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# Means of prevention of early-stage spontaneous combustion in the mines of Ostrava-Karvina coalfield (Czech Republic) and introduction of one-seven system in conditions of the Karviná mine, Lazy locality

*The contribution summarises the methods of prevention of early-stage spontaneous combustion of coal mined in the Ostrava-Karviná coalfield, Karviná mine using fire extinguishing foams. In the article, authors also describe the application of a new technology for solving the problems of prevention of early-stage spontaneous combustion by means of a One Seven6000system in conditions of the locality of Lazy, Karviná mine.This innovative technology has not been used in the Ostrava-Karviná coalfield yet.*

*Key words: Hard coal, spontaneous combustion, prevention, fire fighting, fire extinguishing foam, inertisation, underground mine*

## Introduction

Spontaneous combustion and early-stage spontaneous combustion are oxidation reactions between the coal substance and atmospheric oxygen, in the presence of which the generated heat is not removed sufficiently. The reactions are accompanied by the formation of CO, $CO_2$ and higher hydrocarbons. Some coal seams are extraordinarily prone to spontaneous combustion, which may lead to extensive mine fires. From the point of view of prevention of early-stage spontaneous combustion, the question is the early detection of spontaneous combustion [1].

## Means to prevent and suppress spontaneous combustion

Any exact boundary cannot be delimited as to the division of activities to activities of spontaneous combustion prevention and those of spontaneous combustion suppression. The activities of prevention of spontaneous combustion include e.g. inertisation of caving areas (using nitrogen gas, nitrogen foam), application of antipyrogenic substances to the centre of spontaneous combustion, construction of sealing cups (in places of possible centres), and other activities that remain to be performed even in the case of occurrence of spontaneous combustion but that are performed on a bigger scale and with larger emphasis; to them other activities, such as ventilation control, preparation for area closing, flooding, etc. are added. This always depends on the given local situation [2,3].

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## Extinguishing agents and their effects

Generally, fire fighting is a suppressive action, the aim of which is to interrupt the process of combustion in all its manifestations and forms, and to create conditions excluding the possibility of its re-occurrence using the basic extinguishing media, namely water, nitrogen (inert gas) and fire extinguishing foams [4].

## Nitrogen (inert gas)

Gaseous extinguishing agents (inert gases) dilute the atmosphere in the surroundings of the place of combustion; they are suffocating. Because carbon dioxide is connected in mining practice only to portable fire extinguishers, and other gases, such as Argon and a mixture of gases INERGEN are not currently used, nitrogen presents itself to be most suitable for inerting (and possible fire fighting) in the Ostrava-Karviná coalfield (henceforth referred to as OKC).

In the OKC, nitrogen is mainly used for the purposes of prevention of early-stage spontaneous combustion, suppression of coal spontaneous combustion in mines and suppressive inertisation of mine fires [5].

## Extinguishing foams

Foam as an extinguishing medium is mainly used for fighting class B fires, which are fires of combustible liquids and solid substances that melt due to high temperature, and furthermore for fighting class A fires, where the application of low expansion foams enables rapid fire suppression.

Types of extinguishing foams

- According to the method of preparation:
  Chemical foam prepared using the dry or wet method.
  Air-mechanical (nitrogen) foams, for the production of which foaming screens, foam making branches, ejectors and foam making units are used.
- According to the foam expansion ratio and stability:
  High-expansion foam – expansion ratio less than 20
  Medium-expansion foam – expansion ratio between 20 and 200
  Low-expansion foam – expansion ratio over 200

$$Expansion\ ratio = \frac{Foam\ volume}{Foam\ solution\ volume}$$

Mechanisms of action of nitrogen foam

- Cooling effect – water contained in foams evaporates and withdraws heat; high-expansion foam (expansion ratio <20) has, thanks to the quantity of water contained in its structure, the cooling effect about 7 times higher than low-expansion foam (expansion ratio >200).
- Inhibition effect (foam reduces the rate of reaction between oxygen and coal).
- Sealing effect of applications of nitrogen foam to the caving areas of longwall faces in underground coal mines is represented by a decrease in the filtration rate of air mass flow though the given caving areas = increase in aerodynamic resistance in the caved area.
- Suffocating effect ($O_2$ displacement) induced by injection into the caving areas of longwall faces in underground coal mines with the nitrogen foam is based on the assumption of displacement of the oxygen atmosphere in the given areas by water vapour and nitrogen gas contained in the foam structure.

**Foam generator PG-1**

Until recently, the nitrogen foam was generated in the OKC by means of a pressure foam generator PG-1, generating medium expansion mechanical foam. In the mine, the foam was applied in inaccessible caving areas of faces using so-called "false pipes"Js 100 or fire hoses B 75 and C 52 as part of spontaneous combustion prevention and suppression.

The design of the foam generator PG-1 enables the use of a low-pressure inert gas, which can be achieved in combination with compressed air.

From the above-mentioned parameters of the high-pressure nitrogen foam generator PG-1, basic deficiencies in its use for the application of the foam to caving areas of faces in the mines of the company OKD, a.s. follow, namely:

- Manual preparation of the foam solution in an external tank, which is loaded with inaccuracies in dosing the foam concentrate and with possible pollution. As the external tank, a mine car, which is placed on the floor of the mine working (mostly gate road) and which does not stop suspended locomotives from passing and does not hamper mining operations, is usually used.
- Foam concentrate was transported in barrels having volumes of 220, 60 or 50 litres; if the barrels were made of non-transparent materials, in the course of mixing the foam concentrate there were inaccuracies in dosing.
- Dirt largely fell to the external tank from the roof of a mine working or came from mining operations, or got to the barrels in the course of foam concentrate pumping. In addition, it was brought through the mine pipe line.

With reference to the above-mentioned deficiencies of the foam generator PG-1, new possibilities and new innovative technologies for nitrogen foam generation and use have been searched for in the OKC. One of alternatives is a ONE SEVEN® Mining 6000system developed by a German company; it generates nitrogen (mechanical) foam for inerting caving areas of faces and for direct fire fighting.

**One seven system (Fig.1)**

A One Seven system is fire fighting equipment for the generation of high, medium and low expansion foams. Foams are not generated here in a discharge device but in a special module that is part of a pump.

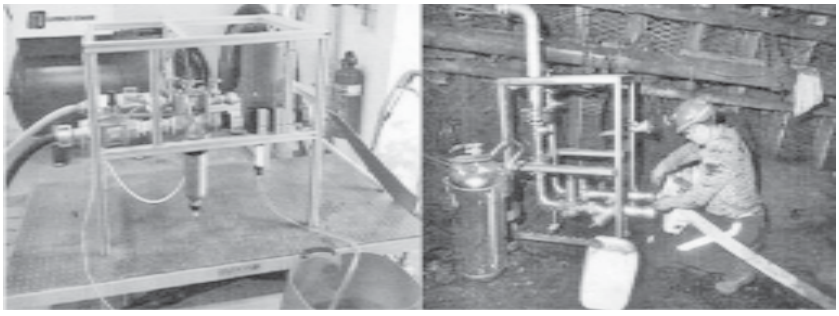

Fig.1 Prototype and functional sample of one seven 6000 system

The foam generation system is called ONE SEVEN EFEKT. The One Seven effect means that from one water drop seven foam bubbles are produced.The manufacturer states that foam bubbles formed like that have properties similar, if not identical, to those of finely dispersed water (water mist); it means that the surface of one foam bubble and the surface of a water drop are almost identical and the amount of heat withdrawn by one foam bubble is comparable with the amount of heat withdrawn by one water drop. The manufacturer states that when using the One Seven system the efficiency of water increases to 80 per cent.

The basic difference in the use between the foam generator PG-1 and the One Seven system consists in a mixing

proportion. While so far, the lowest usual mixing proportion was 3%, the new foam concentrate produced by this system can be added at a proportion 0.1 - 1%. For this purpose, special mixing equipment is however necessary. The used foam concentrate should produce high-quality wet foam at a proportion of 0.3 % and high-quality dry foam at a proportion of 0.4%.

By changing the proportion of water, various foam types can be obtained. Dry foam keeps its form for a relatively long time, has high adherence and passes into solution relatively slowly. Thus it makes a better insulation cover and is more suitable for heat radiation protection than wet foam that has higher fluidity and disintegrates relatively quickly. On the other hand, the wet foam is more suitable for direct fire fighting. First, to fire extinguishing success, the improved thermal bond of the foam structure contributes here; secondly, the water-foam concentrate solution penetrates relatively rapidly to the burning material, and thus extinguishes it permanently.

The application of nitrogen foam in the prevention of early-stage spontaneous combustion in underground mines is based on the theoretical scheme of application of nitrogen form to caving areas (their critical zones) of these longwall faces that are threatened by spontaneous combustion of coal left in the given caving area. The critical zone is characterised by a state when, due to the critical filtration rate of air mass flow though the given caved area, the supply of oxygen into this zone is ensured to such an extent that the oxidation reaction between oxygen and coal can take place; the quantity of heat produced by this reaction being larger than the quantity of this heat transferred by conduction and convection to the surroundings, which results in increases in the temperature of coal substance and the acceleration of oxidation reactions leading to spontaneous combustion.

## One seven® mining 6000

In May 2011, a functional model trial of the One Seven system was carried out in the Lazy plant of Karviná Mine (Fig.1). It was introduced to the face 139 708, where the system was placed in the intake 39 709, at chainage m 213. System hydraulic overpressures were 0.35 MPa (water) and 0.18 MPa (nitrogen); water hydrostatic overpressure was 0.45 MPa, nitrogen volume flow rate was about 500 $m^3.h^{-1}$. Water and nitrogen gas were supplied to the system by means of fire hoses C 52, discharge fittings were connected with the false pipes Js 100, ending 20 m behind the breaking line of the face, by means of a fire hose B 75.

In December 2011, the first One Seven® Mining 6000 system was supplied for the OKD mines.

## Technical characteristics of the system

This purposely developed foam fire extinguishing system for coal mines is designed to produce continuously 6000 litres of One Seven® foam (henceforth referred to as OS foam) per minute.

The system requires the use of 0.3% One Seven® class-A-foam concentrate (henceforth referred to as OS foam concentrate), which represents foam concentrate consumption of mere 0.9 l.min-1.

All structural elements and materials that are there in the mine foam fire extinguishing system are made of stainless steel, brass and red bronze, which are not in any case a potential source of ignition. The proper process of foam generation takes place without the need for electricity.

Inside the frame, near a 150 l stainless steel foam tank, a mixing module is there, in which pressure foam is generated by mixing water, nitrogen, (air) and OS foam concentrate. The OS foam fire extinguishing system is able to control precisely pressure and flows of supplied media. All important volume amounts and pressures will be firmly set in the course of calibration and putting the system into operation and must no longer be changed [6].

### One seven® class A foam concentrate

The highly efficient fire extinguishing agent ONE-SEVEN-class-A, which has a chemical composition 2~(2 butoxyethoxy) ethanol, registration number CAS 112-34-5,is a non-combustible liquid, easily soluble in water. It is used at concentrations between 0.1-1.0%, according to the safety data sheet, and at low concentrations it does not show, after entering water, any toxic effects for aquatic organisms.

## Introduction of one seven® mining 6000in the locality of Lazy, Karviná mine, face 140 702

It is a case of introduction of One Seven Mining 6000 at the active face for the purpose of suppression of beginning early-stage spontaneous combustion.

### Geological data on the seam

- seam No.504 – seam “40”, blocks nos. 7 and 8.
- seam thickness: 300-640 cm, in the east part of the face 520-820 cm
- seam dip:general seam dip-from the initial breakthrough to the end of the face, it moves in a range from 2-17° NW to 2-10° NE
- seam characteristics: seam 504 – “40” belongs stratigraphically to the Saddle Member of Karviná Formation. The face is situated in the south-east part of the Lazy mining claim. From the point of view of chemical and technological properties, it is a case of energetic coal having an ash content of less than 10%.The face is there in the part of the rockburst-hazardous rock mass and is included into a category with the 3rd degree of rockburst hazard.

### Basic parameters of the face

- workable thickness: about 480cm,

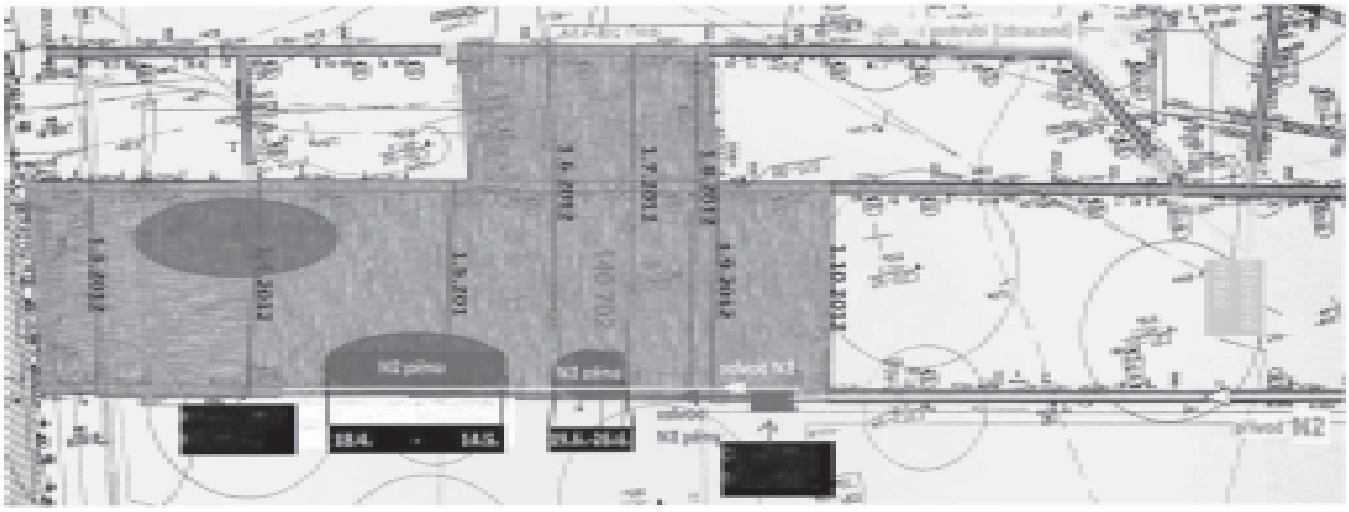

Fig.2 Geological and operating situation at the face 140702, Lazy locality

- face length: about 250m,
- face length along the strike: about 855m.

MINING TECHNOLOGY

Mining uses the method of longwall retreating with controlled caving; equipment consists of 76 pcs of support units(+50 pcs for extension) of the type FAZOS 22/48/0,5-PQz (BSN), longwall conveyor PF 4/932 and under face machinery PZF 08/DH 830 with a crusher DU-1/P7. Coal is won by a shearer KSW-500/5,3-2A2V/2BPH.

### Spontaneous combustion hazard

The face 140 702 is classified as "in danger of coal spontaneous combustion" and requires monitoring the generation of CO. In the period from 14 April 1996 to 25 August 1997, early-stage spontaneous combustion occurred in the overlying seams, namely seams No. 39 and No. 40, four times.

### Situation at the face

Mining operations at the face 140702 were started without complications in February 2012. The caved area of the face was inerted with nitrogen in the amount of about 800 $m^3.h^{-1}$ and in regular periods (not longer than 5 days), transverse sealing dams were built. Moreover, the caved area was flushed with a fly-ash backfill mixture, namely up to 700 $m^3.day^{-1}$ (ash was measured in dry state). For flushing, the ash was mixed with water at an approximate ratio of 1:1.

In spite of all measures to prevent early-stage spontaneous combustion, a trace amount of CO was detected in the return air in March. After measurement, it became clear that it had come from the caving areas and ascended at the upper dead centre of the face, where concentrations below 30 ppm were measured behind the screen.

In mid-April, the situation began worsening; behind the screen, CO concentrations grew. Nevertheless, they did not exceed the concentrations of 30 ppm in the through-circulating current of air. Besides the flushing of the caved area with fly ash, the caved area began to be filled, in the case of lack of ash, with clear water. It was decided that a ONE SEVEN Mining 6000 pump would be used and ventilation would be modified. The modification of ventilation at the lower dead centre consisted in the installation of a bridging air blow duct system, when 100-150 m ahead of the face, a combined fan WPAK 630 was placed, and from it towards the face, 1000 mm diameter flexible air ducts of the type Oldorit were suspended and connected.

At the upper dead centre of the face, an air blow system of connected 1000 mm diameter Oldorit ducts were installed with an electric fan placed in the road 38 890, 10 m below the road 38 807-2 to reduce depression and to dilute and cool air masses.

### Introduction of one seven 6000 pump

A pump was placed in the road about 200 m ahead of the face on the 17th April 2012. One system of false pipes Js 100 was intended for nitrogen. To the other system, pipes for discharging nitrogen foam from the pump were connected through a fire hose "B - 75". A separator was connected to the pipes designed for foam 20-30 m ahead of the face and the foam was put behind the last two constructed sealing dams and to the area behind the closest support units. The dams were formed by textile bags filled with Isoschaum. Foaming began on the 18th April; the daily average consumption of foam concentrate being 330 litres. When the foam began to flow outside the area behind the support units towards the longwall conveyor, the pump operator was required to switch over the points of foam discharge. Dry foam was used to fill the area behind the sealing dam and behind the support units as high as the roof if possible. Improvement in the situation, i.e. decrease in CO concentrations behind the screen at the upper dead centre occurred after 3 days.

Changes were visible within a week, when the CO concentrations behind the screen at the upper dead centre declined to the value of 200 ppm. Nitrogen foam was thus applied till the 14th May, when the CO concentrations at the upper dead centre were of the order of units of ppm. For this reason, the One Seven pump was shut down and removed. Nevertheless, the strict mode of prevention of early-stage spontaneous combustion was still maintained in full operation, i.e. iso-dams were constructed and the caved area was inerted with nitrogen gas and flushed with fly-ash and water. If the water supplied to the caved area had begun to appear at the lower dead centre, it was necessary to wait for the advance of the face; then it was possible to continue flushing. Thus it was sure that part of broken coal was wetted or under water. In addition, the run water cooled the caving area as well and took away heat necessary for coal spontaneous combustion.

At the end of the month of May, the CO concentrations however began to rise again in the return airway and the OS pump was again transported to the road 40 703 and put into service. The pump was operated from the 19th June to the 26th June 2012 and nitrogen foam was used in the same mode as last time. In contrast to the previous increased CO concentrations, these were by two thirds lower, and even in this second case, early-stage spontaneous combustion was brought under control. Then, the face did not need to be operated in emergency mode or even closed.

**Evaluation of one seven 6000 introduction**

- As a consequence of strong erosion in the south side of the face, the face concerned had to be, in contrast to the planned designed block, modified. The above-mentioned erosion was probably the cause of origin of early-stage spontaneous combustion and the area of erosion was its centre.
- Extending the block and its subsequent shortening did not have any basic influence on the course of early-stage spontaneous combustion. Shortening the face was accelerated by means of the already driven road 40 207-4, designed for the removal of support units; thus a delay, possibly caused by the widening face when moving to a given "stop line", connected with another, probably worse course of early-stage spontaneous combustion, was avoided. After shortening the face length, a hydraulic dam No. 4067A with a depth of 12 m was constructed in the road 40 701-1, at chainage m 5, on the 9th October 2012 and a hydraulic dam No. 4070A with a depth of 8 m in the road No. 40 701-2, at chainage m 3.5, on the 23rd November 2012.
- For the whole period, about 35000 $m^3$ and a double quantity of water were transported into the caving areas.This is one of advantages of the face mined upwards in the case of measure to prevent early-stage spontaneous combustion. However, it entailed a negative phenomenon, which manifested itself in the preparation of the adjacent block 140 704, when due to cracks and fissures, the closed road 40 704 and part of the road 40 705 were flooded.
- For the formation of nitrogen foam, it was necessary to increase the supply of nitrogen to the road 40703 to about 1000 $m^3.h^{-1}$ to ensure the correct function of the pump, and thus the quality of produced nitrogen foam, i.e.to ensure a pump pressure of 2 bar as a minimum and inertisation with nitrogen gas [7].
- One seven pump played here a significant role in the suppression of beginning early-stage spontaneous combustion. During its operation, any worsening of the early-stage spontaneous combustion did not occur, but stabilisation occurred and a subsequent tendency towards extinguishing up to full extinguishing, when nitrogen foam put to the caving areas (max 80 cm) and behind the constructed iso-dams fulfilled the inhibiting and sealing function, appeared.

At the beginning of February 2013, the face advanced successfully to the final “stop line”, the artificial roof was laid and machinery was transferred to a new prepared block of the face 138 808.

In the year 2012, the company OKD had in possession 5 One Seven® Mining 6000 systems.

**Conclusions**

It is clear that the ONE SEVEN® Mining 6000 system for nitrogen foam generation represents a step in the right direction; however, it is neither nostrum nor a single means that will aiming at ensuring that coal combustion will take place only at designated places and not in underground coal mines of the company OKD, a.s. However, what is undeniable is that the work of operators of One Seven systems is very facilitated and at present, for operation and generation of nitrogen foam, a early-stage spontaneous combustion are as follows:

- At a low consumption of foam concentrate, a large quantity of foam can be produced. The system is able to produce 6000 litres of foam per minute at a consumption of 0.9 litres of foam concentrate and 300 litres of water; life of foam being up to 5 hours.
- Operational experience confirms that the amount of foam applied in false pipes and mainly areas behind iso-dams is sufficient for the creation of a barrier limiting the flow of air to the caving areas.
- Possibility of wet and dry foam formation.

It can be concluded that the described new means in mining operations in the OKC also contribute to a demonstrable increase in labour productivity. Thanks to the current knowledge and operational experience of workers in

mining, ventilation and of mine rescuers, mining operations can be continuous and, above all, safety of all employees of OKD, a.s. in mining operations is ensured.

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