Algerian Journal of Research and Technology
https://doi.org/10.58681/ajrt.22060206
*A.J.R.T Volume 6 (N°2) (2022) 44 - 49*

# Comparative Study of Ignitability Behavior of Various Wild Land Fuels

H.Boutchiche, O. Mosbah, F. Z. Sabi, S.M. Terrah, N. Zekri

*Université des Sciences et de la Technologie d'Oran, LEPM BP 1505 El Mnaouer Oran, Algeria*

**Corresponding author. {nzekri@yahoo.com} https://orcid.org/0000-0001-7325-4114; hananelimang@gmail.com.*

Received. July 11, 2022. Accepted. September 01, 2022. Published. September 22, 2022.

**DOI:** https://doi.org/10.58681/ajrt.22060206

**Abstract.** An experimental study of the influence of incident heat flux on the ignition and residence time of three different types of vegetation is provided in this paper. The vegetation samples were exposed to different incident heat fluxes ranging from10 to 20 $kW/m^2$delivered by a cone calorimeter. The obtained results show a linearity dependence of the inverse of ignition time on the incident heat flux of the used vegetation. This linearity appears from 10 to 15 $kW/m^2$for *Ph* needles, from 12.9 to 15 $kW/m^2$for *Ec* leaves, and from 17 *to* 20 $kW/m^2$ in the case of straw stems.

***Keywords.*** Ignition time, Residence time, Incident heat flux, Vegetation.

**Nomenclature.**

| | | | |
|---|---|---|---|
| $Ph$ | *Pinushalepensis* | $SVR$ | *Surface-to-volume ratio*$(m^{-1})$ |
| $Ec$ | *Eucalyptus* | $q_{inc}$ | *Incident heat flux (kW/m²)* |
| $St$ | *Wheat straw* | $\rho$ | *Particle density (kg/m³)* |
| $t_{ign}$ / $t_{res}$ | *Ignition / Residence time (s)* | $m$ | *Mass (g)* |

## INTRODUCTION

Ignition and fire propagation depend on several physical processes and parameters. The classification of vegetation from the most to the least flammable requires the knowledge of the ignition properties of forest combustible, as well as its ability to maintain the flame (flame persistence).

The classification of forest fuel according to their rate of flammability makes it possible to fight against fire propagation, and to minimize its damage, for example by planting plants that resist fire. Ignition and flame persistence time depend on the type and the quantity of vegetation (fuel load), its arrangement, its state (live or death), its moisture content, etc.

The study of the conditions and parameters influencing the ignition and flame residence time arouses the interest of several theoretical and experimental researches.

This research aims to understand how forest fire is involved and developed and find a way to predict fire initiation and propagation to minimize and control this moral and material damage.

Sabi et al. (2021) have studied the probabilistic behavior of the ignition time at low incident flux and determined a new method to estimate the critical heat flux corresponding to flammable/non-flammable transition.

Terrah et al. (2020) studied the influence of moisture content on ignition time and found that there is no critical moisture content allowing ignition but there is a characteristic moister content for ignition.

The effect of the drying process on ignition and residence time was examined by Hamamousse et al. (2021).

The influence of the physical parameters such as the density of the fuel, surface to volume ratio, the porosity, flow conditions, and permeability of the fuel bed was strongly investigated to understand ignition and propagation process and reproduce it by numerical and simulation models (Boutchiche et al., 2020; Santoni et al., 2014).

This study aims to compare the ignition process of three different types of vegetation dried *Pinus Halepensis* needles, *straw*, and *eucalyptus* leaves.

## EXPERIMENTAL SETUP

Naturally dried, wheat straw with an average moisture content of 10% and fresh Ph needles harvested from the campus of USTO University is at about $50\%$ moisture, dried for $3\ minutes$ at $800\ W$ in a microwave oven are used as a combustible in this study.

The ignition time of these two types of vegetation is compared with the ignition time of dried *Eucalyptus* leaves realized by Sabi (2021) (Table 1).

Table 1. Fuels characteristics.

| Fuels | $m_i$(g) | $m_d$(g) | SVR($m^{-1}$) | $\rho$ *(kg/m*$^3$*)* |
|---|---|---|---|---|
| *Ph* (Lamorlette et al., 2015, Boutchiche et al., 2020) | 10 | 4.7 | 7377-7440 | 716-789 |
| *St* (Boutchiche, 2019) | 10 | 10 | 2342 | 268-287 |
| *Ec* | 10 (Sabi, 2021) | 4.57 (Sabi, 2021) | 6180 (Brown et al., 1970) | 1800 (Okonkwo et al., 2006) |

A cone calorimeter with an electrical resistance of $3000\,W$ power, used as a heat source, provided a radiation heat flux to the fuel sample.

The vegetation samples were placed in a cylindrical holder of 10 cm in diameter of a mesh shape and 1 cm in height and then exposed to different heat flux ranges.

The radiant heat flux is calibrated by using a water-cooled heat flux sensor of type Hukse flux SBG 01 working in the range $0 - 200\ kW/m^2$.
The ignition process is controlled by a pilot located 1 cm above the sample top surface according to ASTM 1354 standards (ASTM, 2016).
The ignition time $t_{ign}$ is recorded if the flame persistence time is greater than 4s. Five flammability tests were realized for each value of incident heat flux.

## RESULTS AND DISCUSSION

When the sample is exposed to constant heat flux, its surface temperature increase, and volatiles emission starts, once the mixture of flammable gas/oxygen surpasses the flammability lower limit the sample ignites.
The experimental behavior of the inverse of ignition time of three vegetation types by varying the incident heat flux is examined in this section. It is expected from the theory of ignition that the inverse ignition time behaves linearly with the incident heat flux within the limit of large fluxes (Quintiere, 2006). This theory is not valid for the small incident heat flux where the critical region and the probabilistic behavior appear.

$$\frac{1}{t_{ign}} = Cq_{inc} \qquad (1)$$

The linearity is observed in the range from 10.8 to15$kW/m^2$ for Ph needles with a corresponding slope of $0.008\, m^2/kJ$, from 12.9 to 15.4 $kW/m^2$ for Ec leaves with a corresponding slope of 0.013, and from 17 to 20 or more for straw stems with a higher slope than *Ph* and *Ec* (Fi.g.1).

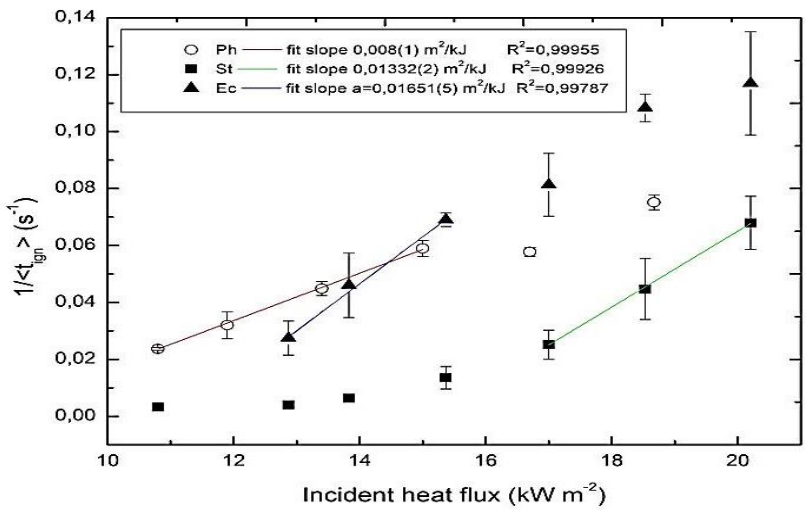


Fig.1. Average inverse ignition time vs. incident heat flux for dry Ph needles, St Stems, and Ec leaves (Okonkwo et al., 2006).

The linear fit is much butter for *Ph* and *Ec* samples. For larger fluxes, the ignition time seems to fluctuate in the case of *Ph* and Ec samples. These fluctuations may be due to the rapid rate of organic components emission by fuel that can hinder the incident flux attenuation. These fluctuations appear in the range of low flux from 9 to 15 $kW/m^2$for straw stems near the critical heat flux.
Based on the theory of ignition, below the linear behavior of the inverse of ignition time, the critical heat flux can be defined. The critical heat flux is lower than 10 $kW/m^2$ for *Ph* needles, lower than 12.9 $kW/m^2$for *Ec* leaves, and lower than 17 $kW/m^2$for *St* stems.

From figure 1, for the fluxes ranging from 9to 14.5 $kW/m^2$, the $Ph$ needles ignite more quickly than the $Ec$ leaves and $St$ stems. Beyond the 14.5 $kW/m^2$ the $Ec$ samples' ignition time will be smaller than that of the $Ph$ and $St$ samples.
The *St* samples have a higher ignition time. This difference in ignition time is caused by the different structure and composition of the used samples, their particle density, their size, and geometry that can be characterized by the Area-to-Volume Ratio (*SVR*).

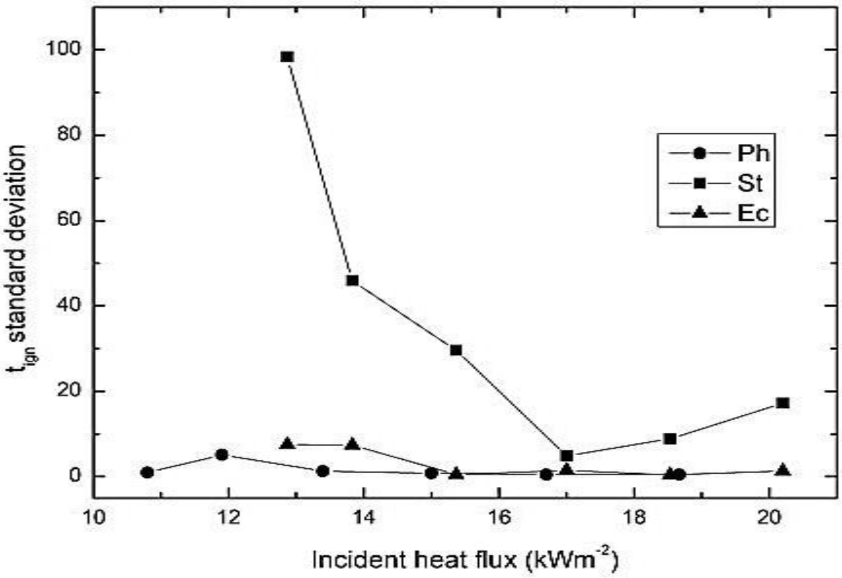


Fig.2. A standard deviation as a function of incident heat flux for the used vegetation

The standard deviation on the measurement of the ignition time is higher for the low fluxes range, it becomes much larger as the critical region is reached (the exposition time becomes higher), in this region some samples did not ignite, and the probabilistic aspect appears which requires a high repetition of ignition tests. This behavior near the critical zone was examined recently (Sabi et al., 2021).
Straw ignition time is larger for the low fluxes (large exposition time) which implies a greater standard deviation than the other two vegetation. These fluctuations may be caused by the condensation of emitted gases that do not quickly reach the lower flammability limit at the top so it hinders the penetration of the incident radiation.
For the high fluxes range the measurement of ignition time standard deviation becomes minimal in view that the exposition time will be reduced. The absorbed energy is much higher and the emission gas rate will be faster, so the lower flammability limit will be reached quickly.
The flame persistence seems to be constant for *Ph* needles and *Ec* leaves within errors, and significantly fluctuates for *St* Stems in the studied range of fluxes. Figure 3 shows that the flame persists in all the flux ranges in the case of *Ph* and *Ec*, which can be due to their chemical composition and their large amount of emission of organic components that allows flame persistence.
However, for straw the residence time increase with heat flux which means that the organic matter needs height energy to degrade.

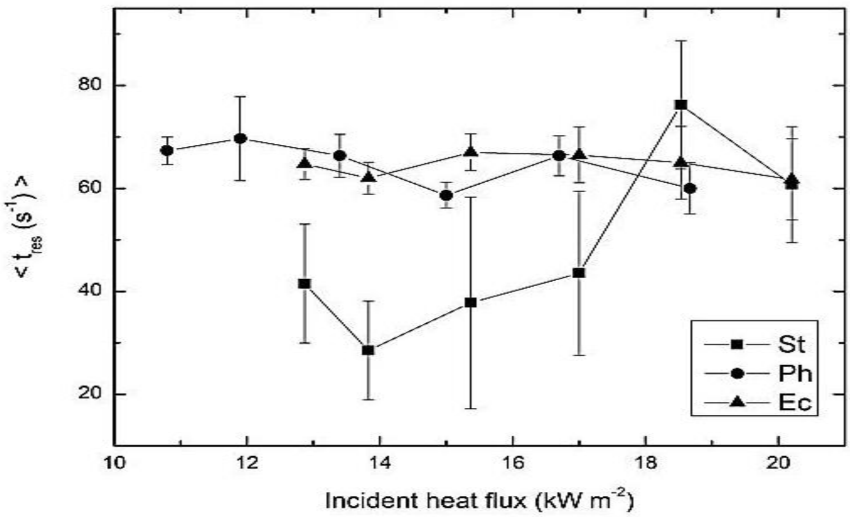


Fig.3. The average residence time vs. incident heat flux for dry Ph needles, St Stems, and Ec leaves (Okonkwo et al., 2006).

**CONCLUSION**

Ignition time and residence time of two types of vegetation are measured in this study, in the heat fluxes ranging from 10to 20 $kW/m2$. The obtained results were compared with the *Eucalyptus* results realized by Sabi(Sabi et al., 2021). The linearity dependence on heat flux is observed for the three types of vegetation in a different range of incident heat fluxes. This difference is due to several parameters such as the particle density, SVR, the fuel load, and particle arrangement which can influence directly the porosity of the fuel and consequently the flow conditions over the samples, causing the observed fluctuations in ignition and residence time. The critical heat flux must be observed below 10 kW/m$^2$, 12.9 kW/m$^2$, and 17 kW/m2, for Ph needles, Ec leaves and St stems respectively.

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