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Engine blow-by with oxygenated fuels: A comparative study into cold and hot start operation

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ABSTRACT

T{(NPI), 1999 #117}his research compares the effects of oxygenated fuels on engine blow-by during engine cold and hot start operation using a common rail, turbocharged diesel engine. Diesel, waste cooking biodiesel and a highly oxygenated additive, triacetin, were used to make a range of fuel oxygen contents (0–13.57%). This study investigated engine blow-by and its correlation with indicated, brake and friction power; and blow-by normalised by different parameters. Result showed that neat diesel produces higher blow-by during cold start than the oxygenated fuels. There was a strong correlation between blow-by and indicated power, and the fuel calorific value was identified as a leading factor. To further analyse the results, this study normalised the engine blow-by by power to reveal the other influences on engine blow-by. The result verified the strong influence of power. This study also furthered the analysis by normalising the blow-by data by exhaust flow rate, intake air flow rate and injected fuel flow rate. It was discovered that oxygenated fuels perform better between hot and cold start, when compared to diesel. The blow-by inhibited properties of oxygenated fuels, such as higher lubricity and viscosity may be the cause for better performance of oxygenated fuels during cold start.

1. Introduction

Cold start is a condition where an engine is started at ambient temperature after a long soak, and includes the period until the engine has warmed to steady-state operational temperature. Cold engine operation is a daily reality for engines worldwide, whether it is a personal, commercial or industrial vehicle or engine. During cold start engines are less efficient due to thermal losses [1]. These losses occur due to the temperature difference between the cylinder walls and combustion, as well as the high viscosity of the cold lubricant causing frictional losses [1]. These frictional losses can be up to 2.5 times higher during cold start [2]. In addition to these losses, the lubricant does not circulate as intended due to its higher viscosity, which can lead to damage of the engine when put under load at this time [2]. It has also been shown by Samhaber et al. [3] that fuel consumption can increase by 12.7–14.1% during cold start.

Many vehicle journeys start and finish during cold start, before the engine reaches optimal temperature. It is estimated that the average car journey in Europe is approximately 10 km in length, and 80% of American car trips are less than 15 km [1]. A previous study in Europe on 35 vehicles found that 52% of journeys were less than 3 km [4], with additional work showing that one third of car trips are completed before the engine reaches thermal equilibrium [5]. Considering also the corresponding prevalence of cold start operation in commercial industries utilising marine, locomotive and automotive engines, it can be seen why developing an understanding of cold start performance is of importance in the drive towards improved engine efficiency.

The literature review returned different definitions for cold start. Some of these definitions of cold start were reviewed by Reiter and Kockelman [6]. After consideration of the literature, this study defines cold start to be when an engine starts after an overnight soak (engine-off time) and operates until the engine coolant temperature reaches 70 °C, according to EU Directive 2012/46/EU. Included in this investigation is a condition in which the engine coolant temperature is greater than 70 °C, but the engine

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lubricating oil is still sub-optimal in relation to full operational temperature. Cold start engine operation affects the engine performance parameters such as engine power, fuel consumption and engine efficiency [2] [3]. It also affects the exhaust emissions. Studies in the literature have mostly focused on regulated exhaust emissions (e.g. CO_2, CO, HC, PM, PN, NO_x) during cold start [2,7], however, other engine emissions, such as blow-by, could be affected by cold start operation.

Engine blow-by is a phenomenon where pressure, in the form of air-fuel mixture is forced past the piston rings into the crankcase of the engine [8]. This occurs primarily during the power stroke of the engine, although compression stroke blow-by does occur [8]. It represents lost efficiency in that the pressure lost in blow-by is not being used to rotate the crankshaft. Blow-by also causes contamination of the engine lubricant as partially and un-combusted air-fuel mixture enters the crankcase. The contamination of the engine lubricant due to blow-by greatly increases the rate of degradation of the lubricating oil, leading to decreased oil longevity and increased engine wear [9,10]. A small addition of soot to the lubricant will also alter the oil viscosity significantly, increasing the frictional losses inside the engine, thus further reducing the mechanical efficiency and increasing fuel consumption [11]. The emitted blow-by mixture is also high in particulate matter contaminants; as blow-by in an engine increases, so does pollution [7].

Solid thermal expansion is a phenomenon which is an influential factor affecting blow-by, and is a reason for considering the clearance and slots among the piston head, rings and cylinder wall when designing engines. It is common in automotive manufacturing for pistons to be designed with an elliptical shape – referred to as “cam-ground” – that allows for the thermal expansion of the piston components as they reach operating temperature [12,13]. It is a noted disadvantage to the design that exposing the piston to high in-cylinder pressures before the engine has warmed can lead over-stressing of the piston components [12]. Therefore, it is very possible that this is a strong contributor to variation in engine blow-by performance during cold start, as the blow-by leak path is changing in geometry between cold and hot start.

Research conducted by Rao et al. [14] found that the blow-by fraction (blow-by mass/trapped massed) decreased exponentially with increasing engine speed, levelling out to a linear decrease at around 1000 rpm. It was concluded that this was due to the inferior splash lubrication of the piston rings at lower engine speeds. This trend is also corroborated by Ebner and Jaschek [15], finding that although the blow-by flow rate in litres per minute increased with speed, the blow-by as a ratio related to intake air flow decreased significantly with increasing speed, falling from 1.42% to 0.44%.

The phenomenon of engine blow-by is noticeably worse during cold start in comparison to hot start. Research shows that poor engine lubrication [2], inferior air-fuel mixing and higher thermal losses [16–18] increase blow-by and lower power output during cold start. These studies, however, only investigated cold start blow-by with diesel fuel. There is also little existing research comparing engine blow-by with alternative fuels during hot start. To the knowledge of the authors, there is no research prior to this work that specifically investigates engine blow-by during cold start with oxygenated fuels, an important topic that should not be ignored.

Interest in biodiesels has grown substantially in recent years with the drive towards renewable energies. Biodiesels are derived from renewable biological sources such as waste plant and animal matter [19]. Biodiesels are lower in energy content per unit volume than neat diesel [20], and the addition of oxygen to the fuel mixture in the combustion chamber has many effects [21]. Using oxygenated fuels leads to a lower brake mean effective pressure (BMEP) as a consequence of the lower calorific value due to the oxygen content [22]. Biodiesels are also more viscous than neat diesel, typically ranging from 35 to 50% more viscous at 40 °C [23–26]; this has a significant effect on the combustion properties of biodiesels.

An experiment by Agarwal [27] analysed the effect of biodiesel on lubricating oil tribology. In this experiment two small diesel engines, one fuelled with biodiesel and the other neat diesel, were run for 32 cycles lasting 16 h each at a rated speed of 1500 rpm, with the lubricants properties measured after every 128 h. The first finding of the study was that the density of the lubricant in the neat diesel sample was higher after each period of use. It was also observed that the ash content (defined as mainly metallic wear debris and dust particles) in the lubricant taken from the biodiesel sample was approximately 15% lower at each sample, indicating less metallic wear. It was discovered that the lubricant viscosity in the biodiesel sample decreased at a lower rate than the neat diesel sample at both 100 °C and 40 °C. The last major finding was that the biodiesel lubricant sample contained approximately 15% less moisture – generally water – at each measurement period. The conclusion of this report was that the higher viscosity of biodiesels reduces blow-by production.

As mentioned, cold start is a daily reality for engines worldwide, with a great deal of daily trips involving vehicles operating under cold start conditions [1]. With blow-by as an area of concern in improving engine performance and the desire to seek renewable fuels in the form of biodiesels, an understanding of the interaction between these occurrences is important. The lack of explicitly relevant prior research on the interaction of oxygenated fuels and engine blow-by during cold start highlights the novelty and importance of this paper.

The purpose of this paper is to investigate the blow-by characteristics of a six-cylinder turbocharged diesel engine with a common-rail injection system during cold start with comparison to hot start, running on four different fuels varying from 0 to 13.57% in oxygen content using a custom test, which is detailed in Section 2.3. In order to analyse the blow-by characteristics, parameters such as blow-by, intake air, fuel consumption, engine brake power, engine speed and in-cylinder parameters will be measured for analysis. To determine the effect that cold start has on engine blow-by, comparisons to hot start tests will be made. In order to have a more fundamental study on the effects of cold start operation and oxygenated fuels, this research, analyses the raw blow-by data, and the blow-by data which is normalised by the engine power, the exhaust flow rate, intake air flow rate and injected fuel flow rate. Conclusions can be drawn as to how oxygenated fuels interact with engine blow-by during cold start when compared to hot start.

2. Materials and methods

2.1. Engine specifications

In this experiment a six-cylinder four-stroke turbocharged Cummins diesel engine with a common rail injection system was used. The exact specifications of this engine are provided in Table 1. An electronically controlled water brake dynamometer was coupled to the engine to control the engine load. The QUT Biofuel Engine Research Facility (BERF), where this experiment was performed, has the ability to program and automatically run different test cycles. Fuel flow rate in litre per minute (LPM) and intake air flow rate in kg/s were sampled from the CANbus at 1 Hz; the exhaust flow rate was calculated based on these two measured flow rates. The blow-by exhausted from the engine crankcase was measured by a commercial blow-by sensor, which sampled the blow-by flow rate in LPM at 1 Hz. An in-cylinder pressure transducer (piezoelectric transducer, Kistler 6053CC60, with ≈ −20 pC/