Fuel 304 (2021) 121450

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Impact of flash boiling multiple injections timing on the combustion and thermal efficiency of a gasoline direct injection engine under lean-burn

Zhe Sun [a], Qinglin Xu [a], Mingli Cui [a], Mohamed Nour [a,b], Xuesong Li [a], David L.S. Hung [a,c], Min Xu [a]

[a] School of Mechanical Engineering, Shanghai Jiao Tong University, Dongchuan Road 800, Shanghai 200240, China
[b] Mechanical Engineering Department, Benha Faculty of Engineering, Banha University, Benha 13512, Egypt
[c] University of Michigan-Shanghai Jiao Tong University Joint Institute, Shanghai Jiao Tong University, Dongchuan Road 800, Shanghai 200240, China

A R T I C L E I N F O

Keywords:
Flash boiling injection
DISI engine
Optical engine
Combustion
Lean burn
Flame diagnostics

A B S T R A C T

Lean burn mode of direct injection spark ignition engines (DISI) can improve the engine's thermal efficiency. However, it showed slow flame propagation and combustion instabilities which are strongly related to mixture distribution. Multiple injections can improve control over in-cylinder charge distribution and consequently on burn mode. Additionally, multiple injections can reduce spray impingement and enhance the turbulence in the compression stroke, particularly with late injection, but the time is not enough for spray evaporation. Fuel injection under flash boiling conditions boosts fuel vaporization and spray-airflow interaction of the late injections. This study investigates the effect of flash boiling multiple injections on the combustion of lean gasoline/air mixture in an optical DISI engine. This work uses Mie scattering, CFD, high-speed imaging, and flame images postprocessing model to investigate spray characteristics, spray-airflow interaction, flame propagation, and CH* digital intensity. The results reveal that flash boiling multiple injections has significantly mitigated the liquid spray intensity indicates the elevated rate of vaporization with reduced spray impingement and better interaction with the tumble flow compared to the subcooled single injection. The optimal engine performance and combustion were achieved when the second injection and highest tumble ratio point were timely synchronized, for example, 260°bTDC at 800 rpm and 280°bTDC at 1500 rpm. Thus, flash boiling multiple injections can effectively enhance the thermal efficiency by 54.65% and 11%, respectivly. The CH* digital intensity and heat release showed that flash boiling multiple injections could effectively improve the lean-burn operation of the DISI engine.

1. Introduction

Gasoline direct injection (GDI), also known as direct injection spark ignition (DISI), is a primary technology used in passenger car engines. DISI engine has lower fuel consumption, lower emissions, and better control of the combustion process. However, DISI engines face technical problems such as poor fuel–air mixing, super knock, and spray impingement, leading to pool firing, lower thermal efficiency, and higher PM and NO_x emissions [1]. Several engines and combustion control strategies have been investigated to potentially mitigate the previous concerns and optimize the DISI engine efficiency and reduce emissions. Among various advanced combustion strategies, lean burn combustion (LBC) aims to revolutionize engine thermal efficiency by enhancing high-pressure efficiency, reducing gas exchange losses, and extending the LBC to higher load operation. In addition, LBC can limit the heat transfer losses by lowering the combustion temperature, thereby further improving the thermal efficiency and reducing exhaust pollutants such as NO_x. However, lean mixtures have lower laminar flame speeds, leading to longer combustion duration, decreasing thermal efficiency.

Additionally, LBC in DISI engines may have a higher cyclic variation due to ignition difficulties of lean mixture zones around the spark plug. Therefore, researchers suggested several methods to overcome these difficulties. First, a high-energy ignition system was used to initiate the flame kernel. Secondly, they enabled stratified charges to overcome ignition challenges. The latter was suggested based on the control of the in-cylinder air/fuel mixture through multiple injections to achieve stratified charges[2]. Finally, late injection creates a rich fuel/air mixture around the ignitor while keeping lean fuel/air mixtures near the cylinder liner for general LBC condition and decreasing heat losses at the

E-mail address: xuesonl@sjtu.edu.cn (X. Li).

https://doi.org/10.1016/j.fuel.2021.121450
Received 7 June 2021; Received in revised form 12 July 2021; Accepted 13 July 2021
Available online 20 July 2021