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BEHAVIOR OF BURNING FIRE IN DRY DECIDUOUS DIPTEROCARP FOREST AT HUAI KHA KHAENG WILDLIFE SANCTUARY, UTHAI THANI PROVINCE

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ABSTRACT

Behavior of burning fire in the dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary was studied in twelve plots, 30 x 30 m^2, with completely randomized design and burning in three plots per each month from January to April in 2003 and 2004. Rates of fire spread, flame heights and flame temperature were recorded for every two minutes in eight cardinal directions during burning. Fire line intensity and flame lengths were determined by using Byram's formula. Comparisons of the result differences among the four months burning, and between the first year and second year were made. The results revealed that the surface fire intensity was not severe. The averages of rate of fire spread, fire line intensity, and flame length from the first year burning were 0.47 m min^{-1}, 66.17 kW m^{-1} and 0.54 m, respectively, and the averages of those from the second year burning were 0.44 m min^{-1}, 44.33 kW m^{-1} and 0.45 m, respectively. Most fire descriptors were higher in heavier load and drier fuel months. However, the large amount rain in 2003 and the lower fuel load in 2004 led to low fire intensity.

INTRODUCTION

Fire is a major disturbance leading to numerous changes in an ecosystem because forest fire occurrence has a number of impacts on the environment. It reduces forest area, retards tree growth rate, and reduces wood quality. Flora is killed by the high temperature and wild animals may become extinct. Soil nutrients will be depleted and repeated forest fires destroy

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the natural soil texture, which leads to escalated water run-off. Rapid water run-off is to a large extent responsible for causing excessive flooding in many areas of the Southeast Asian region. In addition, forest fires cause the global temperature to rise, which in the long run will have a very negative effect on living organisms. The forest fire may directly reduce the beauty of the scenery, and the spreading of its emitted gas and smoke may be harmful to people within the country and neighboring countries. So the forest fire is both a national and international environmental problems.

However, the controlled fire or prescribed burning is a very useful silvicultural tool. It can be used to prepare a site for planting by reducing slash or to prepare a seedbed for seed fall. Prescribed burning can also be used later in the life of a forest for silvicultural purposes, to improve wildlife habitat, to reduce the hazard of wildfire. Moreover, it is a fire controlled for reducing or eliminating the unincorporated organic matter on the forest floor or undesirable vegetation.

In Thailand, forest fire is one of the main causes of forest destruction, and occurs annually during the dry period (December - May) in the deciduous forests of drier environments with the peak period in February. Dry weather and strong wind will accelerate the forest fire intensity (Viriya-rattanaporn, 2001).

Huai Kha Khaeng Wildlife Sanctuary was selected and established as the World Heritage Site by UNESCO since December 1991. The mixed deciduous, bamboo forests and especially the dry deciduous dipterocarp are the main sources of forest fuel. This Sanctuary witnessed one of the most devastating forest fires during the months of February and March in 1998 (Giri and Shresta, 2000). Forest fire occurred from mid December until late April and the peak fire season occured in March. The economic damage in the dry deciduous dipterocarp at Huai Kha Khaeng Wildlife Sanctuary was 6,178.25 Baht rai^{-1} (Sompoh, 1998).

The dry deciduous dipterocarp forest in the protected area serves as a “buffer” for the World Heritage area from the agricultural development area. This buffer zone is very important for both wildlife and livestock. The intensive fire suppression and prevention activities are not only decreasing the frequency of forest fires, but also understory shrubs and hardwoods are becoming denser and fuel is accumulating which will increase the risk of large and damaging wildfires. Although the role of fire is to maintain this forest type’s condition, fire is a critical element in shaping the ecology of Huai Kha Khaeng Wildlife Sanctuary because fire occurs annually.

Thus far, the fuel and forest fire behaviors have been conducted in many areas of dry deciduous dipterocarp forests, mixed deciduous forests and grass lands. The forest fire behaviors would differ from place to place, forest types, fuel quantities and other surrounding factors. This study is designed and planned to determine the behavior of burning fire over various periods in a month time-scale and continued study within the second year after the first year burned on the dry deciduous dipterocarp forest ecosystem. Therefore, fuels and surroundings are significant factors to define fire behaviors and impacts on different manners; it was to evaluate forest behaviors in consecutive durations.

MATERIALS AND METHODS

Behavior of burning fires was studied in the dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Santuary, Uthai Thani Province. Twelve plots of 30x30 m^2 size of each were laid out by using completely randomized design. One 10x10 m^2 control plot (unburned) was located near the burning plots. Three plots of 30x30 m^2 in size of each were burned in each month from January to April in 2003 and again in 2004. Fire behavior data from both years' burning were collected during burning.

Before burning, a metal pole was staked at the center of the 30x30 m^2 plot and other metal posts were staked along 8 cardinal points of the compass, at one meter intervals. Wind speed and relative humidity were measured before burning. Fire was lit at the center of the plot. During burning; fire behaviors including rate of fire spread and flame length were measured. Flame temperature was also measured at 50 points during burning. Fire line intensity and flame length were determined by using Byram's formula (Byram, 1959).

Rate of fire spread

Rate of fire spread was recorded every two minute in every direction. Fire spread maps were sketched. Rate of fire spread (R) was determined by;

$$R\ (\mathrm{m\ min^{-1}}) = \frac{\text{distance of fire spread (m)}}{\text{time of fire spread (min)}}$$

Flame height

During burning, flame height was determined by the height level as marked on the stakes every two minute in every spread direction until the burn was finished.

Flame temperature

During burning, flame temperature was measured at 50 points from the fire flame by Infrared Thermometer (Minolta Spot Thermometer, TA-0510) with the flame temperature data showed as a digital number.

Fire line intensity

Fire line intensity (I_B) was determined by using Byram's formula recommended by Sathirasilapin (1987):

I_B (kWm^{-1}) = 0.007 H Wa R

Where, H = Heat yield ($cal\ g^{-1}$)

Wa = Loading of available fuel ($tons\ ha^{-1}$)

R = Rate of fire spread ($m\ min^{-1}$)

Heat yield calculated from heat of combustion of forest fuel in the dry deciduous dipterocarp forest and analyzed by bomb calorimeter were 4,457.23 $cal\ g^{-1}$ (Sompoh, 1998) minus the heat losses resulting from radiation (666.67 $cal\ g^{-1}$) and vaporization of moisture (Brown and Davis, 1973). Loading of available fuel (Wa) and rate of fire spread (R) were from the study.

Flame length

Flame length (m) was determined by using Byram's formula (Byram, 1959) as follow;

$$L\ (m) = 0.08\ (I_B)^{0.46}$$

Where, I_B = Fire line intensity (kWm^{-1})

Fire behavior comparison included rate of fire spread, fire line intensity, flame height, flame length and flame temperature among studied months and between the first and the second year burning by using a ready-made computer program.

RESULTS AND DISCUSSION

Fire behavior included burn pattern, flame height, rate of fire spread, fire line intensity, flame length and flame temperature were described as below information, while, the fuel bed properties and weather condition before burning are shown in Table 1.

Burn pattern

The study area was nearly flat and the wind was quite light. Burn patterns showed two shapes: an approximately circular area and the shape of an oval (Figure 1). The approximately circular area occurred in the absence of wind, where the fire spread at about the same rate in all directions. In low wind speed conditions, the wind direction was not constant; and as the fire spread along the wind direction, the spread pattern was an oval shape.

Burn patterns in the first year burning were an approximately circular and the fire spread maps were quite narrow line. While, burn patterns in the second year burning showed the shape of an oval and the fire spread maps were wider. Comparison to the first year burning, because the wind speed conditions during the second year burning (0-7 miles hr^{-1}) were higher than during the first year burning (0-3 miles hr^{-1}), so the spread patterns were rather more oval

Table 1. The data of fuel bed properties and weather conditions of the first and the second year burning in the dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary

Variables	Year 2003				Year 2004			
	January	February	March	April	January	February	March	April
Fuel bed properties								
Average fuel moisture content (%)	54.28	58.74	31.17	59.02	55.48	39.77	49.32	26.65
Average fuel height (cm)	42.64	36.50	38.31	26.15	39.73	23.33	19.75	23.92
Average fuel frequency (%)	95.83	75.00	97.92	100.00	100.00	100.00	100.00	93.75
Total fuel coverage (%)	75.83	72.92	66.67	65.00	71.67	82.92	87.50	82.92
Total fuel load (ton ha^{-1})	6.5826	5.1476	7.6007	8.0980	3.924	5.900	5.421	4.755
Weather conditions before burning								
Wind speed (miles hr^{-1})	2.00	2.00	0.00	3.26	2.00	2.50	1.00	2.00
Air temperature (^{o}C)	32.00	38.00	34.00	39.00	39.00	42.00	43.00	43.00
Relative humidity (%)	83.00	80.00	89.00	88.00	79.00	73.00	83.00	79.00

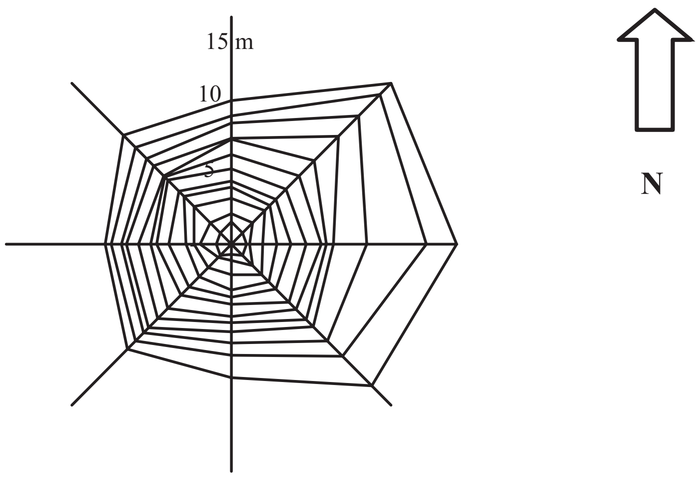
shape. However, burn patterns in this study were not constant and wind was the most influences to the burn patterns. However, shape or pattern of fire depended on degree of slope (Akaakara, 1996).

Fire behavior in each month burning

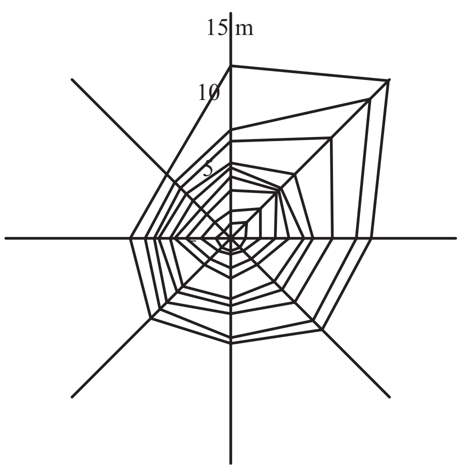
Flame height

Flame height is estimated by observing the average maximum height of continuous flames over a period of time and for some distance around the perimeter of the fire (Mendes-Lopes *et al.,* 1998).

The first year burning showed that the average flame height ranged from 0.19 to 1.80 m. with the highest values was in April (Table 2). The results found no differences among the burn months. In contrast,



The first year burning (2003)



The second year burning (2004)

Figure 1. Burn patterns of the first and the second year burning in the dry deciduous dipterocarp forest

Table 2. Mean (range) of fire behavior descriptors from the burning in the dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary

Month Burning	Flame Height (m)		Rate of fire spread (m min^{-1})		Fire line intensity (kW m^{-1})		Flame length (m) (Byram's equation)		Flame temperature (^{o}C)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
January	0.43 (0.19-0.97)	0.53A1 (0.23-0.88)	0.48A (0.31-0.75)	0.53A (0.33-0.82)	63.50Aa (41.48-88.46)	40.66Ab (18.85-69.96)	0.54a (0.44-0.63)	0.43Ab (0.30-0.56)	124.75Aa (30.4-536)	361.88Ab (78.9-594.0)
February	0.43a[2] (0.29-0.68)	0.32BCb (0.16-0.54)	0.56Ba (0.35-0.72)	0.44Bb (0.32-0.66)	60.32Aa (41.08-84.72)	52.58Bb (24.67-77.79)	0.52a (0.44-0.62)	0.49Bb (0.35-0.59)	130.10Aa (32.1-275.0)	254.74Bb (113-401)
March	0.42a (0.19-1.01)	0.26Bb (0.11-0.38)	0.45ACa (0.23-0.77)	0.31Cb (0.18-0.54)	76.91Ba (27.64-152.03)	34.72Ab (16.90-56.56)	0.57a (0.37-0.80)	0.40Ab (0.29-0.51)	115.51Aa (60.8-199.9)	224.81Cb (176-343.47)
April	0.53a (0.34-1.80)	0.38Cb (0.16-0.76)	0.40Ca (0.22-0.71)	0.49ABb (0.30-0.92)	63.95Aa (44.37-87.59)	49.37Bb (30.81-93.19)	0.54a (0.46-0.62)	0.47Bb (0.39-0.64)	175.36Ba (105.0-274)	206.09Cb (101.84-384)
Average	0.45a (0.19-1.80)	0.37b (0.11-0.88)	0.47 (0.22-0.77)	0.44 (0.18-0.92)	66.17a (27.64-152.03)	44.33b (16.90-93.19)	0.54a (0.37-0.80)	0.45b (0.29-0.64)	136.43a (30.4-536)	261.88b (78.9-594)

Remark : [1] Means followed by the different letter are significantly different ($p<0.05$) among the month burnings.

[2] Means followed by the different letter are significantly different ($p<0.05$) between the 1st and 2nd year burning

the average flame height in the second year burning was 0.37 m. The flame height ranged from 0.11 to 0.88 m. The data in January was significantly higher than that in other months ($F=17.364$, $p=0.000$). Moreover, the average of flame height in the second year burning was significantly different from those in the first year burning ($t=2.980$, $p=0.003$). This might be due to the fuel load and the fuel height in the second year fire being less than those in the first year fire.

The flame height showed a significantly positive correlation with the grass height ($R=0.55$, $p<0.05$), average fuel height ($R=0.48$, $p<0.05$), and grass load ($R=0.47$, $p<0.05$), while it showed a significantly negative correlation with litter load ($R= -0.60$, $p<0.05$) and twig coverage ($R=-0.45$, $p<0.05$).

Rate of fire spread

The results indicated that rate of fire spread in the first year burning was 0.48 m min^{-1} in January and significantly increased in February (0.56 m min^{-1}). In March and April, rates of fire spread slightly dropped to 0.45 and 0.40 m min^{-1}, respectively, while in the second year burning, the average rate of fire spread was 0.44 m min^{-1} and ranged from 0.18 to 0.92 m min^{-1}. The rate of fire spread was highest in January (0.53 m min^{-1}), and lowest in March (0.31 m min^{-1}). However, there were no significant differences in rate of fire spread between the first and the second year burning. The rate of fire spreads were significantly related with grass height ($R= 0.44$, $p<0.05$) and litter load ($R= -0.534$, $p<0.05$). The other reports on fire behavior in dry deciduous dipterocarp forest in Doi Suthep-Pui National Park showed rate of fire spread ranged from 0.28-6.41 m min-1with the average of 1.72 m min^{-1} (Akaakara, 1985). While the rate of fire spread from burning in February in the dry deciduous dipterocarp forest in Sakaerat, Nakhon Ratchasima, was 2.0 m min^{-1} (Sunyaarch, 1989). The average fire spread of head fire in Kanchanaburi during fire season, was 2.81 m min^{-1}. The most severe fire took place in early March when rate of fire spread reached to 6.96 m min^{-1} on a 45 percent slope. Head fire advanced 4.9 times faster than rear fire (Akaakara, 2002).

Fire intensity

Fire intensity is the rate of heat energy released during combustion. Fire intensity can be measured in two ways as fire line intensity, which refers to the release of heat energy per unit time per unit length of fire front (Byram, 1959) and flame length, which is the distance measured from the average flame tip to the base of the flame in the middle of the flaming zone (Teie, 1997).

Fire line intensity

The average fire line intensity in the first year burning was 66.17 kW m^{-1} and ranged from 27.64 to 152.03 kW m^{-1}. The average fire line intensity in head fire was 84.60 kW m^{-1}, while that of the back fire was 51.13 kW m^{-1}. The fire intensities of head fire ranged from 1.5-2 times higher than that of back fire.

The greatest fire intensity found in March (76.91 kW m^{-1}) due to dry surface fuel. Fire line intensity varied across burning month because fire line intensity was affected by five factors; fuel loading, compactness, fuel moisture content, slope and wind speed (Teie, 1997). Although weather conditions during burning in April were more severe and fuel load was higher than the March burns, but the rain that occurred few days before the burn had caused the fuel to be moister. This moister fuel in April, especially undergrowth, might have been the cause of the lower fire intensity than in March. Similarly, high fuel moisture contents, coupled with a lack of fuels in February plots, resulted in a less intense burn. Thereby, the fire line intensity in March was significantly different from those in other months ($F= 2.797, p=0.045$).

The results from the second year burning showed that the average fire line intensity was 44.33 kW m^{-1} and ranged from 16.90 to 93.19 kW m^{-1}. Similar to the first year burning, the average fire intensity of head fire (59.91 kW m^{-1}) was 1.5 to 2 times higher than that of back fire (33.31 kW m^{-1}). The highest fire line intensity occurred in February (52.58 kW m^{-1}), but the value was not significantly different from the burning in April (49.37 kW m^{-1}). Although the weather conditions in the second year burning were more severe but there was lower fuel load, resulted in the fire line intensities being significantly lower than the first year burning in every month. The results of fire line intensity in the present study indicated that fire line intensities were mostly correlated with total fuel load ($R = 0.758, p = 0.000$), while they were significantly correlated with undergrowth coverage ($R = -0.473, p < 0.05$), twig load ($R = 0.653, p < 0.05$) and undergrowth load ($R = 0.520, p< 0.05$). This result suggested obviously that lower fuel load could be reduced fire line intensity.

In the present study, the low fuel loads and the low wind speeds, the gentle sloping topography, the different rate of fire spread measurement and heat yield calculation method, so the fire line intensities were lower than those of the natural fires in the dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary in 2001 to 2002, which the average was 298.31 kW m^{-1} (Forest Fire Research Center, 2003) and in the other dry deciduous dipterocarp forests in Thailand as in Doi Suthep-Pui National Park, Doi Angkhang; Chiangmai and Huai Kha Khaeng Wildlife Sanctuary showed the average fire intensity was 249.26 kW m^{-1}. (Akaakara, 1985), 266.03 kW m^{-1} (Sunyaarch, 1989) and 110.71 kW m^{-1} (Sompoh,1998), respectively. While the fire intensity from burning in February in Sakaerat, Nakhon Ratchasima, was 38,627.83 kW m^{-1} (Boonplain, 1985)

Flame length

The trend of flame lengths was similar to fire line intensity. The greatest flame length was associated with the most intense fire in March (0.57 m), while the lowest flame length was 0.52 m in February. Comparison of the means by the analysis of variance showed no significant differences for all the burning months.

The results from the second year burning showed that flame lengths were 0.43 m, 0.49 m, 0.40 m and 0.47 m in January, February, March and April, respectively. Similarly to the first year burning, the greatest flame length and the differences among the monthly burns in the second year burning were the same values as the fire line intensity. There were significant differences between the first and the second year burning ($t=8.640$, $p=0.000$) because of the difference in the fuel load.

It appeared that, regardless to the strong correlation between the flame length and the fire line intensity ($R = 0.987$, $p = 0.000$), flame length had a significantly strong correlation to total fuel load ($R = 0.728$, $p = 0.000$). Moreover, other significant correlations were the loads of twig ($R = 0.594$, $p < 0.05$), grass ($R = 0.420$, $p < 0.05$) and undergrowth ($R = 0.481$, $p < 0.05$). Moreover, under the abnormal weather conditions, where rain occurred in the summer and the difference in fire line intensity calculation, the flame lengths in this study were shorter than those both in the natural forest fires (0.847 m, Forest Fire Research Center,2003) and in other studies as reported by Sompoh (1998) was 0.70 m and by Sunyaarch (1989) was 2.58 m.

By normal statistical standards this coefficient of determination is rather low. However, experience gained by conducting fire research would indicate that it is virtually impossible to obtain higher levels of precision when modeling such a complex phenomenon as fire behavior. The fact that the result from the statistical analysis was significant, conceptually meaningful and logical, suggests that this result can be used as a guide for predicting the behavior of fire. It should never be forgotten though, that fire is a highly complex phenomenon that is very difficult to model precisely (Trollope *et al.,* 2002).

Flame temperature

Flame temperature is an indicator necessary to be clearly known for the fire fighter safety. High flame temperatures increase the difficulty for fire fighters to approach the fire front. Finally, damaging effects on trees and soil will also be increased by the higher temperature.

The results of flame temperature, showed that the average flame temperatures from the first year burning was 136.43 °C (30.40-536.00 °C). Flame temperature was 124.75 °C, 130.10 °C, 115.51 °C and 175.36 °C in January, February, March and April, respectively. The means of flame temperature in April were significantly higher than those in other months ($F=9.022$, $p=0.000$).

Average flame temperature from the second year burning was 261.88 °C. The lowest flame temperature was in April (206.09 °C), while the highest flame temperature was in January (361.88 °C). Moreover, it was significantly higher than those in other months ($F=57.345$, $p=0.000$). Comparison of the values from both year burnings found that the flame temperature in the second year burning was significantly higher than those in the first year burning ($t=-15.744$, $p<0.001$). This might be due to the weather conditions during the burning that in the second year burning they were more severe than in the first year burning.

Flame temperature showed a significant positive correlation with the coverage of grass ($R = 0.475$, $p < 0.05$), while showed a significant negative correlation with twig height ($R = -0.411$, $p < 0.05$) and undergrowth load ($R = -0.574$, $p < 0.05$).

Most values of fire characteristics were high in the monthly burns, that had high total fuel loads. Fire behaviors were mostly correlated with the fuel bed properties. The properties of forest fuel, especially fuel moisture content and fuel loading, were the main important factors controlling fire behavior. The fire behavior values in this study were low severity due to the low fuel load and the abnormal weather conditions during the period of study.

Fire behavior characteristics determine how and where the fire fighters should fight fire, as well as the strategies and tactics they should use. The results showed that the average fire line intensity and flame length were less than 345.86 kW m^{-1} and 1.22 m, respectively. Fire suppression interpreted that fire can generally be attacked at the head or flanks by fire fighters using hand tools and hand line should hold fire. Two basic principles for safety the fire fighters i.e. training and equipment are very important. A personnel training is necessary in order to teach crews to work as a team, to improve their technical skills and to provide the essential concepts of fire behavior and the necessary of putting safety first. The essential tools and equipment are also important to provide each fire fighter with personnel gear that affords them comfort and protection in the hard conditions of their mission.

CONCLUSIONS

The study of the behavior from burning in the dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province is concluded as followings;

1. The burn patterns were two shapes, approximately circle and oval. The burn patterns of the first year burning were an approximately circular and the fire spread maps were quite narrow line. While, the burn patterns of the second year burning showed the shape of an oval and the fire spread maps were wider because the wind speed conditions during the burning were higher than the first year burning.

2. The averages of flame height of the first and the second year burning were 0.45 m, and 0.37 m, respectively. It was significantly different from the first year burning. This might be due to the less fuel load and the fuel height than the first year burning.

3. Rates of fire spread of the first and the second year burning were 0.47 m min^{-1}, and 0.44 m min^{-1}, respectively. There were no significant differences between the first and the second year burning. Rate of fire spreads were significantly correlated with grass height and litter load.

4. The surface fire line intensity from the burning was not severe due to the low fuel load, the low wind speeds and the gently sloping topography. The averages of fire intensity were 66.17 kW m^{-1} and 44.33 kW m^{-1} in the first year burning and in the second year burning, respectively. This result showed that the lower fuel load can be reduced fire intensity. The rain during the dry season in 2003 and the lower fuel load in 2004 led to the low fire intensity in this study.

5. The averages of flame length were 0.54 m and 0.45 m in the first and the second year burning, respectively. Flame temperatures were 136.43 °C and 261.88 °C in the first and the second year burning, respectively. The weather conditions during the burning led the differences of the flame temperature.

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