THE INFLUENCE OF HYDROGEN ON THE BURNING VELOCITY OF METHANE–AIR MIXTURES AT ELEVATED TEMPERATURES

A. V. Arutyunov[1,2], A. A. Belyaev[1], I. N. Inovenkov[2], and V. S. Arutyunov[1,2]

[1]N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation
[2]M. V. Lomonosov Moscow State University, Leninskie Gory, Moscow 119991, GSP-1, Russian Federation

Abstract: The laminar burning velocity of stoichiometric methane–hydrogen–air mixtures was determined in the initial temperature range of 300–600 K by kinetic modeling. It was shown that the modern kinetic models adequately describe such flames. At low concentrations of hydrogen (< 50%) satisfactory description can be obtained by using a simple overall mechanism. The presence of hydrogen has a little effect on the burning velocity in the investigated temperature range at hydrogen concentrations less than 50%. As the initial temperature increases, the effect of hydrogen on the burning velocity manifests itself at lower concentrations of hydrogen.

Keywords: methane; hydrogen; laminar burning velocity

DOI: 10.30826/CE19120401

Acknowledgments

The reported study was funded by the Russian Foundation for Basic Research, project No. 19-31-90022\19.

References

1. Arutyunov, V. S., A. A. Belyaev, K. Ya. Troshin, A. V. Arutyunov, A. A. Tsarenko, and A. A. Nikitin. 2019. Ob ispol'zovanii metan-vodorodnykh smesey v DVS [About using metane-hydrogen mixtures in ICE]. *Oil Gas Chemistry* 3.
2. Troshin, K. Ya., A. A. Borisov, A. N. Rakhmetov, V. S. Arutyunov, and G. G. Politenkova. 2013. Burning velocity of methane–hydrogen mixtures at elevated pressures and temperatures. *Russ. J. Phys. Chem. B* 7(3):290–301.
3. Sholte, T. G., and P. B. Vaags. 1959. Burning velocities of mixtures of hydrogen, carbon monoxide and methane with air. *Combust. Flame* 3:511–524.
4. Milton, B. E., and J. C. Keck. 1984. Laminar burning velocities in stoichiometric hydrogen and hydrogen–hydrocarbon gas mixtures. *Combust. Flame* 58:13–22.
5. Yu, G., C. K. Law, and C. K. Wu. 1986. Laminar flame speeds of hydrocarbon + air mixtures with hydrogen addition. *Combust. Flame* 63(3):339–347.
6. Halter, F., C. Chauveau, N. Djebaili-Chaumeix, and I. Gokalp. 2005. Characterization of the effects of pressure and hydrogen concentration on laminar burning velocities of methane–hydrogen–air mixtures. *P. Combust. Inst.* 30:201–208.
7. Hermanns, R. T. E. 2007. Laminar burning velocities of methane–hydrogen–air mixtures. *Proefschrift*. Technische Universiteit Eindhoken, 2007. Available at: http://alexandria.tue.nl/extra2/200711972.pdf (accessed November 25, 2019).
8. Burluka, A. A., M. Fairweather, M. P. Ormsby, C. G. W. Sheppard, and R. Woolley. 2007. The laminar burning properties of premixed methane–hydrogen flames determined using a novel analysis method. *3rd European Combustion Meeting*.
9. Hu, E., Z. Huang, J. He, Ch. Jin, and J. Zheng. 2009. Experimental and numerical study of laminar burning characteristics of premixed methane- hydrogen-air flames. *Int. J. Hydrogen Energ.* 34:4876–4888.
10. Dirrenberger, P., H. Le Gall, R. Bounaceur, O. Herbinet, P.-A. Glaude, A. Konnov, and F. Battin-Leclerc. 2011. Measurements of laminar flame velocity for components of natural gas. *Energ. Fuel.* 25(9):3875–3884.
11. Goswami, M., S. Derks., K. Coumans, M. H. de Anderade Olivera, A. A. Konnov, R. J. M. Bastiaans, C. C. M. Luijten, and P. H. de Goey. 2011. Effect of elevated pressures on laminar burning velocity of methane + air mixtures. *23rd ICDERS*. Irvine, CA.
12. Moccia, V., and J. D'Alessio. 2013. Burning behaviour of high-pressure CH_4–H_2–air mixtures. *Energies* 6:97–116.
13. Gockeler, K., E. Albin, O. Kruger, and C. O. Paschereit. 2013. Burning velocities of hydrogen–methane–air mixtures at highly steam-diluted conditions. *4th Conference (International) on Jets, Wakes and Separated Flows*. Nagoya, Japan.
14. Donohoe, N., A. Heufer, W. K. Metcalfe, H. J. Curran, M. L. Davis, O. Mathieu, D. Plichta, A. Morones, E. L. Petersen, and F. Guthe. 2014. Ignition delay times, laminar flame speeds, and mechanism validation for natural gas/hydrogen blends at elevated pressures. *Combust. Flame* 161:1432–1443.
15. Okafor, E. C., A. Hayakawa, Yu. Nagano, and T. Kitagawa. 2014. Effects of hydrogen concentration on premixed laminar flames of hydrogen–methane–air. *Int. J. Hydrogen Energ.* 39:2409–2417.

16. Healy, D., D. M. Kalitan, C. J. Aul., E. L. Petersen, G. Bourque, and H. J. Curran. 2010. Oxidation of C_1–C_5 alkane quinternary natural gas mixtures at high pressures. *Energ. Fuel.* 24(3):1521–1528.
17. Combustion Chemistry Center at NUI Galway: Database Mechanism of Natural Gas (including C_5) Oxidation. Available at: http://c3.nuigalway.ie/media/researchcentres/combustionchemistrycentre/files/mechanismdownloads/nc5_49_mech.dat (accessed November 25, 2019).
18. Nikitin, A. V., K. Ya. Troshin, A. A. Belyaev, A. V. Arutyunov, A. A. Kiryushin, and V. S. Arutyunov. 2018. Gazomotornoe toplivo iz poputnogo neftyanogo gaza. Selektivnyy oksikreking tyazhelykh komponentov PNG [Gas motor fuel from associated petroleum gas. Selective oxycracing of heavier components of APG]. *Oil Gas Chemistry* 3:22–34.
19. Kee, R. J., F. M. Rupley, E. Meeks, and J. A. Miller. 1996. CHEMKIN III. Livermore, CA: Sandia National Laboratories. Technical Report No. SAND96-8216.
20. Basevich, V. Ya., A. A. Belyaev, and S. M. Frolov. 1998. "Global" kinetic mechanisms for calculating turbulent reactive flows. I. The basic chemical heat release process. *Chem. Phys. Rep.* 17(9):1747–1772.
21. Basevich, V. Ya., A. A. Belyaev, and S. M. Frolov. 1998. "Global" kinetic mechanisms for calculating turbulent reactive flows. II. Formation of nitrogen oxide. *Chem. Phys. Rep.* 17(10):1895–1908.
22. Kozachenko, L. S. 1954. Issledovanie zavisimosti skorosti rasprostraneniya plameni ot fiziko-khimicheskikh svoystv topliva i aerodinamiki techeniya gaza [Investigation of the dependence of the flame propagation velocity on physicochemical properties of fuel and aerodynamics of gas flow]. Moscow: IChPh of the USSR Academy of Sciences. DSc. Diss.
23. Lewis, B., and G. von Elbe. 1961. *Combustion, flames and explosions of gases*. New York, NY: Academic Press. 731 p.
24. Iijima, T., and T. Takeno. 1986. Effects of temperature and pressure on burning velocity. *Combust. Flame* 65(1):35–43.
25. Shebeko, Yu. N., S. G. Tsarichenko, A. Ya. Korolchenko, A. V. Trunev, V. Yu. Navzenya, and S. N. Parkov. 1995. Burning velocities and flammability limits of gaseous mixtures at elevated temperatures and pressures. *Combust. Flame* 102(4):427–437.
26. Zabetakis, M. G. 1965. Flammability characteristics of combustible gases and vapors. Washington, D.C.: U.S. Bureau of Mines. No. 627.
27. Gu, X. J., M. Z. Haq, M. Lawes, and R. Woolley. 2000. Laminar burning velocity and Markstein lengths of methane–air mixtures. *Combust. Flame* 121(1-2):41–58.
28. Heimel, S. 1957. Effect of initial mixture temperature on burning velocity of hydrogen–air mixtures with preheating and simulated preburning. NACA TN 4156.

Received October 8, 2019

Contributors

Arutyunov Artem V. (b. 1994) — post-graduate student, Faculty of Computational Mathematics and Cybernetics, M. V. Lomonosov Moscow State University, Leninskie Gory, Moscow 119991, GSP-1, Russian Federation; research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; aarutyunovv@gmail.com

Belyaev Andrey A. (b. 1954) — Candidate of Science in physics and mathematics, 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; belyaevIHF@yandex.ru

Inovenkov Igor N. (b. 1949) — Candidate of Science in physics and mathematics, professor, Faculty of Computational Mathematics and Cybernetics, M. V. Lomonosov Moscow State University, Leninskie Gory, Moscow 119991, GSP-1, Russian Federation; inov@cs.msu.su

Arutyunov Vladimir S. (b. 1946) — Doctor of Science in chemistry, professor, chief research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; chief research scientist, Institute of Problems of Chemical Physics, 1 Acad. N. N. Semenov Prosp., Chernogolovka 142432, Russian Federation; professor, I. M. Gubkin Russian State Oil and Gas University, 65 Leninsky Prosp., Moscow 119991, Russian Federation; professor, Faculty of Fundamental Physical and Chemical Engineering, M. V. Lomonosov Moscow State University, Leninskie Gory, Moscow 119991, GSP-1, Russian Federation arutyunov@chph.ras.ru