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DENSITY MONITORING OF BULK EMULSION EXPLOSIVES IN CONFINED BLASTHOLES

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ABSTRACT

Parameter's control of explosives used in open pit mining operations have become more relevant over the years, bringing a better understanding of detonation performance. Giving into consideration that bulk emulsion density reflects on blasting results due to its importance in product sensitivity and velocity of detonation (VOD), blast designs are conducted assuming that cup density measurements are reliable and explosives gassing agents will perform as per specifications. Nevertheless, confinement conditions in boreholes are often neglected on predictive modelling. This paper describes the assembly of a device equipped with pressure sensors and its utilization in confined boreholes, obtaining in situ monitoring of density variation in explosive columns. The results enabled a comparison between bulk emulsion density variation when acting in different environments, providing detailed insights into how chemically sensitized explosives behave into different circumstances, giving the opportunity to re-evaluate blast design.

KEYWORDS: blasting, detonation, mining.

MONITORAMENTO DE DENSIDADE DAS EMULSÕES EXPLOSIVAS EM FUROS CONFINADOS DE DESMONTE DE ROCHAS

RESUMO

O controle dos parâmetros dos explosivos aplicados em desmontes de rochas de minas à céu aberto tem sido amplamente abordado ao longo dos anos, visando aumentar a performance das detonações. Uma vez que a densidade das emulsões explosivas possui impacto direto na sensibilidade e velocidade de detonação (VOD) do produto, os planos de fogo são elaborados assumindo que a densidade de copo é confiável, e os agentes gaseificantes irão performar conforme especificado. Contudo, as condições de confinamento costumam ser negligenciadas em modelos preditivos. Este trabalho descreve a construção de um dispositivo equipado com sensores de pressão, com o intuito de monitorar a variação de densidade em colunas explosivas confinadas. Os resultados possibilitaram uma comparação entre a variação de densidade das emulsões explosivas quando atuando em ambientes divergentes, provendo informações detalhadas sobre a atuação de explosivos sensibilizados quimicamente em diferentes circunstâncias, garantindo uma retroalimentação assertiva dos parâmetros de plano de fogo.

Palavras chave: detonação, mineração, plano de fogo.

1 INTRODUCTION

The rock fragmentation in mining is a technological process that aims at the disaggregation of the rock mass, forming rock fragments with a satisfactory particle size for feeding primary crushing operations (Sitonio, 2020). Successful blasting operations with bulk emulsions are led by controlling some factors of influence, including explosive composition and its initial charging density. Although bulk emulsion explosives have high reliability and some properties are previously known, there is a lack of fidelity in cup density measurements, leading to incompatible blast designs, especially because gassing expansion is not well known along blastholes columns when they are found in confined situation. Besides environmental hazards, inadequate blasting results often leads to poor efficiency in subsequent mining operations such as loading, hauling, crushing and grinding cycles, increasing overall cost of mineral exploitation.

Egly and Neckar (1964) developed and patented explosive emulsions. With some adding modifications to be considered over the past 50 years, bulk emulsion explosive matrix contains oxidizers dissolved in water as droplets surrounded by an immiscible fuel and is not capable of detonation by its own. To achieve detonating behavior, it requires sensitizer in fixed amount. Due to its rheology, chemically sensitized emulsion explosives need a certain reaction time inside the blasthole to expand its volume and obtain ideal density before stemmed. Medina (2014) mentions that hydrostatic pressure affects final explosive product. Thus, higher densities are found at the bottom of the hole since bubble sizes are lower.

Cudzilo, Kohlicek, Trzcinski and Zeman (2002) studied five explosive performances with glass micro-balloons and ammonium nitrate solution as matrix, mixed with specific nitrates. They observed a reduction in explosive performance when adding metallic nitrite to aqueous solution, besides a great influence in emulsion sensitivity with borehole diameter variation. In contrast, Cheng et al (2017) observed a higher detonating power with increasing titanium hydride rate as sensitizing. Mishra, Rout, Singh and Jana (2017) related VOD with gassing agent's variation and bulk emulsion densities. Sodium nitrite were used as gassing agent with different rates and temperatures. The study observed a linear increase in explosive's VOD with densities from 0.95 to 1.15 g/cc, with detonation failure above 1.27 g/cc. Nevertheless, the study took in consideration density measurements without confinement, like cup measurements, commonly used in open pit operations. Besides that, hydrostatic pressure phenomena were neglected, even it has an important role in real density value. As pointed by Cavanough and Onederra (2011), in situ measurements of VOD, temperature and pressure considering confinement and rock mass properties around blastholes can lead to a better understanding of the explosive charge.

In accordance with pioneer projects developed in the past two decades as Zeman and Trzciński (2002) and Canto (2018), and at the same time aiming to sponsor an evolution in rock blasting operations control, the present work is based in trial tests with an electronic device built to monitoring the density of commercial explosives in open pit mining operations. Since reducing VOD is intrinsically bonded to bulk emulsion explosive's final density, and results in lower detonating pressures through unavailability of shock-wave energy (Yunoshev, Plastinin and Silvestrov, 2012), experiments highlighting its real value are necessary to evaluate blasting quality.

2 METHODOLOGY

2.1 Sensor Assembly

To monitor real-time pressure variation in confined boreholes and relating to the density of bulk emulsion explosives, we assembled a device equipped with two MPX5700 pressure sensors, following its recommended power supply decoupling and output filtering schema. Ideal for microcontroller-based systems, MPX5700AP sensor series delivers a 2.5% maximum error result of absolute pressure measurements, and it is capable of reading proper values in a 0º to 85⁰ C environment situation. Figure 1 shows the sensor output signal relative to pressure input.

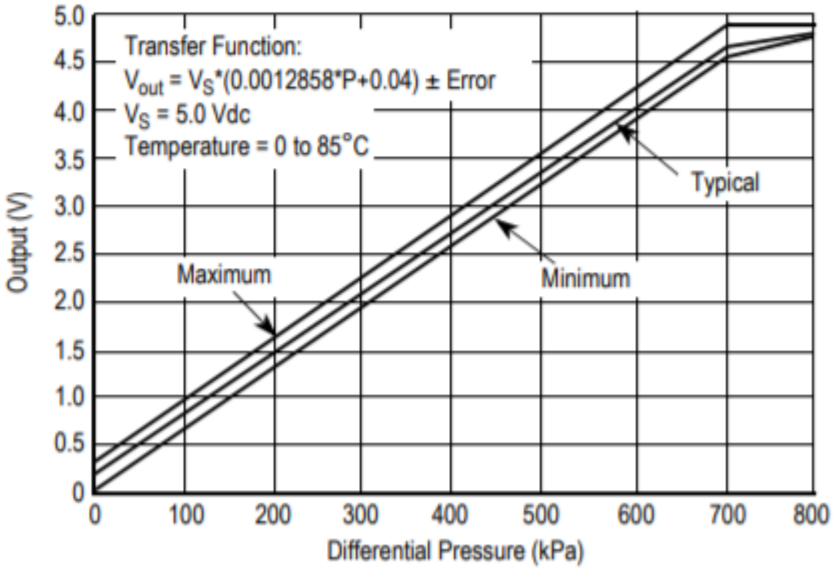

Figure 1: Output vs. Pressure Differential of the MPX5700AP sensor

Responsible for interfacing hardware and software in this project, the Arduino Nano V3.0 is shown in Figure 2, attached to the soldered board with electronic components such as condensers, necessary for MPX5700AP functionality.

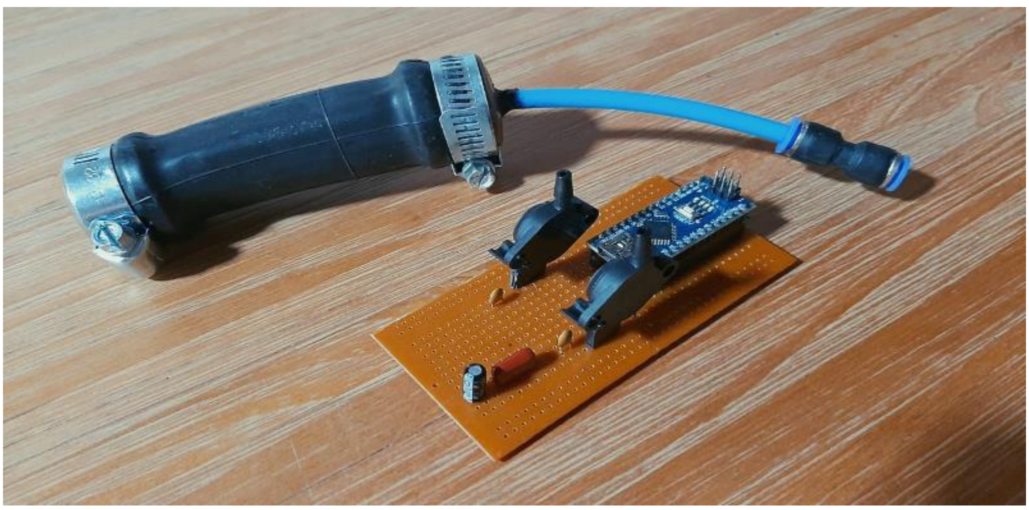

Figure 2: Hardware plate, equipped with two MPX5700AP sensors and Arduino Nano V3.0 board

In addition to assembling all electronic circuit, there was a necessity of creating test probes with capacity to hold high levels of air pressure, as can be seen in Figure 3. Bicycle tube, clamps, hydraulic hose and several connection types were some of the elements used to build them. The probes were capable to hold internal pressures above 100 KPa, as observed in field tests.

Figure 3: Inflated test probe, developed to work in confined situation at high pressure levels

2.2 Sensor Functionality

A given amount of explosive emulsion tends to increase its initial volume because of bubble's continuous formation when sensitized and then charged in boreholes. In consequence, the density of product decreases as gassing reaction proceeds. At the same time, reaction time is controlled by gasifier proportion, emulsion formula and temperature.

The weight that supports each point across the width of the explosive column maintains a distinct pressure gradient up to the borehole end. In that case, the amount of mass at a given point varies depending on the depth, because density also varies in direct relation to the compression gradient. Nitrogen bursts, submitted to different degrees of pressure, presenting different volumes, and these spaces left by the pressed bubble are occupied by emulsion, increasing mass, thus density increase as well.

Equation 1 shows the basis of density calculus, through absolute pressure measurements, in the software developed to receive and process MPX5700AP output data. It is important to mention that, to evaluate the density at a given depth in this project, cup density measurement is also needed.

$$\rho(i) = 1 / (1/Dbg - 1/\rho(i-1)) * (Pt(i-1)/Pt(i) + 1/Dbg)) \quad (1)$$

Where,
ρ(i) = density at a given depth, taking atmosphere as reference, i.e., i = 0 (Kg/m³)
ρ(i-1) = density at past distance reference (Kg/m³)
Dbg = bulk emulsion density before gassing, measured by cup test (Kg/m³)
Pt(i) = hydrostatic pressure at a given depth plus atmospheric pressure (N/m²)
Pt(i-1) = total pressure at past depth reference.

2.3 Density Test Procedure

In order to evaluate the testing procedure and the equipment reaction to the process, the hardware prototype was then tested in a laborathorial environment, using a polyvinyl chloride tube, representing a borehole, filled with water and kitchen oil to check its accuracy in various density measurements. An air pump equipment and hose connections were also used to control pressure flow in the probe, according to Figure 4.

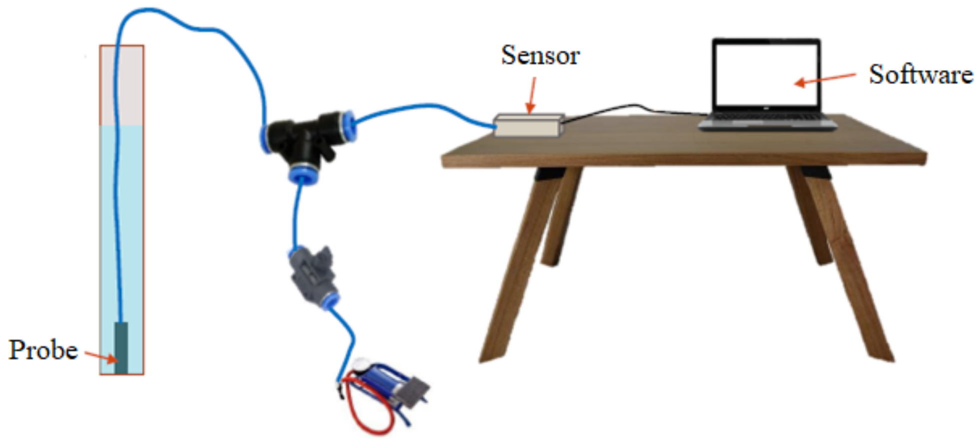

Figure 4: Laborathorial test methodology

The column weight presses the probe when inflated. Immediately, the signal is transmitted by the hydraulic hose to the MPX5700AP sensor, that converts the signal into electric potential difference. The voltage is transformed in pressure units (kPa). This pressure level result is sent to USB port where the Arduino board is connected.

When the inflated probe is slowly deflated, surrounded in a liquid or emulsion, it will be observed that the air flow that leaves the probe detains momentarily when the pressure inside of it is equal to the surrounding pressure. This happens because the flow rate is proportional to the difference of pressure between internal and external environment, so the force unrolled by the elastic walls of the probe are balanced. Figure 5 shows pressure measurements made in field tests captured in software, highlighting the moment where it holds for a higher time, indicating that internal pressure is equal to emulsion explosive environment.

The probe was always first inflated at higher pressure rates than external, and slowly deflated to get the exact instant where external pressure is equal to intern. The process should be repeated three to five times to confirm previous sampling data.

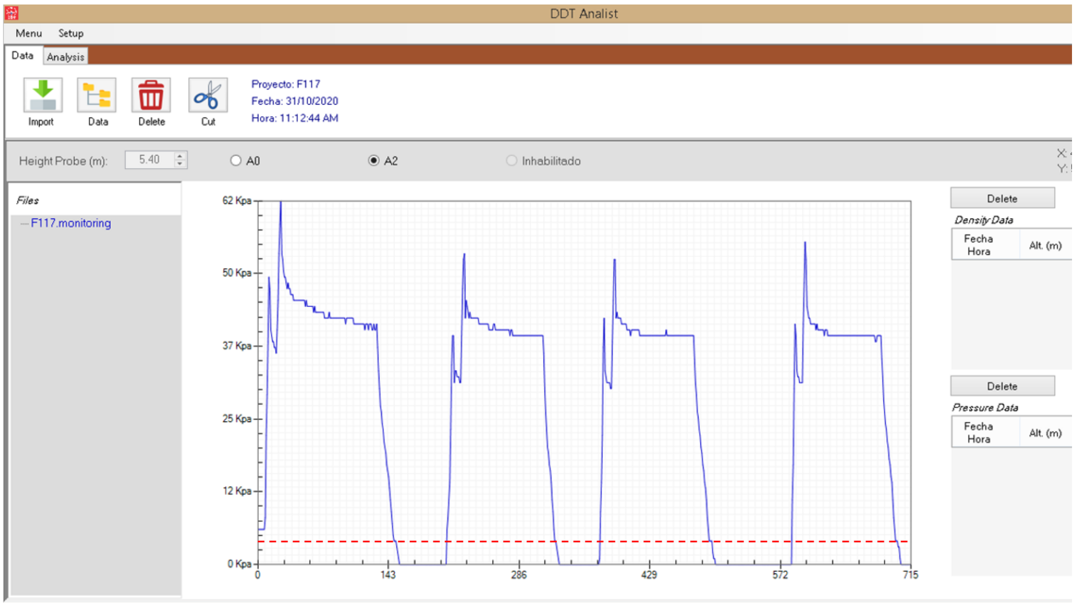

Figure 5: Data acquisition in the software developed for pressure monitoring. The red dashed line highlights the instant where pressure holds in a longer interval when probe is deflated, representing the emulsion pressure in probe walls

2.4 Field Tests

With the procedure successfully evaluated in off-site situation, a small test in a quarry mining blast operation located in Northeast Brazil confirmed its effectiveness in full-scale operations. The methodology was conducted taking in consideration the operational environment, so the mining process was not negatively impacted, and the data acquisition could be realized with precision.

In October 2020, we conducted a major test in a gold ore mining located in North Brazil (Figure 6). 7 of 291 boreholes were then monitored with both bottom and top probes. Aiming to get various data results, we selected holes with diameters of 4 and 5.5 inches, since ore and waste had different diameter specifications. Boreholes with water were also chosen. Figure 7 shows the data acquiring procedure.

Figure 6: Blasting operation of the gold ore mining at North Brazil

Figure 7: Data acquisition in a gold ore mining, located in North Brazil

2.5 Data Processing

Once all data were collected, they were processed and then interpreted, generating an analysis of explosive charging process in the gold ore mining operation. For each borehole and its explosive final density along the detonation column, one monitoring report is produced as shown in Figure 8.

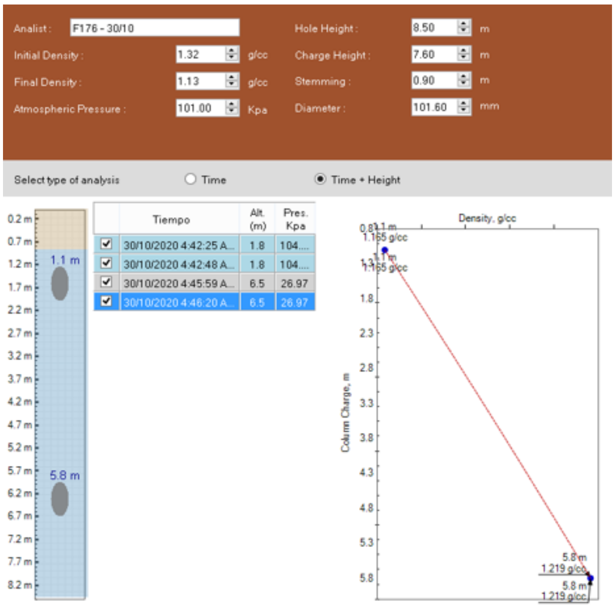

Figure 8: Borehole density monitoring report

3 RESULTS AND DISCUSSION

The following results shown in Table 1 had conformity with theorical basis. As quoted above, hydrostatic pressure effects (that increases with depth) were then observed, once probes located at the bottom of the blasted holes had higher density values if compared with the ones located at the top of the column at the same hole. Additionally, it is important to mention that the hole with ID number 249 for example, which had a higher amount of water in emulsion mixture due to hose blown while charging (in order to unblock its flow), had minimum density results. This inadequate operation is often made and should always be avoided, as test results shows its influence in final density, and probably in the VOD of the explosive.

Table 1: Bulk emulsion Table monitoring results

Hole ID	A0 (m)	A2 (m)	h (m)	Ø (in)	W	T (m)	Dbg (g/cc)	Dag (g/cc)	ρA0 (g/cc)	ρA2 (g/cc)
54	1,7	6,2	8,4	4,0	Y	1,6	1,32	1,13	1,207	1,154
125	1,8	5,8	7,8	5,5	Y	1,6	1,32	1,13	1,219	1,154
176	1,8	6,5	8,5	4,0	N	0,9	1,32	1,13	1,219	1,165
249	2,3	6,0	8,2	4,0	N*	1,7	1,32	1,13	1,189	1,141
82	1,7	6,6	8,6	5,5	Y	1,8	1,31	1,15	1,213	1,167
117	1,1	5,4	7,3	5,5	Y	1,4	1,31	1,15	1,201	1,155
194	2,0	6,5	7,9	4,0	N	1,0	1,31	1,15	1,212	1,157

Where,
A0 = probe height, placed at the bottom of the hole (m)
A2 = probe height, placed at the top of the hole (m)
h = hole length (m)
Ø = hole diameter (pol)
W = presence of water

T = stemming height (m)
Dbg = initial cup density measure, before gassing expansion (g/cc)
Dag = final cup density measure, 30 minutes after gassing expansion (g/cc)
ρA0 = explosive emulsion density, gauged by probe A0 (g/cc)
ρA2 = explosive emulsion density, gauged by probe A2 (g/cc).

Explosive manufacturers use models to predict change. Nevertheless, results prove the necessity to make in-situ measurements to have better accuracy in charge factor and emulsion performance. Density variation is not uniform along the borehole column, once real diameter may change, and geological surrounding can affect it as well. Thus, several conditions and ideas can be used as future work. The next steps using the sensor built for this project will evaluate the ideal stemming time, measuring several variations from 0 to 1 hour of gassing reaction before borehole is confined, to see and how stemming really affects final density of explosive emulsion. Additionally, a temperature sensor will be added to the device, aiming to control one more changing parameter along the borehole column, giving more precise measurements.

4 CONCLUSIONS

a) The use of pressure sensors to verify the compliance of explosive emulsions in rock blasting holes has proven to be efficient and in line with theoretical foundations.

b) However, the limitation of two sensors per hole does not allow for evaluating whether the density variation along the column behaves linearly.

c) 85.7% of the samples proved to be reliable for result analysis. The data from borehole ID 249 were compromised due to an operational deviation.

d) The remaining densities measured in the explosive emulsions were below the critical value of 1.27 g/cc defined as critical for VOD, as defined by Mishra et al. (2017).

e) The density values measured in the probe installed at the top of the detonation holes, except for borehole ID 249, showed an average variation of 0.75% in relation to the target density of the emulsion after gasification (1.15 g/cc). Additionally, a temperature sensor will be added to the device, aiming to control one more changing parameter along the borehole column, giving more precise measurements.

f) The built equipment shows a low-cost solution for mining operations, considering that there is a significant challenge related with using computational tools for enhance operational excellence, as mentioned by Rocha et al. (2018).

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