ARTICLE IN PRESS

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–6

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Short Communication

The viability of biodiesel and hydrogen as complementary fuel vectors in a hybrid platform

Simon Graham

De Courcy Alexander, 35 Kirby Street, London, EC1N 8TE, UK

ARTICLE INFO

Article history:
Received 27 November 2016
Received in revised form
5 June 2017
Accepted 7 June 2017
Available online xxx

Keywords:
Biodiesel
Diesel
Hybrid
Hydrogen
NO_x

ABSTRACT

The majority of hybrid design has focused on combining battery electrical systems with fuel cells or with a separate internal combustion engine which adds costs and complexity. An alternative hybrid, termed H2ICED and developed by Revolve Technologies, uses a common drivetrain to use fossil fuel petrodiesel, vegetable based biodiesel and hydrogen as alternative fuel sources. This hybrid engine was tested in a dynamometer with a fixed intake of hydrogen and variable blends of petrodiesel and biodiesel The use of hydrogen significantly reduced the amount of petrodiesel consumed, the amount of CO and NO_x emitted, and the carbon footprint of the engine in use. The use of biodiesel complemented the reductions. Optimal levels of blend were 80% biodiesel to minimise fuel consumption and CO emissions and 100% biodiesel to gain the lowest carbon footprint and levels of NO_x produced. Using both hydrogen and biodiesel, it was possible to reduce the carbon footprint of the fuel by 99%. This has implications for policy makers, particularly those addressing urban pollution challenges.

Background

The transition from fossil fuelled internal combustion engine to electric vehicles powered by fuel cell or battery will require a number of transitional technologies. Activity in this transition space focuses on hybrids as they allow the use of both fuel sources. The majority of hybrid design has focused on combining battery electric or fuel cell electric vehicles with a separate internal combustion engine. This adds costs and complexity, which can reduce efficiency and reliability.

An alternative hybrid uses a common drivetrain to provide this transition. This has a number of advantages, including the use of existing technology which reduces risk both for development and operation. Particularly, this will aid in eliminating the two major barriers to the adoption of hydrogen technologies [1]. In addition to reducing the risk of new drivetrain technologies such as fuel cells, it also offers the operator certainty of access to refuelling capability while hydrogen infrastructure is being rolled out [2]. Much of this work has involved using compressed natural gas as a transitional fuel (e.g. Ref. [3]).

Simultaneously, the use of biofuels has also grown dramatically [4] and global biodiesel production is expected to continue to grow to over 19 million litres a year before 2020 [5]. Both biofuels and hydrogen are recognised for their help in achieving energy security and reducing carbon emissions [4,6]. There is therefore a desire to combine the positive attributes of biofuels and hydrogen. Biodiesel is frequently used as a blend with diesel in compression ignition vehicles [5], as it shares many attributes with petrodiesel. It is therefore

E-mail address: simon.graham@decourcyalexander.co.uk.
http://dx.doi.org/10.1016/j.ijhydene.2017.06.054
0360-3199/

Please cite this article in press as: Graham S, The viability of biodiesel and hydrogen as complementary fuel vectors in a hybrid platform, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.06.054

proposed that the impact of blending biodiesel and hydrogen be the focus of this study.

This study proposes that increasing the hydrogen and biodiesel content in the fuel used by a compression ignition engine will offer environmental benefits without negatively impacting engine performance. In addition to carbon dioxide (CO_2), the impact on oxides of nitrogen (NO_x) and carbon monoxide (CO) will also be observed.

Literature review

The use of hydrogen in compressed ignition vehicles is well understood at low blends of below 10% hydrogen and 90% petrodiesel (e.g. Ref. [7–10]) to high blends of 80% hydrogen and 20% petrodiesel (e.g. Ref. [11]). The impact of hydrogen has been shown to reduce CO_2 and CO emissions [12]. Similarly, the impact of blending biodiesel and petrodiesel is well documented [13,14]. Using biodiesel is shown to reduce pollutants such as CO, but increases fuel usage and NO_x emissions due to biodiesel's lower calorific value, higher viscosity and lower volatility which results in a slower burn, longer combustion and lower power output [6].

In contrast, the effects of biodiesel and hydrogen blending is less studied, and the conclusions more varied. Introducing low blends of hydrogen into biofuels derived from jatropha [15] and rubber seed oil [16] has been shown to improve brake thermal efficiency and reduce pollutants such as CO both due to the lack of a carbon atom in hydrogen and the enhanced oxidation rates achieved due to the higher combustion temperature in the cylinder.

The effect on NO_x of adding hydrogen to biodiesel has been studied. Some studies (e.g. Ref. [17,18]) demonstrate that the effect of hydrogen injection is to increase the pressure rise rate and peak cylinder pressure, due to the high flame propagation speed of hydrogen combined with a slightly increased ignition delay and thus slightly increase NO_x pollution. Other studies (e.g. Ref. [19,20]) have found that the introduction of hydrogen lowers the temperature of combustion and thus reduces the levels of NO_x emitted. Studies have also looked at the impact of EGR (e.g. Ref. [21]) and water emulsification (e.g. Ref. [22]) on hydrogen and biodiesel, finding that these can also positively impact NO_x emissions. A study with a 20% biodiesel blend and varied inputs of hydrogen (up to 10% of fuel energy) reported a small reduction in NO_x emissions of up to 16.8% [23]. This study takes this work further and looks at the implications of varying the blend of biodiesel and petrodiesel and the impact this makes on carbon emissions, as well as local pollutants such as CO and NO_x.

Technology

To empirically test the application of hydrogen, biodiesel and petrodiesel blending, it was necessary to find a compression ignition engine that is compatible with all three fuels. Revolve Technologies have developed a system termed H2ICED which meets this need. This hybrid uses a Ford Global Puma 2.2 L turbocharged diesel engine combined with a Revolve Technologies hydrogen injection hardware & control system mounted in a Ford Transit Jumbo van. The van carries a store of hydrogen compressed to 350 bar and liquid hydrocarbon fuel. Both petrodiesel, compatible with BSEN2869:2006 and ISO8217:2005, and biodiesel, Fatty-Acid Methyl Ether (FAME) derived from waste vegetable oil (WVO), are used as hydrocarbon fuels. The vehicle can run on, but does not require high grade hydrogen, thus reducing the potential cost of fuel and enabling a wider range of hydrogen infrastructure options.

Combustion formulae

Revolve Technologies used the following formulae and calculation steps in order to calculate the hydrogen fuel and emission mass flow rates during testing (after [24]). An explanation of the symbols and abbreviations used are as follows:

x: Moles of carbon in 1 mol of hydrocarbon fuel (moles)
y: Moles of hydrogen in 1 mol of hydrocarbon fuel (moles)
z: Moles of oxygen in 1 mol of hydrocarbon fuel (moles)
Q: Moles of hydrogen gas per mole of hydrocarbon fuel (moles)
n: Moles of air per mole of hydrocarbon fuel (moles)
A: Moles of nitrogen gas per mole of oxygen gas present in air (moles)
B: Moles of carbon dioxide gas per mole of oxygen gas present in air (moles)
ϕ: Moles of recirculated exhaust gas per mole of hydrocarbon fuel (moles)
a: Moles of carbon dioxide in exhaust gas per mole of hydrocarbon fuel (moles)
b: Moles of carbon monoxide in exhaust gas per mole of hydrocarbon fuel (moles)
d: Moles of water in exhaust gas per mole of hydrocarbon fuel (moles)
e: Moles of oxygen in exhaust gas per mole of hydrocarbon fuel (moles)
f: Moles of nitrogen in exhaust gas per mole of hydrocarbon fuel (moles)
g: Moles of oxides of nitrogen in exhaust gas per mole of hydrocarbon fuel (moles)
h: Moles of unburned hydrocarbon in exhaust gas per mole of hydrocarbon fuel (moles)
ntot: Total number of moles of exhaust gas (moles)
$[CO_2]$: Exhaust gas carbon dioxide molar concentration
[CO]: Exhaust gas carbon monoxide molar concentration
$[O_2]$: Exhaust gas oxygen molar concentration
[NO]: Exhaust gas oxides of nitrogen molar concentration
[HC]: Exhaust gas hydrocarbon molar concentration

The generic formula for the combustion of a hydrocarbon and hydrogen in air is shown in Eq. (1) below:

$$C_xH_yO_z + QH_2 + n(O_2 + AN_2 + BCO_2) + \phi(aCO_2 + bCO + dH_2O + eO_2 + fN_2 + gNO + hC_xH_yO_z) \rightarrow aCO_2 + bCO + dH_2O + eO_2 + fN_2 + gNO + hC_xH_yO_z \quad (1)$$

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