Central European Journal of Energetic Materials
ISSN 1733-7178; e-ISSN 2353-1843

Cent. Eur. J. Energ. Mater. 2026, *23*(1): 44-57; DOI 10.22211/cejem/220087

Research paper

Study of the Effect of Hydrostatic Pressure on the Stability of the Operating Properties of Seismic Emulsion Explosives

Bartłomiej Kramarczyk1), **Piotr Mertuszka**2, *)
1) *NITROERG S.A., 1 Alfred Nobel Square, 43-150 Bieruń, Poland*
2) *KGHM CUPRUM Ltd. Research and Development Centre,*
2-8 Sikorskiego St., 53-659 Wrocław, Poland
* *E-mail:* piotr.mertuszka@kghmcuprum.com

Abstract: Explosives are mainly used in mining to break rocks, but they are also a good and cheap source of seismic energy used in seismic exploration to detect geological conditions underground. They are characterized by high vibration energy in a very wide frequency band and therefore allow for recording of secondary vibrations. The most commonly used explosives in geological exploration are pentolite charges and dynamites. Given that seismic works are most often carried out in deep and water-filled boreholes, and that the explosive charges themselves remain equipped with detonators for a long time, which may cause the release of toxic substances, such as nitroglycerin, 2,4,6-trinitrotoluene or dinitrotoluene into the natural environment, efforts are being made to find alternative explosives for seismic exploration puproses. In this case, emulsion explosives seem to be a reasonable option, since they are a safer and more ecological alternative to classic explosives, such as dynamites. Their advantage is a high level of safety from manufacturing, through transport until the use on site, but also the absence of any explosive particles in their composition. All components are emulsified in a stable water-in-oil emulsion, so they cannot migrate into groundwater, even after long term exposure in water-filled boreholes during seismic engineering works. This paper presents the methodology for testing emulsion explosive charges, in which conditions of high hydrostatic pressures present in boreholes at great depths were simulated in field trials. An analysis confirmed that high hydrostatic pressure does not affect the operating properties of the tested emulsion explosive, which can be used under critical conditions, such as under water and hydrostatic pressure conditions, and in cases where environmental protection is particularly important.

Keywords: emulsion explosives, critical conditions, detonation properties, seismic prospecting, underwater blasting

1 Introduction

Identifying geological structures underground is a difficult problem in oil and gas exploration and development but also in deep mining. Seismic explorations used to assess the geological conditions of underground structures are a relatively mature technology. They apply the law of propagation of seismic waves induced by detonation of explosives in different strata to identify geological conditions underground [1, 2]. Seismic waves generated by explosives are reflected or refracted when coming across different strata and return to the surface [3]. Arrival times and velocities are recorded with specialized sensors, allowing for identification the depths and shapes of the strata to determine their lithology. Vibroseis is a common alternative to explosives for creating seismic sources [4]. It uses powerful truck-mounted vibrators to create seismic waves instead of dynamite. Vibrator sources are usually quite expensive for most small-scale seismic surveys. There are, however, some inexpensive vibrator sources that can produce any desired seismic time sources, but they are not used on an industrial scale so far [5]. Another alternative method for mineral resource evaluation is ground penetrating radar, which transmits electromagnetic waves into the ground and detect the reflections to study the subsurface. This is an non-invasive method but its application is limited to relatively shallow exploration [6, 7]. Different seismic methods have developed considerably and have been applied much more widely over the past few decades, but they are mostly limited to near-surface exploration [8]. Geophysical methods are also widely used in mining for various applications such as deposit mapping, geological fault detection, lithological mapping, geotechnical evaluation, assessment of the rock mass response to mining, detection of voids, location of trapped miners, guidance of drills and mining equipment, as well as detecting and monitoring potential sources of mine water in-rushes [9-12].

Many scholars have considered replacement of explosives as a source for underground seismic exploration by other sources [13-15], however, they are still the most common seismic source in seismic explorations to date. Explosives provide a high energy, reliable source for seismic waves, especially in challenging land and swamp environments where other methods may be less effective. Such explosives for mineral resource evaluation are preferred, which release a great amount of energy at a minimum charge but also minimize environmental and ecological impact. Dynamites and pentolites have been used as a main seismic sources for a long time due to their relatively good pulse characteristic and high energy. As confirmed by Zhang *et al.* [16], selection of the most appropriate high energy dynamite and borehole depth can both improve the dynamite work capability and enhance the excitation energy, which is beneficial to generate high frequency source wavelet with relatively high energy, and to minimize financial investments. Similar conclusions were drawn by Liu already in 1999 [17]. It has been observed that the dynamite as a source of seismic energy provide better data quality than other seismic sources. Even though the dynamite is widely used in seismic exploration, it is not easy to be controlled to generate an ideal waveform [18]. However, Quigley and Thompson [19] have recognized that conventional commercially available seismic explosives were not designed specifically for seismic requirements. Thus, in the early 2000s, a new high energy and high performance pentolite seismic explosive product was introduced [20].

The environmental impact of underwater seismological explosion experiments is significant since it may affect the marine life and underwater ecosystem [21, 22]. The biggest risk is associated with migration of nitro esters, nitro compounds or other toxic substances, such as nitroglycerin, 2,4,6-trinitrotoluene (TNT) or dinitrotoluene into the natural environment, especially underground water. Thus, emulsion explosives seem to be a good alternative, since they are cheaper, safer and more ecological than conventional explosives. In fact, emulsion explosives are less energetic than dynamites or pentolites because of lower density, what is related to higher content of gaseous voids, which in turn reduces the concentration of energy and leads to lower blasting effectiveness. However, Taylor *et al.* [23], almost 80 years ago, have found from conducted field tests that ground amplitude measured in seismic exploration is practically independent of the velocity of detonation (VOD) of explosives. Do Couto *et al.* [24] have made comparative tests of two different explosive sources, *i.e.* emulsion and pentolite based explosives. Results showed that the energy of pentolite is relatively smaller than that of emulsion explosive. This proves that emulsion explosives are suitable for seismic exploration purposes from both energetic and environmental point of view.

Hydrostatic pressure is a critical factor in underwater blasting that is especially important in the seismic explorations, where blasting is conducted in a rather deep and water-filled boreholes. In such a conditions, explosives performance described by VOD and brisance will drop. Moreover, the density of explosive will increase, and therefore initiating sensitivity will be reduced. It should, however, be noted that VOD of explosive for seismic exploration purposes should be constant on the entire length of explosive column. Hydrostatic pressure increases by approximately 10 kPa for every meter of water depth, and even 20% more in brine water. Thus, emulsion explosive used in deep-hole blasting should be characterized by appropriate compression resistance, since the detonation parameters fall at high hydrostatic pressures, leading to complete loss of detonation ability.

The current state of knowledge in the field of emulsion explosive behaviour under hydrostatic pressure conditions is rather limited. Liu *et al.* [25, 26] developed the experimental method and constructed explosive ball tank that can simulate underwater blasting at different depths. The obtained results are very promising and allow to use the small-size models to simulate real blasting engineering and evaluate the performance of explosive. Detonation performance of bulk emulsion explosives under hydrostatic pressure condition was also assessed by Ali *et al.* [27]. They performed the tests using hydrostatic pressure apparatus in which explosive samples were placed and the desired pressured was applied. After certain time, the pressure was released and the VOD was measured. In fact, such conditions do not reflect real conditions present inside the borehole and should be treated as only some approximation. Thus, in this paper the effect of hydrostatic pressure on the VOD and stability of the seismic emulsion explosives has been verified and evaluated using the disposable hydrostatic pressure devices designed and manufactured for the purpose of the tests. Such an advanced research equipment enables to reflect conditions observed in water-filled boreholes at the depth of 50 and 100 m below the ground.

2 Materials and Methods

The main problem when using seismic explosives is the extended dwell time (up to several weeks) in water-filled boreholes at depths of 50 m and more. In such conditions, several technical and physical challenges arise. The explosive charges equipped with detonators are subjected to long-term exposure to water and increased hydrostatic pressure, and after a standby period they must be reliable and able to perform mechanical work, generating strong enough seismic impulse. When developing technologies for the manufacturing of such charges based on emulsion explosives, the above factors should be taken into account in order to identify and select the appropriate final form. The requirements for such explosives are primarily a stable over time VOD, which should achieve 5,500 m/s. In this case, quality control and ensuring that tests are carried out in conditions as close as possible to conditions in which seismic explosives are used are very important. This paper describes the developed methodology for testing seismic charges subjected to hydrostatic pressure for operating conditions prevailing in one of the seismic site.

The research was conducted in the NITROERG company test site in Bieruń, Poland. The subject of the study was selected seismic emulsion explosive sensitised with glass micro-balloons. Plastic-coated charges with a mass of 2 kg and diameter of 57 mm can be used as a pressurised material at a maximum hydrostatic pressure of 0.5 MPa for 10 days. Selected parameters of the tested explosive are shown in Table 1.

Table 1. Selected parameters of the tested explosive based on technical data sheet

Density [g/cm^3]	1.10-1.25
VOD [m/s]	5,500
Relative Weight Strength [%RDX]	≥ 60
Impact sensitivity [J]	> 30
Friction sensitivity [N]	> 360
Thermal stability	48 h at 75 °C
Oxygen balance [%]	–2.38
Volume of gaseous products of explosion [dm^3/kg]	870
Heat of explosion [kJ/kg]	3,093
Concentration of energy [kJ/dm^3]	4,820
Specific energy [kJ/kg]	760

For the purposes of the research, a total of 40 plastic-coated cartridges with a diameter of 57 mm and a weight of 2 kg were produced. In order to reflect the operating conditions in water-filled boreholes, special disposable pressure pipes were developed and manufactured according to the diagram shown in Figure 1. The body was made of a plastic pipe threaded on both sides. External diameter of the pipes was 80 mm, length 800 mm and wall thickness 1.8 mm. Steel end caps were screwed onto both ends, one of which was equipped with a sealing socket and compressed air inlet valve. The socket was used to bring out the wires from the detonator and the wires for measuring the VOD. The connection between the pipe and the end caps was additionally sealed with thread sealant. Each sample consisted of two coupled cartridges using cartridge-to-cartridge thread with a total mass of 4 kg. Cartridges with seismic electric detonators were placed in the pipes, which were then filled with water. After tightening the caps, the pipes were filled with compressed air using air compressor at the specified pressure, *i.e.* 0.5 MPa and 1 MPa (8 samples for a given pressure). Method of sealing the flange and wires is shown in Figure 2, while experimental setup showing explosive charge with detonator in a water-filled pipe and pressurization using compressor in Figure 3.

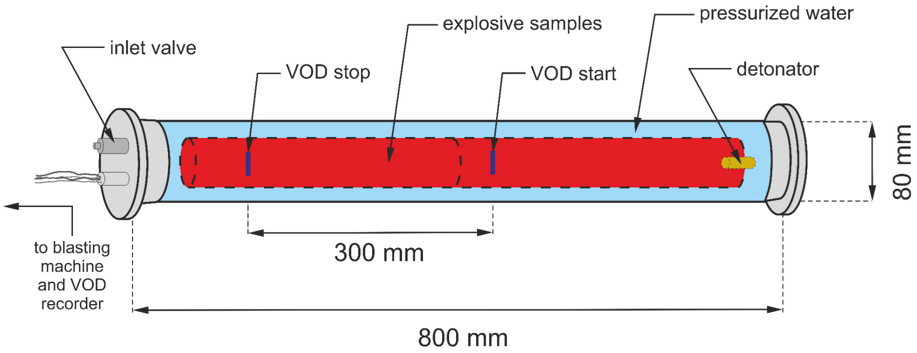


Figure 1. Scheme of the pipe used for testing emulsion explosives under hydrostatic pressure

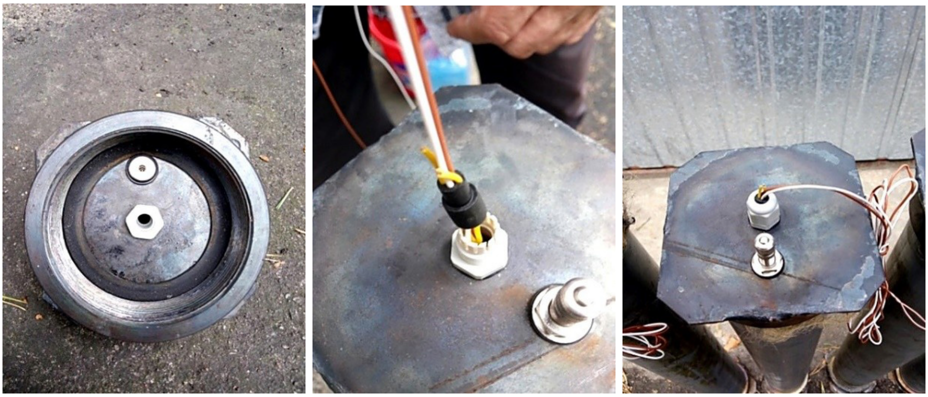


Figure 2. Sealing of the flange and wires

Figure 3. Explosive charge in a water-filled pipe and application of pressure using compressor

One additional sample was prepared for visual evaluation of the plastic coating of cartridge subjected to a pressure of 1 MPa for a period of two weeks. Samples were equipped with fibre optic cables for VOD measurements using a Explomet-Fo-2000 speedometer produced by Kontinitro AG. This start-stop system involves measuring the time intervals between the illumination of two fibre optic sensors located in the explosive sample at a known distance produced by the shock wave travelling through explosive sample. In this system, the first optic fibre to be illuminated gives the starting signal and the other fibre gives the stop signal. This allow measuring the time intervals (in μs) between the illumination of two optic fibres and calculates the VOD in m/s. Figure 4 shows the prepared samples after charging and after pressurization to the desired pressure value.

Figure 4. View of the charged and pressurized explosive samples

Following sample preparation, they were stored horizontally in a explosives depot with a constant ambient temperature of approximately 15 °C. The VOD tests were conducted at 2- and 4-week intervals. The first set of measurements involved firing of 8 samples, *i.e.* 4 samples for each hydrostatic pressure tested. Prior to firing, the pressure values were verified using the pressure gauge. It was confirmed that pressure leaks did not exceed 3%. Samples were placed horizontally on the ground of experimental test site and covered with 30 cm layer of sand for noise requirements. The samples were fired in the same way after 2 weeks.

3 Results and Discussion

The results of VOD of the pressurized explosive samples measured in a given time are shown in Table 2. The measured VOD's for all tested samples ranged between 5,520 m/s and 5,550 m/s. For samples detonated after 14 days of exposure, the average VOD was approximately 5,540 m/s at 0.5 MPa and 5,538 m/s at 1 MPa. Then, after 28 days of exposure, the average VOD values were approximately 5,533 m/s for 0.5 MPa and 5,535 m/s for 1 MPa. The observed variations within each series did not exceed ±15 m/s, corresponding to less than 0.5% relative deviation. The narrow range of obtained values indicates high repeatability of the results and confirms stable detonation propagation in all tested configurations. No signs of detonation failure, partial detonation, or desensitization were observed.

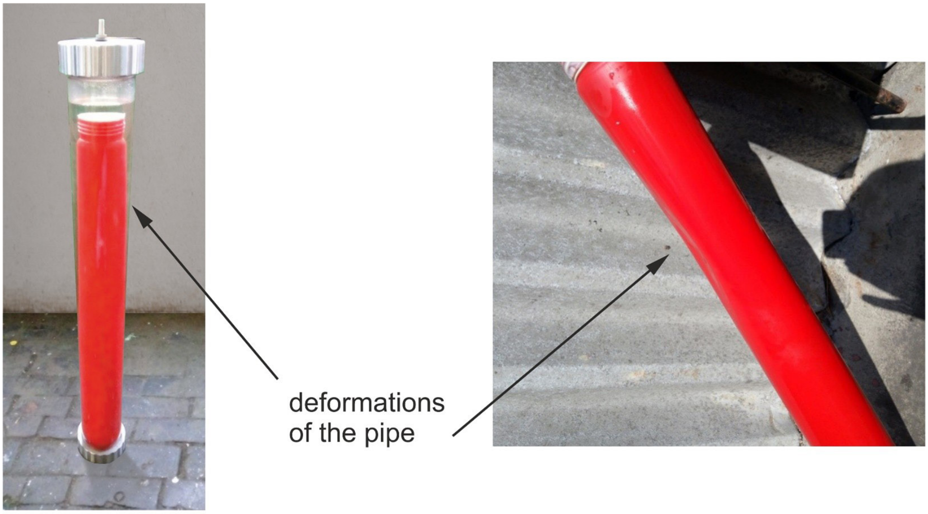
Table 2. Results of VOD tests in relation to applied pressure and storage time

Sample #	VOD [m/s]			
	14 days		28 days	
	0.5 MPa	1 MPa	0.5 MPa	1 MPa
1	5,530	5,540	5,540	5,530
2	5,550	5,540	5,530	5,540
3	5,530	5,520	5,540	5,520
4	5,550	5,550	5,520	5,550

Comparison of the results obtained at 0.5 MPa and 1 MPa shows no significant influence of hydrostatic pressure on the VOD of the tested explosive. Differences between the average VOD's at the tested pressures were limited to a few m/s and are within the expected measurement uncertainty of the VOD meter used. No systematic trend of increasing or decreasing VOD with increasing hydrostatic pressure was observed, either after 14 or after 28 days of exposure. This indicates that hydrostatic pressure corresponding to depths up to 100 m does not affect the detonation characteristics of the tested emulsion explosive. This can be attributed to the inherent physicochemical stability of water-in-oil emulsion, in which the oxidizer phase is effectively isolated from the surrounding environment, limiting water ingress and preventing migration of reactive components.

The comparison between measurements performed after 14 and 28 days of exposure shows no evidence of performance degradation over time. The VOD values remained essentially constant, with differences between the two exposure periods remaining below 10 m/s for both pressure levels. Thus, it may be stated that prolonged exposure to water and hydrostatic pressure does not lead to negative physicochemical changes in the explosive matrix, such as phase separation, water migration into sensitizing structures, or loss of detonation stability. All the tests revealed fully developed and stable detonation, as indicated by almost constant VOD values for all samples and test conditions. Since no measurable effect of hydrostatic pressure on VOD was observed, one may conclude that, within the tested pressure range, compression of the emulsion matrix and sensitizing gas voids does not reach a level sufficient to disrupt the detonation front or significantly alter kinetics of the reaction. This is consistent with previous literature findings indicating that, for seismic applications, the quality and amplitude of generated seismic waves are not directly governed by small variations in VOD. From an implementation perspective, the results confirm that the tested emulsion explosive maintains reliable detonation performance in water-filled boreholes subjected to hydrostatic pressures up to 1 MPa for exposure times of at least four weeks. This is particularly important for seismic applications, where controlled energy release and stability of the waveform characteristics are critical. This proves that tested emulsion is suitable for seismic exploration purposes from energetic point of view.

One additional sample, which was prepared for visual evaluation of the plastic coating of cartridge subjected to a pressure of 1 MPa was opened after two weeks of storage and the explosive charge was taken out. It was observed that the plastic coating was deformed as a results of exposure to the applied pressure (Figure 5(a)). The deformation occurred at the location where the coating wall was the thinnest, without any measurable reduction in charge diameter or detonation capability. Therefore, clear pressure sample was constructed in order to observe the behaviour of the cartridge subjected to hydrostatic pressure of 1 MPa (Figure 5(b)).



(a) (b)

Figure 5. View of the clear test pipe subjected to hydrostatic pressure of 1 MPa (a) and deformation of the explosive charge removed from the test pipe (b)

The results of visual inspection show that deformation of the plastic coating is minimal, and pressures of up to 1 MPa should not affect the detonation capability due to a reduction in diameter. Moreover, it can be stated that the current design of plastic coating already provides sufficient structural integrity for deep water-filled boreholes up to 100 m. The water resistance of the sample sealing was also assessed. Inspection after opening revealed minor water presence. However, the water did not migrate into the emulsion matrix. It means that the applied sealing provided appropriate water resistance, as no migration of water into the internal structure of the emulsion was observed.

The conducted research shows that hydrostatic pressure up to 1 MPa has no significant effect on the VOD of the tested seismic explosive. Extended exposure times of up to 2 weeks under the critical test conditions do not lead to measurable degradation of detonation performance. Tested emulsion explosive exhibits high detonation stability and repeatability, confirming its suitability for seismic applications in deep, water-filled boreholes. It may be expected that at much higher hydrostatic pressures, additional effects such as increased matrix compaction or reduced sensitization efficiency could become relevant. However, such conditions were beyond the scope of the present study and require further investigations.

4 Conclusions

- Presented study investigated the influence of hydrostatic pressure and exposure time on the detonation stability and operating properties of a seismic emulsion explosive intended for use in deep, water-filled boreholes as a sources of seismic energy. Field-scale experiments were conducted using specifically designed disposable pressure pipes that enabled realistic simulation of hydrostatic pressures corresponding to water-filled boreholes at the depths of 50 and 100 m.
- The VOD measurements were performed after 2 and 4 weeks of storage under hydrostatic conditions. The results have shown that the tested emulsion exhibits stable detonation behaviour, with negligible variation in VOD among the considered pressures and exposure periods. Additional visual inspections confirmed that mechanical deformation of the cartridge coating under pressure was minor and did not compromise its detonation capability. This confirms that any potential ingress of water should not result in a loss of explosive performance.
- An analysis confirmed that seismic emulsion explosives constitute a reliable and environmentally favourable alternative to conventional seismic explosives, mainly in applications, which require long dwell times under high hydrostatic pressure conditions. Emulsion explosives represent the most economical option for seismic applications, however, they require improved charge sealing to ensure reliable performance under water-filled borehole conditions. The critical element is the sealing between the plug and the detonator socket. Water migrating under such pressure may capable of damaging the emulsion structure, which may result in a lower initiation capability in the most critical area, particularly in the vicinity of the detonator.
- The lack of degradation over time further indicates that prolonged exposure to hydrostatic pressure does not promote phase separation or chemical destabilization of the emulsion matrix. This is of particular importance in seismic prospecting, where explosives may remain in boreholes for extended standby periods prior to firing. In contrast to conventional dynamites or pentolite-based explosive, which may pose environmental risks due to the potential migration of nitro compounds into groundwater as well as surface waters, the tested seismic emulsion explosive exhibits a high degree of environmental robustness and containment stability.
- Overall, the findings confirm that emulsion explosives represent a technically feasible and environmentally favourable alternative to conventional seismic explosives for use in deep, water-filled boreholes. Their resistance to

hydrostatic pressure and long-term water exposure, combined with stable energy release and repeatable waveform characteristics, proves their relevance for seismic exploration purposes, particularly in environmentally sensitive areas. Future research should focus on testing the VOD using continuous method to verify possible changes of the VOD along the entire sample and/or extending the exposure times, and correlating detonation parameters with recorded seismic signal characteristics to further optimise emulsion-based seismic source.

References

[1] Galante, E.; Haddad, A.; Marques, N. Application of Explosives in the Oil Industry. *Int. J. Oil Gas Coal Eng.* **2013**, *1*(2): 16-22; https://doi.org/10.11648/j.ogce.20130102.11.

[2] Triviño, L.F.; Mohanty, B.; Milkereit, B. Seismic Waveforms From Explosive Sources Located in Boreholes and Initiated in Different Directions. *J. Appl. Geophys.* **2012**, *87*: 81-93; https://doi.org/10.1016/j.jappgeo.2012.09.004.

[3] Dong'an, L.I.; Lixin, Q.I. Full Wave Seismic Exploration Technology. *Petrol. Explor. Develop.* **2022**, *49*(3): 586-595.

[4] Driml, K.; Smith, B.; Saunders, J.; Taylor, R. Vibroseis or Dynamite: Investigating source characteristics. *ASEG Ext. Abstr.* **2004**, *1*: 1-6; https://doi.org/10.1071/ASEG2004ab036.

[5] Haines, S.S. Design and Application of an Electromagnetic Vibrator Seismic Source. *J. Environ. Eng. Geophys.* **2006**, *11*(1): 9-15; https://doi.org/10.2113/JEEG11.1.9.

[6] Francke, J. A Review of Selected Ground Penetrating Radar Applications to Mineral Resource Evaluations. *J. Appl. Geophys.* **2002**, *81*: 29-37; https://doi.org/10.1016/j.jappgeo.2011.09.020.

[7] Singh, K.K.K. MineVue Radar for Delineation of Coal Barrier Thickness in Underground Coal Mines: Case Studies. *J. Geol. Soc. India* **2015**, *85*(2): 247-253; https://doi.org/10.1007/s12594-015-0211-x.

[8] Steeples, D.W.; Schmeissner, C.M.; Macy, B.K. The Evolution of Shallow Seismic Exploration Methods. *J. Environ. Eng. Geophys.* **1995**, *1*(A): 15-24; https://doi.org/10.4133/JEEG1.A.15.

[9] Hatherly, P. Overview on the Application of Geophysics in Coal Mining. *Int. J. Coal. Geol.* **2013**, *114*: 74-84; https://doi.org/10.1016/j.coal.2013.02.006.

[10] Rafat, G.; Lehmann, B.; Toumani, A.; Rueter, H. Characterisation of Rock Ahead and Around Tunnels and Boreholes by Use of Geophysical and Geological Methods. *Int. J. Rock Mech. Min. Sci.* **2001**, *38*: 903-908; https://doi.org/10.1016/S1365-1609(01)00056-9.

[11] Lu, T.; Liu, S.; Wang, B.; Wu, R.; Hu, X. A Review of Geophysical Exploration Technology for Mine Water Disaster in China: Applications and Trends. *Mine*

Water Environ. **2017**, *36*: 331-340; https://doi.org/10.1007/s10230-017-0467-z.

[12] Ge, M.; Wang, H.; Hardy, Jr., H.R.; Ramani, R. Void Detection at an Anthracite Mine Using an In-Seam Seismic Method. *Int. J. Coal Geol.* **2008**, *73*(3-4): 201-212; https://doi.org/10.1016/j.coal.2007.05.004.

[13] Staples, R.K.; Hobbs, R.W.; White, R.S. A Comparison Between Airguns and Explosives as Wide-Angle Seismic Sources. *Geophys. Prospect.* **1999**, *47*(3): 313-339; https://doi.org/10.1046/j.1365-2478.1999.00134.x.

[14] Wang, B.; Qiu, W.; Liu, S.; Sun, U.; Ding, X.; Jin, B.; Zhang, Z. Supercritical CO_2 Source for Underground Seismic Exploration. *J. King Saud Univ. Sci.* **2020**, *32*(2): 1731-1737; https://doi.org/10.1016/j.jksus.2020.01.010.

[15] Chen, Y.; Zhang, X.; Qiu, X.; Ge, H.; Liu, B.; Wang, B. A New Way to Generate Seismic Waves for Continental Crustal Exploration. *Chin. Sci. Bull.* **2007**, *52*: 2264-2268; https://doi.org/10.1007/s11434-007-0247-4.

[16] Zhang, Z.; Liu, C.; Shao, Z. Theory and Experimentation of the Charge Sizes in Seismic-Sources for Seismic Exploration. *Prog. Geophys.* **2003**, *18*(4): 724-728.

[17] Liu, S. Research on the Problem of Dynamite Type Selection in Seismic Prospecting. *Geophys. Prospect. Pet.* **1999**, *38*(4): 66-73.

[18] Nianmin, G.; Gengxin, P.; Fulie, L.; Kaichi, X.; Guangping, P. Explosion Numerical Simulation: A Method for Designing Source Excitation Parameters. *SEG Tech. Program Exp. Abstr.* **2020**: 126-130; https://doi.org/10.1190/segam2020-3417389.1.

[19] Quigley, J.; Thompson, P. A comparison of Seismic Explosives – A Case History. *SEG Tech. Program Exp. Abstr.* **2004**: 25-28; https://doi.org/10.1190/1.1839718.

[20] Bremner, D.; Tite, G.A.; Thompson, P.; Brooks, J. Enhanced Signal-to-Noise Ratio and Bandwidth Through Explosives Design. *SEG Tech. Program Exp. Abstr.* **2002**: 64-66; https://doi.org/10.1190/1.1817337.

[21] Kaushik, A.P.; Himanshu, V.K.; Roy, M.P.; Mishra, A.K.; Mishra, A.; Siddique, H.S. Comprehensive Review on Principles and Practices of Underwater Drilling and Blasting, its Environmental Impacts, and Mitigation Techniques. *Sādhanā* **2024**, *49* paper 21; https://doi.org/10.1007/s12046-023-02395-7.

[22] Girma, M.B.; Kifle, D.; Jebessa, H. Deep Underwater Seismic Explosion Experiments and Their Possible Ecological Impact – The Case of Lake Arenguade – Central Ethiopian Highlands. *Limnologica* **2012**, *42*: 212-219; https://doi.org/10.1016/j.limno.2011.12.002.

[23] Taylor, G.; Morris, G.; Richards, T.C. The Effect of Velocity of Detonation on the Efficiency of Explosives Used in Seismic Prospecting. *Geophysics* **1946**, *11*(3): 350-361; https://doi.org/10.1190/1.1437258.

[24] Do Couto, L.S.; Sartini, A.P.; Barreto, A.C.R.; Soares, A.G.O.; Furtado, D.P.; Michelon, M.F.; Alves, R.V.S.; Cominges, J.C.C.; Côrtes, P.N.; Da Silva, R.C. Comparative Test of Emulsion and Pentolite Based Explosive Seismic Sources. *SEG Global Meeting Abstr.* **2015**, 911-916; https://doi.org/10.1190/sbgf2015-179.

[25] Liu, L.; Wang, X.; Yang, Y.; Wang, G. Experimental Method Study on Emulsion Explosives Under Hydrostatic Pressure in Models Blasting. *Adv. Mater. Res.* **2012**, *524-527*: 569-574; https://doi.org/10.4028/www.scientific.net/AMR.524-527.569.

[26] Liu, L.; Qi, H.; Zhang, H.; Cai, Y. Experimental Study on Emulsion Explosive Blasting Under Different Under-Water Pressure. *J. Phys. Conf. Ser.* **2022**, *2381* paper 012072; https://doi/org/10.1088/1742-6596/2381/1/012072.

[27] Ali, F.; Kumar, A.; Dhar, S.K.; Vishwakarma, A.K.; Kumar, S.; Himanshu, V.K. Investigation on Bulk Emulsion Explosive Performance Under Critical Conditions: Its Detonation Behaviour and Air Over Pressure Analysis. *Propellants Explos. Pyrotech.* **2025**, *50*(10): paper e70018; https://doi.org/10.1002/prep.70018.

Authorship contribution statement

Bartłomiej Kramarczyk:	conception, foundations, methods, performing the experimental part
Piotr Mertuszka:	foundations, methods, other contribution to the publication

Submitted: February 13, 2026
Revised: March 27, 2026