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THE USE OF THERMOVISION IN THE MONITORING OF COAL STORAGE FACILITIES AS AN ELEMENT OF SAFETY MANAGEMENT IN THE WAREHOUSE MANAGEMENT

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Abstract: Spontaneuos combustion (or self-ignition) is the initiation of the burning process without an external source of ignition, such as a flame or spark. This phenomenon often occurs during storage of such substances as hay, straw as well as coal or culm. Like any other type of fire, in addition to potential material losses, it also poses a threat to people. Thanks to the systematic monitoring of landfills using a thermal imaging camera, the dangerous effects of this phenomenon can be avoided. The article presents photos taken on a coal storage site where, as a result of both prolonged heat and wind exposition, a self-ignition phenomenon occurred that was detected early due to the use of thermovision.
Keywords: spontaneous combustion, thermal imaging, safety management

INTRODUCTION

Fire is an extremely dangerous element, often difficult to control. It can be hazardous to the economy in terms of material loss, and, more importantly, to people who became its victims. The statistical data concerning fires is gathered by such organizations as the World Fire Statistics Centre (affiliated organization of The Geneva Association) and the Center of Fire Statistics of the International Association of Fire and Rescue Services (fr. *Comité Technique International de Prévention du Feu*, CTIF). According to them, in Poland, an average of 555 people in 2008-2010 (data from WHO, see Geneva Association 2014), and an average of 521 people in 2012-2015 (Brushlinsky et al. 2018) died of fires each year. In 2016, Poland ranked 13th in the world in terms of the number of fires per 1000 inhabitants (Brushlinsky et al. 2018). This clearly shows that fires are still a serious problem in ensuring human safety.

SPONTANEUS COMBUSTION PHENOMENON

Self-ignition is the initiation of the burning process of a material, without the contact of the material with an external source of ignition, such as a flame or spark. It consists of many physical, chemical and biological processes. It can occur in a variety of stored materials such as: materials of vegetable origin (hay, clover, cereal grains, dry leaves, straw, sawdust, wood chips, lignite, coal, peat), artificial fertilizers and chemical compounds (fluoride hydroxide, calcium nitrate, potassium carbonate, potassium sulphate), flour, starch, dextrin powders, oily wool, cotton, tow, hemp, etc. The course of the auto-ignition process and, consequently, spontaneous combustion is different in these materials, hence the induced fire can be divided into fires caused by biological self-ignition - arising with the participation of microorganisms (bacteria, yeast, mold) and chemicals - the result of exothermic reactions that occur when chemical substances react with each other (Kordylewski 2008).

According to the statistics of the State Fire Service, self-ignition of stored materials, is the cause of a relatively small number of fires (less than 0,5%). However, in reality the causes of many fires cannot be determined. Fires, which causes are filed as "unspecified" account for about 12% of all fires (see Table 1). It is suspected that many of those fires can be in fact caused by self-ignition (Sawicki 2012)

Table 1

Share of fires started by spontaneous combustion and unspecified causes

Year	Total no. of fires	Fires started by biological self-ignition	Share %	Fires started by chemical self-ignition	Share %	Fires started by unspecified causes	Share %
2015	184 793	437	0,236	84	0,045	22 117	11,968
2016	126 214	303	0,240	42	0,033	15 397	12,199
2017	125 871	261	0,207	51	0,041	15 697	12,471

Source: Own elaboration based on statistical data of the National Headquarters of the State Fire Service, (www.kgpsp.gov.pl, retrieved 12.2018)

Fires caused by auto-ignition are classified as endogenous fires. Particularly dangerous are endogenous fires in coal mines (Jaskółowski and Kasperkiewicz 2012, Singh 2013), as well as spontaneous fires in coal storage yards (Fierro et al. 1999; Gierasimczuk 2009), which are a common phenomenon caused by the accumulation of heat resulting from exothermic oxidation of coal (Quintero et al. 2009).

The problem of self-heating and self-ignition of coal has been the subject of many scientific papers (Arisoy and Akgiin 1994; Bhat and Agarwal 1996; Liu et al. 1998; Fierro et al. 1999; García-Torrent et al. 2012; Yauan and Smith 2012).

The tendency of self-ignition of coal depends on its type, the ability to adsorb oxygen through coal, the fraction of finely divided coal, and the proportion of volatile parts, moisture, pyrite and egzynite. The storage method, the size of the storage site and the ease of oxygen access to the inside of the heap are of great importance. Wind plays an important role - spontaneous combustion occurs most often on the windward side.

The self-ignition process is distinguished by:

• incubation period taking place at a slightly elevated temperature,

• self-heating, in which the temperature rises to 60-80 °C,

• temperature increase causing evaporation of the substance over the heap, emission of CO and aromatic hydrocarbons

In order to reduce the amount of endogenous fires, scientists focus on a more thorough investigation of self-heating and self-ignition mechanisms, improvement of fire prevention and methods and techniques to reduce the risk of spontaneous combustion, and the development of new, more effective methods for monitoring landfills.

LEGAL REGULATIONS REGARDING SAFETY OF OPEN STORAGE OF MATERIALS

The problem of safe storage of coal is not fully regulated by law. Few legal regulations (Journal of Laws 2003, 2009, 2010, 2018) do not define the specific requirements in this matter. For example, in the Regulation of the Minister of Labor and Social Policy of 26 September 1997 on general health and safety at work regulations, such coal storage requirements can be found:

“§ 74.

1. When bulk materials are stored loose, there should be ensured:

1) a component surface that, while maintaining the angle of natural chute, will enable the passage to be maintained around the heap;

2) strength of dams suitable for the pressure of stored bulk material;

3) as necessary resulting from the protection of neighboring work zones and technical capabilities - tight enclosure of the reloading site and reloading devices and connection with dust extraction devices at the place of dust creation;

4) safe working methods, especially when manually picking and transferring materials.

2. Entrance of workers on piles of bulk materials threatening to backfill is only allowed in cases of exceptional necessity, with the use of bridges or other devices ensuring safety, as well as with the securing from a second employee and adequate supervision.

§ 76.

When storing materials susceptible to spontaneous combustion, they should be protected against self-ignition, in particular, by limiting the amount of storage, use of ventilation chimneys and transfering or often flipping the heaps.” (Journal of Laws 2003, own translation).

As seen on the above example, the regulations not only do not specify in detail how the coal should be stored or monitored, but also mislead by requiring the use of ventilation chimneys or frequent shifting of landfills. The common consent in the literature is that self-ignition is favored by the access of oxygen as well as the loose arrangement of the material susceptible to spontaneous combustion. More information on the proper storage of coal (and other materials prone to self-ignition) are listed by Zieliński (2017), although the specific guidelines included in his book do not come from legal regulations, but from theoretical knowledge and practical experience.

AN EXAMPLE OF THE USE OF THERMOVISION IN THE MONITORING OF A COAL STORAGE SITE.

At one of coal storage sites combined with a heating plant in Częstochowa, around 2000 metric tons of culm coal (granulation up to 20 mm) with the heating value of 24-25 MJ/kg is stored. However, as it turns out, even such relatively small amounts (in comparison with other coal storages) may pose a danger of self-ignition and, as a consequence, fire. Such a situation took place in September and October of 2014, after the summer heat wave. Despite the correct method of storage and consolidation of successive layers of the heap, small visible signs of spontaneous combustion appeared in the form of wet stains and light fog floating above particular places in the repository. After excavating these places with the loader, it turned out that the coal had increased temperature and a changed color, proving an advanced oxidation process. After wetting with large amounts of water, the temperature of the stored coal was reduced. However, it was decided by the storage site's management to pay more attention to the monitoring of the coal.

The „traditional" method of monitoring, common in the local storage sites, is to immerse the steel rod in the stored coal and check the temperature of the rod with the thermometer (although in practice using bare hands is also common). Because this method poses a great danger to employees (entering a heap that could cause a collapse or burn), the management of the heat plant decided to use the thermal imaging camera supplied by the Material Quality Testing laboratory of the Technical University of Częstochowa. This enabled the safe monitoring of the storage site and the rapid prevention of fire due to spontaneous combustion.

Due to restricted range and field of view of the thermal camera, the general overview of the whole heap only gave limited information; the camera showed increased temperature of the heap, but the range of temperature in different parts of the heap was not clearly seen from a distance (fig. 1). It was, however, enough to guide the camera operator to the point of ignition, clearly seen from a couple of meters (fig. 2). The thermal imaging camera also proved useful as a replacement of a thermometer to indicate the temperature of a steel rod immersed in the heap in a traditional way (fig. 3). Eventually, the thermal analysis showed that one of the causes of self-ignition was the wind penetrating the heap through a damaged concrete retaining wall (fig. 4). The pictures taken during the analysis gave the basis for submitting an application for the construction of a new wall. The project of building a new wall has already been completed.

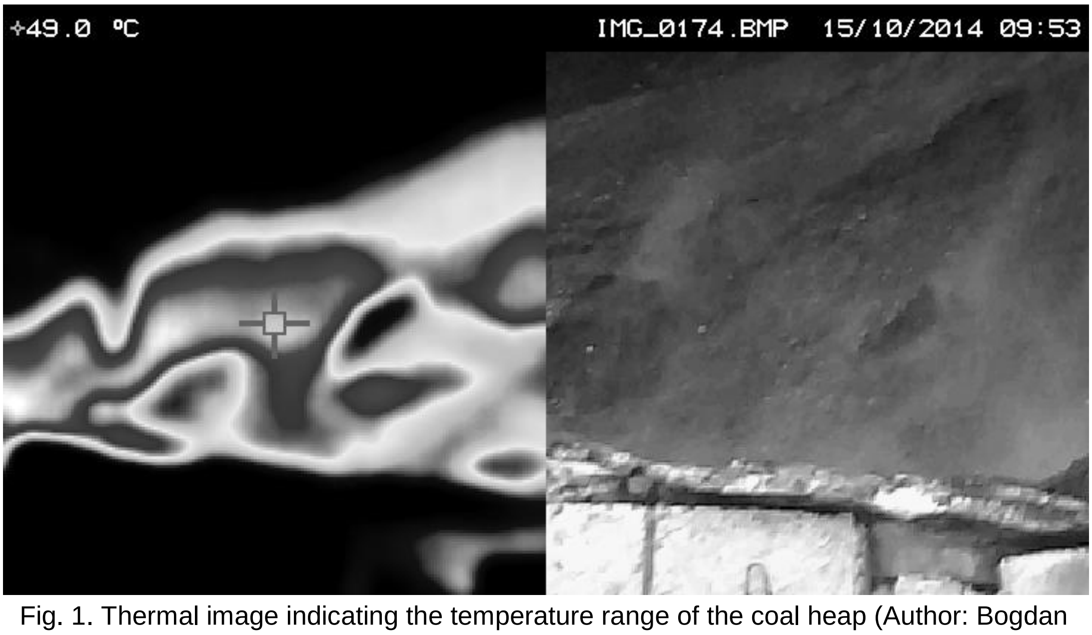

Fig. 1. Thermal image indicating the temperature range of the coal heap (Author: Bogdan Sobociński)

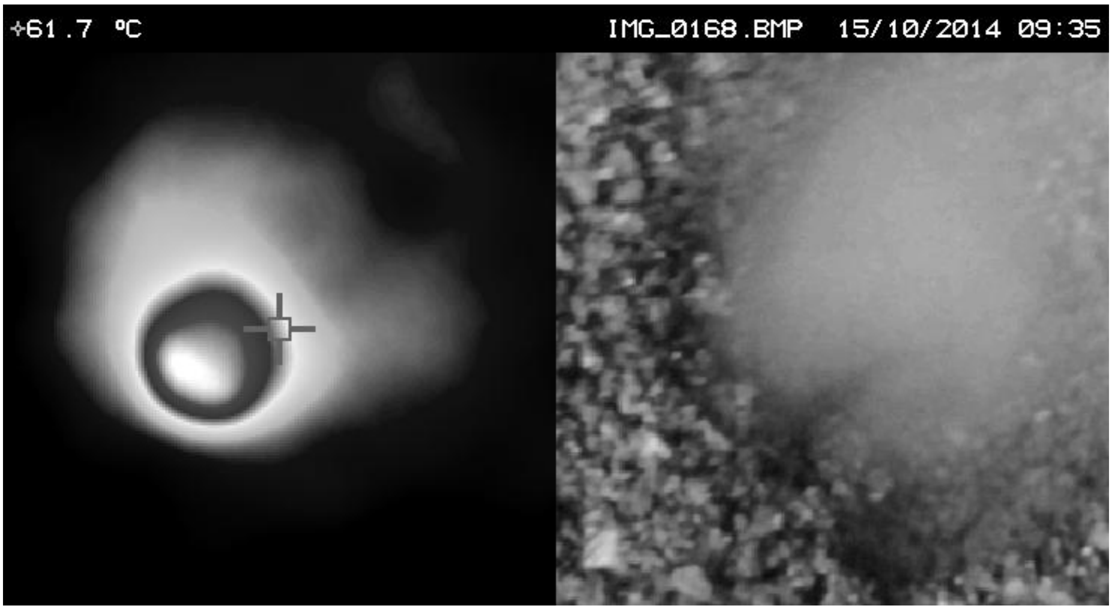

Fig. 2. Thermal image indicating the potential source of self-ignition (Author: Bogdan Sobociński)

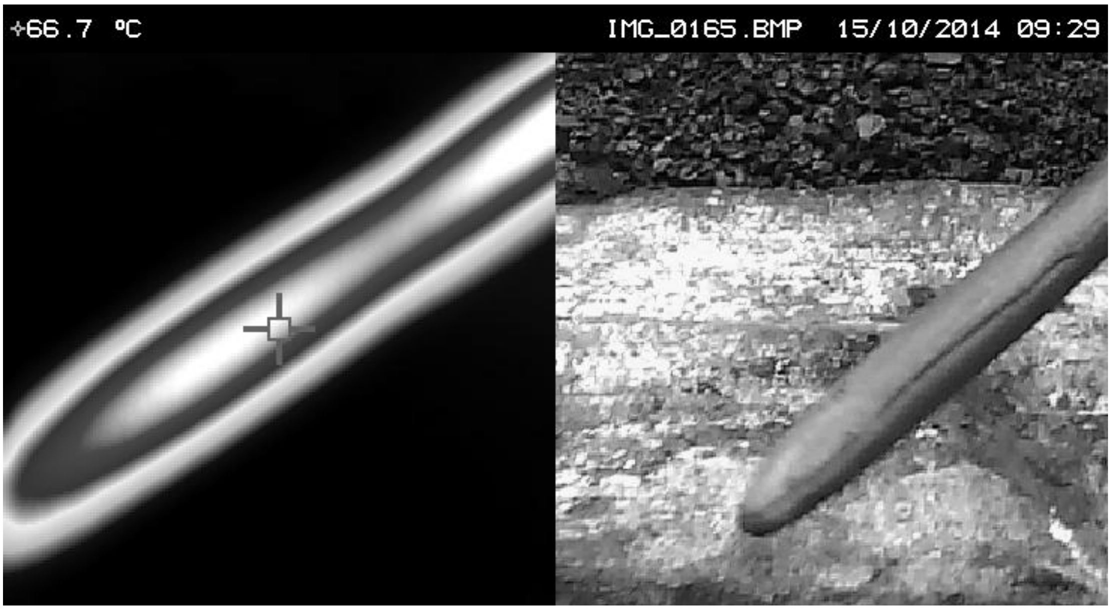

Fig. 3. Thermal image of a steel rod after immersion in the coal heap (Author: Bogdan Sobociński)

Fig.4. Thermal image indicating the rise of temperature of stored coal in place of damaged retaining wall (Author: Bogdan Sobociński)

Of course, in the case of large landfills, a single thermal imaging camera itself would not solve the problem of safe monitoring of the heaps. The camera has a limited field of view and would require frequent and time consuming operation by the plant's employees (a thorough analysis of every heap from every angle), which, performed on foot in a large storage site, can pose a risk for the operator. However, thermal imaging systems for monitoring of storage sites of coal, biomass, sulfur, tires and other materials stored in heaps are already available (see e.g. Introl 2018). Such a system usually consists of two (or more) thermal imaging cameras and a server with software that provide monitoring and automatic alarm activation when a self-ignition spot is detected.

CONCLUSIONS

Self-ignition can cause fires resulting not only in material damage but also being a threat to the health and lives of employees. While self-ignition is commonly regarded as a rare occurrence, it is often difficult to prove. It is possible that fires resulting from self-ignition often count towards fires started by “unspecified” causes. Traditional landfill monitoring methods also pose a significant threat to employee safety. The legal requirements on the storage of coal and other self-igniting materials should be clarified. Particular attention should be paid to the development of storage sites monitoring regulations, taking into account the latest available technical equipment (thermal imaging cameras and complete monitoring systems). Both correct storage of self-igniting materials and safe methods of monitoring them constitute an important element of reducing occupational risk, playing an important role in occupational safety management.

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