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Case study

FIRE HAZARDS OF COAL STORAGE SITES - MONITORING AND PROTECTION

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A b s t r a c t

Coal's high propensity for spontaneous combustion can be the cause of fires in coal heaps located at mine sites, power plants, distribution or coal handling points. The application of appropriate measures to prevent coal from self-igniting and consequently to protect against fire. This paper presents optimal methods for monitoring and fire protection of coal stockpiles. The selection of suitable stockpiles for testing was carried out, followed by an assessment of the condition of the stockpiles (measurements of the temperature of the surface and interior of the facility, studies of the chemical composition of the atmosphere inside the facility, and the composition of the atmospheric air on the facility and in its immediate vicinity. Continuous monitoring of the dump was carried out for visible changes indicative of possible thermal phenomena. This was followed by the selection of the method and method of application of the antipyrogen (injection and spraying) and trials with the antipyrogen. Application of the product was followed by further monitoring of the dumps and analysis of the results obtained.

Keywords: coal storage site, fire hazard, monitoring

1. INTRODUCTION

The susceptibility of coal to spontaneous combustion depends on a number of factors, but above all on the following properties of the coal: degree of

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metamorphism (coal type), pyrite sulphur content, moisture content, volatile matter content, porosity, crushability, petrographic properties, thermal conductivity. In addition to the factors mentioned above, the size of the heap, its height, the method of spreading and atmospheric conditions, in particular insolation, moisture and wind, have an impact on the spontaneous combustion of coal stored in heaps in the open air [1-4].

The high susceptibility of coal to spontaneous combustion can be a cause of fires on coal heaps located within a mine site (Fig. 1), power plant, distribution or handling points. The application of appropriate measures to prevent coal from self-igniting, and consequently to protect against fire, may be a necessity in situations where there is prolonged storage or transport of coal [5-7].

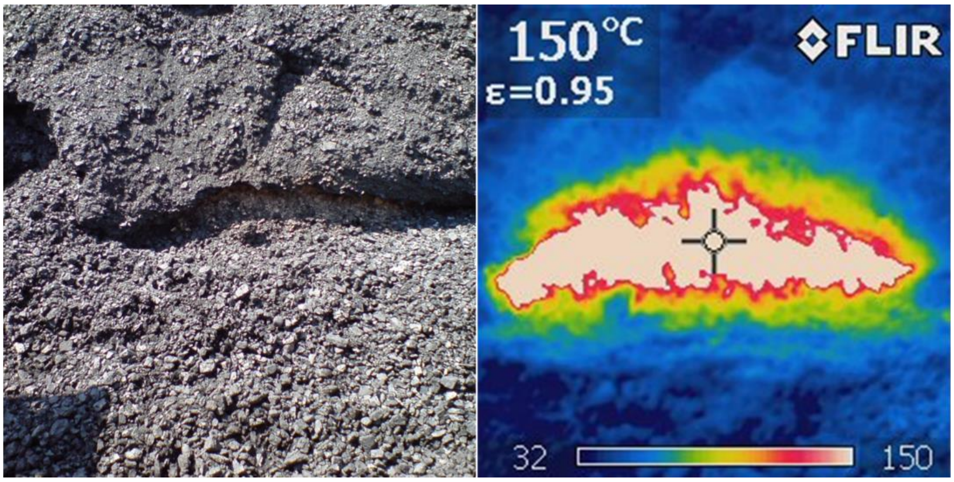

Fig. 1. Self-heating of coal in the heap [source: own materials]

2. MATERIALS AND METHODS

2.1. Selection of the test site

It was tentatively assumed that the following factors would determine the choice of repository:

- The ability to conduct measurements and tests without problems.
- The method of construction and duration of the repository will determine the choice of the appropriate method of applying the antipyrogenic agent (agent applied to the surface of successive layers or, if a repository already exists, surface and in-depth).

The antipyrogens used in the study are substances used for preventive measures as well as for active firefighting. The selected agent is a very strong inhibitor of the coal oxidation process (Class V). It interrupts the self-heating process of coal.

Blocks pores limiting oxygen access to the coal surface. Reduces the tendency to spark during the movement of rocks in the collapse. It is a non-flammable product. According to the manufacturer, the product does not alter the readings of mine atmosphere sensors.

The survey area covered a total of 700 m^2 (300 and 400 m^2) - one parcel of 30x10m delineated on the eastern slope (Fig. 2) and a second parcel of 40x10m delineated on the southern slope (Fig. 3).

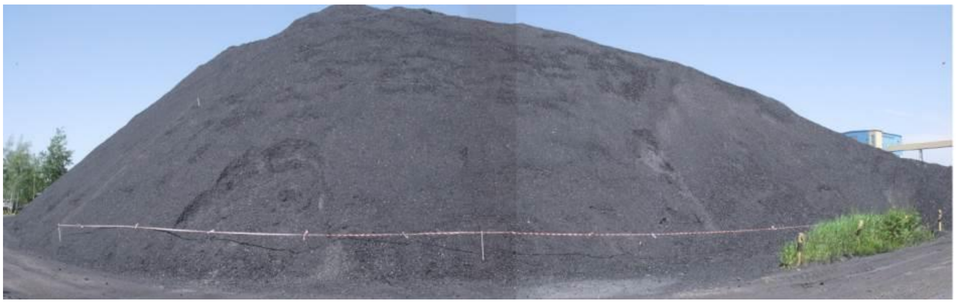

Fig. 2. Parcel delineated on the eastern slope [source: own materials]

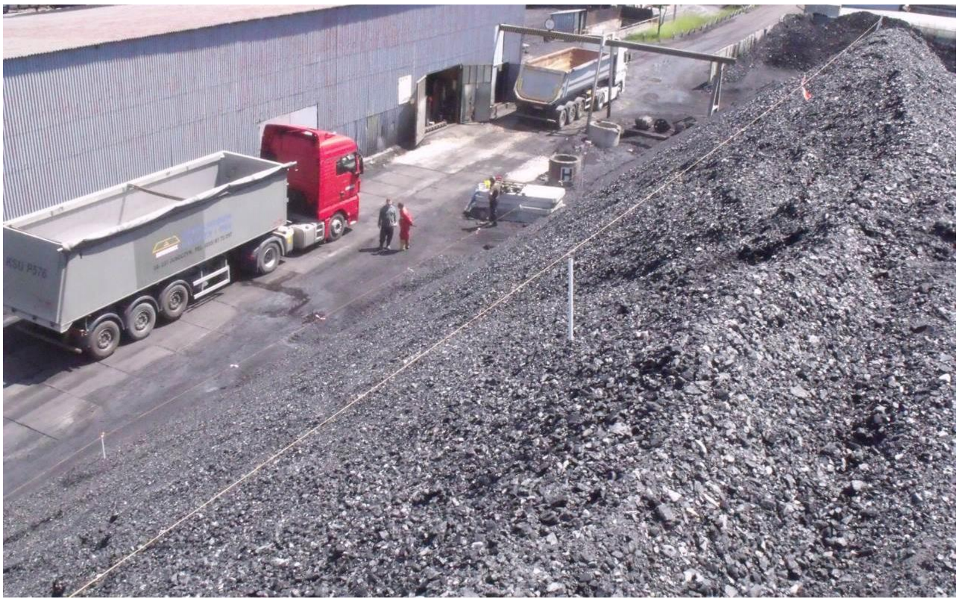

Fig. 3. Parcel delineated on the southern slope [source: own materials]

The parcels were delineated so as to contain within their area features representative of the entire dump (coal type and fractions, orientation with respect to geographical directions, slope angle, etc.). To facilitate identification, for the purposes of the study, the nomenclature colloquially used by the workers was adopted and they were referred to as the "south scarp" and the "east scarp".

2.2. Heap condition assessment - history and method of coal storage

Both parcels were located on heaps that had been in existence for several months, one of which had been subjected to further dumping and, at the same time, to coal pick-up for sale to customers. It should be noted that the survey parcels were not disturbed in any way during the entire survey cycle. As already mentioned, the heaps in their existing form had been in operation for several months (8-10).

From the interview with those responsible at the mine, it appeared that there had been incidents on these heaps in the past related to involving self-heating of coal. This was confirmed by observations of the surface of the heap with visible areas of necessary „undercuts" of the stored material (Fig. 4) that had become self-heated (Fig. 5).

Fig. 4. South scarp with traces of underbrush and self-heating coal [source: own materials]

Fig. 5. Self-ignition of coal on the surface of the heap [source: own materials]

2.1. Assessment of the thermal condition of the coal heap

Special measuring probes (Fig. 6) were used to assess the thermal condition of the coal heap, measuring the temperature of the heap at a depth of approximately 1 m. Infrared technology was used to locate potential areas where self-heating processes could occur. Measurements were taken using modern thermal imaging cameras with high sensitivity and resolution. During these measurements, it was possible to identify several potential locations where coal self-heating processes could have taken place. self-heating of coal.

Fig. 6. Depth probe measurements [source: own materials]

3. RESULTS AND CONCLUSION

3.1. Research on atmospheric air composition

Gasometric measurements were taken as part of the present study. Concentrations of gases such as oxygen, carbon monoxide and dioxide, methane, hydrogen, sulphur oxides, nitrogen oxides and hydrogen sulphide were determined. All measurements were made with certified electronic measuring instruments (Fig. 7). In several cases, exceedances of the permissible standards used in underground mines were observed. For the utilitarian purposes of the work, the exceedances were important, as they could be indicative of thermal phenomena taking place in the heaps. This information, together with other observations, was the basis for the monitoring of the repository described in the next section.

Fig. 7. Gasometric measurements on the surface of the heap [source: own materials]

3.2. Monitoring the storage site for visible changes indicative of possible thermal phenomena

As already mentioned in the previous section, the work involved continuous monitoring of the storage site for visible changes indicative of possible thermal phenomena. The storage sites were inspected daily for a period of about 3 weeks before and about 4 weeks after the antipyrogenic agent testing. The visual observations mainly involved looking for damp patches on the surface of the coal (observed in the morning and disappearing after sunrise, places where precipitation dries out quickly, the occurrence of water vapour clouds, the formation of ash and sulphur deposits, the escape of fumes with a characteristic smell). In addition, the temperature of the surface of the landfill was measured using pyrometers (Fig. 8) in order to select places where the surface temperature of the landfill is at least 3°C higher than the ambient temperature. Measurement tables were drawn up with the plot surface temperatures monitored. Measurements were taken daily (at the same time of the day - in the morning before the surface of the heap was warmed up by sunlight) with a pyrometer using a specially created measurement grid (Fig. 9). Every 2-3 days, measurements were also made using a thermal imaging camera (Fig. 10) of the entire surfaces of the objects under examination. Where thermal processes were suspected, measurements were taken using a depth probe in each case.

Fig. 8. Measurements of storage site surface temperature using a pyrometer [source: own materials]

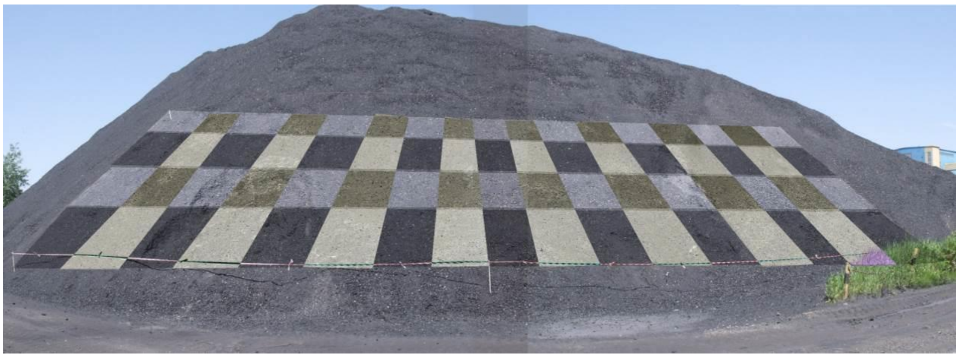

Fig. 9. Survey grid on the eastern slope [source: own materials]

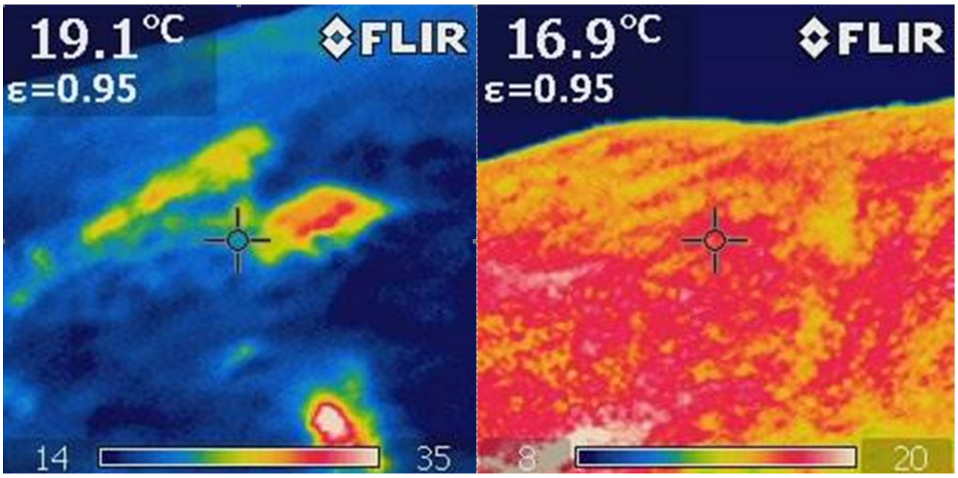

Fig. 10. Images from thermal imaging cameras (left south slope, right east slope) [source: own materials]

3.3. Choice of method and route of antipyrogen administration

In order to develop the correct method and method of administration of the antipyrogen, a previous analysis was made of the possibility of using an antipyrogenic agent in fire prevention. The infrastructure in the vicinity of the dumps, the available technical resources and the possibilities of administering the antipyrogenic agent were analysed. The analysis of available resources and technical possibilities led the authors of this article to decide to carry out trials with two different methods of applying the antipyrogenic agent and a variant involving a combination of the two methods (injection and spraying).

In the vicinity of the dumps, there was no simple means of connecting electrical equipment that could be used to power the equipment needed during the trials. Access to running water was also difficult, but, due to hydrants nearby, usable. There was continuous heavy vehicle traffic (haul roads) near the dumps themselves. For this reason, it was decided to set up a site in the immediate vicinity of the heaps and to use a generator with a compressor and the antipyrogenic agent feed pumps it supplied (Fig. 11). Due to the varied location of the parcels, where there was a safe possibility to enter the heap (relatively low slope of the slope) it was decided to attempt to inject the antipyrogenic agent deep into the heap.

The above-mentioned factors also necessitated the use of suitably long and efficient hoses to supply the antipyrogenic agent to the special feeding tips (Fig. 12 and Fig. 13).

Fig. 11. Compressor, tanks and pump supplying the antipyrogenic agent [source: own materials]

Fig. 12. Injection tip [source: own materials]

Fig. 13. Handles and connection of the injection tip [source: own materials]

In order to assess the applicability of the antipyrogenic agent, two main delivery methods (injection and spray) were selected. The third method was a combination of the two main methods. The selection of these methods essentially necessitated an appropriate methodology for testing the effectiveness of the delivery of the antipyrogenic agent and analysis of its effectiveness. The modification of the test methodology involved the need to determine the sites of antipyrogen injection and the amount of injected or sprayed antipyrogen as accurately as possible (Fig. 14).

Fig. 14. Antipyrogenic agent feed pump and flow meter mounted on the supply line [source: own materials]

The solution chosen was to use a liquid flow meter mounted on the supply line of the injection/injection nozzle. During the injection of the antipyrogenic agent, the temperature of the heap surface was measured continuously (with pyrometers at designated points - nodes where the antipyrogen was injected - and with a thermal imaging camera using the sector method). In addition, control measurements were taken using depth probes (at a depth of approx. 1.0m) in the vicinity of the injection sites.

During the spraying of the antipyrogenic agent, the temperature of the heap surface was measured continuously (with pyrometers and a sector thermal imaging camera of the entire sprayed surface).

Photo and video documentation was made of the trials.

After the trials were completed, the parcels were subjected to monitoring. In order to detect areas of temperature anomalies on the surface of the spoil heap, as well as to determine the size of zones affected by thermal processes (due to the size of the measured areas), temperature measurements were carried out with an infrared thermometer from a distance of approx. 15-20 m (not more than 25 m) from the object, in regular, parallel strips 3 - 5 m wide. Measurement tables were drawn up with the parcel surface temperatures plotted at designated points - nodes. Every 2-3 days, the entire surface of the surveyed objects was also measured using a thermal imaging camera. The aim of this procedure was to locate places with the highest temperatures on the surface of the object (i.e. potential fire outbreaks

occurring under the surface of the object), where additional measurement points were set up and marked, and possibly to correct the positions of the already marked measurement points. At the location of the identified temperature anomaly, a hole was drilled approximately 1m deep, in which the following tests were carried out:
- temperature measurement, °C,
- determination of carbon monoxide CO, % vol,
- determination of carbon dioxide CO_2, % vol,
- determination of oxygen concentration O_2, vol. %.

All measurement results were archived so that the results obtained could be analysed on an ongoing (partial) and later (comprehensive) basis.

3.4. Testing with antipyrogen - sprays, depth delivery

Two parcels were designated for testing. These were located in different parts of the main dump. On each of them, it was decided to use a different method of antipyrogen administration, and in addition, on the parcel where injection was used, its surface was also covered with antipyrogenic agent. After an approx. 3-week preparatory period (monitoring of the heap), the antipyrogen trials were commenced.

A generator with a compressor was set up on the previously prepared sites (in the immediate vicinity of the heaps), which powered a pump feeding the antipyrogenic agent from special tanks with a capacity of 1,000 l. Using appropriate hoses, the antipyrogenic agent was fed to special injection or spray (spraying) tips.

Injection feeding

A special injection nozzle was screwed into the heap to a depth of approx. 1m by a previously trained worker (Fig. 15). Then 20 litres of antipyrogenic agent was injected at a time. The operation was repeated in succession, moving in 2m-wide strips from the top of the parcel downwards. The injection holes were 2m apart, forming a 2x2m grid. During the injection of the antipyrogen, the amount of injected agent was measured and the surface temperature of the parcel was measured using pyrometers and thermal imaging cameras. Half of the delimited parcel was injected, so that the thermal phenomena occurring in the injected part and the part where the antipyrogen was not applied could be observed.

Fig. 15. Depth delivery of the antipyrogenic agent (screw-in injection tip) [source: own materials]

Spraying

The antipyrogenic agent was sprayed directly onto the surface of the heap using a special tip (Fig. 16). The height of the designated parcel made it impossible to apply the agent from the foot of the slope (working pressure too low), it was therefore necessary to spray the upper part of the parcel by an employee located halfway up the parcel. The lower part of the parcel was sprayed from the foot of the slope. Exactly half of the designated parcel was sprayed so that it was possible to directly compare the effects of the spraying with the other half of the parcel, where spraying was not carried out. The sprayed area was sprinkled twice at an interval of approximately one hour for precise coverage. During the spraying, the amount of agent used was measured and the temperature of the parcel surface was measured using pyrometers and thermal imaging cameras.

Fig. 16. Spray feeding of the antipyrogenic agent (first lane, first sector) [source: own materials]

Combined method (depth and spray application)
On the parcel in which the antipyrogenic agent was previously injected after one week, an additional double spray was made on the surface of the heap (Fig. 17).
In this case, the location of the parcel made it possible to conduct the entire spray from the foot of the slope. The spraying was carried out using the strip method, where the width of the sprayed strip was approx. 2.5m. During spraying, the amount of agent used was measured and the temperature of the parcel surface was measured using pyrometers and thermal imaging cameras. Half of the parcel area was sprayed (exactly in the area where the antipyrogenic agent was previously injected).

Fig. 17. Spray feeding of the antipyrogenic agent (first lane, second sector) [source: own materials]

As part of the trials, measurements, tests and analyses carried out, the authors of the study came to the following conclusions, among others:

- For the administration of the antipyrogenic agent, it is necessary to create such equipment so that it works in all conditions, at any mine or other coal storage site.
- The equipment must be mobile, with the capacity to deliver mixtures over long distances in order to eliminate the need to transport them over the stored coal on the heap; the selection of the individual components and their installation system is also important.
- Following trials with the injection and spray method, it is suggested that research and development be extended to a type of device whose installation is capable of covering the entire surface of the coal, for example during its

transport to the heap (restricting workers from staying in hazardous areas of coal storage sites).

- Another possibility is to use the spraying method when laying each successive layer of the heap, taking into account the thickness of the layer in relation to the amount of agent to be injected.
- The injection method should not be used as a means to combat endogenous fire (burning heap), but can be used as a preventative method where no other method has been used before.
- The application of the new technology may result in a significant reduction in the loss of stored material - coal, reduction of the involvement of people and equipment in fighting a possible fire and reduction of the nuisance of the vicinity of the storage site (smoke, dust, risk of fire spreading).
- During the trials, measurable effects were obtained in the form of a reduction in the temperature of the heap and a significant reduction in dust.
- The proposed solution can cover the safeguarding of coal not only on mine heaps, but also at customers who store it, as well as during its transport (power plants, ports, railways).

4. SUMMARY

In the injection method, a total of 4,500 litres of antipyrogenic agent were used over an area of approximately 200 m^2 (all on the south slope).
In the injection method, a total of 2,500 litres of antipyrogenic agent were used over an area of approximately 350 m^2 (of which 1,000 litres on the eastern slope and 1,500 litres on the southern slope).
During injection, the method of hole drilling and injection necessitated the need for a worker to be on the surface of the slope (heap). On each occasion, these workers were specially trained and secured, but it should be emphasised that this method of injecting poses a risk of potentially dangerous events. Mine regulations prohibit workers from entering the heaps. In this case, permission was obtained from the Mine Site Manager after agreement and additional safety measures.
During the administration of the antipyrogen by the injection method, no significant changes in the surface temperature of the measured parcel were observed.
With the spray method, an almost immediate effect of lowering the coal surface temperature was observed. This effect persisted for several consecutive hours or even days.
The surface of the parcels sprayed with the antipyrogenic agent showed no tendency to dust. After drying, impregnation of the coal took place, and a so-called film was formed, covering the entire surface of the coal (including visible pores and crevices).

Immediately after the agent was sprayed onto the surface of the heap, sticking of coal grains was observed. The coal grains consolidated and, after drying, formed a so-called "crust" from which it was possible to separate them in the form of compact lumps (Fig. 18).

Fig. 18. Consolidated carbon grains after drying of spray-applied antipyrogenic agent [source: own materials]

An attempt was also made to extract a sample of the injected material from within the heap. The use of heavy equipment (excavator) proved necessary for this purpose. The material excavated to the surface also showed features of consolidation, but not as strong as the material from the surface of the heap.

It should be noted that the heap stored coal of fine and very fine fractions (fines) was stored on the heap, which, under conditions of increased air velocity (gusts of wind), caused significant dusting of the air. The surface to which the antipyrogenic agent was applied showed no tendency to dust.

ADDITIONAL INFORMATION

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REFERENCES

1. Cygankiewicz, J 2000. About Determination of Susceptibility of Coals to Spontaneous Combustion Using an Adiabatic Test Method. *Archives of Mining Sciences* **45**, 247-273.
2. Garcia–Torrent, J et al. 2012. Determination of the risk of self-ignition of coals and biomass materials. *Journal of Hazardous Materials* **213–214**, 230-235.

3. Yauan, L and Smith, A C 2012. The effect of ventilation on spontaneous heating of coal. *Journal of Loss Prevention in the Process Industries* **25**, 131-137.
4. PN-G-04558:1993. Hard coal. Determination of the spontaneous combustibility index (Węgiel kamienny. Oznaczanie wskaźnika samozapalności).
5. Słota, K et al. 2015. Research towards the development of technologies to reduce spontaneous combustion and dust hazards occurring in coal stockpiles - an analysis of options (Badania w kierunku opracowania technologii ograniczania zagrożeń samozapłonem oraz pyleniem występujących na składowiskach węgla – analiza możliwości). *Inżynieria Górnicza* **4**, 54-58.
6. Drenda, J et al. 2006. Elimination of incineration as part of the reclamation of the landfill of post-coal waste in Siemianowice Śląskie - Bańgów (Likwidacja zapożarowania elementem rekultywacji składowiska odpadów powęglowych w Siemianowicach Śląskich – Bańgowie). *Zeszyty Naukowe Politechniki Śląskiej* **272**, 31-39.
7. Sawicki, T 2004. Spontaneous combustion in a stock piles as a reason of a fire (Samozapalenie węgla w zwale jako przyczyna pożarów). *Karbo* **1**, 56-59.

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