ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 63(2): 131−142, 2021
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2021.63.2.11

CHRISTMAS TREE IGNITION BY SPARKLERS

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ABSTRACT

The paper deals with the potential of sparklers to ignite a Christmas tree. The conclusions from the experimental measurements when four fir trees decorated with Christmas ornaments were tested and burning sparklers were used for the ignition of a Christmas tree are presented in the paper. The measured temperatures were recorded by means of thermal imagers throughout the measurement process. The maximum temperatures during combustion are presented. Based on the measurements, it can be stated that sparklers are a possible source of ignition. There was always a flare through an easily ignitable Christmas decoration, not from the contact of the sparkler with a needle or branch itself. During the experiment, there was a total ignition of a decorated tree in only two cases.

Key words: sparklers, Christmas fir tree, ignition source, flash point, thermal imaging camera.

INTRODUCTION

Although hanging sparklers on a Christmas tree has become almost a tradition in some households, the incidence of fires caused by sparklers is very low. Recent years have shown that in apartments, family houses or other types of housing, fewer than ten cases are registered every year. Over the last decades, the highest number of events of this type was recorded in 2019, when a total of 7 fires ignited by a burning sparkler were registered (NEDĚLNÍKOVÁ 2020). No one has been killed as a result of a fire ignited by a sparkler in the Czech Republic so far.

Christmas tree fires are rare in other parts of the world as well, yet they can still cause serious damage to health or even death. For example, according to estimates based on the US statistics, an average of 160 Christmas tree fires occurred annually in the USA in the period of 2013–2017. The fires resulted in 10 deaths and 20 injuries, with property damage in excess of USD 17 million (TU, NG 2019).

On average, German insurance companies report 10,000 claims each year in connection with fires of Advent wreaths, Christmas trees and fireworks, with total damages reaching EUR 32 million (GDV 2018).

Although the officially reported numbers of fires caused by sparklers in the Czech Republic are very low, there have not been any experiments to date to determine the fire causes through verification of the distance and conditions under which a burning sparkler can ignite modern, often plastic, decorative material used on Christmas trees.

The aim of the experimental measurements was to confirm or refute the hypothesis that a burning Christmas sparkler can ignite a Christmas tree.

The secondary aims of the experiment were to measure the temperature during sparkler combustion, to determine the duration of combustion, and to assess the potential of the flame to spread to the surrounding flammable objects.

Sparklers as a source of ignition

In order to initiate the combustion process, interaction between a flammable substance, an oxidizing agent and an ignition source is necessary. Any flammable substance can be ignited by a source that reaches a defined minimum ignition temperature and is able to deliver the required amount of energy to the flammable substance over a given time interval. This time interval must be longer than the induction period of the respective flammable set (DAMEC 1998)

Sparklers are classified in the F1 fireworks category (CSN EN 15947-2 (668300) 2019). This category includes products that present a very low hazard, produce negligible noise and are intended for indoor use, including residential buildings.

The fire properties of the Christmas sparklers used in the experiment were not measured. However, records from 1996 are available, when Christmas sparklers (MOI – DG FRS CR. 1996) were tested according to the ČSN 640149 testing method in a certified testing laboratory. Christmas sparklers with the lengths of 10 cm, 28 cm, and 70 cm were tested. The flash point of these sparklers was 410 °C, the flash time 102 seconds, the ignition temperature 415 °C, and the ignition time 103 seconds. According to the results (RESEARCH INSTITUTE OF INDUSTRIAL CHEMISTRY 1997), the surface of the sparklers consisted of a mixture of flammable material (deposit) composed of 50% barium nitrate, 6% pyro aluminium, 5% kaolin, 25% steel and cast iron sawdust, and 10% dextrin.

The fire properties of wood are described in the literature (FIRE PROTECTION UNION 1980). Wood consists of a mixture of organic substances with a cellulose content of 50%. The ignition temperature of wood is in the range of 330–470 °C. At temperatures up to 100 °C, chemically bound water evaporates from the wood; above 200 °C, the wood decomposes. At the temperatures above 270 °C, the wood is carbonized and forms a self-igniting mass. The flammability and ignition susceptibility of wood depends on the moisture content, content of resins and wax, hardness of the wood and the size of the wood particles. The ignition temperature of pine is 399 °C, spruce ignites at 397 °C, and fir at 270 °C. The flash point of fir-needles and natural forests is 270–350 °C (DEHANN, ICOVE 2011).

Before conducting the Christmas tree ignition experiment, ancillary measurements were performed in the second half of 2019 in order to clarify the behaviour of sparklers according to the specifications below.

Sparklers of various lengths (16 cm, 28 cm, 70 cm, 90 cm) were used for the measurements. The experiment determined the maximum surface temperature of burning sparklers in various positions, the maximum distance of flying burning sparks from vertically and horizontally placed sparklers, the potential of burning sparks to ignite test specimens, the potential of burning sparklers to ignite test specimens by direct contact or by placing a burning sparkler in/on a specimen, and the potential of a sparkler to ignite test specimens immediately after the sparkler had been extinguished.

Several specific conclusions can be drawn from the measurements:

- shorter sparklers reach higher absolute burning temperatures than longer sparklers.
- the maximum temperature of burning sparklers measured using a thermal imaging camera ranged from 600 °C to 1,000 °C.
- the temperature of the burnt part of the sparkler drops very quickly to less than 100 °C.
- burning sparkler particles fell to a maximum distance of 20 cm from the vertical axis of the burning sparkler.
- for 16 cm long sparklers, maximum temperatures between 800 °C and 1,000 °C were measured. The average sparkler burn time was 40 seconds.

- for 28 cm long sparklers, maximum temperatures between 800 °C and 1,000 °C were measured. The average sparkler burn time was 90 seconds.

EXPERIMENTAL PART

Experimental setup

The experiment was performed in the Experimental and Training Laboratory of the Fire Cause Investigation Laboratory of the Population Protection Institute. For the experiment, Christmas trees of the Caucasian fir (*Abies nordmaniana*) variety were used, which had been used as Christmas decorations in households during the Christmas holidays. In January 2020, the trees were stored outdoors for 7 days. Subsequently, the trees were stored in a closed, unheated room for seven days before Experiments 1 and 2, and for fourteen days before Experiments 3 and 4. The experiments were performed in a testing unheated room at 5 °C. The testing room is equipped with ventilation unit and installed filters, but it is not equipped with heating. For this reason, the ambient temperature during the experiment did not correspond to normal temperatures in household rooms.

A total of four trees were selected for the experiments and decorated with Christmas decorations. The height of the fir trees was in the range of 1.8-2 m. The tested materials included traditional Christmas tree ornaments made of straw as well as contemporary ornaments that are commonly available in supermarkets. The decorations consisted of plastic balls, decorative garlands and bows. A 2 m long Christmas garland was placed on the trees. The number of other decorations intentionally differed from one measurement to another.

In all cases, 16 cm long sparklers were hung on the fir trees. Their average weight was 1.46 g with an average layer length of the pyrotechnic mixture of 10 cm.

All measurements were recorded using thermal imaging cameras (FLUKE Ti32 and Ti400) and video cameras, and digital still photographs were also taken. Thermal imaging recordings were evaluated using specialised software (smartView 3.15, smartView 4.3). The Thermal imaging camera FLUKE Ti400 was located 5,5 m from the fir.

Experimental measurements procedure

Contact thermometers or non-contact thermometers can be used to measure temperature. Contact thermometers are mostly used for stationary objects. However, since the flame temperature of the burning sparkler changed over a very short time period (thermocouples require a certain amount of time for the actual measurement), it was not possible to use thermocouples to measure the temperature change curve.

For these reasons, a thermal imaging camera was used to measure the temperature of the samples continuously. Spectral emissivity depends on the wavelength, temperature and material.

Thermal imaging cameras support manual adjustment of emissivity (e.g. value of 1 – black body; wood (70 °C) 0.94; plastic PE, PP, PVC (20 °C) 0.94; wall (40 °C) 0.93; colour (90 °C) 0.92–0.96 (FLUKE CORPORATION 2013).

For the purposes of our experiment, emissivity was set to 0.95. Fluke Ti32 thermal imaging camera temperature measurement range allows temperature measurements up to+ 650°C. The Ti 400 thermal imaging camera took radiometric video with a temperature measurement range up to +1200°C. These thermal imaging cameras scan at 320x 240 (76800 px) infrared resolution with accuracy +- 2°C and 2% at nominal temperature of 25°C. The distance of measured object from the thermal imaging camera was measured by the integrated laser distance meter.

RESULTS AND DISCUSSION

Evaluation of experimental measurements

Experiment no. 1

The Christmas tree was decorated with a Christmas garland on one half of the tree, and 7 Christmas ornaments (balls and bows) on the other one. Two sparklers, each 16 cm in length, were placed on the tree with the lower part of the sparklers touching the Christmas ornaments and garlands.

Evaluation of experiment no. 1 – Two sparklers were lit. They burned down within 40 seconds. The Christmas tree garland was not broken and the tree branches did not burn off. The tree did not ignite.

Experiment no. 2

The Christmas tree was decorated with Christmas garlands only. Only one sparkler was placed on the tree. The central part of the sparkler was touching the garland. (The experimental measurements showed that this specific Christmas garland ignited within 3 seconds of placement of the burning sparkler on the garland; the maximum surface temperature measured was 863 °C.

Evaluation of experiment no. 2 – After the burning sparkler came into contact with the garland, the garland ignited and subsequently, the flames spread on both sides of the garland. The maximum temperature measured on the tree with the burning garland was 584 °C. The garland was completely burned within 3 minutes of the lighting of the sparkler, but due to the radiant heat it emitted and the gradually igniting needles, heat accumulated in the upper part of the tree, which preheated the remaining needles and branches. At 03:30 minutes, the upper part of the tree ignited and the flames began spreading in all directions. During the fourth minute the temperature reached 905 °C. During the fifth minute the entire tree was in flames. Temperatures of around 1,000 °C were measured. The flames extinguished themselves during the sixth minute. Only glowing remnants of the needles were visible. Fig. 1 – Fig. 3 are thermographic images of the burning tree in experiment no. 2. Fig. 4 shows a spreading of the fire at 210 seconds.

Experiment no. 3

The tree was decorated with various Christmas ornaments including several Christmas garlands wound around the tree and tinsel that had been subsequently placed evenly around the tree. 15 Christmas decorations in the shape of a ball were used for decoration. The balls were made of polystyrene. There was a layer of paint on the surface of the polystyrene ball. Balls with different surfaces were used - 5 pieces with a matte surface, 5 pieces with a glossy surface and 5 pieces with a roughened surface with glitter. The average weight of the ornaments was 8.25 g. The tree was still decorated with fringes (same material as the decorative chain). Three sparklers were hung on the tree. Two of the sparklers were touching the garland (the upper half of the first sparkler and the lower half of the second sparkler) and the third sparkler was hung above the Christmas ornaments but was not touching the ornaments.

Evaluation of experiment no. 3 – The sparkler, which did not touch the Christmas garland, simply burned off. Both sparklers, touching the garland, spread flame along the length of the garland as they burned off. (Fig. 6). Parts of the Christmas ornaments located in the proximity of the garland were burned, but the flames did not spread to the needles or branches (Fig. 7). Temperatures of about 400 °C were measured on the burning garland. The fire extinguished itself during the seventh minute of the experiment.

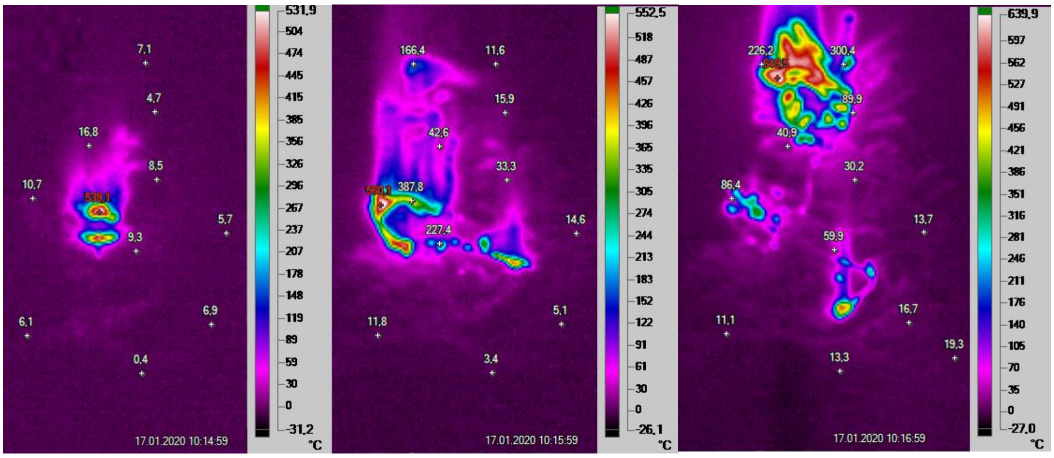

Fig. 1a, 1b,1c - Experiment no. 2 – Spreading of the fire at 30 seconds, 90 seconds, 150 seconds.

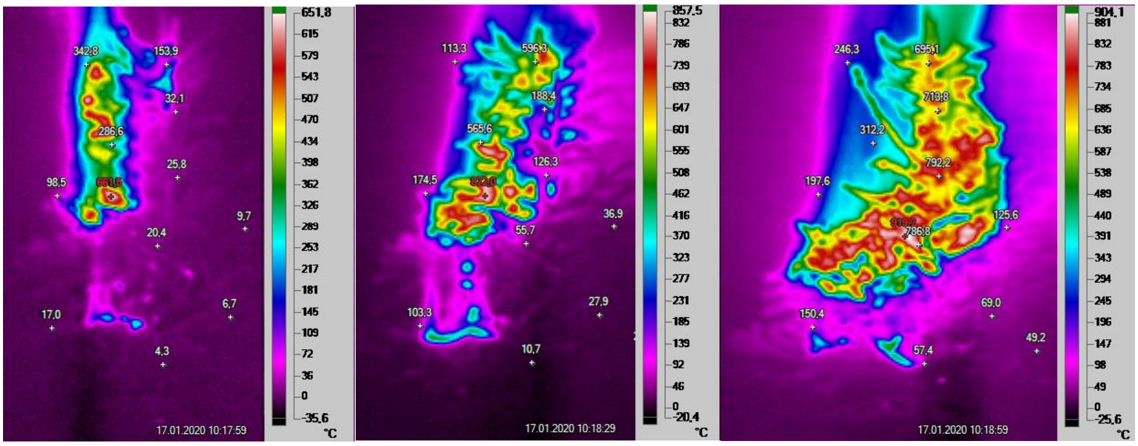

Fig. 2a, 2b,2c - Experiment no. 2 – Spreading of the fire at 210 seconds, 240 seconds, 270 seconds.

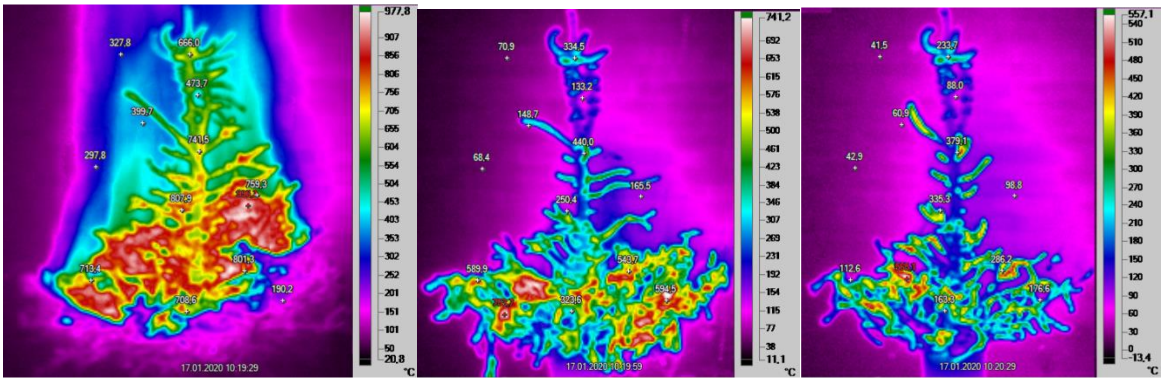

Fig. 3a, 3b,3c - Experiment no. 2 – Spreading of the fire at 300 seconds, 330 seconds, 360 seconds.

<u>Experiment no. 4</u>

The tree was decorated with various Christmas ornaments, including several Christmas garlands wound around the tree and tinsel which had been subsequently placed evenly around the tree. Three sparklers were placed on the tree. One of the sparklers was placed so that its central part was touching the Christmas garland.

<u>Evaluation of experiment no. 4</u> – After the sparklers were lit, the Christmas garland was ignited by the sparkler which was touching it. One minute after the start of the experiment, the temperature of the burning tree was in the range of 400–760 °C. At 2 minutes and 30 seconds, flames covered approximately 75% of the tree. Three minutes after the start of the experiment the tree was completely consumed by flames. The height of the flames from the

floor was up toca. 4 m (the height of the tree including the stand was 2 m). At 3 minutes and 30 seconds only glowing needles remained on the tree and the temperature ranged from 290 to 450 °C. Over the next two minutes, the glowing of the needles gradually subsided and the temperature reached 250 °C. Fig. 8 – Fig. 10 are thermographic images of the burning tree in experiment no. 4. Fig. 5 shows spreading of the fire at 150 seconds.

Fig. 4 Experiment no. 2 - The spreading fire at 210 seconds

Fig. 5 - Experiment no. 4 – Spreading of the fire at 150 seconds

Fig. 6 Experiment no. 3 – Spreading of flames on the Christmas garland

Fig. 7 Experiment no. 3 – View of the burned garland and a partially burned ornament

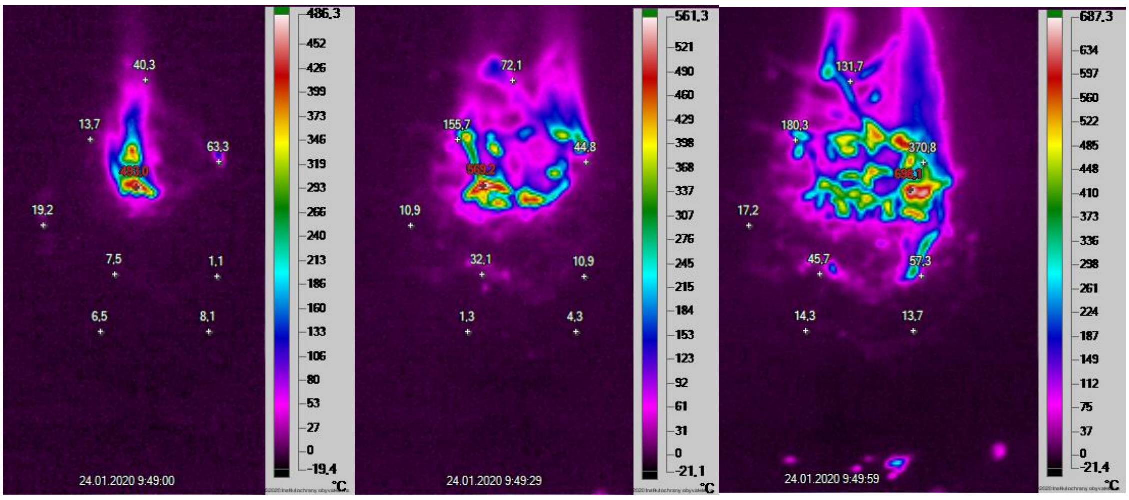

Fig. 8a, 8b,8c - Experiment no. 4 – Spreading of the fire at 30 seconds, 60 seconds, 90 seconds.

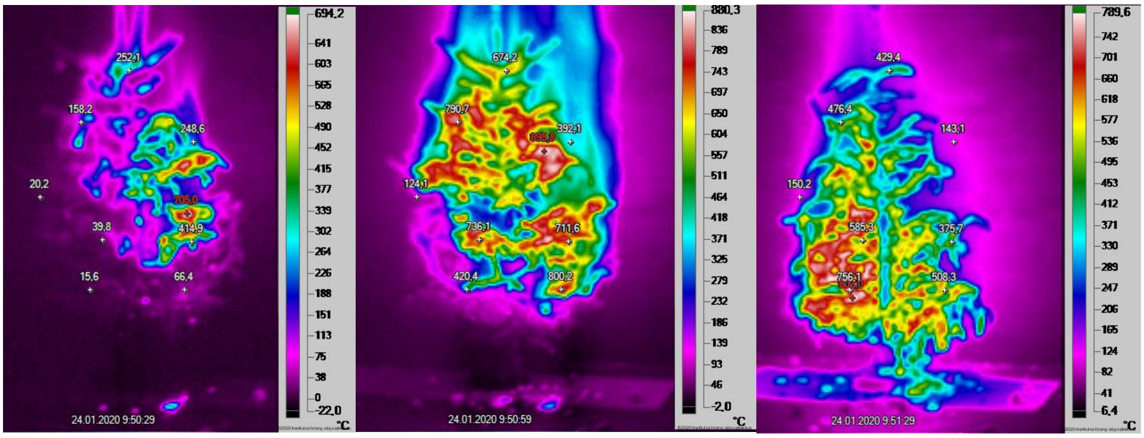

Fig. 9a, 9b, 9c - Experiment no. 4 – Spreading of the fire at 120 seconds, 150 seconds, 180 seconds.

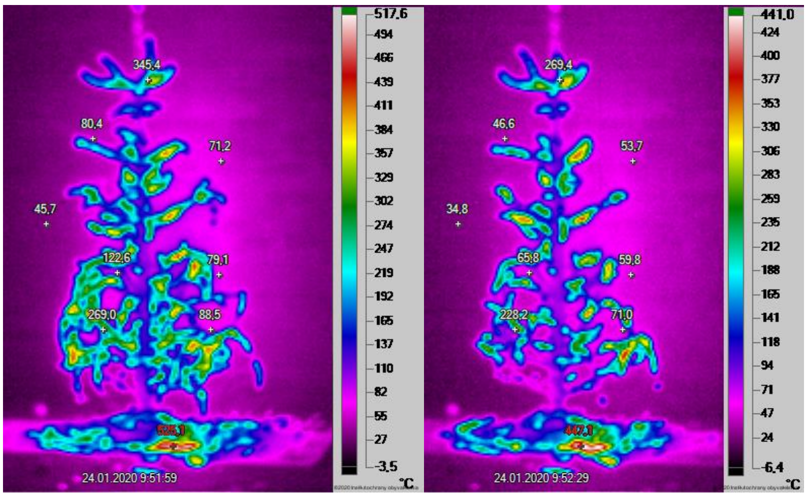

Fig. 10a, 10b - Experiment no. 4 – – Spreading of the fire at 210 seconds, 240 seconds.

Tab. 1 Maximum temperatures measured on the decorated Christmas tree.

[°C] [s]	15	30	45	60	75	90	105	120
Experiment no. 1	260	240.8	129.8	65.0	37.7	29.7	x	x
Experiment no. 2	260	539.1	518.8	540.5	464.4	560.1	541.8	501.6
Experiment no. 3	205.9	419.6	391.8	352.9	315.5	320.6	291.7	308.3
Experiment no. 4	260	487.8	537.2	569.2	735.5	698.1	784.1	705.1

[°C] [s]	135	150	165	180	195	210	225	240
Experiment no. 1	x	x	x	x	x	x	x	x
Experiment no. 2	626.6	649.5	578.5	483.3	481.8	661.5	830.4	872.0
Experiment no. 3	370.1	348.8	428.8	370.1	348.8	428.8	353.8	278.2
Experiment no. 4	681.3	895.8	968.3	803.0	642.9	447.7 525.1*	395.1 471.2*	376.4 447.1*

[°C] [s]	255	270	285	300	330	360	375	390	405
Experiment no. 1	x	x	x	x	x	x	x	x	x
Experiment no. 2	927.0	919.7	971.4	996.2	753.7	565.1			x
Experiment no. 3	308.4	362.1	384.4	345.6	247.6	260.0	260.0	231.8	120.1
Experiment no. 4	357.2 432.4*	361.2 441.1*	343.3 441.2*	346.3	x	x	x	x	x

*The highest temperature was measured on the fallen material around the tree

The authors of the paper focused on searching information about fires, their ignition and investigation of fires caused by sparklers. Detailed information on pyrotechnics can be found in the literature, but specifically the issue of sparklers is not addressed (except for the burning temperature).

The book Kirk's Fire Investigation (DEHANN, ICOVE 2011) describes the principles of how wood burns and the characteristics of pyrotechnics and explosives, but does not include details about the properties of sparklers.

The publication NFPA 921 (TECHNICAL COMMITTE ON FIRE INVESTIGATIONS 2020), which addresses fire cause investigation, does not contain information about sparklers as an ignition source. It mentions e.g. the principles of combustion, fire triangle, spreading of forest fires, and fireworks as an ignition source.

The bachelor's thesis Analysis of Temperature Changes During Launching of Fireworks (MEJZLÍK 2018) gives a summary of measurements of maximum surface temperatures and heat flow to selected fireworks. The measurements were conducted using both contact (Type K thermocouple) and non-contact methods. The objectivity of the temperature measurements was negatively affected by the selection and placement of a Type K thermocouple, and also by the selection of a thermal imaging camera that only depicts the maximum measured temperature. Furthermore, it was not possible to take a detailed thermographic image from any measurement location.

The publication *Propellants, explosives, pyrotechnics* (SABATINI, NAGORI 2011) lists the properties of various substances and compounds that are used as ingredients in pyrotechnics and their role in activation of pyrotechnics.

The NFPA (AHRENS 2020) has also developed fire safety conditions for the use of fireworks and other pyrotechnics, e.g. safe handling of pyrotechnics and related injury statistics and also states that the temperature of sparks from pyrotechnics is 1200° F (648° C).

The association NFPA and the Institut für Schadenverhütung have created videos that show flames from a burning Christmas tree spreading to objects in the room. These videos also show the time elapsing as the flames spread. However, the fires in these cases were started by different ignition sources. In case (NFPA 2018), the likely ignition source was a short-circuit on an electrical Christmas garland (the authors did not clearly state the ignition source). In the case (NIST 2017), the source was a candle that came loose from the candleholder as it burned down and then fell on wrapped presents under the tree. Video (NFPA 2007) shows the spreading of flames under a Christmas tree that was watered daily and then the spreading of flames under a Christmas tree with dry needles. The videos do not show the temperatures during the fires.

Wood is a thermally degradable and combustible material. Applications range from a biomass providing useful energy to a building material with unique properties. Wood products can contribute to unwanted fires and be destroyed as well. Flame spread is the sliding movement of the flaming ignition point over the surface of a solid combustible. The flame provides the ignition source as well as mixing of volatiles and air. The quasisteady time response of the material to heat flux distribution from the flame and external sources in reaching the surface temperature of rapid volatilizations determines the rate of flame spread. Rate of flame spread generally decreases with increases in density, moisture content, surface emissivity, surface temperature at ignition, and thermal conductivity (WHITE, DIETNBERGER 2001).

The article (ZACHAR *et al*. 2017) dealing with comparison of the activation energy requires for spontaneous ignition and flash point of the Norway spruce wood and thermowood specimens presents following conclusions. The results obtained within particular experiments showed that the spontaneous ignition temperature of Norway spruce wood specimens varied in the temperature range of 429 °C to 472 °C. The results achieved by the Thermowood specimens were comparable to Norway spruce wood specimens results (temperature range of 418 °C to 462 °C). The minimum flash point temperature was reached at a temperature of 346 °C in the case of the Thermowood specimens. The Norway spruce wood specimen flash point occurred at the temperature about 9 °C higher, i.e. 355 °C. The activation energy needed to reach the spontaneous ignition was very similar for both Norway spruce specimen kinds tested. The papers dealing with flash point of the fir we did not find.

Evaluation of experiments

In the experiments, thermographic images were used to measure the surface temperature of burning sparklers and the temperature after they had burned, along with the temperature of the combustion of ornaments and the Christmas tree.

Four sets of measurements were taken. The highest temperatures measured on the burning Christmas tree are listed in Table no. 1.

Within experiment No. 1, when the sparklers burned off, the Christmas garland, burning for one minute, extinguished itself.

The temperatures reached in experiment No. 2 after the sparkler ignited reached temperatures of up to 600 °C in the first two minutes. This temperature oscillated for the next minute and a half. In the 3rd minute and 45 seconds, there was a total ignition of the tree. In the 5th minute after the sparkler ignited, complete ignition of the tree was achieved. For the next minute and a half, the tree extinguished itself.

In experiment no. 3, the Christmas garland gradually burned along with the adjacent needles. There was not a massive amount of falling, burning needles.

In experiment no. 3, temperatures of approximately 400 °C were measured, which lasted for almost the entire first 5 minutes of the experiment. In contrast, the highest temperatures in experiment no. 4 were measured only until the third minute. In experiment no. 4, the temperatures were higher (almost 1,000 °C), the ignition of the tree was also more forceful and the height of the flames was up to 4 m from the floor. After lighting a sparkler, the temperature rose to almost 550 °C in one minute. After the first minute, the temperature oscillated around 710 °C. The highest temperature of almost 1000 °C was reached within the 2nd minute and 45 seconds. This was followed by burning of the entire tree and subsequent self-extinguishing. From the 3rd minute and 30 seconds, the highest surface temperatures were measured on flown material and fallen on the ground around the tree. At this time, only a part of a twig burned locally on the tree (450 °C), the average temperature measured on the tree was 164 °C. The average temperature in the fourth minute was 104.5 °C.

Based on the data from the experiment, it can be assumed that when a Christmas tree is placed on a carpet in e.g. an apartment in a housing estate, the flames could reach the ceiling of the room. Without a doubt, the flames would spread extremely quickly to the surrounding furnishings, Christmas presents, etc.

The maximum surface temperature of burning sparklers and emitted sparks can be as high as 1,000 °C. However, because the induction period is very brief, neither the tree nor the ornaments actually ignite.

The proof of this statement is the fact that although the temperatures measured on burning sparklers in two cases of this experiment were actually higher than the ignition temperature of needles or Christmas ornaments, the Christmas tree did not ignite.

CONCLUSION

The experiments confirmed the hypothesis that burning sparklers can be a potential ignition source for fires on decorated Christmas trees. Connection between a larger number of decorations on the tree and a larger fire were proven. In the case of experiment No. 2, only one sparkler was used. The tree was decorated only with a Christmas garland, without any other Christmas decorations, but it still caused a fire. In experiment No. 3, the Christmas tree was decorated with both garlands and Christmas ornaments. Three sparklers were used, the tree did not ignite, but only a partial burning of the Christmas garland. In all cases where the flame spread, it initially spread along the Christmas garland. If the sparkler was loosely hung on the tree (it did not touch the ornaments), it only burned out. Also if the sparkler hung on the tree and touched the needles, the flames did not spread to the tree.

The sub-objective of the measurement was met because a large amount of data containing temperature values over time was obtained during the experimental measurement, and it is possible to return to these measured values at any time and re-measure at any point in the burning tree. These measured values can also be used for the purpose of fire cause investigation.

Sparklers are undoubtedly a source of high ignition energy that exceeds 1,000 °C under ideal conditions. Nonetheless, this temperature is not maintained over of the entire surface of the sparkler, but only in the part of the sparkler that is actually burning. As a result, the burning surface of the sparklers affects surrounding materials for only a very brief period of time. This fact means that sparklers are capable of igniting only highly flammable materials, e.g. dry pinecones, foam, some types of textiles, etc., upon contact.

Ignition of a Christmas tree or its needles, if sufficiently dry, could also be caused by a sparkler. The experiments, however, demonstrated that ornaments on a decorated Christmas tree ignite more readily than needles. But in these cases ignition occurs only when the ornament and the sparkler are actually touching. In the case of straw ornaments, however, the energy of sparks that have flown away is sufficient for ignition.

Therefore, sparklers are a dangerous pyrotechnic, but the safety risk is low. Sparklers may be categorized as an ignition source with the potential to ignite common, highly flammable substances, but only when the given substance is in immediate contact with a burning sparkler. Sparks alone do not have this potential, or rather, their potential is limited to highly flammable materials (such as dry hay) or flammable gases.

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