Energy for Sustainable Development 43 (2018) 60–67

Contents lists available at ScienceDirect

Energy for Sustainable Development

Study on performance enhancement and emission reduction of used fuel-injected motorcycles using bi-fuel gasoline-LPG

Khanh Nguyen Duc [a], Vinh Nguyen Duy [b,c,*]

[a] Department of Internal Combustion Engine, School of Transportation Engineering, Hanoi University of Science and Technology, 1 Dai Co Viet Road, Hanoi, Vietnam
[b] Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[c] Faculty of Electrical & Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam

ARTICLE INFO

Article history:
Received 28 June 2017
Revised 14 August 2017
Accepted 31 December 2017
Available online xxxx

Keywords:
Bi-fuel
Liquefied petroleum gas
Flexible vehicle
Fuel injection
Exhaust emission

ABSTRACT

The paper presents a simulation and experimental study on using bi-fuel gasoline - liquefied petroleum gas (LPG) for currently used fuel-injected motorcycles in Vietnam. Consequently, an innovative fuel supply system was designed to make the original gasoline motorcycles can flexibly operate on either gasoline or LPG. In this research, simulation processes were conducted by using a dedicated software analysis tool to optimize the operation process of the fuel system in order to maintain its stability and efficiency based on the characteristics of each type of fuels. Meanwhile, the original fuel supply system of the test motorcycle will be modified in the experiment by developing the second Electronic Control Unit (ECU) to control LPG quantity supplied for the one. The results showed that the test motorcycle well operated on either gasoline or LPG on the new design. In addition, when running on LPG the specific fuel consumption and exhaust emissions of the test motorcycle were reduced significantly. The investigation suggests that the old generation of fuel-injected motorcycles can be run flexibly on bi-fuel in order to reduce the fuel consumption and exhaust emissions.

Introduction

The polluted environment has become a serious problem in Vietnam, especially in big cities due to the industrialization process of this country. According to the Vietnam Ministry of Natural Resources and Environment, the main reason of air pollution in large cities is vehicular traffic, which contributes 85% of the amount of carbon monoxide (CO) in the environment (As Vietnam urbanises, air pollution grows in big cities). As shown in (Khanh et al., 2016), with more than 40 million vehicles, the motorcycle has speedily become the main transportation vehicle, and the main pollution sources in this country due to the poor infrastructure, lack of awareness of drivers and government's mismanagement. To deal with air pollution from motorcycles, the Vietnam government formulated a strategy to control emissions. As a result, Euro III emission standards regulation for new motorcycles will become effective in July 2017. However, this solution cannot solve the problems related to the number of largely used motorcycles circulated in Vietnam.

As listed in many studies (Changwei et al., 2017; Gandhi et al., 2003; Hsieh et al., 2002; Jahirul et al., 2010; Khanh et al., 2016; Lodice et al., 2016; Park et al., 2010; Winkler et al., 2008; Xiaolei et al., 2012), the main exhaust constituents of vehicles retrofitted gasoline engine include CO_2, CO, NO_x and unburned hydrocarbons (HC) since the fuel supplied to the engines cannot be completely combusted causes for the formation of CO and HC. Meanwhile, NO_x is produced as a result of the thermal dissociation of molecular oxygen to give oxygen atoms reacting with nitrogen molecules known as the Zeldovich mechanism (Khanh et al., 2016; Manzetti & Andersen, 2016). CO, HC and NO_x emissions affect directly to human health since they cause in many diseases, including respiratory problems, eye irritation, heart disease as well as potential to cause cancer (Bogarra et al., 2016; Chowdary et al., 2016; Demir, 2015; Yu et al., 2015). On the other hand, CO_2 does not affect directly to human health; however, it has a significant impact on global warming because of its abundance in the atmosphere. In addition, CO_2 emissions are also directly related to the fuel consumed by vehicles. Consequently, Vietnam is necessary to find out the suitable method to reduce the emissions from the motorcycles in order to minimize the polluted environment and energy consumption.

Recently, alternative energies have been performed as the solution to replace traditional energy sources used for internal combustion engines such as gasoline, diesel. Known as propane autogas, LPG is a clean-burning, high-energy alternative fuel that has been being considered by scientists worldwide to use for vehicles. P.R. Chitragar et al. performed an experimental study to analyze the combustion and emission of a 4-stroke gasoline engine running on LPG. It revealed that toxic

* Corresponding author at: Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam.
E-mail address: nguyenduyvinh@tdt.edu.vn (V.N. Duy).

https://doi.org/10.1016/j.esd.2017.12.005
0973-0826/

emissions CO, HC, and NO_x were improved for LPG at idle conditions than gasoline (Chitragar, 2016). The investigation of the ultra-lean combustion direct-injection LPG engine for passenger-car applications under the FTP-75 mode was also conducted by J. H Kim et al. as shown in (Kim et al., 2016). Their results showed that the particle emissions of the lean combustion were higher than those of the original combustion, but considered as acceptable levels based on the upcoming emission standards. In another research, the effects of the LPG temperature on the engine operating characteristics were experimentally investigated on a test spark ignition engine. Consequently, the LPG temperature contributing to the change in a wide band of the spark ignition engine effects directly to engine performance and NO emission characteristics.

In Vietnam, the scientists have recently focused on finding out renewable and alternative energy sources to replace traditional energy and contribute to developing agriculture in the countryside. Many studies have concentrated on using ethanol as the potential energy source applied to motorcycles (Khanh et al., 2016). They showed that motorcycles can well operate with a fuel mixture of ethanol and gasoline corresponding to the low content of ethanol. Some studies have also performed to use LPG for light-duty vehicles or motorcycles using a carburetor. These studies obtained some worthy results, and are the foundations for the development of renewable and alternative energy in Vietnam. However, they are limited in application due to the cumbrous design and high cost of the modified fuel supply systems.

This research aims to investigate a new fuel supply system for fuel injected motorcycles in order to flexibly run on either LPG or gasoline. Due to the difference between physical-chemical properties of LPG and gasoline such as the density, kinematic viscosity, heat value and latent heat of vaporization, it is necessary to modify the structure of the original fuel supply system. Consequently, LPG fuel was injected into the intake manifold by an independent gaseous injector and controlled by a second ECU. The performance and emission of the test motorcycle using either LPG or gasoline were evaluated after the modification. The results of this study are the foundation for applying widely LPG as the alternative energy to replace the traditional gasoline fuel in order to solve the energy crisis and environmental problems.

Simulation and experimental procedures

Simulation procedure

In this research, the engine simulation model was conducted by using AVL Boost software as showed in Fig. 1. Theoretical backgrounds including the basic equation and calculation models for all components of the model are clearly described in (AVL, 2013; Heywood, 1988). The model of the engine was simulated at fully opened throttle with gasoline and LPG, the engine speed has been increased from 2000 to 8000 rpm at an interval of 1000 rpm. In each simulation modes, supplied fuel in the case of gasoline and LPG was adjusted to maintain the air excess ratio constantly equals 1.

Basic conservation equations

The calculation of the high-pressure cycle of an internal combustion engine is based on the first law of thermodynamics as given in Eqs. (1) and (2).

$$\frac{d(m_c.u)}{d\alpha} = -p_c.\frac{dV}{d\alpha} + \frac{dQ_F}{d\alpha} - \sum\frac{dQ_w}{d\alpha} - h_{BB}.\frac{dm_{BB}}{d\alpha} \tag{1}$$

$$\frac{dm_c}{d\alpha} = \sum\frac{dm_i}{d\alpha} - \sum\frac{dm_e}{d\alpha} - \sum\frac{dm_{BB}}{d\alpha} + \sum\frac{dm_{ev}}{dt} \tag{2}$$

where m_c is the mass in the cylinder, u is the specific internal energy, p_c is the cylinder pressure, V is the cylinder volume, Q_F is the fuel energy and Q_W is the wall heat loss, α is the crank angle, h_{BB} is the enthalpy of blow-by, m_{BB} is the blow-by mass flow, d_{mi} is the mass element flowing into the cylinder, d_{me} is the mass element flowing out of the cylinder and m_{ev} is the mass of evaporating fuel. It means that the change of the internal energy in the cylinder is equal to the sum of piston work, fuel heat input, wall heat losses and the enthalpy flow due to blow-by. Eq. (1) is valid for engines with internal and external mixture preparation. However, the terms, which take into account the change of the gas composition due to combustion, are treated differently for internal and external mixture preparation. For internal mixture preparation as in a

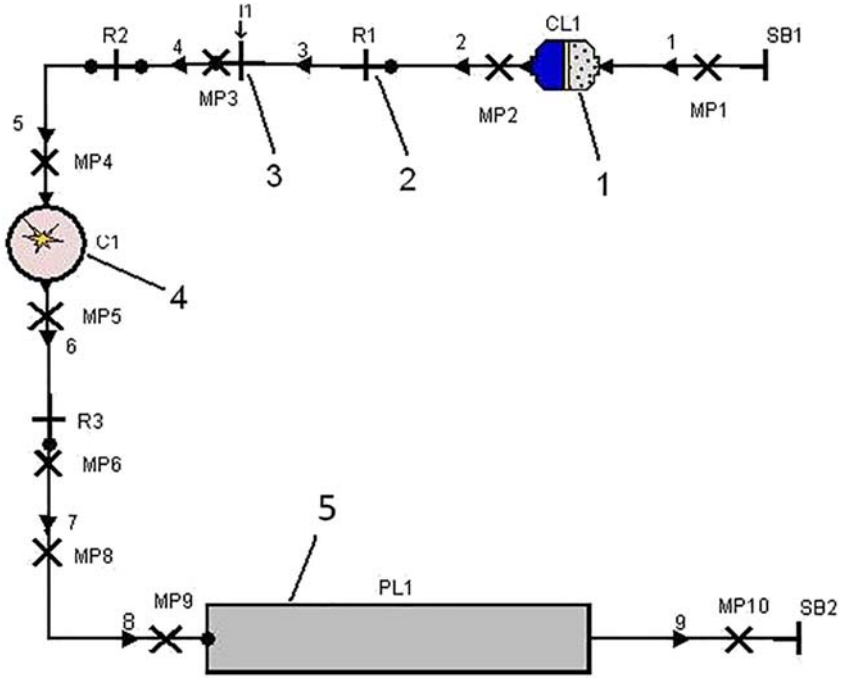

Fig. 1. Simulation model of tested engine. Whereas: 1-Air cleaner; 2-Restriction; 3- Injector; 4-Cylinder; 5-Pleum.