COMBUSTION OF THE FUEL–AIR MIXTURE IN THE CAVITY UNDER THE BOAT BOTTOM: EXPERIMENT AND SIMULATION

S. M. Frolov[1,2,3,4,5], S. V. Platonov[6], K. A. Avdeev[1], V. S. Aksenov[1,2], V. S. Ivanov[1,3], A. E. Zangiev[1], I. A. Sadykov[1], R. R. Tukhvatullina[1], F. S. Frolov[1,3], and I. O. Shamshin[1,3]

[1]N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation
[2]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), 31 Kashirskoe Sh., Moscow 115409, Russian Federation
[3]Scientific Research Institute for System Analysis, Russian Academy of Sciences, 36-1 Nakhimovskii Prosp., Moscow 117218, Russian Federation
[4]National University of Science and Technology MISIS, 4 Leninskii Prosp., Moscow 119049, Russian Federation
[5]A. G. Merzhanov Institute of Structural Macrokinetics and Material Science, Russian Academy of Sciences, 8 Academician Osipyan Str., Chernogolovka, Moscow Region 142432, Russian Federation
[6]"Almaz" Central Marine Design Bureau, 50 Warshavskaya Str., St. Petersburg 196128, Russian Federation

Abstract: Experimental studies of pulsed combustion of propane–air mixture in a model cavity under a boat bottom (without boat contours), immersed in a pool with quiescent water, are carried out. In the experiments, air and fuel consumption, flame propagation, as well as buoyancy and propulsive forces acting on the model cavity are recorded. The experimental results are compared with the results of three-dimensional calculations based on the physical and mathematical model of combustion of a premixed fuel–air mixture in a semiclosed volume above a free surface of water, developed earlier: by the shape and position of the flame front and the gas–water interface at different times and in dynamics of the forces acting on the cavity. Satisfactory qualitative and quantitative agreement is obtained between the results of calculations and measurements.

Keywords: boat with a gas cavity; fuel–air mixture; pulsed combustion in the cavity; experiment; mathematical model; flame propagation; propulsive force; buoyancy force

DOI: 10.30826/CE19120408

Acknowledgments

The work was supported by the subsidy given to the N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences to implement the state assignment on the topic No. 0082-2016-0011 "Fundamental studies of conversion processes of energetic materials and development of scientific grounds of controlling these processes" (Registration No. AAAA-A17-117040610346-5) and to the Scientific Research Institute for System Analysis to implement the state assignment on the topic No. 0065-2019-0005 "Mathematical modeling of dynamic processes in deformed and reactive media using multiprocessor computational systems" (Registration No. AAAA-A19-119011590092-6). The work was also supported by the Russian Foundation for Basic Research (project 16-29-01065ofi-m).

References

1. Frolov, S. M., S. V. Platonov, K. A. Avdeev, V. S. Aksenov, V. S. Ivanov, A. E. Zangiev, A. S. Koval', and F. S. Frolov. 2016. Gorenie toplivno-vozdushnoy smesi v gazovoy kaverne pod dnishchem skorostnogo sudna [Combustion of fuel–air mixture in gas cavity under the bottom of the high-speed vessel]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 9(4):12–21.
2. Frolov, S. M., and S. V. Platonov. 11.05.2018. Sposob snizheniya gidrodinamicheskogo soprotivleniya dvizheniyu sudna [Method of hydrodynamic vessel movement resistance reduction and the device for its implementation]. Patent of Russian Federation RU 2653664. Priority 01.06.2017.
3. Frolov, S. M., S. V. Platonov, K. A. Avdeev, V. S. Aksenov, A. E. Zangiev, I. A. Sadykov, and I. O. Shamshin. 2018. Chislennoe i experimental'noe issledovanie pod"emnoy sily, sozdavaemoy iskusstvennoy gazovoy kavernoy pod dnishchem katera [Numerical and experimental investigation of the lift force created by an artificial gas cavity under the bottom of the boat]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 11(3):60–73. doi: 10.30826/CE18110308.
4. Frolov, S. M., S. V. Platonov, K. A. Avdeev, V. S. Aksenov, V. S. Ivanov, I. A. Sadykov, R. R. Tukhvatulli-

na, F. S. Frolov, and I. O. Shamshin. 2019. Gorenie toplivno-vozdushnoy smesi v ob"eme nad svobodnoy poverkhnost'yu vody [Combustion of the fuel–air mixture in the volume over the free water surface]. *Goren. Vzryv (Mosk.) — Combustion and Explosion* 12(3):58–68. doi: 10.30826/CE19120307.

5. Frolov, S. M., S. V. Platonov, K. A. Avdeev, V. S. Aksenov, V. S. Ivanov, I. A. Sadykov, R. R. Tukhvatullina, F. S. Frolov, and I. O. Shamshin. 2019. Trekhmernoe modelirovanie goreniya toplivno-vozdushnoy smesi nad svobodnoy poverkhnost'yu vody [Three-dimensional simulation of combustion of fuel–air mixture over the free water surface]. *6th Minsk Colloquium (International) on Physics of Shock Waves, Combustion and Detonation Proceedings*. Minsk: A. V. Lyikov Institute of Heat and Mass Transfer, NAS of Belarus. 193–199.
6. Frolov, S. M., V. S. Ivanov, B. Basara, and M. Suffa. 2013. Numerical simulation of flame propagation and localized preflame autoignition in enclosures. *J. Loss Prevent. Proc.* 26:302–309. doi: 10.1016/j.jlp.2011.09.007.
7. Frolov, S. M., K. A. Avdeev, V. S. Aksenov, A. A. Borisov, F. S. Frolov, I. O. Shamshin, R. R. Tukhvatullina, B. Basara, W. Edelbauer, and K. Pachler. 2017. Experimental and computational studies of shock wave-to-bubbly water momentum transfer. *Int. J. Multiphas. Flow* 92:20–38. doi: 10.1016/j.ijmultiphaseflow.2017.01.016.
8. Patankar, S. V., and D. B. Spalding. 1972. A calculation procedure for heat, mass and momentum transfer in three-dimensional parabolic flows. *Int. J. Heat Mass Tran.* 15(1):1510–1520.
9. Barth, T. J. 1992. Aspects of unstructured grids and finite-volume solvers for the Euler and Navier–Stokes equations. *Special course on unstructured grid methods for advection dominated flows*. AGARD. 61 p.
10. Voinov, A. N. 1957. Issledovanie detonatsii i samovosplameneniya v usloviyakh dvigateley legkogo topliva [Investigation of detonation and self-ignition under conditions of engines operating on light fuels]. Moscow: Inst. Chem. Phys. USSR Acad. Sci. DSc Thesis.

Received November 5, 2019

Contributors

Frolov Sergey M. (b. 1959) — Doctor of Science in physics and mathematics, head of department, head of laboratory, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; professor, National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), 31 Kashirskoe Sh., Moscow 115409, Russian Federation; senior research scientist, Scientific Research Institute for System Analysis, Russian Academy of Sciences, 36-1 Nakhimovskii Prosp., Moscow 117218, Russian Federation; professor, National University of Science and Technology MISIS, 4 Leninskii Prosp., Moscow 119049, Russian Federation; head of laboratory, A. G. Merzhanov Institute of Structural Macrokinetics and Material Science, Russian Academy of Sciences, 8 Academician Osipyan Str., Chernogolovka, Moscow Region 142432, Russian Federation; smfrol@chph.ras.ru

Platonov Sergey V. (b. 1971) — Candidate of Science in technology, chief designer, "Almaz" Central Marine Design Bureau, 50 Warshavskaya Str., St. Petersburg 196128, Russian Federation; platsv@yandex.ru

Avdeev Konstantin A. (b. 1971) — Candidate of Science in technology, 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; kaavdeev@mail.ru

Aksenov Victor S. (b. 1952) — Candidate of Science in physics and mathematics, senior research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; associate professor, National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), 31 Kashirskoe Sh., Moscow 115409, Russian Federation; v.aksenov@mail.ru

Ivanov Vladislav S. (b. 1986) — Doctor of Science in physics and mathematics, senior research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; research scientist, Scientific Research Institute for System Analysis, Russian Academy of Sciences, 36-1 Nakhimovskii Prosp., Moscow 117218, Russian Federation; ivanov.vls@gmail.com

Zangiev Alan E. (b. 1986) — junior research scientist, N. N. Semenov Institute of Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; sydra777@gmail.com

Sadykov Ilyas A. (b. 1993) — junior research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; churus1314@rambler.ru

Tukhvatullina Ruzana R. (b. 1988) — Candidate of Science in physics and mathematics, research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; tukhvatullinarr@gmail.com

Frolov Fedor S. (b. 1981) — Candidate of Science in physics and mathematics, senior research scientist,

N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; research scientist, Scientific Research Institute for System Studies, Russian Academy of Sciences, 36-1 Nakhimovskii Prosp., Moscow 117218, Russian Federation; f.frolov@chph.ru

Shamshin Igor O. (b. 1975) — Candidate of Science in physics and mathematics, senior research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; research scientist, Scientific Research Institute for System Analysis, Russian Academy of Sciences, 36-1 Nakhimovskii Prosp., Moscow 117218, Russian Federation; igor_shamshin@mail.ru