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Enhancing idle performance of an n-butanol rotary engine by hydrogen enrichment

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ABSTRACT

Rotary engine generally sustains poor fuel economy and emissions performance at idle condition. Hydrogen has excellent physicochemical properties that can serve as an enhancer to improve the performance of the original engine. In this paper, a modified rotary engine equipped with dual fuel (hydrogen and n-butanol) port injection system and electronic ignition module was developed to explore the influence of hydrogen supplement on enhancing the idle performance of n-butanol rotary engine. In this study, the engine was run at the idle and stoichiometric with the original spark timing. Hydrogen volume percentage in the total intake was gradually increased from 0% to 7.9% by adjusting the fuel flow rate of n-butanol. The experimental results indicated that the engine instability and fuel energy flow rate were both reduced by enlarging the hydrogen supplying level. Combustion periods were shortened thanks to the enrichment of hydrogen. The peak chamber temperature was heightened as hydrogen fraction increased due to the improved combustion. HC and CO emissions were severally reduced by 50.4% and 85.8% when the hydrogen volume percentage was raised from 0% to 7.9%. However, NOx emissions were mildly increased because of the raised chamber temperature by increasing hydrogen fraction.

Introduction

As a promising alternative for the conventional reciprocating engines in the specific fields [1–3], the rotary engine generally possesses the advantages of high rotational speeds, few parts, simple mechanism and low noise level [4,5]. Thus, the rotary engine has been used in both civil and military fields. Some manufacturers have successfully employed well-developed rotary engine in many fields [6–8], such as Mazda sports car, mobile power supply and aircraft [6–8]. On the other hand, the rotary engine also possesses some unwished drawbacks, including high fuel consumption and pollution emissions (mainly referred to HC and CO emissions) [9–12], which is mainly induced by its unusually long-narrow combustion chamber and excessive heat transfer area [13–15]. Performance of the rotary engine is constrained at its geometric shape, operating condition, ignition timing as well as fuel properties. Taking these into account, the exploration on performance of a specific rotary engine might be of great interest. In recent years, researches about rotary engine fueled with natural gas [11–17], ethanol [2,5] and gasoline [1,3,6–9]

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have been done. Beyond that, n-butanol has been successfully used in rotary engine by Ji et al. [5] at part load condition.

As an important operating condition of internal combustion engines, idle condition has its unique operating characteristics compared with other engine operating conditions. During this operation, the throttle keeps almost fully closed, therefore, the intake pressure is much lower than that at normal condition [18,19]. The airflow and diffusion are generally weak at idle condition. The high in-charge fluctuation, high residual gas fraction and low combustion temperature belong to the operating characteristics of idle condition [20–22]. As a result of the above factors, the engine tends to suffer unexpectedly poor combustion, high fuel consumption and exhaust emissions at idle operation. It has been normally accepted that near 30% of total fuel is consumed at idle condition for the engine [22,23]. Thus, idle condition has a great influence on the engine fuel economy. Moreover, as for the rotary engine, unburned hydrocarbon at the idle is generally high, due to the low combustion temperature and increased unburnt fuel causing by the irregular working chamber type. Thus, high emissions at idle condition is another concern for the engine, especially for the rotary engine [7,8]. According to the previous publications, improving fuel properties is a feasible means to improve the performance for both rotary [6–9] and reciprocating [23,24] engines.

Hydrogen is known as a substitutable fuel with distinctive physical and chemical characteristics [24,25], such as low ignition energy requirement, wide flame range, high diffusion rate and fast flame speed [25–27]. Thus, some individuals and institutions have employed hydrogen as enhancer to improve the properties of the original fuels [28–31]. The low ignition energy (only 0.02 mJ) of hydrogen could easy the ignition event of the mixture. The wide flammability of hydrogen allows the hydrogen-blended mixture to be burnt normally in the unexpected ultra lean regions. Since hydrogen diffuses fast, blending hydrogen can increase the charge homogeneity of mixture. The high flame speed of hydrogen can accelerate the combustion velocity of the original mixture. By taking the advantages of hydrogen, adding proper proportion hydrogen into the original fuel could improve the combustion quality of fuel/air mixture, and hence reduce the fuel consumption and unwished emissions. Motive by this, Huang et al. [32–34] studied the impact of hydrogen addition on combustion of base fossil fuel and demonstrated that hydrogen replenishment could improve the mixture combustion process. Meanwhile, concentrations of O, H and OH radicals were increased after the addition of hydrogen, which could promote the chain reaction during the combustion process [32]. As for the practical engine, Ji and Wang [35,36] added hydrogen into gasoline to study idle performance of the engine. They proved that hydrogen addition was helpful for the improvement in thermal efficiency, burning quality and emissions reduction. Beyond that, many researchers also declared that hydrogen was a splendid fuel to engines, due to its recyclability [37,38], clean combustion and high thermal efficiency [39,40], and low carbon-based pollution [41–43]. Furthermore, surveys made by Amrouch et al. [1–4] showed that performance of the gasoline rotary engine could be improved when hydrogen was introduced into the working chamber. Ji and Wang et al. [5] also studied the influence of hydrogen supplement on performance of the n-butanol rotary engine. It was found that performance of the n-butanol rotary engine was obviously improved when hydrogen was introduced into the n-butanol/air mixture.

At the present, although researches on idle performance of the hydrogen-enriched gasoline rotary engine have been conducted, idle performance of the hydrogen-enriched n-butanol rotary engine is rarely reported. Since n-butanol is a feasible fuel candidate of spark-ignited engines, it is of necessity to quantitatively investigate the effect of hydrogen addition on idle performance of this engine. This paper aims to study the combustion and emissions characteristics of a hydrogen-blended n-butanol rotary engine at idle and stoichiometric conditions.

Experimental setup and procedure

Experimental setup

The experimental-used engine is based on a side-ported rotary engine with a displacement of 0.16 L, whose schematic diagram and specifications could be seen in Fig. 1 and Table 1, respectively. The original engine was equipped with a magneto and carburetor. For the purpose of accurate control in spark timing and fuel injection, the magneto and carburetor were replaced by an electronically controlled ignition system and a stand-alone fuel (n-butanol and hydrogen) management system. The intake pipe after modifying is shown in Fig. 2, injector A is for hydrogen and injector B is for n-butanol. The injector configuration is also an issue for the engine [44,45], in a short word, the trademarks and models for injector A and injector B are Bosch 0280158827 and WJ22 BBS VI, respectively. This can ensure the tested engine to be fueled with n-butanol/hydrogen/air mixture and also realizes the precise control of excess air ratio (λ) and hydrogen volume fraction (α_{H_2}). Hydrogen and n-butanol are mixed with air outside the tested engine. The injection durations of hydrogen and n-butanol are directly controlled by a hybrid electronic control unit (HECU) developed for the tested engine, which is also adopted to govern the spark mode. Thus, the injection durations of fuel (n-butanol and hydrogen) and desired spark advance could be acquired by adjusting the program in HECU.

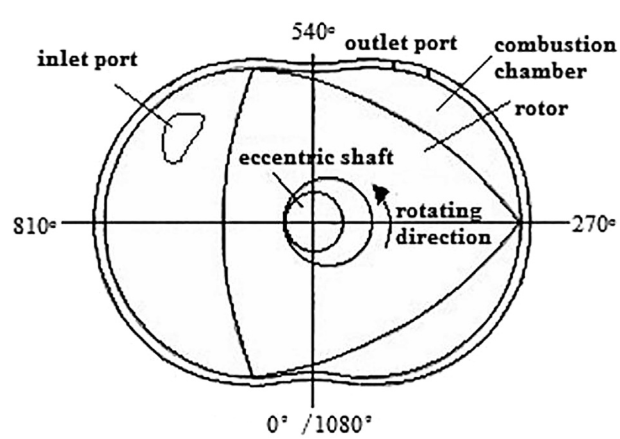

Fig. 1 – Schematic of the tested engine.

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