Diminishing of the dust quantity during the management of granular material in an underground space

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Abstract

There are many situations in which a high quantity of dust is produced in the mining industry and civil works: blasting, drilling, bulk material conveying, etc. The management of these materials (minerals, cement, dirt...) usually implies dust production at the conveying and unloading points. In this work, a real case is analysed. A relatively high dust quantity is produced at the mineral spilling point from one belt conveyor to another in an underground mine where this dust is especially harmful. First, the ventilation system drags the dust to areas where workers are exposed to serious health problems (air pollution) and safety problems (less visibility). On the other hand, this dust after exiting is emitted to the atmosphere producing an environmental impact. To diminish the dust quantity, a simple system based on water spraying was used. The particulate concentration in the air recorded with and without the system allowed its effectiveness to be determined.

Keywords: dust monitoring, mine-workers dust exposure, mineral handling, coal mining, atmosphere dust emissions, dust regulations.

1 Introduction: regulations

Underground coal mining is an industry in which there is a relatively high dust concentration atmosphere. The results of measurements done in several Spanish underground mines (Instituto Nacional de Silicosis [1]) are shown in the fig. 1. To work in this polluted environment without adequate preventive measures was the cause of many miners got pneumoconiosis in the past. With the aim of improving the working conditions and after intensive researches (Fidalgo [2],
Pedraja [3]), in 1985 the Spanish Standard ITC 04.8.01 [4], and its regional development in the Principality of Asturias ASM-2, became into force. This standard ASM-2, with application in mining and underground workings, obliges to a) characterise periodically the working places based on dust concentration and dust SiO$_2$ content and b) take preventive measures if it is necessary (table 1).

![Image of bar chart](image_url)

**Figure 1:** Dust quantity in mines.

Instead of the efforts, every year new cases of pneumoconiosis appear (the average value for the last ten years is 255 workers per year, after Instituto Nacional de Silicosis). This reality obliges to continue researching in this field in order to improve the working conditions as much as possible.

**Table 1:** ASM-2 (04.8.01).

<table>
<thead>
<tr>
<th>Work class</th>
<th>Dust concentration for each SiO$_2$ range</th>
<th>Preventive measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;10% SiO$_2$</td>
<td>10-30% SiO$_2$</td>
</tr>
<tr>
<td>Class I</td>
<td>&lt; 6 mg/m$^3$</td>
<td>&lt; 3 mg/m$^3$</td>
</tr>
<tr>
<td>Class II</td>
<td>6-10 mg/m$^3$</td>
<td>3-6 mg/m$^3$</td>
</tr>
<tr>
<td>Class III</td>
<td>&gt; 10 mg/m$^3$</td>
<td>&gt; 6 mg/m$^3$</td>
</tr>
</tbody>
</table>

On the other hand, it is known the air pollution potential of coal industry (Jones [5]). The Spanish Laws for the environment protection establish suspended particulate matter emissions limit at 150 mg/m$^3$ for this kind of industry (RD 833/1975 [6]) and suspended particulate concentration limit at 150 µg/m$^3$ (RD1635/1985 [7]). Related to respirable particulate matter, the European Directives establish a new limit for PM$_{10}$ concentration limit at 40-50 µg/m$^3$ (1999/30/CE [8]). Data about the air pollution in an area near the mine are represented in fig. 2 (Principality of Asturias [9]).
2 Brief test description

The test was to measure the dust concentration in several mineral (granular material) spilling points. The mineral, after it has been won, is conveyed by means of conveyor belts through the mine galleries to the surface. It is necessary to use several belts due to the large distance of the run (approximately 2 km), and then several loading, unloading and spilling points exist. These places have been selected because it is very usual that miners do some work near these points and then it is very important to maintain the dust concentration as low as possible.

A very interesting parameter is the quantity of mineral mass carried (coal output) during the test. This parameter is not recorded at measurement stations, nevertheless the overall mine coal output is recorded and then it is possible to do an estimation of the mineral mass carried by the conveyor belts at these points at a given moment.

The water sprayed system (see fig. 3 left) consist in a cylinder connected to two tubes of water and of compressed air. Because of the pressure, the air and water flows are mixed within the cylinder and go out through a slots generating a fog that in contact with the dust make it to sediment.

In the mine, the water quantity sprayed, that will determine the characteristics of the fog, is regulated manually in a simple way. After opening the air pass valve, the water one is opened more or less in order to achieve the highest dust reduction (which it is very easy to appreciate in the gallery). In these cases, for air and water flows used, the experience shows that increasing the water quantity diminish the dust concentration. For this reason the maximum quantity of 4.8 l/min was used in all the trials.

Recent studies related to the control of explosions by means of water (López [10]), in which authors have collaborated, prove that the efficiency of a water spray depend very much on the water drop diameter. On the other hand, the drop diameter depends on several factors and one of the most important is the
water/air relationship. This aspect has not been studied in this paper, in spite of its importance, due to its complexity.

The monitoring system used (see fig. 3 right) is a real-time direct-reading instrument, based on light-scattering technology. It allows instant readout of respirable dust levels and is thus important diagnostic tool for detailed study of dust sources and dispersal. Two monitors, for PM$_{10}$ and PM$_{2.5}$ particulate concentrations, were used simultaneously. Dust concentration estimated by the ASM standard procedure (values that appears in table 1) is always between these two values, then PM$_{10}$ is a representative sample. With the aim of contrasting the results, conventional apparatus were also used. Only a caution must be taken into consideration: water sprays can cause erroneously high readings of PM$_{2.5}$, if the mass median diameter of the aerosol must is about 1 µm. (Sioutas et al. [11]). In our case, the drop diameter is much greater and the equipment includes a heating system for erasing the humidity. An exhaustive description of instrument for dust monitoring in coal mines can be seen in Kenny et al. [12].

![Figure 3: Water spray and PM$_{10}$ monitor.](image)

3 Tests down the mine

3.1 Previous considerations

In each measurement station particulate concentration PM$_{10}$ and PM$_{2.5}$ were done. The following relationship between both can be inferred from the records:

$$PM_{2.5} = 0.55PM_{10}$$  \(1\)

This proportion, that is real in every analysed case, is shown in the fig. 4. Taking this relationship into consideration, in the following only PM$_{10}$ concentration is used because the other is easily deduced. The value PM$_{10}$ is taken as a representative of dust concentration because it is bigger than the value given by the standard procedure (while PM$_{2.5}$ is smaller, then it is not representative).

The first test was done in the gallery in absence of activity in order to obtain the bottom dust concentration value. The average and maximum values of PM$_{10}$
corresponding to a period of no activity were 0.65 mg/m$^3$ and 0.94 mg/m$^3$ respectively. In all the trials, it could be proved that the bottom value is quickly reached (in a few minutes) after stopping the mineral carriage. On the other hand, the quantity air flow in the gallery, about 6.5 m$^3$/s (air velocity near 0.5 m/s), is practically constant all the time.

![Figure 4: PM$_{10}$-PM$_{2.5}$ relationship.](image)

3.2 Trials at spilling points

Trials were done at three spilling points, called A, B and C, where coal is spilled from one conveyor belt to another. The variations of the parameters having influence in the dust quantity during the tests for each station A, B and C are resumed in table 2. The water flow rates corresponded to two fix positions of a valve easily achieved.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period min</td>
<td>Output ton/h</td>
<td>Water l/min</td>
<td>Period min</td>
</tr>
<tr>
<td>0-30</td>
<td>200</td>
<td>0.0</td>
<td>0-15</td>
</tr>
<tr>
<td>30-60</td>
<td>450</td>
<td>0.0</td>
<td>15-20</td>
</tr>
<tr>
<td>60-90</td>
<td>450</td>
<td>4.8</td>
<td>20-60</td>
</tr>
<tr>
<td>90-120</td>
<td>450</td>
<td>3.4</td>
<td>60-100</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>100-120</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In the graphics of the figs. 5, 6 and 7, the record of instantaneous PM$_{10}$ concentration is represented with the average value of each period. The average
values for all the 120 minutes of the test at A, B and C are 2.39, 1.80 and 0.78 mg/m$^3$ respectively.

Figure 5: PM$_{10}$ at A station.

Figure 6: PM$_{10}$ at B station.

Figure 7: PM$_{10}$ at C station.
The dust concentration at points A and B reaches the level of class II works, or even class III, and then preventive measures must be taken according to the Spanish standard. The station C is an example of a point with less polluted air. There are some causes that have influence on it. Nevertheless, in this case the main reason is that C is far away from the working face, in which particles are produced, and this dust has been put on the air in the previous spilling points.

PM$_{10}$ and PM$_{2.5}$ particulate concentration were registered during the tests. It has been proved that the dust concentration variations take place quickly after any variation both mineral output or sprayed water flow. The dust concentration was registered for several hours. Nevertheless, the two hour period shown in the graphics of the figures represent what has happened.

4 Test at the mine exit gallery

With the aim of analyse the environmental impact of the mine dust emissions, the PM$_{10}$ and PM$_{2.5}$ concentrations were measured at the exit of the exhaust air gallery. In this case, particulate concentration is less variable than in the mine, and it reaches average values of PM$_{10} = 0.125$ mg/m$^3$, PM$_{2.5} = 0.113$ mg/m$^3$. These levels of air emissions can not be considered high compared with the maximum value of an emission, 150 mg/m$^3$, allowed by the Spanish law for industries different from electric power stations.

5 Conclusions

5.1 Health and safety analysis from tests down the mine

Analysing the periods in which water is not used, it is possible to define at each station the relationship between output and PM$_{10}$ that is shown in the graphic of the fig. 8. There is a delay between the mineral output variation and the concentration variation due to dust diffusion through the air, but this delay is not significant (approximately 1 or 2 minutes at stations near the spilling point).

As it can be seen in the graphic, PM$_{10}$ concentration changes slightly at point C while it varies significantly with the output at the other two points. The estimated linear relationship between two parameters at A and B stations is:

\[ PM_{10} = 0.83 + 0.0045P \]  

(2)

where P is mineral output in ton/h and PM$_{10}$ is concentration in mg/m$^3$.

This relationship is only an approach, but it is very interesting for the mine engineers because it allows estimate approximately the dust concentration, or a range of it, from a variable that it is known beforehand (the output can be planified). On the other hand, the carried mineral mass comes from several working faces (roadheaders, longwall...etc.) in which the maximum output is known. Then, it is possible to know the level of air pollution which will be reached in each case (one, two or more active working faces).

Another relationship between particulate concentration and water flow sprayed can be obtained assuming an output of 450 ton/h (figs. 9 and 10). From the results of the test at point A it can be inferred that PM$_{10}$ concentration
decreasing is moderate, about 15%, with a water flow of 3.4 l/min but it is significant, about 30%, if a 4.8 l/min is used. This reduction is a bit less in the case of PM$_{2.5}$: 10% and 25% respectively.

![Figure 8: PM$_{10}$ and output](image)

The PM$_{10}$ particulate decreasing at B station is greater than at A one: about 40%. It is similar at C station, but in this case quantifying the effect of the water is not accurate because the value of dust concentration is near the bottom value.

From a practical point of view, the most important aspect is that a mining work can be passed from one class to another with a low effort (an easily used installation) that implies some achievements that must be taken into consideration.

For example, when the output is near 450 ton/h in the A station dust concentration is near 3.0 mg/m$^3$ without water system usage. In this case, assuming 10%-30% of quartz (SiO$_2$) content in the dust, the work that almost could be classified as class II work according to the standard, is now clearly within the class I works. If the SiO$_2$ content is greater than 30%, the work that almost could be classified as class III work, is now clearly within the class II works or class I depending of the water system efficiency.
It is not easy to know the dust SiO$_2$ content at a given moment because it depends on the type (sandstone or siltstone) and proportion of rock that exist at the working coal face. The results of periodical measures show that it varies very much in the gallery where A, B, C points are. Some values of this SiO$_2$ content are, for example: 7.7%, 11.2%, 13.8% and even 20.4%. Nevertheless it is not relevant because if the quartz content trends to increase, the water system will become more necessary and useful.

From a management point of view, if a work is within class III the mining company is obliged to inform to the mining authority about it, which will impose some instructions. The minimum exigence according to ASM standard is to limit the presence of personnel at the work face to less than 7 hours per day and less than 1050 hours per year. This implies a reduction of the productivity and a definition of more complex manshift. On the other hand, if the work is of class II, the mining company will take preventive measurements, without administrative negotiations, in order to carry the work to class I and the limit of the presence of personnel is not so drastic.

Nevertheless, the real importance of the fact is that these little changes in air pollution are very profitable for miners’ health. As it is mentioned above, the likelihood of getting pneumoconiosis after the working life increases exponentially with miner dust concentration exposure.

Although this problem has not been studied in this job, it is also necessary to point out that diminishing the dust in the atmosphere at the working place increases the visibility and consequently increases the safety of the miners.

### 5.2 Environmental impact analysis from test at the mine exit gallery

It is important to point out that the concentrations relationship is PM$_{2.5}$/PM$_{10}$=55% near the dust production focus down the mine and it is PM$_{2.5}$/PM$_{10}$=90% at the exit of the mine. An explanation is that the bigger size particles sediment along the 2000 m of galleries from these points to the exit of the mine, whereas the smaller size particles do not sediment and they are transported to the atmosphere. This fact can be easily demonstrated based on simple assumptions. Under the mine conditions, a 10 $\mu$m diameter particle runs through the galleries 200-300 m before it sediments while a 2.5 $\mu$m particles runs...
much more, approximately 2000-3000 m, and then they reaches the exit and pass to the atmosphere.

It can be assumed that dust emission reduction of PM$_{2.5}$ particulate is near to dust concentration reduction at the focus (because of a great proportion of 2.5 µm particles reaches the exit). Then, the using of water spray system in all the spilling points would allow to decrease PM$_{2.5}$ emissions near to 10%-20% which is a contribution that have not be neglected. It is to say, the usage of water system is good for improving both health and safety conditions down the mine and environmental conditions around it mine.

References

[8] Directiva 1999/30/CE, Valores límite de dióxido de azufre, dióxido de Nitrógeno, Óxidos de Nitrogeno, partículas y Plomo en el aire ambiente (DO L 163 de 29.06.1999)