Abstract

By using the laser-induced spark ignition method, the challenges associated with environmental pollutants and the production of clean energy can be possibly addressed. In this regard, the method was applied using two lasers (one with low pulse energy (LPE) of 270 μJ/pulse, and another with high pulse energy (HPE) of 50 mJ/pulse) to investigate the ignition phenomenon of the atomized ethanol-air spray. With the LPE, no display of ignition was observed even though it fulfils the threshold conditions. Therefore, the experiment with LPE raises some questions to our current understanding. This study answers these questions by highlighting some points raised by pioneers in this field. These answers were further supported by providing experimental evidence while applying a HPE. It was observed that the breakdown created by the LPE was unable to ignite ethanol-air spray mixture because the lifetime of the plasma kernel was very small (in microseconds). While performing the study with HPE, it was observed that the breakdown becomes a sufficient condition for ignition only when the lifetime of the kernel lasts for few milliseconds. If the kernel does not continue for milliseconds, then ignition will not occur even after energy deposition, the energy left with plasma kernel is higher than minimum ignition energy (MIE).

To clearly understand the interaction of the breakdown plasma and the fuel spray this study provides some important additional data of laser-induced breakdown (LIB) in ambient air. This additional data led to an enhanced physical understanding of blast wave, third lobe, and plasma kernel. In addition, this understanding aided in answering the questions regarding requirements for initiation of ignition by LPE. To make a useful guideline for designing practical laser ignition system, this study has proposed the favourable conditions for initiating ignition after LIB, which also summarises the overall phenomenon into three chronological stages with their physical time of occurrence. Knowledge of the proposed conditions is not only important for the fundamental understanding of the laser-ignition process, but it can also play a vital role in the selection of lasers, optical windows, and beam delivery system for the design of a practical laser ignition system. A new framework is presented in this study to explain a previously unexplained (generation of third-lobe) and newly observed physical phenomena (generation of fourth-lobe and multiple shock-waves). Additionally, this study also presents the role of the third lobe to help ignition, a new two temperature photoionization equation based on Saha ionization equation, relativistic approach for calculation of shockwave expansion, spray formation process with their effect on spray velocity and spray ignition, and successive laser energy deposition to enhance the lifetime of the plasma kernel.