EXPERIMENTAL STUDY ON THE POTENTIAL APPLICATION OF COTTONSEED OIL–DIESEL BLENDS AS FUELS FOR AUTOMOTIVE DIESEL ENGINES

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Abstract: This paper presents the results of an experimental study on the direct application of cottonseed oil–diesel blends as fuel for diesel engine vehicles without using additional retrofit mechanical systems. The use of biofuels is one of the main actions promoted by the European Union and member states in an effort to tackle global warming, enhance energy security and contribute to regional development. Here, the possibility to blend cottonseed oil directly with fossil diesel as a fuel for diesel engines is examined. This option has lower cost and larger well-to-wheel greenhouse gas benefits than fatty acid methylesters. The paper presents measurements of important fuel properties, density, viscosity, cetane number and cold flow characteristics. In addition, a common rail Euro 3 compliant diesel car is tested using 10% v/v cottonseed oil-diesel blends in order to examine the effects on performance and emissions of regulated pollutants and CO_2. Furthermore, particle emission characteristics are studied, including total and solid particle number concentrations and particle size distributions over driving cycles and steady state modes. The results indicate that the test fuel presents good operating characteristics and limited effects on regulated emissions and vehicle performance. These results would justify further research on the direct use of vegetable oils as automotive fuels.

Keywords: biofuels; cottonseed oil; greenhouse gas emissions; exhaust emissions.

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INTRODUCTION

The use of vegetable oil blends with diesel fuel is foreseen in the European Union (EU) with the Directive 2003/30/EC (EC, 2003), which recognises pure vegetable oils as biofuels. These fuels are associated with interesting benefits such as low cost, fewer CO_2 emissions over lifecycle, direct use without expensive installations and equipment requirements and no by-products. The application of such fuels may act as a precursor for future more sophisticated bio-fuels, providing the necessary time to the local economies and consumers for adapting in the new conditions. Furthermore vegetable oil–diesel blends present significant interest for all developing countries which lack energy sources and have agriculture based economies.

So far, several types of vegetable oils have been investigated for direct application as diesel engine fuel such as rapeseed oil, jatropha oil (Forson *et al.*, 2004), coconut oil, rubber oil (Ramadhas *et al.*, 2005), cottonseed oil (He and Bao, 2005), cooked vegetable oils (Zaher *et al.*, 2003) and even tomato seed oil (Giannelos *et al.*, 2005). These studies reveal the potential vegetable oils have as fuels either directly or through transesterification. However they are usually limited to the analysis of the physical properties of the oils and fuels. In the preliminary work conducted in this study (Fontaras *et al.*, 2006), results from an extensive (20 000 km) test fuel application on a Euro 2, 1.9 l turbo diesel vehicle indicated that using cottonseed oil–diesel blends is feasible for older diesel engines without a high pressure injection system. Nevertheless because of the need to limit emissions, improve fuel efficiency and optimise driveability, high pressure injection and common rail technology are currently the state of the art in diesel passenger cars and light trucks. These sophisticated systems are very sensitive to fuel quality and characteristics and thus any diesel fuel substitute should comply with the existing standards and not affect durability and performance. In the following the potential of vegetable oil application and the methodological

approach adopted for the evaluation of the test fuels are described. Additionally, results are presented of measurements conducted both on the fuel physical properties and the performance of a common rail vehicle operated under laboratory and real world conditions.

MOTIVATION

Driven by the Kyoto protocol commitment and the need to reduce their dependency on fossil fuel imports, EU member states are in need of new renewable and domestic energy sources. With directive 2003/30/EC, the EU recognises the important role bio-fuels will play in a new sustainable and competitive economy. The directive proposes that bio-fuels should replace by the end of 2010 the 5.75% of the total fuel energy content used in transport (EC, 2003). Important efforts have been made towards creating the necessary background and infrastructure for supporting such a transition, but it is still doubtful that member states will achieve this target. Although the EU is currently the world leader in vegetable oil methylesters production (IEA, 2004), commonly known as bio-diesel, the production of gasoline bio-fuel substitutes remains very low, a fact which impends the achievement of the 5.75% goal. Furthermore since diesel consumption in EU road transport has surpassed that of gasoline (IFP, 2005) it is more sensible to target towards the development of diesel type biofuels. Second generation biofuels such as Biomass to Liquid products and Fischer Tropsch diesel bare important potential, but the necessary industrial facilities are still under development and will not be available before 2010 (BIOFRAC, 2006). It is evident that diesel-like biofuels should be exploited in the most efficient way.

For southern European economies such as Greece, biofuels can play an important role by stimulating their relatively grown agricultural sector and reducing oil dependency. Local agriculture can provide the raw material for various biofuels and ensure the necessary supply chain. Nevertheless, the raw material production differentiation, the level of industrialization and the ability to implement various production technologies and strategies may require different solutions for different countries. Direct use of vegetable oils such as cottonseed oil as fuels offers several advantages especially in countries that lack industrial infrastructure and know-how to produce biofuels, but have a significant vegetable oil production. In these cases the application of vegetable oils can help accelerating the incorporation of biofuels in the country's economy and gradually help building-up the necessary framework to support advanced biofuels. It can also provide the time in order for agriculture to adapt to the cultivation of new energy plants by starting with crops and practises producers are already familiar with.

Greece in particular, according to 2003/30/EC should replace at least 150kTOE of automotive diesel by the end of 2010. Today approximately 80 000 people and 57 corporations are involved in cotton cultivation and production in Greece resulting in the production of 90–100 ktons of cottonseed oil, which however is not an efficient raw material for biodiesel production. It becomes clear that taking advantage of the energy potential of cottonseed oil bares significant interest for the Greek economy. Based on these ideas and the fact that Greece has, amongst other vegetable oils, a significant cottonseed oil production, the authors, in collaboration with local stakeholders and supported by the Greek state, have initiated a continuous experimental effort in order to investigate the possibility of pure cottonseed oil, as fuel for automotive applications.

METHODOLOGY AND RESULTS

The approach adopted in the present study for the evaluation of cottonseed oil–diesel fuel blends was based mainly on the current EU legislation. According to Directive 2003/30/EC 'pure vegetable oils produced from oil plants through pressing, extraction or comparable procedures, crude or refined but chemically unmodified are recognised as biofuels—plain or blended with diesel—when compatible with the type of engines involved and the corresponding emission requirements'. With regard to the legislative provisions the measurements conducted had two distinct targets:

- Examine if and at what proportion cottonseed oil - diesel blends comply with the existing diesel fuel quality standards (diesel engine compatibility).
- Run vehicle exhaust emission tests (emission standard requirements).

A preliminary set of measurements of some key fuel properties (density, viscosity, cetane number) was conducted for blends of various oil concentrations in order to limit the number of possible fuel–oil concentrations that fulfil the basic fuel standard requirements. The test fuels were then applied on a VW Golf 1.9 TDi passenger car Euro 2 compliant for a mileage of 20 000 km in order to test the effectiveness and applicability of the test fuels. Regular measurements of the vehicle emissions and performance where conducted in the laboratory during this phase. The ratio of the average value measured using the test fuels over the average baseline measurement values for each driving cycle and pollutant is presented in Table 1. Results showed that the presence of cottonseed oil did not significantly affect the vehicle emission and consumption levels. After 20 000 km no important problems appeared due to the use of the test fuels with the exception of engine start-up difficulties under cold weather conditions (Fontaras *et al.*, 2006) which highly depend on the oil concentration. It was concluded that the concentration of cottonseed oil that complied better with existing legislation and presented better operational characteristics was 10% v/v.

In view of the findings of the initial test phase new measurements were conducted focusing on the standardized properties set for diesel fuel in Europe and some additional non-legislated cold flow characteristics. Moreover extensive application and detailed laboratory measurements were decided for evaluating the compatibility of the test fuel with modern common rail technology vehicles.

Cottonseed Oil–Diesel Blends Properties Measurements

The fuel properties investigated were density, viscosity at 40°C, higher heating value, cetane number, cetane index, cold filter plugging point, cloud point, pour point, flash point and copper strip corrosion test. The fuels tested were cottonseed oil–diesel fuel blends of low oil concentration (10 and 20% v/v) and standard diesel fuel for reference. As vegetable oil properties can be affected by several factors