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Combustion Characteristics of Moroccan Wood Species and of the Wood Constituents

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The thermal treatment of *Acacia wood* and of the wood constituents (xylan, cellulose and lignin) was studied by thermogravimetric analysis in an inert (nitrogen) and an oxidative (oxygen) atmosphere. Combustion of wood can be described in terms of different steps, namely preheating and drying of wood, followed by devolatilization of the constituent hydrocarbons. the solid residue then combusts in the presence of oxygen. The wood constituents combustion differs in position and shape. The lignocellulosic materials are less reactive in nitrogen environment than under a flowing oxygen atmosphere.

INTRODUCTION

Thermoanalytical methods such as thermogravimetry (TG) have been used extensively in studies related to wood pyrolysis and combustion[1–6], especially regarding the degradation and oxidation of different materials. The advantages of the thermogravimetric methods are their speed, accuracy, and reproducibility of weight loss determination. In addition, the temperature information and the rate of burning is used to identify or characterize coal and related products.

The ignition and combustion of lignocellulosics is a major source of destructive residential and forest fires. Much of the relevant research in the literature[7–10] has been carried out on cellulose, whereas in most fire situations the combustible material is lignocellulose such as wood and wood-derived materials.

Wood consists of three main components: cellulose of a linear polymer repeated with glucosan units; lignin of macromolecules; and hemicellulose of a group of polymers. Cellulose amounts to about 50% of weight of wood. Lignin and hemicellulose vary from 20 to 35%.[8]

In the present work, some new results are presented for combustion process of *Acacia mearncii* and of wood constituents. This is followed by a description of thermogravimetry (TG) and derivative thermogravimetry (DTG).

EXPERIMENTAL

Thermogravimetric analyses were performed using a Mac Bain and Baker thermobalance described in the previous work[1]. All the experiments were carried out under the same operating conditions. In order to avoid intraparticle heat and mass transfer problems, small particle sizes were used. The weight losses for *Acacia* wood and wood constituents were measured in an oxygen and inert atmosphere.

The thermal decomposition of each component, xylan (representing the hemicellulose), cellulose and lignin, was studied separately.

RESULTS AND DISCUSSION

The results of the analysis carried out on xylan, cellulose and lignin in a flow of oxygen (9 cm^3 min^{-1}) indicate that the combustion process occurs in a number of phases. The differences in chemical structure between wood constituents give rise to differences in the evolution of the remaining weight with temperature. Thus, Figure 1 proved that the xylan, cellulose and lignin combustion differs in position and shape.

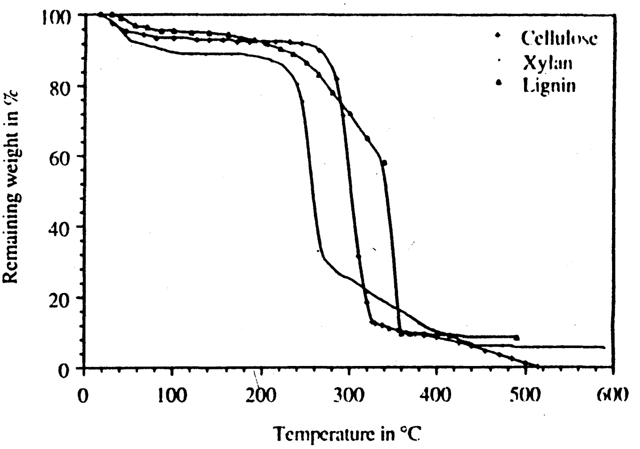

Fig. 1 Changes in TG curves in oxygen atmosphere

Heat transfer into sample occurs along and across the grain. As the temperature of the sample reaches boiling point, the moisture present in the sample vaporises, its presence has the effect of ignition. The organic matter and other extractives vaporise when the sample temperature reaches the appropriate boiling point and then diffuse out of the structure.

The hydrocarbons present in these components undergo a complex series of decomposition reactions under the influence of heat. The products are volatile gases and char. The different constituents react at different temperatures and yield different product mixtures. The gaseous products formed by pyrolysis migrate to the layer surrounding the sample, where they combust in the presence of oxygen. The flames surrounding the sample provide a major source of heat to the sample.

Furthermore the combustion processes of these combustibles have been visually followed. This allows to distinguish different zones where combustion stages take place.

Xylan treatment: Under oxygen atmosphere, the volatile matters combust during pyrolysis stages which are followed by a slight shrinking. This phenomenon appears at temperatures ranging from 160 to 280°C. After this stage, the char that remains then combusts slowly to produce a low amount of ash. Figure 2 shows the rate of transformation curves for xylan in nitrogen and oxygen environment.

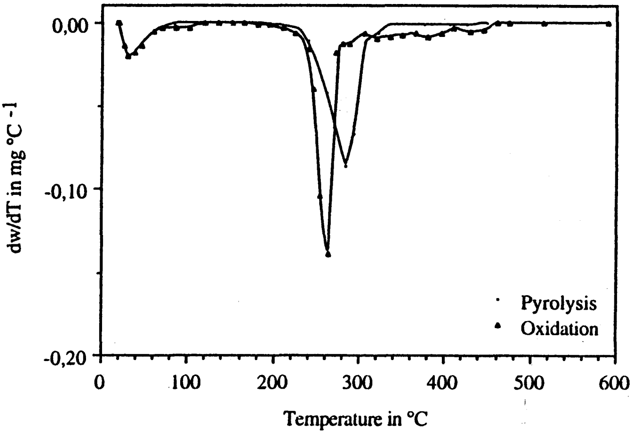

Fig. 2 DTG curves of yxlan in oxygen and in nitrogen environment

The xylan decomposition in flowing nitrogen and oxygen becomes noticeable respectively at 285°C ad 260°C. Thus the start of the weight loss, the temperature range, and the temperature of maximum decomposition characterize the thermal behaviour of xylan in the two different atmospheres. The temperatures at which the maximum of weight loss occurred are listed in Table-1. It appears that the rate of transformation values increases with oxygen.

TABLE-1
VALUES OF THE MAXIMUM RATE OF TRANSFORMATION FOR XYLAN IN OXYGEN AND NITROGEN ENVIRONMENT

Parameters	Atmosphere	
	Inert	Oxidative
Temperature (°C)	285	260
Maximum rate of transformation in mg $°C^{-1}$	86×10^{-3}	140×10^{-3}

The analysis of the results obtained suggests that the reasons for the higher divergences are mainly due to exothermic reactions of flammable gas, which create increase in reactivity.

Cellulose treatment: In this case cellulose begins weight loss at temperature above 220°C and most rapidly completes the loss; the particle sizes exhibit simultaneously a large reduction to yield the least char which burns easily. Since a series of secondary reactions can occur during primary pyrolysis such as flammability, cellulose is less reactive in nitrogen environment than under a flowing oxygen atmosphere which is shown as function of temperature in Figure 3.

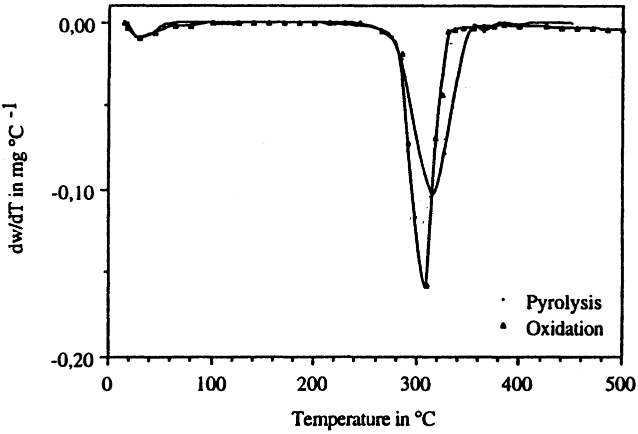

Fig. 3 DTG curves of cellulose in oxygen and in nitrogen atmosphere

For both atmospheres, the temperatures at which the maximum of weight loss was reached are ranging from 310 to 320°C, the basis for comparison was the atmosphere which is given in Table-2. It can be observed that the speed of transformation is much lower in nitrogen than in oxygen.

TABLE-2
VALUES OF THE MAXIMUM RATE OF TRANSFORMATION FOR CELLULOSE IN OXYGEN AND NITROGEN ENVIRONMENT

Parameters	Atmosphere	
	Inert	Oxidative
Temperature (°C)	320	310
Maximum rate of transformation in mg $°C^{-1}$	100×10^{-3}	160×10^{-3}

Lignin treatment: With regard to thermal behaviour of lignin under oxidative atmosphere, Figure 1 shows that the thermogram related to lignin decomposition, exhibits a different shape from those obtained with xylan and cellulose. In fact the thermal decomposition of lignin under nitrogen atmosphere occurs in two steps: the first between 150 and 500°C corresponds to a weak weight loss, the second more important takes place beyond 600°C. Thus, for instance, the TG oxidative and pyrolysis curves of lignin presented in Figure 4 show weight loss between ambient and 500°C.

At low temperature (T < 280°C), the thermal decomposition in both atmospheres is forming in the same way. At temperatures higher than those indicated before, a noticeable divergence between the combustion and the pyrolysis curves can be observed. In first approach, this divergence may be caused by the different nature of the secondary reactions which occur in each atmosphere. In fact between 280 and 340°C, the gaseous products formed by pyrolysis migrate through the sample to the layer surrounding where they combust in the presence of oxygen. The exothermic phenomena support and acceletate the solid degradation; this stage is followed by a very important increase in particle sizes.

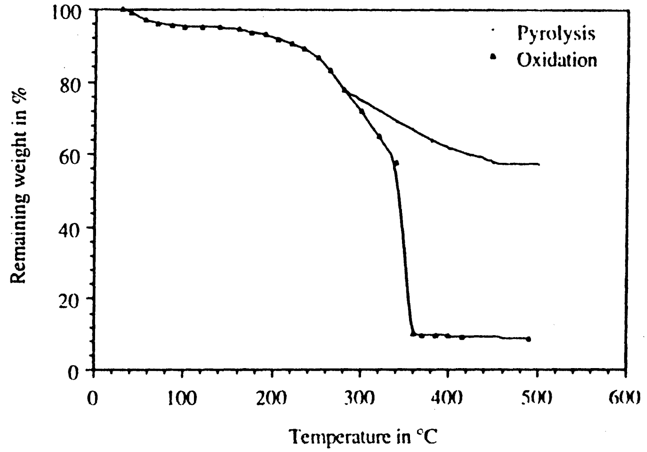

Fig. 4 TG curves of lignin in oxygen and in nitrogen environment

At 340°C, the weight losses in oxygen atmosphere are practically equivalent to those obtained at 520°C under the nitrogen environment. Therefore, the observed brute fall in the thermogram related to the oxidation is due to the lignin chars combustion. After this step the remaining residue looks like butter-scotch which burns with difficulty at higher temperatures.

Thermal behaviour of *Acacia mearncii* under oxygen

The experimental method and data analysis used are similar to those employed for the individual constituents. This allows the comparison of the results obtained with these individual constituents and with *Acacia mearncii.* DTG curves and data were numerically derived from the measured TG data.

Almost all TG runs were carried out at heating rate of 15°C min^{-1} in an atmosphere of oxygen flowing at the rate of 9 cm^3 min^{-1}. These rates were kept constant throughout each dynamic experiment.

Figure 5 shows the burning profile of *Acacia mearncii*; 5 mg of sample were heated to 500°C. As the temperature of the sample increases, the weight loss observed at initial stage of sample heating is due to the evaporation of free moisture in wood can influence its combustion significantly.

The hydrocarbons present in wood (mainly cellulose, hemicellulose and lignin) undergo a complex degradation during thermal treatment. The combustion process is accompanied with thermal decomposition of sample; it is also complicated by a number of simultaneous reactions. Thus the progress of degradation is influenced by the residence time of products inside the wood. The products are char and volatile matter. Approximately 77% (on dry basis) of the wood mass is lost during this phase. It should be noted that this process is more active in oxygen than in an inert atmosphere (Figure 6). The decomposition reactions yield a considerable amount of volatile substances. The ignition and combustion of volatile substances is accompanied with the temperature increase of the sample and the acceleration of the decomposition process; the reaction is highly exothermic.

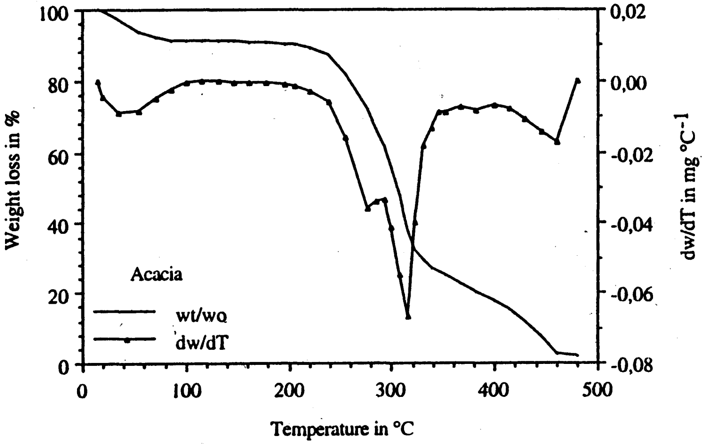

Fig. 5 Burning profiles of *Acacia mearncii*

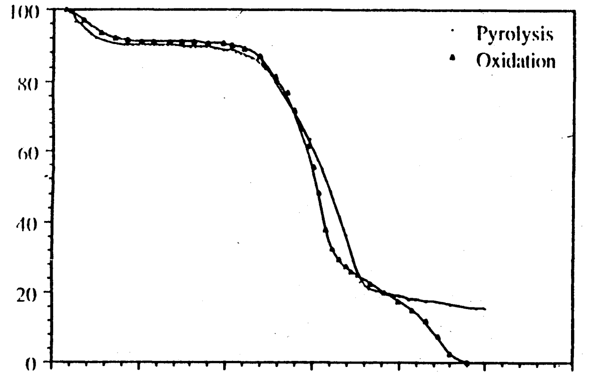

Fig. 6 TG curves of the pyrolysis and the combustion of *Acacia mearncii*

Figure 6 shows the thermogram of *Acacia mearncii* in nitrogen and in oxygen for comparison of pyrolysis and oxidation effects. The effects of oxygen are significant in both the first rapid weight loss phase and also in the behaviour of the char. The first phase is generally accelerated to lower temperatures by oxidative processes but the first inflection in the differential thermal gravimetry (DTG) curve (Figure 5), which is associated with low temperature degradation of hemicellulose and to some extent lignin, is present in both nitrogen and in oxygen. The char, of course, oxidizes in oxygen but not in nitrogen; the oxidation accelerates suddenly at about 420°C with the onset of smouldering combustion and a resultant sharp peak in the DTG curve.

The cellulose decomposes rapidly to yield the greatest amount of volatiles and char of all wood components, as shown by DTG curves in Figure 7. On the other hand, lignin and hemicellulose decompose with lower rates to produce much more char, although the threshold temperatures of weight losses are lower than those of cellulose.

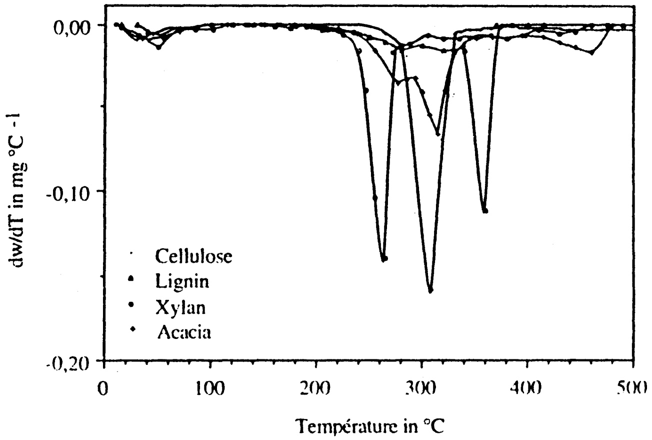

Fig. 7 DTG curves of *Acacia mearncii*, xylan, cellulose and lignin in oxygen atmosphere

At the last stage simultaneously proceeding reactions of combustion of volatile components and active combustion of char are observed. This is composed primarily of carbon with a small percentage of ash and other compounds. Char combustion involves penetration of oxygen into the char, reaction between carbon and oxygen, then the diffusion of product gases out of the sample and into the surrounding atmosphere. It is the most prolonged stage of the process; its rate is not greatly dependent on temperature.

Conclusion

The mechanism of organic matter degradation during thermal treatment in both atmospheres is very complex, this is because a series of secondary reactions can occur. It has been established that oxygen contributes to more intensive degradation. The main weight loss of wood samples by TG was caused by pyrolysis of cellulose which supported the flaming combustion of wood. It is obviously difficult to accurately establish the limits of the temperature intervals mentioned in this work. However, the results published in the literature, and our own results, suggest different temperature intervals in which the decomposition of one or several constituents is dominant.

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