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Article

Significant Impact of Flash Boiling Spray on In-Cylinder Soot Formation and Oxidation Process

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ABSTRACT: The use of flash boiling atomization has demonstrated potential in improving engine efficiency and reducing particulate matter (PM) emissions because of its stronger phase change process and consequentially finer droplets during the atomization. However, it is unclear how flash boiling has contributed to achieving such capacities in engine applications. This study utilized an optical engine facility operated with both subcooled and flash boiling sprays, with their combustion processes and emission characteristics recorded. To understand the properties of sprays and soot/soot precursor inside the cylinder, a high-speed external laser was used to illuminate the spray and soot. Then, the spray and soot distribution were evaluated by Mie scattering of the scatters, which is, more specifically, an elastic laser scattering (ELS) method for soot detections. Furthermore, to illustrate the soot motions inside the cylinder, the optical flow method was used to qualitatively capture the velocity of soot filaments under both conditions. It was found that flash boiling atomization achieves a better combustion performance with a higher indicated mean effective pressure (IMEP) and lower PM emissions, which is attributed to the stronger vaporization and faster oxidization of the soot/soot precursor under flash boiling conditions.

1. INTRODUCTION

With the increasingly stringent regulations on thermal efficiency and combustion emissions of internal combustion (IC) engines, the need for further reducing harmful emissions, such as particulate matters (PM), has become a significant but even more challenging technical issue. Direct injection spark ignition (DISI) gasoline engines have been the primary trend for passenger car applications since injecting the fuel directly into the combustion chambers can minimize fuel consumption and improve fuel efficiency.[1] However, the fuel−air mixing process and spray impingement under DISI conditions will cause issues such as hot spots and wall wettings, with consequential pool fires on the cylinder wall, piston wall, and injector tip.[2−4] Many techniques such as split injection/multiple injection schemes and ultrahigh-pressure injection have been adopted to slow the wall wetting phenomena, while the issues are not completely addressed with the current popular techniques.[5]

As an alternative solution to achieve the goal of better combustions, flash boiling atomization can address many issues associated with high-pressure injection, such as longer spray penetrations.[6−9] The realization of flash boiling atomization is usually enabled by increasing the fuel temperature or reducing the ambient in-cylinder pressure. Under such circumstances, the local saturated vapor pressure of the fuel will be higher than the local ambient pressure, which will lead to rapid evaporation/boiling of the fuel in or out of the injector nozzle. The stated flashing phenomenon can help the fuel convert into its vapor phase faster. The microexplosion can also form smaller spray droplets, which will enhance fuel−air mixing and homogeneity. Therefore, the combustion in the cylinder will be more complete and prevent soot formations during engine operations.

There have been many investigations on the use of flash boiling atomization and combustion in fundamental analysis. For instance, Kabasin et al.[10,11] have shown that flash boiling combustion can reduce harmful combustion emissions by the use of a heated fuel injector. Yang et al.[12] studied the flame colors inside the cylinder of an optical DISI engine under cold-start conditions using high-speed imaging measurements. They found that flash boiling can reduce the yellow/sooty flames in the cylinder, which was also justified by PM measurements of the engine exhaust. In other studies, the same research group investigated split injection flash boiling,[13] flash boiling with high-energy spark ignitions,[14] and flash boiling combustion with alternative fuel blends (butanol),[15] with positive results seen in these studies. In fact, under many engine operating conditions, the fuel spray is flash boiled to some degree due to the temperature rise of the cooling water.[16−18] Therefore, flash boiling combustion is very common during engine runs, while this phenomenon has not been thoroughly investigated with many questions unsolved.

For the fundamental problem of soot formations under flash boiling conditions, distinguishing yellow-ish and blue-ish flames can somehow reveal the soot formation process

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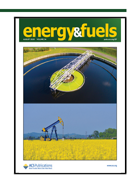

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