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Abstract: Biodiesel use in local public transport could be especially significant in improving air quality in cities. The purpose of the experiments described in this paper was to evaluate the various (10, 20 and 50%) blends of biodiesel with diesel in the context of the engine and pollution aspects. As regards the experimental use of these findings on municipal buses, these experiments were the first reference in Hungary. The ages (15-20 years) and types of buses (Ikarus-280, Ikarus-260) used in the experiments are still common vehicles in Hungarian public transport. During our measurements, there was a significant difference between the change in fuel consumption of articulated and solo buses in traffic when compared to test bench measurements. The proportion of the engine performance reduction is nearly the same as that for biodiesel share in the blends. Most pollutants were decreasing (both at idle and full rpm), but this reduction is not directly proportional to the increase of the blending percentage. However, as for CO2, emission increase was observed in the case of idle rpm in comparison to normal diesel operation, even though this phenomenon was not due to biodiesel use, but the catalytic converter and the fact that biodiesel was used for the first time in the engine concerned.

**Highlights (for review)**

1. Our experiments in this topic were the first references in Hungary.
2. Biodiesel use results 13.3% increase in the fuel consumption of articulated buses.
3. Increasing the proportion of biodiesel results to similar decrease in performance.
4. All pollutants except for $CO_2$ showed a reduction.
5. The extent of this reduction is not proportional to share of blended biodiesel.

# Technical and environmental effects of biodiesel use in local public transport

## Highlights

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## 1. Introduction

Traffic in the EU-28 is one of the most significant sector with around €562 billion in Gross Value Added a year at basic prices (4.9% of total), with 11 million employees (5.1 % of total), with 6465 billion passenger km (on average around 12700 km per person) and with 1173 million ton $CO_2$-equivalent (24.3 % of total) in 2013 (EU, 2015). The largest potential in $CO_2$ emissions can be achieved with switching to alternate fuels (Borjesson et al., 2014) and (in the future) decarbonization of electricity (Pathak and Shukla, 2016). Growing concerns of fossil fuel depletion, oil-price fluctuations, escalating energy demands and stringent emission regulations are driving the scientific community to find alternative renewable biofuels for use in diesel engines (Datta and Mandal, 2016; Rajesh Kumar and Saravanan, 2016). Today, biodiesel has been touted as the most promising substitution for petroleum-derived diesel (Foo, 2015; Shahir et al., 2015).

The private car stock in a country has major impacts for the local and global environment. Economic imparities among regions, population migration, policy influences and their interactions to the number of private cars have been investigated by (Han and Hayashi, 2008). Their results indicate that the total number of private cars, but also the volume of related pollutant emissions will shoot up to considerably higher levels in the near future if recent behavioral trends and the present technical aspects of private car use persist. Theoretically the existence of good public transport can deter car ownership. Paper of Cullinane and Cullinane

(2003) asserts, however, that once a car has been acquired, there is a tendency for it to be used irrespective of how good the public transport is.

The starting and destination stations of transport are nearly always located in the same inhabited areas. Furthermore, traffic within settlements accounts for a significant part of total travel but the increasing mobility needs pose a serious problem both from the aspect of pollution and traffic safety. The specific per capita pollutant emission of public transport is much lower than that of car transport. The specific (per passenger km) emission of even the most modern car is still higher than the specific pollutant emission of an obsolete bus. This is especially true if the fuel itself is environmental friendly. For this reason, biodiesel is especially recommended for use in cities and their catchment areas.

Following a significant amount of preparatory work, a biodiesel experiment was carried out with the cooperation of the Centre for Agricultural Sciences of the University of Debrecen and Hajdú Volán and the coordination of the Mayor’s Office of Debrecen, within the framework of the CIVITAS program whose aim is to develop environmental friendly urban transport. Although there were already periods when biofuel plants sold biodiesel to transport companies authorised to blend biodiesel into fuel, these examinations were the first Hungarian reference of experimental use of biodiesel in municipal buses.

The experiments described in this paper envisaged the trial of different blends of biodiesel with diesel. In addition to the standard quality biodiesel blend (containing 4.4% biodiesel), 10, 20 and 50% blends were tested in traffic and on test bench. This study presents the engine and pollution-related results of these examinations, as well as the correlations between them. The buses of the same type and average age as those used in the experiment (15-20-year-old Ikarus-280 and Ikarus-260 buses) are still in use in Hungarian public transport (Szász, 2014).

## 2. Literature review

### 2.1. Significance of bus traffic

Shifting trips from automobiles to public transport can help mitigate environmental and social problems, by reducing energy consumption and $CO_2$ emissions, curbing traffic congestion and fatalities, and providing mobility to disadvantaged groups without access to cars (Buehler and Pucher, 2011). Altogether, passenger traffic in the EU increased by 17% between the years of 1995 and 2013. However, the significance of bus traffic significantly decreased after 2000. In

2012, the share of buses in all traffic was only 9.1% in the EU. In Hungary, this transport mode is much more widespread, its share – in terms of passenger km – is the highest (21.5%) among the member states in the EU (EU, 2015). In terms of population size, it is also Hungary which has one of the highest rate of passenger km per capita in the EU (1650 passenger km per capita, (KTI, 2014)). According to the estimation of the Institute for Transport Sciences (Hungary), 55% of all passenger traffic in Hungary takes place inside settlements, while the share of local transport within the number of trips can even reach 80% (KKK, 2013). Since many trips are local, the analysis by the Department for Transport (UK) shows that 44% of all $CO_2$ emission from cars comes from journeys of between 5 and 25 miles (Marsden and Rye, 2010). Although the pollutant emission of buses per passenger kilometre is higher than those for trains and trams, their energy consumption is nearly identical and much better than individual transport and airplanes (Figure 1).

**Figure 1. The average consumption of the transport modes and their $CO_2$emission**

Source: (KTI, 2014)

The pollutant emission of electric vehicles (trains, trams) is largely dependent on the feedstock used in power plants; therefore, it cannot be changed. On the contrary, the emission of buses running on diesel can be greatly improved by blending with biodiesel. The engine and pollution-related effects of such action are greatly affected by the vehicle concerned and the rate of blending; therefore, the purpose of the experiments presented in this paper is to examine these effects.

### 2.2. Engine and pollution-related effects based on special literature

While many motoric factors contribute to vehicle emissions, such as engine speed, air-to-fuel ratio, and catalyst pass fraction, they are most influenced by engine power and fuel use (Avetisyan et al., 2014). The fuel properties of biodiesel are strongly influenced by the properties of the individual fatty acid methyl esters in different feedstocks, which were detailed by Wan Ghazali et al. (2015). Carbon monoxide (CO) is produced by the incomplete combustion of carbon-containing substances in the presence of oxygen within the engine cylinder. It is obvious that the emissions of $CO_2$ and CO are interrelated i.e., if $CO_2$ emission increases then CO emission decreases naturally. It is expected that CO emission will decrease with the increasing biodiesel percentage in the biodiesel–mineral diesel blends as biodiesel itself contains 11% oxygen in its molecules (Datta and Mandal, 2016). The main reasons of higher NOx emission of biodiesel compared with fossil diesel value are the followings:

- the effect density/bulk modulus differences during injection processes,
- the effect of higher viscosity and surface tension on spray processes,
- the effect of higher distillation temperatures on vaporization process,
- the presence of fuel bound oxygen provides additional oxygen for NOx kinetics
- the influence of cetane/iodine number on the ignition delay process, and
- the absence of carbonaceous and soot particles resulting in higher flame temperatures (Rajesh Kumar and Saravanan, 2016).

Mazzoleni et al. (2007) measured and logged the emission data of 200 school buses which were operated with diesel at first and then a 20/80 biodiesel/ normal diesel blend. According to the observations of the authors, the particulate matter emission of engines increased nearly 1.8 times after having been switched to the 20/80 biodiesel blend. The CO emission also increased, but the NOx and hydrocarbon emission somewhat decreased.

Turrio-Baldassarri et al. (2004) carried out an emission comparison of urban bus engines fuelled with diesel and 'biodiesel' blend. For determining the chemical and toxicological characteristics of emissions, the exhaust gases were produced by a turbocharged EURO 2 heavy-duty diesel engine operating on the European test 13 mode cycle (ECE R49). Regulated and unregulated emissions, such as polycyclic aromatic hydrocarbons (PAH) and nitrated derivatives (nitro-PAH), carbonyl components and light aromatic hydrocarbons were quantified. The effect of these fuels under investigation on the size distribution of particulate matter (PM) was also evaluated. The use of biodiesel blend resulted in small reductions of pollutants of most of the aromatic and polyaromatic components; these differences had no statistical significance at 95% confidence level. The formaldehyde emission has a statistically significant increase of 18% with biodiesel blend.

Petrovic et al. (2009) examined the opportunity of using alternative fuels including biodiesel in Belgrade’s bus transport. The authors refer to their results, which only available in Serbian (Ivkovič et al., 2007), which show that the emission of buses running on biodiesel decreased by nearly 60% on average, while the $SO_2$ emission decreased to 10% and the NOx emission also decreased to some extent. It was found that buses' particulate matter emission is nearly one third of that of buses running on conventional diesel.

Serrano et al. (2012) examined the impact of diesel blended with biodiesel at different rate (B0, B10, B15, B20, B30, B50 and B100) on the performance of a bus fleet of 168 vehicles in North Portugal. The overwhelming majority of buses (106) did not comply even with the Euro 1 standard. The review indicates that the fuel consumption of buses increased by around 10-20%, in comparison with the values of biodiesel, depending on engine load. It was also concluded that higher rate of blended biodiesel result in higher consumption – buses running on B100 used even up to 20% more fuel in certain cases. However, buses running on B10 and B20 showed 4-6% less fuel consumption in the case of several engine load scenarios.

Buczek (2014) in Austria recycled frying oil methyl esters (RFO-ME) have been commercially produced since 1992 and used to fuel buses serving the city of Graz. In 2004, fifty buses were running on RFO-ME covering a total annual distance of 3 million kms and, in the following year more than a hundred buses were operating on RFO-ME. The viscosity and carbon residue of this fuel tend to be slightly higher. The freezing point is higher than that of fatty acid methyl ester (FAME), so during the winter, RFO-ME was blended with diesel. In fact, a 20% RFO-ME blend with diesel in buses would eliminate the black smoke, actually unburned fuel. It was also reported that the $NO_{x,}$ CO, HC and $CO_2$ components with RFO-ME were more favourable than those of rape seed-biodiesel, soya-biodiesel and diesel blends. Because of the biodiesel, fuels have 11% oxygen by weight, so these fuels burn more completely than diesel.

Bunger et al. (2012) draw attention to the potential threats of using biodiesel. Based on the comparison of the results of 27 technical literature sources, it was highlighted that the hydrocarbon emission of engines running on biodiesel is 60%; their CO emission is 80%, while their particulate matter emission is around 65% of those of engines running on normal diesel. However, their $NO_x$ emission is 120% of that of diesel engines. It has to be noted that the results of the technical literatures used as a basis show a wide range of values, sometimes amounting up to 50-80% difference between other results.

Bunger et al. (2012) analysed the emission values of fuels with various concentrations of biodiesel components (B5, B10, B20, B30 and B50). Here, emission savings were significantly lower and there were even cases when the emission of pollutants (hydrocarbons, $NO_x$ and particulate matter) increased. The most favourable results were obtained in the case of B20, with an approximate 15% reduction of hydrocarbon and CO emissions and nearly 20% reduction of particulate matter emissions. However, the emission of $NO_x$ increased by 2-3%. The emission data of several other dangerous compounds were collected based on 10-10 technical literature sources. Usually, technical papers do not focus on these emissions data but such compounds can have a negative impact on human health. It was found that the emission of polycyclic aromatic hydrocarbons (PAH) usually decreases when biodiesels of various concentrations (B5, B10, B20, B100) are used. However, as regards the emission of aldehydes and ketones, significantly higher, even 250% higher emission increase was observed in 10 out of 17 cases.

Buyukkaya (2010) investigated the emission particles from heavy duty engines (Euro 4 Diesel) powered by diesel oil (EN 590) and two biodiesels with their blends. The engine fuels were RME (EN 14214) and hydrotreated vegetable oil (HVO) 30% blends with EN 590 and 100% HVO with or without oxidative catalyst. The PM mass emissions with RME were larger and with HVO were smaller than those for diesel oil, but both biofuels produced lower PAH contents in emission PM. Emission pollutants PM with EN 590 and with 30% HVO blended in EN 590 induced the strongest genotoxic responses, which were significantly greater than those with EN 590+cat or 100% HVO. Finally, authors concluded the harmfulness of the exhaust emissions from vehicle engines cannot be determined merely on basis of the emitted PM mass. Both the study condition and engine type significantly affect the toxicity of the emitted particles. The plain HVO fuel performed greatly well in emission decrease and in diminution the overall toxicity of emitted PM but the 30% blend of HVO in EN 590 was no better in this respect than the plain EN 590. From the toxicological point of view the RME fuel generally reduced the toxicity compared to different fuels.

Angelovič et al. (2013) also focus on the particulate matter emission of biodiesel in a review paper with 68 references. The following statements were made about biodiesel:

- The particulate matter (PM) emission of biodiesel is significantly lower than that of fossil diesel but the lower the proportion of biodiesel in the fuel, the smaller this advantage is.
- Emission values are affected both by the chemical composition of biodiesel and the feedstock used

- It calls for further research to make it possible to use biodiesel and its various blends without engine conversion. However, it has to be noted that other technical literature sources state that B20 does not cause damage to engines.

Demirbas (2009) determined that biodiesel impacts on exhaust pollutant components vary depending on the type of biodiesel and on the category of traditional diesel oil. The traditional biodiesel significantly decreased PM exhaust emissions (75-83%) but $NO_x$ components increased slightly compared to diesel fuel. The chain length of the compounds had a little effect on $NO_x$ and PM pollutants, while the influence was larger on HC and CO emissions, the latter being reduced with decreasing chain length. The unsaturated fatty acid components causes a growth in $NO_x$ exhaust gases.

Altun (2014) examined the emission values of biodiesels of different degrees of saturation (iodine value). Of the examined feedstock (palm oil, cotton seed oil, waste anchovy fish oil), only palm oil is considered to be a traditional biodiesel feedstock. Experimental results showed that biodiesel fuels resulted in lower emissions of nitrogen oxides, carbon monoxide, and smoke opacity, with some increase in emissions of unburned hydrocarbons. With their low energy contents, neat biodiesel fuels resulted in an increase in fuel consumption compared to the conventional diesel fuel (ultra-low sulphur diesel). The degree of unsaturation of biodiesel fuels had effects on engine emissions via its effect on the cetane number and adiabatic flame temperature while engine performance was not significantly affected by the type of biodiesel fuel or its degree of unsaturation. The biodiesel having lowest iodine number had highest cetane number, and lowest density and adiabatic flame temperature, which was good to reduce NOx emissions, as it agreed with experimental results. Additionally, more unsaturated biodiesel fuels showed higher NOx emissions, smoke opacity, and lower HC emissions. It can be said that cetane number and adiabatic flame temperature are responsible for such results.

Tomic et al. (2013) analised the use of various biodiesel blends (B15, B25, B50, B75, B100) in tractor engines. With respect to the diesel fuel, the test fuels B15, B25, B50, B75, and B100 had higher specific fuel consumptions by 1.32 – 13.35%, respectively, for the entire measuring range. Low heating value and high fuel density are the reasons for such increase in the specific fuel consumption. Given that the heating values of fuels B15, B25, B50, B75, and B100 are less than those for diesel fuel for 1.96 – 12.84%, respectively, it can be concluded that the combustion of a mixture biodiesel and fossil diesel fuel is more complete. It was found that $CO_2$ emission decreases by 2.05 - 8.99% as a result of increasing the proportion of biodiesel, while CO emission decreases by 1.84 – 13.15 % and $NO_x$ emission increases by 1.51 – 11.38%.

Kaplan et al. (2006) compared SME and diesel fuels at full and partial loads and at different r.p.m. The loss of torque and power ranged between 5-10% and particularly at full load, the loss of power was closer to 5% at low r.p.m. and to 10% at high r.p.m. According to these values, the authors highlighted that the traditional diesel fuel has the greatest brake power, while the specific fuel consumption of biodiesel is higher than that of diesel oil.

Wang and Gao (2011) investigate travelers' exposure to PM 2.5 across walking on the streetside, automobile driving, and riding subway trains, and at ground-level intermodal stations, underground stations and parksin New York City. It was found that PM 2.5 mass concentrations showed moderate correlations with $CO_2$, CO and relative humidity and a high correlation with temperature. The correlations between fine particle numbers and other parameters is not as significant, except for a moderate correlation with $CO_2$ inside a vehicle.

Shahir et al. (2015) summarized the results of 18 tests and confirmed that use of biodiesel can reduce HC, CO and PM emissions, but the NOx emission showed dissimilar tendencies in the differencial measures.

This topic was also examined by Hungarian researchers. Gyimes et al. (2011) analysed 3 types (sunflower oil, palm fat, canola oil) of used frying fats as fuel. Measurements such as bench test, emission test and laboratory test were made. The test vehicle was an IKARUS 280.40 "A" typed articulated city bus, which had a RÁBA D 10 turbocharged engine with air to air cooled and Euro 2 environmental classification. Based on the evaluation of the results, the following statements can be made:

- The power and torque could not be changed significantly; even the results for torque have increased slightly by used frying oils.
- Contrary to expectations, neither specific, nor absolute fuel consumption increased by using a blend of frying oils.
- Between 1000-1800 1/min RPM, the temperature range of exhaust gases narrowed between 600-650 $^{o}$C.

Compared to the diesel fuel operating, the blend fuel produced less smoking by nearly 50% at cold and 30% at warm running. A similar trend was noticed about soot emission. It has been decreased by 50% at idle and 30% at full loading.

In addition to these resources, a lot of research was carried out in relation to the impact of biodiesel made from various feed stocks on engines, the newest ones of which are shown in Table 1.

**Table 1. The impact of various biodiesels on the engine**

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| | Durability test | | Combustion characteristics test | | Performance test | |
|---|---|---|---|---|---|---|
| Type of biodiesel | Engine | Test results | Engine | Test results | Engine | Test results |
| palm oil methyl ester | 4-Cylinder, NA, WC, IDI, 1.8 L | Wear reduction with increasing biodiesel content (Kalam and Masjuki, 2002) | 4-Stroke, DI, NA, WC, 1-cylinder | Higher CP and lower HRR (Sharon et al., 2012) | TC, DI | increased BSFC, decreased BTE (Benjumea et al., 2009) |
| rape seed methyl ester | 6-Cylinder WC, DI, 11L | Similar carbon deposit but injector more cleaner than diesel (Pehan et al., 2009) | 6-Cylinder, DI, TC, 4-stroke | Lower CP, lower HRR (Buyukkaya, 2010) | | |
| soybean oil methyl ester | 1-Cylinder DI | Small amount injector deposit (Wander et al., 2011) | 1-Cylinder, NA, 4-stroke, WC, DI | Higher CP and lower HRR (Qi et al., 2009) | 1-Cylinder DI | increased BSFC, decreased power (Qi et al., 2009) |
| sunflower oil methyl ester | | | | | 4-Cylinder, TC, DI | increased power, torque, BSFC and BTE (Mofijur et al., 2013) |
| jathropha oil methyl ester | - | - | 4-Cylinder, CI | higher CP and HRR (Rahman et al., 2014) | | |
| cotton seed oil | TC | More carbon deposit, ash and wear in combustion chamber (Nabi et al., 2009) | | | 1-Cylinder, NA, DI | increased BSFC, decreased BTE (Nabi et al., 2009) |
| algae oil methyl ester | | | 1-Cylinder, IDI, NA | Higher CP, higher HRR (Haik et al., 2011) | | |

Abbr.: WC-water cooled, DI-direct injection, TC-turbocharged, NA-natural aspirated, CP-cylinder pressure, HRR-heat release rate, BFSC-brake-specific fuel consumption, BTE-brake thermal efficiency

The German company Kreiswerke Heinsberg GmbH carried out experimental operation on 30 buses between 1993-1999. The observations made during the experiment can be summarised as follows:

- There was no technical malfunction in the case of biodiesel conforming to the DIN E 51606 standard.
- Although the viscosity of lubricating oil decreased, it still stayed within the acceptable range after one year (60 thousand km) of operation.
- There was a sharp decline in the pollutant content of exhaust gas.
- The opinions of the repair experts and the population were clearly positive.
- The average consumption did not change, values different from normal diesel were dependent on the type and age of the given bus.
- Maximum torque was achieved at lower rpm.
- No significant decrease in performance was observed.
- During the project period, the price of biodiesel was cheaper than normal diesel which greatly decreased fuel costs.

During the experiments, around 2 million litres of biodiesel were used. The feedstock demand of this quantity was produced on 1500 ha agricultural land, it stabilised 40 jobs in agriculture and created 10 new jobs in the processing industry. From the aspect of environmental protection, the specific $CO_2$ saving was 3.2 kg $l^{-1}$, amounting to 6400 t altogether.

The results of the above-mentioned experiments are very controversial in environmental aspects. The experiments show different (sometimes extremely different) trends with regard to each of the harmful gases due to the use of biodiesel, which supports the necessity of our tests. The measurement of each harmful gas was not possible because of the missing instruments but – despite of the majority of the previous tests – not only the effect of the ratio of biodiesel was analysed but of the speed of rotation in the context of gas emission and motor performance. Regarding fuel consumption – because of the very different traffic conditions – the effect of speed of rotation could not been measured.

Based on the above-mentioned references, B-20 blend and idle speed were considered optimal either performance (Kaplan et al., 2006), or fuel consumption (Serrano et al., 2012), or environmental (Bunger et al., 2012) aspect. This is the reason why (in addition to other biodiesel/normal diesel ratios) the effect of B-20 blend was analysed, too.

## 3. Methods of conducting the experiments

The specific preliminary work of experiments focusing on the actual use of biodiesel started with the replacement of certain parts of buses to be involved in the experiment, as well as their technical examination and brake bench tests for environmental protection reasons. Four buses were selected for the tests. The plate numbers of these buses were the following:

| | | |
|---|---|---|
| • solo: | GNX-309 | Ik. 260.30M |
| | GNX-340 | Ik. 260.30M |
| • articulated: | DUD-999 | Ik. 280.40 |
| | HPR-618 | Ik. 280.40 |

Prior to the biodiesel tests, each bus underwent a special examination consisting of the full inspection of the vehicle, oil and air filter inspection and replacement where needed.

During the tests four main aspects were examined in relation to the different blending proportions and normal diesel:

- comparison of specific fuel consumption in traffic conditions,
- comparison of engine characteristics based on test bench results (engine performance, fuel consumption),
- measurement of emission parameters (soot emission, CxHy, CO, $CO_2$),
- comparison of vehicles running on blend and normal diesel fuel based on car drivers' observations.

Buses designated for testing underwent specific diesel test bench measurements and pollutant emission tests before the actual tests. These measurements constituted the basis for comparison analysis, as this is the only way to compare experiments conducted with blends to the starting characteristics, as well as the impact of biodiesel on the engine. Each of the selected buses underwent four benchmark tests, the primary purpose of which was to examine the engine performance of each bus by using the various biocomponents. The first measurements focused on normal diesel operation, followed by test bench examinations of 10/90, 20/80 and 50/50 biodiesel blends. The most important properties of the biodiesel used in the tests (given by the seller company, Inter-Tram (2013) Ltd) are shown in Table 2.

**Table 2: The most important characteristics of biodiesel during the tests**

Source: (Inter-Tram, 2013)

However, the actual fuel consumption of vehicles can be most easily and accurately determined by examining vehicles in traffic. Comparing the blend fuel consumption of buses with their fuel consumption data registered during the months prior to these tests is the most successful method, since all technical parameters can be considered unchanged and constant.

Pollutant emission measurements were also performed after test bench measurements. After pollution measurements, the whole amount of diesel was withdrawn from each bus. The empty diesel system of buses was fully loaded with the 10/90 biodiesel blend. The vehicles underwent repeated measurements similarly to those made for the diesel tests.

The 10% blend test was finished on the 12th day and the four buses used more than 2000 litres of blend fuel. Since there was no damage done to the vehicles during the fuel test, the testing of the 20% blend was started.

The public transport company Hajdú Volán Zrt. tested the 20% blend for the longest time, namely for 24 days. During this period, the tested buses used 5600 l blend fuel.

The bus with plate number DUD-999 was taking part in the 20% blend test only for five days as it was forced to stop running for a longer period due to the technical malfunction of the engine control; therefore, it could not be tested. After the engine was opened up, it was also completely renovated. However, the renovated engine could not take part in any further tests, since in Hungary it is forbidden to expose the freshly renovated “raw” engine to increased load during the break-in period. Since the test bench measurement is considered to be increased load, it was necessary to involve a similar bus (type and age) to perform further tests. No connection was observed between the damage of the bus engine and the biodiesel test; therefore, the engine was not damaged by the blend fuel.

The bus of plate number DUD-999 was replaced by the articulated bus of type IK 280.40 and plate number DUD-997. For this reason, this bus only took part in the 20% and 50% blend tests after the test of diesel operation.

The step from the 20% blend test to the 50% blend test was carried out gradually in order to protect engines. The concentration was increased by adding 50% blend to the 20% blend fuel. Buses were fuelled every day; therefore, the biocomponent content was increased in the fuel tank by around 10% each day continuously up to 50% blend.

After the tests, the buses were fuelled with the remaining 50% blend for 18 days. There was no more left; therefore, the four buses used approximately 3600 l 50% blend fuel.

The pollutant emission of buses was examined using the AVL DiCom 4000 exhaust gas evaluation method. During the test, the measurement principle needed for drawing up the pollution was based on checking the characteristics of smoke (also called as opacity) [%] and the so-called k value (light absorption coefficient) [m-1]. The purpose of tests was to measure as many characteristics as possible; therefore, the limit values which are not compulsory to be checked in diesel operation but only in gas operation (CO [vol%] and CH [ppm]) were also measured. Following the test bench measurements of buses, the pollutant emission was also measured for all blending rates.

Analyses of variance (ANOVAs) were used in the following analyses. As required by ANOVA, the assumptions of approximate normality and equality of variances were fulfilled (Field, 2009). One-way and two-way ANOVA LSD post hoc multiple means comparison were used (Howell, 2013). All statistical analyses (one-way and two-way ANOVA) were conducted by using SPSS 17.

# 4. Results and Discussion

## 4.1. The effect of biodiesel use on consumption

The average consumption of buses during the measurements period is shown in Table 3. The average consumption of buses changed by 2-10%, in comparison with normal diesel operation. Generally, higher values were observed for articulated buses and higher biodiesel concentration.

**Table 3. Average consumption (l/100km)**

Source: own tests

The actual consumption of buses in comparison with the normal diesel consumption of months 1-3 increased by 3-9% on average with the biodiesel blend, however, higher biodiesel blend led to less fuel consumption in several cases. The diesel operation tests following the tests of biofuels blend clearly showed that the average consumption of vehicles increased after the normal diesel operation.

On average, the test bench results did not show any difference in terms of the consumption of various blends; the observed fluctuation was just between -3% and +2%. Therefore, no clear conclusion can be drawn from the measured data in relation to fuel consumption, for example higher fuel consumption with higher rate of biocomponents, since the values provided by the consumption measurement function of the bench showed larger differences than in the case of performance measurement.

The changes in the fuel consumption of solo and articulated buses showed significant differences in traffic in comparison with test bench results ($F(1.49)= 21.657$, $p<0.001$; type: $F(1.49)= 69.002$, $p<0.001$; location * type: $F(1.49)= 18.753$, $p<0.001$). However, no significant difference was found at solo buses. On the contrary, a significant increase of 13.3% in fuel consumption was observed in articulated buses (Figure 2). The increased fuel consumption is assumed to be due to increase in weight in comparison with empty (test bench) weight. Furthermore, the distribution of passengers in the bus is also different in traffic conditions regardless the number of passengers.

**Figure 2. Change of the fuel consumption of solo and articulated buses in traffic in comparison with the test bench results**

Note: Different letters show statistically significant differences

Source: own tests

As a next step, difference in fuel consumption was observed between various blending proportions rates in terms of location and bus type. In two cases significant differences were observed between the measurement results. As regards standard diesel – similarly to the previously cumulated consumption data –, significant differences were found for articulated buses ($F(3.14)= 14.736$, $p<0.001$), as well as between test bench and traffic data for 20% biodiesel blend ($F(3.5)= 14.495$, $p<0.01$) (Figure 3-4).

**Figure 3. The change of standard diesel consumption in traffic in comparison with the test bench results**

Note: Different letters show statistically significant differences

Source: own tests

**Figure 4.Change of fuel consumption of the 20% biodiesel blend in traffic in comparison with test bench results**

Note: Different letters show statistically significant differences

Source: own tests

As a further step, the difference in fuel consumption between various blending rates was measured in the case of different locations and bus types. A difference in fuel consumption was observed only for articulated buses in traffic (Figure 5). A significant difference ($p<0.01$) was shown between the control and 20% biodiesel blend consumption of this bus type. However, in the case of the fuel type following the biodiesel test, only a difference at the level of $p<0.1$could be shown. The reason for this difference is probably the low sample number and the previously mentioned difference in passenger number.

**Figure 5.The effect of biodiesel on the fuel consumption of articulated buses in traffic**

Note: Different letters show statistically significant differences

Source: own tests

### 4.2.The effect of biodiesel use on engine performance

The differences measured during the test of engine performance change are shown in Table 4. Based on the initial data, the reduction of engine performance was shown with regard to the rate of biodiesel against standard diesel. The measurement results show that higher biodiesel concentration results in lower engine performance. The reduction of performance is negligible (2-3%) for the 10% biodiesel blend, while it is 7-9% for the 20% biodiesel blend and 21-23% for the 50% blend compared to the desired engine performance.

**Table 4. Statistical characteristics of engine performance (kW)**

Source: own tests

Based on Figure 6, it can be concluded that higher biodiesel rate causes nearly the same reduction of performance which results in statistically significant difference for normal, 20% and 50% blending. The differences between the 40 and 50 km/h speed tests are negligible.

**Figure 6. The effect of biodiesel on engine performance**

Source: own tests

Note: Different letters show statistically significant differences ($p<0.05$)

### 4.3. Pollution-related observations of biodiesel use

Based on the measured data, no significant reduction in pollutant emission was observed altogether. There was no consequent decrease or increase or any tendency in the measured values. Although the measurement device and methodology used during the tests were the same during every measurement, there was no notable (or even detectable) difference between the pollutant emissions values of the various blending rates for most pollutants and buses (Table 5).

**Table 5. Average emission values of the buses examined during the experiment**

Source: own tests

As regards smoking, in the case of the examined buses, decreasing emission could be observed for all three blends at idle rpm compared to standard diesel operation. A slight increase was recognised for 50% blend compared to the 20% blend which is still significantly below that of normal diesel operation.

The examination of K (light absorption coefficient) shows how polluted the exhaust fume is with particulate matter on one square meter. The use of biodiesel had a favourable effect on this index. Basically, the obtained results were identical to the tendencies observed for smoking, even though the reduction is rather low at idle rpm.

There is a less obvious situation in the case of CO, as the 10% blend shows the same result as normal diesel and it even increases at full rpm. However, it has to be noted that none of the obtained data exceed the allowed limit values. In addition, any further increase of the biodiesel rate in diesel reduces the pollutant emission.

As for $CO_2$, all of these idle rpm data were slightly above the initial values measured in diesel operation. The emission tendencies observed at full rpm are the same as those of CO emission. Well known that biodiesel gave a more complete combustion, so CO could be transformed into $CO_2$. The used diesel engine (RÁBA-MAN D 2156 HM6U) has middle-spherical combustion chamber in the cylinder. Typically the fuel is sprayed on the hot wall of this combustion chamber forms a film with 12-15 micrometer thickness which may reduce auto ignition, so the ignition begins slowly, the liquid fuel remains relatively cold on the piston wall, so the soot formation decreases. However the combustion chamber is sensible for angular size, narrow speed range and it has significant smoke in case of acceleration at low revolution.

However, the increase of $CO_2$ and CO emission is assumed to be the result of catalyst converters instead of the biodiesel concentration, since this equipment converts CO to $CO_2$, which poses less threat to human health. The other possible explanation lies in the first use of biodiesel, since biodiesel might have dissolved the accumulated matter and the gases, which were released as a result, could have gotten into the exhaust system. It is the opinion of the authors of this paper that the data obtained with subsequent measurements should be taken as a basis in the long run; therefore, the use of biodiesel reduces the emission of these pollutants, especially at full rpm.

The most interesting results were collected in relation to hydrocarbon emission. A definite reduction was observed at full rpm, while the reduction measured for lower concentration at idle rpm was followed by a slight increase. However, it can be concluded that the various blends mostly show lower emission results in comparison with standard diesel operation.

Altogether, it can be stated that there is a statistically proven ($P<0.1$) increase of $CO_2$ emission with the increase of biodiesel blending rate at low rpm. For blending rates above 10% at high rpm, contrasting and much greater emissions were observed for both $CO_2$ and CO ($p<0.01$, Figure 7).

**Figure 7.The effect of biodiesel on CO and $CO_2$ emission**

Source: own tests

Note: Different letters show statistically significant differences

In addition to the above mentioned observations, the appearance of the so-called “French fries” smell referred to in technical literature sources was a significantly positive factor. This smell was present even when using a 10% blend. The smell released during the ignition of vegetable oil in the engine greatly reduced the unpleasant, pungent smelling, strong smoke of diesel, which elicits tearing in closed spaces. The oil smell became increasingly intensive with the increasing blending rate of biocomponents.

Regarding optimal percentage of biodiesel/normal diesel mixture, our test results confirmed the previous experiences in case of consumption (20/80 % blend) and of environmental considerations (20-50 % biodiesel content depending the type of exhaust gas and rpm). However biodiesel rate causes nearly the same reduction of performance in our tests which is higher than of the cited references. The comparison of parameters of solo buses and of articulated buses in our study might look as novelty.

## 5. Conclusions

The performed measurements supported the technical literature expectations regarding biodiesel use (higher consumption than in the case of normal diesel operation, reduced engine performance, decreased pollutant emission), but their extent greatly differed and the change was not always proportional to the biodiesel rate.

There was a great difference in the change of fuel consumption of articulated and solo buses in traffic when compared to test bench results. There was a statistically significant difference ($p<0.01$) in traffic only for articulated buses when compared the 20% blending rate to normal diesel operation.

The rate of engine performance reduction is nearly identical to biodiesel content. There were statistically significant differences in nearly all tested cases, independently of the 40 and 50 km/h speed.

The statistical analysis of data obtained during pollution measurements, as well as their comparison to normal diesel operation show the following differences:

- The amount of pollutants emitted by buses show significant fluctuation, but neither of them are higher than the allowed limit value.
- If the various blending rates are examined against normal diesel operation, it is obvious that a significant conclusion is difficult to be drawn. Reduction was observed for most pollutants (both at idle and full rpm), but these values do not change proportionally with the percentage increase of blending. However, there was an increase in $CO_2$ emission at idle rpm in comparison with normal diesel operation, the reason of which are engine-related and also due to the fact that biodiesel was used for the first time in the vehicle concerned.

Based on our results it should be stated that biodiesel use (especially as 20-50 % biodiesel/normal diesel blend) is highly recommended environmentally and technically.

## References

Altun, S., 2014. Effect of the degree of unsaturation of biodiesel fuels on the exhaust emissions of a diesel power generator. *Fuel* 117, 450-457.

Angelovič, M., Tkáč, Z., Angelovič, M., 2013. Particulate Emissions and Biodiesel: A review. *Scientific Papers: Animal Science and Biotechnologies* 46(1), 192 - 198.

Avetisyan, H.G., Miller-Hooks, E., Melanta, S., Qi, B., 2014. Effects of vehicle technologies, traffic volume changes, incidents and work zones on greenhouse gas emissions production. *Transportation Research Part D: Transport and Environment* 26, 10-19.

Benjumea, P., Agudelo, J., Agudelo, A., 2009. Effect of altitude and palm oil biodiesel fuelling on the performance and combustion characteristics of a HSDI diesel engine. *Fuel* 88(4), 725-731.

Borjesson, M., Ahlgren, E.O., Lundmark, R., Athanassiadis, D., 2014. Biofuel futures in road transport - A modeling analysis for Sweden. *Transport Res D-Tr E* 32, 239-252.

Buczek, B., 2014. Diesel Fuel from Used Frying Oil. *Sci World J*.

Buehler, R., Pucher, J., 2011. Making public transport financially sustainable. *Transport Policy* 18(1), 126-138.

Bunger, J., Krahl, J., Schroder, O., Schmidt, L., Westphal, G.A., 2012. Potential hazards associated with combustion of bio-derived versus petroleum-derived diesel fuel. *Crit Rev Toxicol* 42(9), 732-750.

Buyukkaya, E., 2010. Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. *Fuel* 89(10), 3099-3105.

Cullinane, S., Cullinane, K., 2003. Car dependence in a public transport dominated city: evidence from Hong Kong. *Transport Res D-Tr E* 8(2), 129-138.

Datta, A., Mandal, B.K., 2016. A comprehensive review of biodiesel as an alternative fuel for compression ignition engine. *Renew Sust Energ Rev* 57, 799-821.

Demirbas, A., 2009. Progress and recent trends in biodiesel fuels. *Energ Convers Manage* 50(1), 14-34.

EU, 2015. *EU Transport In Figures – Statistical Pocketbook 2015*. Luxembourg: Publications Office of the European Union, Belgium.

Field, A.P., 2009. *Discovering statistics using SPSS : (and sex, drugs and rock 'n' roll)*, 3rd ed. SAGE Publications, Los Angeles.

Foo, K.Y., 2015. A vision on the opportunities, policies and coping strategies for the energy security and green energy development in Malaysia. *Renew Sust Energ Rev* 51, 1477-1498.

Gyimes, E., Bíró, I., Nagy, V., Farkas, F., Szabó, P.B., Beszédes, S., Kertész, S., 2011. Begyűjtött és kezelt étkezési használt zsíradék motorhajtóanyagként való alkalmazhatóságának kísérleti igazolása és hatásvizsgálata. SZTE Mérnöki Kar, Szeged, Hungary, p. 77.

Haik, Y., Selim, M.Y.E., Abdulrehman, T., 2011. Combustion of algae oil methyl ester in an indirect injection diesel engine. *Energy* 36(3), 1827-1835.

Han, J., Hayashi, Y., 2008. Assessment of private car stock and its environmental impacts in China from 2000 to 2020. *Transport Res D-Tr E* 13(7), 471-478.

Howell, D.C., 2013. *Statistical methods for psychology*, 8th ed. Wadsworth Cengage Learning, Belmont, CA.

Inter-Tram, L., 2013. The most important characteristics of biodiesel (Biodízel üzem - Biodízel szabvány). Inter Tram Ltd.

Ivkovič, I., Kaplanovič, S., Žeželj, S., 2007. Višekriterijumsko rangiranje konstrukcijsko-koncepcijskih rešenja autobusa u cilju stvaranja održivog JMTP-a u Beogradu. *Journal of Applied Engineering Science* 5(15), 57 - 66.

Kalam, M.A., Masjuki, H.H., 2002. Biodiesel from palmoil - an analysis of its properties and potential. *Biomass Bioenerg* 23(6), 471-479.

Kaplan, C., Arslan, R., Surmen, A., 2006. Performance characteristics of sunflower methyl esters as biodiesel. *Energ Source Part A* 28(8), 751-755.

KKK, K.K.K., 2013. NATIONAL TRANSPORT STRATEGY (NTS). Hungarian Transport Administration, Budapest, Hungary, pp. 1 - 78.

KTI, 2014. Trends, graphical database. Passanger transport. , 2014 ed. Institute for Transport Sciences Non Profit Ltd,, pp. 1 - 3.

Marsden, G., Rye, T., 2010. The governance of transport and climate change. *J Transp Geogr* 18(6), 669-678.

Mazzoleni, C., Kuhns, H.D., Moosmuller, H., Witt, J., Nussbaum, N.J., Chang, M.C.O., Parthasarathy, G., Nathagoundenpalayam, S.K.K., Nikolich, G., Watson, J.G., 2007. A case study of real-world tailpipe emissions for school buses using a 20% biodiesel blend. *Sci Total Environ* 385(1-3), 146-159.

Mofijur, M., Masjuki, H.H., Kalam, M.A., Atabani, A.E., Shahabuddin, M., Palash, S.M., Hazrat, M.A., 2013. Effect of biodiesel from various feedstocks on combustion characteristics, engine durability and materials compatibility: A review. *Renew Sust Energ Rev* 28, 441-455.

Nabi, M.N., Rahman, M.M., Akhter, M.S., 2009. Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions. *Appl Therm Eng* 29(11-12), 2265-2270.

Pathak, M., Shukla, P.R., 2016. Co-benefits of low carbon passenger transport actions in Indian cities: Case study of Ahmedabad. *Transport Res D-Tr E* 44, 303-316.

Pehan, S., Jerman, M.S., Kegl, M., Kegl, B., 2009. Biodiesel influence on tribology characteristics of a diesel engine. *Fuel* 88(6), 970-979.

Petrovic, J., Ivkovic, I., Vujacic, I., Zezelj, S., 2009. Possibilities of Buses on Alternative Fuel in Public Urban Transport in Belgrade. *Technol Econ Dev Eco* 15(1), 78-89.

Qi, D.H., Geng, L.M., Chen, H., Bian, Y.Z., Liu, J., Ren, X.C., 2009. Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil. *Renew Energ* 34(12), 2706-2713.

Rahman, S.M.A., Masjuki, H.H., Kalam, M.A., Abedin, M.J., Sanjid, A., Rahman, M.M., 2014. Assessing idling effects on a compression ignition engine fueled with Jatropha and Palm biodiesel blends. *Renew Energ* 68, 644-650.

Rajesh Kumar, B., Saravanan, S., 2016. Use of higher alcohol biofuels in diesel engines: A review. *Renewable and Sustainable Energy Reviews* 60, 84-115.

Serrano, L.M.V., Camara, R.M.O., Carreira, V.J.R., da Silva, M.C.G., 2012. Performance study about biodiesel impact on buses engines using dynamometer tests and fleet consumption data. *Energ Convers Manage* 60, 2-9.

Shahir, V.K., Jawahar, C.P., Suresh, P.R., 2015. Comparative study of diesel and biodiesel on CI engine with emphasis to emissions-A review. *Renew Sust Energ Rev* 45, 686-697.

Sharon, H., Karuppasamy, K., Kumar, D.R.S., Sundaresan, A., 2012. A test on DI diesel engine fueled with methyl esters of used palm oil. *Renew Energ* 47, 160-166.

Szász, P., 2014. BKV-buszmustra: a 25 éves Ikarusoktól a Citaróig. mfor.hu.

Tomic, M.D., Savin, L.D., Micic, R.D., Simikic, M.D., Furman, T.F., 2013. Effects of Fossil Diesel and Biodiesel Blends on the Performances and Emissions of Agricultural Tractor Engines. *Therm Sci* 17(1), 263-278.

Turrio-Baldassarri, L., Battistelli, C.L., Conti, L., Crebelli, R., De Berardis, B., Iamiceli, A.L., Gambino, M., Iannaccone, S., 2004. Emission comparison of urban bus engine fueled with diesel oil and 'biodiesel' blend. *Sci Total Environ* 327(1-3), 147-162.

Wan Ghazali, W.N.M., Mamat, R., Masjuki, H.H., Najafi, G., 2015. Effects of biodiesel from different feedstocks on engine performance and emissions: A review. *Renewable and Sustainable Energy Reviews* 51, 585-602.

Wander, P.R., Altafini, C.R., Colombo, A.L., Perera, S.C., 2011. Durability studies of mono-cylinder compression ignition engines operating with diesel, soy and castor oil methyl esters. *Energy* 36(6), 3917-3923.

Wang, X., Gao, H.O., 2011. Exposure to fine particle mass and number concentrations in urban transportation environments of New York City. *Transport Res D-Tr E* 16(5), 384-391.

**Table_1**

Table 1. The impact of various biodiesels on the engine

| Type of biodiesel | Durability test | | Combustion characteristics test | | Performance test | |
|---|---|---|---|---|---|---|
| | Engine | Test results | Engine | Test results | Engine | Test results |
| palm oil methyl ester | 4-Cylinder, NA, WC, IDI, 1.8 L | Wear reduction with increasing biodiesel content (Kalam and Masjuki, 2002) | 4-Stroke, DI, NA, WC, 1-cylinder | Higher CP and lower HRR (Sharon et al., 2012) | TC, DI | increased BSFC, decreased BTE (Benjumea et al., 2009) |
| rape seed methyl ester | 6-Cylinder WC, DI, 11L | Similar carbon deposit but injector more cleaner than diesel (Pehan et al., 2009) | 6-Cylinder, DI, TC, 4-stroke | Lower CP, lower HRR (Buyukkaya, 2010) | | |
| soybean oil methyl ester | 1-Cylinder DI | Small amount injector deposit (Wander et al., 2011) | 1-Cylinder, NA, 4-stroke, WC, DI | Higher CP and lower HRR (Qi et al., 2009) | 1-Cylinder DI | increased BSFC, decreased power (Qi et al., 2009) |
| sunflower oil methyl ester | | | | | 4-Cylinder, TC, DI | increased power, torque, BSFC and BTE (Mofijur et al., 2013) |
| jathropha oil methyl ester | - | - | 4-Cylinder, CI | higher CP and HRR (Rahman et al., 2014) | | |
| cotton seed oil | TC | More carbon deposit, ash and wear in combustion chamber (Nabi et al., 2009) | | | 1-Cylinder, NA, DI | increased BSFC, decreased BTE (Nabi et al., 2009) |
| algae oil methyl ester | | | 1-Cylinder, IDI, NA | Higher CP, higher HRR (Haik et al., 2011) | | |

Abbr.: WC-water cooled, DI-direct injection, TC-turbocharged, NA-natural aspirated, CP-cylinder pressure, HRR-heat release rate, BFSC-brake-specific fuel consumption, BTE-brake thermal efficiency

Table 2: The most important characteristics of biodiesel during the tests

| Specification | Unit | Requirements | | Test method |
|---|---|---|---|---|
| | | minimum | maximum | |
| Ester content | % (m/m) | 96,5 | | EN 14103 |
| Density 15 C | Kg/m$^3$ | 860 | 900 | EN ISO 3675 |
| | | | | EN ISO 12185 |
| Lower heating value | MJ/kg | 37 | | |
| | MJ/l | 33 | | Directive 2009/28/EC |
| Flash point | 0 C | 120 | - | prEN ISO 3679 e |
| Sulphur content | mg/kg | - | 10,0 | prEN ISO 20846 |
| | | | | prEN ISO 20884 |
| Cetane number | | 51,0 | | EN ISO 5165 |
| Water content | mg/kg | - | 500 | EN ISO 12397 |
| Acid number | mg KOH/g | | 0,50 | EN 14104 |
| Iodine value | g iodine/100 g | | 120 | EN 14111 |
| Methanol content | % (m/m) | | 0,20 | EN 14110 |
| Content of monoglycerides | % (m/m) | | 0,80 | EN 14105 |
| Content of diglycerides | % (m/m) | | 0,20 | EN 14105 |
| Content of triglycerides | % (m/m) | | 0,20 | EN 14105 |
| Free glycerol | % (m/m) | | 0,02 | EN 14105 |
| | | | | EN 14106 |

Source: (Inter-Tram, 2013)

Table 3. Average consumption (l/100km)

| | | Control | 10 % | 20 % | 50 % | Biodiesel blend | Average |
|---|---|---|---|---|---|---|---|
| Traffic | Articulated | 40.80 | 42.55 | 44.56 | 43.20 | 43.29 | 42.49 |
| | Solo | 34.14 | 37.84 | 35.74 | 35.18 | 35.37 | 35.40 |
| Test bench | Articulated | 37.31 | 37.87 | 36.11 | - | - | 37.15 |
| | Solo | 35.19 | 35.65 | 35.01 | - | - | 35.26 |
| Total | Articulated | 39.40 | 40.68 | 41.18 | 43.20 | 43.29 | 40.78 |
| | Solo | 34.66 | 36.74 | 35.37 | 35.18 | 35.37 | 35.34 |
| | Average | 37.30 | 38.93 | 38.60 | 39.19 | 40.12 | 38.36 |

Source: own tests

Table_4

Table 4. Statistical characteristics of engine performance (kW)

| Speed | | Mean | Std. Error | Significant difference |
|---|---|---|---|---|
| 40 km/h | standard diesel (4.4% biodiesel) | 124.4 | 4.8 | ab |
| | 10% biodiesel | 122.3 | 6.6 | abc |
| | 20% biodiesel | 116.2 | 7.7 | bc |
| | 50% biodiesel | 96.8 | 2.6 | c |
| 50 km/h | standard diesel (4.4% biodiesel) | 147.9 | 8.4 | a |
| | 10% biodiesel | 143.2 | 9.6 | a |
| | 20% biodiesel | 134.6 | 12.1 | ab |
| | 50% biodiesel | 115.2 | 9.4 | bc |

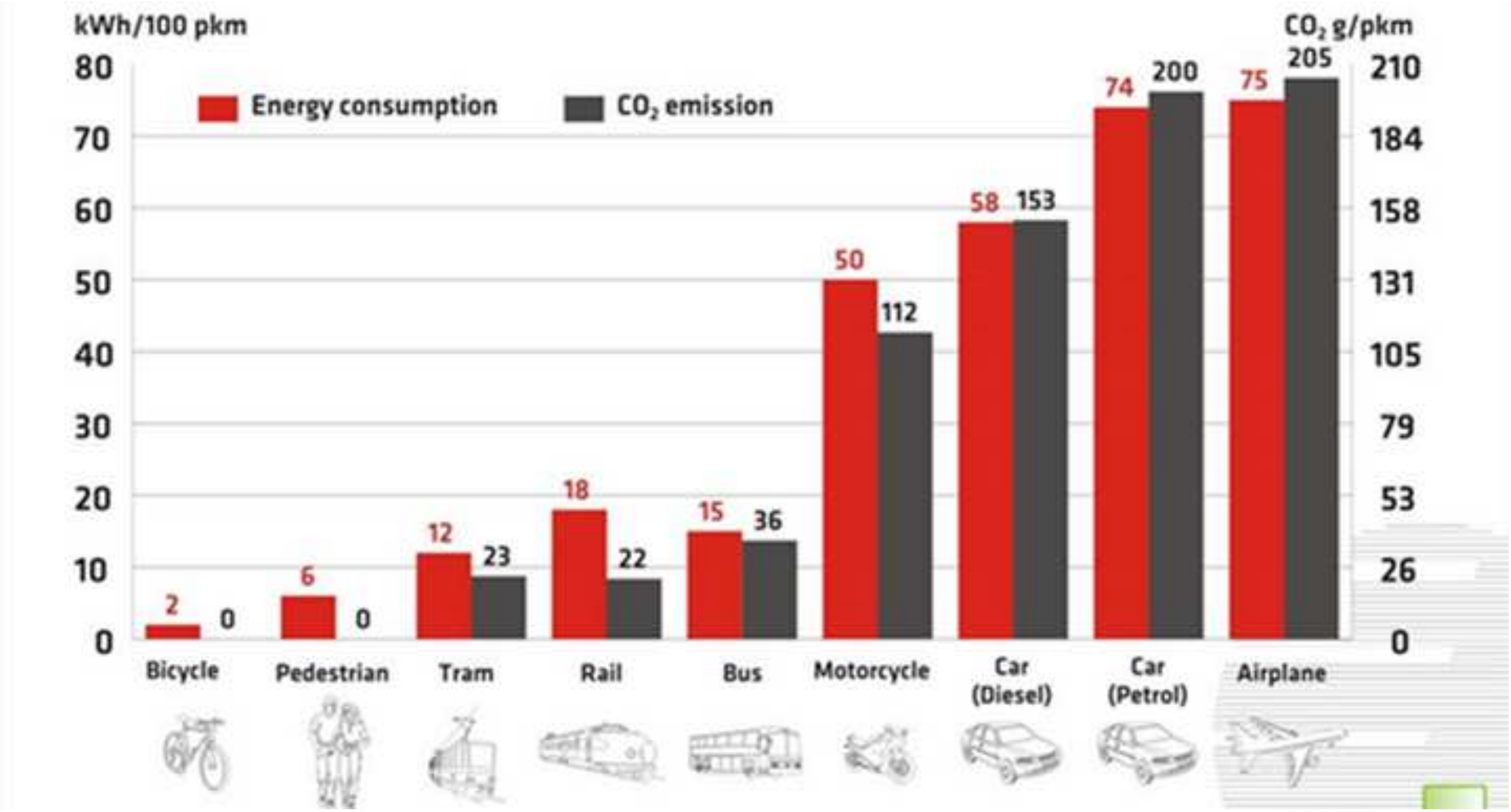
Source: own tests

Table 5. Average emission values of the buses examined during the experiment

| Description | | Standard diesel | 10% blend | 20% blend | 50% blend |
|---|---|---|---|---|---|
| Smoke | idle rpm | 1.125 | 1.1 | 0.9 | 0.8 |
| | full rpm | 8.825 | 4.925 | 2.025 | 4.075 |
| K value ($m^2$) | idle rpm | 0.023 | 0.02 | 0.015 | 0.015 |
| | full rpm | 0.225 | 0.118 | 0.048 | 0.093 |
| CO (%vol) | idle rpm | 0.013 | 0.013 | 0.01 | 0.01 |
| | full rpm | 0.048 | 0.173 | 0.053 | 0.02 |
| $CO_2$ (%vol) | idle rpm | 1.35 | 1.5 | 1.475 | 1.525 |
| | full rpm | 3.1 | 3.85 | 2.85 | 2.325 |
| HC ppmHEx | idle rpm | 13.75 | 10.25 | 12.25 | 13 |
| | full rpm | 19.25 | 19 | 18 | 15.5 |

Source: own tests

Figure 1.


kWh/100 pkm
CO₂ g/pkm
Energy consumption
CO₂ emission
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184
158
131
105
79
53
26
0
2
0
6
0
12
23
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22
15
36
50
112
58
153
74
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75
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Bicycle
Pedestrian
Tram
Rail
Bus
Motorcycle
Car (Diesel)
Car (Petrol)
Airplane

**Figure 2.**

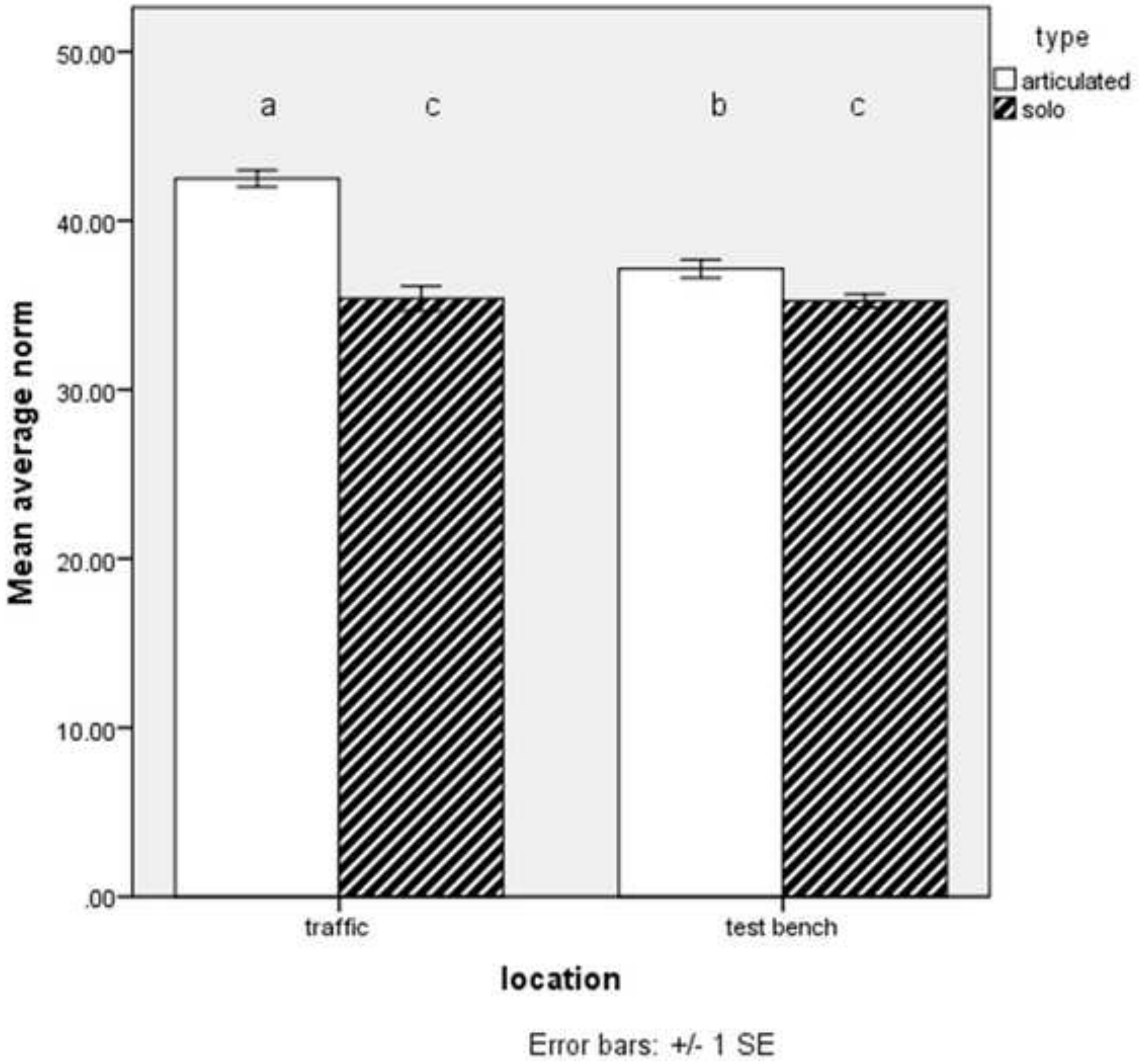
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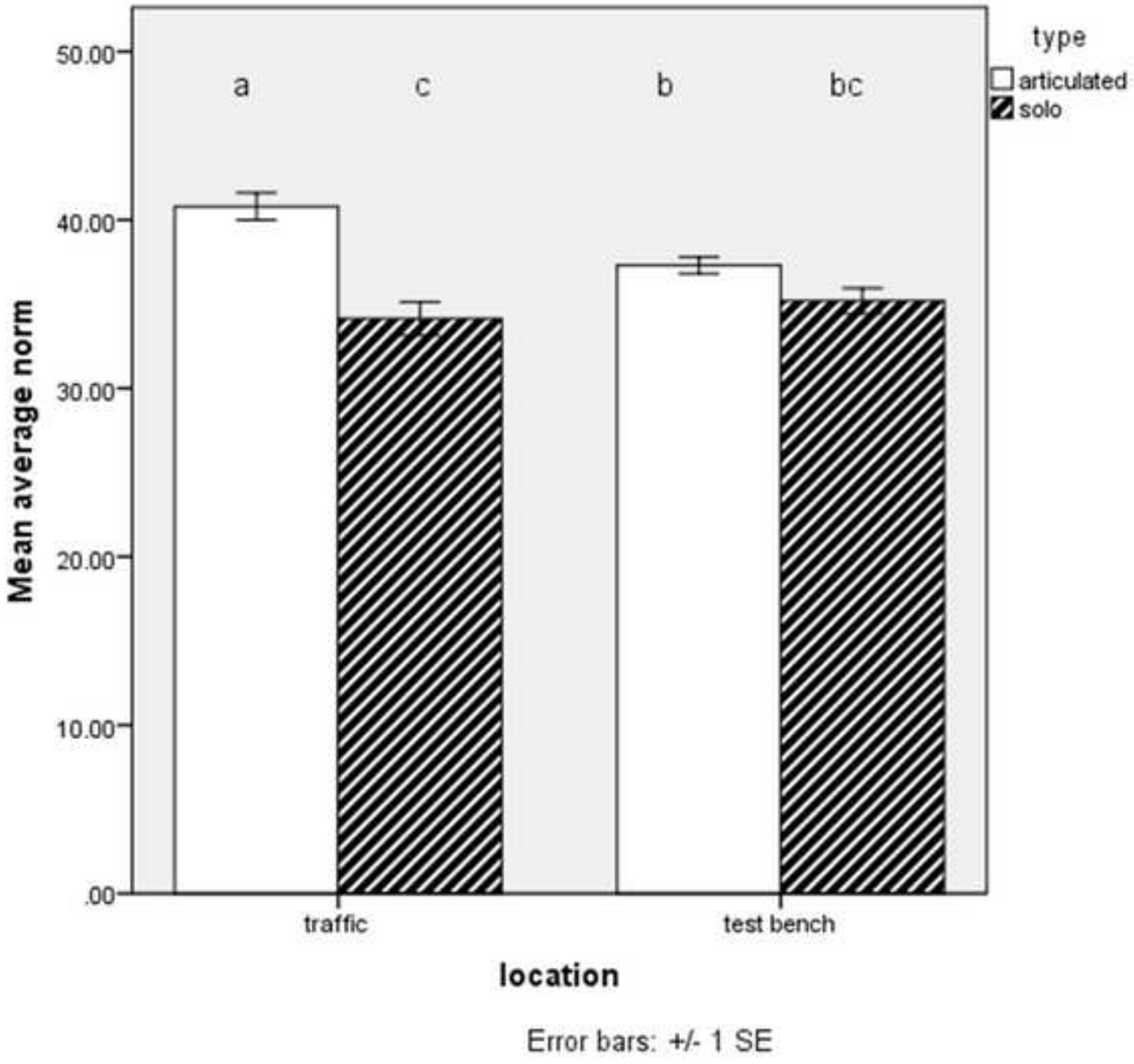
**Figure 3.**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Error bars: +/- 1 SE

Figure 4.

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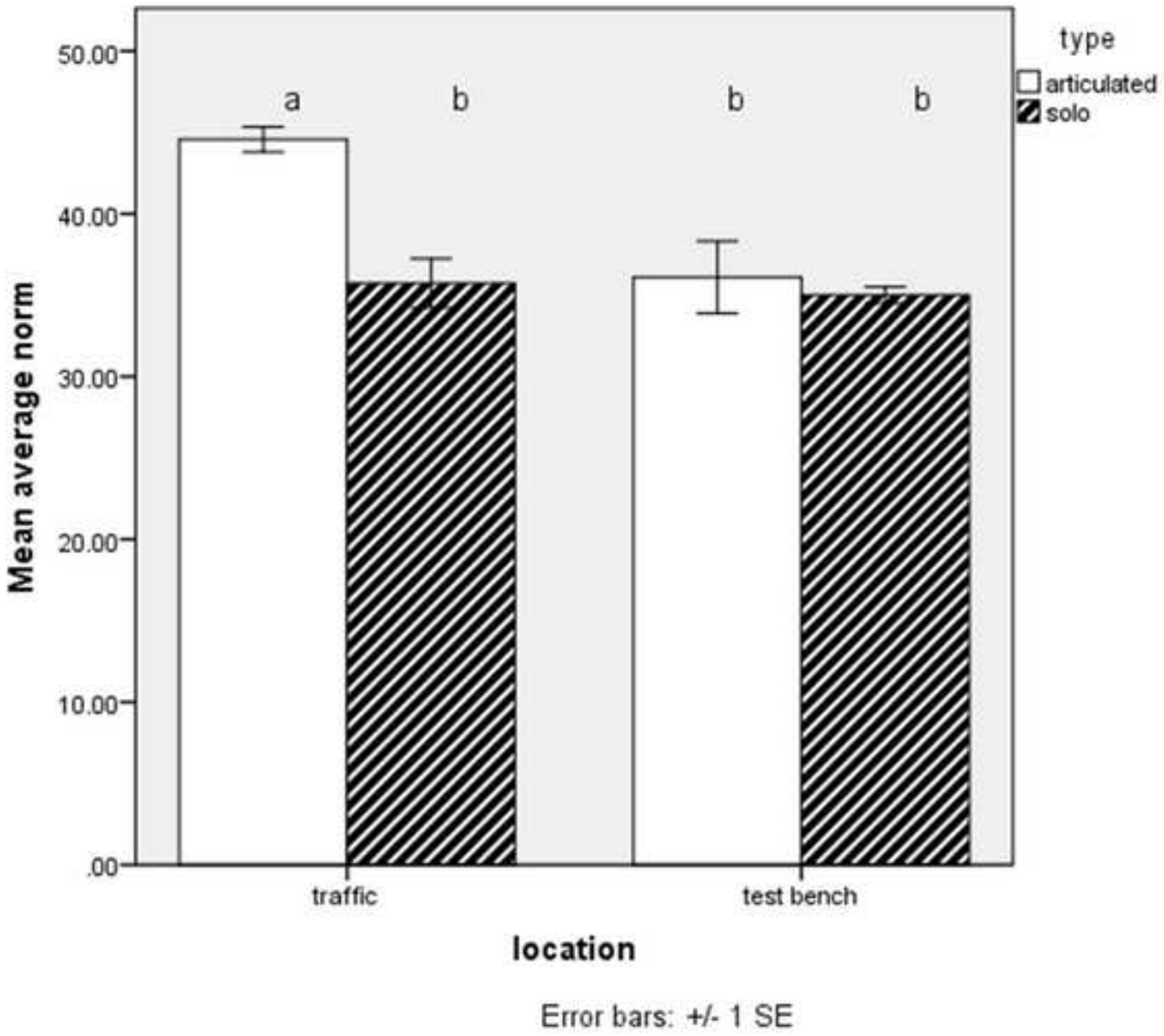

**Figure 5.**

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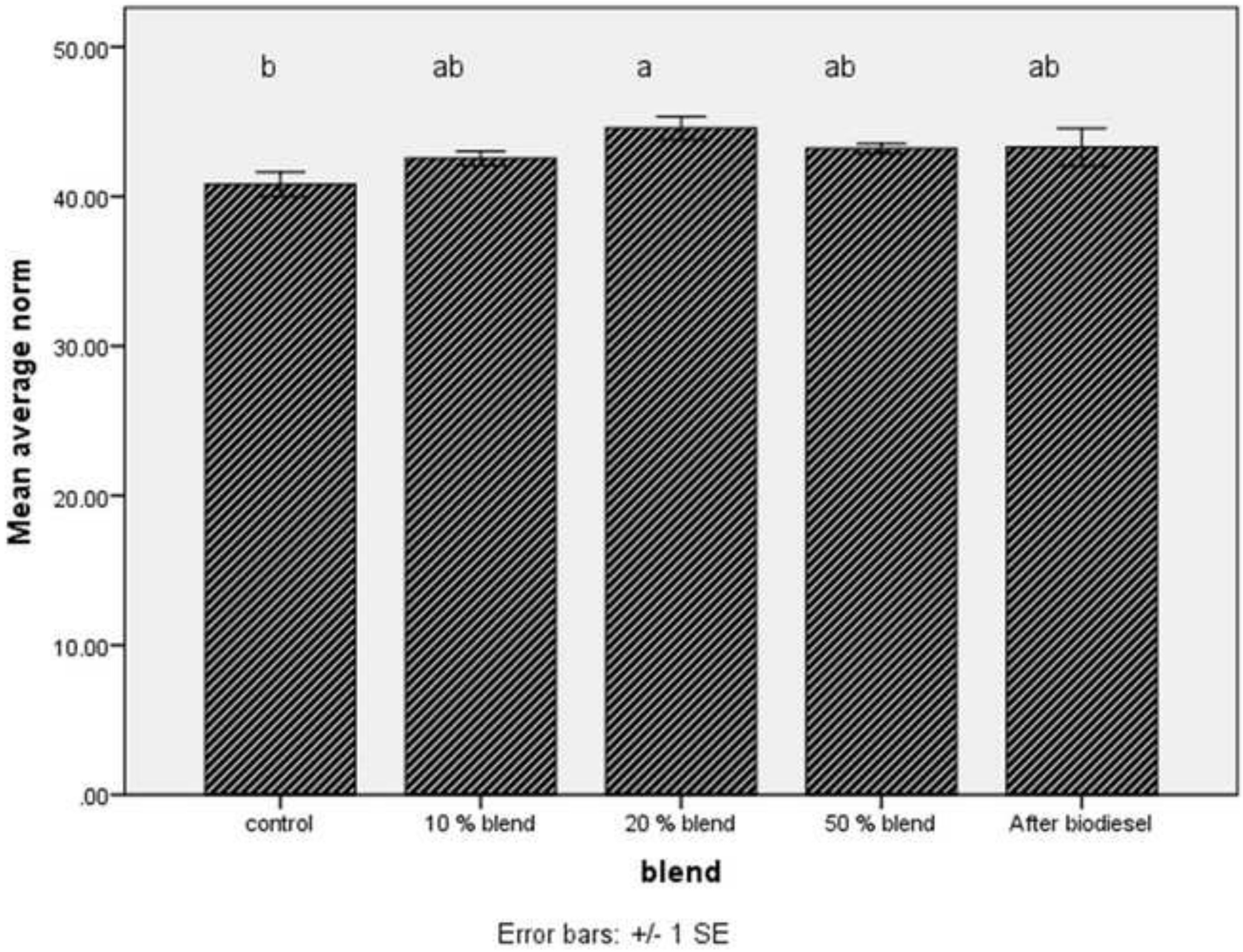

**Figure 6.**

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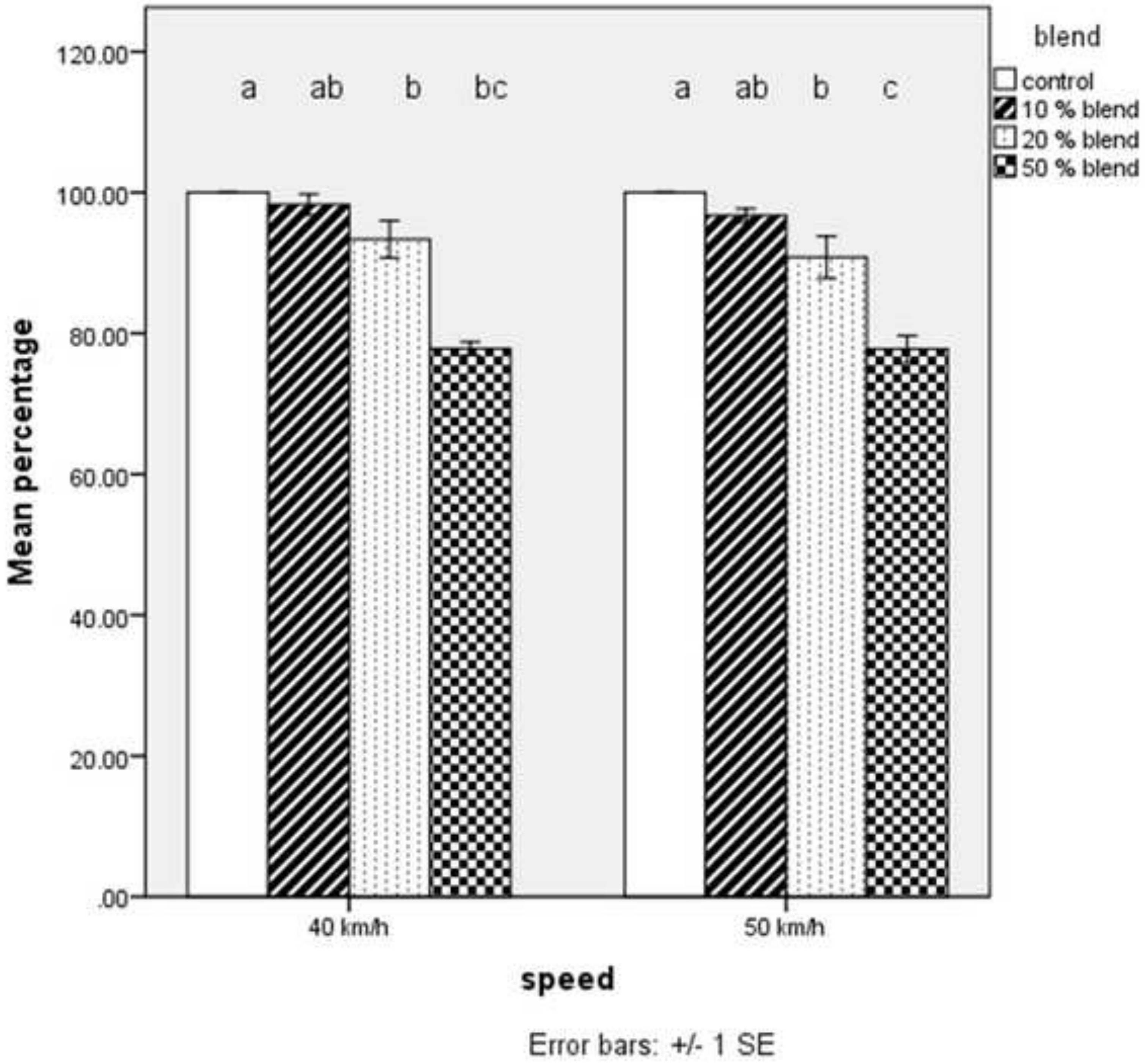

**Figure 7.**

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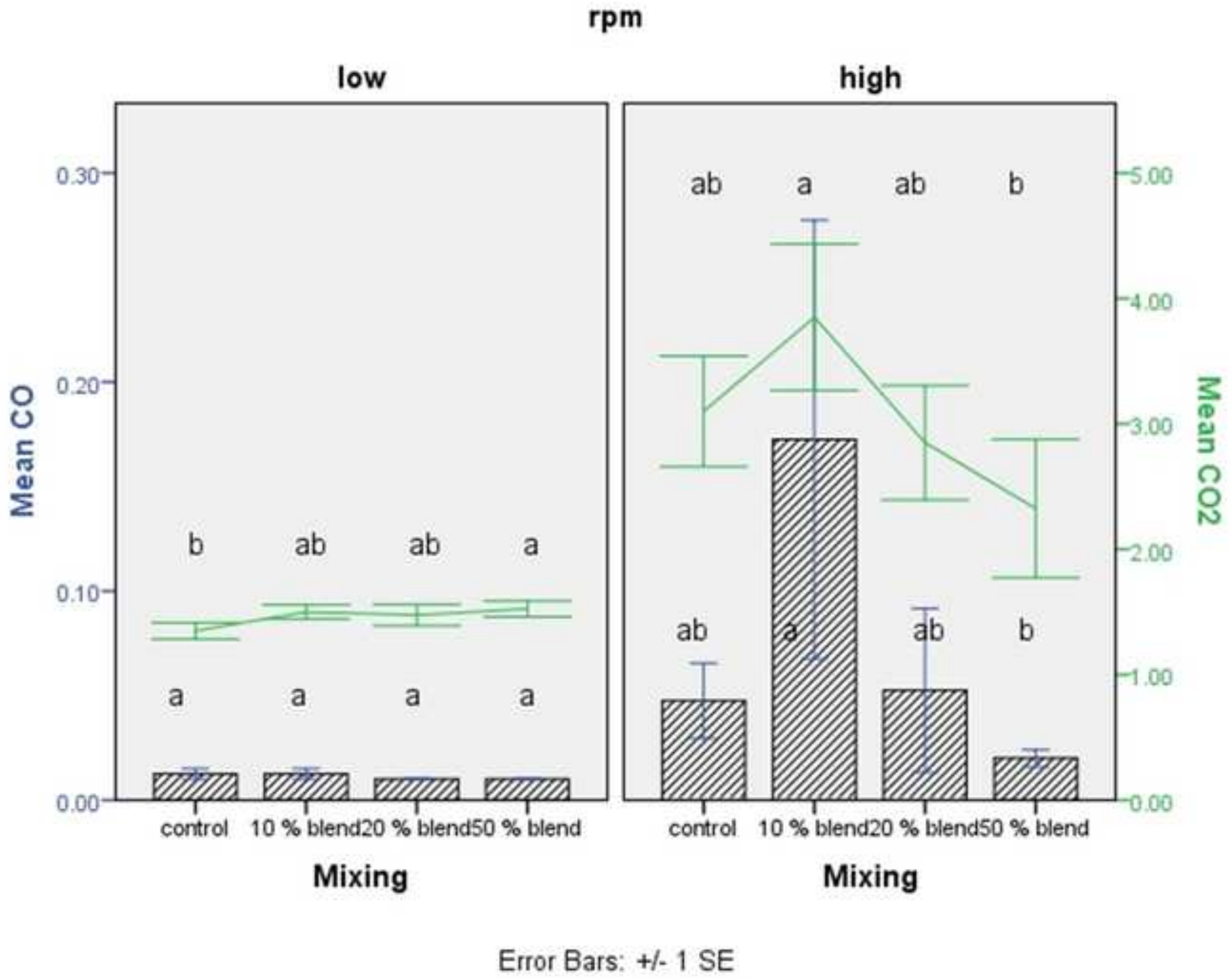

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**To: Professor H. Oliver Gao**
Editor-in-Chief
Transportation Research Part D: Transport and Environment

**Dear Professor Gao,**

With reference of your email of 25 May 2016, I send the revised version of our manuscript entitled „Technical and environmental effects of biodiesel use in local public transport" written by Attila Bai et al. for your consideration. I am very grateful for the helpful instructions, we accepted all of them and did our best to carefully prepare the revised manuscript for submission. The corrections and supplements are highlighted by yellow colour in the manuscript. I enclose the detailed list of changes and rebuttals in post scriptum. I hope it will be acceptable for both the reviewers and you.

Thank you for the possibility you gave us to revise our manuscript!

Looking forward to hearing from you soon.

***Debrecen, 6th June 2016***

Yours sincerely: **Dr. Attila Bai**
associate professor
first and corresponding author

P.S.: Corrections and rebuttals

**Reviewer 1**

*Comment 1:*

„ Do not use words like "we" "they" in the manuscript*.”*

Answer:

We accepted the comment and modified all the challenged pronouns personal from “we” and “they” to “the authors of this article”, “the authors of the cited reference”, or from the normal constructions of sentences to passive mode in every occurrence.

*Comment 2:*

„ Proper explanation of increase of $CO_2$ is missing*.”*

Answer:

We agree with the statement and supplemented the manuscript with the following related references and own explanations:

- line 90 – 96. “Carbon monoxide (CO) is produced by the incomplete combustion of carbon-containing substances in the presence of oxygen within the engine cylinder. It is obvious that the emissions of $CO_2$ and CO are interrelated i.e., if $CO_2$ emission increases then CO emission decreases naturally. It is expected that CO emission will decrease with the increasing biodiesel percentage in the biodiesel–mineral diesel blends as biodiesel itself contains 11% oxygen in its molecules (Datta and Mandal, 2016).”
- line 524 – 531. “Well known that biodiesel gave a more complete combustion, so CO could be transformed into $CO_2$. The used diesel engine (RÁBA-MAN D 2156 HM6U) has middle-spherical combustion chamber in the cylinder. Typically the fuel is sprayed on the hot wall of this combustion chamber forms a film with 12-15 micrometer thickness which may reduce auto ignition, so the ignition begins slowly, the liquid fuel remains relatively cold on the piston wall, so the soot formation decreases. However the combustion chamber is sensible for angular size, narrow speed range and it has significant smoke in case of acceleration at low revolution.”
- It should be noted that a relevant explanation was already described in the original manuscript, in line 533 – 540.: “However, the increase of $CO_2$ and CO emission is assumed to be the result of catalyst converters instead of the biodiesel concentration,

since this equipment converts CO to $CO_2$, which poses less threat to human health. The other possible explanation lies in the first use of biodiesel, since biodiesel might have dissolved the accumulated matter and the gases, which were released as a result, could have gotten into the exhaust system. It is the opinion of the authors of this paper that the data obtained with subsequent measurements should be taken as a basis in the long run; therefore, the use of biodiesel reduces the emission of these pollutants, especially at full rpm.

*Comment 3:*

„ *Biodiesel properties are missing.*”

Answer:

We entirely accepted the comment and added a new table (Table 2, line 343 – 347.) to the manuscript, including the most important characteristics of the biodiesel used during the tests.

Table 2: The most important characteristics of biodiesel during the tests

| Specification | Unit | Requirements | | Test method |
|---|---|---|---|---|
| | | minimum | maximum | |
| Ester content | % (m/m) | 96,5 | | EN 14103 |
| Density 15 C | Kg/$m^3$ | 860 | 900 | EN ISO 3675<br>EN ISO 12185 |
| Lower heating value | MJ/kg | 37 | | |
| | MJ/l | 33 | | Directive 2009/28/EC |
| Flash point | 0 C | 120 | - | prEN ISO 3679 e |
| Sulphur content | mg/kg | - | 10,0 | prEN ISO 20846<br>prEN ISO 20884 |
| Cetane number | | 51,0 | | EN ISO 5165 |
| Water content | mg/kg | - | 500 | EN ISO 12397 |
| Acid number | mg KOH/g | | 0,50 | EN 14104 |
| Iodine value | g iodine/100 g | | 120 | EN 14111 |
| Methanol content | % (m/m) | | 0,20 | EN 14110 |
| Content of monoglycerides | % (m/m) | | 0,80 | EN 14105 |
| Content of diglycerides | % (m/m) | | 0,20 | EN 14105 |
| Content of triglycerides | % (m/m) | | 0,20 | EN 14105 |
| Free glycerol | % (m/m) | | 0,02 | EN 14105<br>EN 14106 |

Source: (Inter-Tram, 2013)

*Comment 4:*

„ Please cite recent papers more.*”*

Answer:

We absolutely accepted the proposal and considerably extended the manuscript with ten additional up-to-date references (from 2014 to 2016), on the following lines.

*lines 11- 21.*

Traffic in the EU-28 is one of the most significant sector with around €562 billion in Gross Value Added a year at basic prices (4.9% of total), with 11 million employees (5.1 % of total), with 6465 billion passenger km (on average around 12700 km per person) and with 1173 Mt $CO_2$-equivalent (24.3 % of total) in 2013 (EU, 2015). The largest potential in $CO_2$ emissions can be achieved with switching to alternate fuels (Borjesson et al., 2014) and (in the future) decarbonization of electricity (Pathak and Shukla, 2016). Growing concerns of fossil fuel depletion, oil-price fluctuations, escalating energy demands and stringent emission regulations are driving the scientific community to find alternative renewable biofuels for use in diesel engines (Datta and Mandal, 2016; Rajesh Kumar and Saravanan, 2016). Today, biodiesel has been touted as the most promising substitution for petroleum-derived diesel (Foo, 2015; Shahir et al., 2015).

*lines 86 – 104.*

While many motoric factors contribute to vehicle emissions, such as engine speed, air-to-fuel ratio, and catalyst pass fraction, they are most influenced by engine power and fuel use (Avetisyan et al., 2014). The fuel properties of biodiesel are strongly influenced by the properties of the individual fatty acid methyl esters in different feedstocks, which were detailed by Wan Ghazali et al. (2015). Carbon monoxide (CO) is produced by the incomplete combustion of carbon-containing substances in the presence of oxygen within the engine cylinder. It is obvious that the emissions of $CO_2$ and CO are interrelated i.e., if $CO_2$ emission increases then CO emission decreases naturally. It is expected that CO emission will decrease with the increasing biodiesel percentage in the biodiesel–mineral diesel blends as biodiesel itself contains 11% oxygen in its molecules (Datta and Mandal, 2016). The main reasons of higher NOx emission of biodiesel compared with fossil diesel value are the followings:

- the effect density/bulk modulus differences during injection processes,
- the effect of higher viscosity and surface tension on spray processes,
- the effect of higher distillation temperatures on vaporization process,
- the presence of fuel bound oxygen provides additional oxygen for NOx kinetics
- the influence of cetane/iodine number on the ignition delay process, and
- the absence of carbonaceous and soot particles resulting in higher flame temperatures (Rajesh Kumar and Saravanan, 2016).

*lines 248 – 250.*

Shahir et al. (2015) summarized the results of 18 tests and confirmed that use of biodiesel can reduce HC, CO and PM emissions, but the NOx emission showed dissimilar tendencies in the differencial measures.

*Comment 5:*

*„* Back up the claims made with previous references*.”*

Answer:

We perfectly agree with the comment and supplemented the „Results and Discussion” section with a paragraph contained the differences between the statements of the references and our results:

- lines 560 – 565. „Regarding optimal percentage of biodiesel/normal diesel mixture, our test results confirmed the previous experiences in case of consumption (20/80 % blend) and of environmental considerations (20-50 % biodiesel content depending the type of exhaust gas and rpm). However biodiesel rate causes nearly the same reduction of performance in our tests which is higher than of the cited references. The comparison of parameters of solo buses and of articulated buses in our study might look as novelty.”
- It should be mentioned that we tried to summarize the necessity of our environmental tests (lines 298 – 301.) connected to previous references in the original manuscript: „The results of the above-mentioned experiments are very controversial in

environmental aspects. The experiments show different (sometimes extremely different) trends with regard to each of the harmful gases due to the use of biodiesel, which supports the necessity of our tests.”