

COMPARATIVE ANALYSIS OF BIODIESEL AND MINERAL DIESEL FUEL IN CASE OF USE FOR URBAN BUSES

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Introduction

The urbanization, which occurring in different-size cities around the world and is characterized by rapid development, means that not only that more people than ever before will be living and working in cities but also that more people and more goods will be making more trips in urban areas, often over longer and longer distances [1]. It means that anthropogenic load on the environment will constantly increase mainly because of exhaust emissions.

It's obviously that urban transport (including buses, state and private vehicles) has substantial impacts on global life-support systems, non-renewable resource consumption, sustainability of production of renewable resources, living conditions and human health and safety [2]:

- Global life-support systems can be significantly affected by transport-related emission of carbon dioxide and methane which contribute to the "greenhouse" effect. Vehicle emissions of carbon monoxide, hydrocarbons and nitrogen oxides reduce oxidation, i.e. the cleansing efficiency of the atmosphere.

- Transport affects sustainability of renewable-resource production because emissions of nitrogen and sulfur oxides lead to atmospheric acidity which causes water and soil pollution, degradation of vegetation and a decrease in agricultural and forestry outputs. Furthermore, there is an impact of transport-related emissions through corrosion damage to building materials.

- Gaseous and particulate emissions from vehicles, using fossil fuels, create smog and excessive concentrations of carbon monoxide, nitrogen oxides and lead. The movement of vehicles is also the main source of noise pollution. These phenomena affect, directly or indirectly, physical and mental health of all urban residents.

- Transport consumes about 40 percents of commercial energy in the developed countries mainly responsible for the world's total energy use in transport. In developing countries, with low levels of industrial development, the share of transport in commercial energy consumption is, often even higher, reaching 80 to 90 percents.

That's why in the context of sustainable urban development, among the crucial transport issues are how to make social and economic progress of mankind possible with the least damage to the natural and built environments, while saving non-renewable resources.

Using of biodiesel 'instead of' or 'in mixture' with traditional mineral fuel looks enough attractive in terms of emissions exhaust decreasing and substitution of non-renewable natural resources by biomass fuel. Although biodiesel as alternative fuel is known for long time already, unfortunately it is not use widespread. There are a lot of different reasons, most of which connected with inner-state policy, suppliers of traditional mineral power and other 'important' things deals, which finally are not so important in compare with that what we really do to save environment from irreversible changes.

In this article the advantages and disadvantages of complete or partial substitution of mineral diesel fuel by biodiesel, produced from renewable biomass resources, were studied in case of use on urban buses. Today, in time, when air pollution reaching maximum level and natural fossil recourses depleted, question about alternative energy, in this case about bio-diesel, rises more acute than in previous years. To understand what positive and negative sides of mineral diesel substitution are, it's necessary to consider known parameters, which reflect characteristics of biodiesel and petroleum diesel. In this article there is considered results of

life cycle investigation, results of combustion and also comparison of characteristics for biodiesel and petroleum diesel.

Urban buses as a subject of this investigation are not random choice for study, because such type of cities transport takes a significant volume in transport sector. And it's important to show that substitution of diesel by biodiesel can improve ecological situation of the city and has positive effect on human health. Developing new fuels can provide a wide range of potential social benefits, such as diversifying fuels that have few current substitutes, reducing dependence of the transportation sector on vulnerable fuel supplies, improving the environmental characteristics of the transportation sector, or improving its energy efficiency.

What is Biodiesel? What is Petroleum Diesel?

Biodiesel is the clean burning alternative fuel, produced from plant renewable resources. Biodiesel contains no petroleum, but it can be blended at any level with mineral diesel fuel to create a biodiesel blend. It can be used in compression-ignition (diesel) engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics [3].

Diesel or petroleum diesel is a fuel that is used to operate a diesel engine – internal combustion engine. Most commonly, it refers to a specific liquid fuel obtained by the fractional distillation of petroleum, often called petrodiesel. At that biodiesel is made through a chemical process called “transesterification whereby the glycerin is separated from the fat or vegetable oil. To be considered as viable transportation fuels these so called alkyl esters of fatty acids, must meet stringent quality standards, otherwise they become standard industrial chemicals that are not suitable for diesel applications.

Usually, biodiesel is made from a variety of natural oils [5, 7]. Chief among these are soybean oil and rapeseed oil. Rapeseed oil, a close cousin of canola oil, dominates the growing biodiesel industry in Europe.

To quantify and compare the comprehensive sets of environmental flows (to and from the environment) associated with both biodiesel and petroleum-based diesel, over their entire life cycles LCI was used [6]. Generally, life cycle flows are characterized for all raw materials from the point of extracting their primary components from the environment. For example, methanol use in the biodiesel manufacturing facility contributes life cycle flows that go back to the extraction of natural gas used as a feedstock. Likewise, life cycle flows from intermediate energy sources such as electricity are included - back to extraction of coal, oil, natural gas, limestone, and any other primary resources needed.

LCI results in this article are presented for 100% biodiesel (known as “B100”), a 20% blend of biodiesel with petroleum diesel (known as “B20”), and petroleum diesel [8]. These results include estimates of:

- Overall energy requirements;
- CO₂ emissions;
- Other regulated and non-regulated air emissions. Regulated pollutants include carbon monoxide (CO), particulate matter less than 10 microns in size (PM10), non-methane hydrocarbons (NMHC) and nitrogen oxides (NO_x). Non-regulated air emissions include methane (CH₄), formaldehyde, benzene, total hydrocarbons (THC), and total particulate matter (TPM);
- Water emissions;
- Solid wastes.

Major analytical results are presented below [9, 10, 11, 12]:

– *Energy Balance.* Biodiesel and petroleum diesel have very similar energy efficiencies. The base case model estimates life cycle energy efficiencies of 80.55% for biodiesel versus 83.28% for petroleum diesel. The lower efficiency for biodiesel reflects slightly higher process energy requirements for converting the energy contained in rapeseeds oil to fuel. In terms of effective use of fossil energy resources, biodiesel yields around 3.2 units of fuel product energy for every unit of fossil energy consumed in the life cycle. By contrast, petroleum diesel's life cycle yields only 0.83 units of fuel product energy per unit of fossil energy consumed. Such measures confirm the

“renewable” nature of biodiesel. The life cycle for B20 has a proportionately lower fossil energy ratio (0.98 units of fuel product energy for every unit of fossil energy consumed). B20’s fossil energy ratio reflects the impact of adding petroleum diesel into the blend.

– *CO₂ Emissions.* Given the low demand for fossil energy associated with biodiesel, it is not surprising that biodiesel’s life cycle emissions of CO₂ are substantially lower. Per unit of work delivered by a bus engine, B100 reduces net emissions of by 78.45% compared to petroleum diesel. B20’s life cycle CO₂ emissions of CO₂ are 15.66% lower than those of petroleum diesel. Thus, use of biodiesel to displace petroleum diesel in urban buses is an extremely effective strategy for reducing CO₂ emissions.

– *Total Particulate Matter (TPM) and Carbon Monoxide (CO) Emissions.* The biodiesel (B100) life cycle produces less TPM and CO (32% and 35% reductions, respectively) than the petroleum diesel life cycle. Most of these reductions occur because of lower emissions at the tailpipe. PM10 emissions from an urban bus operating on biodiesel are 63% lower than the emissions from an urban bus operating on petroleum diesel. Biodiesel reduces tailpipe emissions of CO by 46%.

– *NO_x Emissions.* At the same time, NO_x emissions are 13% higher for the B100 life cycle compared to the petroleum diesel life cycle. B20 has 2.67% higher life cycle emissions of NO_x. Again, this increase is attributed to higher NO_x emissions that occur at the tailpipe. An urban bus run on B100 has NO_x emissions that are 8.89% higher than a bus operated on petroleum diesel.

– *Total Hydrocarbons (THC).* There is also report 35% higher life cycle emissions of THC compared to petroleum diesel. Tailpipe emissions of THC are actually 37% lower for B100, compared to petroleum diesel. The increase in hydrocarbon emissions is due to release of hexane during rapeseeds processing and to volatilization of agrochemicals applied on the farm.

– *Water and Solid Waste.* Results show that biodiesel has life cycle wastewater flows that are almost 80% lower than those of petroleum diesel. Hazardous waste generation is also much lower for biodiesel. Biodiesel generates only 5% of the amount of hazardous waste generated by petroleum diesel. However, it’s difficult to get a consistent basis for comparing these flows because their final disposition and composition are so different.

– *Water consumption.* B100 uses water at a level that is three orders of magnitude higher than petroleum diesel, on a life cycle basis.

Comparison of Fuel Properties of Petroleum Diesel and Biodiesel

A significant advantage of biodiesel use is that biodiesel and its blends with petroleum diesel can be used directly in diesel engines with no impact on engine performance and engine life. Although compatibility of biodiesel with engines - internal combustion engine is a proved fact, but there are some certain caveats.

The most important of these are:

- Biodiesel exhibits cold weather problems;
- Some types of biodiesel have exhibited storage instability that could lead to engine problems;
- Diesel additives may not provide the same benefits when used with biodiesel;

From other side biodiesel has some significant advantages over petroleum, such as zero aromatic content, higher cetane numbers, zero sulfur content and low flash point [13, 14, 15, 16, 17].

Cetane Number

The cetane number of the fuel is a measure of its ignition quality. The cetane number of biodiesel exceeds that petroleum diesel, which implies that biodiesel may provide cetane enhancement when used neat or in

blends, and may provide emission benefits that have been correlated to cetane number. Higher cetane numbers (as high as 55 to 60) generally improve diesel emissions, but above that level little improvement is demonstrated.

The cetane number of biodiesel depends on the oil or fat feedstock. Fatty acids consist of long chains of carbon atoms attached to carbonyl groups. Fats and oils contain a distribution of carbon chains of varying lengths, typically ranging from 10 to 18 carbons (referred to as C10 to C18 chains). Some carbon chains contain 0, 1, 2, or more double bonds between the carbons, and have carbonyl groups in different locations. Cetane number increases with chain length, decreases with number and location of double bonds, and changes with various locations of the carbonyl group. As bonds or carbonyl move toward the center of the chain, the cetane number decreases. Cetane numbers increase from 47.9 to 75.6 when the number of carbons in the fatty acids in biodiesel increases. When the number of carbons in the fatty acid chains exceeds C12, the cetane number exceeds 60. Generally, the cetane number for a blend of biodiesel and petro-diesel fuel is a nearly linear function equal to the average of the cetane numbers for the fuels. This implies that the neat cetane numbers for diesel and biodiesel can be used to estimate the cetane number over the entire range of mixtures of biodiesel with diesel fuel.

Flash Point

Flash point is a measure of the temperature to which a fuel must be heated such that a mixture of the vapor and air above the fuel can be ignited. All diesel fuels have high flash points (54°C, minimum; 71°C, typical). The flash point of neat biodiesel is typically greater than 93°C. From the perspective of storage and fire hazard, biodiesel is much safer than diesel. In blends, the diesel flash point will prevail.

The Engine Manufacturers' Association (EMA 1995) expressed concern that the oxidative instability of some types of biodiesel may result in fuels that have unacceptably low flash points after storage. Some biodiesels have excellent storage histories; others have tended to oxidize rapidly.

The number and location of the double bonds have been identified as possibly contributing to the instability of biodiesel fuels. Fatty acid chains can be saturated (adding hydrogen or alcohol) to reduce the number of double bonds, and it may be possible to remove the fatty acids with excessive double bonds if indeed, these characteristics are confirmed as sources of the problem. In addition, rapeseeds oil contains natural antioxidants, which can be added back to the fuel if removed during processing. And a number of antioxidants have been identified that significantly reduce the amount of oxidation that occurs during storage.

Distillation

Biodiesel fuels have a narrow range of boiling points from 327°C to 346°C. The Engine Manufacturers' Association and others have reported that intake valve deposit formation is a problem with methyl esters at light load, which may be related to the large percentage of olefinic content in the B20 mixtures. Excess glycerine and glycerides in the fuel have also been associated with deposits.

Energy Content

Generally, fuel consumption is proportional to the volumetric energy density of the fuel based on the lower or net heating value. Based on test data, petroleum diesel contains about 131,295 Btu/gal while biodiesel contains approximately 117,093 Btu/gal. The ratio is 0.892. If biodiesel has no impact on engine efficiency, volumetric fuel economy would be approximately 10% lower for biodiesel compared to petroleum diesel. However, fuel efficiency and fuel economy of biodiesel tend to be only 2%-3% less than that of mineral diesel.

Flow Properties (Cold Temperature Sensitivity)

The key flow properties for winter fuel specification are cloud and pour point. These are static tests that indicate first wax and non-flow temperatures for the fuel. Cloud point is a measure of the temperature at

which the first wax crystals form, and is related to the warmest temperature at which these will form in the fuel. Wax crystals cause fuel filter plugging. Pour point is a measure of the fuel gelling temperature, at which point the fuel can no longer be pumped. The pour point is always lower than the cloud point.

Additives called flow improvers do not generally affect the cloud point of conventional diesel fuel; however, they do reduce the size of the wax crystallites that form when the fuel cools. Additives tend to allow the fuel filters to operate at lower temperatures.

The cloud point of methyl ester, used in this study, can be 30°C higher than that for diesel. The difference in pour points may be 10°C higher for methyl ester. The relevant structural properties of biodiesel that affect freezing point are degree of unsaturation, chain length, and degree of branching.

Fully saturated fatty acid chains tend to become solids at relatively high temperatures (tallow, hydrogenated soy oil, palm oil). Rape and canola methyl esters have lower cloud and pour points than soy methyl ester. Producing biodiesel with ethanol instead of methanol tends to reduce the cloud and pour points by a few degrees. Rape ethyl esters have cloud points of 10°C and a pour point of 15°C. Isopropyl alcohol has been used to make a biodiesel with a pour point 90°C lower than methanol-based biodiesel; pour point temperature was reduced by 30°C.

Traditionally, cloud and pour points of biodiesel blends have been modified by changing the amount of biodiesel in the blends. Biodiesel blends mineral diesel show that cloud and pour points increased as the amount of biodiesel increased.

Oxidative Stability

Oxidative stability is a major industry issue for diesel and biodiesel fuels. The degree of saturation of the fatty acid chains tends to be correlated with its stability.

Oxidation products formed in biodiesel will affect fuel life and contribute to deposit formation in tanks, fuel systems, and filters. Gum number is one of several possible measures of oxidative stability of a fuel, iodine value is another. Fuels with high iodine numbers may possess high gum numbers. Thermal and oxidative instability, and fuel oxidation during storage can lead to deposit formation and other potential engine problems.

Sulfur, Aromatic, Ash, Sediments, Water, Methanol, Glycerine, and Glyceride Content

These contaminate, if they exist at all, are limited less than 2% in the biodiesel, in total. The ester content of a fuel-grade biodiesel generally exceeds 98%. Biodiesel is nonaromatic and does not contain sulfur.

Sodium and potassium containing ash may be present because of contamination from catalysts used in transesterification. Phosphorous may be present from inferior oil refining (poor gum removal). Water and sediments may be by-products of long-term storage. Glycerine and methanol in the biodiesel may scavenge water. Glycerine, glycerides, and excess alcohol are major fuel contamination problems, and newly developed industry standards have taken aim at controlling these contaminants. Sediment may result from oxidation of esters and reactive glycerides in the fuel. Algae growth may also produce sediment.

Comparison of Biodiesel and Diesel Fuel Economy in Case of Use for Urban Buses

The fuel economy of the bus burning biodiesel is based on combustion data in a modern four-stroke diesel engine. Table 1 [18] below represents fuel economy data for the same four-stroke diesel engine used to calculate the fuel economy of the diesel fuel. The data clearly show the following:

- The energy efficiency determined by both methods (based on CO₂ and on fuel use) for each blend is the same within experimental error. Thus, the fuel composition and lower heating value data used to estimate fuel economy from CO₂ and fuel flow data are internally consistent.
- Within experimental error, the energy efficiency is independent of biodiesel content. The neat biodiesel actually shows a better fuel economy of around 3%.

Biodiesel increases emissions of NO_x and decreases emissions of PM₁₀ in urban bus engines. One approach often used to mitigate the NO_x increase associated with biodiesel is to change the timing of the engine [19]. Retarding the timing of these engines tends to reduce NO_x emissions at the expense of increasing PM₁₀ [20]. An oxidation catalyst can be added to the engine to bring PM₁₀ emissions down again.

Neat biodiesel and biodiesel blends should exhibit a fuel economy proportional to the lower heating value of the blend [21]. No improvement in energy efficiency is expected. Therefore, the fuel economy of the biodiesel bus is assumed to be the same as for a conventional diesel fueled bus $\frac{3}{4}$ 7.5 MJ/bhp-h.

Table 1: Economy Data for Biodiesel Fuels in a Modern Series 60 Engine

% Biodiesel by Volume in Diesel Fuel	Engine Efficiency	
	Calculated from Measurements of CO ₂ Emissions	Calculated from Fuel Consumption Data
0	7176	7326
20	7040	7192
35	7080	7130
65	7006	7133
100	7038	7038
avg/ stdv	7116	97 (1.4%)

The lower heating value of biodiesel is used to determine the amount of fuel needed per functional unit. The lower heating value of biodiesel is assumed to be 36.95 MJ/kg. Therefore, 0.203 kg of biodiesel are required per brake horsepower hour of engine use.

The fuel economy of the diesel bus is based on combustion in a modern four-stroke diesel engine. The fuel economy for petroleum diesel is based on data collected by Graboski investigations [22]. Fuel economy was determined for a four-stroke diesel engine operating on a range of fuels including low- sulfur diesel and blends of biodiesel from 20% to 100%. The fuel economy does not vary as a function of biodiesel blended in the fuel. Also fuel economy can vary from engine to engine. This approach allows comparing relative performance of the two fuels using the same engine data for fuel economy. These were by fuel mass and by the emissions-based carbon balance for EPA transient testing.

The fuel economy for our combustion model is 7,250 Btu/bhp-h, or 7.5 MJ/bhp-h.

The lower heating value of mineral low-sulfur diesel fuel is used to determine the amount of fuel needed per functional unit. The lower heating value of diesel fuel is assumed to be 43.5 MJ/kg. Therefore, 0.172 kg of diesel fuel is required per brake horsepower hour of engine use.

Comparison of Biodiesel and Diesel Tailpipe Emissions from Urban Buses

Considering emissions data, NO_x, CO, NMHC, PM₁₀ and SO_x there is necessary to separate into data for older two-stroke engines and also moderate four-stroke engines. This article is focused on new four-stroke engines.

Biodiesel combusted in the bus engine contains carbon that is derived from biomass and from fossil fuels. Methanol chemically coupled to the fatty acids from rapeseeds oil contains fossil carbon. The fatty acid portion of the methyl ester contains only biomass-derived carbon. The distinction is important in identifying the amount of CO₂ derived from biomass. This portion of the CO₂ emissions does not contribute to total CO₂ in the atmosphere because of its recycle in the production of oil. As well-known, biodiesel contains 73.2% biomass carbon and 4% fossil-derived carbon. Thus, 73.2% of the total CO₂ emitted at the tailpipe is recycled in the agriculture step of the life cycle for biodiesel [23].

Engine which completely combusts the carbon in the fuel all the carbon would end up in CO₂. The emissions from diesel engines include PM₁₀, CO, and NMHC, as well as CO₂. The carbon is partitioned among all four components.

The carbon partitioned in CO is estimated as the product of the total mass of CO times the percent carbon in each molecule. The percent carbon in CO is 42.9%⁶⁴. The complex natures of the CH and PM make this calculation more difficult [4].

PM contains two basic components: soot and the volatile organic fraction (VOF). Soot is essentially 100% carbon resulting from pyrolysis reactions during combustion. The amount of soot present in the particulates is strongly affected by the amount of biodiesel-derived oxygen in the fuel [4].

Petroleum diesel in volume 100% emits PM containing 54% carbon as soot. B100 emits PM with only 30% carbon as soot, while blends contain soot at levels between the values for each neat fuel.

In the table 2 [24] shows emissions from petroleum diesel and biodiesel blends. The change in tailpipe emissions resulting from the biodiesel use is assumed to be linear. Therefore, emissions for other biodiesel blends can be extrapolated from the results shown in Table 2.

Table 2: Effect of Biodiesel on Tailpipe Emissions (g/bhp-h)

Emissions	Diesel Fuel Baseline	20% Biodiesel Blend	100% Neat Biodiesel
Carbon Dioxide (fossil)	633.28	534.10	136.45
Carbon Dioxide (biomass)	0	108.7	543.34
Carbon Monoxide	1.2	1.089	0.6452
Hydrocarbons	0.1	0.09265	0.06327
Particulate Matter (PM10)	0.08	0.0691	0.02554
Sulfur Oxide (as SO ₂)	0.17	0.14	0
Nitrogen Oxide (as NO ₂)	4.8	4.885	5.227

In conclusion it is necessary to say that this article was prepared to identify and quantify the advantages of biodiesel as a substitute for petroleum diesel. These advantages are substantial, especially in the area of energy security and control of greenhouse gases. Also there are identified weaknesses or areas of concern for biodiesel—such as its emissions of NO_x and THC. However these weak sides are only opportunities for further research to resolve these concerns.

This study provides the building blocks for others to assess the relative merits of this fuel under a wide variety of circumstances, to which it could be exposed.

On a smaller scale, it provides the type of information that local regulators always seek when developing approaches to solving our air, water, and solid waste problems.

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