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A Comparative Study of the Combustion Characteristics of Rubberwood and Some Malaysian Wood Species

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The combustion characteristics of rubberwood and eighteen common Malaysian wood species were examined and compared using two complementary methods of analysis, namely differential thermal analysis (DTA) and thermogravimetry (TG). The DTA experiments were carried out in fluidised beds, as opposed to static beds in the conventional method. The results obtained indicate that rubberwood is relatively easy to burn and that, in general, the lighter a wood species, the easier it is to burn. Increasing the oxygen supply to the combustion chamber resulted in the wood burning faster but did not seem to have a major effect on its relatively combustibility. The effects of ash and moisture content of the wood on its combustion were discussed.

Wood is composed of three basic polymers, namely cellulose, the hemicelluloses and lignin. Added to these are the extractives which may be extracted from the wood using water or organic solvents. In general, hardwoods contain around 40% cellulose, 33% hemicelluloses, 20% lignin and 7% extractives, on a weight basis[1]. Elementally, wood consists of around 52% carbon, 41% oxygen, 6% hydrogen and 1% ash[2].

The combustion of wood begins with pyrolysis during which it is decomposed into gases and vapours (known as the volatiles) and a solid residue called char. In the presence of oxygen, the volatiles burn with a flame while the char burns by glowing combustion without flame. Cellulose and the hemicelluloses promote flaming combustion as their degradation products consist mainly of the volatiles while the lignin fraction supports glowing combustion as it contributes the most to char formation[1].

Although different wood species have only a minor difference in their elemental compositions[3], they vary considerably in their combustion characteristics. Some wood species burn easily while others burn less readily. The thermal behaviour of wood may be studied using several methods[4,5], including differential thermal analysis (DTA) and thermogravimetry (TG). In DTA, the difference in temperature between a sample and an inert reference material is recorded as a function of temperature while in TG the weight of a sample is recorded as a function of temperature. These two techniques are, therefore, complementary to each other.

A study using DTA and TG was carried out to compare the combustion characteristics of rubberwood, which is widely used as fuelwood in this country, with those of some common Malaysian wood species whose off-cut timbers are also being used as fuel. The DTA experiments were conducted in fluidised beds instead of in static beds as in the conventional method. This was to overcome the problem of non-uniformity of bed temperature and also to allow larger testpieces to be used. The results of this study are presented here.

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EXPERIMENTAL

Apparatus

A reactor and a furnace were used. The reactor was made up of three components, namely a pair of reaction tubes, a stainless steel block and a stand as illustrated in *Figure 1.* The two reaction tubes were connected to a common gas coil of 10 mm internal diameter by a 'T'. An orifice plug inserted at the entrance of each tube ensured that the gas flow rates in both the tubes were uniform. The gas distributor consisted of a circular piece of ceramic fibre ('Kaowool') of 13 mm thickness. It was supported by a 125 mm high stainless steel frame placed at the bottom of each tube. The stainless steel block served as a heat sink and sat on a steel stand with a 19 mm thick base. The reactor was placed inside an electrically heated furnace of 576 mm height, with 66 mm of each reaction tube protruding out of the lid. The lid and the reactor could be lifted out of the furnace with the aid of a crane for fan cooling at the end of each run.

Materials

Nineteen wood species, including rubberwood, were used. These are listed in *Table 1,* in order of density. All of them are hardwoods, except oil palm wood and coconut wood which are obtained from 'palms' and not 'trees'. Oil palm wood and coconut wood are agricultural by-products and are presently not used for sawn timber production in Malaysia.

The testpieces were of 5 mm diameter and 11 mm height. A uniform sample size of 1 g (oven-dried wood) was used in the DTA runs. The number of wood pieces in a sample varied from species to species as it was dependent on the density of the wood; in the case of rubberwood, there were seven pieces. In TG analysis, a sample size of 1 g was used in runs carried out in an inert atmosphere (to compare the char yields of different wood species) and 0.6 g in those conducted in an oxidative environment. The test samples of rubberwood, oil palm wood and coconut wood were obtained from trunk sections of 5 cm thickness and 20-30 cm diameter. Those of the other wood species were derived from hand samples measuring 75 × 100 × 18 mm prepared by the Forest Research Institute of Malaysia.

Differential Thermal Analysis

Thirty grammes of sand of particle size $-85+100$ mesh was poured down each tube onto the gas distributor. The static height of each bed was 40 millimetres. The test sample was dropped into the sample tube, after which both the beds were fluidised by the desired fluidising medium. The gas flow rate in each tube was adjusted at 2 litres per minute to give a gas velocity of around three times the minimum value required for fluidisation of the sand, *i.e.* 0.02 m per second. Following this, the reactor was heated at a constant rate of around 5.5°C per minute. The temperature difference between the two beds and the reference bed temperature were measured using 1 mm diameter chromel/alumel thermocouples and were recorded on a Watanabe hot-pen recorder. The experiment was terminated when all the testpieces had been burnt and the DTA trace had returned to the base line.

Two sets of experiment were carried out, the first using air and the second using a mixture of oxygen (80% volume/volume) and nitrogen (20% volume/volume) as the fluidising medium.

Thermogravimetry

The experimental set-up for TG analysis is shown in *Figure 2.* The sample holder consisted of a cylindrical basket of 16 mm diameter and depth made from 100-mesh stainless steel screen. It was suspended at the end of a long wire, the other end of which was hooked onto the bottom of a digital balance which read up to three decimal places. After the test sample had been loaded, the carrier gas was passed through the two tubes with a combined flow rate of 0.8 litre per minute in the case of nitrogen gas and 0.4 litre per minute in the case of air. The reactor was then heated at around 5.5°C per minute, as in the DTA runs. Readings on the balance were recorded from the time the sample began to lose weight, at intervals varying from 1 min (at the height of pyrolysis) to 5 min until they remained constant or nearly constant. The actual heating

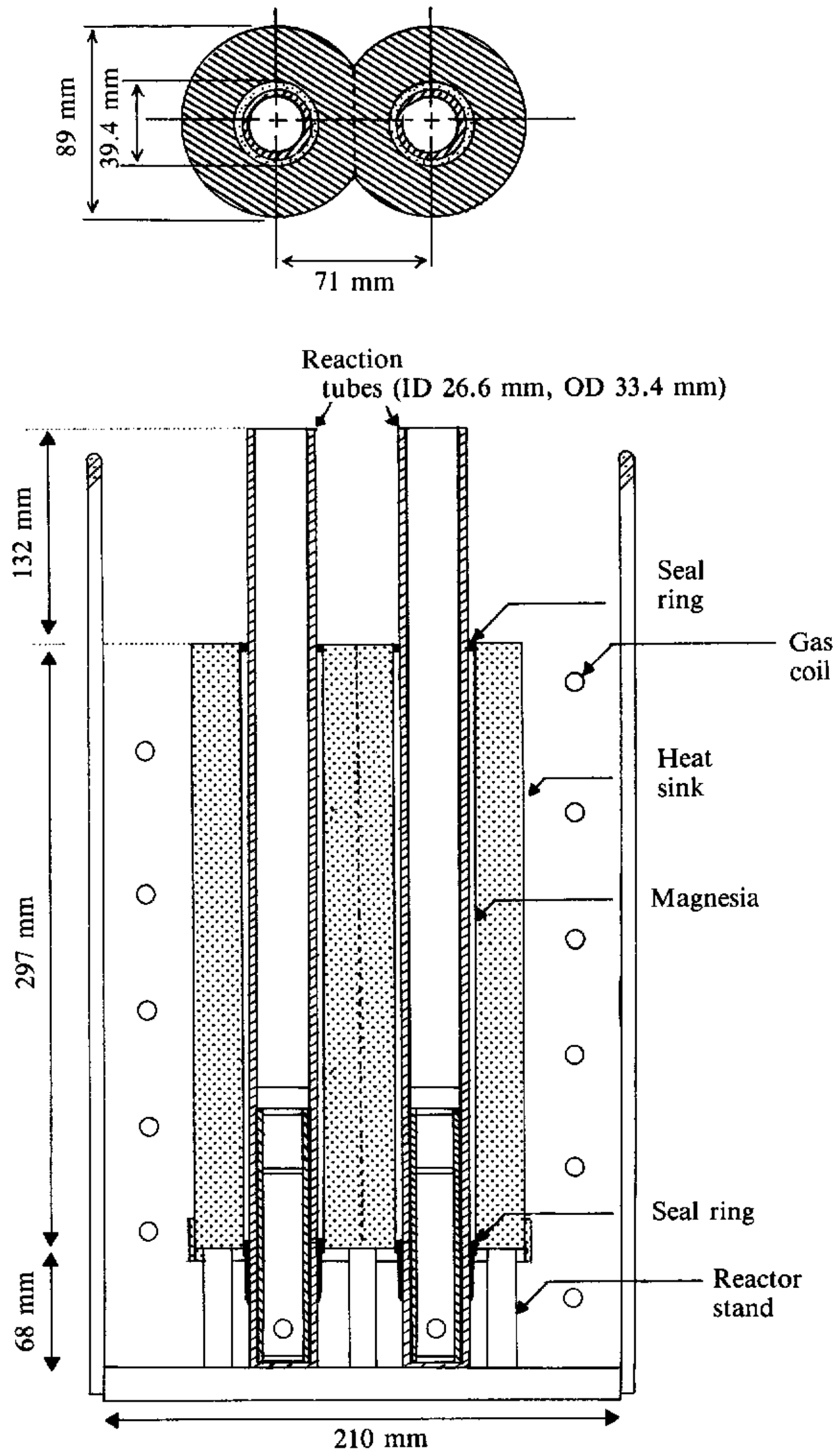

Figure 1. Schematic representation of reactor.

TABLE 1. WOOD SPECIES USED IN THE STUDY

Common name	Botanical name	Density at 15% moisture content[a] (kg/m^3)
Oil palm wood[b]	*Elaies guineensis*	196
Jelutong	*Dyera costulata*	445
Mengkulang	*Heritiera* spp.	490
Pulai	*Alstonia* spp.	505
Mersawa	*Anisoptera* spp.	557
Meranti, light red	*Shorea* spp.	610
Meranti, dark red	*Shorea* spp.	643
Sepetir	*Sindora* spp.	675
Rubberwood	*Hevea brasiliensis*	698
Nyatoh	Spp. of *Sapotaceae*	732
Keruing	*Dipterocarpus* spp.	796
Tualang	*Koompassia excelsa*	810
Ramin	*Gonystylus* spp.	822
Tembusu	*Fagraea* spp.	833
Merbau	*Intsia palembanica*	871
Kempas	*Koompassia malaccensis*	873
Chengal	*Balanocarpus heimii*	920
Coconut wood[b]	*Cocos nucifera*	1 004
Balau	*Shorea* spp.	1 005

[a]Determined from testpieces
[b]Outer wood

rate was determined from the temperature curve, after which the TG curve was plotted as a function of the reference temperature.

RESULTS AND DISCUSSION

Differential Thermal Analysis Curves of Rubberwood

The DTA curve in air of rubberwood contained two overlapping exotherms *(Figure 3)*, with peak temperatures of 343°C and 426°C and a dip at 372°C*. The first exotherm, which began at around 270°C, was attributed to oxidative degradation of the volatiles while the second exotherm was attributed to both oxidative degradation of the volatiles (released at higher temperatures) and decomposition of the residual char. The heights of the two peaks, measured on a temperature scale, were: first peak, 8.9°C and second peak, 16.3°C. No flaming or glowing combustion occurred during the run, *i.e.* the volatiles did not burst into flame, neither did the char turn 'red hot'.

In the run in 80% oxygen, ignition of the volatiles occurred at 285°C, resulting in flaming combustion which lasted for less than 1 minute. When ignition took place, there was quite a loud explosion in the sample tube. It was observed that the wood pieces burnt at almost

*Unless otherwise stated, all temperatures referred to hereafter are those of the reference bed. The corresponding sample bed temperatures, in the case of DTA, can be deduced from the DTA curves.

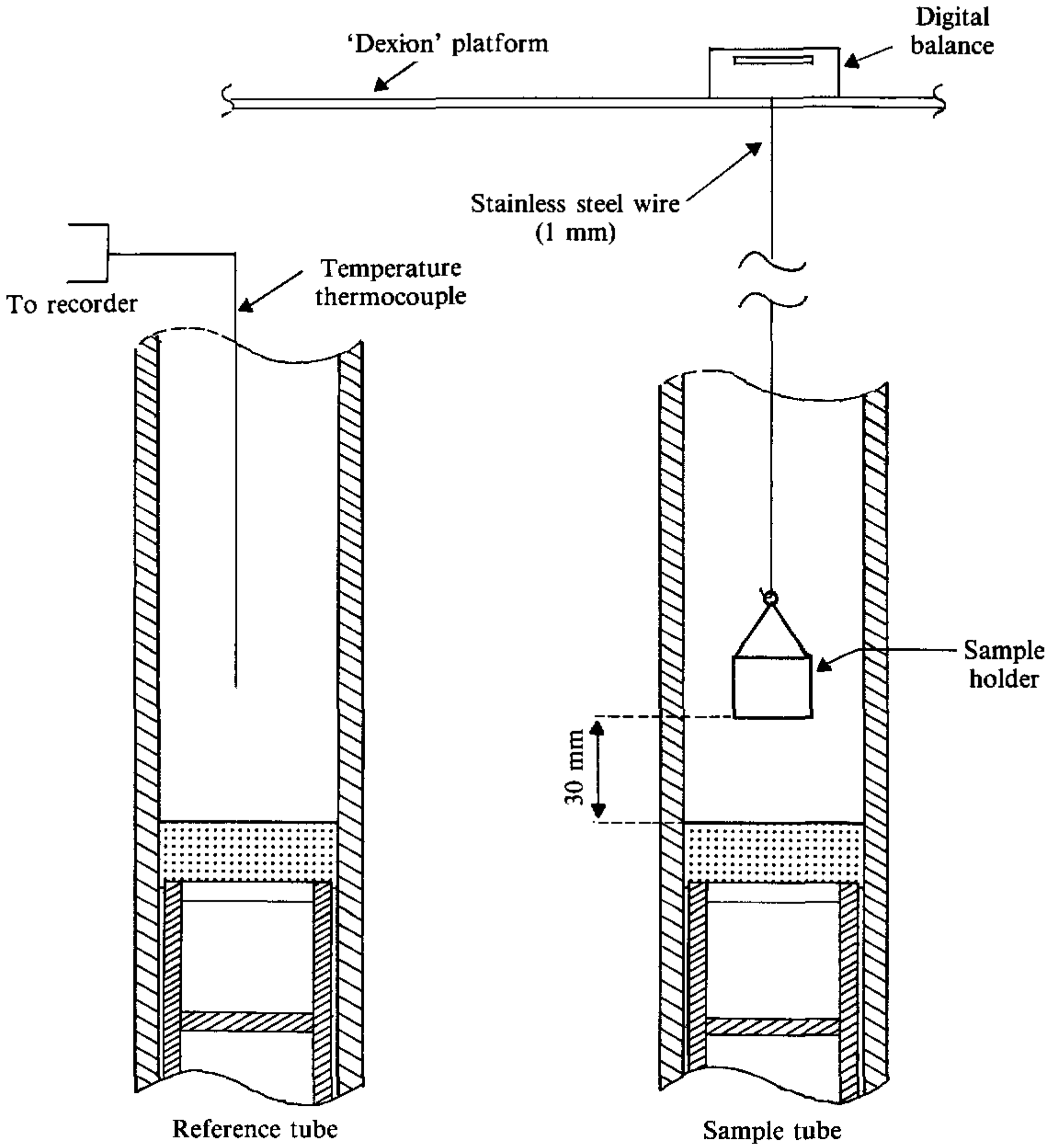

Figure 2. Experimental set-up for TG analysis.

the same time but independently, *i.e.* each of them had its own flame front. The flaming combustion was rather noisy, like the firing of crackers, and this is believed to be due to the volatiles being released in 'bursts'. All the char pieces began to burn by glowing combustion as soon as the flaming combustion had subsided and before the DTA trace had made its way down. This resulted in only one peak being formed, at 295°C, with a height of 54°C *(Figure 4).* These results appear to show that it is possible to burn off the pyrolysis products

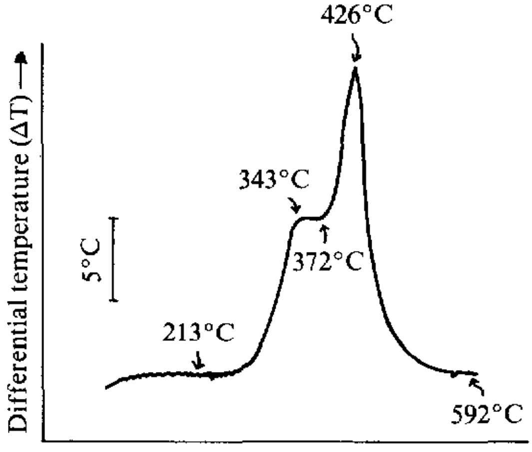

Figure 3. DTA curve in air of rubberwood.

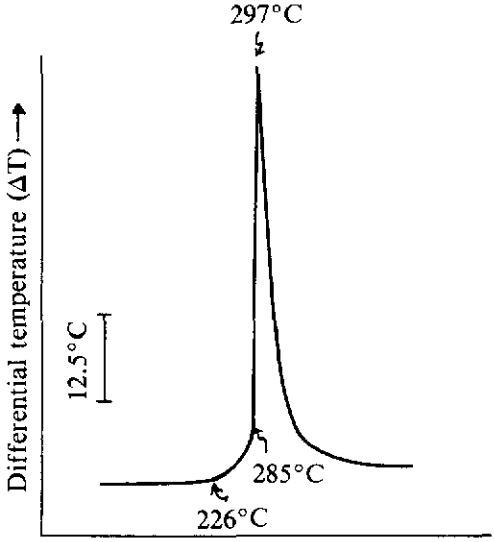

Figure 4. DTA curve in 80% oxygen of rubberwood.

at a lower temperature with an increased oxygen supply. Similar observations have been made by Stott and Baker[6] in studies on coal pyrolysis and combustion.

Besides oxygen supply, the shape of a DTA curve is also influenced by other factors, including the heating rate and the particle size of the wood[7,8].

Comparison with Other Wood Species

The DTA curves in air and in 80% oxygen of the other wood species are given in *Appendix A* while particulars of their respective reaction peaks are presented in *Tables 2* and *3*.

No flaming or glowing combustion occurred in any of the runs in air of the other wood species. Each of the resultant DTA curves contained two overlapping exotherms, as in the case of rubberwood. However, the first exotherm of some of the wood species appeared more like a shoulder than a peak. Except for oil palm wood, the second exotherm was considerably larger than the first. The first peak temperature varied from 302°C for oil palm wood to 364°C for Nyatoh, Tembusu and Chengal and the second from 401°C for oil palm wood to 501°C for Chengal. The heights of the two peaks also varied from species to species, the first from 3.9°C for Balau to 12.5°C for oil palm wood and the second from 13.3°C for dark red Meranti to 24.0°C for Nyatoh. As the first peak is attributed to the volatiles, its height gives an indication of the rate of pyrolysis of the sample, *i.e.* the higher the peak, the faster the wood pyrolyses and the better the resolution of the two peaks, as in the case of oil palm wood. Since the first peak of rubberwood's DTA curve is the fourth highest of all the wood species tested, the inference is that it is relatively easy to pyrolyse.

It was rather difficult to determine the combustion time of each sample as its DTA trace did not immediately return to the base line when it was completely burnt. For this reason, the location of the second peak was used as the basis for comparing the combustion times of different wood species since the farther it was from the origin, the longer the wood took to burn to completion. Thus, since the second peak temperature of oil palm wood was the lowest of all the wood species tested, its combustion time was the shortest. The difference between the second peak temperatures of two test samples divided by the heating rate gave approximately the difference in their burning times. Based on this criterion, the burning times of the various wood samples relative to that of oil palm wood were calculated

TABLE 2. PEAK TEMPERATURES AND HEIGHTS (DIFFERENTIAL THERMAL ANALYSIS IN AIR)

Species	First peak		Second peak	
	Temp. (°C)	Height (°C)	Temp. (°C)	Height (°C)
Oil palm wood	302	12.5	401	14.2
Jelutong	338	10.7	432	16.5
Mengkulang	353	6.3	435	22.5
Pulai	347	9.8	436	16.5
Mersawa	351	4.6	458	21.0
Meranti, light red	348	6.0	463	13.9
Meranti, dark red	363	5.0	472	13.3
Sepetir	339	8.9	428	18.0
Rubberwood	343	8.9	426	17.0
Nyatoh	364	4.7	449	24.0
Keruing	356	4.7	478	17.5
Tualang	359	5.7	464	19.0
Ramin	341	7.1	426	18.5
Tembusu	364	4.6	490	13.4
Merbau	356	5.9	451	19.5
Kempas	356	5.0	480	14.8
Chengal	364	4.0	501	15.7
Coconut wood	360	4.9	474	18.8
Balau	361	3.9	498	16.0

and presented in *Table 4*. It is noted that, compared with oil palm wood, the other wood species took between 4.5 min and 18.2 min longer to burn. The results show that, in general, the greater the density of a wood species, the longer it takes to burn. Rubberwood was ranked second, together with Ramin, in terms of ease of burning.

In the runs of the other wood species in 80% oxygen, ignition occurred in only four of them, *i.e.* in those of oil palm wood, Jelutong, Pulai and Sepetir. This brings to five the number of wood species whose samples burnt with a flame in runs in 80% oxygen. Each of their DTA curves contained only one peak, as in that of rubberwood. The DTA curve of Ramin also contained a single peak although no flaming combustion occurred in its run. This was because its char began to burn at a relatively low temperature (around 310°C), resulting in the two reaction peaks merging into one. The DTA curves of the other wood species exhibited the usual two reaction peaks which were higher and also located at lower temperatures compared with those resulted from the first set of runs. In all the runs in 80% oxygen, the residual char burnt by glowing combustion. Again oil palm wood was the first to burn to completion. The combustion times of the other wood species relative to that of this wood were determined in the same way as before. As shown in *Table 5*, the other wood species took between 4 min and 34 min longer to burn compared with oil palm wood. Again, with a few exceptions, the lighter species burnt faster. This time rubberwood was ranked fourth, in terms of rate of burning. The order of the various wood species in combustion time obtained from the second set of experiments was about the same as that obtained from the first. This indicates that, for the majority of the wood species tested, an increase in the oxygen supply merely resulted

TABLE 3. PEAK TEMPERATURES AND HEIGHTS (DIFFERENTIAL THERMAL ANALYSIS IN 80% OXYGEN)

Species	First peak Temp. (°C)	First peak Height (°C)	Second peak Temp. (°C)	Second peak Height (°C)
Oil palm wood	263	85.0	—	—
Jelutong	284	64.0	—	—
Mengkulang	310	8.3	362	54.0
Pulai	287	65.0	—	—
Mersawa	322	7.9	385	48.0
Meranti, light red	321	8.5	406	27.0
Meranti, dark red	338	7.6	409	36.0
Sepetir	295	59.5	—	—
Rubberwood	295	54.0	—	—
Nyatoh	350	6.5	393	55.0
Keruing	354	6.2	425	37.0
Tualang	340	9.0	408	36.0
Ramin	316	42.0	—	—
Tembusu	360	5.5	449	28.0
Merbau	325	9.5	375	44.0
Kempas	335	9.3	411	28.5
Chengal	357	5.2	438	39.5
Coconut wood	330	5.7	402	37.0
Balau	358	4.5	449	39.0

in the wood burning faster and did not alter its relative combustibility.

In *Table 6*, the various wood species are listed in descending order of their first peak heights from the first set of runs. It is noted that the first five slots are occupied by species whose samples burnt with a flame in the runs in 80% oxygen. This is not surprising since the height of the first peak is related to the rate of pyrolysis and the higher the peak, the faster is the evolution of the volatiles and the greater is the tendency for ignition to take place.

If desired, the heat released by each test sample can be determined by first performing an internal calibration involving the insertion of a heating coil into one of the beds in a blank run and noting the area under curve of the resultant peak for a certain power input. This is another advantage of performing the DTA experiments in fluidised beds[9].

Thermogravimetry

The TG curves in nitrogen gas and in air of rubberwood are shown in *Figure 5*. It can be seen that although each of the test samples began to lose weight at around 130°C, the bulk of the weight loss occurred above 200°C. Pyrolysis of the wood *(Portion I)* took place mainly between 300°C and 370°C in nitrogen gas and below 300°C in air. It is clear that the rate of pyrolysis of the wood was faster in air than in nitrogen gas. The char yield at a particular temperature may be determined from *Portion II* of *Curve (a)*. At 500°C, for example, it amounted to 27.8%. In an oxidative environment, the char is decomposed or burnt, leaving behind ash. *Portion II of Curve (b)* corresponds to decomposition of the char.

As in the case of rubberwood, the rate of pyrolysis of the other wood species was higher in air than in nitrogen gas, as shown in their

TABLE 4. *BURNING TIMES RELATIVE TO THAT OF* OIL PALM WOOD (DIFFERENTIAL THERMAL ANALYSIS IN AIR)

Species	Ranking in density	Extra burning time (min)
Oil palm wood	19	.0
Rubberwood	11	4.5
Ramin	7	4.5
Sepetir	12	4.9
Jelutong	18	5.1
Mengkulang	17	6.2
Pulai	16	6.4
Nyatoh	10	8.7
Merbau	5	9.1
Mersawa	15	10.4
Meranti, light red	14	11.3
Tualang	8	11.5
Meranti, dark red	13	12.9
Coconut wood	2	13.3
Keruing	9	14.0
Kempas	4	14.4
Tembusu	6	16.2
Balau	1	17.6
Chengal	3	18.2

TABLE 5. *BURNING TIMES RELATIVE TO THAT OF* OIL PALM WOOD (DIFFERENTIAL THERMAL ANALYSIS IN 80% OXYGEN)

Species	Ranking in density	Extra burning time (min)
Oil palm wood	19	.0
Jelutong	18	3.8
Pulai	16	4.4
Rubberwood	11	5.8
Sepetir	12	5.8
Ramin	7	9.6
Mengkulang	17	18.0
Merbau	5	20.4
Mersawa	15	22.2
Nyatoh	10	23.6
Coconut wood	2	25.3
Meranti, light red	14	26.0
Tualang	8	26.4
Meranti, dark red	13	26.5
Kempas	4	26.9
Keruing	9	29.5
Chengal	3	31.8
Tembusu	6	33.8
Balau	1	33.8

TG curves in *Appendix B*. The char yield at 500°C varied from 26.6% for oil palm wood to 39.5% for Merbau *(Table 7)* and did not appear to be related to the density of the wood. Except for Sepetir, those species which burst into flame in the DTA runs recorded the lowest char yields. This is to be expected in view of the fact that the lower the char yield, the higher is the amount of volatiles produced and the greater is the tendency for ignition to occur. It is necessary to add that besides yield, the rate of production of the volatiles is also important. This is because if the volatiles are released slowly over a wide temperature range, the likelihood of the fuel mixture being rich enough for ignition to take place becomes less.

In the runs conducted in an oxidative environment, oil palm wood was the first to burn to completion, as in the case of DTA. The combustion times of the other wood species relative to that of this species were calculated, using the 5% weight mark as the end point since the exact end point could not be ascertained. As shown in *Table 8*, the other wood species took between 4 min and 33 min longer to burn compared with oil palm wood. Only three of the wood species tested burnt faster than rubberwood, namely oil palm wood, Jelutong and Pulai. With one or two exceptions, the order of the wood species in combustion time obtained from the TG runs was about the same as that obtained from the DTA runs. This shows that the two methods gave fairly similar results.

It needs to be mentioned that in the DTA and TG experiments, the ash formed did not

TABLE 6. FIRST PEAK HEIGHTS (DIFFERENTIAL THERMAL ANALYSIS IN AIR)

Species	Ranking in density	Height of first peak (°C)
Oil palm wood	19	12.5
Jelutong	18	10.7
Pulai	16	9.8
Rubberwood	11	8.9
Sepetir	12	8.9
Ramin	7	7.1
Mengkulang	17	6.3
Meranti, light red	14	6.0
Merbau	5	5.9
Tualang	8	5.7
Kempas	4	5.0
Meranti, dark red	13	5.0
Coconut wood	2	4.9
Keruing	9	4.7
Nyatoh	10	4.7
Mersawa	15	4.6
Tembusu	6	4.6
Chengal	3	4.0
Balau	1	3.9

TABLE 7. CHAR YIELDS AT 500°C

Species	Ranking in density	Char yield (%)
Oil palm wood	19	26.6
Jelutong	18	27.1
Rubberwood	11	27.8
Pulai	16	28.4
Ramin	7	30.2
Tembusu	6	30.2
Keruing	9	31.0
Meranti, light red	14	31.2
Kempas	4	32.6
Sepetir	12	32.9
Coconut wood	2	33.2
Mengkulang	17	33.2
Mersawa	15	33.7
Tualang	8	34.2
Nyatoh	10	35.2
Balau	1	36.1
Meranti, dark red	13	36.7
Chengal	3	38.8
Merbau	5	39.5

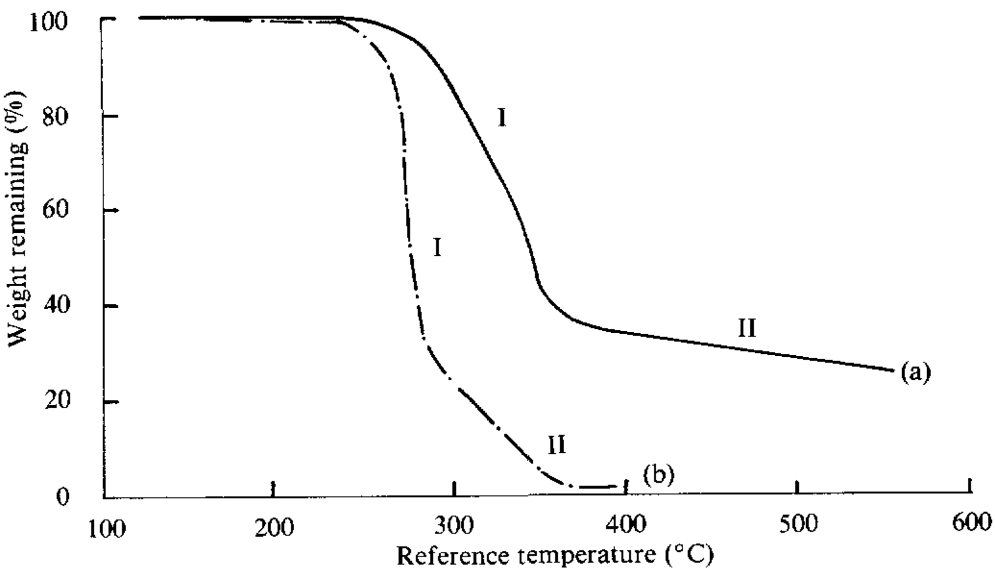

Figure 5. TG curves of rubberwood: (a) in nitrogen gas and (b) in air.

TABLE 8. BURNING TIMES RELATIVE TO THAT OF OIL PALM WOOD (THERMOGRAVIMETRY IN AIR)

Species	Ranking in density	Extra burning time (min)
Oil palm wood	19	.0
Jelutong	18	3.7
Sepetir	12	4.7
Rubberwood	11	5.3
Pulai	16	6.5
Ramin	7	8.2
Mengkulang	17	11.1
Tualang	8	11.8
Merbau	5	12.7
Mersawa	15	14.4
Nyatoh	10	16.2
Meranti, light red	14	17.1
Meranti, dark red	13	17.4
Kempas	4	17.4
Tembusu	6	19.1
Coconut wood	2	23.3
Keruing	9	24.7
Chengal	3	32.4
Balau	1	32.9

adversely affect combustion of the test samples as it was either removed automatically or small in quantity. In practice, especially in static beds, the ash formed around the wood or on top of the fuel bed, if not removed constantly, may impede the flow of oxygen into the wood and adversely affect its combustion. The problem is usually greater for species which have a high ash content. Thus, the results obtained from the DTA and TG studies are more applicable for combustion of wood in systems where the ash formed is removed constantly, either naturally such as in fluidised beds or by some device.

The test samples used in the experiments were oven-dried for uniformity of moisture contents. This is not normally done for fuelwoods which are mostly air-dried. The purpose of drying the wood is to reduce its moisture content so as to improve its combustion efficiency. If the wood is too wet, combustion becomes unstable and the flame may be extinguished. Rubberwood, Pulai and Jelutong, besides being relatively easy to burn, are also comparatively easy to dry[10], which gives them an added advantage over the other wood species for use as fuel. The air-drying characteristics of oil palm wood, another of the species which burns easily, are not available.

CONCLUSIONS

Fluidised-bed DTA appears to be a suitable technique for the study of wood combustion. The rapid transfer of the heat of combustion from the sample bed to the surrounding walls results in a fairly good separation of the reaction peaks of the different pyrolysis products. The variation in the shapes of the DTA curves of different wood species provides a means for comparing their combustion characteristics.

The lighter wood species are generally easier to burn than the denser ones. Rubberwood, although of average density among the wood species tested, appears to be relatively easy to burn. The results of TG analysis on the order of combustibility of the various wood species were in good agreement with those of DTA.

ACKNOWLEDGEMENT

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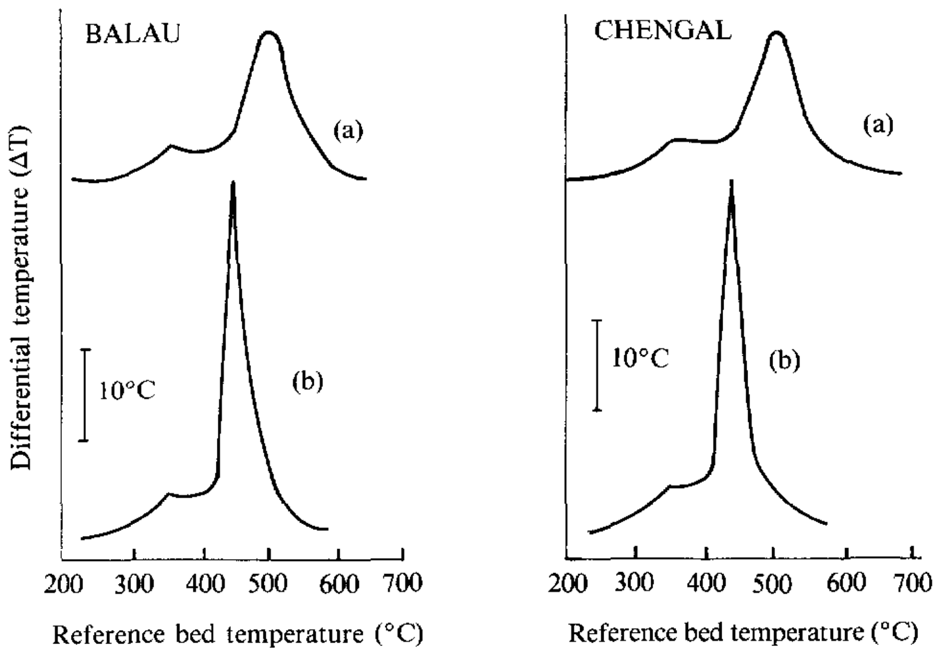
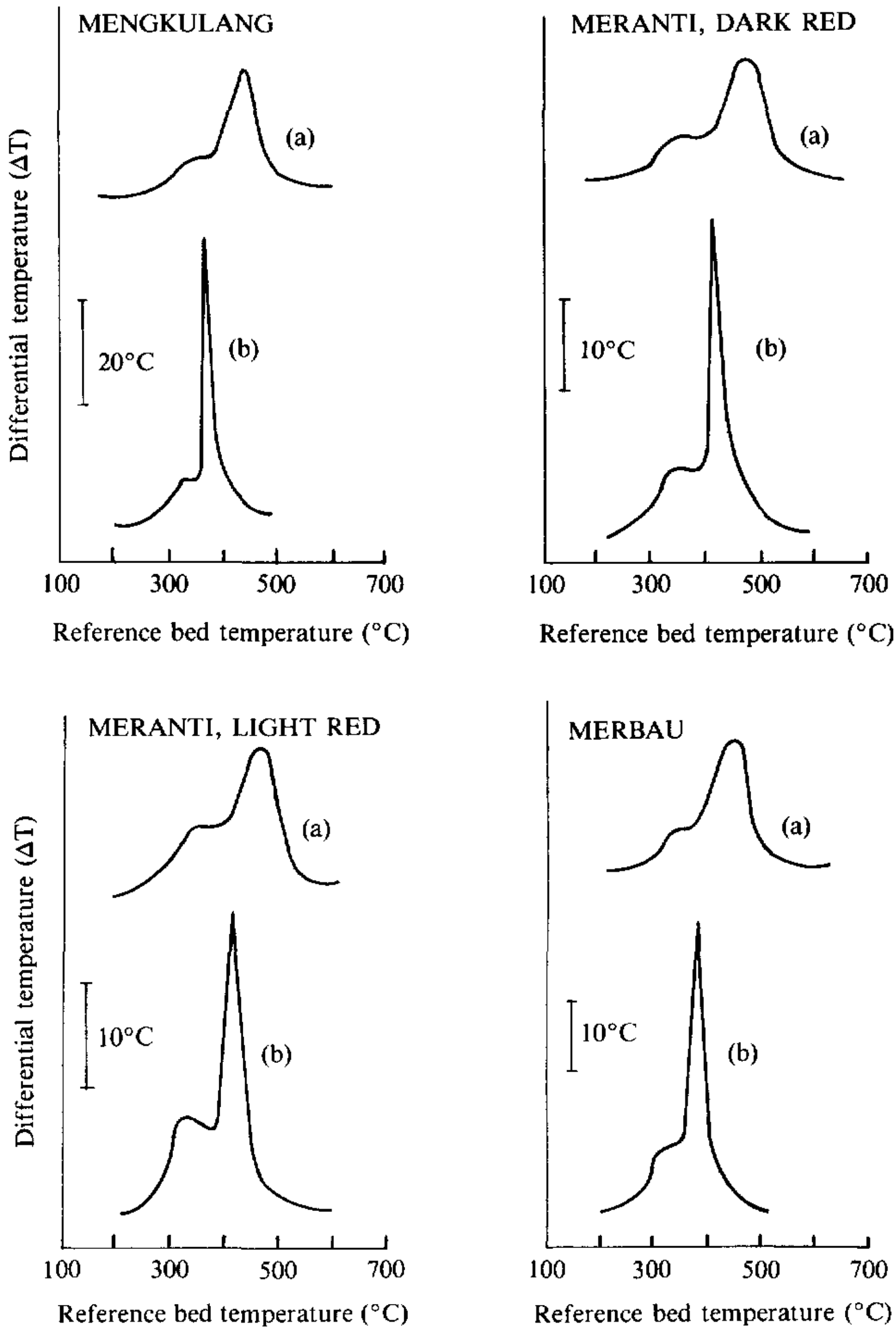
APPENDIX A

DIFFERENTIAL THERMAL ANALYSIS CURVES OF SOME MALAYSIAN WOOD SPECIES: (a) IN AIR AND (b) IN 80% OXYGEN



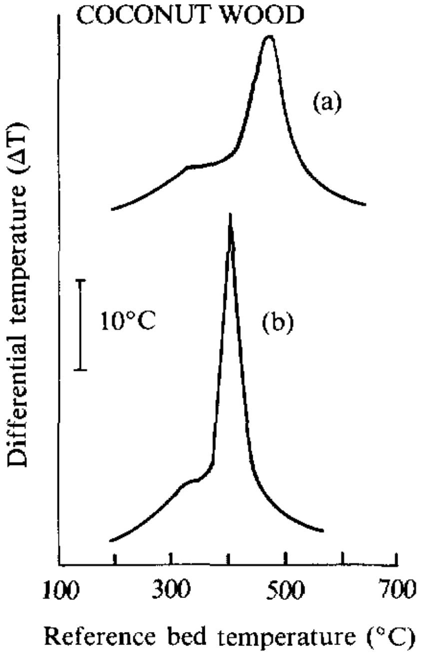
APPENDIX A (CONTD)

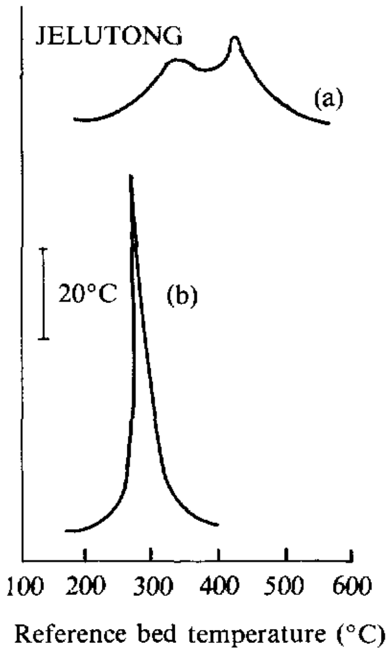
DIFFERENTIAL THERMAL ANALYSIS CURVES OF SOME MALAYSIAN WOOD SPECIES:
(a) IN AIR AND (b) IN 80% OXYGEN

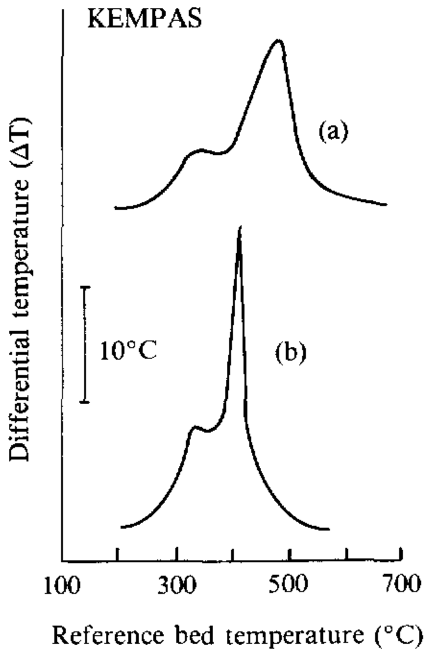


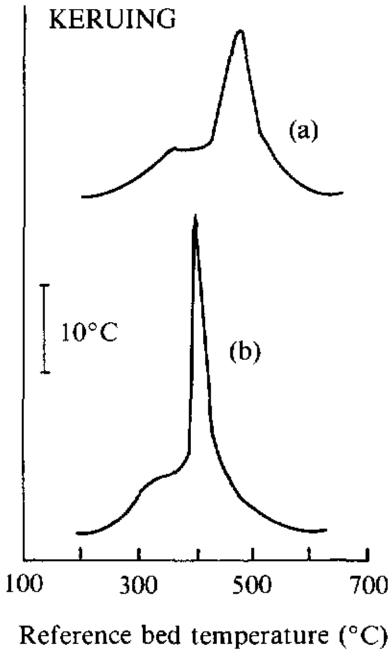
APPENDIX A (CONTD)

DIFFERENTIAL THERMAL ANALYSIS CURVES OF SOME MALAYSIAN WOOD SPECIES:
(a) IN AIR AND (b) IN 80% OXYGEN



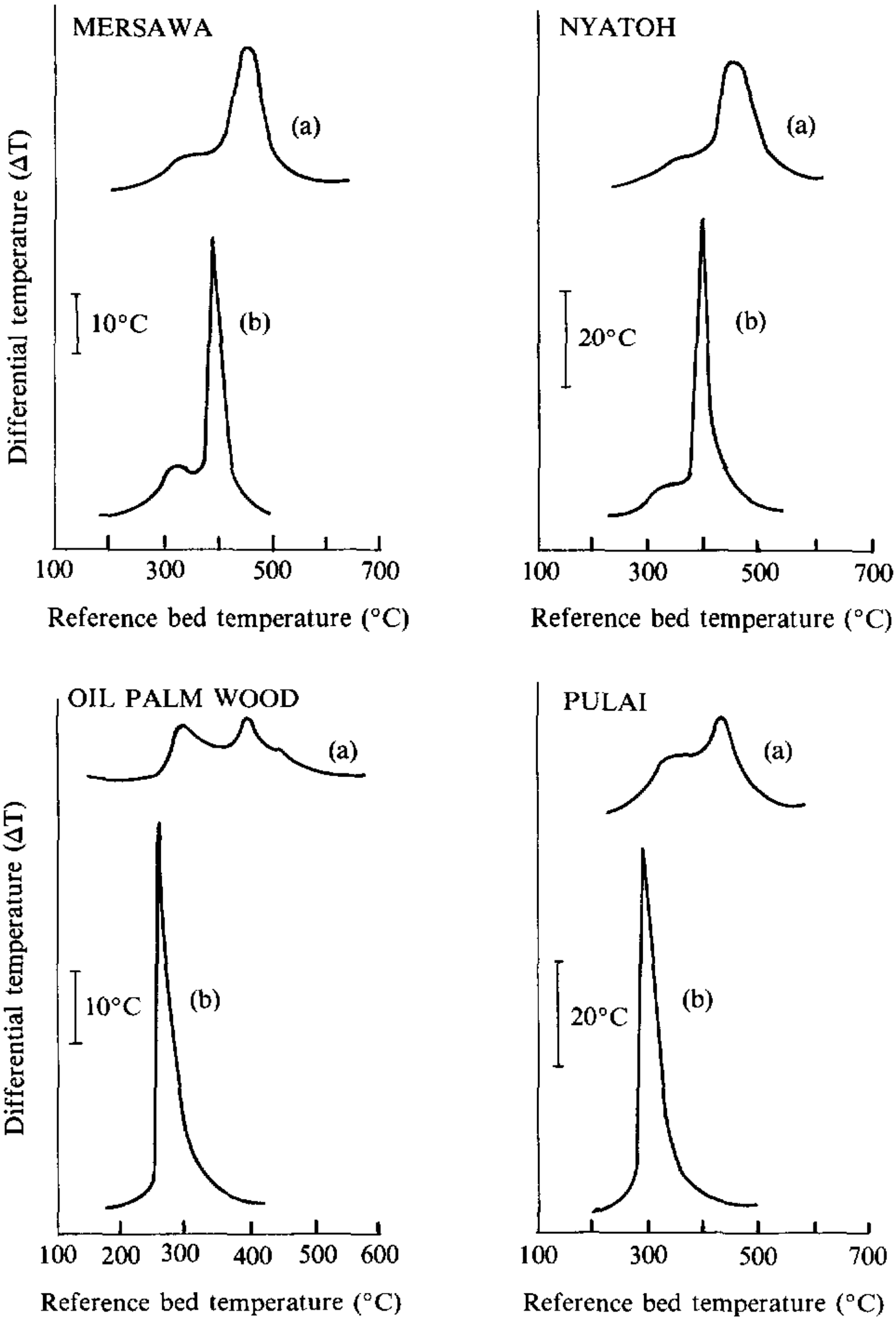






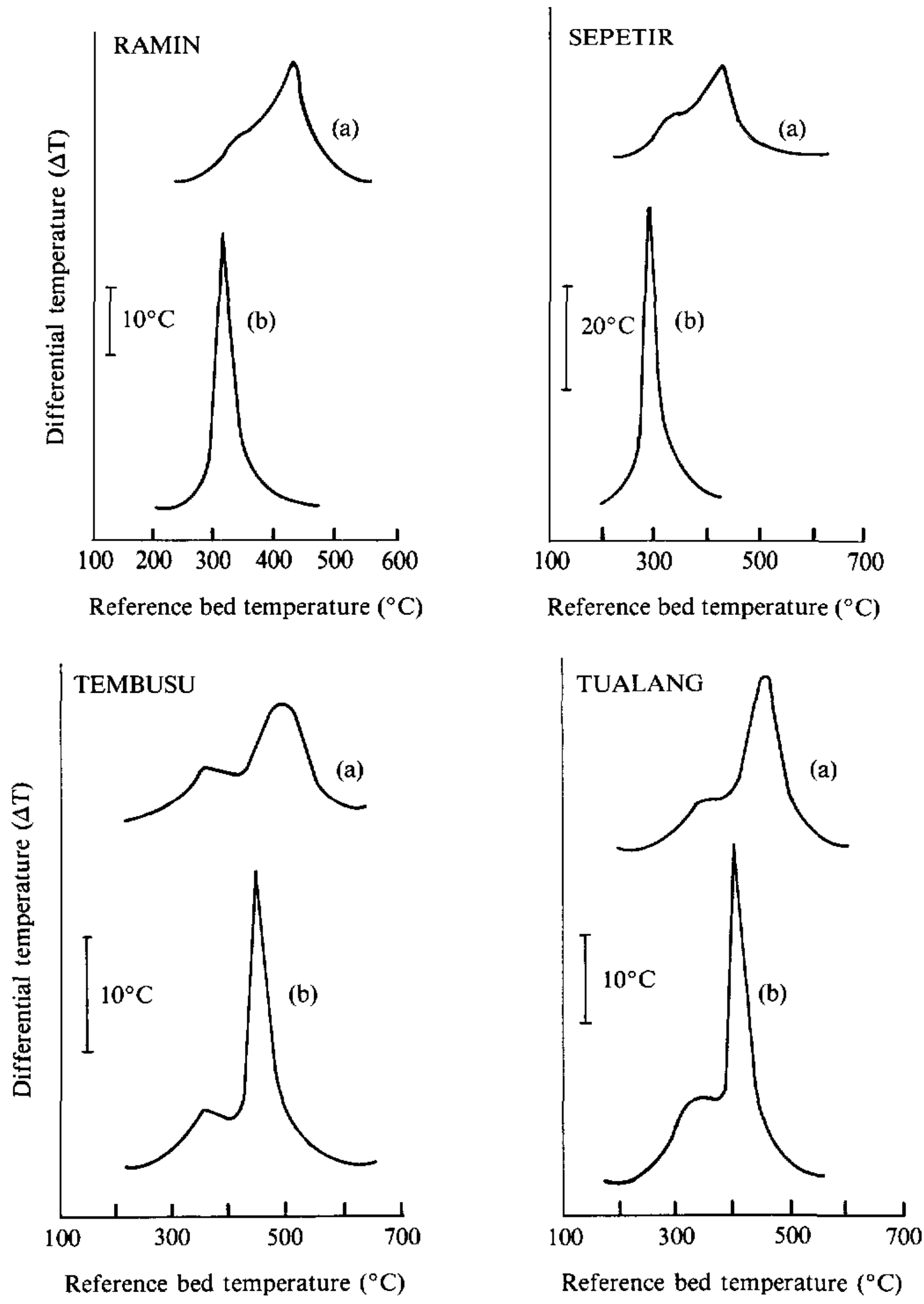
APPENDIX A (CONTD)

DIFFERENTIAL THERMAL ANALYSIS CURVES OF SOME MALAYSIAN WOOD SPECIES: (a) IN AIR AND (b) IN 80% OXYGEN



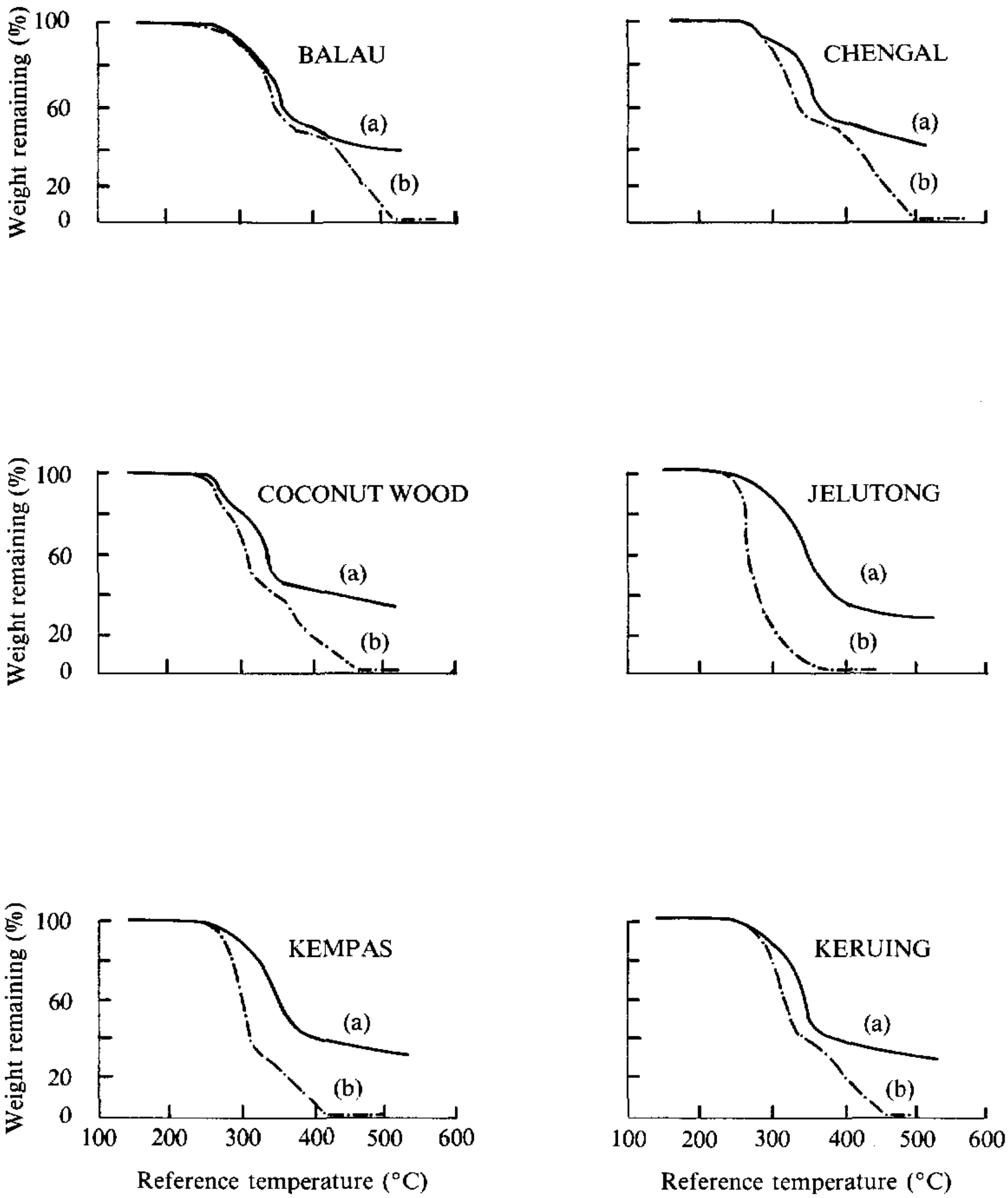
APPENDIX A (CONTD)

DIFFERENTIAL THERMAL ANALYSIS CURVES OF SOME MALAYSIAN WOOD SPECIES:
(a) IN AIR AND (b) IN 80% OXYGEN



APPENDIX B

THERMOGRAVIMETRY CURVES OF SOME MALAYSIAN WOOD SPECIES:
(a) IN NITROGEN GAS AND (b) IN AIR



APPENDIX B (CONTD)

THERMOGRAVIMETRY CURVES OF SOME MALAYSIAN WOOD SPECIES:
(a) IN NITROGEN GAS AND (b) IN AIR