular site reaches inflammability. It is, however, not so reliable for registering daily variation in the zones of inflammability. Nevertheless, for untrained men, a properly prepared tray of twigs affords a very much better guide to the inflammability of the forest than does a tray of full-layer duff alone.

For each tray, 600 grams oven-dry weight of twigs are gathered from the forest floor. Only twigs which show little or no evidence of decay should be taken, that is, those which have fallen recently. They should be in the proportion of 300 grams of material ranging uniformly from 1/8 to 1/4 inch in diameter, and 300 grams ranging from 1/4 to 1/2 inch in diameter, and 6 to 8 inches long.

This material should be carefully dried to equilibrium at a temperature of 212°F in an oven with free circulation of air between the inside and outside. Six hundred grams oven-dry weight should then be distributed evenly over the bottom of the standard litter tray. If this tray is then placed upon the duff in the site, the moisture content of the contents determined by periodic weighing will, after the first soaking rain, give a fair idea of the moisture content of the top-layer duff.

The twig method is recommended for the practical use of field men rather than for research purposes. Experiments are now under way on the use of untreated match splints for this purpose.

Loss in Weight per Day
of Forest-Fire Fuels Due to Decomposition
Measured in Percentage of Initial Oven-Dry Weight

| Type of Fuel | Site | | 1929 | 1930 | 1931 | Average of All Years |
|---|---|---|---|---|---|---|
| Twigs up to ½ inch diameter lying on forest floor | P.W., P.R. | (Rapid-drying) | | .046 | .021 | .033 |
| | P.W., P.R. | (Slow-drying) | .044 | .062 | .025 | .044 |
| | P.R. | (Rapid-drying) | | .028 | .013 | .020 |
| | P.J., P.R., P.W. | (Medium-drying) | | | .029 | .029 |
| | Mixed Hardwoods, P.W., P.R. | (Medium-drying) | .025 | | | .025 |
| | Cut-over, P.J., P.R., P.W. | | | .016 | .021 | .018 |
| Average of All Sites | | | .034 | .038 | .022 | .031 |
| Full-layer duff in contact with underlying humus | P.W., P.R. | (Rapid-drying) | | .073 | .024 | .048 |
| | P.W., P.R. | (Slow-drying) | .065 | .110 | .030 | .068 |
| | P.R. | (Rapid-drying) | | .122 | .041 | .082 |
| | P.J., P.R., P.W. | (Medium-drying) | | .059 | .096 | .078 |
| | Mixed Hardwoods, P.W., P.R. | (Medium-drying) | .050 | | | .050 |
| Average of All Sites | | | .057 | .091 | .048 | .065 |
| Top 5/8 inch Needles on forest floor | P.R. | (Rapid-drying) | | .067 | .067 | .067 |
| Bracken in Trays, 6 in. above forest floor | Mixed Hardwoods, P.W., P.R. | (Medium-drying) | .040 | | | .040 |
| | Cut-over, P.J., P.R., P.W. | | | .083 | .082 | .082 |
| Average of All Fuels | | | .045 | .067 | .041 | .051 |

Note:- P.W. = white pine; P.R. = red pine; P.J. = Jack pine

The above experiments all fell within the period May 24th to September 24th.

This loss in weight of duff is usually more than compensated for by the fall of new needles which becomes noticeable about August 15.

In the mixed red and white pine sites, the average gain during 110 days prior to September 24 was 15 per cent of initial oven-dry weight.

In pure red pine sites the average gain during 78 days prior to September 18 was 19 per cent.

In mixed jack, red, and white pine in 1931 the gain was only 5 per cent in the same 78 days.

Oven-drying of Fuels

The moisture content of any material is usually expressed as the fraction or percentage of its weight under stated conditions. Where possible, the moisture content is best expressed as a fraction of the bone-dry weight of the material. In a laboratory with proper equipment, the bone-dry weight could be determined by keeping the material in a chamber with the air at normal temperature and zero per cent relative humidity, until it ceased to lose weight. This method would require many days for the material to reach a bone-dry condition.

For practical field use it is necessary to adopt an alternative method for determining oven-dry weight which will not require complicated apparatus and which will speed up the operation. In the present study all oven-dry weights are defined as the equilibrium or minimum weight reached by the material when retained at a temperature of 212°F in a double-walled oven where the air is free to circulate through the oven at atmospheric pressure. It is found that the air in such an oven maintained at a temperature of 212°F will have a relative humidity of about 1 per cent at normal outside air temperature and humidity. With the air in the room at 60°F and a relative humidity of 80 per cent, the relative humidity in the oven at a temperature of 212°F will be in the vicinity of 1.5 per cent. From tests made by oven-drying samples at oven humidities as low as 0.5 per cent, allowing them to reabsorb moisture and again drying them at an oven humidity of 1.5 per cent, it does not appear that for practical purposes there is any appreciable difference in the oven-dry weights.

It has been found that when pine needles which have been dried to equilibrium at 80°F and 0 per cent relative humidity, are again brought to equilibrium at a temperature of 212°F and a relative humidity of under 1 per cent, they lose approximately a further 2 per cent of their weight. This loss arises from the driving off at 212°F of volatile matter other than water. In the case of pine twigs the additional loss is somewhat less.

The following study of the effect of oven-drying pure red pine duff at different temperatures is of interest.

After 2½ hours' drying at 170°F the loss in weight was 21.4 per cent

A further 2 hours' drying at 212°F produced an additional loss of 2.7 per cent

A further 2 hours' drying at 240°F produced an additional loss of 0.5 per cent

Percentages of loss in this instance are based on the net weight of duff before drying.

It will be seen, therefore, that in order to secure low oven humidities and rapid drying without expensive equipment, it is necessary to use an oven temperature in the vicinity of 212°F. In doing this a certain amount of volatile matter other than water is given off. However, if 212°F is adopted as the standard oven temperature and all samples are dried to equilibrium at that temperature, the results can be accurately compared.

## Field Laboratory Equipment

### Drying Ovens

A suitable drying oven for small samples is one designed for a two-burner kerosene cooking stove. It should have double walls and top and a close fitting door. The heated air entering at the bottom is distributed by a baffle plate, rises and passes through a series of holes along the tops of the inside walls of the double ends, passes downwards between the walls and escapes through a series of holes near the bottom of the outer end walls. A hole one inch in diameter is cut in the centre of the top to carry a cork, through which a thermometer is inserted to measure oven temperature. The temperature of the oven is easily regulated by adjusting the burners of the oil stove. When the room temperature is fairly constant and free from drafts, the temperature of the oven is easily maintained within two degrees of the desired value, without any automatic thermostatic control.

For drying the contents of standard duff trays without disturbing them, a larger oven is necessary. Such an oven must be specially built as none can be found on the market. A design is shown in Fig. 17.

This oven has been submitted to careful tests, and the temperature throughout the interior was never found to vary more than two degrees from that indicated by the thermometer in the top. The holes in the bottom are cut to fit the two-burner oil stove.

### Scales

For field weighing of standard trays, a 2,000-gram vertical spring scale graduated in 10-gram divisions is used. This scale can be easily read to within 5 grams. With prolonged use the spring in this scale undergoes a change and an index correction must be applied. The scale should be carefully checked throughout its range at the beginning of the season and once a month thereafter by the use of standard gram weights. If necessary a curve may be drawn showing the index correction at each point on the scale. With this precaution the readings of the scale may be relied upon for an accuracy within 5 grams. This scale is manufactured by John Chatillon and Sons, New York.

For weighing standard trays of fuels in the laboratory a 1500 or 2000 gram balance weighing to an accuracy of 0.1 gram is required. For small samples an auxiliary balance with a capacity of about 400 grams and an accuracy of 0.01 gram should be used.

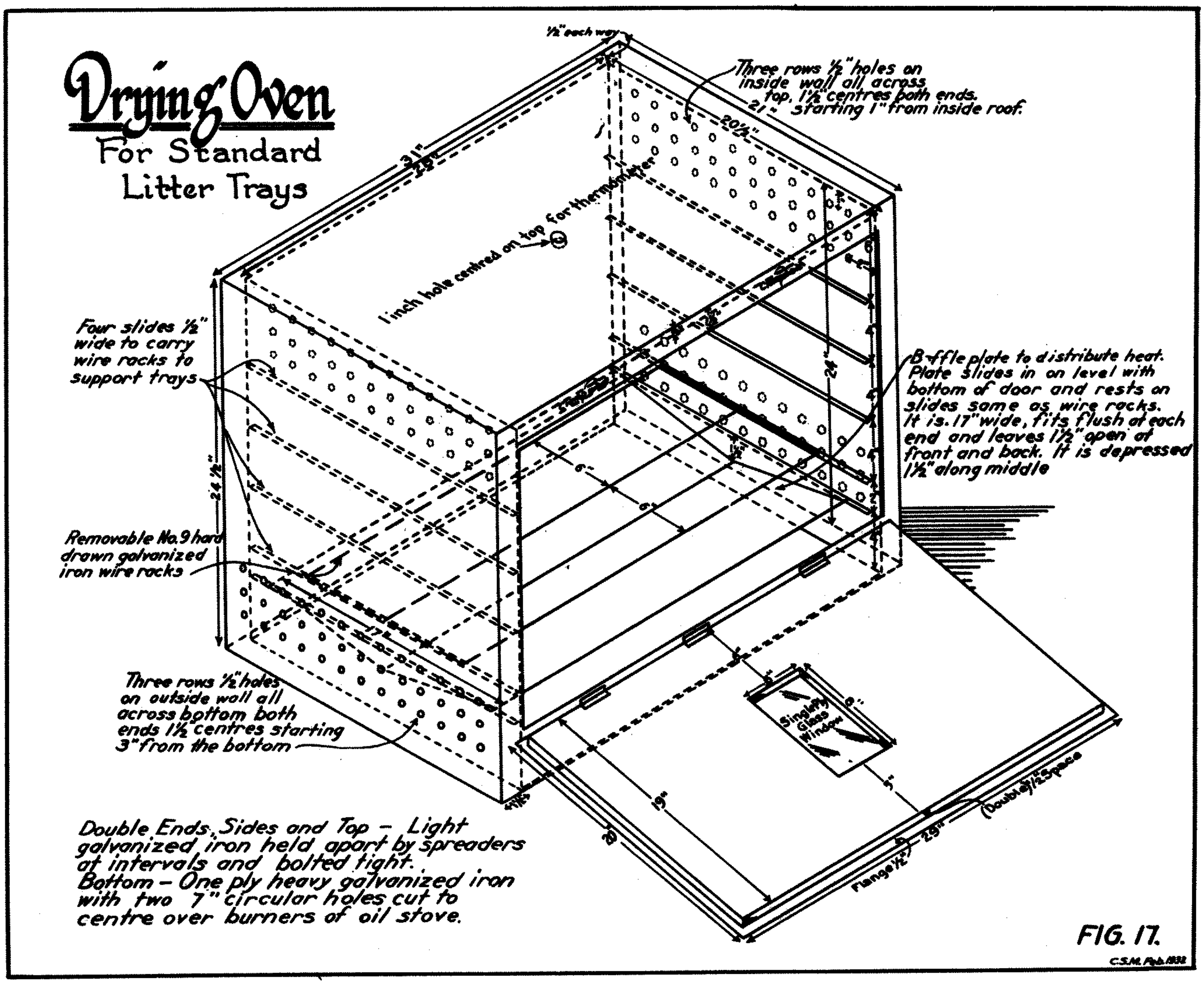

Drying Oven
For Standard
Litter Trays
½" each way
31"
29¾"
Three rows ½" holes on inside wall all across top, 1½" centres both ends. starting 1" from inside roof.
21"
20½"
1 inch hole centred on top for thermometer
Four slides ½" wide to carry wire racks to support trays
24½"
24"
Baffle plate to distribute heat. Plate slides in on level with bottom of door and rests on slides same as wire racks. It is 17" wide, fits flush at each end and leaves 1½" open at front and back. It is depressed 1½" along middle
6"
6"
Removable No. 9 hard drawn galvanized iron wire racks
17"
Three rows ½" holes on outside wall all across bottom both ends 1½" centres starting 3" from the bottom
Single Ply Glass Window
6"
8"
19"
20
29"
Flange ½"
(Double) ½" Space
Double Ends, Sides and Top – Light galvanized iron held apart by spreaders at intervals and bolted tight.
Bottom – One ply heavy galvanized iron with two 7" circular holes cut to centre over burners of oil stove.
C.S.M. Feb. 1932

FIG. 17.

## Measurement of Weather Factors

It has already been pointed out that weather observations for use in connection with forest-fire hazard studies should be taken in what may be termed a standard site, that is, one which will give representative results for a large area. Observations taken under forest cover or in small sheltered clearings will be representative only of such sites. The ideal site is a fairly level, cleared area several acres in extent, so situated that it has a normal exposure to winds from all directions.

### Wind Velocity

It has been shown that wind velocity is an important factor in the rate of spread of fire, the rate of spread increasing approximately as the square of the wind velocity.

Wind velocity is best measured with a three-cup type of electrical anemometer designed by Mr. John Patterson, Director of the Meteorological Service of Canada, which has been adopted as standard weather-station equipment by the United States and Canada. The anemometer should be erected at a height well above the tree-tops and free from eddy currents arising from the roofs of buildings or unusual topographical features.

When no anemometer is available it is advisable to estimate the wind velocity. Hitherto this has been done by the aid of the Beaufort Wind Scale. It has been found, however, that the Beaufort Scale is not suitable for measuring wind velocities in forest areas, the tendency being to estimate the velocities much too high. This probably arises from the fact that velocity equivalents in the Beaufort scale are based upon such phenomena as drifting smoke, movement of paper on the ground, and tree movements, all of which have presumably been observed in the open away from forest areas.

An attempt has been made to develop a wind-scale suitable for forest use. Some 200 observations of wind velocity were made just above the tree-tops in a mixedwood stand of large-toothed aspen and red pine. The tree movements in the crown-cover were observed and correlated with the wind velocity. These data were collected and worked up by Mr. H. W. Beall, B.Sc.F. (Figs. 18 and 19).

When this scale is used in types similar to the one from which it was designed, it gives an accuracy of within one mile per hour at the lower velocities and well within two miles per hour at the upper ranges.

For best results in using the scale the tree movements should be observed for a period of five minutes if the wind is gusty. The behaviour of both the softwoods and the hardwoods during the gusts and also during the lulls should be noted. Four values can then be taken from the chart (Fig. 19), and their average will give the average wind-velocity for the five-minute period.

Routine readings of wind velocity should be made at 8.00 a.m., noon, and 5.00 p.m.

# Beall Wind Scale

*For Estimating Steady Wind in Mixedwood Stand 45-50 Feet High, 0.7 Canopy*

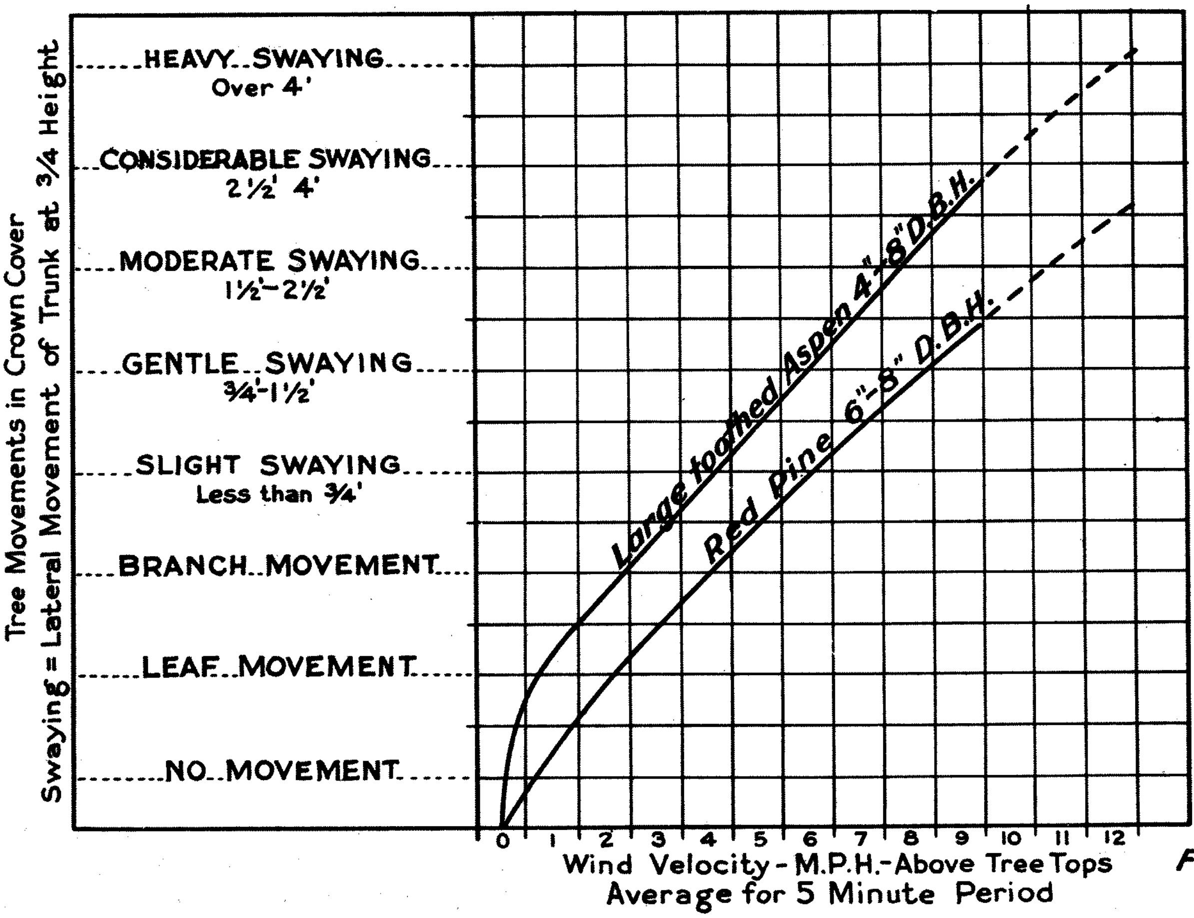



*FIG. 18.*

# Beall Wind Scale

*For Estimating Gusty Wind in Mixedwood Stand 45–50 Feet High, 0.7 Canopy*

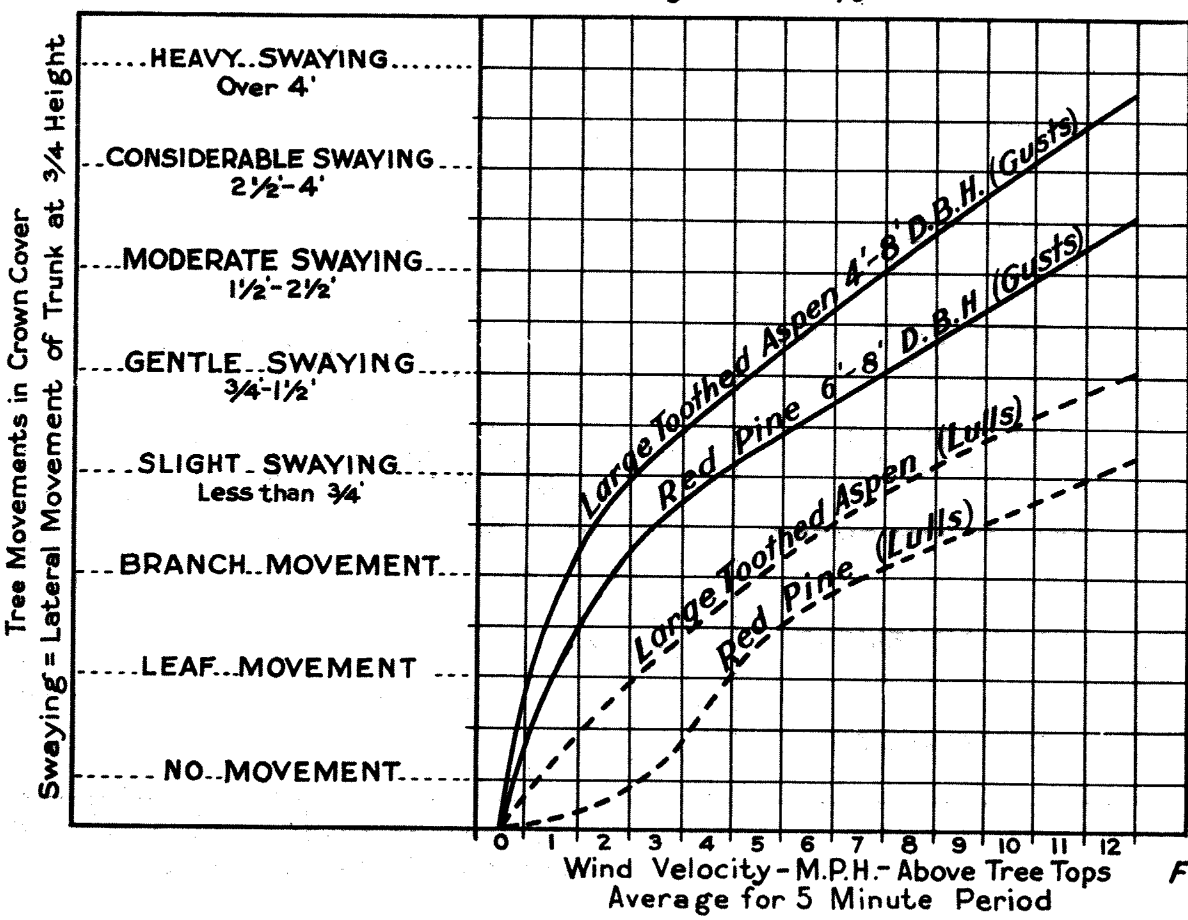



FIG. 19.

Rainfall

For the purposes of these studies, rainfall should, when possible, be measured with a recording rain-gauge reading to 0.01 inch. The tilting bucket type of recording rain-gauge is satisfactory. This instrument records by means of a tilting bucket the time during which each one-hundredth of an inch falls. It thus records the duration and intensity of the rain as well as the time, all of which are important factors in this study.

If no automatic rain-gauge is available, measurements should be made with an ordinary rain-gauge of five inches in diameter. This gauge should be read morning and evening, and a note made at each reading of the time the rain started and stopped.

Relative Humidity

A continuous record of relative humidity is obtained with a hygrograph; or, preferably, both temperature and humidity may be recorded on a hygro-thermograph. A satisfactory type of the latter instrument is one which uses a double chart. The temperature is recorded on the upper half of the chart and the relative humidity on the lower half. With this type of instrument there is no danger either of confusing the two curves, or of difficulty in making allowance for the two pens passing each other, as in instruments which record both temperature and humidity on a single chart.

## The Hygro-Thermograph

There are several makes of double-chart hygro-thermographs on the market. In the present study the instrument manufactured by Negretti and Zambra, London, England, has been found to give excellent results and has been adopted as standard equipment. A description of this instrument and directions for using it follow.

The Principle

This instrument gives a continuous record of relative humidity and temperature. The changes in relative humidity are measured by the changes in length of a bundle of specially treated human hair. A rise in the relative humidity of the air causes the hair to expand or lengthen; a decrease in humidity causes the hair to shrink in length. These changes in length are communicated direct by a level to the pen arm, and the pen traces a curve of the relative humidity on the chart on a cylinder which is rotated once a week by a clock inside the drum.

The temperature is measured by a spiral metallic thermometer, and the record registered on the chart by a temperature pen arm. Both charts are printed on the same sheet of paper; the upper chart is the temperature chart, and the lower the humidity chart.

To Unpack and Set Up

For shipment the two pen arms are carefully fastened with string to the vertical rod seen through the glass window, to prevent damage in transit. Unlock and swing back the cover of the chart case and carefully cut the strings holding the pen arms to the vertical rod. This vertical rod is for the purpose of swinging the pens clear of the chart.

To Wind Clock

The clock is inside the chart drum. Remove the cover of the drum by simply lifting on the knob. The clock key will then be seen, and the direction in which it is to be turned is indicated by an arrow. To set the clock to the proper time, turn the whole drum carrying the chart until the pens rest over the proper day and hour on the chart. This simply corresponds to turning the hands of a clock, and does not injure the instrument.

Care of the Pens

A bottle of purple ink is supplied with each instrument. Partially fill the reservoir of each pen. A slip of thin hard paper may be drawn between the points of the pens to start the flow of the ink. Do not allow dust or particles of paper to collect on the pens, and see that no ink remains on their exterior surfaces. If the pens become corroded or clogged up with dried ink so that they do not register satisfactorily, they may be removed from the pen arms and carefully washed in warm water, special care being taken not to bend or distort the delicate points. The pens can be removed by simply sliding them off the end of the pen arm.

When the pens have been filled ready for use and the chart drum brought to the proper day and hour under the pens, swing in the vertical rod, thus allowing the pens to come in contact with the chart.

To Change Charts

The charts should be changed, the clock wound, and the pens supplied with ink each Monday morning. Swing the pens clear of the chart. Remove the cover of the chart drum and unscrew the centre nut holding down the drum. Lift out the drum and release the clamp holding the chart in place. Put on a new chart, being sure that its lower edge rests upon the projecting rim at the bottom of the drum. Replace drum on its shaft and lower it gently until the gears at the bottom interlock.

Before putting on a new chart, write the month, date, and year after the word "Monday" on the chart, e.g., Monday, May 3/25. If this means of identification is omitted, the charts will be useless for further study. File the charts carefully for future reference.

Adjustments

The part of the instrument most likely to require adjustment is the relative-humidity element. This part is liable to get out of adjustment through the air stretching under tension and never fully returning to its original length. Throughout the season, the instrument should be checked at least once a week with a sling psychrometer. However, unless the humidity readings show a continued tendency to error in one direction, no adjustment should be attempted. As a rule, no adjustment should be attempted for an error of less than five per cent. The check readings with the sling psychrometer, together with the chart readings and time, should be noted on a memo card. When the chart is removed these check readings should be written on the chart, so that in interpreting the chart the proper corrections may be applied.

When adjustment of the humidity element is necessary, it is effected by increasing or decreasing the tension on the bundle of hair. If the instrument reads too high, increase the tension; if too low, reduce the tension. This may be done by turning the screw which will be found inside the chart case.

There is one other adjustment of the humidity element; this, however, should seldom be required. After an instrument has been in use for a long time, it may be found that, due to certain gradual changes in the structure of the hairs, the pen, if set to read a low humidity correctly, will be found to be badly in error for high humidities, and vice versa; that is, it may be found that the pen will not remain in adjustment throughout the entire range of the scale. When this happens, it is necessary to change the leverage on the pen arm, in order to vary the speed with which the pen will move across the chart. At the right-hand end of the bundle of hairs will be found a small pin or lever, one end of which passes through the axle to which the pen arm is attached and is held in place by a small set screw. By loosening this set screw, the length of the pin acting as a lever may be varied. If the pen moves too slowly, shorten the leverage; if too rapidly, lengthen it. This is a very painstaking adjustment and may require many trials before the desired results are obtained. For this reason, it should not be resorted to unless the readings at the extremes of the scale are badly in error.

Sling Psychrometer Check Readings

To get accurate results in standardizing or checking with the sling psychrometer, care must be taken to see that the wick on the wet bulb is clean. If the wick becomes impregnated with solids from evaporated water, or becomes soiled from contact with the hands, oil, or grease, the instrument will not give correct results until a new wick is put on. Wet the wick, preferably in distilled or rain water, and whirl until the maximum difference in readings between the wet and dry bulbs is attained. The instrument should be used in the shade as far as possible, as bright sunshine has the effect of causing the temperature of the dry bulb to rise suddenly after whirling stops. Under such conditions, it is difficult to avoid getting too low a reading of relative humidity, unless the dry bulb is read very rapidly after whirling stops. The relative humidity is obtained by consulting a set of relative humidity tables which is supplied with each sling psychrometer or by reference to the chart in Fig. 6A.

Temperature Element

The adjustment of the temperature element is very simple and is effected by turning the screw which regulates the tension of the spiral metallic thermometer. The temperature check readings may be taken from the dry-bulb reading of the sling psychrometer. Both the hygro-thermograph and the psychrometer should be in the shade at the time the comparison is made, as the direct rays of the sun on a thermometer produce fictitious temperatures.

Shelters

The hygro-thermograph should be housed outside in a ventilated shelter designed for the purpose. Unless the instrument is thus exposed to free circulation of outside air, it will not register representative results. Results obtained by setting up the instrument indoors, even with the windows open, will differ greatly from those obtained outside.

## Relative Humidity Value to be Used

For the purpose of these studies the value of relative humidity used is the average for the lowest two-hour period each day. This is readily obtained from a hygrograph chart by means of a piece of tracing paper. Draw a horizontal line on the paper exactly two hours long according to scale. Move this line down the U-shaped curve until the two ends touch the curve. Estimate the position of a horizontal line which will bisect the area of the curve which falls below the line on the paper. This will give the average humidity for the two-hour period.

## Relative Humidity by Sling Psychrometer

At any points not equipped with automatic instruments, the relative humidity can be determined with a sling psychrometer and set of relative humidity tables or the chart in Fig. 6A. It has been found by correlating a large number of two-hour minimum readings with time of occurrence, that if sling psychrometer readings are taken at 2.30 and 4.30 p.m. daily and the lowest reading adopted, the result will give the average two-hour minimum for the day in question on about 90 per cent of the days with an accuracy of within 4 per cent. Sling psychrometer readings should, therefore, be taken at 2.30 and 4.30 p.m. each day, and the lowest of these readings adopted for that day. If the precautions previously outlined under the heading Sling Psychrometer Check Readings are observed, very satisfactory results will be obtained.

The hours of 2.30 p.m. and 4.30 p.m. are expressed in Eastern Standard Time and are, therefore, correct only for points on approximately the same meridian of longitude as the Petawawa Forest Experiment Station (Long. 77°27' W). It will be shown in a later publication that 2.10 and 4.10 p.m. Local Mean Time are the best hours at any point regardless of longitude. It will, however, be sufficiently correct for all practical purposes if the readings are taken at 2.25 p.m. and 4.25 p.m. Eastern Standard Time at all points in the time belt west of the 75th meridian of longitude and at 1.55 p.m. and 3.55 p.m. Eastern Standard Time at all points in the time belt east of this standard meridian.

## Rate of Evaporation

The Livingstone porous cup atmometer has been adopted as standard in these studies for measuring rate of evaporation. In this instrument the water is evaporated from the surface of a white porous clay sphere or cup which is mounted over a bottle of distilled water. At the beginning of a period the bottle is filled up to a mark on the neck. At the end of the period the bottle is again filled up to the mark, the quantity inserted being measured with a burette graduated in cubic centimeters. The number of cubic centimeters inserted is the amount of evaporation during the period. This value before being used must be multiplied by a coefficient marked on the neck of the instrument by the manufacturer, the purpose of which is to reduce the readings of all instruments to a common basis.

The instrument must be fitted with a rain-correcting mounting to prevent rain from passing through the porous cup and adding to the water in the bottle, thus impairing the readings. A satisfactory mounting is shown in Fig. 20. The bulb or expansion in the valve is made by sealing the ends of a section of large glass tubing around the smaller tubes at the inlet and outlet. Water from the bottle may pass freely by displacing the mercury into the expansion. Rain cannot get down the long tube as it is counterbalanced by the column of mercury which rises in the short arm.

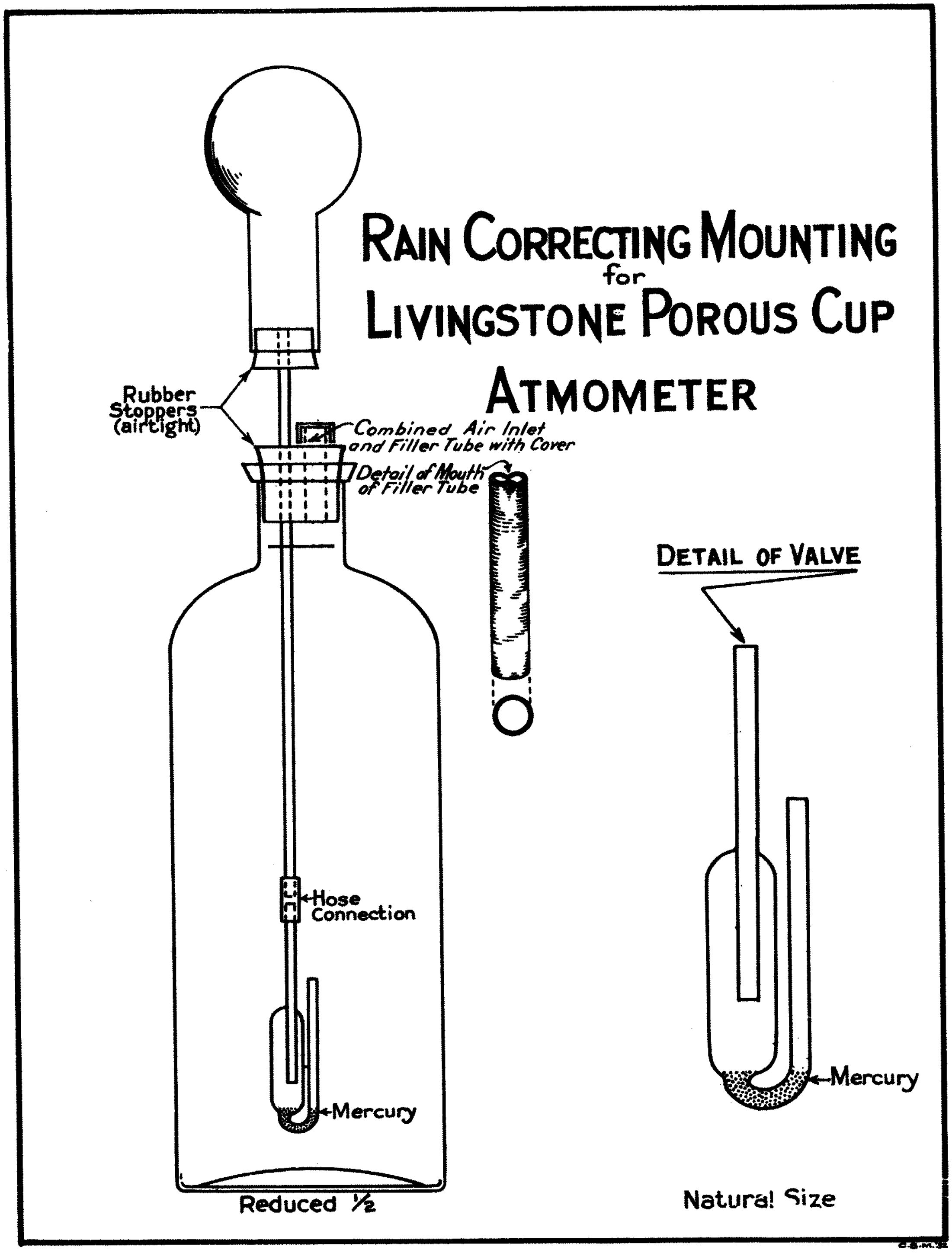

RAIN CORRECTING MOUNTING
for
LIVINGSTONE POROUS CUP
ATMOMETER
Rubber
Stoppers
(airtight)
Combined Air Inlet
and Filler Tube with Cover
Detail of Mouth
of Filler Tube
DETAIL OF VALVE
Hose
Connection
Mercury
Mercury
Reduced ½
Natural Size

FIG. 20.

The porous cups should be immersed in distilled water for twenty-four hours before they are put in use in order that all air in the pores may be displaced by water. The instrument is assembled as follows:-

Invert the porous cup and fill it with water. Place sufficient mercury in the valve so that when all the mercury is forced into the short arm it will form a column slightly over one inch high. Invert the tube, allowing the mercury to run into what is normally the upper end of the expansion. Attach a piece of rubber tubing to the short arm and force in sufficient water to completely fill the entire tube system, the water being prevented from running out by placing the finger over the lower end of the tube. With the glass tube still inverted, pinch the rubber tube, remove the finger from the end of the glass tube, and force the rubber stopper and tube firmly into the neck of the inverted porous cup. Any air bubbles will rise to the top of the U. Carefully bring the apparatus to the upright position in such a way that any air bubbles will escape through the short arm. Remove the piece of rubber tubing from the short arm and insert the glass tubing and valve into the bottle, which should be nearly full of distilled water. Force the rubber stopper firmly into the neck of the bottle.

To make sure that no air bubbles remain in the system, place the finger over the end of the filler tube, and carefully invert the bottle in such a manner that the mercury runs back into the expansion. Rock the instrument back and forth a few times and allow any air-bubbles to escape through the short arm. This should be repeated at intervals during the season to ensure that no air accumulates in the top of the clay sphere. Set the instrument upright, add sufficient water to bring the level to the mark on the neck of the bottle, and the instrument is ready for use.

In use, the instrument should be set up four feet from the ground. A suitable stand can be made by driving into the ground two boards, four inches wide and four inches apart, and at their upper ends nailing on sides and bottom to form a small box or socket three inches deep to hold the bottle.

Pure distilled water only should be used in the Livingstone atmometer. Clean rain water may be used if no distilled water is available. Ordinary water contains solids in solution, and these will clog the pores in the clay sphere if such water is used. In purchasing distilled water from garages, make sure that it does not contain traces of battery acid.

If dust or other foreign matter accumulates on the sphere, it may be removed without disturbing the instrument by gently scrubbing with distilled water only, using a fine nail-brush.

Used in the open, this instrument generally gives satisfactory results for a whole season, but the clay sphere should be renewed each spring. A very slight frost will break the instrument, and it should be taken indoors at night if frost threatens.

When a number of instruments are operated at different points, it is well to have an extra one by which all may be compared. The extra instrument may be operated side by side for a few days with each instrument in turn and their relative behaviour observed.

Evaporation Pan

While the Livingstone atmometer has been adopted as standard in these studies for measuring rate of evaporation, very fair results may be obtained with a small pan of water of standard dimensions exposed in a standard manner.

The investigation of this method of measuring rate of evaporation, extending over a period of three years, was begun by using a pan made from the lower half of a five-pound baking powder tin. The dimensions were 5.2 inches in diameter and 3.5 inches in height. All comparisons between the Livingstone atmometer and the evaporation pan have been based on this size of pan. The level of the water is accurately set by a fine-pointed wire using the well known principle of the hook gauge. Two types of pan with dimensions are shown in Fig. 21.

In use the pan is placed on a stand built as follows:-

Drive a post solidly into the ground to a height of 3 feet 9 inches. On top of this, nail a truly horizontal board shelf 14 inches square. Set the evaporation pan at the exact centre of the square and drive a few small nails around the edge of the pan to hold it in place.

Over the pan place a screen made as follows:- Make a cylinder 12 inches in diameter and 6 inches high of chicken wire of exactly ½ inch mesh. On top of this fasten, either by soldering or tying at the edge with fine wire, a cover made from a flat sheet of tin 12½ inches in diameter with ¼ inch turned down vertically around the outer edge, leaving the net diameter of the cover 12 inches. Place this screen over the pan and centre the two carefully. A few small nails should be driven into the shelf around the edge of the screen to guide it into place and keep it from sliding off with the wind.

The screen and evaporation pan should be painted inside and out a shade of gray made up of 20 parts white paint to 1 part black paint.

It is important that the foregoing specifications be followed closely in all details. Any slight variation in dimensions, or in the shade of gray paint, may materially alter the performance of the apparatus. It is most important that the flat cover of the screen be exactly six inches above the bottom of the pan.

The shelter should be set up in the open where there is a maximum circulation of air. If it is used in a protected site where there is not full exposure to the wind, the readings will not be comparable with those from the Livingstone atmometer.

Remove the wire screen and fill the pan with water from a measuring glass until the fine wire point barely shows as a pin point on the surface, so that a few drops more will submerge the point. Read the measuring glass, then add the few drops necessary to just cause the point to disappear and again read the glass. The two readings should be nearly the same and their average will be the true reading of the amount of evaporation since the pan was last filled. Replace the screen, and the apparatus is ready for use.

# Design of Evaporation Pans

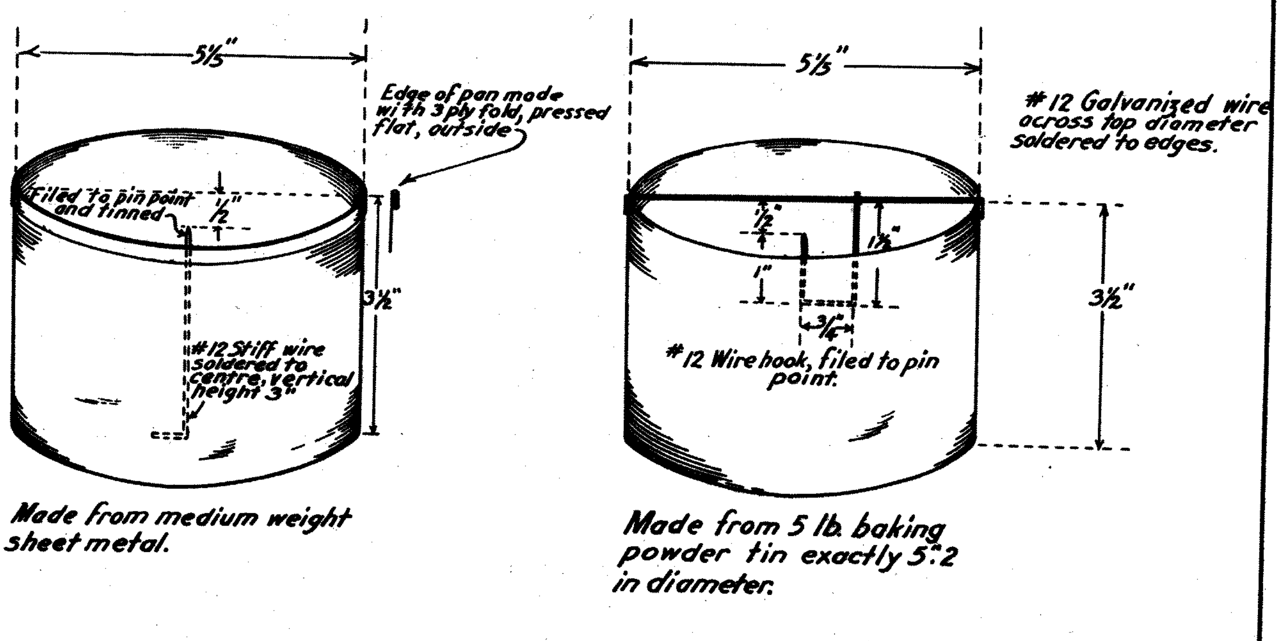



FIG. 21.

The amount of water added may be measured with a glass burette or graduate in cubic centimeters. A 100-cubic-centimeter graduate is perhaps the most convenient, although not quite so accurate as the burette. The evaporation from the pan is nearly double that from the Livingstone atmometer, and if a burette of convenient size is used it may have to be filled several times. A very long burette is awkward to handle and easily broken.

To reduce the readings in cubic centimeters from the pan to the same basis as the Livingstone atmometer, they must be multiplied by the coefficient 0.40.

It is not intended that this pan method should replace the Livingstone atmometer for research purposes. It is, however, very suitable for the use of unskilled operators. It is inexpensive, durable, does not get out of order, and is not affected by moderate frost. If a pan and an atmometer are operated at the same site, the rate of evaporation per day as indicated by the two methods after coefficients are applied will seldom differ by more than three units.

It is intended to further develop this pan method by using a five-inch pan and measuring the rate of evaporation in hundredths of an inch, using the measuring glass of a five-inch rain-gauge. It will, however, take some time to secure data to work out the necessary coefficients.

## Time of Evaporation Readings

In these studies, for the purpose of preparing rate-of-drying curves or tables, the value of evaporation used is the evening reading, which gives the total evaporation for the previous twenty-four hours. For research purposes it is advisable to read the evaporation instruments in the early morning and again shortly before sunset. The sum of these two readings gives the evaporation value, which influences the rate of drying between one afternoon and the next. For practical purposes a single reading of evaporation each day taken just before sunset is sufficient.

## Analysis of Data and Preparation of Forest-Fire Hazard Tables

The methods by which fuel moisture and weather data are worked up into the form of fire-hazard tables are somewhat involved and will be dealt with under a separate report.

## PUBLICATIONS IN THIS SERIES



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Copies of these publications may be obtained from:

Forest Fire Research Institute
Department of Forestry and Rural Development
Sir Guy Carleton Building
161 Laurier Ave., West
Ottawa 4, Canada