Contamination by particulated material in blasts: analysis, application and adaptation of the existent calculation formulas and software

J. Toraño, R. Rodríguez, I. Diego & A. Pelegry
Mining and Mine Prospecting Department, University of Oviedo

Abstract

In the setting of a research project about the blasting negative effects granted with public funds coming from the Spanish Ministry for Development, several measurement campaigns were developed, in various locations and situations, where earth vibrations, aerial waves and dust in suspension simultaneously measured. Taking into account the dust negative effects (for human health, inhabited environment or plants) it is interesting to have available tools that allow the estimation of the particulated material quantities ejected in a blast (already studied by our research team in other cases). Here we show the application of the standardised computational methods for atmospheric contamination (developed for other applications) in the specific case of blasting in mining and civil works. To do so we have used the field data collected in blasts at a maritime port and at a limestone quarry. We will also show the advantages of using CFD when solving some of these problems, which is being studied in other research projects.
Keywords: particulated material, blast, atmospheric contamination, dust.

1 Dust generation in a blast

One of the main particle sources of the atmospheric contamination are the industrial activities. From their size and nature we can infer the affections that dust can induce in human beings. According to dust size we can categorize it in three groups: breathable dust (particles so small that go directly to lungs), inhaled dust (one part is retained by the upper part of the human breathing system, whit diameters around 10 μm) and total dust. Up to recent dates it was thought that the harmful action of those particles in people was limited to breathing system (National Institute for Silicosis Disease [4]) with the result of a first classification according to human beings affections: pneumoconiotic dust, toxic dust, inert dust and allergic dust.

Studies done "ad hoc" proof that during the last years there are more evidences of carcinogenic effects of dust containing free silica (International Agency for Cancer Research [5]) and the contribution of those particles to the cardiovascular pathologies (Ballester [6]). We must point out that the diseases produced by these contaminations have a special importance on children (World Health Organization Reports [7]). Blasting, or rock explosions, involves a high level of contamination by particulated material. This dust sources are intermittent, frequent, sporadic and very short in time. A cloud is produced, formed by the pulverized rock, the perforation debris and the projection of the dust previously settled in the blasting area.

2 Measurement campaigns to characterize the dust produced in a blast

The 4 measurement campaigns selected for this study were done in "El Musel" maritime port (blasts in concrete structures) and in "El Perejil" limestone quarry, both in Asturias, northern Spain. During the measurement campaigns we used dust collectors Met One (< 50 μ), which allow continuous measurement of PM-2.5, PM-10, total particles, atmospheric pressure and temperature, as well as meteorological stations (sensors E-sampler EX034 and HR-E Sampler EX593) in order to measure continuously air humidity and wind speed and direction.

2.1 Blasts in a maritime port

First blasts were done in 10th of April, 2004 at the dock of "La Osa" wharf (Figures 1 and 2), where a 100 meters long concrete dock wall was being demolished. The blasting characteristics are shown in Table 1. Meteorological conditions during the test were: temperature of 8ºC, 1022 millibar atmospheric pressure, clouds, no rain, wind speed ranging 1-2 m/s and 40-60º of bearing in relation to the concrete wall, very small sunshine ratio (due to clouds) and relative humidity between 60-80%. We can say also that the ground was wet due to past days rain and the area was a suburban zone with wind flow obstacles in the back side of the dock and completely free from obstacles in the wind upcoming area.

Table 1: Blasting characteristics.

Height, Burden and shots spacing(m)	3.80, 1.3 and 1.2
Length, diameter, slope, clay stopper	4 m, 54 mm, 5 (º) and 2.4 m
Main and Bottom Load	0.87 kg and 0.46 kg, dynamite
Number of shots and type of firing	80, non electric detonators

Figure 1: Port location.

Figure 2: Dock wall and installed dust collectors.

In a first step the dust sensors were installed together 40 meters apart from the blast, one measuring PM-2.5 and another one PM-10; in a second step we brought one of the sensors close to the blast (12 m from it), measuring both of them total particles before and after the blast. Before the blast the PM-10 dust concentration ranged from 0.02 to 0.025 mg/m^3; PM-2.5 ranged again from 0.02 to 0.025 mg/m^3. Figures 3 and 4 show the concentration increase of total particles. Calculations done from the samples give values of: 40 m apart from the dock (C) = 0.220 mg/m^3 and 12 m from the dock (C) = 0.359 mg/m3. In 2 minutes, approximately, the particle concentration measurement gets stabilized again, as the dust cloud has already been displaced by the wind.

On 19th April, 2004 other two dock concrete pieces were blasted, as is shown in Figure 5. Meteorological conditions were: temperature of 11ºC, 1007 millibar atmospheric pressure, clouds, no rain, wind speed ranging 4-5 m/s and 5-15º of bearing in relation to the concrete wall, very small sunshine ratio (due to clouds) and relative humidity between 60-80%. Again the ground was wet due to previous the day's rain and there were no obstacles to wind in the area. 2 dust collectors were installed 25 m and 50 m respectively apart and perpendicular to the dock. Table 2 and Table 3 show the blasts main characteristics. The sensor measured the particle concentration increase due to the 2 blasts in the same way as the previous blast. Dust concentration produced by blast in the points where the sensors were installed were: 25 m from the dock (C) = 1.069 mg/m^3, and 50 m from the dock (C) = 0.829 mg/m^3.

2.2 Blasts in a limestone quarry

The quarry is located in the core of the downfold geological structure and produces limestone (Figure 7). The meteorological conditions in the first measured blasts, 13th May 2004, were: temperature of 18ºC, 1022.5 millibar atmospheric pressure, sunny day with no clouds, no rain, wind speed ranging 1-2 m/s and 90º of bearing in relation to the trench face, high sunshine ratio and relative humidity between 50-60%, upper part of bench wet. Country area. Blast characteristics are shown in Table 4 and Figure 8.

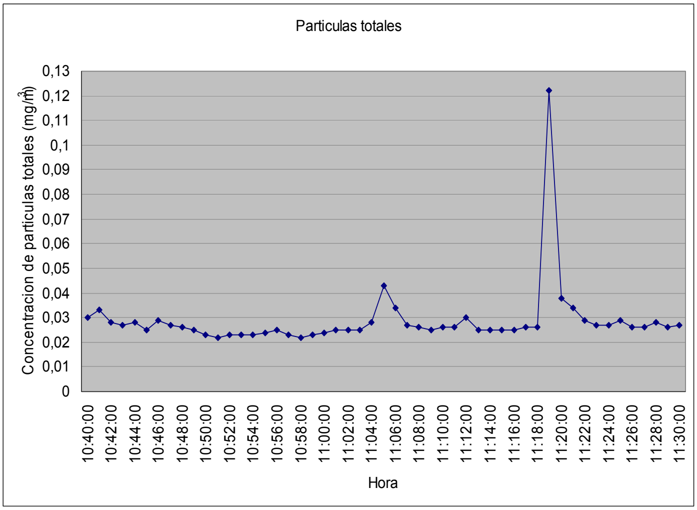


Figure 3: Total particle sample @ 40m collector.

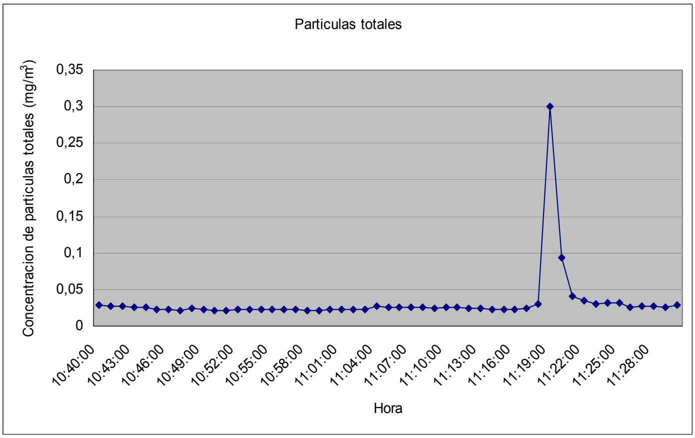


Figure 4: Total particle sample @ 12m collector.

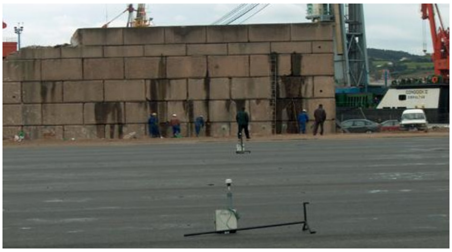


Figure 5: Initial time.

Figure 6: Dust dispersion.

Table 2: Blast characteristics – First section of dock

Height, Burden and shots spacing(m)	3, 1,4 and 1,2
Length, diameter, slope, clay stopper	54 mm, vertical and 2,4 m
Main and Bottom Load	1,45 kg and 0.69 kg
Number of shots and type of firing	64 non electric detonators

Table 3: Blast characteristics – Second section of dock

Height, Burden and shots spacing(m)	4.5, 1.4 and 1.2
Length, diameter, slope, clay stopper	54 mm, vertical + horizontal, 2.4 m
Main and Bottom Load	1.74 kg, 0.69 kg and 1.71 kg
Number of shots and type of firing	44, non electric detonators

Two dust collector were installed 125 meters apart from the bench in the covering area, measuring PM-2.5 and PM-10 before blasting; further on total particles were measured before and after the blasting (Figures 9 and 10).

Figure 7: “El Perecil” quarry map.

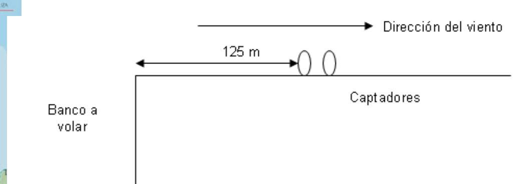


Figure 8: Sensors location.

Table 4: Characteristics of the bench blasting (UEE explosives).

Height, Burden and shot spacing (m)	18, 4 and 5
Length, diameter, slope, clay stopper	120 mm, 15º, horizontal, 3 m
Total Load (dynamite), Nr of shots	1175 kg and 13
Bottom and Head firing, Detonating cord type and firing	EZDET (25/350 ms) and Ms Nº 16 (450 ms)
Firing and detonating cord	Electrical Nr 0 and EZTL (17ms);20m

The particle PM-2.5 concentration ranged between 0.03 and 0.05 mg/m^3 and PM-10 concentration ranged between 0.035 and 0.06 mg/m^3. Total particle concentration alter the blast were similar, with values of 0.156 mg/m^3 and 0.199 mg/m^3 , which means a mean value of 0.177 mg/m^3. Figures 11 and 12 show the dust formation and dispersion phases, as well as the position of the dust collectors. Although the blast boost down and straight the dust cloud it then follows the wind direction, slides over the bench face, overpass it and then were dispersed.

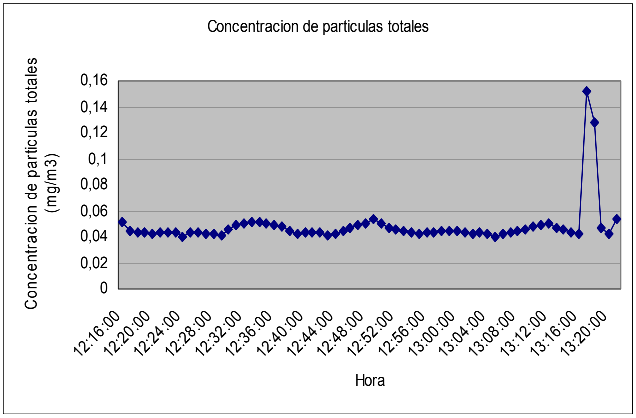


Figure 9: Total particules sample – collector 1.

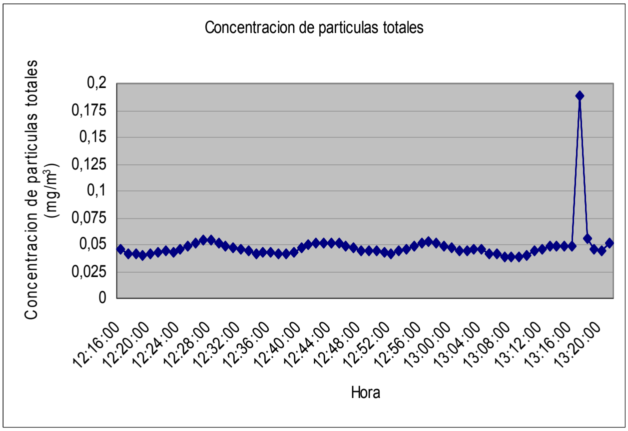


Figure 10: Total particules sample – collector 2.

Figure 11: Dust creation.

Figure 12: Samplers detail.

21st May 2004 blasts and its main characteristics are shown in Table 5. Dust concentration produced by the blast was, where the dust collectors were installed, 0.406 mg/m^3 200 m apart from the bench and 0.733 mg/m^3 120 m apart. In the same way as in the previous cases, dust was boosted down and straight and then back following wind direction.

Table 5: Characteristics of the blasting (UEE explosives). 21-04-04.

Height, Burden and shot spacing (m)	16,2, 4 and 5
Length, diameter, slope, clay stopper	120 mm; 15º and horizontal; 2,83 m
Total Load (dynamite) and shot Nr	1300 kg ; 12
Bottom and Head firing	EZDET(25/350ms);Ms Nr16 (450ms)
Firing and detonating cord	Electrical Nr0;EZTL (17ms); 19 m

3 Blast simulation using isc3 software

3.1 Maritimal port blast

We will use ISC3 software [8] and [9] in order to simulate the blasts measured. Meteorological field data are introduced in the ISC3, obtaining Table 6 as the meteorological values output. Figure 13 shows the inferred wind rose. Dust sources are introduced defining the size of the blasted dock, its emission height and the amount of emitted pollutant. Source used will be polygonal type, as it allows us to define the irregular shape of the dock, using UTM coordinate systems in order to maintain portability with software Aermod. We will also define in the software the particle nature, its size distribution and its density, s well as the source coordinates and the measuring point's coordinates in order to simulate the same configuration as we had in the blast measuring campaigns.

Starting from the coordinates assigned to the source we establish two receptors types. The first is a discrete network made by 2 node receptors that simulate the position of the samplers in the field tests and that will allow us to check the modelization against the field measurements. The second one is a regular Cartesian mesh of receptors, located in the wind downstream that will show us the pollution level where we do not have samplers. So once we have checked with the first type of receptors that the software is doing right by comparing measured values with the simulated ones, we can rely on the simulated values that are given by the second type of receptors.

Table 6: Meteorological calculated values.

Random Flow Vector	Wind Speed (m/s)	Ambient Temperature (K)	Stability Category	Rural Mixing Height (m)	Urban Mixing Height (m)	Friction Velocity at the Application Site (m/s)	Monin-Obukhov Length at the Application Site (m)	Roughness Length at the Application Site (m)	Global Horizontal Radiation (W/m2)	Relative Humidity (%)
141,0000	1,5433	280,9	4	398,2	613,8	0,3179	-56,3	1,0000	0	70

The emission rate by area unit is the parameter that will be modified, tuned, until we get the adjustment of the simulation to the field data. Once all the parameters are introduced we obtain results shown in Figure 14 and Table 7, where we are showing respectively concentration isosurfaces and the values obtained by the software simulation in the sampled points. We can clearly see how the dust is dispersed in the wind direction in an opening cone shape (figure 15). If we proceed in the same way with the second blasting measurements we obtain analogue outputs shown in Figures 16, 17 and Table 8. This time the source has to be double, as the dock is made by two different areas (one point source and another polygonal source).

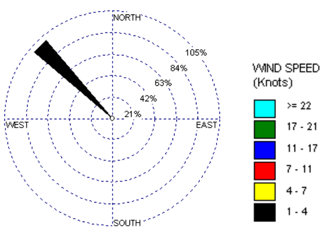


Figure 13: Wind rose.

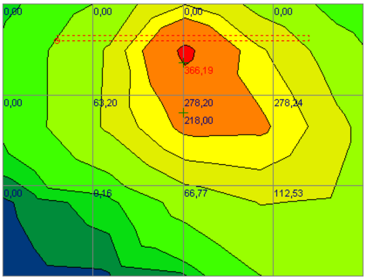


Figure 14.

Table 7.

Dust concentration	
Field measures	ISCT3 Simulation
359 µg/m^3	366 µg/m^3
220 µg/m^3	218 µg/m^3

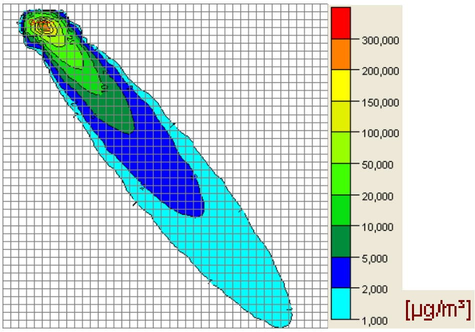


Figure 15.

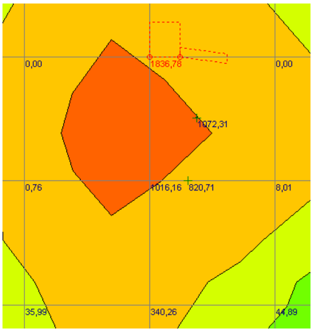


Figure 16.

Table 8.

Dust concentration	
Field measures	ISCT3 Simulation
1069 μg/m^3	1072 μg/m^3
829 μg/m^3	820 μg/m^3

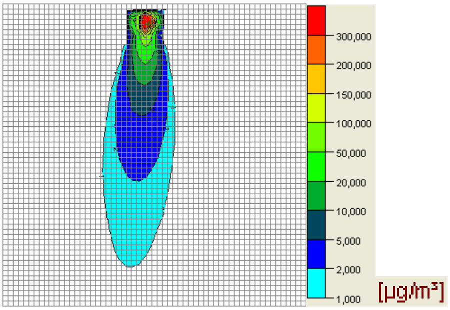


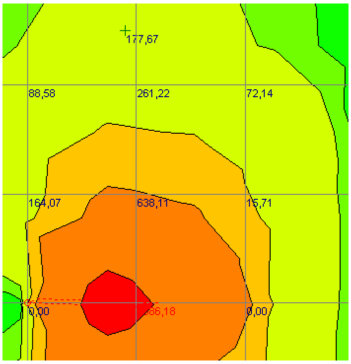
Figure 17.

3.2 Limestone quarry blasting

Following the methodology described in the previous case the results for the first group of samples are shown in Table 9 and in figure 18. Figure 19 shows the cone dispersion (concentration) of the particulated material as was obtained from the simulation.

Table 9.

Dust concentration	
Field measures	ISCT3 Simulation
177 μg/m^3	177 μg/m^3



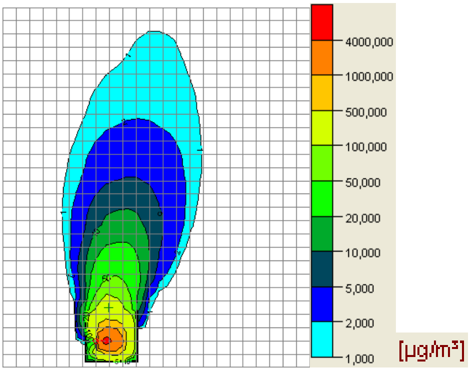


Figure 18. Figure 19.

Proceeding again in the same way the second group of blasts calculations are shown in Table 10, Figure 20 and Figure 21.

Table 10.

Dust concentration	
Field measures	ISCT3 Simulation
733 $\mu g/m^3$	825 $\mu g/m^3$
406 $\mu g/m^3$	400 $\mu g/m^3$

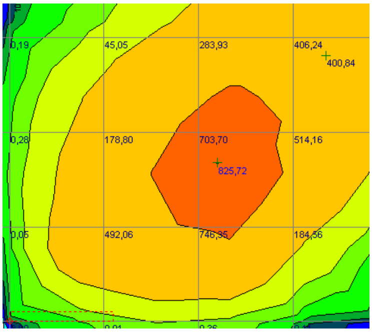


Figure 20.

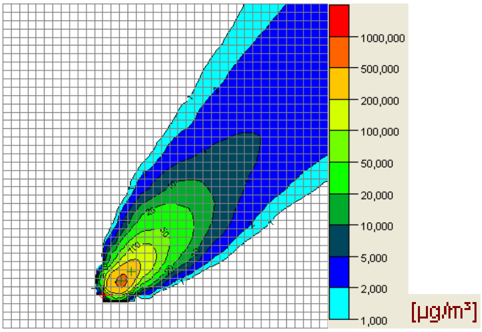


Figure 21.

4 Conclusions

In mining and civil works blasts is possible to establish prediction models that simulate with enough accuracy and simplicity the behaviour of the emission and propagation of the particulated material using easy-to-use software as ISC3, [8] and [9]. This is done through the adjustment of the software using a simple measurement campaign deploying dust collectors and meteorological sensors. In case of complex blasting geometries or highly irregular terrain is necessary to use other modelization tools as numerical codes (CFD).

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