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Review Article

Availability analysis of a coke oven gas fueled spark ignition engine

Hongqing Feng [a,*], Weiwen Zhang [b], Jing Zhang [a], Xinyi Wang [a], Xiaodong Zhang [c]

[a] Department of Energy and Power Engineering, China University of Petroleum, 266580 Qingdao, China
[b] R&D Center, Weichai Power Co.,Ltd, 261061 Weifang, China
[c] Key Laboratory of Biomass Gasification Technology of Shandong, 250014 Jinan, China

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ABSTRACT

The current work investigates a coke oven gas fueled spark ignition (SI) engine from the perspective of the first and second laws in order to understand the energy conversion performance of fuels and achieve highly efficient utilization. A detailed energy and exergy analysis is applied to a quasi-dimensional two-zone spark ignition engine model which combines turbulence flame propagation speed model at 1500 rpm by changing gas fuel types, compression ratio, load and ignition timing. It was found that the irreversibility of methane is the maximum and that of syngas is the minimum among the three different fuels. The irreversibility in the combustion process of a coke oven gas fueled SI engine is reduced when the compression ratio or the throttle valve opening angle is increased and the ignition timing is delayed. Increasing the compression ratio and delaying the ignition timing can improve the first and second law efficiency and reduce the brake specific fuel consumption (BSFC). The power performance and fuel economy are good and the energy is also used effectively when the compression ratio is 11, the throttle angle is 90% and the ignition time is −10° CA ATDC respectively.

Contents

* Corresponding author.
E-mail address: fenghongqing@upc.edu.cn (H. Feng).
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Introduction

With the rapid consumption of oil resources and the increasingly serious environmental pollution, the application of the clean and renewable gas fuels in the traditional vehicle internal combustion engine is becoming a hot issue [1,2]. At present, methane, hydrogen, natural gas and biogas are relatively common gas fuels. China is the largest coal producer in the world and coke oven gas is one of the important by-products of the coal-coking process which mainly consists of methane and hydrogen. Although coke oven gas can be further made of methanol, dimethyl ether and other substances that can also be used as a fuel for internal combustion engines [3–8], the problem includes increased production costs, complicated processes and methanol poisoning, corrosion and other shortcomings, resulting in uneffectively utilization of coke oven gas. Actually coke oven gas is a high calorific value gas fuel, the ignition temperature is low, about 600–650 °C, and the combustion products are clean. Coke oven gas is an alternative hydrogen-rich fuel for vehicles [9–11] and using coke oven gas as the fuel of internal combustion engine can improve utilization, simplify technology and reduce costs.

A comparison between the physical and chemical properties of natural gas, hydrogen and coke oven gas is shown in Table 1 [12,13]. It can be observed that the physical and chemical properties of coke oven gas are between natural gas and hydrogen. The hydrogen component can increase the combustion temperature, extend flammability limits and reduce ignition energy, and the methane component has a positive effect on steady combustion and lower emissions. Therefore, the combustion characteristics of hydrogen and natural gas in internal combustion engines can be used as a reference for the study of combustion processes in the engine fueled with coke oven gas.

Table 1 – Comparison of physical and chemical properties of natural gas, hydrogen and coke oven gas.

Property	Natural gas	Hydrogen	Coke oven gas
Main components	CH_4	H_2	CH_4、H_2、CO
Relative molecular mass	16	2	8.8
Density (kg/m^3)	0.715	0.0899	0.39
Stoichiometric air/fuel ratio (kg/kg)	17.25	34.41	14.86
Lower heat value (MJ/m^3)	16–17.5	35.8	10.8
Flame propagation speed (cm/s)	34–37	270	68

The first law of thermodynamics has been widely used to evaluate the performance of energy conversion devices such as the internal combustion engine. The second law of thermodynamics is not only often used to analyze the availability and irreversibility of the system, but also an effective tool for evaluating the quality of the system [14,15]. In recent years, availability analysis for many different kinds of alternative fuels from the second law application has been published. Caton [16] studied the performance of eight fuels, including hydrogen, carbon monoxide, methane, isooctane, propane, hexane, methanol and ethanol, which were used in a spark-ignition engine based on the analysis of the first and second law of thermodynamics. Results showed that carbon monoxide has the lowest destruction (about 8% of the fuel exergy) while isooctane has the highest value (about 21% of the fuel exergy) for the conditions examined. Rakopoulos [17] studied a methane, methanol, and dodecane fueled four-stroke diesel engine from the second law perspective. It was found that using methane and methanol can decrease the combustion irreversibility, and the main source of irreversibility during the engine operation is combustion irreversibility. Rakopoulos [18] also studied the generation of combustion irreversibility in a biogas–hydrogen mixtures fueled spark ignition engine using multi-zone thermodynamic model combined with quasi-dimensional combustion model. Results indicated that the closed cycle second law efficiency increased from 40.85% to 42.41% and the normalized combustion irreversibility decreased from 18.25% to 17.18% when the volumetric fraction of hydrogen in biogas increases from 0% to 15%. Moreover, increasing the amount of hydrogen in biogas can promote the extent of reversibility of the burning process during the combustion of the later burning gas. Daw [19] carried out the first and second law analyses of a conceptual isobaric combustion process and demonstrated that this idealized hydrogen combustion process has higher retained thermodynamic availability than conventional combustion theoretically. Rakopoulos [20] studied availability analysis of hydrogen/natural gas blends fueled internal combustion engine using a zero-dimensional combustion model. Results showed that the irreversibility in the combustion process decreases and the second law efficiency increases with the hydrogen content in natural gas increasing. And he also studied syngas fueled spark ignition engine using a multi-zone combustion model [21]. It was found that the destroyed availability caused by combustion increases from 14.19% to 15.02% of the fuel chemical availability, while the percentage of the cumulative heat availability decreases from 13.37% to 9.05% respectively. The performance and emissions of a four-stroke single-cylinder direct injection compression ignition engine fueled by hydrogen-rich coke oven gas have been investigated [10]. The results showed that the coke oven gas