

Cold and Warm Start Characteristics using HVO and RME Blends in a V6 Diesel Engine

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ABSTRACT

The first several cycles determine the quality of an engine start. Low temperatures and air/fuel ratio cause incomplete combustion of the fuel. This can lead to dramatic increases in HC and PM emissions. In order to meet Euro V legislation requirements which have stricter cold start emission levels, it is critical to study the characteristics of cold and warm starting of engines in order to develop an optimized operation. The NO and THC emissions were measured by fast CLD and Fast FID gas analyzers respectively and PM in both nucleation and accumulation modes were measured by DMS500. The coolant temperature was controlled in order to guarantee the experiment repeatability. The results show that at cold start using RME60 produced higher NO and lower THC than the other tested fuels while combustion of HVO60 produced a similar level of NO but lower THC compared with mineral diesel. Meanwhile, the nucleation mode of mineral diesel was similar to RME60 but higher than HVO60. The accumulation particle of using mineral diesel was higher than RME60 but lower than that of HVO60. As the engine coolant temperature increased to 90°C, the NO emission of each fuel was increased by varying amounts. THC and PM of all fuels were decreased except for HVO60 which increased THC and nucleation mode PM dramatically.

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INTRODUCTION

Diesel engine emissions at engine start have always been a problem. The low temperature and air/fuel ratio causes incomplete combustion of the fuel which leads to dramatic increases in HC, NO and PM emissions. In order to meet the Euro V legislation which has a more restricted level for cold start emissions, it is critical to study the characteristics of cold and warm start for optimized engine operation.

Bielaczyc et al. investigated the cold and hot start emissions from a DI diesel engine [1]. Their results showed that more than 40% of total emissions were produced in the first 60 s during the 3 min cold start operation. They noted that more than 50% of PM was emitted during the first 60 s. They also reported that the THC and PM of cold start were several times greater than that of warm start during the first 3 min, while CO of cold start was almost two orders higher. The emissions of cold start are related to incomplete combustion due to engine design and operating factors. Those factors include ambient temperature [2, 3, 4], injection strategies [4, 5, 6], fuel properties [7-8], cranking speed [5],

compression ratio [9] and some other control strategies, like EGR applied [10]. Since different types of biodiesel and blending ratios are used in different regions, more attention was given to fuel properties in this study.

L. Starck et al. concluded that the increase in volatility and cetane number reduced the start instability [11]. Octavio Armas et al. tested vegetable oil methyl ester during start and reported that biodiesel content reduced the smoke opacity because of the oxygen molecule content and the absence of aromatics [12]. J. Schramm et al. pointed out that the total PM of biodiesel may still increase due to higher SOF (soluble organic fraction) produced by biodiesel [13]. They also concluded that SOF was the major part of the PM emissions when using biodiesels at warm start, the ratio was 50%-90% (dependent on fuel). Both the regulated and unregulated gaseous emissions were investigated by Amanda Lea-Langton et al [14]. They started the engine from cold and reached the required load without an idling period. Their results showed that the THC and CO emissions obtained using biodiesel were reduced at low target power but almost

identical with those of mineral diesel at high target power. On the contrary, formaldehyde emission, the predominant aldehyde, obtained using biodiesel showed a similar trend with that of mineral diesel at low target power.

However, there is not much literature available about cold start performances and emissions using Hydrogenated Vegetable Oil (HVO). In this study, two different types of biodiesels, Rapeseed Methyl Ester (RME) and HVO, were used at both cold and warm start. They were blended in mineral diesel within 60% by volume separately. The influence of RME60 and HVO60 on cold and warm start performances and emissions are investigated experimentally.

EXPERIMENTAL SETUP AND PROCEDURE

The Engine

Tests were conducted on a Jaguar 3.0-litre common rail direct injection six-cylinder diesel engine. The engine was equipped with EGR intercooled system for NOx control. Split injection strategy consisting of two pilot injections and a main injection was employed at steady idling for high engine performance. An external engine coolant circulation with 3KW heat capacity was built for engine coolant warming up before engine start. A circulating pump was installed to circulate the engine coolant from the engine block to the heater and then back to the engine block. By this circulation, the engine coolant in the engine block can be heated up and resulted in a warm engine block and head. The engine specifications are shown in table 1.

Ambient relative humidity was monitored and kept approximate 35-40%. The engine room was isolated well with specific ventilation to maintain the room temperature at approximately 20°C.

Table 1. The experimental engine specifications

Bore X Stroke	84.0 mm X 90.0 mm
Swept Volume	2993 cc
Max CP	180 bar
Max Power	199 KW @ 4000rpm, 475Nm
Max Torque	600 Nm @ 2000rpm
Max Speed	5000 rpm @ no Load
Injection Type	CRDI
Max Inj Press	2000 bar

The Diagnostic System

The data acquisition and processing systems are shown in Figure 1. A Cadet V14 System from CP engineering was used to control the engine throttle and dynamometer as required. An INCA system from ETAS provided communication with the ECU and also recorded some engine parameters, such as the mass air flow, fuel injection quantity and engine speed.

In-cylinder pressures of cylinder 2 and 5 were measured by a piezo-electric pressure transducer and the cycle by cycle data from engine start was recorded by an AVL Indimodule 621 and then processed through AVL indicom. The pressure measurement was triggered by an AVL optical encoder with 720-degree resolution on the crankshaft. Fuel temperature was controlled by the CP Engineering FCU1000 fuel cooling unit. The Combustion Fast FID/CLD and DMS500 were connected before the exhaust catalyst to measure the emissions of THC, NO and particle matter. The NOx detector of fast CLD was disabled in order to reduce the measurement delay. The THC and NO signal were recorded by a Labview data acquisition program through a NI card. To synchronize all the control and measurements variables from the different systems, the starter motor voltage and in-cylinder pressure signal were recorded together with emissions signals in real time.

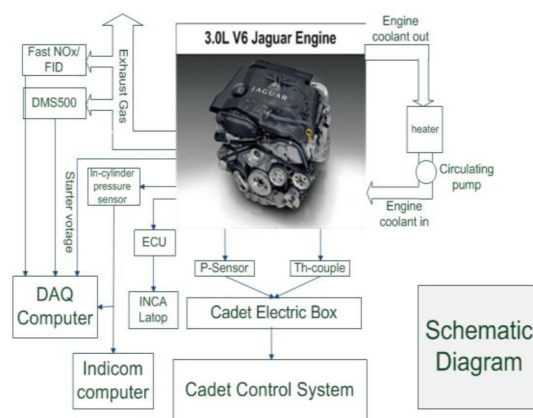


Figure 1. Diagnostics and data processing arrangement of the test engine

The Experiment Procedure

To ensure good repeatability, the engine has to be soaked at room temperature for at least 9 hours before start. With the battery fully charged and measurement equipments fully warmed up, the engine was started and kept at idling for 3 minutes. After engine stop, the starter was cranked without fuel injection to eliminate the residual gas in cylinder. In addition, the crank shaft was adjusted to the same position manually after every test. Each test was repeated three times, so that their average value and standard derivation could be calculated to check the repeatability.

In the warm start test, the procedures were almost the same with cold start. The only difference was that the engine coolant was heated to 90°C before the tests. The aim is to set the engine condition close to that of a hybrid electric vehicle (HEV). In the HEV system, the engine coolant might be warm even engine was not running due to the heat exchange of the battery or other facilities. Thus, it is possible to start the engine at the conditions with warm coolant but the engine oil and other parts remain cool. In addition, researchers also developed a thermal energy storage device (TESD) which is able to charge the coolant temperature before engine start [15]. By heating up the coolant only, the effect of engine coolant temperature can also be investigated.

Fuel Properties and Chemical Compositions

Fuel property is an important parameter which affects engine performance and emissions. Table 2 shows the properties of biodiesel blends and mineral diesel used in the experiments. Both of the biodiesel blends have higher cetane number than mineral diesel. But the other properties of the two fuels are different compared with those of mineral diesel. HVO60 has higher energy density but lower viscosity and surface tension than those of mineral diesel while RME60 has lower energy density, higher viscosity and surface tension. This is caused by the different chemical composition they have. The paraffin content in HVO is formed of high saturated long chain hydrocarbons which contain higher energy and are of a lower density. However, the oxygen in the methyl ester component of RME reduced the molecule energy and increased its density. RME60 also has the highest initial boiling point of the three fuels [16].

Table 2. Properties of each fuel

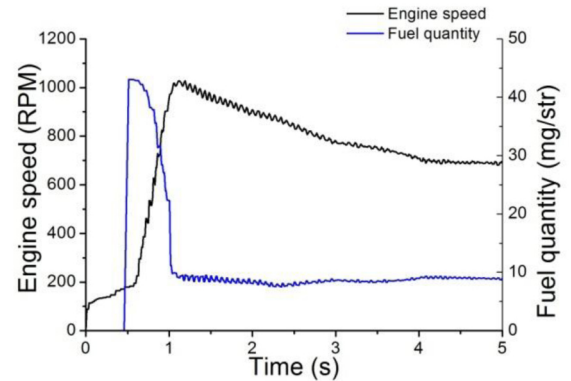
		Mineral diesel	RME60	HVO60
Fuel Properties	Unit			
Cetane number		56.7	60.3	64.3
density	Kg/m ³	832.7	863.3	798.7
Carbon content	%	85.9	79.9	85.1
Hydrogen	%	13.6	12.3	14.4
gross heat of combustion	MJ/kg	45.62	41.6	46.72
net heat of combustion	MJ/kg	42.72	38.98	43.66
Viscosity	10-3Pa.s	3.6	5.27	3.43
surface tension		26	27.1	25

RESULTS AND DISCUSSIONS

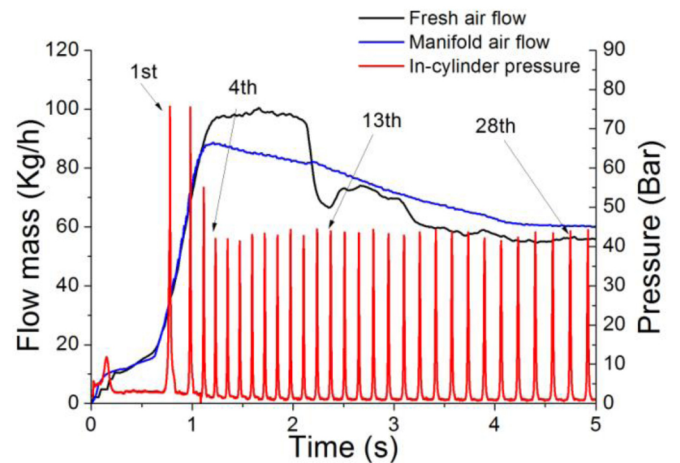
Cold Start Characteristics

Figure 2 describes the cold start characteristics of the engine when it is fueled with mineral diesel. The engine was

first cranked by the starter. Once a certain speed was achieved, the initial quantity of fuel injected was large to ensure firing. The high power of the first 2 fired cycles increased fresh air inlet mass and pressure for better combustion at engine start. This period is called the acceleration period and finished at a time of 1s or the 2nd cycle according to the fuel injection quantity and in-cylinder pressure curves.



(a)



(b)

Figure 2. Characteristics of cold start with using mineral diesel (a) engine speed and fuel injection quantity. (b) In-cylinder pressure, flow mass of fresh air and air in manifold.

After the acceleration, fuel injection quantity was decreased to a low level and kept steady. Engine control parameters, such as the opening rates of VGT and EGR valves, were adjusted to ECU setting values. During this period, the fresh air inlet pressure was so high that almost 20% fresh air was lost through the EGR hose from cycle 3 to cycle 12. This air loss wasted the turbocharger's power and increased the instability of fresh air mass. It also led to EGR rate fluctuation during this period.