# DETONATION OF FUEL-RICH MIXTURES OF GASEOUS INDUSTRIAL HYDROCARBONS WITH OXYGEN

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**Abstract:** The technology of producing hydrogen and, at the same time, nanoscale detonation carbon (NDC) based on the detonation decomposition of gaseous hydrocarbons is considered. Studies of the detonation process of methane ($CH_4$), mixture of methane with acetylene ($0.85CH_4 + 0.15C_2H_2$), acetylene ($C_2H_2$), ethylene ($C_2H_4$), ethane ($C_2H_6$), propylene ($C_3H_6$), propane ($C_3H_8$), and butane ($C_4H_{10}$) in the presence of the minimum possible oxygen additives up to the upper detonation limit determined by spin have been carried out on a pulsed gas detonation device (PGDD). Detonation decomposition was performed at the initial atmospheric pressure of fuel–oxygen mixtures. For the listed hydrocarbons, data on the productivity of PGDD for hydrogen and NDC were obtained.

**Keywords:** gaseous industrial hydrocarbons; pulsed gas detonation device; detonation decomposition; hydrogen; nanoscale detonation carbon

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## Figure Captions

**Figure 1** Schematic of PGDD: *1* — gas supply system; *2* — spark plug; *3* — mixing–ignition chamber with a booster charge; *4* — barrel; *5* — trigger sensor for starting measurements; *6* — first pair of sensors; *7* — second pair of sensors; *8* — oscilloscope; and *9* — detonation products

**Figure 2** Trace print on a smoked foil: single-headed spin in acetylene–oxygen mixture $C_2H_2 + 0.07O_2$

**Figure 3** Dependence of the detonation velocity in fuel-rich fuel–oxygen mixtures on the fuel content up to the upper detonation limit for a tube with a diameter of 26 mm: *1* — ethane; *2* — butane; *3* — propane; *4* — propylene; *5* — ethylene; *6* — methane; *7* — acetylene; curves — calculations according to [23]; and signs — experimental data

## Table Captions

**Table 1** Parameters of fuel–oxygen mixtures corresponding to the upper concentration limit of detonation: $k_0 = [O]/[C]$ — the ratio of the atomic content of oxygen and carbon in the mixture; $V_b$ — the volume of the booster charge; $D_e$ — measured detonation velocity; and $D_c$ — detonation velocity calculated according to [23]

**Table 2** The PGDD performance for hydrogen, NDC, and carbon monoxide

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## References

1. Hamburg, D. Yu., V. P. Semenov, N. F. Dubovkin, and L. N. Smirnova. 1989. *Vodorod. Svoistva, poluchenie, khranenie, transportirovanie, primenenie* [Hydrogen. Properties, production, storage, transportation, and application]. Eds. D. Yu. Hamburg and N. F. Dubovkin. Moscow: Khimiya. 672 p.
2. Statista (a global data and business intelligence platform): Hydrogen production worldwide in 2018 and 2030. Available at: https://www.statista.com/statistics/1121207/global-hydrogen-production/ (accessed February 22, 2024).
3. IEA (International Energy Agency). Hydrogen. Available at: https://www.iea.org/energy-system/low-emission-fuels/hydrogen (accessed February 22, 2024).
4. Sazali, N. 2020. Emerging technologies by hydrogen: A review. *Int. J. Hydrogen Energ.* 45:18753–18771. doi: 10.1016/j.ijhydene.2020.05.021.
5. Bal, B., B. Cetin, F. C. Bayram, and E. Billur. 2020. Effect of hydrogen on fracture locus of Fe–16Mn–0.6C–2.1Al TWIP steel. *Int. J. Hydrogen Energ.* 45:34227–34240. doi:

10.1016/j.ijhydene.2020.09.083.

6. Yang, F., T. Wang, X. Deng, J. Dang, Z. Huang, S. Hu, Y. Li, and M. Ouyang. 2021. Review on hydrogen safety issues: Incident statistics, hydrogen diffusion, and detonation process. *Int. J. Hydrogen Energ.* 46:31467–31488. doi: 10.1016/j.ijhydene.2021.07.005.
7. Kistiakovsky, G. B., G. D. Halsey, M. E. Malin, and H. T. Knight. 1954. Detonation process of making carbon black. U.S. Patent No. 2690960.
8. Knorre, V. G., T. D. Snegireva, T. V. Tekunova, and A. V. Chulkov. 1972. A study of the thermal decomposition of acetylene and the properties of the soot formed under the conditions of a constant volume bomb. *Combust. Explo. Shock Waves* 8(4):437–439. doi: 10.1007/BF00741200.
9. Knorre, V. G., M. S. Kopylov, and P. A. Tesner. 1974. Formation of carbon black with the detonation of acetylene. *Combust. Explo. Shock Waves* 10(5):690–694. doi: 10.1007/BF01463987.
10. Knorre, V. G., V. E. Nizovtsev, E. A. Prjadkina, and V. N. Sidorov. 2008. Sposob polucheniya tekhnicheskogo ugleroda [Method of industrial carbon production]. Patent RF No. 2325413.
11. Ivanov, B. A. 1969. *Fizika vzryva atsetilena* [Physics of acetylene explosion]. Moscow: Khimiya. 180 p.
12. Manzhalei, V. I. 1975. Detonation of acetylene near the limit. *Combust. Explo. Shock Waves* 11(1):128–130. doi: 10.1007/BF00742874.
13. Sorensen, C., A. Nepal, and G. P. Singh. 2016. Process for high-yield production of graphene via detonation of carbon-containing material. U.S. Patent No. 9440857.
14. Batraev, I. S., A. A. Vasilev, A. V. Pinaev, V. Yu. Ulianitsky, A. A. Shtertser, V. A. Likholobov, A. G. Shaytanov, Y. V. Surovikin, and D. K. Rybin. 2018. Sposob polucheniya nanougleroda [Method for obtaining nanocarbon]. Patent RF No. 2641829.
15. Shtertser, A. A., V. Yu. Ulianitsky, I. S. Batraev, and D. K. Rybin. 2018. Production of nanoscale detonation carbon using a pulse gas-detonation device. *Tech. Phys. Lett.* 44(5):395–397. doi: 10.1134/S1063785018050139.
16. Shtertser, A. A., D. K. Rybin, V. Yu. Ulianitsky, W. Park, M. Datekyu, T. Wada, and H. Kato. 2020. Characterization of nanoscale detonation carbon produced in a pulse gas-detonation device. *Diam. Relat. Mater.* 101:107553. doi: 10.1016/j.diamond.2019.107553.
17. Shtertser, A. A., V. Yu. Ulianitsky, D. K. Rybin, I. S. Batraev, E. S. Prokhorov, and M. S. Vlaskin. 2022. Production of hydrogen and carbon black by detonation of fuel-rich acetylene–oxygen mixtures. *Int. J. Hydrogen Energ.* 47(30):14039–14043. doi: 10.1016/j.ijhydene.2022.02.164.
18. Shtertser, A. A., V. Yu. Ulianitsky, D. K. Rybin, I. S. Batraev, and D. V. Dudina. 2024. Detonation decomposition of hydrocarbons to produce hydrogen. *Int. J. Hydrogen Energ.* 55:118–123. doi: 10.1016/j.ijhydene.2023.11.125.
19. Frolov, S. M., V. A. Smetanyuk, I. A. Sadykov, A. S. Silantiev, V. S. Aksenov, I. O. Shamshin, K. A. Avdeev, and F. S. Frolov. 2022. Avtotermicheskaya konversiya prirodnogo gaza i allotermicheskaya gazifikatsiya zhidkikh i tverdykh organicheskikh otkhodov ultraperegretym vodyanym parom [Autothermal natural gas conversion and allothermal gasification of liquid and solid organic wastes by ultrasuperheated steam]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 15(2): 75-87. doi: 10.30826/CE22150207.
20. Frolov, S. M., V. A. Smetanyuk, I. A. Sadykov, A. S. Silantiev, I. O. Shamshin, V. S. Aksenov, K. A. Avdeev, and F. S. Frolov. 2022. Vliyanie ob”ema reaktora na avtotermicheskuyu konversiyu prirodnogo gaza i allotermicheskuyu gazifikatsiyu organicheskikh otkhodov ultraperegretym parom [Effect of reactor volume on autothermal natural gas conversion and allothermal gasification of organic waste by ultrasuperheated steam]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 15(3):71–87. doi: 10.30826/CE22150308.
21. Ulianitsky, V. Yu. 2013. CCDS2000 — oborudovanie novogo pokoleniya dlya detonatsyonnogo napyleniya [CCDS2000 — new-generation installation for detonation spraying]. *Uprochnyayushchie tekhnologii i pokrytiya* [Strengthening Technologies and Coatings] 10:36–41.
22. Shtertser, A. A., V. Yu. Ulianitsky, D. K. Rybin, and I. S. Batraev. 2022. Detonation decomposition of acetylene at atmospheric pressure in the presence of small additives of oxygen. *Combust. Explo. Shock Waves* 58:709–718. doi: 10.1134/S0010508222060089.
23. Kal’kulyatory termodinamicheskykh protsessov i prostykh gazodinamicheskikh techeniy [Calculators of thermodynamic processes and simple gas-dynamic flows]. Available at: http://ancient.hydro.nsc.ru/chem/ (accessed February 22, 2024).
24. Pruuel, E. R., and A. A. Vasil’ev. 2021. Equation of state of gas detonation products. Allowance for the formation of the condensed phase of carbon. *Combust. Explo. Shock Waves* 57:576–587. doi: 10.1134/S0010508221050075.
25. Baum, F. A., L. P. Orlenko, K. P. Stanyukovich, V. P. Chelyshev, and B. I. Shekhter. 1975. *Fizika vzryva* [Physics of explosion]. Ed. K. P. Stanyukovich. Moscow: Nauka. 704 p.
26. Batraev, I. S., A. A. Vasil’ev, V. Yu. Ul’yanitskii, A. A. Shtertser, and D. K. Rybin. 2018. Investigation of gas detonation in over-rich mixtures of hydrocarbons with oxygen. *Combust. Explo. Shock Waves* 54(2):207–215. doi: 10.1134/S0010508218020107.
27. Chapman–Jouguet detonation problem. Available at: https://cearun.grc.nasa.gov (accessed February 22, 2024).
28. Duff, R. E., H. T. Knight, and H. R. Wright. 1954. Some detonation properties of acetylene gas. *J. Chem. Phys.* 22(9):1618–1619. doi: 10.1063/1.1740482.

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