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Investigating the causes of fires. Spontaneous combustion of plant material

Summary

The article describes the process of spontaneous combustion of plant material. It is divided according to the various development phases of the process. The topic of spontaneous combustion of plant material is presented in general terms in the context of biological and chemical processes. The included photographic documentation provides comparative and educational material for those involved in the investigation of causes of fires but also for those who are responsible for the safety of plant material storage. The author's aim was to indicate important details related to the examination of stored material and investigation of fire sites.

The purpose of the conducted study was to show and explain the poorly known topic of combustion as well as to define the general investigation schemes.

The information included in the article will help to classify the stored plant material into the correct phase of spontaneous combustion and assess, in a simple manner, if there are already any risks present.

It can also help to develop means of protection of the stored plant material from fire and prevent from losing large property of high value.

Spontaneous combustion of organic material exists and constitutes an important cause of fires in rural areas.

The increasing quality of storage buildings, which are airtight, leads to inadequate ventilation of the stored material and results in the lack of proper cooling and drying mechanisms. The material stacked in large amounts cannot cool down and retains high humidity. Consequently, the material stored in this way is susceptible to spontaneous combustion.

Keywords causes of fires, spontaneous combustion of plant material

Introduction

Many years of studies related to the post-fire investigation of plant material, along with laboratory research, have shown that many experts engaged in the examination of the causes of fires are unable to correctly identify the phenomenon of spontaneous combustion. The cases of this phenomenon are often deemed to be caused by deliberate human activity — arson.

The wrong identification of this combustion process results from the lack of studies and publications on this topic as well as from the level of professional qualifications of experts and their lack of knowledge on thermodynamics, chemistry, physics and biology.

The understanding and correct identification of the phenomenon of spontaneous combustion will contribute to the recognition of biological and chemical processes as occurring spontaneously in case of improper storage conditions or when the biological material (plants) is not yet suitable for storage and contains a high amount of moisture (water).

As a result of many years of observations and laboratory examinations using specialized gas chromatography equipment, it can be concluded with high probability that the investigated plant material is highly susceptible to the process of spontaneous combustion.

Plant-based spontaneous combustion

How can spontaneous combustion be defined?

The phenomenon is highly exothermic and involves the generation and accumulation of large amounts of heat during biological and chemical or strictly chemical processes, which are characterized by the self-heating of the stored solids and liquids, without heat absorption from other sources, until the material reaches its ignition temperature, which results in spontaneous combustion.

The following factors are involved in the occurrence of spontaneous combustion:

- Temperature
- Humidity
- Pressure
- Biological and chemical properties of the material
- The amount of oxygen supplied
- Catalysts
- Ability to oxidize

In general, the cases of spontaneous combustion of various materials can be divided into:

- biological and chemical,
- chemical,

and depending on their temporal occurrence:

- energetic (very fast and dynamic)
- progressive (slow).

Among the most common materials susceptible to the spontaneous combustion of the biological and chemical type are:
hay, straw, grain, green plants, peat, bituminous coal, lignite coal, animal fat, vegetable fat, rapeseed, oil plants, seeds, plant waste, animal feces (manure), cellulose pulp and other material.
Among the materials susceptible to the spontaneous chemical combustion are substances and their mixtures that react, e.g., in case of contact with air or water, resulting in an exothermic process (generation of high amounts of heat) which immediately generates a flame.

Energetic (dynamic) spontaneous combustion is a very fast process occurring in a short period of time, distinguished by fast temperature increase until the appearance of a flame.

The process is called dynamic because of the short time of its occurrence (seconds, hours, but no more than a few days).

Progressive (slow) spontaneous combustion is characterized by a long-term development, lasting a few days or a few weeks up to several months.

The occurrence mechanism of spontaneous combustion is complex and requires observation and long-term advanced examination.

The results of these examinations not always match those obtained in the field, i.e. in the natural storage conditions.

In order to understand the mechanism occurrence of biochemical spontaneous combustion, one should consider two processes observed in plants:

1. Absorption of carbon dioxide from the air and water, as well as release of oxygen. This process is commonly known as assimilation or photosynthesis and it requires light.
2. Absorption of oxygen and release of carbon dioxide. This process occurs during the day and at night and it is called respiration. Even in case of cutting, breaking or twisting off plants, the above mentioned processes still occur for some time until the full desiccation.

Many species of microorganisms live in symbiosis with plants, such as:

- bacteria
- fungi
- algae
- protozoa
- Actinobacteria.

Microorganisms (microflora) originate from soil, water and air and are essential for biochemical processes. These are mostly bacteria of the following genera: Aerobacter, Alcaligenes, Clostridium, Escherichia, Pseudomonas, Streptococus, Urococcus, Urobacillus, Spirillum, Bacillus, Micrococcus, Scarina, as well as amoebas, oligochaetes, ciliates and rotifers. Microorganisms include also yeasts: Rhodorula, Aspergillus, Mucom, Rhizopus, Dematium, Turulopsis, Cladosporium.

The biochemical processes occurring in the environment allow for the circulation of such ingredients as: carbon, oxygen, potassium, sulfur, magnesium, phosphorus, carbon dioxide, nitrogen, water, as well as compounds of containing these ingredients, such as: phosphates, nitrates and many other.

In the biochemical reactions, large amounts of heat are emitted (exothermy).

Depending on the temperature of the environment in which bacteria occur, they can be divided into the following groups:

- psychrophilic bacteria (12–18°C)
- mesophilic bacteria (25–40°C)
- thermophilic bacteria (55–65°C)
- Phases of biochemical spontaneous combustion

Phase 1

In the first phase of the process leading to spontaneous combustion, fast growth of bacteria, fungi and yeasts occurs. There is an increased level of respiration and oxygen absorption. Respiration process lasts longer, depending on the quantity of thick stems and leaves that contain large amounts of water. Respiration of plants is a process reverse to photosynthesis. During respiration, photosynthesis products are absorbed. The rate of respiration is the same with or without photosynthesis. Respiration occurs in green plant cells and in all living cells of other organisms.

During the process of respiration, oxygen as well as nutrient and organic substances, such as glucose, are consumed. When glucose is decomposed, thermal energy is generated. The decomposition of 1 g of glucose releases an amount of energy of approximately 4 kcal (exactly 3.74 kcal). The examples of heat generation during the alcoholic fermentation of a glucose molecule are shown below:

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 + 28\ kcal$$

Heat generation during the oxidation of alcohol to acid:

$$CH_3CH_2OH + O_2 \rightarrow CH_3COOH + H_2O + 117\ kcal$$

Complete fermentation of a sugar (hexose) molecule:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 674\ kcal/mol$$

One kilocalorie is the amount of thermal energy needed to increase the temperature of 1 kg of water by 1°C from 14.5 to 15.5°C.

Enzymes, as the catalysts of chemical reactions, have a very significant impact on the process of respiration by enabling the generation of large amounts of thermal energy. In the first phase, respiration is the most intensive at the temperature between 20–35°C. The highest activity within this temperature range is demonstrated by mesophilic bacteria. As the temperature gradually increases, water evaporation occurs. Such conditions favor a rapid development of microorganisms and decomposition of complex substances into simpler compounds. The amount of oxygen decreases. Water (moisture), temperature and the large quantities of microorganisms give rise to the putrefaction and fermentation processes, which significantly reduce the amount of oxygen.

Phase 2

The processes of anaerobic decomposition of carbohydrates and anaerobic enzymatic decomposition of proteins and amino acids initiate.

Due to the large thermal resistance, good isolating properties of plant material and minimal heat loss, the temperature increases to 60–90°C and heat accumulation occurs. Plants lose moisture, which leads to pectin decomposition as well as to generation of formic acid (HCOOH), ammonia (NH_3) and acetic acid (NH_3COOH).

Irritating odor can be smelled at that time.

Fig. 1. Plant mass emitting the irritating odor of ammonia.

Common examples of plants that heat up to 40–90°C and above are: feces (manure), hay, straw, humid grain.

Microorganisms develop at the temperatures ranging from a few degrees above zero to 90°C.

At the temperatures between 90–100°C, further decomposition of protein occurs. Hydrogen sulfide and furfural are generated. The plants desiccate and agglomerate.

Fig. 2. Agglomerated hay.

The intensity of chemical reactions increases and the microbial activity decreases. At the temperature of approx. 100°C, almost all microorganisms perish. Above the temperature of 100–110°C, water completely evaporates from the plant mass. The temperature continues to increase. Above the temperature of 150°C, the plants fossilize.

This moment can be considered as the beginning of dry distillation of plant mass.

Dry distillation is a decomposition process of lignified plants or wood as an effect of exposition to high temperatures with limited or no access to air. During dry distillation, a number of substances and gases are released, which participate in many subsequent simple and complex reactions that may affect each other. These reactions may be reversible or irreversible. The interaction between the chemical processes causes the generation of gases with different chemical composition. The final effect is different depending from the stored material and depends on the composition of the generated gases.

The factors that influence gas generation include the temperature, at which the chemical decomposition occurs, and the pressure inside the stack (stored material). Due to the various humidity of the stored plant mass, desiccation and decomposition take place at the same time in different storage locations. The effect of the high temperature on the plant mass depends on the thickness and the size of each plant.

Taking into account the large masses of stored plant material (in most cases, filling the entire height of storage buildings) and poor thermal conductivity (high thermal resistance of plant mass), the heat accumulates inside the stored plant mass and is not dissipated.

This causes further temperature increase. Above 180°C, the decomposition gains intensity and speed. Hemicellulose, which is one of the components of plant cell wall, becomes almost completely degraded. It can be found in wood, straw, seeds and bran.

The name of hemicellulose originates from the fact that it is chemically and structurally similar to cellulose.

The duration of the thermal process depends on the amount of moisture in the stored plant mass.

During the further chemical degradation, numerous chemical compounds are formed, such as hydrocarbons, phenols, alcohols, aldehydes, ketones, bases, acids, carbon and many other.

A carbon compound with the following chemical composition is formed:

C: 90.2%, H: 3.1%, O: 6.7%. Its ignition temperature is 170–210°C.

The plant mass changes its color to brown and black.

As a result of the occurring physicochemical processes, compounds of various composition and nature are formed, including methane, carbon dioxide, carbon monoxide, ethylene, acetylene and other.

The table below shows the examples of gas samples taken from putrefying mass (cellulose) and the analysis of the gas composition using gas chromatography.

Table 1 Gas concentration in air samples

L.p.	The number of sack	Location of air sample according to client date	C_2H_6 Ethane	C_2H_4 Ethylene	C_3H_8 Propane	C_3H_6 Propylene	C_2H_2 Acetylene	CO Carbon monoxide	O_2 Oxygen	N_2 Nitrogen	CO_2 Carbon dioxide	CH_4 Methane	H_2 Hydrogene	C_nH_m Unsaturated hydrocarbons
			ppm	ppm	ppm	ppm	ppm	ppm	%	%	%	%	ppm	ppm
Date of analysis: 2012.10.12 (Tuesday). Location of air samples: experiment														
1	3-b	Sample no. 4 (date of sampling: 2012.10.02)	0,61	0,03	0,05	0,36	0,001	2	0,26	1,30	53,96	44,48	0,6	1,051

The temperature inside the stack amounts to 230–260°C. The accumulated heat is insulated from external factors outside the stack. There is virtually no cooling and heat loss is minimal. The high temperature causes an increase in the pressure of vapor and gas in the stake. At the temperature between 250–260°C, ignition of the generated gas occurs and the so-called pyrophoric carbon is formed, which has a high capacity to absorb oxygen.

The temperature increases and the carbon is starts to glow. The incandescence causes the burning of the so-called fire channels (sleeves). Usually the fire channels lead to the frontal, lateral or upper surface of the stack. Once the fire channel is burned, the external surface of the stack sets aflame. The intensity of fire increases rapidly when the flame comes into contact with the air (oxygen).

Based on many years of experience and observation, it can be also noticed that due to spontaneous combustion in the stacks that are set on fire, a rapid ignition of carbon monoxide cloud and methane occurs.

Examples of spontaneous combustion of plant material (straw, hay, herbs) are given below.

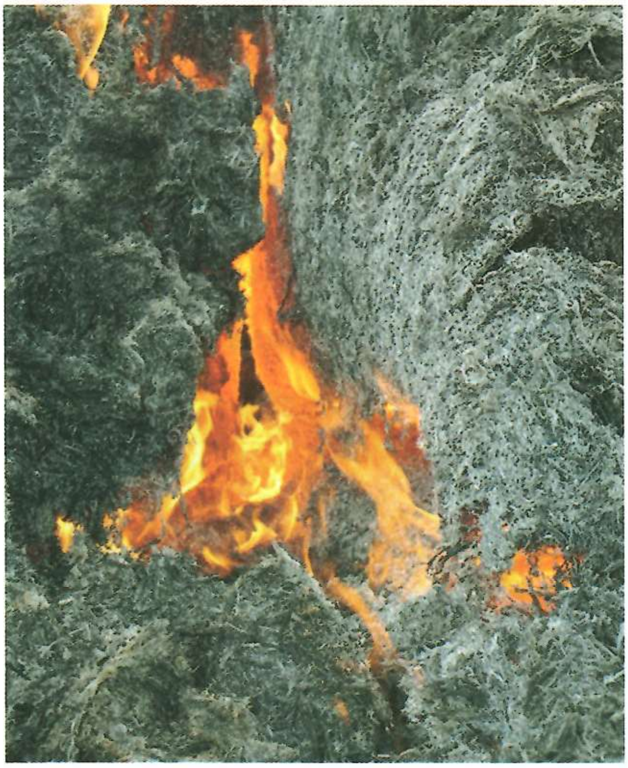

Fig. 3a. Burned-out fire channel.


Fig. 3b. Flames coming from the inside of the stack can be seen.


Fig. 4. Ignition occurred in the middle of the stack.


Fig. 5a. Burned-out fire channel.


Fig. 5b. Open fire channel.


Fig. 6a. Burned-out fire channel.


Fig. 6b. Burned-out fire channel.


Fig. 7. Burned-out fire channel.


Fig. 8. Burned-out fire channel.

Fig. 9a. Burned-out fire channel.

Fig. 9b. Burned-out fire channel.

Conclusions

The examples shown above and the general statistics confirm the occurrence of spontaneous combustion of plant material.

The number of fires resulting from the process of spontaneous combustion of stored plants is significant in comparison to fires resulting from other causes.

Due to the lack of understanding of the subject matter of spontaneous combustion by individuals designated to determinate the causes of fires, the phenomenon is very often misinterpreted and linked with criminal cases.

The general description of the process of spontaneous combustion and the example pictures of this process will enable more effective investigation of fire sites and determination of the real sources of combustion.

In order to protect the stored plant material from spontaneous combustion, the following factors shall be considered:

1. Proper structure and positioning of stacks (height, slope of the land, draining rainwater)
2. Proper storage of stacks in buildings (height, weight, pressure, spatial dimensions)
3. Moisture measurement
4. Temperature measurement
5. Construction of ventilation systems
6. Measurements inside stacks

The above factors are essential for the protection of plant material and have an impact on the occurrence of spontaneous combustion.

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Source

Figs. 1–9: author
Tab. 1: author

Translation Ronald Scott Henderson