EMPIRICAL EQUATIONS FOR EVALUATING TNT-EQUIVALENT OF UNDERWATER EXPLOSION

M. N. Makhov

N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation

Abstract: Empirical relations have been developed for estimating the TNT-equivalent (TE) of an underwater explosion in terms of the gas bubble energy and the shock wave energy. The calculation method is based on the use of calorimetric values of the heat of explosion. The equations were obtained by statistical processing of the data array including the TE values both for the explosive materials that do not contain Al and for the aluminized explosive compositions. The test results demonstrated a satisfactory agreement between the calculated and experimental data. The TE evaluations were conducted for a number of mixtures of explosives with powdered Al. The maximum gain of TE was obtained for the compositions based on the explosives with a positive oxygen balance. Calculations have shown the absence of advantages in TE for the compositions with nanosized Al over the mixtures with microsized Al.

Keywords: TNT-equivalent; explosive material; heat of explosion; aluminum; nanocomposite

DOI: 10.30826/CE22150411 **EDN:** RIJTXQ

Figure Captions

Figure 1 Experimental (symbols) and calculated (lines) values of TNT-equivalent for the composition RDX/Al depending on the Al concentration; dashed line and triangles — TNT-equivalent in terms of the gas bubble energy, solid lines and circles — TNT-equivalent in terms of the shock wave energy

Figure 2 Convergence of the calculated and experimental values of TNT-equivalent in terms of the gas bubble energy (*a*) and shock wave energy (*b*); triangles — Al-free explosive materials, circles — aluminized explosive materials, straight lines — function: $y = x$

Figure 3 TNT-equivalent in terms of the gas bubble energy (*1*) and shock wave energy (*2*) for the composition RDX/Al depending on the Al concentration; solid lines — Al(15), dashed lines — Al(7), dash-dotted lines — Al(0,1), dotted lines — nanocomposite with Al(0,1)

Figure 4 TNT-equivalent in terms of the gas bubble energy (dashed lines) and shock wave energy (solid lines) depending on the Al concentration of compositions with explosives: *1* — BTNEN; *2* — CL-20; *3* — HMX; and *4* — TNT

Acknowledgments

The work was carried out within the framework of the State task “1.5 Fundamental research of energy-saturated materials and electrochemical systems in order to increase the efficiency and safety of their use.”

References

1. Makhov, M. N. 2020. Determination of the heat of an explosion of aluminized blasting compounds. *Russ. J. Phys. Chem. B* 14(5):821–828. doi: 10.1134/S1990793120050085.
2. Makhov, M. N., and V. I. Arkhipov. 1989. Velocity of shell dispersion. *Combust. Explo. Shock Waves* 25(3):87–89.
3. Makhov, M. N. 2002. The effect of charge density on the explosion heat of high explosives. *33rd Annual Conference (International) of ICT Proceedings*. Karlsruhe. Paper 73. 13 p.
4. Makhov, M. N. 2005. Metod otsenki teploty vzryva alyuminizirovannykh VV [Method for evaluating the heat of explosion of aluminized HE]. *Conference (International) “7th Kharitonov Topical Scientific Readings” Proceedings*. Sarov: RFNC–VNIIF. 53–58.
5. Cole, R. H. 1980. *Underwater explosions*. Ann Arbor, MI: University Microfilms International. 437 p.
6. Bjarnholt, G., and R. Holmberg. 1976. Explosive expansion work in underwater detonations. *6th Symposium (International) on Detonation Proceedings*. Coronado, CA. 540–550.
7. Bjarnholt, G. 1980. Suggestions on standards for measurement and data evaluation in the underwater explosion test. *Propell. Explos. Pyrot.* 5:67–74. doi: 10.1002/prep.19800050213.
8. Xiang, D., J. Rong, X. He, and Zh. Feng. 2017. Underwater explosion performance of RDX/AP-based aluminized explosives. *Cent. Eur. J. Energ. Mat.* 14(1):60–76. doi: 10.22211/cejem/68443.
9. Xiang, D.-L., J.-L. Rong, and J. Li. 2014. Effect of Al/O ratio on the detonation performance and underwater ex-

plosion of HMX-based aluminized explosives. *Propell. Explos. Pyrot.* 39:65–73. doi: 10.1002/prep.201300026.

10. Swisdak, M. M. 1978. *Explosion effects and properties. Part II. Explosion effects in water*. Silver Spring, MD: Naval Surface Weapons Center. 109 p.
11. Roth, J. 1983. *Underwater explosives in Encyclopedia of Explosives and Related Items*. Dover, NJ: U.S. Army Research and Development Command. 9:U38–U81.
12. Strømsøe, E., and S. W. Ericsen. 1990. Performance of high explosives in underwater applications. Part 1: CHNO explosives. *Propell. Explos. Pyrot.* 15(2):48–51.
13. Strømsøe, E., and S. W. Ericsen. 1990. Performance of high explosives in underwater applications. Part 2: Aluminized explosives. *Propell. Explos. Pyrot.* 15(2):52–53.
14. Komissarov, P. V., A. A. Borisov, G. N. Sokolov, and V. V. Lavrov. 2016. Energeticheskie kharakteristiki podvodnogo vzryva neideal'nykh sostavov s vysokim soderzhaniem alyuminiya: sravnenie s rasprostranennymi vzryvchatymi veshchestvami [Energy characteristics of underwater explosion of nonideal aluminum-rich eplosive mixtures: Comparison with conventional high explosives]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 9(4):148–154.
15. Komissarov, P. V., A. A. Borisov, S. S. Basakina, and V. V. Lavrov. 2019. Enhancement of underwater blast wave directed from of a metallized explosive to a bubble channel in continuous water. *Russ. J. Phys. Chem. B* 13(4):585–595. doi: 10.1134/S1990793119040195.
16. Langer, G., T. Keicher, W. Ehrhardt, A. Happ., A. Keßler, and A. Kretschmer. 2003. The influence of particle size of AP and Al on the performance of underwater explosives. *34th Annual Conference (International) of ICT Proceedings*. Karlsruhe. Paper 12. 16 p.
17. Junting, Y., Y. Baohui., Z. Tao, L. Gang, and R. Xinlian. 2017. The effect of nano-aluminum powder on the characteristic of RDX based aluminized explosives underwater close-filed explosion. *MATEC Web Conf.* 95:03009. doi: 10.1051/matecconf/20179503009.
18. Gogulya, M. F., M. N. Makhov, M. A. Brazhnikov, A. Yu. Dolgoborodov, V. I. Arkhipov, A. N. Zhigatch, I. O. Leipunskii, and M. L. Kuskov. 2008. Explosive characteristics of aluminized HMX-based nanocomposites. *Combust. Explo. Shock Waves* 44(2):198–212.

Received September 5, 2022

Contributor

Makhov Michael N. (b. 1946) — Candidate of Science in chemistry, leading research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; mmn13makhov@yandex.ru