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A Study of the Carbonization of some Tasmanian Timbers

By

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and

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1.—INTRODUCTION

Most experiments on the carbonization of wood in closed retorts have been designed for the study of the distillates, and thus have usually been made on wood of irregular sizes, the temperature in the retort, but not in the wood, being measured. If it is a question of the production of good charcoal, it is desirable to know as much as possible about the progress of the carbonization reaction in the wood and the effect on the charcoal of such factors as log size and external temperature conditions. The present experiments have been made from this point of view on single cylindrical logs of varying sizes under controlled external conditions.

It is well known that the carbonization reaction (¹) is exothermic and sets in at a temperature in the neighbourhood of 300° C. Gaseous and condensible distillates are given off during the reaction with a violence which will be shown below to vary greatly with the size of the log and the external conditions. If the heating is continued after the initial violent reaction is over, there is a steady, slow, evolution of volatile matter, accompanied by shrinkage of the charcoal, but there is no considerable change in the structure or hardness of the charcoal. Thus the final product may be regarded as produced in two stages, (I.) the carbonization reaction, and (II.) subsequent heating. In the experiments described below these two stages will be separated as far as possible. In §§ 2-4 the external temperature conditions are arranged so that their influence is small compared with that of the heat generated by the carbonization reaction itself, while cases in which the influence of external conditions predominates are considered in § 5. In §§ 2, 3, 5 only the temperatures developed are discussed, their influence on the nature of the charcoal is considered in § 8. The yield and nature of the species charcoal produced under low temperature conditions is given in §§ 4 and 8. The effect of continued heating after the carbonization reaction is over is considered in §§ 6-8.

The whole of §§ 2-9 refer exclusively to 'dry' wood, i.e., to wood of moisture content of, say, 25 per cent or less; the behaviour of green wood is discussed in § 10.

(¹) Throughout this paper 'carbonization reaction' is taken to refer to the violent initial reaction and not to the complete reaction giving the final charcoal. It is also convenient to speak of it as setting in at a definite temperature.

2.—THE TEMPERATURES ATTAINED DURING THE CARBONIZATION REACTION

In the present experiments wood is carbonized in single cylindrical pieces of varying diameters up to 7″ and of lengths up to 2′. These are heated in an electrically heated retort, and the temperatures at various points of the log are measured by thermocouples. The gases given off are passed through a water-cooled condenser, and the quantities of condensate and of non-condensible gas are measured. The heating has usually been made in two stages, the first at a low current which gives a constant temperature of about 200° C. through the log after twelve hours; the current is then increased giving a slowly rising external temperature. This procedure has been adopted partly for convenience and partly to eliminate the effect of moisture and to treat all logs as far as possible on a standard basis.

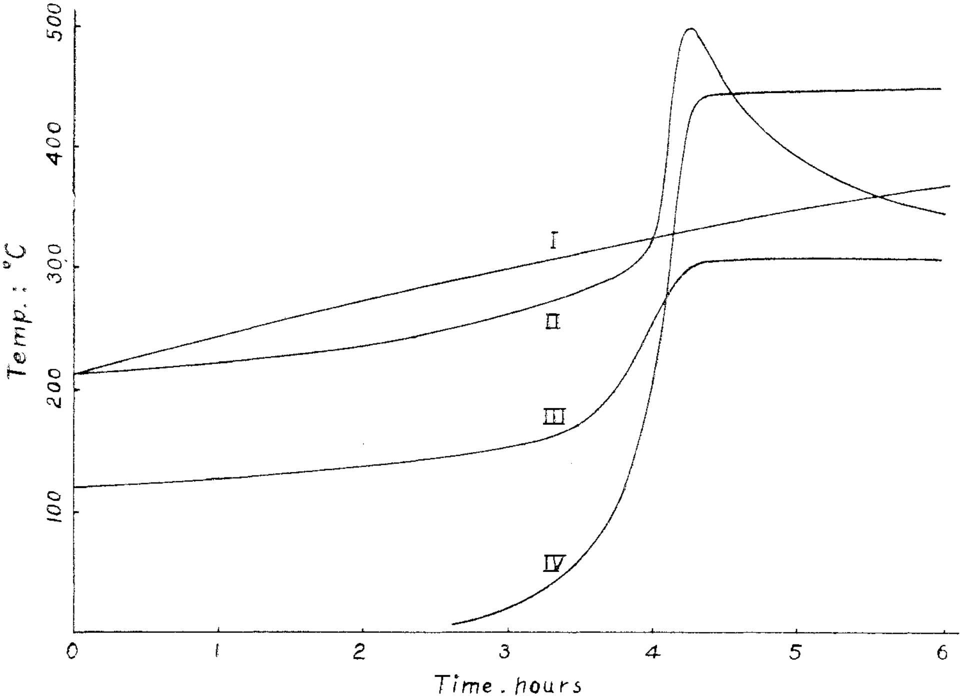

Fig. 1.

Typical behaviour under these conditions is shown in fig. 1 for a 6″ diameter log of *E. linearis*, 13″ long, weight 13·74 lb., moisture content 18·5 per cent. Curve I shows the retort temperature and Curve II the temperature at a point on the axis of the cylinder 6″ from one end. The volumes of condensate and non-condensible gas given off are shown in Curves III and IV respectively; the total volume of condensate is 2·88 litres, and the total volume of gas given off is 452 litres. Although the observed temperatures might be expected to be affected by cracking in the wood or in the charcoal, the curves of fig. 1 are quite characteristic and surprisingly reproducible; as an example of this the maximum temperatures recorded in five experiments under the same conditions on 6″ logs of *E. linearis* were 502, 500, 500, 495, 492° C.

It will be seen that, when the external temperature reaches a value in the neighbourhood of 300° C., the rate of flow of distillate increases and evolution of gas commences; these both fall off very sharply at the conclusion of the reaction. The most interesting point about fig. 1 is the magnitude and steepness of the temperature rise; these are greatest at the centre of the log, but they do not vary much over the cross-section of the log, except close to the surface; this matter is discussed in detail in § 3.

If the external temperature of the log is raised steadily, instead of in two stages as above, there is very little difference in the behaviour provided the external rate of increase of temperature is of the order of those in fig. 1. In the early stages of the heating the temperature at the centre of the log will lag considerably behind the outside temperature, so that, when carbonization commences, the rise of the internal temperature to its maximum will be steeper than that shown in fig. 1. The maximum temperature attained is unaffected.

TABLE I

Diameter (inches).	7	4·5	3	2·6	2·2	1·8	1·2
Max Temp. (° C.)	500	500	468	435	401	351	321
Max. Rate of Increase of Temp. (° C./min.)	30	30	21	16	8	4	1·2
Average Volatile (%)	25	26	29	30	32	39	42

For the same external conditions the maximum temperature attained in the log varies with the diameter of the log, this effect is shown in Table I for *E. linearis* carbonized under the standard conditions described above. The cause of this effect cannot be settled until a more careful study of the thermal constants of charcoal has been made, it must be due in part at least to the relatively greater loss of heat from the smaller logs to the surroundings. The volatile contents given in Table I, and the nature of the charcoal produced, will be discussed in §§ 6 and 8. Of course not only the maximum temperatures, but also the maximum rates of increase of temperature and of flow of distillate, in fact the violence of the reaction, increase with increase of diameter.

3.—THE PROGRESS OF CARBONIZATION THROUGH THE LOG

Carbonization will set in at the point of the log which first attains the carbonization temperature; heat will be liberated at this point, and will be propagated through the log. For a long cylinder with external temperature constant along its length, the propagation will be radially inwards; this behaviour is approximated to if the outside of the log attains its carbonization temperature while the internal temperature is still fairly low. If there is not much temperature variation within the log, as is the case under the standard conditions of § 2, carbonization will commence at the hottest point of the length of the log and there will be a combination of radial and longitudinal propagation. This is shown in fig. 2 for a 6″ log of *E. linearis*. In this experiment the temperature at the centre of the retort was a little higher than at the ends, and the temperature maximum is propagated from the centre towards the ends.

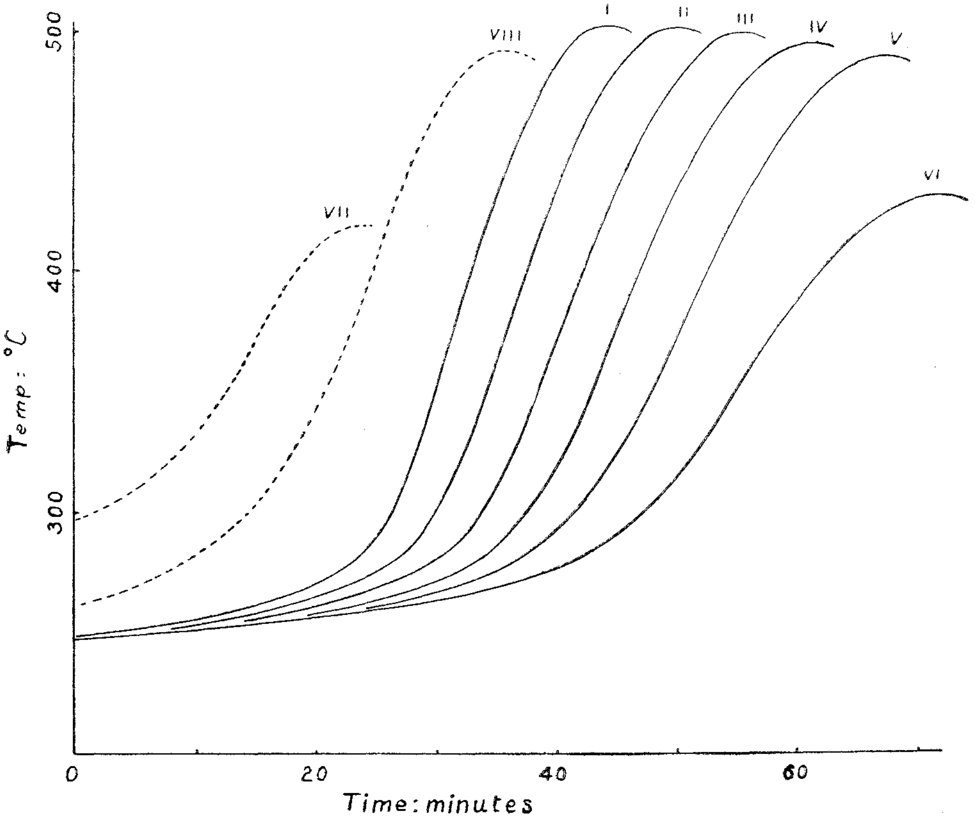

Fig. 2.

Curves I-VI show respectively portions of the temperature curves for points on the axis of the log distant 5½″, 4½″, 3½″, 2½″, 1½″, ½″ from the end of the log; the isothermals can be seen to be travelling at a rate of about 1″ in 4 minutes. Curve VII shows the temperature at a point just under the surface and 5½″ from the end; the temperature rise here is less in magnitude, and earlier, than at the corresponding point on the axis. Curve VIII shows the temperature at a point ¾″ below the surface and 5½″ from the end; here, already, the maximum temperature attained is almost equal to that on the axis.

4.—Behaviour of Different Timbers

Behaviour similar to that of fig. 1 for *E. linearis* is shown by all the timbers which have been examined. The variation between different species carbonized under the same conditions is shown in Table II. All timbers have been carbonized in cylinders 3″ diameter and 15″ long under the standard conditions referred to in § 2, the external rate of increase of temperature being about 0·5° C. per minute. The first column shows the maximum temperature attained on the axis, the second column its maximum rate of increase in ° C. per minute. The third column shows the maximum rate of flow of distillate expressed as the percentage given off per minute of the total distillate (from the dry wood). The yields of charcoal, stated as the amount of dry charcoal of 15 per cent volatile (¹) as a percentage of the dry weight of wood, are given in the last column. The number of experiments on which Table II is based varies from about 30 on *E. linearis* and *E. regnans*, which, with *Acacia dealbata*, have been most carefully studied, to one or two for the less important timbers. It is seen from Table II that all timbers examined give yields of the same order. Figures obtained for the same timber carbonized in different ways, and for green and dry timber (corrected as above for differences in volatile content), do not differ by more than two or three per cent.

TABLE II

Common Name.	Botanical Name.	Max. Temp. ° C.	Max. Rate of Increase of Temp.	Max. Rate of Flow of Distillate.	Yield. %
White Peppermint	*Eucalyptus linearis*	455	22	2·1	37
Black Peppermint	*E salicifolia*	468	19	2·2	39
Stringybark	*E. obliqua*	472	22	2·1	36
Swamp Gum	*E. regnans*	465	19	2·2	36
White Gum	*E. viminalis*	463	14	2·8	36
Cabbage Gum	*E. pauciflora*	468	18	1·6	38
Black Gum	*E ovata*	455	9	2·1	38
Blue Gum	*E. globulus*	435	16	1·3	36
Gum-topped Stringybark	*E. gigantea*	428	8	1·5	39
Victorian Red Gum	*E. rostrata*	364	3·5	0·9	43
Silver Wattle	*Acacia dealbata*	450	20	3·1	34
Black Wattle	*A. decurrens*	450	25	2·8	34
Prickly Wattle	*A verticillata*	465	20	3·0	35
Blackwood	*A. melanoxylon*	442	12	2·0	38
Myrtle	*Nothofagus Cunninghamii*	430	8	2·0	35
She Oak	*Casuarina quadrivalvis*	450	13	2·1	36
Bull Oak	*C suberosa*	441	13	2·0	34
Sassafras	*Atherosperma moschatum*	440	12	2·2	34
Manuka	*Melaleuca* sp.	440	15	1·8	32
Wild Pear	*Pomaderris apetala*	414	8	3·4	34
Currijong	*Plagianthus sidoides*	460	24	3·5	34
Redwood	*Beyeria viscosa*	405	8	3·0	37
Honeysuckle	*Banksia marginata*	366	4	1·8	37
Dogwood	*Bedfordia salicina*	410	7	1·5	35
Tea Tree	*Leptospermum* sp.	....	...	....	32
Leatherwood	*Eucryphia Billardieri*	....	....	....	35
Celerytop Pine	*Pkyllocladus rhomboidalis*	....	....	....	35

It will be seen that, while all timbers behave in the same way, there are considerable differences in the violence of the reaction. Roughly it may be said that high values of the maximum temperature, the maximum rate of temperature rise, and the maximum rate of flow of distillate are associated and form a 'violent' reaction; while low values, again, are associated to form a 'quiet' reaction. Thus

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(¹) The final temperature in these experiments is 350° C., and the volatile contents range from 25-35 per cent. The yields have all been reduced to 15 per cent volatile in Table II.

E. linearis shows a typical violent reaction, and *E. rostrata* (1) a very quiet one. A quiet reaction usually gives a solid charcoal in very large pieces; the charcoal from a violent reaction is much more broken. This question will be returned to later.

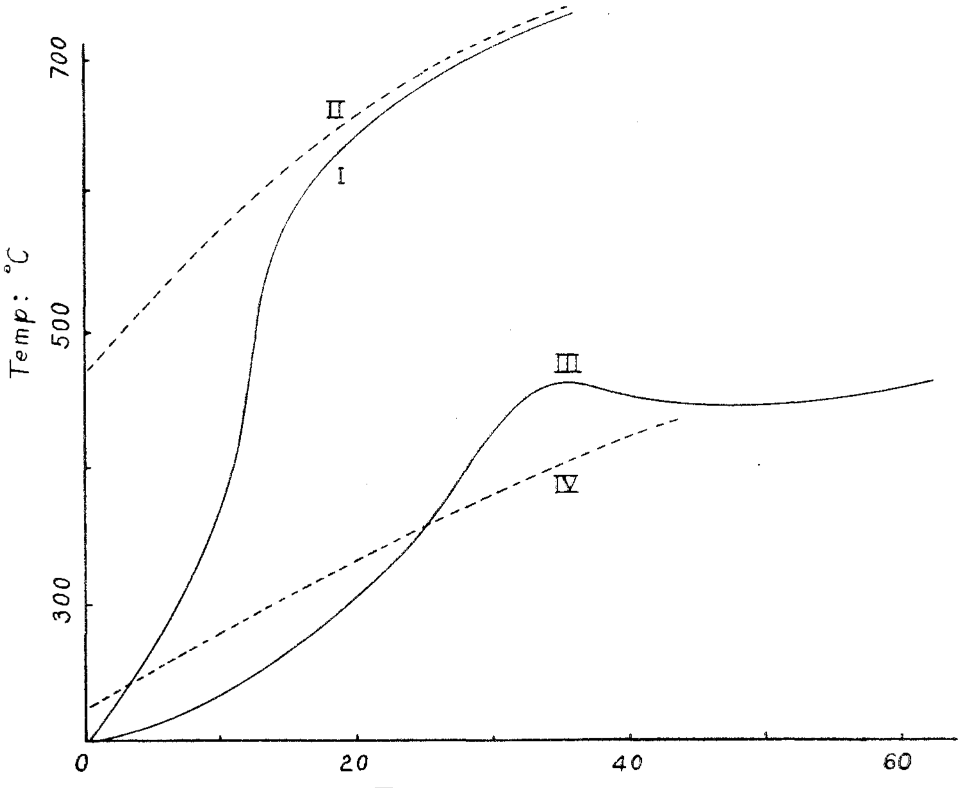

Fig. 3.

5.—The Temperature in a Rapidly Heated Log

If the external temperature of a log is raised rapidly, instead of slowly as in §§ 2 and 3, there is still an increase of temperature in the interior due to the heat evolved during carbonization, but the maximum of fig. 1 is less pronounced or disappears. This is illustrated in fig. 3 for *E. linearis* 2″ diameter; Curves I and III are portions of the axial temperature curves corresponding to the external temperature variations II and IV respectively. In Curve I the characteristic maximum of fig. 1 has disappeared; in Curve III it is still present, though not so marked. The maximum rates of increase of temperature are greater than those of Table I, their values being about 80° C. per minute for Curve I and 20° C. per minute for Curve II.

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(1) Throughout this paper *E. rostrata* refers to a single piece of the timber sent from the mainland. It is discussed partly because the standard testing charcoal is made from this timber, and partly because of its extreme behaviour. The piece in question is apparently from the centre of a large tree and is very short in fibre.

6.—THE VOLATILE CONTENT

It has been shown above that the violence of the carbonisation reaction may vary very considerably with the log size and the external temperature conditions. If the charcoal is allowed to cool immediately the reaction is over, it would be expected that the product of a violent reaction would have a lower volatile content than the product of a quiet reaction. That this is the case is shown by the figures of Table I; in all cases the retort is allowed to cool (taking about 12 hours) after the reaction is over. Under these conditions, also, there is a noticeable variation of volatile content over the cross-section of the timber; its value is least at the centre and greatest at the outside. Typical figures for a 6″ log of *E. linearis* are: outside 31 per cent, mid-radius 26 per cent, on the axis 24 per cent. Reasons for this variation are presumably (I.) that the temperature rise is greatest on the axis, (II.) that the wood on the axis is the last to carbonize, and (III.) that cooling is slower on the axis.

If heating is continued after the carbonization reaction is over, volatile matter continues to be evolved slowly, so that, if the charcoal is given a period of soaking at a final temperature, before being allowed to cool, the volatile content of the final product may be expected to depend on this temperature as well as on the violence of the reaction. Clearly, if the final temperature is less than the maximum temperature attained during carbonization, the resulting volatile content will depend in a complicated manner on both these temperatures and cannot be correlated with either. However, if the final temperature is greater than the maximum temperature (¹), and the charcoal is given a reasonable soaking at the final temperature, a volatile content is attained which depends mainly on the final temperature. The following figures for *E. linearis* with a final temperature of 500° C. will illustrate

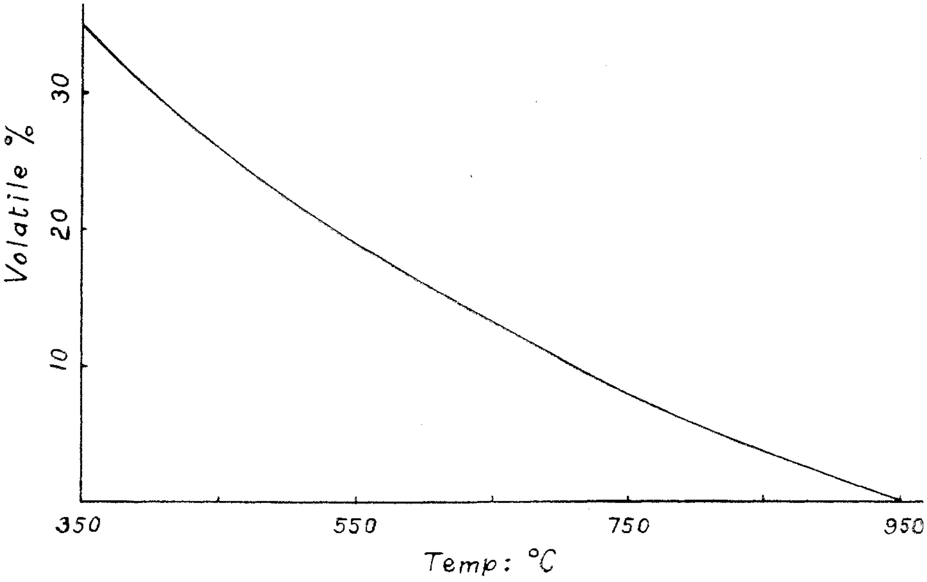

Fig. 4.

(¹) To satisfy this condition for final temperatures less than 500° C., it is necessary to carbonize the wood in small pieces, cf. Table I.

this; they are for wood carbonized in various ways, e.g., strips, green wood, large dry wood, and reheated charcoal: with a 3-hour soaking at the final temperature, the figures obtained were 23, 23, 22, 22, 21 per cent, and, with a 12-hour soaking, 24, 23, 23, 23, 22, 20 per cent.

Fig. 4 shows the variation of volatile content with final temperature for *E. linearis* (the final temperature being greater than the maximum temperature attained during carbonization). The curves for *E. obliqua* and *E. regnans* are similar, but fall off rather more rapidly.

7.—SHRINKAGE

The shrinking of charcoal during and after the carbonization reaction clearly plays an important part in the breaking up of charcoal during heating. While the amount of shrinkage in the carbonization of wood in large pieces may not be quantitatively the same as that in the carbonization of small pieces, the behaviour of the latter should give a good qualitative guide to that in the former. Accordingly, longitudinal shrinkages were measured on pieces 4″ long by ½″ square, and radial and tangential shrinkages on trapezoidal pieces about ½″ thick and 1½″ square, with sides following the rays and rings. In all cases the wood has been carbonized slowly to avoid cracking during carbonization (for this see § 8). Values of the shrinkages, expressed as percentages of the dry length of the wood, are given in Table III for various final temperatures; they are to be regarded as typical values only, since there is a good deal of variation between experiments. In all cases the charcoal has been kept for three hours at its final temperature.

TABLE III

	E. linearis.	*E. regnans.*	*E. obliqua.*	*E. rostrata.*	*Ac. dealbata.*	Sassafras.
350° C. Long.	5	6	4	3	6	6
500° C. Long.	12	13	13	10	13	13
900° C. Long.	19	18	18	15	21	21
350° C. Rad.	12	20	14	7	13	19
500° C. Rad.	19	26	19	11	19	25
900° C. Rad.	25	33	26	20	29	34
350° C. Tang.	16	24	18	12	23	22
500° C. Tang.	23	29	22	17	30	28
900° C. Tang.	30	36	29	21	37	38

It will be seen that the radial and tangential shrinkages are much greater than the longitudinal, and that in all cases there is a considerable shrinkage on subsequent heating after the carbonization reaction is over. Thus, particularly when carbonization is propagated radially, and when external temperatures are fairly high, differential shrinkage may be expected to be the chief mechanism of the breaking up of charcoal into smaller pieces. Shrinkages for all timbers examined are seen to be of the same order, those for *E. rostrata* being lowest.

8.—THE EFFECT OF EXTERNAL CONDITIONS ON THE NATURE OF THE CHARCOAL

In §§ 2-5 the temperatures attained in a log when carbonizing have been studied and have been found to be considerably influenced both by the size of the log and the external temperature conditions. For example, it follows from Table I that for *E. linearis* it is possible only with small diameter wood and with a low rate of increase of external temperature to keep the internal temperature of the wood low and to produce a 'quiet' reaction. The nature of the charcoal produced by the experiments of Table I varies very widely; thus the 1·2″ diameter wood yielded a very hard homogeneous charcoal, all in one piece; with the increase in diameter the charcoal commences to break up into small pieces, and also becomes more friable. The breaking up is presumably due to differential shrinkage caused by the increase of internal temperature. The increase of friability appears to be due in part to another cause, namely, the increasing violence of the reaction which causes the gases given off to burst small channels in the carbonizing wood for their escape. These channels appear as small cracks (1) in the charcoal, and cause a great decrease in its strength.

It is reasonable to suppose that it is the rate of increase of temperature near the carbonization temperature that gives rise to a violent reaction. To determine the effect of rate of increase of temperature, experiments were made on strips ½″ square by 4″ long, which could be heated rapidly in a small retort in a muffle. In Table IV for *E. linearis* the rates of increase of retort temperature, the violence of the reaction (as observed qualitatively from the evolution of distillates), and the nature of the charcoal are shown. The actual rates of increase of temperature in the wood will be greater than those shown in Table IV, but for such thin strips the difference will not be large.

TABLE IV

Rate of Temp. Rise ° C./min.	Reaction.	Charcoal.
20	Very fast	Much broken
18	Fast	Less broken
15	Medium	Small cracks only
11	Slow	Practically solid
6	Very slow	Solid

It follows that, for production of best quality charcoal from small pieces of wood, a rate of temperature rise of about 10° C. per minute is critical. A rate of the same order might be expected to be critical in the interior of the timber, and, as a larger rate (20° C. per minute) is recorded in Table II for *E. linearis*, it seems that a certain amount of loss of mechanical strength is to be expected from this cause in timber of any size. The other timbers examined in this way are *E. obliqua*, *E. regnans*, *E. rostrata*, *Acacia dealbata*, and Sassafras. The first two eucalypts show behaviour practically identical with that of *E. linearis*. *E. rostrata* (2), *Acacia dealbata*, and Sassafras will stand a greater rate of increase of temperature without deterioration, and the former also shows a much smaller maximum rate of increase of temperature in Table II.

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(1) These are not due to shrinkage of the wood in drying; check experiments of Table IV have been made with oven dried wood.

(2) It may be remarked that the experiments proposed by Miss Plante [*J. Council for Scientific and Industrial Research*, 14, 3 (1941)] in which wood is carbonized in strips 1″ square will, for the reasons discussed above, not be a reliable guide to the mechanical properties of charcoal produced from larger logs, though experiments with *E. rostrata* might indicate that they were.

In cases such as those of § 5 in which the maximum rate of increase of temperature is very high, a very poor quality charcoal is produced.

9.—PRACTICAL CONCLUSIONS

The most immediate practical application of these results is to carbonization in large retorts. It might be hoped that by a slow carbonization a very solid charcoal might be obtained; however, unless the wood is carbonized in small pieces, the improvement in quality is not very great.

The reason for the poor quality of open-pit charcoal is fairly clear, namely, the high external temperature which gives a violent carbonization reaction. Differential shrinkage will cause the subsequent breaking up of the charcoal.

In the Kurth continuous kiln the conditions seem to be very similar to those in the experiments above: most of the heat is obtained from the reaction itself, and the charcoal has some time to soak at the maximum temperature generated by the reaction. It may thus be expected to attain a temperature of 500° C. and to emerge with a volatile content from fig. 4 of about 22 per cent. Only *E. regnans* has been burnt in this kiln, and the observed volatile contents are about 15 per cent, in good agreement with the equivalent for *E. regnans* of fig. 4.

10.—GREEN WOOD

The behaviour of green, and half dry, wood is entirely different from that previously described, for the following reason: if heating takes place at temperatures of the order of those occurring in charcoal burning practice, the wood checks severely while drying during the early part of the heating and splits up into flakes about ⅛″ thick, running radially inwards, separated by air spaces of much the same size. The sap wood alone remains solid. The flakes of wood carbonize as an assemblage of thin strips, rather than as a single piece, and thus their behaviour resembles that of small pieces of wood. The reaction is thus 'quiet', and the maximum temperature attained less than that for dry wood. For example, a 3″ diameter piece of *E. linearis* of moisture content 66 per cent shows, under the conditions of Table II, a maximum temperature of 395° C., a maximum rate of increase of temperature of 7° C. per minute, and a maximum rate of flow of distillate of 1·4. The maximum rate of flow of gas is also much less for green than for dry wood.

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