Available online at www.sciencedirect.com
ScienceDirect
J. Anal. Appl. Pyrolysis 78 (2007) 430–437
JOURNAL of ANALYTICAL and APPLIED PYROLYSIS
www.elsevier.com/locate/jaap

Complexity and origin of the smoke components as measured near the flame-front of a real forest fire incident: A case study

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Received 5 December 2005; accepted 20 October 2006
Available online 20 November 2006

Abstract

A case study of a real forest fire incident is presented, where field measurements held out near the flame-front in smoky, hostile conditions. Permanent gases, such as CO, CO_2, NH_3, volatile organic compounds (VOCs) and particulate matter ($PM_{2.5}$, PM_{10}) were monitored. Complexity and possible origin of some of the forest fire smoke components are examined and discussed; styrene identified seems that was originated mostly from the combustion of plastics, due to the forest fire expansion to a plastics storehouse. A new approach, regarding the chemical composition of forest fire smoke and possible origin of smoke components depending on the flame-front expansion (e.g. to rural fields, rural and urban constructions or landfills), is presented in the format of a road-map. The case study tests part of the validity of the road-map, which could be used for air-quality indications and risk assessment in a forest fire. Criteria for monitoring air-quality in a forest fire, for health and safety issues, are also discussed.

Keywords: Forest fuel pyrolysis and combustion; Forest fire smoke; Air-quality; Flame-front; Road-map; Field chemical analysis

1. Introduction

Forest fire smoke is a complicated mixture of gases, liquids and solids. Forest fuel combustion has been studied so far in lab scale [1–4], as well as, in prescribed burning [5]. Measurements in a distance from the flame-front have been carried out during large-scale forest fires, such as the ones that took place in SE Asia in 1998 [6], in USA. Montana in 2000 [7] and in Russia during May 2003 [8], in order to assess the impact of the resultant haze.

However, composition of forest fire smoke can become much more complicated if the forest fire expands, i.e. to rural fields, rural/urban constructions, or landfills. As a result, wood, plastics, fertilizers, pesticides, fungicides, wastes can also be burned and hence, some of the components of the forest fire smoke can have a different origin than that of the forest fuel. In addition, forest fire smoke can mix or even react with urban or industrial pollutants, if it passes over urban or industrial areas and hence, secondary products can be produced [9]. As a result, forest fire smoke can have serious short- and long-term health impacts on the fire-fighters and the exposed population [10–12].

It is in the purpose of this work to present a case study of a real forest fire incident, where field measurements were carried out in a smoky, hostile environment close to the flame-front; in addition, to show that some of the forest fire smoke components determined had different origin than that of the forest fuel, due to the forest fire expansion to a plastics storehouse. Classification of forest fire smoke components takes place in the format of a road-map. Possible health effects, due to the exposure to forest fire smoke, are also discussed.

2. Experimental part

The case study is based on a forest fire that took place in Attica, Greece. It was initiated in a forest at an altitude of 400 m, which was situated in the interface of an urban area. The forest was covered with pine trees and bushes with high vegetation density. The fire was initiated during the midday (12.45 p.m.), where the temperature was 32 °C and the relative humidity (RH%) was 22%. Due to the North strong wind (35–40 km h^{-1}),

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doi:10.1016/j.jaap.2006.10.011

the fire was extended with a burning rate of about 5 km h^{-1} and co-burned 10 houses, as well as, a storehouse of plastics that were nearby the forest. As a result, wood and other building materials (due to the houses), as well as, significant quantities of plastics, such as polystyrene (due to the plastics storehouse), were co-burned with the pine trees. The total area burned was 24.2 ha and the fire lasted for about 35 h. It should be noted that while the storehouse was burning, large quantities of black smoke were produced.

Measurements were carried out near the flame-front under smoky conditions, at the side of the plastics storehouse, by using a portable unit and taking all necessary personal protection measures.

2.1. Instrumentation

2.1.1. Portable unit

The portable unit consisted of various portable devices, such as a small meteorological station, a particle analyser (Dustrack TSI, linearity area: 0–100 mg m^{-3}), a CO electrochemical detector (Anagas CD 98 plus, linearity area: 0–500 ppm), a CO_2 infrared detector (Anagas CD 98 Plus, linearity area: 0–60%) and a NH_3 electrochemical detector (TX 2000 Oldham S.A., linearity area: 0–100 ppm). Filters were used to protect the sensors from possible contamination, due to the heavy environment of sampling (soots, tars, ash). A VOCs sampling system was also used to collect samples of smoke in multibed sorbent tubes, by using a portable pump. An open filter holder (Aluminum Gelman), with a glass microfibre filter (GF/A Whatman, ∅47 mm), was put on the top of the tube to protect sorbent materials from contamination. The portable unit also included personal protective tools (masks), communication devices and a GPS.

2.1.2. TDU/GC/MS instrument

Sorbent tubes were thermally desorbed to an HP 5890/5972 gas chromatography/mass spectrometry (GC/MS) system, by using an in-house-made thermal desorption unit (TDU/GC/MS). Details of TDU are explained elsewhere [13,14]. A standard mixture of hydrocarbons was used in four replicates of 1 μL, in order to define the relative standard deviation (R.S.D.) of the system. More specifically for hexane, with concentration 3.508 mg mL^{-1} in the above mixture, the R.S.D. was estimated 5%. Linearity (r^2) and sensitivity were identified for hexane, by using a volume range between 0.5 and 1 μL of this mixture to make the respective calibration curve; they were found 0.899 and 6×10^7 au μg^{-1} respectively, where au is attributed to the arbitrary units given by the mass spectrometer, which were detected as signal intensities of the specific quantities of the standard used.

2.2. Field sampling

On-line measurements and smoke samples were taken during the fire at four different sites (A–D), in a distance of 70–150 m from the flame-front. The GPS was used to record the coordinates of the sites. It should be noted that replicates of smoke samples for each site were very difficult to be taken, because of the heavy environment and for safety reasons.

The sorbent tubes used were glass multibed tubes with dimensions of 11.5 cm × 6 mm o.d. × 4 mm i.d., Supelco (60:80 Carbopack C/60:80 Carbopack B/60:80 Carbosieve SIII), so as to capture organic compounds of low, medium and high volatility. A methanolic solution of chlorobenzene-d_5 (1 μL) was used as an internal standard (i.s), spiked into the sorbent tubes, before taking them to the field for sampling. More details about preparation of sorbent tubes before sampling are described elsewhere [13]. The sampling was done at a flow-rate of 200 mL min^{-1}.

The sorbent tubes where transferred in a freezing box to the lab and analyzed 1 day after, by the TDU-GC-MS instrument.

2.3. TDU-GC-MS analysis of VOCs

For the thermal desorption of VOCs, He flow was set at 30 mL min^{-1} (column head pressure 25 psia). Thermal desorption of the sorbent tube lasted for 20 min at 200 °C, to maximize recovery. The cryotrap capillary was 22 cm, 0.53 mm i.d., AT-Q, Q-Plot column (Alltech Associates). The dimensions were chosen to trap ultra-VOCs and contribute to the increase of chromatographic resolution. In order to achieve flash ''injection'' to GC column of the traped analytes, a heating pulse of 20 s was set. Cryotrapping was done by using liquid nitrogen.

An intermediate SPB-624 capillary column with 1.4 μm film and dimensions 60 m × 0.25 mm (Supelco) was used for the high-resolution chromatographic separation. Heating of the GC column started at 60 °C for 4 min and increased with a temperature rate of 4 °C min^{-1} to 225 °C, where held for 30 min. The MSD was in full scan operation mode, with mass range 35–200 amu and the benefit of 1.8 scans s^{-1}. Transfer line temperature was at 280 °C.

2.4. Data processing

The qualitative identification of chromatographic peaks was done by using the Wiley 138 library and the data base ''Easy Id'' HP Chemstation. The semi-quantitative determination of VOCs was carried out by using the respective relative response factors (RRF). More details regarding the semi-quantitative determination procedure are described elsewhere [13]. Prior to quantitation, substraction of the background took place. Background measurements were carried out in long distance from the flame-front.

3. Results and discussion

3.1. Classification of forest fire smoke components

In Table 1, classification of forest fire smoke components takes place in the format of a road-map, where possible physical and chemical processes, as well as, chemical components of forest fire smoke and their physical and chemical properties, are correlated to the forest fire flame-front and smoke pathway.