Monitoring of Thermal and Gas Activities in Mining Dump Hedvika, Czech Republic

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Abstract. The negative consequences of mining of the black coal is occurrence of extractive waste storage locations - mining dumps. The mining activities carried out within the area of Ostrava are responsible for at least six mine dumps of loose materials arising as wastes from mining of mineral resources, many of which show presence of thermal processes. The thermal activity in dumps is responsible for many hazardous substances that pollute the environment and harm human health in the surroundings. This paper deals with the results of the first phase of project CZ.11.4.120/0.0/0.0/15_006/0000074 TERDUMP, on exploration of thermally active mining dumps are published in the article. As a first studied thermally active dump was a Hedvika dump. To localize of hot spots with hot gas emission was used a thermovision scanning by drone. The place with high temperature (49.8 °C) identified natural gas emission through natural cracks. Analysing the occurring pollutants in Hedvika Dump using the GC-MS or HPLC, respectively and the inert gases (CO2, CO and SO2) were determined by ion chromatography. The pollutants were determined in five sampling points during two measurements executed from July to August 2017.

1. Introduction

Intensive mining of black coal in the underground mines in the Ostrava-Karviná district (OKR) has left behind a large number of dumps that have resulted from the weighing of the produced carboniferous tailings as mining waste. In OKR, mining from deep mines was carried out on a hail, and extracted carbon tailings from the sorting process, preparatory works, and the treatment of hard coal was necessary to be placed on the surface [1]. As a consequence of the deposition of the tailings after the surface treatment of coal, dumps were basically found at all mines from the beginning, which can be considered as a characteristic feature of the mining landscape. About 50 dumps of 600 ha were created within the region of Ostrava and its surroundings.

The tailing deposited on the dumps of the OKR consists mainly of the admixtures of the rocks of Petřkovice and Hrušín layers, which consist mainly of sandstone, dust, claystone and also coal residues. Just these residues of black coal of the Upper Silesian Basin create also the main flammable component of the dump [2]. As mentioned above, due to the imperfect sorting of the tailing from the mineral, a considerable amount of coal substance remained in the rolling stock. Then they were susceptible to self-ignition under certain conditions. This phenomenon can occur primarily by aerating a carbon-rich coal tar. Oxygen and water vapor are therefore critical factors for this self-inflammation. The greatest amount of heat is released primarily through the oxidation of unsaturated organic substances and is supported by exothermic reactions. The humidity of the environment is mainly due to the reactions of water molecules with oxygen and coal. This accelerates oxidation and water vapor
condenses on the surface of the coal. The result is sensory changes not only on the surface but also in the body of the rock. If the released energy is not continuously removed, occurs desorption of coal gas when the temperature is below 160 °C. On the contrary, oxidative complexes are formed at higher temperatures, and burning occurs above 300 °C [3]. So this may result in radiant heat fires. In the aeration zones, the gases can both ignite and reduce the temperature to the surface air. This generation of gaseous substances is nothing special and occurs on a shallow surface. Substances that emerge at these sites can be crystallized in the effluent and react with the tailing material. Conversely, endothermic reactions occur in the part of the dump body without air access. Thermal decomposition of the carbonaceous matter starts and at a temperature above 1 000 °C there is a high temperature carbonization and consequently a number of secondary products are formed [4].

The arising risks from the deposited carbon sinks are permanent. Pollutants as well as gaseous combustion products can be released into the water. Due to carbonization, emissions of volatile and partially volatile organic compounds are released into the atmosphere. Their condensation then produces PAHs. In case of inadequate oxygen supply to the combustion zone, burning downstream producers produce mainly CO₂, CO, NOx, SOx, HCl, HF, hazardous metals and many other substances [5]. In general, the composition of gaseous substances which are released from the thermally active dumps into the atmosphere differs not only in relation to the composition of the deposited material but also to the presence or absence of soil cover. Thermically active dumps, due to processes with varying intensities in their bodies, they produce large amounts of pollutants into the air and, due to unfavorable diffusion conditions in the atmosphere, they can further concentrate and subsequently negatively affect the health of the population living near the dumps [6].

Thermically active dumps can also cause falls in dumps, surrounding forest fires, and health hazards due to airborne dust emissions, gaseous pollutants, hazardous elements and organic compounds. Unchecked coal fires can cause property destruction and ecosystem degradation. An important aspect of the thermodynamic activity is the composition of the heap. Dumps degrades aesthetic values of the landscape and its ecological functions [7].

Thermically active dump Hedvika was monitored within the framework of screening. The exact date of establishment of the Hedvika dump is unknown. It is supposed that the rock was weighed here since 1903, originating from the excavation and opening works. There was probably deposited material from the digging of the pit and the openings of the mine of the Hedvika (the original name the Albrecht mine). Surface was spread from the original area of the Hedvika mine's own area to the surroundings, especially in the northwest direction, directly to Michalkovice. At the turn of the 1960s and 1970s there was a period of intense widening of the dump to roughly today's surface area. The deposition of tailings in the cesspool was completed in 1998, when the disposal of part of the tailings production from the nearby mine Pokrok [8].

Dump is located on the eastern outskirts of cadastral areas of Radvanice and Michálkovice (Ostrava district) in the local parts of Chotebuz and Zaryje, on the border of the former districts of Ostrava and Karvina. The eastern part of the area under Karvina is part of the area of Petrvald near Karvina. It is a massive, powerful and vastly formed formation of tailings that follow the northern and western edges of the Hedvika plant of the former J. Fucik Mine. Its own dump is an extensive area that occupies an area of about 32 hectares. In the northeast, it is bordered by the Michalkovice-Petrvald road and in the southwest adjoins the mine site. With increasing volumes of mining, it was spreading northwest to Michalkovice. The transport of tailings was done by mines. This well is reclaimed and partially biologically stabilized with progressive revitalization (partly rainforest, partially set up by recultivating tree species). The part of the dump at the northern edges is formed by relatively fresh embankments [9].

It is a massive area-wide formation of tailings with an area of approximately 40.6 ha and an average height of the ridges of 12-15 m at present. The maximum height of the dump to the surrounding natural environment is up to 32 m. Thus the morphologically shaped complex of tailings with a high proportion of the residual coal substance is predisposed to the formation of fumes and the development of endogenous fires. Thermal processes have been registered in various parts of the dump since the 1950s. According to preserved documentation, however, they were locally eliminated,
in particular by extraction, extinguishing, and above all by covering with insulating layers. These interventions, however, failed to prevent the massive development of thermal activities, especially in the central part of the dump during the 1990s, when the temperatures in the focus of the fire exceeded 500 °C. However, the last experimental remediation of thermal activity in 2006 by flooding the hotbeds with liquid clay slurry was not effective enough and so these experiments were completed. After the initial multi-year stabilization of the outbreak, dynamic temperature migrations have been observed since 2010, also in the direction of the original area of the Hedvika mine, which is built up by building objects of various uses [10].

2. Material and methods

2.1. Characteristic of locality and sampling points
Two sampling points were selected for the thermically active dump so as to objectively include, if possible, all intensively thermally active sites. Their initial choice was based on the conclusions of thermovision, but with regard to the real situation in the field (gas leakage, vents, etc.) was specified directly on the site. The first sampling point 1F (GPS: 49° 49'36.2, N 18° 21'36.6 E) is located on the left side of the forest road embankment. On the right side of the forest road there is a takeoff point 2F (GPS: 49° 49'35.6, N 18° 21'37.6 E). More thermically-active point 2F is located on a significantly fallen surface over the surrounding terrain. It is clear that thermal activities occur here, due to the presence of burning residues of higher plants.

2.2. Thermovision
Identification of the most thermically active locations on Hedvika’s dump was performed by an air thermovision using a drone realized by Fly Vision (Czech Republic). The measurement was performed on a 100×50 m early in the morning (temperature-avoidance), with a view to the representativeness of the results, repeatedly to eliminate the possible accidental effects (28th March 2017 and 3rd June 2017).

2.3. Analytical Methods
Due to the main objective of the project is to compare and subsequently unify the methodologies of sampling and adaptation of individual samples and used analytical methodologies in the framework of close cooperation between VSB-TUO and GIG Katowice with the aim of their mutual compatibility and the most objective evaluation. Initial screening was also attended by experts from both sites for gas emissions.

Sampling was carried out by employees of the Health Institute with headquarters in Ostrava (hereinafter referred to as ZU OVA). For sampling (July 19, 2017), specially pretreated PUF cartridges SKC, 22×60 mm, were used in conjunction with a quartz fiber filter. Subsequent extraction was carried out in a Tecator device using dichloromethane for 8 h. The extracts were then concentrated with nitrogen in a TurboVap and subsequently transferred to a solvent compatible with the mobile phase. For the chromatographic analysis, the extracts were diluted so that the analyte responses were in the range of the calibration curve used and the linear response of the detector used. For quantification, a certified calibration standard, Absolute Standard, was used. Custom analysis, data acquisition and evaluation were performed using Empower software.

Determination of PAHs was performed at VSB-TUO by high performance liquid chromatography (HPLC) on a Waters Acquity UPLC I-Class device with dual detection. Separation was performed on a Waters PAH C column 18.5 μm 150×2.1 mm i.d. by gradient elution with acetonitrile/water.

3. Results and discussion
It was important to find those sampling points that exhibited the highest thermal activity for primary screening. For this purpose, infrared thermography was used. When there is enough air that enters the drain, it initiates the oxygen contained by the spontaneous combustion of the stored material. During the burning of coal residues a crack is formed on the surface, through which it escapes together with
flue gases and heat. It can be seen from figure 1 that it practically burns the entire surface of the Hedvika dump. Under the surface of the dump there is a huge amount of coal that has accumulated here as a result of mining, and not quite effective treatment processes in the past. The maximum surface temperature measured by thermovision imaging was 71.6 °C. Clearer places to represent a temperature difference of about 50 °C. The ambient temperature in this case was 3.4 °C.

**Figure 1.** Overall view of thermically active dump Hedvika (June 2017).

As part of the initial joint screening carried out on July 19, 2017, an analysis of PAHs representatives was carried out, captured in the concentrate of the GIG Katowice and captured on the PUF (VSB-TUO). The results of individual PAHs at the most thermically active sampling point 1F for the initial screening are shown in table 1.

**Table 1.** PAHs identified in the most thermically active point of dump Hedvika.

| Analyte                  | μg m⁻³ | Sampling point 1F | Sampling point 2F |
|--------------------------|--------|-------------------|-------------------|
|                          | Concentrate | PUF | Σ | Concentrate | PUF | Σ |
| Naphthalene             | 110.00 | 0.35 | 110.35 | 27.67 | 0.25 | 27.92 |
| Acenaphthylene          | *      | <0.01 | <0.01 | *      | <0.01 | <0.01 |
| Acenaphthene            | <0.05 | <0.05 | <0.05 | <0.05 | 1.10 | 1.10 |
| Fluorene                | 13.17 | 0.72 | 13.89 | 24.83 | 0.59 | 25.42 |
| Phenanthrene            | 26.67 | 4.00 | 30.67 | 92.17 | 5.06 | 97.23 |
| Anthracene              | 0.83  | 0.52 | 1.36 | 12.83 | 0.50 | 13.33 |
| Fluoranthene            | 13.83 | 0.44 | 14.27 | 36.00 | 0.38 | 36.38 |
| Pyrene                  | <0.05 | 0.32 | 0.32 | 30.50 | 0.31 | 30.81 |
| Benzo[a]anthracene      | <0.05 | 0.18 | 0.18 | <0.05 | 0.14 | 0.14 |
| Chrysene                | <0.05 | 0.19 | 0.19 | <0.05 | 0.16 | 0.16 |
| Benzo[b]fluoranthene    | <0.05 | 0.09 | 0.09 | <0.05 | 0.10 | 0.10 |
| Benzo[k]fluoranthene    | <0.05 | 0.03 | 0.03 | <0.05 | 0.03 | 0.03 |
| Benzo[a]pyrene          | <0.05 | 0.07 | 0.07 | <0.05 | 0.07 | 0.07 |
| Dibenzo[ah]anthracene   | <0.05 | 0.01 | 0.01 | <0.05 | 0.03 | 0.03 |
| Benzo[ghi]perylene      | <0.05 | 0.04 | 0.04 | 8.17 | 0.07 | 8.24 |
| Indeno[1,2,3-cd]pyrene  | <0.05 | 0.58 | 0.58 | <0.05 | 0.03 | 0.03 |
| Σ16 PAHs                | 164.50 | 7.53 | 172.03 | 232.17 | 8.81 | 240.98 |

Note to the table: * not determined

Based on the screening analysis, it is not yet possible to reach overall conclusions, but some general assumptions have already been confirmed. For example, some concentrations of PAHs, whether measured in the concentrate or captured in PUF, are worth mentioning. It is true that low molecular weight PAHs (2-3 benzene nucleus) are contained in the atmosphere only in the gas phase as diffusion-moving molecules, whereas higher molecular weight polyaromatic hydrocarbons are
bound to aerosol particles or sorbed on organic matter. In the concentrate, the presence of mainly multi-agent representatives of PAHs, with the exception of Benzo[ghi]perylene (8.17 \(\mu g\) m\(^{-3}\)), was detected below the limit of determination. Higher concentrations of Phenanthrene and Pyrene, which can be considered as indicators of high temperature pyrogenic processes, have also been confirmed. At the most thermically active sampling point 2F, Phenanthrene (97.23 \(\mu g\) m\(^{-3}\)) and Pyrene (30.81 \(\mu g\) m\(^{-3}\)) were found at a much higher concentration than at the sampling point 1F, which no longer exhibits such thermal activity. Thermically active dump will be regularly monitored, at intervals of 3 months.

4. Conclusion
Based on a screening analysis of PAHs representatives on a thermically active dump Hedvika, was found that endogenous fire causes release of gaseous emissions, the dominant component of which is Phenanthrene. The composition of emissions as well as the concentration of individual pollutants will be affected by many factors, most likely the most significant being the seasons and the current meteorological conditions.

Taking into account to the heterogeneous nature of the material of the dump, which affects the resulting concentrations of pollutants during thermal activity, it is necessary to implement long-term monitoring of the monitored pollution indicators directly in the individual vents. In order to better understand the ongoing thermal processes, for regular quarterly monitoring of PAHs, VOCs and inorganic gases (CO, \(CO_2\), \(H_2S\), \(SO_2\), etc.) there will be drilled boreholes for permanent probes on thermically active dump Hedvika.

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