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EVALUATION OF BROWN COAL SPONTANEOUS COMBUSTION AND SOURCES GENESIS PROGNOSES

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Abstract:
This article presents summarizing information about the solution of partial part of research problem of prognoses of deposited brown coal spontaneous combustion sources genesis as a part of project TA01020351 – program ALFA. We will gradually describe the results of long term measurements carried out on selected brown coal heaps realized from 2011 to 2013. The attention is devoted to characterization of key parameters. These parameters influence the genesis of combustion. The second problem is the comparison of results of thermal imaging with laboratory results of gas and coal samples sampled in situ, with the influence of atmospheric conditions (insolation, aeration, rainfall, atmospheric pressure changes etc.), with influence of coal mass degradation, physical and chemical factors and another failure factors to brown coal spontaneous combustion processes.

***Key words**: lignite, brown coal, deposit, heap, coal self-ignition, monitoring*

INTRODUCTION

Current operating mining companies as well as their customers – coal burning power plants and heating plants – need to carry out buffer and homogenization deposits to eliminate the fluctuations of supply, both in quantity and in quality, in order to achieve the required qualitative parameters according to customer specifications. Within the course of long-term storage of coal fuels, spontaneous processes occur frequently inside the bodies of such deposites, which lead to self-heating and spontaneous combustion of coal.

The Czech national standard ČSN 44 1315 "Storage of solid fuels" lays down methods for storage of solid fuels, and measures for monitoring to achieve economical and safe storage in power plants, industrial plants, warehouses and coal cellars of consumers. This standard requires obligatory control of the surface of solid fuels heaps, the measurements of surface temperature and inner temperature in several points. Such a measurement of the internal temperature is not sufficiently informative about the distribution of temperatures in the monitored housing and, in addition, using a sufficiently dense network of measuring points is difficult to run in time and financially challenging and for large bodies even technically unfeasible. The recommended point measurements of surface temperature using thermometers are not capable (in a real network of measuring points and in real time) to provide the image of the temperature status in the landfill all over. Therefore they cannot, with sufficient probability, reveal all of the centers (niduses) with irreversible temperatures, they cannot specify all critical statutes precisely enough and their thermal displays on the surface and inside the coal deposit, in particular in relation to the internal state of the coal body and in the same way regarding the applicability of this method to the forecasting of self-heating in subsurface deposits. The measurements do not include also yet unqualified influences on the dynamics of the development of self-heating effects [1].

This is confirmed by the fact that despite these control measurements required by the CSN standard and measures applied in advance, unexpected self-heating statutes and fires occur very often. The current state of monitoring of the thermal state of the body does not allow sufficient identification of the thermal state of the body in terms of both space and time, and therefore does not allow nor effective prediction of outbreaks of self-heating and fires and their subsequent timely disposal.

COMPLEX LONG-TERM MEASUREMENTS

Within the second and third phases of the project, six comprehensive long-term measurements in total were carried out at landfills of brown coal in the area of Vršanská uhelná, a.s. – locality Hrabák, see Fig. 1 and the company Sokolovská uhelná, a.s., in the Coal Terminal (TUM), see Fig. 2 [2, 6].

1. The first "test" measurement on brown coal housing with a capacity of approximately 2000 tones in the locality Hrabák was carried out on 7. 11.-10. 12.2011.
2. The second "spring" comprehensive long-term measurement on deposit was carried out in the Hrabák within the days 28. 4-31. 5.2012.
3. The comparative measurement using an one point probe on the operating landfill Hrabák was carried out within 14. -16. 6.2012.
4. The third comprehensive long-term measurement on the "summer" deposit with a capacity of 830 m^3 in the locality Hrabák was done in the days of 16.5-3.8.2012.

5. The fourth comprehensive long-term measurement on "winter" deposit with the volume about of 506 m3 on the Hrabák was initiated on 1.11.2012 and ended 15. 1.2013.
6. The fifth comprehensive long-term measurement on the "spring" deposit with a capacity of 584 m^3 on the coal terminal in Sokolov was initiated on 12. 2.2013 and ended 9.4.2013.
7. The sixth comprehensive long-term measurement on "autumn" deposit on the coal terminal in Sokolov was initiated on 11.10.2013. This last measure, despite the original assumptions, prolonged until February 2014.

The extensive database of information about the development of the state variables and the composition of the gases desorbed from the studied bodies (heaps) of brown coal obtained during the above mentioned long-term measurements carried out at the selected operators was then thoroughly evaluated. Consequently, the results obtained by the assessment of the thermal images from the sampled thermograms were compared with the results of gas and coal samples, with the influence of atmospheric conditions (insulation, aeration, addition of rainfall water, alterations of the barometric pressure, etc.), with the impact of the degradation of coal mass, of physico-chemical factors, and the impact of other factors on the processes of spontaneous combustion of coal. The gas samples collected in-situ were compared with the laboratory gas indicator images of spontaneous combustion obtained by the method of thermal oxidation with the aim to find a correlation to the temperature of self-ignition.

Fig. 1 Locality of the monitored „test" heap at the Hrabák deposit

Fig. 2 Locality of the monitored „test" heap at the Sokolov terminal

EVALUATION OF THE OBTAINED RESULTS

Based on the evaluation of significant amounts of captured data [3, 4, 5, 7, 8, 10], resulting from the long-term field measurements and laboratory investigations of coal samples, gathered in the overview tables and charts, the following conclusions can be proposed:

Internal temperature

1. The highest temperatures are usually at depths of 2 to 3 meters under the surface of the stored coal masses – in the summer period in the lower part of this sub range (positions on the measuring probe no. 2 and 3), in winter in the upper part (deeper – positions of the measuring probe no. 4 and 5) see the following charts – Figure 3.
2. In these depths (2 to 3 m), temperatures gradually, almost linearly, rise to a value in the interval 80-95°C. In summer, the temperature rise is steeper, in winter, the temperature rises more slowly.
3. Temperatures deeper than 3 meters under the surface of the heap decrease step wisely. These findings were confirmed using the special 10-m-long probe installed in the pile no. 5.
4. In the next development stage, temperatures at depths of 2 to 3 meters stagnate and the internal temperatures rise at all depths – temperature compensation occurs throughout the body to the values (80-95°C), which so far have been only in depths of 2 to 3 feet under the surface of the stored coal masses.
5. In the final part of the development process of self-ignition (in the short term before the spontaneous combustion of coal mass), a local dynamic increase of the internal temperature occurs (in a few cases even up to 150°C in depths from 2 to 4 meters). In the case of non-compliance with all the basic conditions for the final beginning of the spontaneous combustion, the same rapid decline of the internal temperature, usually to the original value, occurred in all recorded cases within the next 24 hours. This fact is evident from the following charts – Figure 4.
6. The final ignition occurs at the moment when the temperature compensation has already occurred throughout the whole body (or its part) of the coal deposit. The value of this compensated temperature attacks the value of the temperature of 100°C.
7. Centers of spontaneous combustion are located exclusively at the toe (bottom part) and close to the surface of coal deposit and even in the places, which even before the 24 hours showed no surface temperature anomalies.

METEOROLOGY

Temperature. The influence of the external temperature on the spontaneous combustion process as well as the influence of other measured parameters described in the text was clearly proved, both from measurements carried out in the various seasons in situ and the laboratory investigation of the oxidation heat of brown coal samples. This effect of the outside temperature on the process of self-ignition of the deposited coal, can be divided into two contradictory effects:

– the first one is the heat from the external environment supplied into the heap of the stored coal material from the higher temperatures of the ambient air in the summer months, and mainly as a result of the additional heating of coal by direct sunlight. The carried out investigations showed that the temperature increase of approx. 15°C leads to a doubling of the speed of oxidation of (brown) coal samples and shortening of the time of spontaneous combustion of coal by one half during the summer and winter months. The investigation on coal heaps showed that on the sunlit places the surface temperature of substrate materials can exceed 60°C, which represents "non-oxidizing" heating of (approximately) 30°C compared to the coal surface in the shadow. This may establish a different ("more advantageous") temperature conditions for the "start kick" of the process of the self-ignition in such heated places,

– on the other site, the heat is transferred from the heap into the cooler air of the surrounding environment, particularly in the winter months and in the later stages of the self-ignition process. Due to this exchange of heat from the surface of the coal heap in the ambient air, the places with the highest measured temperature are shifted in the larger depths, as has already been described in the paragraph – the internal temperature.

The above described facts are also apparent and evident from the charts in Figure 3 (red line). The time shortening in the summer months by one half to heat the internal temperature from the initial values in both cases about 20°C to approx. 75°C is obvious. In the summer period, the temperature increase to the indicated value occurred in less than a month, and in the winter period within two months. In addition, the noticeable move of the long term highest measured temperatures from the positions 2 and 3 in the summer months to positions 3 and 4 in the winter months is evident on these charts.

Wind. The field measurements in situ and laboratory investigations clearly demonstrated the effect of the wind, representing the main source of the oxygen needed for the development of the spontaneous ignition process. One of the generally accepted knowledge about the phenomena of the spontaneous ignition process of coal in landfills is the fact that the center and beginning of the process occur exclusively on their windward sides. A vital role in the formation of spontaneous ignition have winds that "face" on the walls of the landfill and represent the major source of the oxygen needed for the development of the self-ignition process. The importance of speed and direction of winds on the dynamics of the self-ignition process development was clearly confirmed even by our computer simulations. The influence on the spontaneous ignition of coal, however, is more complex (Fig. 5).

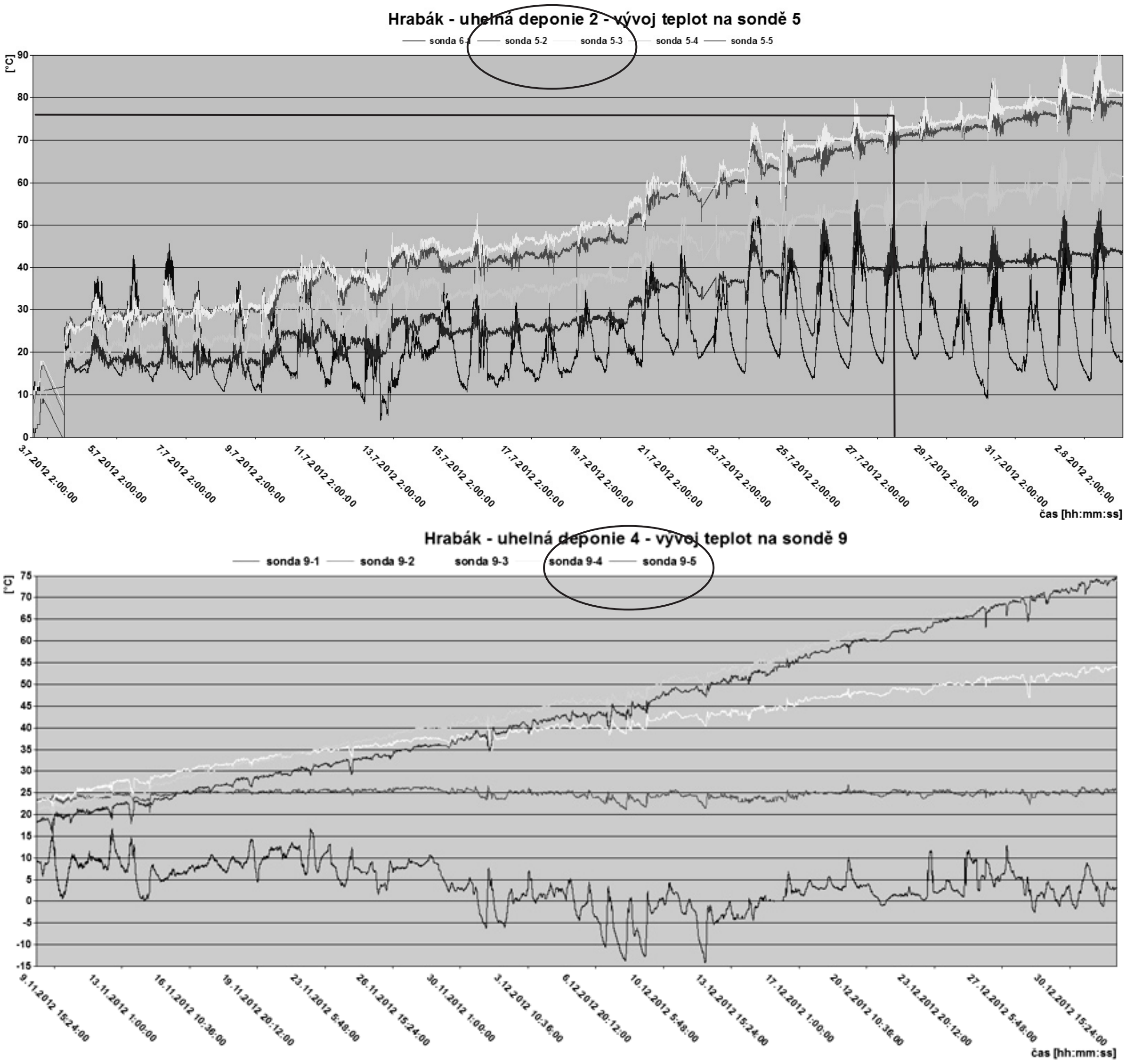


Fig. 3 Comparison of temperatures measured in summer and winter

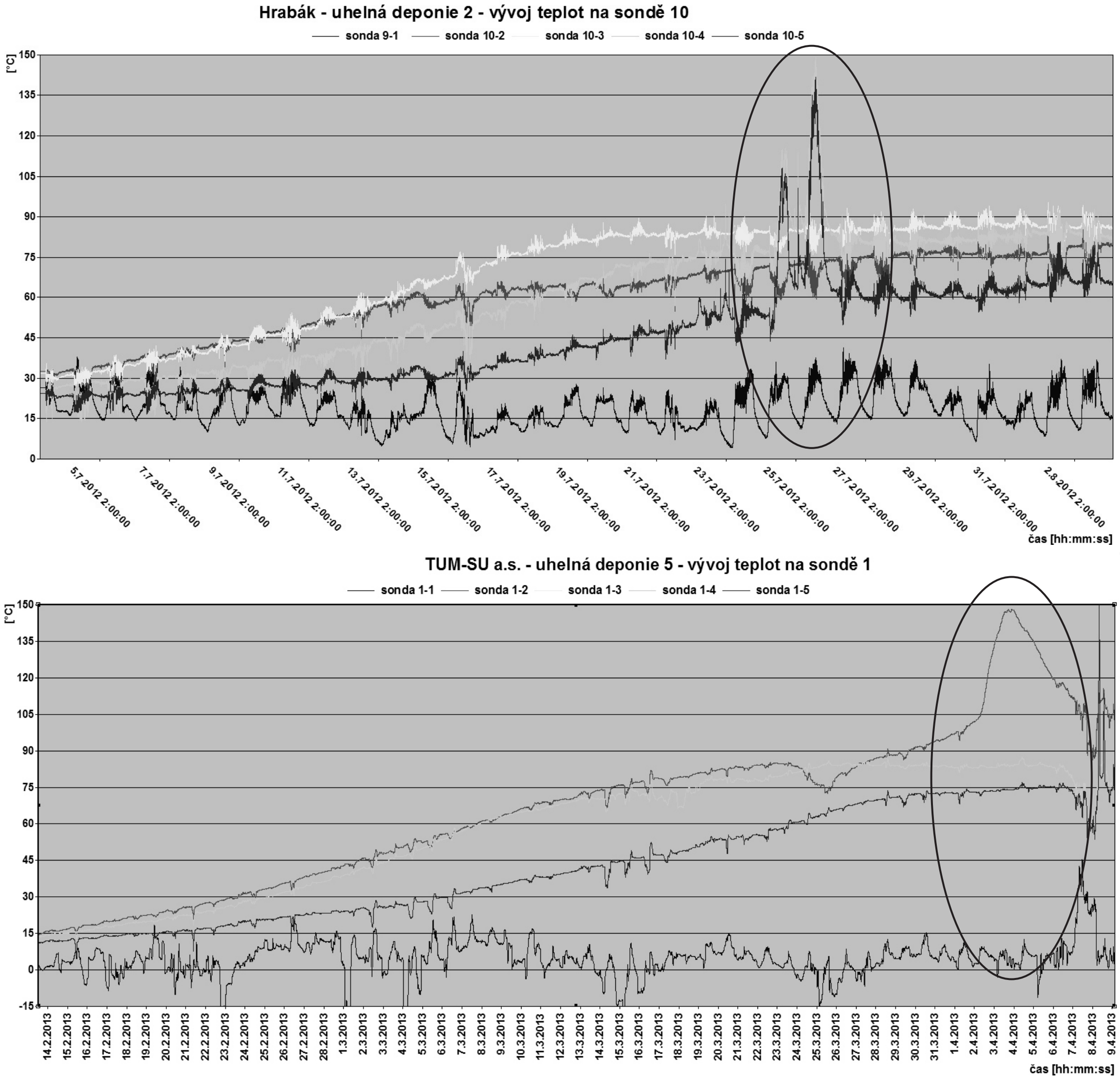


Fig. 4 Demonstration of the local temperature anomalies

An illustrative example is given on the following charts from the fifth long-term measurements. In the period by 25.3., there has been an increase in the wind speed, according to the record from the weather station, to the places in the coal pile, where the probes no. 1 (measuring Central EMS DV803) and no. 14 (measuring central OM-USB-5201) were placed. Each of the probes was connected to the stand-alone measuring system. Both probes demonstrate the temperature decrease in the depth about 1 meter and the probe no.14 even in the depth 2 meters due to the cooling of the sharp cold wind. In contrast, already heated wind caused a partial subsidy of oxygen into the deeper locations – at a depth of 3 and 4 meters on the probe no. 14 – and these locations are characterized by an increase in temperature.

Humidity. The influence of the moisture content of coal at its oxi-reactivity (expressed using values of the heat of oxidation q30) was within the framework of this project studied especially last year, when the samples of brown coal from the mines Centrum and ČSA were measured. The measurement results confirmed the fundamental influence of moisture on the resulting value of the heat of oxidation, but this impact is not obviously "monotonous". While reducing the moisture content of coal from the original values (about 28%) at the lower levels of humidity leads to a significant increase of the heat of oxidation, further sample drying causes the apparent decrease in the heat of oxidation. Therefore, talking about the spontaneous combustion by coal oxidation in situ, it actually refers to a system of "coal-oxygen-water", when the resulting behavior of the coal to the oxygen also includes the information about the possible interaction of present water. The influence of water on this process is however more complex. A considerable amount of heat can be released by a simple contact of liquid water with coal – without the necessity of oxygen presence. We are talking about "*coal wetting*" and in a real environment of the coal dump it actually corresponds to the "wetting" of coal by the rain. Wetting of less bituminous brown coal releases the heat of more than 100 J/g, which (assuming adiabatic conditions) may represent an increase in the temperature of the system about the tenth of °C by the "purely non-oxidizing way". Obviously, this can significantly increase the temperature level of the oxidized coal and as a result, it can be (naturally) expected to speed up the self-ignition process of "wetted" coal. With increasing moisture content of coal the value of "wetting" heat (of course) progressively reduce. This fully corresponds to the knowledge of the practice. Therefore it is obvious that, the current moisture content of coal plays a crucial role by this wetting process and has important influence due to the wetting heat of coal – as the aspect supporting the development of spontaneous combustion process – together with the possibility of direct contact with rainfall (Fig. 6).

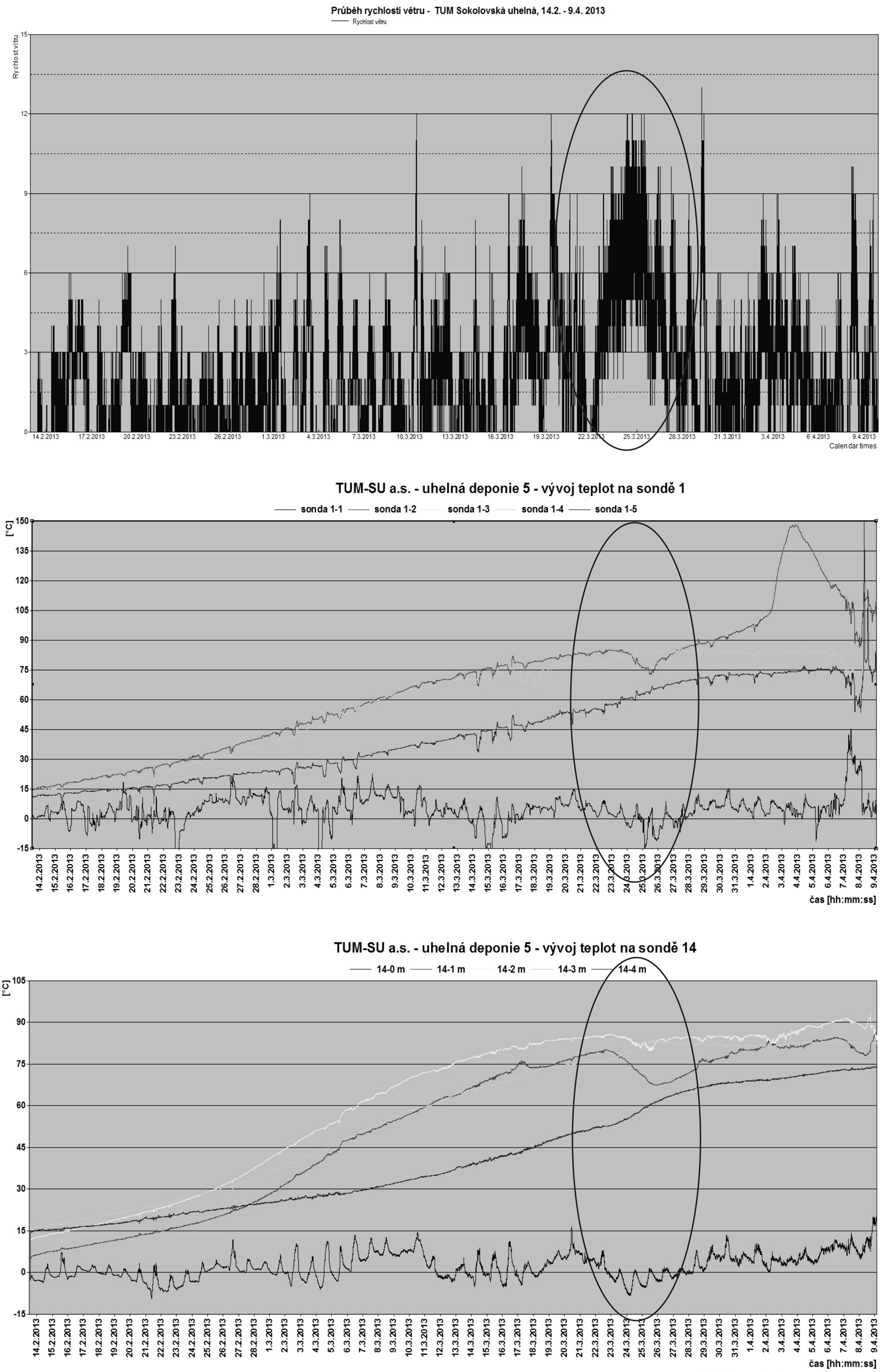
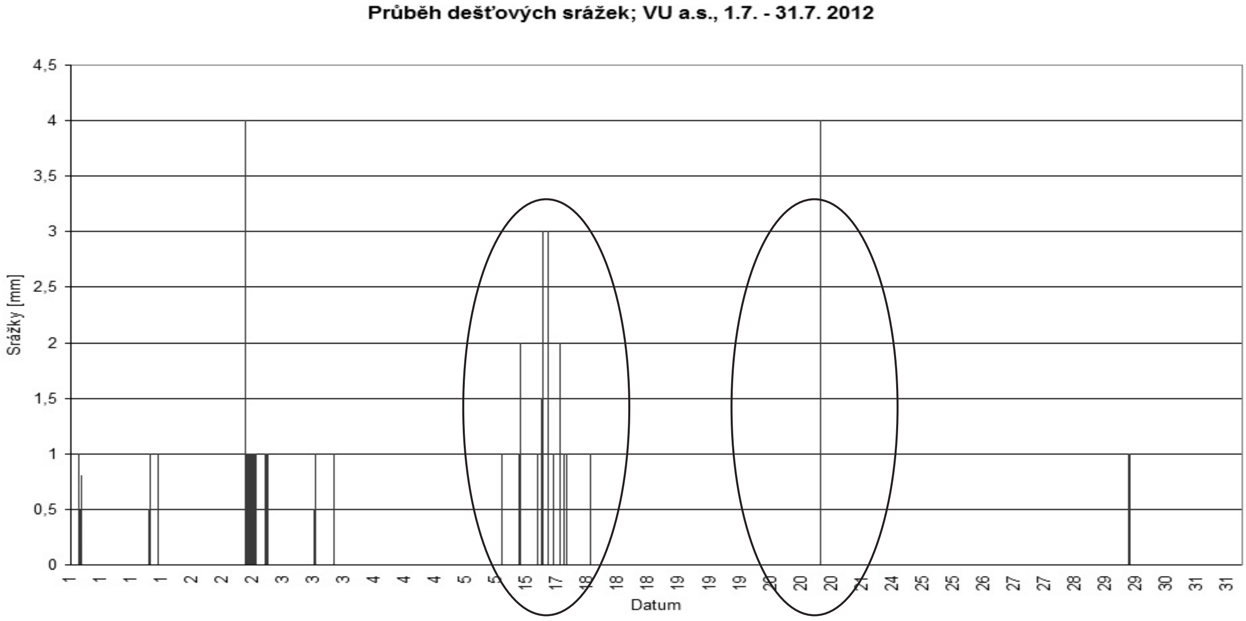
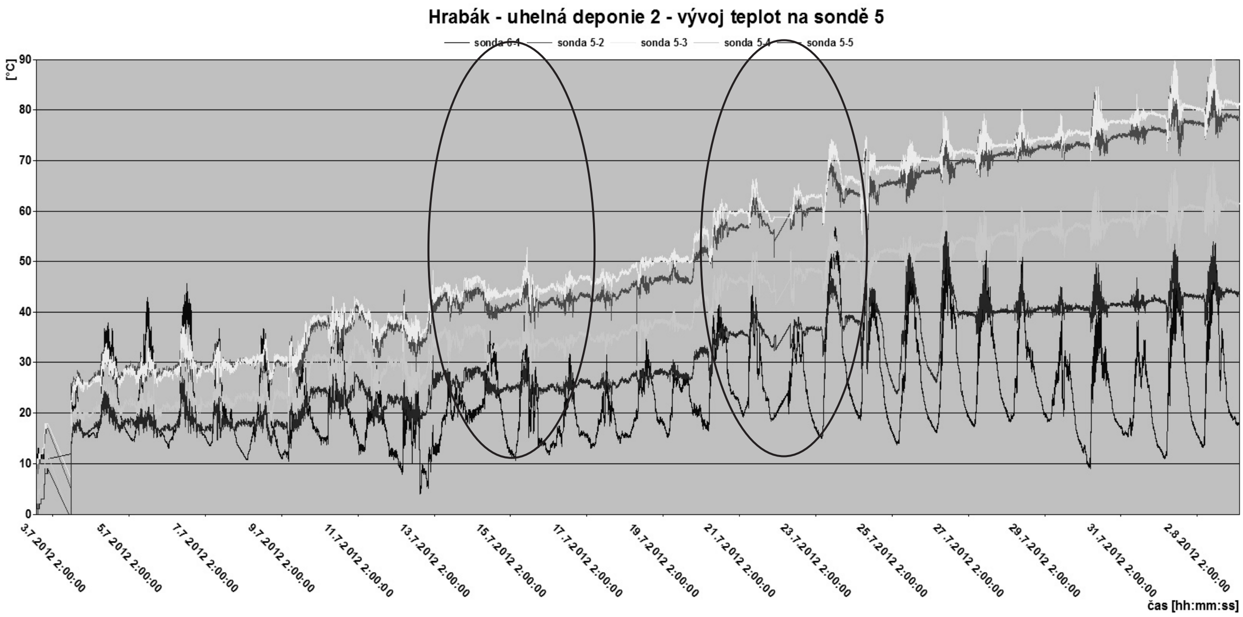


Fig. 5 Examples of the wind influence





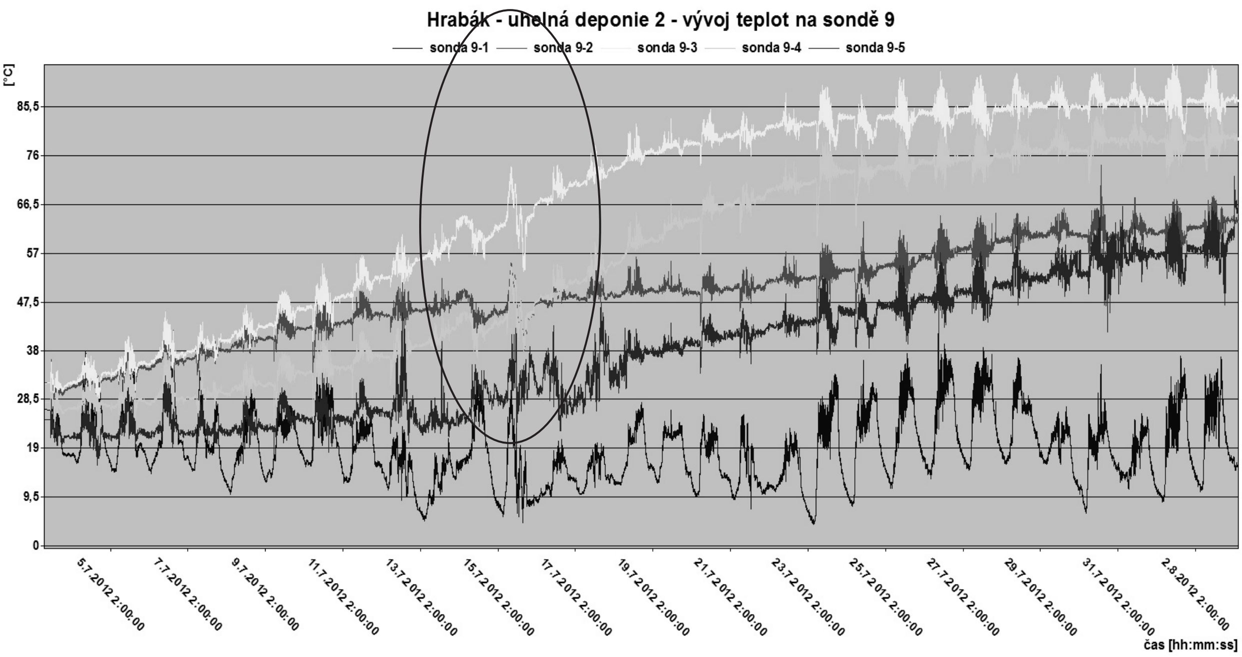


Fig. 6 Examples of the rain fall influence

Measurement	Start	End	Number of days	Number of probes for gas sampling and temperature on-line measurement
1 Testing	07.11.2011	10.12.2011	34	2
2 Spring	28.04.2012	31.05.2012	34	2
Comparing	14.06.2012	16.06.2012	3	2
3 Summer	26.06.2012	03.08.2012	38	8
4 Winter	01.11.2012	15.01.2013	66	10
5 Spring	12.02.2012	09.40.2013	58	10
6 Autumn	11.10.2013	Up to date	So far 69	10

CONCLUSIONS

In the project frame were carried out up to today:

1. Six long-term complex measurements in total – see the following table, representing 302 round-the-clock measurements of the internal temperatures, gas sampling and meteorological conditions recording.
   The following information were recorded and evaluated on an ongoing basis in the course of these six complex long-term measurements:
   – internal temperature of the deposit (coal heap) – (measuring system and thermo imaging – VÚHU),
   – outer surface temperature of the deposit (thermo imaging – VÚHU),
   – content of CO_2, O_2, CO and other gases (VŠB),
   – 12 gas sampling to determine hydrocarbons content (VŠB),
   – atmospheric conditions – temperature, pressure, wind, rain fall, UV radiation, sunshine – (weather station – VÚHU),
   – samples of deposited coal (labs of VÚHU),
   – samples of deposited coal (labs of VŠB).
   Partial conclusions based on the evaluation of significant amounts of collected data (e.g. only the internal temperature include nearly 3.5 billion values from a total of 170 measuring points), which were gathered during the long-term field measurements and implemented laboratory investigations on samples of coal are as follows. All data were processed in the overview tables and graphs, which are together with the results of the measurements of temperature and the gases included in separate outputs (news, studies, databases, catalogues, etc.).
2. Two certified procedures:
   – procedure for measurement of temperatures on the brown coal deposits,
   – procedure for the measurement of the indicative gasses of the spontaneous combustion process in the endogenic air volumes of coal deposit bodies.
   The certified procedure consists of:
   – procedure itself,
   – certificate of compliance evaluation issued by the Accredited body,
   – standpoint of the respective legal body – Regional mining authority responsible for the area of the coal depositing.
3. Proposal of the „Mathematical model of the temperature field development of the coal deposit together with the identification of factors influencing spontaneous combustion“.
4. Proposal of the „Assessment of the spontaneous combustion process of brown coal on the deposits“ (criterion MHU).
5. Patent application for measurement and sampling probes.

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