Measurements of dust concentration at workplaces in a hard coal mine processing plants after installation of the NEPTUN spraying system

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Abstract. The article presents the place and scope of testing the NEPTUN prototype spraying system intended for neutralization of total and respirable dust at workplaces in the processing plant of Bolesław Śmiały mine. The testing procedure and the results of dust concentration measurements at each workplace, covered by the operational range of the NEPTUN spraying system are presented. In the final part, the results of tests were analyzed and the reduction efficiency of total and respirable dust at the tested workplaces is given.

1. Introduction
Exploitation of hard coal deposits exposes workers to technical and natural hazards. In addition to natural hazards such as methane, rock bursts, floods, fires, gas and rock outbursts as well as climate hazard, a treat associated with the presence of coal dust, should be mentioned. Due to hard coal mine activities aimed at increasing the work safety as well as employees awareness, no coal dust explosion has been reported for over a decade [7]. However, the presence of coal dust in the mine atmosphere above the maximum permissible concentrations (NDS), exposes the respiratory system of workers to dust, causing pneumoconiosis, i.e. an incurable occupational disease. Despite the use of the state-of-the-art methods and measures to control the dust [1] [2], there are still several hundred cases of new cases of pneumoconiosis per year (Figure 1) [7].

![Figure 1. Number of pneumoconiosis cases observed within the years 2013-2017 for employees of operating coal mines [7].](image-url)
Main sources of mine airborne dust are related to mining the coal wall by shearers, development of roadway workings, moving the powered roof supports units and crushing and transporting the run-of-mine (especially at the chutes) [4]. Hard coal processing plants are the places in hard coal mines exposed to high concentrations of dust, where the following processes: classification, grinding and beneficiation take place. The main sources of dust include: preliminary screens, along with transfer and receiving shafts, pre-cut crushers, pre-classification screens with vibratory feeders or transfer shafts, non-metallic contaminant removal tapes and iron trapping, or crusher for selective separation of coarse-grained waste [6]. The paper [5] presents the results of analyses of coal dust concentration at workplaces in the processing plants of all the Polish mines. They showed that almost in all the processing plants there were the workplaces with dust concentration over the MAC (Figure 2).

Figure 2. Total number of workplaces in hard coal mines processing plants threatened by dust hazard between 2010 and 2012 [5].

The presented results clearly showed that further work was needed to reduce the amount of dust generated at workplaces in the processing plants. The NEPTUN spraying system, applied in the Mechanical Processing Plant of Polska Grupa Górnictza sp. z.o.o. Bolesław Śmiały Mine is the latest solution, designed at KOMAG, for a reduction of dust concentration at workplaces below MAC [3]. The NEPTUN spraying system is designed for a precipitation and elimination of dust particles emitted in the result of feeding the material in the area of belt conveyors, chutes and screens, using water drops produced by spraying nozzles (Figure 3) [5].

Figure 3. Spraying stream forming mist for a precipitation of dust particles from air on one of the protected workplaces [9].

A task of the system, installed in the processing plant, is to reduce dust concentration at workplaces to the level required by the standards for inhalable and respirable dust, in accordance with the
regulation of the Minister of Family, Labor and Social Policy of 12 June 2018 [8]. PN-Z 04008-7 of August 2002 Standard was used to develop the testing methodology, on air purity protection and principles of air sampling in the work environment as well as interpretation of results. The research work was aimed at verifying the correctness and efficiency of the NEPTUN system in reduction of dust hazard.

2. Place and scope of tests
The NEPTUN spraying system solution for a dust reduction in a processing plant consists of seven independent spraying installations in five places [3]:
- tanks, loading and unloading devices for coal and stone,
- beneficiation devices,
- crushing and transporting devices,
- tanks, coal loading and unloading equipment,
- feeders at the level of +3.70 m.

The NEPTUN spraying system uses water drops with the appropriate size and energy characteristics for a precipitation of dust particles. The spraying system uses special ultrasonic atomizers, in which compressed air is an additional medium. They enable to operate in the low pressure range of water and compressed air, which does not significantly increase water content in the transported material. For such protected workplaces, dust concentration measurements were taken to determine the dust reduction efficiency. The tests were carried out for properly working spraying installations and to compare the results, with the switch on installation. The people, working on the stations with the NEPTUN installation, were equipped with measuring devices. Dust concentration measurements were taken with the following two types of gravimetric personal dust meters:
- CIP-10R for measuring the respirable dust fraction,
- CIP-10I for measuring the inhalable dust fraction.

Amounts of dust from the measuring cups of personal dust meters were weighted by the employees of the Laboratory of Air Pollution Measurement of the Central Mining Institute in Katowice, which is a body accredited by the Polish Center for Accreditation (PCA) in Warsaw in the scope of environmental tests.

Amounts of dust collected at each workplace enabled to determine the inhalable and respirable dust concentration in the conditions of operating spraying installations, and then to compare them with the results of inhalable and respirable dust concentration when the spraying installation was switched off. This allowed to determine the effectiveness of the installed NEPTUN spraying system.

3. Testing procedure
After starting the NEPTUN spraying system, employees working at each workplace were equipped with the measuring devices. The person equipped with the measuring device, consisting of a dust meter to determine the inhalable and respirable dust concentration went to the workplace with operating spraying system (Figure 4).
Figure 4. NEPTUN installation for a reduction of dust concentration at one of the protected dust generating points [9].

The people equipped with the measuring devices were instructed about the need to perform activities being within the scope of their duties and checking the signaling lamps on the devices confirming their correct operation. The personal dust meters (Fig. 5) CIP-10I (for measuring the inhalable dust fraction) and CIP-10R (for the measurement of the respirable fraction) were placed on the chest. These devices took air samples for a set time with an air output equal to a human demand during a typical activity (about 10 l/min).

Figure 5. Personal dust meter (on the left CIP-10I for measuring the inhalable fraction, and on the right CIP-10R for measuring the respirable fraction [9])

Twenty measuring cups were used for a collection of respirable and inhalable dust. The cups were prepared and marked before the measurement, so it was possible to identify the workplace from which the dust samples were taken. The tests were conducted for four hours. Similarly, dust concentration measurements were taken with the NEPTUN spraying system switched off, with the air sampling time of about 1 hour. The shortened test time with the spraying system switched off was dictated by the need to limit the exposure of employees to harmful conditions. After the tests, the measuring cups were removed from the dust meters and protected against unwanted dust spillage out. The cups
secured in this way were transported to the laboratory in which they were subjected to the following procedures:

- drying at 50-60° C for two hours,
- seasoning in the desiccator over a period of 3 hours,
- weighing.

Dust concentration measurements at the Mechanical Processing Plant of Polska Grupa Górnicza S.A., Bolesław Śmiały Coal Mine, enabled to determine the inhalable and respirable dust concentrations at each workplace with the dust control installation switched on and off.

4. Results of measurements

Dust amounts, collected in the cups during the tests, are presented in Table 1, which contains dust amounts obtained from the measurement of the inhalable and respirable fraction in each workplace, with the operating NEPTUN dust reduction system and the measurement time. In turn, Table 2 presents the dust amounts obtained from the measurements of the inhalable and respirable dust fraction in individual work stations, with the NEPTUN installation switched off together with the measurement time.

**Table 1.** Dust amounts, measurement time and measuring cup marking for each workplace, when the NEPTUN spraying system is switched on.

| Workplace | Type of dust fraction | No. of cup | Dust weight in the cup [mg] | Measurement time [min] |
|-----------|-----------------------|------------|-----------------------------|------------------------|
| I         | respirable            | 8k         | 2.59                        | 215                    |
|           | inhalable             | 10k        | 12.73                       |                        |
| II        | respirable            | 2k         | 1.1                         | 210                    |
|           | inhalable             | 1k         | 4.95                        |                        |
| IIIa      | respirable            | 9k         | 0.45                        | 210                    |
|           | inhalable             | 6k         | 2.43                        |                        |
| IIIb      | respirable            | 3k         | 0.24                        | 195                    |
|           | inhalable             | 7k         | 2.86                        |                        |
| IV        | respirable            | 5k         | 1.3                         | 195                    |
|           | inhalable             | 4k         | 3.72                        |                        |

**Table 2.** Dust amounts, measurement time and measuring cup marking for each workplace, when the NEPTUN system is switched off.

| Workplace | Type of dust fraction | No. of cup | Dust weight in the cup [mg] | Measurement time [min] |
|-----------|-----------------------|------------|-----------------------------|------------------------|
| I         | respirable            | 157k       | 1.21                        | 60                    |
|           | inhalable             | 178k       | 7.13                        |                       |
| II        | respirable            | 160k       | 1.32                        | 64                    |
|           | inhalable             | 158k       | 3.47                        |                       |
| IIIa      | respirable            | 154k       | 0.34                        | 60                    |
|           | inhalable             | 167k       | 1.87                        |                       |
| IIIb      | respirable            | 171k       | 0.59                        | 65                    |
|           | inhalable             | 183k       | 3.55                        |                       |
| IV        | respirable            | 187k       | 0.84                        | 62                    |
|           | inhalable             | 156k       | 2.47                        |                       |

The dust amounts from dust concentration measurements with the NEPTUN spraying system switched on and off enabled to determine the average respirable and inhalable dust concentration at
the selected workplaces. To determine the concentration of dust in the air, the following relationship was used:

\[
\bar{S} = \frac{m}{\dot{V} \times \tau}
\]  

(1)

where:
- \( \bar{S} \) – dust concentration at the measurement site [mg/m\(^3\)]
- \( \dot{V} \) – air flow rate in CIP 10 [dm\(^3\)/min]
- \( \tau \) – measurement time [min]
- \( m \) – weight of dust in the measuring cup after the exposure time \( \tau \) [mg]

The calculation results of inhalable and respirable dust concentrations at the tested workplaces, for the NEPTUN spraying system switched on and off, are presented in Table 3.

Table 3. The average inhalable and respirable dust concentration obtained during tests at each workplace with the NEPTUN spraying system switched on and off.

| Workplace | Type of dust fraction | Average dust concentration - installation switched on [mg/m\(^3\)] | Average dust concentration - installation switched off [mg/m\(^3\)] |
|-----------|----------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| I         | respirable           | 1.20                                                          | 2.02                                                          |
|           | inhalable            | 5.92                                                          | 11.88                                                         |
| II        | respirable           | 0.52                                                          | 2.06                                                          |
|           | inhalable            | 2.36                                                          | 5.42                                                          |
| IIIa      | respirable           | 0.21                                                          | 0.57                                                          |
|           | inhalable            | 1.16                                                          | 3.12                                                          |
| IIIb      | respirable           | 0.12                                                          | 0.91                                                          |
|           | inhalable            | 1.47                                                          | 5.46                                                          |
| IV        | respirable           | 0.67                                                          | 1.35                                                          |
|           | inhalable            | 1.91                                                          | 3.98                                                          |

For these inhalable and respirable dust concentrations, with the NEPTUN spraying system switched on and off, at each workplace, it was possible to determine the efficiency of dust reduction. The dust reduction efficiency is defined as the quotient of the difference between the concentration of dust (inhaled and respirable) measured with the spraying system switched off and the concentration of dust (inhaled or respirable) measured with the spraying system switched on and the concentration measured with the spraying system switched off.

The percentage efficiency of dust reduction was determined from the following formula:

\[
\eta_{\text{red cup}} = \frac{\bar{S}_1 - \bar{S}_2}{\bar{S}_1} \times 100\%
\]  

(2)

where:
- \( \bar{S}_1 \) – dust concentration with the spraying system switched off
- \( \bar{S}_2 \) – dust concentration with the spraying system switched on

The determined dust reduction efficiency, resulting from the use of NEPTUN dust reduction equipment at each workplace, is shown in Table 4.
Table 4. Dust reduction efficiency (inhalable and respirable dust fraction) obtained at individual workplaces with use of the NEPTUN spraying system.

| Workplace | Type of dust fraction | Efficiency of dust reduction [%] |
|-----------|-----------------------|----------------------------------|
| I         | respirable            | 40                               |
|           | inhalable             | 50                               |
| II        | respirable            | 75                               |
|           | inhalable             | 57                               |
| IIIa      | respirable            | 62                               |
|           | inhalable             | 63                               |
| IIIb      | respirable            | 86                               |
|           | inhalable             | 73                               |
| IV        | respirable            | 51                               |
|           | inhalable             | 52                               |

5. Analysis of results

On the basis of the tests carried out and of the results of inhalable and respirable dust concentration at each workplace, after the NEPTUN spraying system was installed, there were no exceeded values in maximum allowable dust concentrations, which for inhalable dust reach 10 mg/m³, and for respirable dust up to 2 mg/m³ [8]. (Figure 6)

![Figure 6](image-url)  
**Figure 6.** Concentrations of inhalable and respirable dust measured at workplaces with the NEPTUN Spraying System switched on [9].

At the workplaces No. II, IIIa, IIIb and IV protected by the spraying installation, low concentration of inhalable and respirable dust can be observed, not exceeding 3 mg/m³ for inhalable dust which is 30% of MAC and 1 mg/m³ for respirable dust which is 50% of MAC. In the case of workplace No. I, there is a high disproportion in the dust concentration results, which in the worst case is five times the lowest measured concentration at the workplace No. IIIa. Stone dust from crushers located near the workplace No. I has an impact on inhalable dust (~6 mg/m³) and respirable dust (~1.2 mg/m³) concentration (60% of MAC for inhalable and respirable dust). The places of installation of crushers were not covered by the spraying system. Dust concentration measurements with the dust reduction installation switched off, despite the short measurement time, showed the exceeded value of the Maximum Allowable Concentrations. Exceeding of MAC for inhalable and respirable dust was observed at workplace No. I and No. II. The inhalable and respirable dust concentrations at each workplace with the NEPTUN system switched off are shown in Figure 7.
Figure 7. Inhalable and respirable dust concentration measured at the workplaces with the NEPTUN Spraying System switched off [9].

The lowest dust reduction efficiency 50% was obtained at the workplace No. I, and the highest one at the workplace IIIa (63%) and IIIb (73%) (Figure 8).

Figure 8. Efficiency of dust reduction at individual workplaces, with the NEPTUN Spraying System [9].

When comparing the results of the respirable dust concentration measured with the operating spraying system and the results of the respirable dust concentration measured with the spraying system switched off, the worst dust reduction efficiency, about 40%, was detected at the workplace I (Figure 9).
6. Conclusions

The NEPTUN spraying system presented in the article, developed at the KOMAG Institute of Mining Technology, is designed to reduce a concentration of dust particles by precipitating them with use of water drops generated by air-water atomizers. The system was manufactured and installed at the Mechanical Coal Processing Plant of Polska Grupa Górnicza S.A. "Bolesław Śmiały" Coal Mine by the Elektron Innovation and Implementation Company. The measurements of inhalable and respirable dust concentrations at each workplace clearly showed a positive effect in reduction of dust concentration below the MAC by the NEPTUN Spraying System. In assessment of efficiency, despite unfavourable conditions (lower efficiency of the feed during the measurement of dust concentration with the spraying system turned off), showed at least 50% effectiveness in the case of inhalable dust reduction (site I - where the stone crusher was unprotected by the system), reaching even more than 70% efficiency at the workplace IIIb. In turn, the efficiency of the spraying system in the reduction of respirable dust was at least 40% (site I - where the stone crusher was unprotected by the system), reaching even 86% efficiency in the case of IIIb. In other cases, the efficiency of respirable dust reduction (apart from position IV, where efficiency was 51%) reached 60%. The highest respirable dust reduction efficiency by the spraying system was achieved at the workplace II (75%) and IIIb (86%). The presented results indicate that with a properly designed spraying system for a precipitation and catching dust particles by water drops of proper size, it is possible to reduce dust concentration below MAC, with a small water consumption below 10 dm$^3$/min/atomizer. Use of air-water spraying system allows for a significant reduction of dust concentration at workplaces in Mechanical Coal Processing Plants. It is assumed that a similar efficiency would be achieved by a similar system installed in coal feeding systems of coking plants or combined thermal and power plants.

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