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Enhancing the fuel economy and emissions performance of a gasoline engine-powered vehicle with idle elimination and hydrogen start

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HIGHLIGHTS

- We studied effects of idle elimination and H_2 start on vehicle performance.
- A hydrogen/gasoline dual-fuel engine-powered vehicle model is built.
- An on-board hydrogen production and storage system model is used.
- Fuel economy is improved by idle elimination strategy under NEDC.
- CO and HC emissions are decreased for hydrogen start and idle elimination.

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ABSTRACT

Idle elimination is a feasible way for reducing the fuel consumption and emissions at idle. The challenge for adopting idle elimination on gasoline engine is the high emissions during restart because rich mixtures have to be used at starting. This paper tries to start the engine with pure hydrogen at the restart for gasoline vehicles which adopt idle elimination. The investigation was done based on models built on AVL CRUISE. In the model, the vehicle was run under the New European Driving Cycle (NEDC). The hydrogen used on the vehicle was online produced and stored by an on-board hydrogen production and storage system. The energy for producing hydrogen is taken into account in the total fuel consumption. The simulation results showed that, with the adoption of gasoline start-idle elimination strategy, the vehicle fuel consumption during NEDC was reduced by 0.69 L/100 km, and NO_x emissions were decreased by 5.5% compared with the original vehicle without idle elimination. However, HC and CO emissions at the restart were respectively increased by 87.5% and 18.1% for the gasoline vehicle due to the adoption of rich mixtures. Comparatively, with the adoption of hydrogen start-idle elimination strategy, the vehicle fuel consumption during NEDC was reduced by 0.79 L/100 km, HC and CO emissions were decreased by 70.8% and 13.6%, respectively. This shows a good capability of hydrogen combustion on reducing HC and CO emissions at the restart. However, NOx emissions were slightly increased by 7.9% under the hydrogen restart mode.

1. Introduction

Facing the daily strict regulation on the environment protection, more and more researches have been dedicated to explore clean alternative fuels for internal combustion engines, such as natural gas [1,2], methanol [3,4] and biofuels [5–7]. Compared with other alternative fuels, the hydrogen contains no carbon atom which makes the combustion of hydrogen is free of carbon related emissions [8]. Moreover, the hydrogen also possesses good combustion properties, such as wide flammability, high diffusion speed, low ignition energy and high flame propagation speed [9–12]. These properties enable the hydrogen engine to run with high efficiency and low emissions [13,14]. The wide flammability of hydrogen also helps engines run smoothly at lean conditions which could further improve the engine fuel economy and reduce toxic emissions [15]. However, the commercialization of hydrogen engines is still challenged by the pre-ignition, backfire and high level of NOx emissions. According to Yang et al. [16–18], methods such as water injection and carefully controlling the spark timing are necessary for achieving the smooth operation of the pure hydrogen. Besides, the massive on-board storing of hydrogen and

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Nomenclature

$m_{g,H2producer}$	the gasoline consumption mass of the original engine under NEDC with hydrogen producer (kg)
$m_{g,O}$	the gasoline consumption mass of the original engine under NEDC without hydrogen producer (kg)
R	energy conversion rate from gasoline to hydrogen (J/J)
$V_{H2,g}$	hydrogen production volume (L)
ρ_{H2}	hydrogen density (g/L)
$LHV_{gasoline}$	low heat value of gasoline (J/kg)
LHV_{H2}	low heat value of hydrogen (J/kg)
m_g	accumulative consumption mass of gasoline (kg)
$m_{H2,c}$	accumulative consumption mass of hydrogen (kg)
$\dot{m}_g$	transient consumption rate of gasoline (kg/s)
$\dot{m}_{H2,c}$	transient consumption rate of hydrogen (kg/s)
t	time (s)
m_{HC}	accumulative emissions mass of HC (g)
m_{CO}	accumulative emission mass of CO (g)
m_{NOx}	accumulative emissions mass of NOx (g)
X_{HC}	transient emissions concentrations of HC (ppm)
X_{CO}	transient emission concentrations of CO (ppm)
X_{NOx}	transient emissions concentrations of NOx (ppm)
K_{NOx}	humidity correction factor
$\dot{m}_e$	transient emissions mass flow rate (kg/s)
$\dot{m}_{air}$	transient air mass flow rate (kg/s)
$m_{H2,p}$	accumulative production mass of hydrogen (kg)
$P_{H2production}$	rated power of on-board hydrogen producer (W)
$\eta_{H2production}$	energy conversion efficiency of on-board hydrogen producer (%)
Δm_{H2}	hydrogen mass variation of hydrogen storage system (kg)
$t_{H2,p}$	running time of hydrogen producer (s)
$d_{hydrogen}$	hydrogen volume difference between the hydrogen consumption and production (L)

difficulties on hydrogen refilling also restrict the progress of pure hydrogen-fueled engine [19–22].

Comparatively, the engine adopting a dual-fuel strategy using mixtures of hydrogen and hydrocarbon could mitigate the above challenges [23]. Huang et al. [24–28] studied the effect of hydrogen addition on the combustion of natural gas with constant volume combustion bomb, shock tube and spark ignition engines. Their investigations showed that the hydrogen enrichment benefited increasing the fuel burning speed and improving the stability of flame structure and position. It was also confirmed that the hydrogen enrichment promoted formations of O, H, and OH radicals which availed the complete combustion of hydrocarbon fuels. Park et al. [29–31] investigated the effect of hydrogen enrichment on the combustion and emissions characteristics of a heavy-duty spark-ignition engine fueled with the compressed natural gas. The test results indicated that the thermal efficiency was improved and emissions were reduced as the hydrogen enrichment ratio was increased. Ji and Zhang [32–35] conducted a series of studies to investigate the combustion and emissions characteristics of a hydrogen-enriched methanol engine. Their researches confirmed that the hydrogen enrichment benefited extending the engine lean burn limit, reducing the engine cyclic variation and elevating the peak engine speed and pressure during the cold start. The same conclusions were also obtained on hydrogen-enriched gasoline engine researches [8,36,37].

In urban traffic conditions, vehicles idle operation accounts for relatively long time. This means that the engine idle performance also plays an important role in the overall fuel economy and emissions characteristics [36]. Engine Start/Stop System could eliminate the idle time by shutting the engine down and restarting the engine when the brake pedal is released or the clutch pedal is pressed, which is an attractive approach to improve fuel economy and emissions performance [38]. Chen et al. [39] numerically investigated the effect of Start/Stop System on vehicle performance. Their study showed that, with the Start/Stop System, the vehicle 100-km fuel consumption was decreased by 3.63% and the emissions were also decreased dramatically. It is known that combustion characteristics at the restart are very important for spark-ignited engines applied Start/Stop strategy. Generally, the low cylinder temperature provides a poor thermal condition for the complete and clean combustion at the start, which results in the sharp increase in HC and CO emissions, or even misfired cycles [40]. Eng [41] numerically and experimentally researched the emission performance of gasoline-fueled engine at starting condition. Their results indicated that, HC emissions accounted for 80–90% of the total emissions in the first 20 s during the cold start process. This was because the low temperature deteriorated the evaporation of gasoline. Thus, to compensate the reduction of fuel vaporization, the rich fuel/air mixtures were used in the engine start, which leaded to the increase of incomplete combustion [42]. On the other hand, the low temperature and inhomogeneity of the mixtures also resulted in the decrease in efficiency of catalytic systems, which means that the three way catalytic convertor (TWC) could not catalyze the pollutant with high efficiency at the frequent starting conditions [43]. Same problems were also found in the LPG (liquefied petroleum gas) [44], methanol [45,46] and ethanol [47] engines.

In view of the above discussions, it could be seen that although idle elimination is feasible in stopping the fuel consumption and emissions at the idle, the engine may expel more HC and CO during the restart process. Comparatively, since the hydrogen is a carbonless fuel with low ignition energy and wide flammability, engines fueled with the pure hydrogen at either cold or warm start could obtain better emissions and combustion characteristics. Ji et al. [48] compared the emissions characteristic for the vehicle starting with the pure gasoline and pure hydrogen through experiments done on chassis dynamometers. The results showed that both HC and CO were reduced over 60% under the NEDC condition.

Although there are some experimental and numerical researches which have investigated the performance of SI gasoline engines with Start/Stop System or hydrogen enrichment, up to now, there is no publicly report on the performance of hydrogen/gasoline dual-fuel engine-powered vehicles with idle elimination and hydrogen start. Thus, this paper built a dynamic model for a dual-fuel engine-powered vehicle to investigate the fuel economy and emissions performance. Models for the vehicle dynamic system and on-board hydrogen production and storage systems were built using the vehicle performance analysis code AVL CRUISE. The engine operating range during the NEDC was analyzed and effects of the adoption of on-board hydrogen producer, idle elimination and hydrogen start strategies on vehicle fuel economy and emissions levels were investigated.

2. Numerical model and experiment

The modeled vehicle is a 1.6 L manual transmission gasoline engine vehicle manufactured by Hyundai Motor Company. As it is shown in Fig. 1, the dynamic model for hydrogen/gasoline dual-fuel engine-powered vehicle is built based on AVL CRUISE.