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Reducing volatile organic compound emissions from diesel engines using canola oil biodiesel fuel and blends

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ABSTRACT

Volatile organic compounds (VOCs), a group of environmental pollutants, are emitted in large quantities when fossil fuel is burned in automobiles. This research investigates the VOCs in the exhaust emissions from a common rail diesel engine fueled with canola oil biodiesel fuel (COBF), conventional diesel fuel (CDF), and B20 (20% COBF blended with 80% CDF by volume) at various engine loads (30 Nm, 80 Nm, 130 Nm) and a constant engine speed of 1500 rpm. The results indicate that the regulated emissions (CO, HC, PM) were reduced obviously when COBF and B20 were used in a CRDI diesel engine, and a larger number of VOCs (about 30 types) are emitted with CDF and the quantity emitted is greater than with B20 and COBF. The total VOC emissions (TVOC) of B20 were lower than those with the other test fuels at all experimental conditions. In addition, this paper presents a simple approach for sampling VOC emissions from diesel engines, uses a gas chromatography/mass spectrometry (GC/MS) analysis, and also confirms that COBF blended with CDF in a volume fraction of 20–80 is an excellent alternative fuel based on VOC emissions.

1. Introduction

Volatile organic compounds (VOCs) are harmful air pollutants that pose a serious threat to human health and negatively impact the environment. VOC sources are divided into indoor and outdoor [1,2]. Indoor sources include building materials [3], painting materials [4], packaging materials [5], and furniture items [6]. Outdoor sources include combustion of fossil fuels [7], vehicle exhaust [8–11], and industrial exhaust [12,13]. Overexposure to VOC in humans can produce dizziness, nausea, vomiting, weakness of limbs, and other symptoms of discomfort. Prolonged exposure to VOCs can lead to kidney failure, cancer, and death [14–16]. In addition, with sufficient illumination, a photochemical reaction between VOCs and NOx produces ozone, which also threatens human health as well as that of animals and plants [17]. Therefore, reducing the VOC content in the air is a particularly important topic in the field of environmental protection research.

Currently, there are two main ways to reduce VOCs in the air, and these, like diesel engine exhaust emissions, can be divided into "post-treatments" and "pre-treatments." The "post-treatment" technique involves adsorbing or decomposing VOCs using some sort of adsorbent material [18–20]. As nanocomposite technology has developed, a variety of nanocomposite adsorption materials for air purification [21–23] have been developed. Some researchers have used electrospinning technology to synthesize nanocomposite films [24–26] that offer good VOC adsorption from air. For example, Kim et al. [25] succeeded in combining fly ash (FA) powder with polyurethane (PU) using electrospinning technology. They reported that PU with 30 wt% FA can adsorb about 35 μg of benzene and 40 μg of toluene per gram of fiber. Celebioglu et al. [27] reported that hydroxypropyl-beta-cyclodextrin and hydroxypropyl-gamma-cyclodextrin electrospun nanofibers have high adsorption capability for the VOCs aniline and benzene. Nanofibers produced by electrospinning technology have higher surface area than the same materials in powder form. Many materials can adsorb VOCs, such as activated carbon [28], activated carbon nanofiber material [29], cyclodextrin polymers [30], and titanium dioxide [31]. However, despite the many modern materials [32,33] that can adsorb VOCs, associated treatments merely reduce VOCs after they have been emitted; they cannot solve the problem at the source. Pre-treatment techniques, such as biodiesel fuels, can reduce the amount of VOCs emitted into the air by fossil-fuel combustion applications [34,35].

Biodiesel fuels, an alternative to fossil fuels, can be produced from vegetable oils or animal fats and have the unique advantages of being non-toxic, harmless, recyclable, environmentally friendly, and biodegradable [36,37]. Fig. 1 compares the exhaust emissions of fossil fuels and biodiesel fuels. Since the 1890s, when Rudolph Diesel first discovered that vegetable oil could be used in diesel engines, the study of

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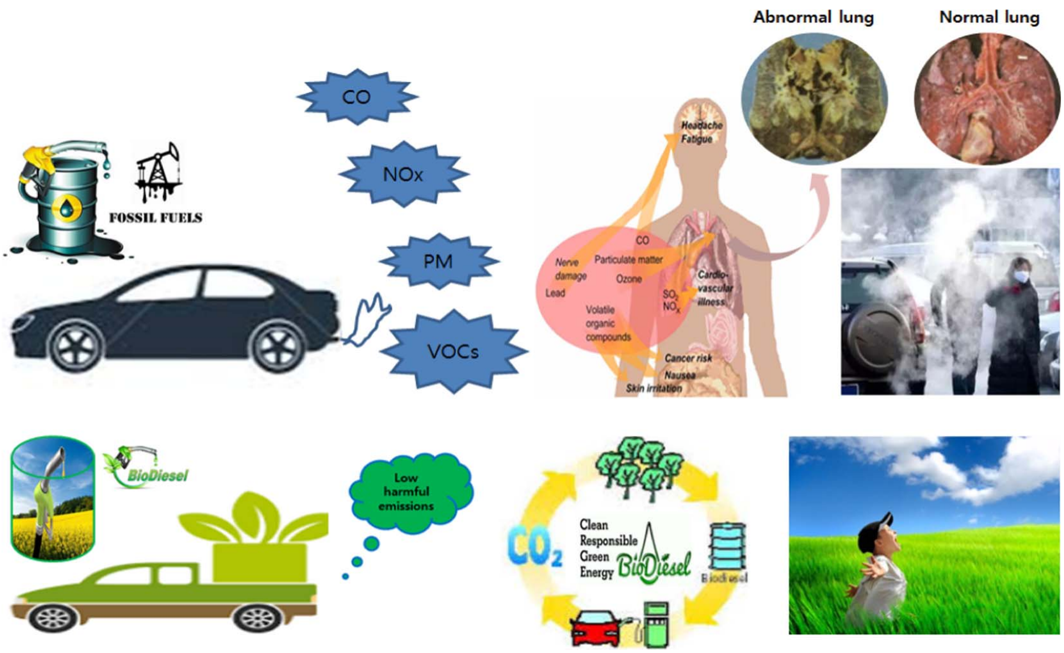

Fig. 1. Exhaust emissions comparison between fossil fuels and biodiesel fuels.

biodiesel fuels has been ongoing [38–40]. Many researchers have demonstrated that biodiesel fuels can be applied directly to unmodified diesel engines [41,42]. However, unmodified diesel engines cannot operate long-term on pure biodiesel fuels because their high density and viscosity erode the engine's rubber rings and tubing, clog nozzles, and increase carbon deposition. Therefore, biodiesel has to be blended with conventional diesel fuel [43–45].

At present, the research on VOC emissions from a diesel engine fueled with biodiesel fuel is inadequate. In this study, the emissions of 15 types of VOCs (1-butene, 1-pentene, furan, 2-propenal, 2-propanone, dichloromethane, 2-methyl-1-pentene, chloroform, benzene, toluene, o-xylene, n-nonane, benzaldehyde, octane, and n-octyl ether) were investigated in a common rail direct injection (CRDI) diesel engine fueled with canola oil biodiesel fuel (COBF), conventional diesel fuel (CDF), and B20 (20% COBF blended with 80% CDF by volume) at various engine loads (30 Nm, 80 Nm, 130 Nm) and a constant engine speed of 1500 rpm. The total VOC emissions (TVOC) from burning B20 were lower than those from CDF and COBF at all experimental conditions. We also offer improved data about COBF applications to diesel engines based on our previous studies [46–48].

2. Materials and methods

2.1. Characteristics of test fuels

Previous studies [46–48] found that, when the volume ratio of biodiesel to diesel reached 20%, the engine had excellent engine combustion performance and emitted only a small amount of harmful exhaust. Therefore, we selected CDF (SK self-service gas station, Jeonju-si, Korea), B20, and COBF (GS Bio, Yeosu-si, Korea) as test fuels. COBF, an alternative fuel, has been a research focus for a long time because of its low cost, safety, high environmental stability, rich oil content, and other desirable properties. Their physical and chemical properties are shown in Table 1. Clearly, the density and lower heating value of CDF and COBF are very similar, and the COBF has a high cetane number and oxygen content. They operate well in diesel engines as a good blended fuel because of their mutual dissolution properties.

Table 1
Properties of CDF, B20, and COBF.

Properties	Unit	CDF[1]	B20[2]	COBF[3]
Density (at 15 °C)	(kg/m^3)	830.1	840.1	880
Viscosity (at 40 °C)	(mm^2/s)	2.872	3.016	4.290
Lower Heating Value	(MJ/kg)	42.31	41.756	39.49
Cetane Number	–	48.5	51.1	61.5
Flash Point	(°C)	93	110.8	182
Pour Point	(°C)	−21	–	−8
Oxidation Stability	(h/110 °C)	25	–	15
Ester Content	(%)	–	–	98.9
Sulfur	ppm	500	–	0
Oxygen	(%)	0	–	10.8

[1] Conventional diesel fuel.
[2] 80% conventional diesel fuel blended with 20% canola oil biodiesel fuel by volume.
[3] Canola oil biodiesel fuel.

2.2. VOC emissions sampling system and VOC emissions analysis system

2.2.1. VOC emissions sampling system

The temperature of exhaust emissions increases by about 350 °C when the CRDI diesel engine runs under high speed or high load conditions, and that high temperature can easily burst the sampling bag, causing collection failure. Therefore, a cooling device is needed to reduce the temperature of the exhaust gas enough for it to be safely collected by the sampling bag. A schematic diagram of the VOC emissions sampling system used in this experiment is shown in Fig. 2. The cooling fan from a diesel engine (2004 Hyundai Santa Fe, Ulsan, Korea) was used to cool the exhaust gas to a constant temperature of 30 ± 3 °C. A manifold was arranged at the rear end of the exhaust pipe after the cooling system. The VOC emissions sampling bag (5L, TD-AP05, Aluminum Gas Sampling Bag, LKLABKOREA Inc., Gyeonggi-do, Korea) was connected to the manifold through a valve, and 5 L of exhaust gas for each of the 3 test fuels (CDF, B20, COBF) were collected at engine loads of 30 Nm, 80 Nm, and 130 Nm, all at a constant engine speed of 1500 rpm.

2.2.2. VOC emissions analysis system

The VOC emissions from the three test fuels were analyzed using a Purge & Trap analyzer (JDT-505II/2010GC/QP2010MS, Japan