INVESTIGATION OF MINIMUM LASER IGNITION ENERGIES OF COMBUSTIBLE GAS MIXTURES[1]

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Demonstration of a compact 'laser plug' [1] accelerated research in the field of combustible gases optical ignition to evaluate optimum impact parameters. Laser ignition takes place due to gas optical breakdown followed by plasma and shock wave formation, those lead to deflagration core onset (detonation and autocatalytic reaction are also possible) [2]. Laser breakdown threshold (unlike electric) in gases decreases with pressure increase up to 10s of MPa [3], so smaller ignition energy is needed at higher compression. Minimum ignition energy (MIE) values for electric spark have been calculated and experimentally evaluated long ago, but for laser ignition significantly higher values were found, as explained, due to shorter duration and smaller size of the laser impact region [4].

MIE is known to be strongly dependent on mixture equivalence ratio φ and pressure. For electric spark ignition is has been shown, that MIE dependency on φ has a pronounced minimum that moves towards richer mixture with fuel molecular weight increase. Existing data confirm this tendency for laser ignition also. The feature of electric breakdown ignition is high energy input rate in the discharge channel. For laser ignition, energy input rate depends on gas spectral absorption. So only a percent of incident laser energy may be deposited in laser spark near breakdown threshold. However, at combined laser impact, significant threshold decrease can be reached [5]. It is worth mentioning, that MIE for certain gas mixture contents and pressure is expected to be independent on the way of energy deposition. MIE is strongly dependent on air-to-fuel ratio and pressure, and is virtually independent on laser pulse length, at least in pico- to microsecond range [6]. There is a mess in published data on laser ignition energies, because authors often do not state whether incident or deposited energy is mentioned; experimental conditions features, such as laser focusing [7], gas velocity and temperature [8] are often not described properly.

To resolve these discrepancies, minimum pulse energy (MPE) term is suggested for laser impact, and is a more practical one. Although MPE is easy to measure, its value depends a lot on experimental conditions, which are not always properly documented. So the best way to compare MPE's for different fuel mixtures is to perform experimental series at the same conditions. And this was the aim of our work.

Minimum laser pulse energies for ignition – MPE – have been experimentally evaluated for hydrogen, methane, propane and butane based fuel mixtures of different equivalence ratios (φ~0.5–2) and pressures (*p*~0.5–6 bar) at the impact of 1064 nm, 532 nm, 355 nm, 266 nm, 213 nm radiation of nanosecond (~12 ns) Nd:YAG laser. Experimental setup was similar to described in [9]. Obtained values are compared to MIE and laser breakdown thresholds at the same conditions. MPE, as expected, decreases significantly with pressure increase, same as gas optical breakdown threshold does. Minimum of MPE(φ) dependency drifts towards richer mixture, but at the same time, curve meander broadens making ignition less sensitive to pulse energy in a wider range of equivalence ratios. To evaluate efficiency of laser ignition we suggest to use MPE to breakdown threshold ratio. The obtained results are of great importance for laser ignition systems development.

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[1] This work has been performed using 'Beam-M' research facility and was supported by the Russian Ministry of Education and Science (task No. 13.6918.2017/8.9).