Measuring the Particle Flammability of Forest Species from Wildland/Urban Interface (WUI) near Athens by Thermal Analysis

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***Abstract* – In this study the flammability properties of seven dominant Mediterranean plant species from a wildland/urban interface area near Athens were determined, using thermal analytical techniques (TG, DTG and SDTA) in oxygen atmosphere. The forest materials examined were: *Pinus halepensis, Quercus coccifera, Pistacia lentiscus, Arbutus unedo, Cistus incanus, Erica manipuliflora, Phillyrea latifolia* and forest litter. In addition, the moisture content and the total ash content were determined, in order to correlate flammability properties with these parameters. According to thermal analysis the ignition delay time, heat content, combustion duration and the mass residue were determined. Based on these data, the forest species were ranked into three categories, the least, the moderate and the most flammable ones. Among the forest species examined, the most flammable is *Pinus halepensis* and the least flammable one is *Pistacia lentiscus*.**

I. INTRODUCTION

Thermal analysis is widely used in combustion research for both fundamental and practical investigation. Efficient wildland fire management requires the determination of flammability properties of forest fuels involved. The flammability study of forest species is very important towards the management of forest fires, i.e. facilitates the selection of the appropriate afforestation species for reducing wildfire danger. The flammability of forest species, according to Anderson aspects [1], includes three components: ignitability, combustibility and sustainability. The ignitability determines how easily the fuel ignites. Combustibility is the rate of burn after ignition. Sustainability counts the stability of burning rate or how well the fuel continues to burn [2]. These components can be determined by measuring the burning parameters of the forest fuels, i.e. ignition temperature, ignition delay time, combustion duration, heat content and mass residue. These parameters can be determined by thermogravimetric analysis.

Thermal degradation of forest fuels can be simplified by considering two consecutive steps. The first is the pyrolysis, which is an endothermic process and breaks down the forest matter into low molecular mass gases, known as volatiles, tars, carbonaceous char and mineral ash. Pyrolysis and its products have been extensively studied using various analytical methods [3-8]. Thermogravimetric analysis methods have been used by Susott [6,7] to determine the pyrolysis gases evolved from solid fuels as a function of temperature. A kinetic study of the pyrolysis of white straw have been reported by Stenseng et al. [8], who also have determined the heat of reaction of two biomass types and cellulose, using simultaneous thermal analysis.

The second step is the burning process, which is exothermic and is known as combustion. Combustion properties are usually studied under air flow, in order to simulate open-air fire conditions, where combustion takes place in ambient air [9,10]. Phases of combustion according to Johnson and Miyanishi [11] are the preheating, flaming, smoldering and glowing combustion, which are markedly different phenomena that contribute to the diversity of combustion products. Ignition is the transition between the first and second step. Two types of ignition are distinguished: pilot and spontaneous. Spontaneous ignition characteristics of forest fuels have been studied using thermal analysis by Liodakis et al. [12].

Another important factor related to the flammability of forest species is their heat content (heat of combustion) which is measured by two parameters: the high heating value (HHV) and the low heating value (LHV). According to Nunez-Regueira et al. [13,14], HHV is the amount of energy released by complete combustion and LHV facilitates the evaluation of forest resources from the energetic point of view. Also, Dimitrakopoulos and Panov [15,16] have ranked some dominant Mediterranean species according to their heat content and Siafaca et al. [17] have reported data on the caloric content of leaves, barks and woods of plants dominating phryganic ecosystems in Mediterranean region.

During the last 30 years, Greece has gradually acquired a serious fire problem in wildland/urban interfaces, mostly intensified around metropolitan and tourist locations [18]. The development of WUI areas, either due to the expansion of large cities or the development of summer housing, coincides with the increase in both forest fire numbers and burnt areas [19]. The wildland/urban interface (WUI) is the area where houses meet or intermingle with undeveloped wildland vegetation. WUI is composed of both interface and intermix communities [20]. Intermix WUI are areas above a threshold of 6.17 housing units/km^2 that is dominated by wildland vegetation (>50%) and interface WUI are areas above 6.17 housing units/km^2 that contained <50% wildland vegetation, but are within 2.4 km of an area that is heavily vegetated (>75% wildland vegetation) [20,21]. Both of these areas can be classified depending on housing density and vegetation percentage at low, medium and high housing density.

The objective of the present work is to determine the flammability properties of forest species dominating wildland/urban interface (WUI) zone near Athens, using thermal analysis techniques. Oxygen was selected as a carrier gas in

order to ensure complete combustion of forest species. The tests were performed after reducing plant leaves into a fine, uniform substance (particle foliar flammability). The main purpose of this study is to find the relative fire hazard properties of seven very common forest materials from a WUI zone in the Mediterranean region and to rank them into categories.

II. EXPERIMENTAL

A. Samples

The forest materials examined were: *Pinus halepensis* Mill. (Aleppo pine), *Quercus coccifera* L. (Holly oak), *Pistacia lentiscus* L. (Mastic tree), *Arbutus unedo* L. (Strawberry tree), *Cistus incanus* L. (Pink rockrose), *Erica manipuliflora* Salisb. (Heather), *Phillyrea latifolia* L. (Mock privet) and forest litter (leaf litter). These species are very common in the Mediterranean region and frequently devastated by forest fires, especially in wildland/urban interface (WUI) zones in area of Athens and generally in coastal of Greece. The sampling of the leaves and needles of forest materials took place in Thrakomacedones area at the foothill of mountain Parnitha, northern of Athens. All samples were collected after a long drought period in order to avoid moisture effects. Collection data as well as density values of forest samples examined are shown in Table I.

B. Sample preparations

The foliage forest samples gathered were placed into firmly closed polyethylene bags, brought immediately to the laboratory and dried into a vacuum oven for 48 h under pressure of 10 Torr and temperature of 60 °C. The dried samples were ground and a fraction size between 0.1 and 0.2 mm was separated and used for the tests (Table I). The grounded samples were placed into a conditioning box, set at temperature of 31.3 °C and relative humidity of 8%. The equilibrium moisture content of the tested forest samples was found 2% by linear insertion, according to the tables given in a standard method [22].

C. Thermal analysis

Thermogravimetric analysis (TGA), differential thermogravimetry (DTG) and differential thermal analysis (DTA) were conducted using a Mettler TGA/ SDTA 851 apparatus. The analyses were carried out on 15 to 17 mg samples using open type alumina sample holder. The samples were heated under non-isothermal conditions (25 °C to 600 °C) with a linear heating rate of 10 °C min^{-1}. All runs were conducted in oxygen atmosphere with a flow rate of 100 mL min^{-1}, in order to ensure complete combustion. In addition, the heat content of forest species was measured using a Parr Instrument Company plain oxygen bomb calorimeter in oxygen atmosphere and 1.0 g samples. Heat content values of the samples are presented in Table II.

TABLE I
FOREST SAMPLES TESTED

Forest species	Apparent density/ g mL^{-1}	Absolute density/ g mL^{-1}
Pinus halepensis	0.38 (0.02)	1.57 (0.01)
Forest litter	0.33 (0.03)	1.64 (0.03)
Pistacia lentiscus	0.47 (0.00)	1.52 (0.01)
Arbutus unedo	0.45 (0.01)	1.23 (0.03)
Cistus incanus	0.57 (0.02)	1.16 (0.05)
Phillyrea latifolia	0.51 (0.02)	1.28 (0.02)
Erica manipuliflora	0.56 (0.02)	1.07 (0.06)
Quercus coccifera	0.62 (0.01)	1.30 (0.00)

Collection data: The sample collection of *Pinus halepensis*, *Pistacia lentiscus* and Forest litter took place at 22 October 2005. Sampling site had geographical coordinates: 38º 07′ 50″ N, 23º 46′ 22″ E, altitude: 323 m, average inclination: 10%, exposition: E (97º) and dominated petrologic formation: Coarse-grained fluviolacustrine formation on Parnitha piedmont. The other forest species were collected on 23 October 2005. Sampling site had geographical coordinates: 38º 08′ 46″ N, 23º 45′ 26″ E, altitude: 590 m, average inclination: 60-70%, exposition: S (190º) and dominated petrologic formation: Limestone, dolomites limestone and dolomite. The geographical coordinates and the altitude where found by GPS and the exposition with a compass. The sampling area was 50 m around the above-mentioned geographical coordinates.

D. Measurements

The moisture content of the forest materials was determined by drying the samples into a vacuum oven under pressure of 10 Torr and temperature 60 °C, until constant weight. In Table II is presented the moisture content of the samples, as the percentage of dry weight.

Total ash content was determined using a standard method [23,24]. The ash content was expressed as the percentage of residue after dry oxidation at 590 °C (Table II).

TABLE II
HEAT CONTENT, MOISTURE AND TOTAL ASH CONTENT OF WUI FOREST SPECIES

Forest species	Ash content (% w/w)	Moisture content (% o.d.w)	Heat content (cal/g)
Pinus halepensis	3.17 (0.2)	113.5 (0.4)	4.584
Erica manipuliflora	4.44 (0.1)	88.4 (0.4)	4.729
Quercus coccifera	4.69 (0.2)	74.1 (0.3)	5.514
Arbutus unedo	4.21 (0.3)	109.2 (0.2)	3.080
Pistacia lentiscus	5.75 (0.2)	95.6 (0.1)	5.645
Cistus incanus	6.46 (0.3)	160.5 (0.5)	3.683
Phillyrea latifolia	5.62 (0.1)	81.3 (0.2)	4.098
Forest litter	10.92 (0.3)	15.3 (0.1)	3.596

Note: The ash and moisture content data given in Table are the mean values of three replicate measurements and in parenthesis are given the corresponding RSD values.

TABLE III

THERMOGRAVIMETRIC ANALYSIS IN OXYGEN ATMOSPHERE OF WUI FOREST MATERIALS

WUI Forest species	**Ignition delay time** (min)	**Start of active combustion** (^oC)	**Temperature of maximum weight loss rate** (^oC)	**End of active combustion** (^oC)	**Combustion duration** (min)	**Mass residue** (% o.d.w)
Pinus halepensis	28.1 (0.2)	280.8 (1.4)	311.9 (2.9)	331.0 (2.9)	5.0 (0.2)	0.8 (0.5)
Quercus coccifera	26.6 (0.3)	265.5 (2.8)	301.7 (1.2)	323.4 (2.4)	5.8 (0.2)	4.2 (1.5)
Pistacia lentiscus	26.0 (0.4)	259.8 (3.4)	299.6 (1.9)	318.4 (3.8)	5.9 (0.1)	4.9 (2.0)
Arbutus unedo	26.2 (0.2)	262.2 (2.0)	296.8 (2.4)	317.7 (0.9)	5.6(0.1)	2.5 (2.7)
Cistus incanus	26.6 (0.2)	265.8 (1.7)	300.9 (2.4)	328.2 (0.3)	6.2 (0.2)	5.3 (3.5)
Phillyrea latifolia	26.6 (0.1)	266.4 (1.0)	301.4 (2.3)	327.7 (2.3)	6.1 (0.1)	3.8 (3.1)
Erica manipuliflora	27.7 (0.1)	277.0 (1.0)	311.8 (1.1)	337.5 (0.8)	6.1 (0.0)	2.9 (0.6)
Forest litter	28.3 (0.3)	283.4 (2.7)	312.8 (1.7)	336.0 (2.3)	5.3 (0.2)	4.6 (1.5)

Note: The data given in Table are the mean values of three replicate measurements and in parenthesis are given the corresponding RSD values.

III. RESULTS & DISCUSSION

The TG, DTG and SDTA curves of the forest species examined are shown in Fig. 1. The data derived from thermal analysis were: ignition delay time, combustion duration and mass residue are presented at Table III. According to previous studies [2] the fuels with high ignition delay time have low flash point values. Thus, they are the most ignitable fuels and they burn easily by flame. Also, the fuels with high heat content, low combustion duration and low mass residue are the most flammable. The combustion duration is related to the combustibility as well with the sustainability of fuel, with the most combustible fuels having shorter combustion duration and the most sustainable having longer ones.

Based on the above criteria we found that, *Pinus halepensis* is the most combustible fuel and the *Cistus incanus* the least one. Forest litter is the most ignitable fuel and *Pistacia lentiscus* the least one. Furthermore, forest litter has the highest temperature of maximum weight loss rate and *Arbutus unedo* the lowest one. *Pinus halepensis* has the lowest mass residue and total ash content (most flammable) and Cistus incanus has the highest ones (least flammable). Also, *Pistacia lentiscus* and *Quercus coccifera* have the highest heat content and *Arbutus unedo* the lowest one.

Concluding, the forest fuels examined were ranked into three groups:

1. The most flammable species group: *Pinus halepensis*, *Erica manipuliflora*, Forest litter
2. The moderate flammable species group : *Phillyrea latifolia*, *Arbutus unedo*, *Quercus coccifera*
3. The least flammable species group: *Cistus incanus*, *Pistacia lentiscus.*

The forest litter, one of the most flammable fuels, consists of pine-needles at a percentage of 90%. Thermal analysis measurements confirmed a correlation between forest litter and *Pinus halepensis*. Furthermore, forest litter presents higher fire hazard under a moisture level lower than 15 % o.d.w.

Topics for further research could be focused on the correlation of WUI species flammability with their elemental composition, as well as with their cellulose and lignin content.

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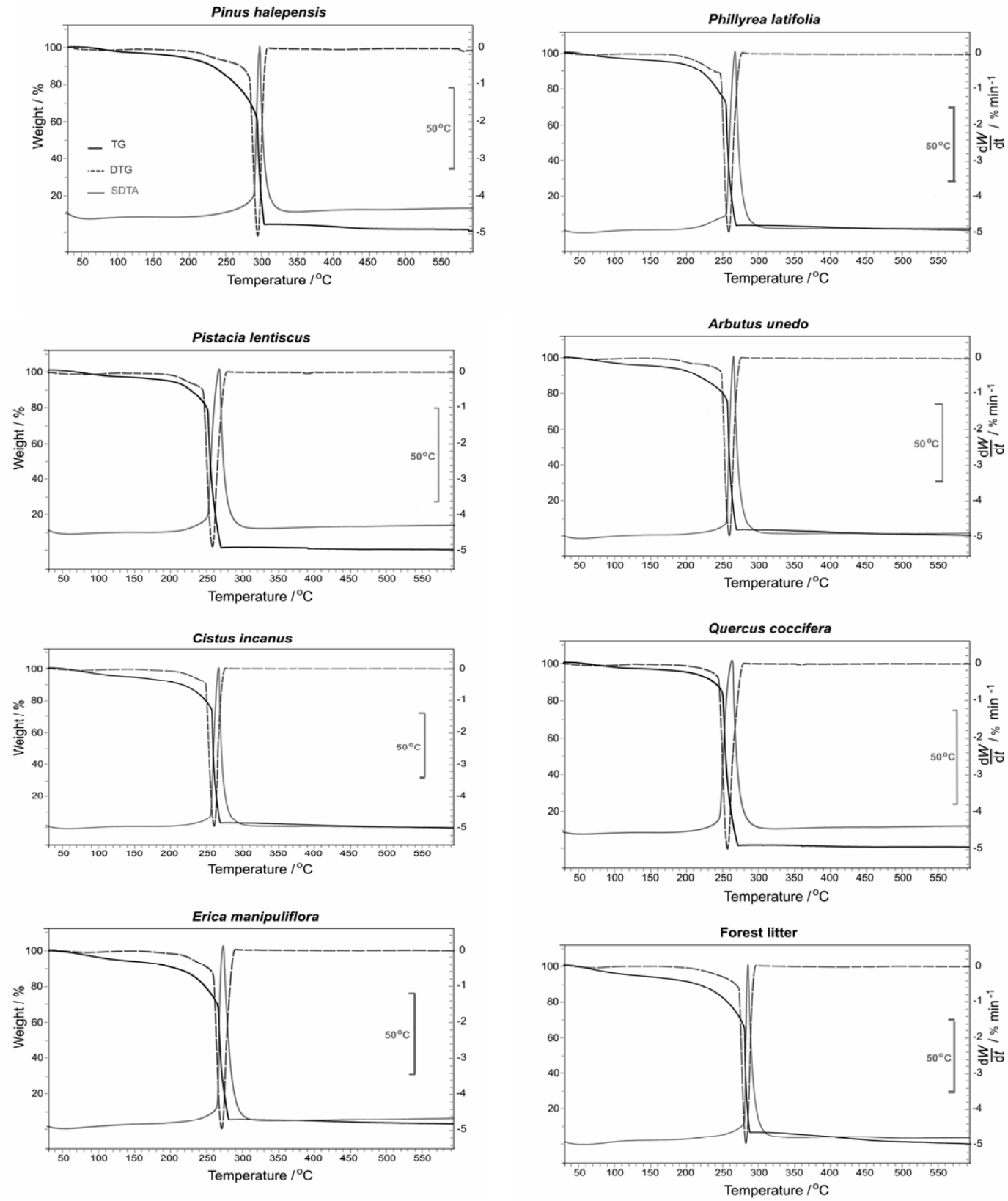

Fig. 1. TG, DTG, SDTA curves of wildland/urban interface plant species near Athens area.

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