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The effect of air/fuel composition on the HC emissions for a twin-spark motorcycle gasoline engine: A wide condition range study

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HIGHLIGHTS

- HC emissions of a twin-spark engine were studied over a wide range condition.
- The combined simulation approach between GT-Power and ChemKin was presented.
- HC amount, intermediates and reaction pathway were studied in motorcycle engine.
- The foundation "perfect" oxidation data were added for comparison analysis.
- The SOA formation potential in "in-cylinder" environment was investigated.

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ABSTRACT

Motorcycles are one of the main transportations in many Asian countries, and the huge amount of motorcycles in developing countries face various challenges, such as safety, increasing fuel price and air pollution. Previous studies observed that, the ratios of mean emission in g/km from motorcycles and cars are very high, especially for HC in urban driving. The motorcycle industry is now faced with the pressure of emission regulation upgrade. In the present study, the possibility and degree of emission (especially for HC) reduction through lean burn were tried to be explored. In this paper, the HC emissions were studied by experimental measurements and combined simulations on a twin-spark motorcycle gasoline engine over a wide range condition. The appearance HC amount, detailed reaction pathway and intermediate products were thoroughly investigated, and the main interest is the influences of relative air/fuel ratio. The results illuminated that, the overall trend of engine-out HC amount decreases as relative air/fuel ratio becomes larger. For example, when λ changes from 0.85 to 1.2, at 100% engine load the HC amount drops, by ~55% and ~53% for 3000 rpm and 4000 rpm, respectively. Besides, the PAHs (polycyclic aromatic hydrocarbons), soot and SOA (secondary organic aerosol) formation potentials were also analyzed in this paper. The results and analysis process indicated that, the combined simulation (between the GT-Power and ChemKin) is a useful tool to analyze the formation process of pollutants during combustion.

1. Introduction

Motorcycles are one of the main transportations in many Asian countries, for instance, Asia accounted for 77% of the total number of worldwide motorcycles in 2012 [1]. In Asia, China has the highest number of motorcycles, followed by India and Indonesia. According to CAAM (China Association of Automobile Manufacturers) [2], about 12.8 million motorcycles were sold by Chinese manufacturers from January to September of 2017.

The huge amount of motorcycles in developing countries faces challenges, such as safety, increasing fuel price and air pollution. Although motorcycles have lower fuel consumption per individual relative to four-wheel passenger cars due to their smaller engine capacity and lighter weight, motorcycles emit more pollutants per driving

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Table 1
Engine specifications.

Item	Content
Engine type	4 Stroke &1 Cylinder, twin-spark, motorcycle-used
Cooling model	Water cooling with an external oil cooler
Bore (mm)	100
Stroke (mm)	83
Compression ratio	10.5
Fuel supply model	Port injection with a Delphi electronic control injection system
Max Power (kW/rpm)	32/7000–7500
MaxTorque (N·m/rpm)	53/5000–5500
Min BSFC (g/kW·h)	320

mileage (known as emission factor), since motorcycle engine usually operates at incomplete combustion status, and what is worse, it has poorer emission control/aftertreatment technologies. By experimental measuring exhaust emissions from 8 motorcycles, and comparing to that of passenger cars, Vasic and Weilenmann [3] observed that, the ratios of mean emission in g/km from motorcycles and cars are very high, especially for HC in urban driving (factor of 222). When the emission was measured in fuel-based emission factor (g/L), similar phenomenon was also observed by Zhou et al. [4]. For instance, they stated that, the fuel-based HC emission factors of LDMCs (light duty motorcycles) and HDMCs (heavy duty motorcycles) registered in or after 2000 were about 100 and 20 times higher than those of LDGVs (light duty gasoline vehicles) of the same age group. In fact, the emission standards for motorcycles are behind by 2–3 stages relative to those of passenger cars (see Table 1 of Ref. [5] for details). Therefore, motorcycles exhaust emissions cannot be ignored in total motor vehicles emissions. Sun et al. [5] investigated the vehicle emissions in Shandong province, China, and found that motorcycles were the primary source of vehicular CO and NMVOC (Non-Methane Volatile Organic Compounds) emissions and accounted for 36.0% and 60.2% of those emissions during the period from 2000 to 2007. In the national investigation of China, motorcycles also contribute to a big fraction in total vehicle HC and CO emissions. For example, motorcycles occupied 41% of total vehicle HC emission and 35% of CO emission in 2013, respectively, according to Wu et al. [6] evaluation.

So, the advanced combustion emission control technologies are also chased nowadays in motorcycle industry. It is concluded by Alvarez et al. [7] that the pollutant emission levels of modern motorcycles have been clearly improved compared with older certification categories. Nevertheless, comparison with the emission performance of gasoline passenger cars of the present certification category indicates that there is still considerable scope for further reducing pollutant emissions of motorcycles. The authors further stated, optimizing the combustion process and the exhaust after-treatment systems are assumed to be the key issues. Actually, big achievement has been obtained in motorcycle engine, especially for the fuel injection system, as reviewed by Muslim et al. [8]. In a modern motorcycle engine, a port fuel injection (PFI) scheme with electronic control is commonly used. This is expected to be one of the most promising technologies to improve fuel economy and driving performance as well as engine-out pollutant emissions. Besides, lean burn is considered as an effective means to improve thermal efficiency and reduce emissions of engines [9–10]. However, its application in engine is limited due to the narrow lean burn limit and slower flame speed of gasoline [11], which results in combustion instability. Multipoint ignition is an effective way to reduce or solve these problems [12]. The usage of multipoint ignition (especially twin-spark plugs per cylinder) has been a long history, and lots of relevant excellent researches have been done. As early in 2002, the Honda Company developed a 1.3 L 2 plug/cylinder four-cylinder gasoline engine, and large reduction in fuel consumption and emissions was achieved through precise sequential ignition control [13]. Li et al. [14] improved the flow kinetic energy through optimizing the intake system in a twin-spark-plug SI engine. Maji et al. [15] also found by experiments, the engine performances were improved when using dual spark plug operation at WOT (Wide Open Throttle) condition. Ramtilak et al. [16] investigated two motorcycle engines by experiments. The results illuminated that, after using twin-spark operation, the emissions (especially for CO) reduced largely, simultaneously with the reduction in cycle-to-cycle variation and the improvement in power output, at all investigated conditions (full load and part load at three speeds respectively). However, the studies of air/fuel ratio effects on HC emission (and its formation process) under twin-spark operation, especially in wide condition range, are rare.

In the present work, the influence of air/fuel ratio on raw HC emission is studied in a four-valve (single cylinder), twin-spark motorcycle engine by experiments and simulations over a wide operating condition range. The main goal of this study is to investigate the behaviors of HC (including its appearance amount and intermediates formation/decay pathways) during combustion under twin-spark ignition mode of a motorcycle engine at different air/fuel ratios. And the possibility of lean burn operation for motorcycles, from HC emission aspect, will be explored. So that, the possible approaches for meeting future regulations of fuel consumption and pollutant emissions can be further discussed. In the present paper, the engine-out HC emissions were mainly concerned. Other performances will be specially discussed elsewhere. The analysis process of this study is presented in Fig. 1, during which an integrated simulation between GT-Power and ChemKin (of course calibrated by experiments) was carried out, to authors' knowledge, this is the first time for such combined simulation. Such that, not only the appearance amount of HC emission but also detailed intermediate products and reaction pathways can be observed, which was rare under twin-spark operation in literatures. Interestingly, the SOA (secondary organic aerosol) formation potential was introduced to the study content in engine "in-cylinder" environment, which is useful for understanding the connection between the emission source and pollution of atmosphere by aerosol particles.

2. Experiment set-up

The experiment set-up is similar to authors' previous researches [17–18], only a brief description is given here. The experiments were performed on a single-cylinder, 4-stroke, twin-spark SI engine, as listed in Table 1. The equipment used in the tests is reported in Table 2. The

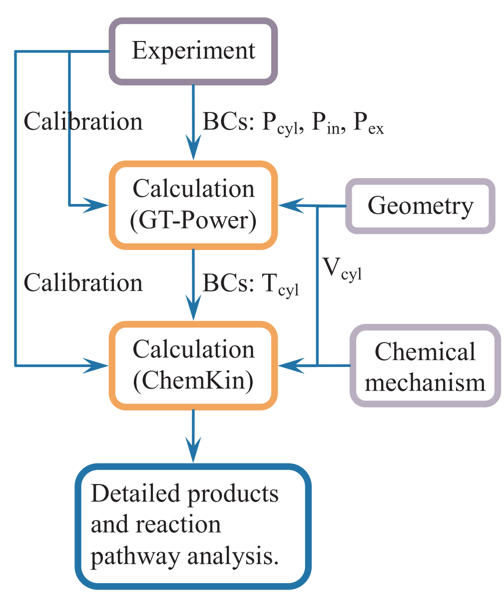

Fig. 1. Flow chart of analysis process.