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Carbon speciation of exhaust particulate matter of public transit buses running on alternative fuels

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HIGHLIGHTS

- Change from ultra-low sulfur diesel (ULSD) to biodiesel (BD) in different idling mode.
- Carbon source profile for both alternative fuels.
- Eight carbon fractions.
- OC/EC ratio.
- Carbonaceous fraction

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ABSTRACT

This paper examines the change from ultra-low sulfur diesel (ULSD) to biodiesel (BD) in different idling mode with respect to organic carbon (OC) and elemental carbon (EC) for public transit buses in Toledo, Ohio. The carbon source profile for both alternative fuels for eight carbon fractions was developed through real time experiments. The average OC and EC concentrations in biodiesel fueled bus were 109.53 and 12.06 $\mu g/m^3$. The average OC and EC concentrations in ULSD fueled bus were 91.78 and 19.54 $\mu g/m^3$. By comparison, it is clear that the ULSD fueled bus emits more elemental carbon and less organic carbon than the BD fueled bus. The OC/EC ratio was 9.82 for the BD fueled bus and 5.66 for the ULSD fueled bus. The carbonaceous fraction (CF) was 0.87 for the BD fueled bus and 0.88 for the ULSD fueled bus. The CF was 0.90 for hot idling and 0.86 for cold idling. OC1, OC2, and EC2 accounted for about 24.8%, 32.5%, and 47.2% of the Total Carbon (TC), respectively. Correlation analysis was also carried out for identifying the main fractions of OC and EC. The results indicated that the use of BD instead of ULSD is environmentally sustainable based on the above chemistry approach.

1. Introduction

Carbon is one of the elements in diesel exhaust particulates that occupies about 80–90% of PM concentration and mainly exists in the form of OC and EC (known as graphitic carbon) [1]. EC (the non-volatile and strong light-absorbing portion) is predominantly emitted by combustion sources, such as biomass burning and fossil fuel combustion (especially by diesel engines), and is not formed by secondary reactions [2]. The OC fraction (the volatile and light-scattering portion) of Diesel Particulate Matter (DPM) is made up of hundreds to thousands of individual organic species [3].

The health hazards of diesel exhaust are largely established along with some uncertainty in interaction mechanisms [4]. Due to the DPM catalytic properties and high specific surface area, carbonaceous particles are involved in various chemical processes in the atmosphere [5]. In particular, EC particles, which are the main components of DPM, play a crucial role in the catalytic oxidation of SO_2/NOx [6], leading to the formation of sulfuric/nitric acid in the presence of humidity [7]. Carbonaceous DPM largely determines particle scattering albedo in the atmosphere [8]. Hence, in the global climate change calculation by aerosol, carbon is one of the most uncertain components [9]. Information concerning the source profiles for OC and EC is still quite limited despite their noted significance in atmospheric chemistry and physics [32]. Although recent work suggests the possibility that PM emissions from the tailpipe emissions may contribute to in-cabin PM [10], no study has examined in detail the carbon speciation of PM in the tailpipe exhaust emission source of the public transit buses. The transition from diesel to BD can also be understood as a transition from sulfur-to-carbon fuel, so it is important that the nature of the carbon particulates emitting from the primary anthropogenic sources should be clearly understood.

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Fuel composition and engine operating conditions have considerable effects on the OC and EC contributions of the diesel particles [11]. Using BD in place of petroleum diesel is considered by several city transportation authorities to be a viable strategy for reducing the exposure to DPM viz. Toledo Area Regional Transportation Authority (TARTA) [12]. The reduced aromatics and sulfur content in the fuel, together with a higher hydrogen-to-carbon ratio, influence total particulate mass emissions by reducing the organic fraction of particles [13]. In addition to implementing reduction technologies for mobile emissions from public transit buses, US-DOT has also identified the reduction or elimination of public transit bus idling as a potential component of future state implementation plans [14]. The public transit buses are often idled in the morning prior to their initial bus route and in the day while waiting to pick up the passengers to take them to their destination. Public transit bus idling occurs for multiple reasons viz. to keep the engine and fuel warm in cold weather, to provide heat inside the bus in cold weather, and to provide power for lighting for safety purposes [15,16].

The population of Toledo as of the 2010 Census was 287,208, while the Toledo metropolitan area had a population of 651, 409 [17]. TARTA has been the "Ride of Toledo" since 1971 and has over 40 routes in the metropolitan area, serving nine communities and carrying almost 5 million passengers every year. TARTA buses are considered among of the major contributors to air pollution in the area [18]. It is important to study transit buses since they typically operate in densely populated areas where they can contribute to urban pollutant exposure. This study characterizes the aerosol emitting directly out of the tailpipes of two buses fueled with alternative fuels viz. BD and ULSD. The elemental and PAH components have already been described [19]. No other studies have ever reported the eight fractions of carbon PM from the tailpipes of public transit buses running on alternative fuels. The results of this study will provide more insight into the potential advantages and disadvantages of using BD fuels for controlling the emissions of carbonaceous aerosols.

An intensive monitoring period was conducted in the month of November, 2009, focusing on DPM in the TARTA garage in Toledo. This exhaust tailpipe category may also be considered a source-specific profile, especially for those samples taken right from the bus tailpipe. The goal was to characterize the source profile of PM, OC, and EC concentrations at the exhaust tailpipe, which were not influenced by any other source. Specific objectives include the following:

(1) To gather a comprehensive set of carbon speciation data on freshly emitted particles, fuel variation, and idling conditions.
(2) To determine the relationship among the concentrations of eight carbon fractions (OC1, OC2, OC3, OC4, EC1, EC2, EC3, and PCR) to find the characteristic profile for BD and ULSD.

2. Materials and methodology

It was of vital importance to design the data collection program carefully so that the resulting data are used to their maximum extent for exhaust carbon emission characterization. An intensive monitoring period was conducted in November 2009, focusing on fine particulate matter in the TARTA garage in Toledo. A total of 75 filters were collected during the monitoring program. There were two 15-min particulate exposures in which the exhaust PM data was collected. A stopwatch was used for keeping track of time. In order to study the effects of fuel formulation on PM, the emission tests on the public transit bus were performed with two different fuels: the ULSD and B20. Bus 506 was filled with B20, and Bus 536 with ULSD. The fuel specifications and engine parameters are mentioned in Shandilya and Kumar [19]. Public bus exhaust emissions' testing was conducted at the TARTA garage at the location shown in Fig. 1 of Shandilya and Kumar [19].

2.1. Idle-engine emission test cycle

Idle-engine (i.e. acceleration and the speed were zero) testing was conducted in the TARTA garage, as mentioned above in Section 2. Hot-start emissions were collected during nights when the bus would come back to the garage from its regular route. The cold-start emissions were collected the following mornings before the bus would leave for its specified route. The analyzer set-up was connected to the exhaust pipe, and the PM was collected. The sampling of DPM emissions is described in detail in Shandilya and Kumar [19].

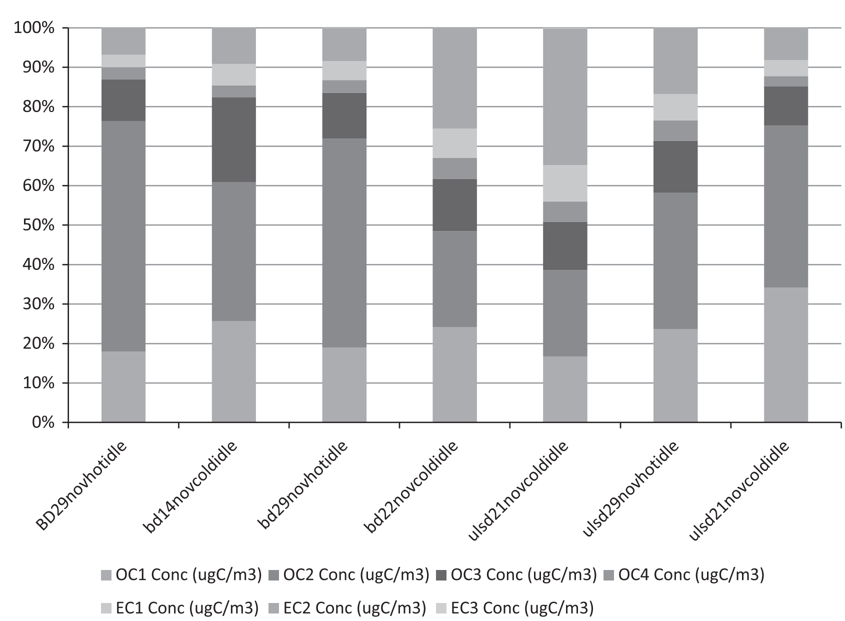

Fig. 1. OC and EC percentage to total carbon.