INFLUENCE OF POROUS COPPER ON THE DYNAMICS OF THE FLAME FRONT IN ACETYLENE–AIR MIXTURES

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Abstract: The influence of porous copper on the dynamics of a flame front in premixed acetylene–air mixtures was studied experimentally in open and semiopen channels with sudden expansion. The mixture was ignited by a spark discharge in a narrow channel. Porous copper was installed in the channel with an expansion and with a transverse dimension of 20 × 40 mm. The average linear pore size was 3.5 mm and the copper foam length varied from 10 to 90 mm. The velocity of the flame front in the free segment of the measuring section was determined using a high-speed camera together with a shadow device. The propagation of the flame front inside the porous copper was recorded using an infrared camera. The contribution of the porous copper to the acceleration of the flame front due to turbulence was determined. It was shown that the ratio of the flame front velocity across the porous sample is linear depending on the length of the foam. The results obtained can be used both to increase the efficiency of combustion in gases and to ensure the explosion safety of the designed gas equipment.

Keywords: porous cooper; flame front; quenching; turbulization

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Figure Captions

Figure 1 Schematic of the experimental setup. Dimensions are in millimeters, l — foam length

Figure 2 Photograph of porous copper

Figure 3 High speed infrared (*a*) and schlieren (*b*) image sequences of the flame front propagation through the porous copper in acetylene–air mixture with $\phi = 0.6$ (670 fps)

Figure 4 Dependence of the flame front velocity on the position in the measuring section in the acetylene–air mixture with $\phi = 0.8$ in an open (*a*) and in a semiopen (*b*) channels: *1* — empty channel; *2* — $l = 10$ mm; *3* — 30; *4* — 60; and *5* — $l = 90$ mm

Figure 5 Flame front velocity in front of the porous sample (*a*) and after passing through the sample (*b*): *1* — $\phi = 0{,}8$; *2* — 0,7; *3* — 0,6; *4* — 0,8; *5* — 0,5; *6* — $\phi = 0{,}6$; empty signs — open channel; and filled signs — semiopen channel

Figure 6 Velocity ratio u_2/u_1 for acetylene–air mixtures in open (*a*) and semi-open (*b*) channels: *1* — $\phi = 0{,}8$; *2* — 0,7; *3* — 0,6; *4* — 0,8; *5* — 0,5; *6* — $\phi = 0{,}6$; empty signs — empty channel; and filed signs — channel with a porous sample

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References

1. Li, J., J. Huang, M. Yan, D. Zhao, J. Zhao, Z. Wei, and N. Wang. 2014. Experimental study of n-heptane/air combustion in meso-scale burners with porous media. *Exp. Therm. Fluid Sci.* 52:47–58. doi: 10.1016/j.expthermflusci.2013.08.021.
2. Samoilenko, M., P. Seers, P. Terriault, and V. Brailovski. 2019. Design, manufacture and testing of porous materials with ordered and random porosity: Application to porous medium burners. *Appl. Therm. Eng.* 158:113724. doi: 10.1016/j.applthermaleng.2019.113724.
3. Babkin, V., A. Korzhavin, and V. Bunev. 1991. Propagation of premixed gaseous explosion flames in porous media. *Combust. Flame* 87:182–190. doi: 10.1016/0010-2180(91)90168-B.
4. Nie, B., L. Yang, and J. Wang. 2016. Experiments and mechanisms of gas explosion suppression with foam ceramics. *Combust. Sci. Technol.* 188(11-12):2117–2127. doi: 10.1080/00102202.2016.1218161.
5. Wu, J., Z. Li, J. Cai, Y. Zhao, R. Zhou, and L. Pang. 2022. Experimental analysis of suppression effects of crosswise arranged porous iron–nickel materials on the natural gas explosion in utility tunnels. *J. Loss. Prevent. Proc.* 77:104775. doi: 10.1016/j.jlp.2022.104775.
6. Kamal, M. M., and A. A. Mohamad. 2005. Enhanced radiation output from foam burners operating with a nonpremixed flame. *Combust. Flame* 140:233–248. doi:

10.1016/j.combustflame.2004.12.001.

7. Burkina, R. S. 2000. Filtration combustion of a gas in a semiinfinite porous medium. *Combust. Explo. Shock Waves* 36(4):417–427. doi: 10.1007/BF02699471.
8. Bubnovich, V. I., S. A. Zhdanok, and K. V. Dobrego. 2006. Analytical study of the combustion waves propagation under filtration of methane–air mixture in a packed bed. *Int. J. Heat Mass Tran.* 49(15-16):2578–2586. doi: 10.1016/j.ijheatmasstransfer.2006.01.019.
9. Oliveira, A., and M. Kaviany. 2001. Nonequilibrium in the transport of heat and reactants in combustion in porous media. *Prog. Energ. Combust.* 27:523–545. doi: 10.1016/S0360-1285(00)00030-7.
10. Bubnovich, V., and M. Toledo. 2007. Analytical modelling of filtration combustion in inert porous media. *Appl. Therm. Eng.* 27(7):1144–1149. doi: 10.1016/j.applthermaleng.2006.02.037.
11. Kuleshov, F. S., S. V. Golovastov, and G. Yu. Bivol. 2022. Vliyanie poristoy poliuretanovoy peregorodki na gidravlicheskie kharakteristiki potoka i na rasprostranenie fronta plameni v otkrytom kanale [Influence of a porous polyurethane partition on hydraulic characteristics of the flow and on flame front propagation in an open channel]. *Herald Bauman Moscow State Technical University Ser. Natural Sciences* 3(102):110–123. doi: 10.18698/1812-3368-2022-3-110-123.
12. Krittacom, B., and K. Kamiuto. 2009. Radiation emission characteristics of an open-cellular porous burner. *J. Therm. Sci. Tech. — Jpn.* 4(1):13–24. doi: 10.1299/jtst.4.13.
13. Dai, H., X. Wang, X. Chen, X. Nan, Y. Hu, S. He, B. Yuan, Q. Zhao, Zh. Dong, and P. Yang. 2020. Suppression characteristics of double-layer wire mesh on wheat dust flame. *Powder Technol.* 360:231–240. doi: 10.1016/j.powtec.2019.09.077.
14. Cheng, F., J. Lu, T. Li, and Z. Luo. 2022. Study on the influence of obstacle on the flame behaviors of methane/air in a semi-confined pipe with wire mesh installed. *J. Loss Prevent. Proc.* 78:104826. doi: 10.1016/j.jlp.2022.104826.
15. Shao, H., C. Wang, and H. Yu. 2020. Effect of copper foam on explosion suppression at different positions in the pipe. *Powder Technol.* 360:695–703. doi: 10.1016/j.powtec.2019.09.078.
16. Wan, Y., C. Wang, Q. Li, and X. Luo. 2020. Experimental study of premixed hydrogen-air flame quenching in a channel with the perforated plate. *Fuel* 263:116733. doi: 10.1016/j.fuel.2019.116733.
17. Wen, X., Zh. Guo, F. Wang, R. Pan, Zh. Liu, and X. Zhang. 2020. Experimental study on the quenching process of methane/air deflagration flame with porous media. *J. Loss Prevent. Proc.* 65:104121. doi: 10.1016/j.jlp.2020.104121.
18. Duan, Y., S. Wang, Y. Yang, and Y. Li. 2021. Experimental study on explosion of premixed methane–air with different porosity and distance from ignition position. *Combust. Sci. Technol.* 193(12):2070–2084. doi: 10.1080/00102202.2020.1727900.
19. Wang J., G. Liu, L. Zheng, R. Pan, C. Lu, Y. Wang, Z. Fan, and Y. Zhao. 2022. Effect of opening blockage ratio on the characteristics of methane/air explosion suppressed by porous media. *Process Saf. Environ.* 164:129–141. doi: 10.1016/j.psep.2022.06.008.
20. Joo, H. I., K. Duncan, and G. Ciccarelli. 2006. Flame-quenching performance of ceramic foam. *Combust. Sci. Technol.* 178(10-11):1755–1769. doi: 10.1080/00102200600788692.
21. Yu, Y., J. Zhang, J. Wan, and D. Wang. 2022. Flame propagation behavior of propane–air premixed combustion in a confined space with two perforated plates at different initial pressures. *Energy Sci. Eng.* 10:2940–2953. doi: 10.1002/ese3.1180.
22. Jin, K., Q. Wang, Q. Duan, and J. Sun. 2020. Effect of single-layer wire mesh on premixed methane/air flame dynamics in a closed pipe. *Int. J. Hydrogen Energ.* 45(56):32664–32675. doi: 10.1016/j.ijhydene.2020.08.159.
23. Tropin, D., and V. Temerbekov. 2022. Numerical simulation of detonation wave propagation through a rigid permeable barrier. *Int. J. Hydrogen Energ.* 47(87):37106–37124. doi: 10.1016/j.ijhydene.2022.08.256.
24. Bedarev, I. A., and V. M. Temerbekov. 2022. Modeling of attenuation and suppression of cellular detonation in the hydrogen–air mixture by circular obstacles. *Int. J. Hydrogen Energ.* 47(90):38455–38467. doi: 10.1016/j.ijhydene.2022.08.307.
25. Lewis, B., and G. Elbe. 1987. *Combustion, flames and explosions of gases*. Orlando, FL: Academic Press Inc. 738 p.
26. Kumar, R. K., and H. Tamm. 1985. Turbulent combustion of hydrogen in large volumes. *Can. J. Chem. Eng.* 63(4):662–667. doi: 10.1002/cjce.5450630420.
27. Moen, I. O., M. Donato, R. Knystautas, and J. H. Lee. 1980. Flame acceleration due to turbulence produced by obstacles. *Combust. Flame* 39(1):21–32. doi: 10.1016/0010-2180(80)90003-6.
28. Golovastov, S. V., G. Y. Bivol, F. S. Kuleshov, and V. V. Golub. 2022. Influence of polyurethane foam on flame front propagation of hydrogen–air and acetylene–air mixtures in an open channel. *J. Loss. Prevent. Proc.* 77:104786. doi: 10.1016/j.jlp.2022.104786.
29. Dobrego, K. V., and S. A. Zhdanok. 2002. *Physics of filtration combustion of gases*. Minsk: A. V. Luikov Heat and Mass Transfer Institute of NAS of Belarus. 203 p.

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