Fuel 235 (2019) 603–609

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Improvement of engine performance and emissions by biomass oil filter in diesel engine

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ARTICLE INFO

Keywords:
Engine oil filter
Impurity adsorption
Engine exhaust emissions
Engine performance
Diesel engine

ABSTRACT

In this study, a modified-sawdust lubricant oil filter (MSF) was developed and its effect on emission characteristic and performance of diesel engine was studied compared with conventional fiber-paper oil filter (CPF). The tests were performed using a six-cylinder, heavy-duty direct injection diesel engine. In steady state, the brake-specific fuel consumption (BSFC), engine output power and engine oil pressure were measured at nine different typical engine speeds. Exhaust emissions of nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO) and hydrocarbons (HC) were analyzed according to European Steady-state Cycle (ESC). Besides, lubricant oil samples were extracted from the crankcase in the equipment of MSF and CPF individually. Then the kinematic viscosity, colloids and metal content of oil samples were determined. The results showed that MSF effectively reduced wear metal accumulation and insoluble colloids in lubricating oil, and thus retarded deterioration of oil viscosity. Compared with CPF, an increase of 2.7 kW in maximum output power and decrease of 1.66–2.85% in BSFC were observed for MSF. In addition, the using of MSF significantly reduced HC (60.9%) and PM (12.5%) emission while increased CO and NOx emission slightly. The results proved that MSF is a suitable choice for diesel engine to improve engine performance and reduce exhaust emissions.

1. Introduction

Nowadays, the depletion of non-renewable fossil resources and the deterioration of global air condition that has caused irreversible human health problems are two challenges faced any countries and citizens. With the development of internal combustion engine, these two issues have been increasingly serious. It would be very urgent to save fossil resources and to reduce harmful exhaust emissions produced by internal combustion engine vehicles in the coming decades [1,2]. It has been reported that transportation engine emissions account for 23.5% of air pollution and many countries have drawn up stringent environmental laws and regulations [3]. Diesel engines are the most widely used engine for its high fuel-energy conversion efficiency, as a consequence diesel exhaust emission becomes an important source of atmospheric pollution [4,5]. A lot of technologies have been developed to meet the strict environmental regulations and reduce consumption of petroleum-based fuel.

Currently, many researchers have focused on the development of alternative biofuel or fuel additives to improve fuel economy and to reduce exhaust gas emissions. Asokan et al. [6] found that diesel engine fueled by bio-diesel/diesel blend produced lower CO and HC emission as well as lower diesel consumption rate. Wei et al. [7] reported lower NO_X emission in diesel engine fueled with waste cooking oil biodiesel blends. However, it still has a long way to go for its widespread because of low calorific value. At the same time, many researchers have proposed improvement method that based on the optimization of stroke structure and design of the fuel injection system to improve the engine efficiency. Park et al. [8] developed a secondary injector to make exhaust gas lean and rich conditions for controlling LNT system to reduce NOx emissions. Gumus et al. [9] found that the increasing of injection pressure could decrease BSFC, CO, and HC emissions. Although the above auxiliary operation and technology can promote fuel efficiency and reduce emissions to a certain degree, is still suffer from high cost and may not practical for the existing internal combustion engines and on-road vehicles.

The lubrication system in internal combustion engine plays an important role in maintaining its normal running. Industry and transport sector are mainly dependent on the petroleum-based lubricant that can clean the mechanical parts, seal piston and cylinder wall as well as prevent corrosion. The lubricant can also reduce friction loss thus directly save fossil resource [10,11]. However, lubricating oil is easy to be contaminated by various impurities such as wear metal particulate and

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https://doi.org/10.1016/j.fuel.2018.08.038
Received 5 May 2018; Received in revised form 6 August 2018; Accepted 9 August 2018
0016-2361/

Nomenclature

MSF	Modified-sawdust lubricant oil filter
CPF	Conventional fiber-paper oil filter
RS	Raw sawdust
MS	Modified sawdust
BSFC	Brake-specific fuel consumption
ESC	European Steady-state Test Cycle
ECU	Electronic control unit
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometer
rmp	revolutions per minute
CO_2	Carbon dioxide
HC	Hydrocarbons
PM	Particulate matter
NO_X	Nitrogen oxides

fuel residue especially for engines that has run for a long time. At high temperature, lubricant oil is prone to be oxidized by air and generate colloids which are detrimental to lubrication property [12,13]. Recent research indicates that the quality and composition of lubricant oil have a direct impact on the engine emissions [14] and performance [15,16]. Once replaced by new lubricant, the used oil will also pollute environment if not properly handled. Furthermore, the disposal would require a complex technology and large cost [17,18]. Therefore, to prevent environmental pollution and save petroleum sources, the properties of lubricants need to be maintained to promote engine performance, extend drain intervals and reduce emissions in the long-term running. The impact of oil filter on lubricating oil stability and engine performance has been of interest to researchers for a long time [19]. In early years, some additives were added into the oil filter element to extend the useful life of lubricating oil in an internal combustion engine [20]. Afterward, Watson et al. [21,22] developed an innovative oil filter with chemical modification which performed well in controlling of engine oil acidity. In recent years, Gulzar et al. [23] modified the oil filter element with sodium hydroxide which showed great prospect in improvement of lubricant sustainability and reduction of exhaust emissions.

The most widely used materials for oil filter are the synthetic fiber paper or metal mesh on the market, which can effectively remove particulate impurities but show deficiency in the removal of insoluble colloids from lubricant. Renewable and easy available biomass materials, such as plant residues, straw, and sawdust possess rich pore structure and natural texture which show large adsorption capacity to dyes, oil, toxic salts, and heavy metals [24]. These materials have aroused great interest of researchers as an economic adsorption material for the remove of heavy metals in sewage and grease in industrial drainage [25,26]. However, it is rarely reported for the filtration of oily substances. In our early work, a chemical modification method has been developed for raw sawdust and the modified sawdust showed good adsorption ability for impurities from used lubricant in the laboratory adsorption experiments [27]. In this work, the modified sawdust was processed as a lubricant oil filter, which was defined as MSF. Its effect on diesel engine performance and exhaust emissions were investigated on automotive engine test bench compared with CPF. Besides, the effect of this novel oil filter on lubricant property changes and impurity content was also investigated in the actually running engine. In this paper, heavy-duty vehicle diesel engine was used as an example of all kinds of diesel internal combustion engine to illustrate the impact of MSF on engine performance and emissions. This research provides fundamental basis for industry, vehicle and marine engine's online applications of MSF.

2. Materials and methods

2.1. Preparation of modified sawdust oil filter

The mixture of eucalyptus sawdust raw material and birch sawdust at a mass ratio of 10:1 was modified via chemical treatment of alkaline solutions [28]. Typically, the mixed solvent consists of tetraethyl ammonium bromide (TEAB), triethanolamine (TEOA), lithium bromide, sodium carbonate, and distilled water at a mass ratio of 0.2:0.3:2.5:12:70. All reagents came from Sinopharm Group Co., Ltd and were used as received without further purification. The modification of sawdust was carried out according to following standard procedure. The mixed sawdust (500 g) was immersed in the above solvent (500 g) and stirred at 323 K for 48 h. Afterwards, the sawdust was washed with distilled water until the filtrate was mainly clear with the pH value around 7. At last, modified sawdust was obtained by drying in an oven at 353 K for 10 h and cooled in desiccator. The sawdust with a size between 20 and 35 mesh screens before and after modification was analyzed by FT-IR spectra in Nicolet6700 with a resolution of 4 cm^{-1} at 64 scans by KBr disks. The above MS was processed into lubricant oil filters as filter elements and it was processed as industrial practical shape. Comparison of final form of MSF (Savon JX0818) with CPF used in this study was shown in Fig. 1.

2.2. Fuel and lubricant oil

The test engine was fueled by commercially available, ultra-low sulfur diesel fuel obtained from Sinopec Beijing Yansan Co. Ltd. The diesel fuel used in our test fulfills standard normative EN590-2008 and some of fuel specifications were given in Table 1. The lubricating oil used in this process was CF-4 15W-40 grade oil from Petro China Lanzhou Petrochemical Co. Ltd. In order to explicitly illustrate the effect of MSF on vehicle engine emission and performance in long-term running, the lubricating oil, which has already lubricated the vehicle engine for 12000 km (marked as 12 K) was used in the test of MSF and

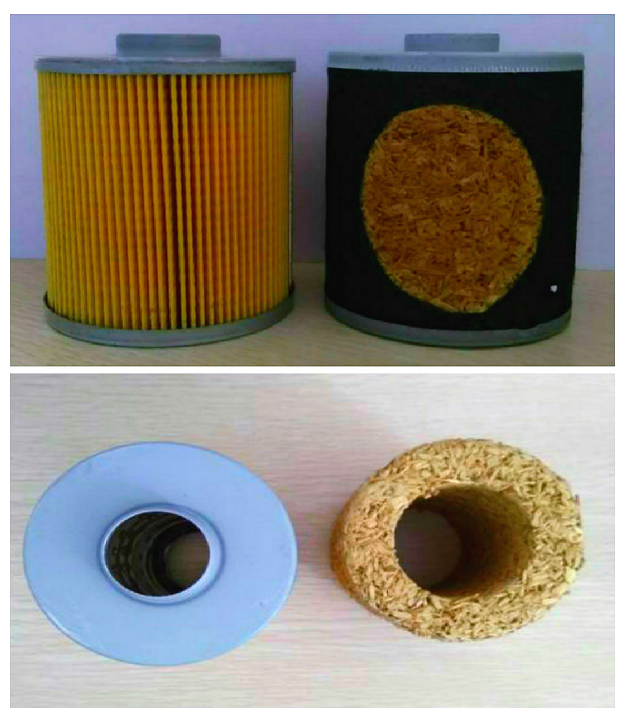

Fig. 1. Appearance of conventional fiber-paper filter (left) and modified sawdust oil filter (right).