Measurement of the number density of droplets in an aerosol by laser-induced breakdown method

H. Yashiro*, M. Kakehata
Electronics and Photonics Research Institute (ESPRIT), National Institute of Advanced Industrial Science and Technology (AIST), Japan
* Correspondent author: hidehiko.yashiro@aist.go.jp

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Laser-induced breakdown method is proposed as a diagnostic method to evaluate the absolute number density of droplets in an aerosol ejected from spray nozzles with high temporal resolution (<several ns) and spatial resolution (~100 μm) [Yashiro 2010a]. This method utilizes the large difference of the laser-induced breakdown threshold intensity between liquid droplets and gases [Pinnick 1988]. When a pulse laser is focused on a spot in atmosphere condition below the breakdown threshold of air, the breakdown generation indicates that some droplets or particles exist in the focal spot. The volume, in which laser intensity exceeds the breakdown threshold of droplets, is evaluated by laser focus diameter and Rayleigh length, and intensity ratio between actual laser irradiation and the breakdown threshold of droplets. The number of droplets in this volume is evaluated from the experimentally measured breakdown probability using Poisson distribution formula.

Fuel aerosol is injected several times in each combustion cycle in a diesel engine with very high speed such as sound velocity. The fuel injection parameters as timing, amount, droplets size, density distribution decide the engine performance. We think that this measurement method can be utilized for the measurement of number density of droplets especially for intermittent aerosol because of high temporal and special resolution. In order to confirm this measurement method, three types of experiments have done. First is the measurement of number density experimental for a steady state ejected aerosol by laser-induced breakdown method [Yashiro 2010a]. The experimental result measured by the laser-induced breakdown is reasonably coincident with another measurement result, which depends on the precipitation rate, droplets diameter distribution, and velocity at the measurement point. Second is the application for an intermittent aerosol measurement as a simulation of a diesel engine [Yashiro 2010b]. The temporal density variation is clearly measured and obviously explained by the results of the steady state aerosol measurements, those are the number density of steady state aerosol, aerosol velocity as a function of valve pressure and temporal variation of valve pressure. Spatial distributions of the number density of droplets are also experimentally demonstrated by this method. The total number of droplets decreased as the distance from the nozzle increased due to diffusion of the aerosol along vertical direction. That of droplets also decreased as the distance from the center of the aerosol increased. Last is the comparison of the breakdown threshold intensities of high pressure gases and water droplets [Yashiro 2011]. The breakdown threshold of the gases decreases exponentially as increase of gas pressure. Therefore, the difference of the breakdown thresholds between high pressure air and fuel droplets becomes small. This indicates that high pressure aerosol becomes difficult to measure the number density by laser-induced breakdown method. Moreover, the laser-induced breakdown of fuel droplets generates the explosion, which disturbs the measurement of number density in an engine. Appropriate gas, which has high breakdown threshold intensity, must be selected as a gas to avoid explosion. The breakdown threshold intensities of dust free air, N₂, He and Ar gases are measured as a function of their pressure. The breakdown threshold of air is coincident with that of N₂ gas. And N₂ gas has highest breakdown threshold intensity at 2.0 MPa, which is 7-fold higher than the water droplets. The breakdown threshold intensities of fuel droplets as diesel or alcohol were measured to be lower than those of water droplets [Chylek 1990]. This intensity ratio is enough large to measure the number density by laser-induced breakdown method [Yashiro 2010c].

These three experimental results indicate that the laser-induced breakdown method can be applied to diagnose the fuel aerosol in a diesel engine.

References