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EVALUATION ANALYSES OF SOME RENEWABLE FUELS REGARDING THEIR USAGE IN DIESEL-ENGINE

PhD thesis booklet

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January, 2019.

C O N T E N T S

1. Introduction, background of the topic

The transport and energy sectors' energy consumption are forecasted to go up basically until 2030, moreover also until 2050 in the European Union and on a global scale as well. This expanding in the demand of energy means a growing in environmental pollution and environmental load from these sectors. A wide range of alternative sources is offered in the transport sector, among them, biofuels can be a solution from demand's side. There can be several reasons for introducing renewable fuels:

- Diversification of energy sources;
- Reducing the consumption of fossil fuels;
- Increasing energy security;
- Utilization of agricultural products and by-products;
- Job creation.

Fossil diesel is a traditional fuel for compression ignition engines. Diesel fuel is the traditional energy source of CI (Compression Ignition) engines. Use of CI engines in on-road HDVs (Heavy Duty Vehicles; e.g. buses) and in other machines (e.g. non-road mobile machinery; e.g. excavators, bulldozers) is almost autocrat compared to the SI (Spark Ignition) engines thanks to their better efficiency and higher specific power.

A wide range of alternative sources is offered in the transport sector, among them, biofuels can be a solution from demand's side. Biodiesel standards for regulating the quality of biodiesel vary from region to region. Different standards are in the EU, in the USA, in Australia, Brazil, India, Japan, and in South Africa. There are significant differences among the standards, which can be traced back on the various feedstocks, which is available in the given country.

Diesel engines can be propelled – besides conventional fuels – by different fuels derived from biomass. Among them the most frequently used are the Fatty-Acid-Methyl-Esters called biodiesel, which are produced from different basic stocks, as well as the other compounds with oxygen content. In addition to a wide range of fuel production technology, the number of naturally occurring raw materials from which diesel fuel can be produced in Diesel-engines is increasing. Beside the traditional esterification technologies appear the green fuel production processes, also known as glycerol-free production processes.

Despite the benefits of renewable fuel in energy supply, it is questionable whether they have benefits during their use:

Most of the ICE (Internal Combustion Engine) relevant physico-chemical properties of the vegetable oil methyl-esters for combustion in Diesel-engines are in most cases less favorable than the same properties of diesel. Renewable fuels have a minor improvement on the combustion process of compression-ignition internal combustion engines. Based on the in-cylinder pressure as a parameter for combustion, the engine operation with renewable materials slightly shifts the combustion phase of the indicator curve toward the theoretical cycle;

In terms of gaseous emissions from engines, the results show an enhancing combustion process with bio-based fuels against those for diesel fuel. Specifically, this indicates that the level of CO (Carbon-monoxide) and HC (Hydrogen-carbon) harmful substances is decreasing, the value of the NO_x (Nitrogen-oxides) component increases. The extent of the deviation depends on several additional factors related to the tests;

FSN (Filter Smoke Number) and smoke opacity are reduced in all cases when vegetable oil methyl-ester is used in comparison to diesel, regardless of the engine being tested, the test procedure, the fuel mix ratio, and the engine operating point. It is also valid during a transient test cycle. Particle mass and size-number characteristics (eg. total particulate numbers) are more complex. The effect of bio-derived fuels on these parameters depends mainly on the engine being tested and on the fossil-renewable blending ratio of the tested fuel, i.e., decreasing and increasing effects have been shown.

2. Aim of the work

The aim of the doctoral research work was to evaluate the overall impact of certain renewable fuels on diesel engine operation on the basis of the the results of a targeted series of tests. It was a part-aim to examine and evaluate a new type of renewable fuel, which has not yet been investigated.

For the overall assessment, I have defined five sub-areas, which are as follows:

- Determining, comparing and evaluating the most important ICE relevant physico-chemical properties of fuels;
- As the first part of the engine test, the engine's external, economical parameters;
- Burning parameters that can be recorded during combustion;
- Impact of fuels on engine emissions;
- The external-cost calculations based on the pollutants emitted by the engine, which can be used to evaluate fuels economically beyond the technical assessment from the point of view of use.

I place great emphasis on the evaluation of renewable fuels for engine emissions, including particulate matter emissions. I do this for several reasons. First of all, this is one area where clear trends in renewable materials cannot be taken into account when processing international literature. Secondly, the air pollutant particulates emitted by internal combustion engines have a very damaging effect on both the living being and the built environment.

The aim of the work is therefore to provide a research result that combines the above-mentioned subject areas with the results of high mixing ratios of rewenable fuels in the investigated fuel. Based on the results, I carry out a complex evaluation of these areas.

The test series also includes two types of renewable fuels, one of which is a new type fuel which is a result of a new production technology.

According to my intentions, the measurement results produce new scientific results that can be utilized well in this field of internal combustion engines, and further useful, forward-looking research directions can be identified.

3. Investigated fuels

For our comparative tests, we have purchased diesel fuel as a reference fuel that complies with the relevant standard from a MOL fuel filling station. According to the standard, the reference fuel may contain 7 V/V % fatty acid methyl ester. This data was taken into account in the preparation of the mixtures.

The first fuel from bio source tested was the standardized fatty acid methyl-ester (FAME). It is used to produce a blend of diesel fuel that is sold at fuel filling stations across Europe. We purchased the fuel from its Hungarian manufacturer.

TBK Biodiesel - the second tested renewable fuel - or English called Triglycerides of Modified Structure (TOMS), is a new type of renewable fuel. The main advantage of TBK biodiesel is that no by-product is produced during its production process, so no glycerin is produced, ie. the raw vegetable oil is entirely used as fuel.

In addition to the use of the above-mentioned three fuels unmixed, four controlled blends were created, so we worked with 7 different fuels. The blends were created by mixing renewables at 25 V / V% and 75 V / V% for diesel.

4. The used engine

The engine tests performed were carried out at the KTI Nonprofit Kft., in the engine test laboratory. The tested engine was a RÁBA D10 UTSLL 160. This engine is a widely used engine in the Hungarian bus fleet. For this reason, it has a significant impact on the air pollution and immission status of roads and big cities in Hungary. The main parameters of the engine are shown in **Table 1**. During the tests with different fuels, there was no change in the design or in the adjustment of the engine.

This engine is considered to be outdated today with regard to emission classification, fuel supply system, mixing, and emission after-treatment.

Table 1. The most important parameters of the used engine

Parameter	**Scale / Property**
Bore	120,5 mm
Stroke	150 mm
Number of cylinders	6
Cylinder layout	In line
Compression ratio	15,2
Displacement	10350 cm^3
Combustion chamber	undivided (direct injection)
Type of chamber	Saurer
Exhaust gas recirculation	no
Exhaust gas aftertreatment	no
Turbo	Schwitzer S3
Intercooler	yes
Emission approval	EURO II
Rated power	160 kW / 1900 rpm
Rated torque	900 Nm / 1300 rpm

5. Method

The test method consists of three steady state engine operating points. We have pre-selected these points for the purpose of significantly different combustion conditions. Therefore, engine emissions are also expected to be significantly different at the three points. It is very important to note that measuring more than three points was not possible for several reasons. On the one hand, the detailed particle tests consisted of a 30-50 minutes measurement time, which is very fuel demanding. On the other hand, to avoid damaging the measurement system at high load points where high temperatures of exhaust gas occur. The parameters of the three selected measuring points of the torque-speed operating range of the engine are given in **Table 2**. These measurement points were part of the type approval test required for engine emission classification.

Table 2. Engine operating points

Engine operating point / Speed - load	Torque [Nm]	Power [kW]	Properties of the engine operating point
1. / 1300 rpm – 50% load	450	61	Low speed, low flow velocity, a worse air-fuel mixing expected. Mean load therefore mean air-fuel ratio. **Mean intensity of combustion.**
2. / 1900 rpm – 25% load	200	39,5	High speed, high flow velocity, a better air-fuel mixing expected. Low load therefore high air-fuel ratio. **Low intensity of combustion.**
3. / 1900 rpm – 75% load	600	115	High speed, high flow velocity, a better air-fuel mixing expected. High load therefore high air-fuel ratio. **High intensity of combustion.**

6. Experimental set up

The measuring systems used for the tests are shown in **Figures 1** and **2**. **Figure 1** shows the measurement system used for indication and gaseous emissions. The most important parts of the indicator system are the water-cooled indicator crystal, the crystal on the fuel line, the engine speed transmitter, the charge amplifiers, the opto-coupler, the data processing unit and the computer with the evaluation program. For the determination of gaseous emissions, the sample was taken from the raw exhaust gas of the engine. The measured components are CO, CO_2, HC, NO_x and O_2. A non-dispersive infrared measurement detector for determining CO and CO_2 components, the principle of flame ionization measurement for HC emissions, the principle of chemiluminescence to determine NO_x emissions have been used and finally, the paramagnetic measurement principle was used to determine O_2.

The measurement system used to determine the particulate relevant emission is shown in **Figure 2**. The four different measurement principles used are as follows: 1. Opacity, or opacity of the smoke column, 2. FSN filter paper method, 3. Particulate mass and 4. Particulate number. The first two measurement methods are an optical method for which the sample was taken from the raw exhaust of the engine. To determine the particle mass and number, the sample was diluted using a dedicated full-flow dilution system. Full flow dilution means diluting the total exhaust of the engine.

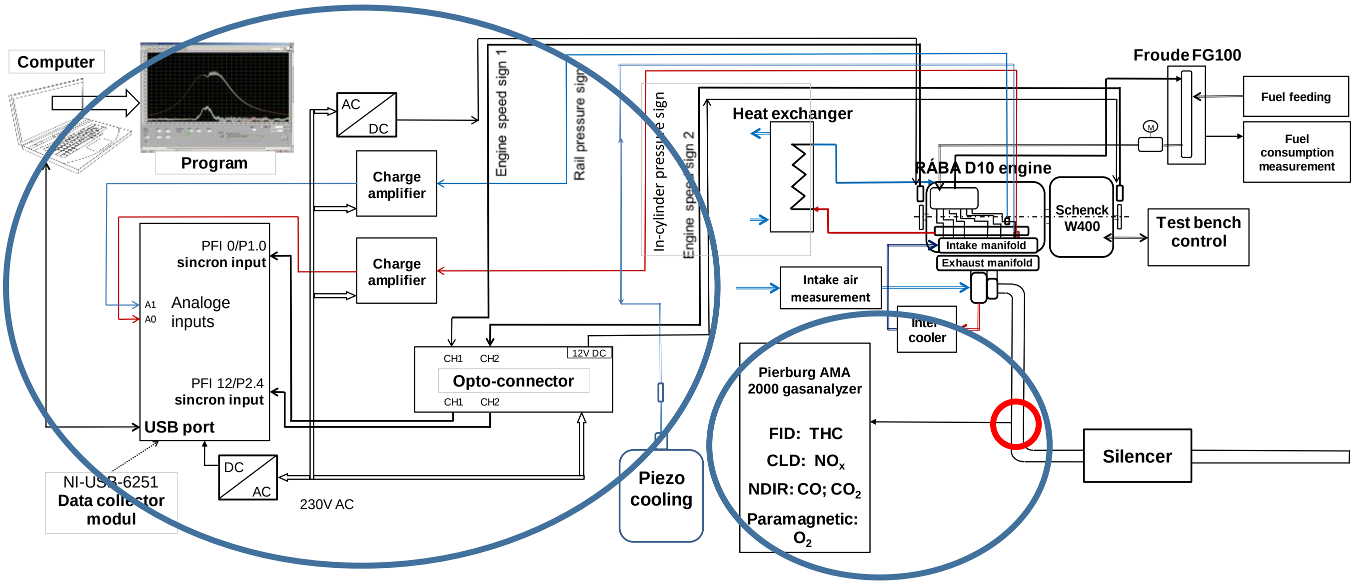


Figure 1. Experimental set up for indicating and for measuring the gaseous pollutants of the engine

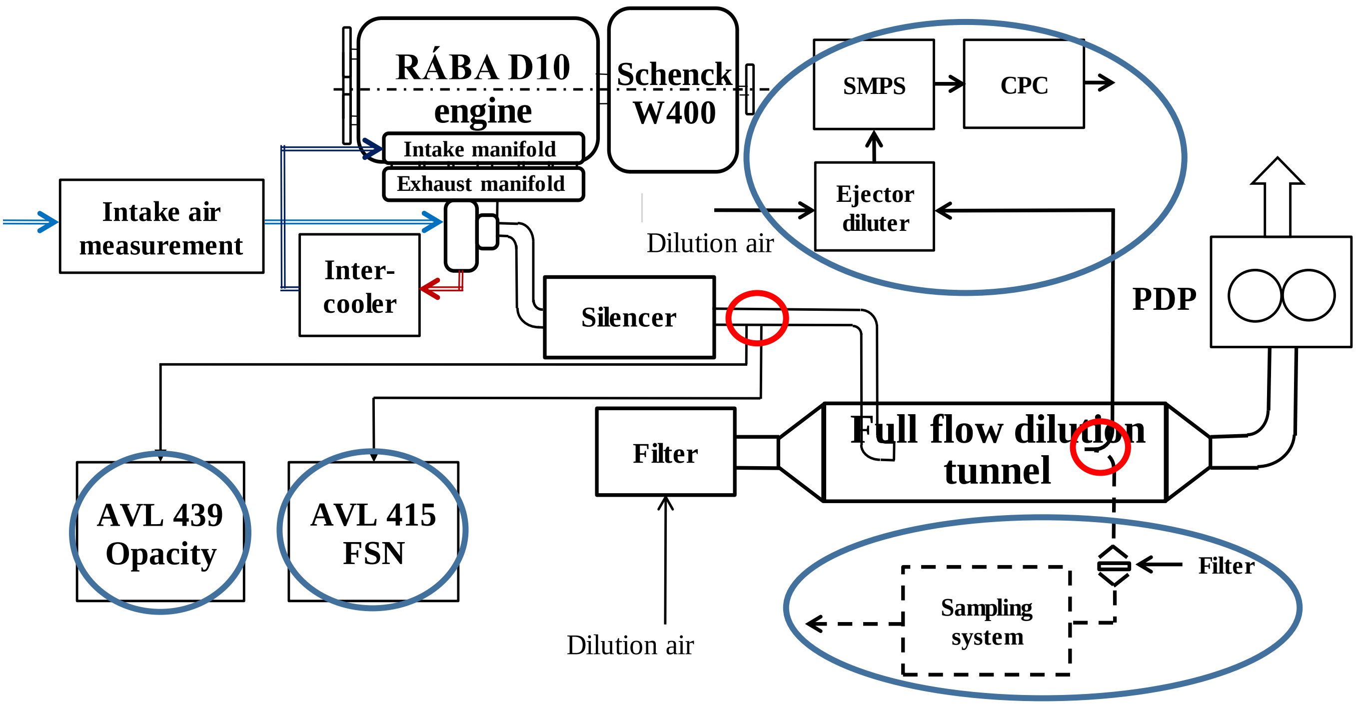


Figure 2. Experimental set up for measuring the particulate relevant emission of the engine

7. Thesis

In my dissertation I investigated the use of certain renewable fuels in a Diesel-engine, in the framework of which several parameters were analyzed in several parameter groups. The scientific results achieved can be formulated as follows:

Thesis 1: The physico-chemical properties of the fuels tested and the combustion processes (pressure, heat release) in the diesel engine under test are closely related.

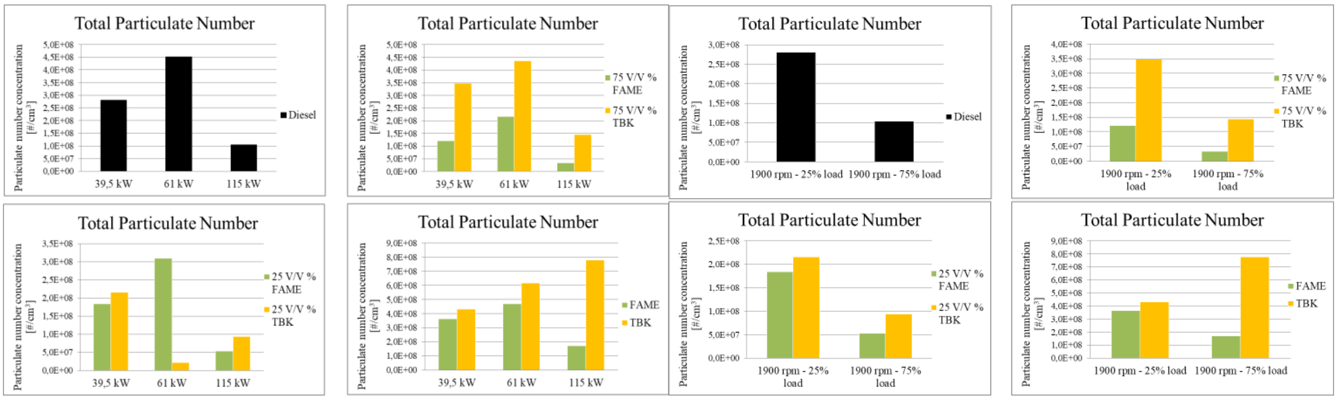
The in Diesel-engine usable and tested renewable fuels' (standardized FAME and non-standardized TBK) most important ICE relevant physico-chemical properties are less favourable than the same properties of fossil diesel. This is done by examining the density, kinematic viscosity, flash point, elemental composition, heating value, evaporation properties of fuels. Based on the indicator diagrams taken during the engine tests and the calculated heat release, I find out, that at the three steady state points of engine examined, at the same power level for each tested fuel despite the less favourable physico-chemical properties of fuels with bio-origin a slight improvement can be recorded in the initial stage of the combustion process of the Diesel-engine. (Chapters 3.1.-3.6 and 4.5.1.-4.5.2.; [TP 4], [TP 5], [TP 7], [TP 8], [TP 11]), [TP 12], [TP 15])

Thesis 2: In the case of engine tests with renewable fuels, the gaseous pollutants emitted by the tested Diesel-engine (NO_x, HC) show a tendency of improvement in combustion i.e., NO_x emission increases, HC emission decreases compared to NO_x and HC emissions from engine running on diesel.

The in Diesel-engine useable and tested renewable fuels (standardized FAME and non-standardized TBK) and the fossil-fueled Diesel-engine has a slight, but tendencious different in emission of gaseous components. An increase in the amount of nitrogen oxides emitted by the Diesel-engine powered by renewable fuels can be observed at the three steady state points of engine tested, at points, for each power level of the engine for fuel tested (the average deviation between the NO_x results of the unmixed diesel and the non-blended renewable fuels is 3.4%), while there is a decrease in emission of hydrogen-carbons (the average deviation between the HC results of unmixed diesel and non-blended renewable fuels is -17.2%). (Chapter 5.1.; [TP 4], [TP 5], [TP 7])

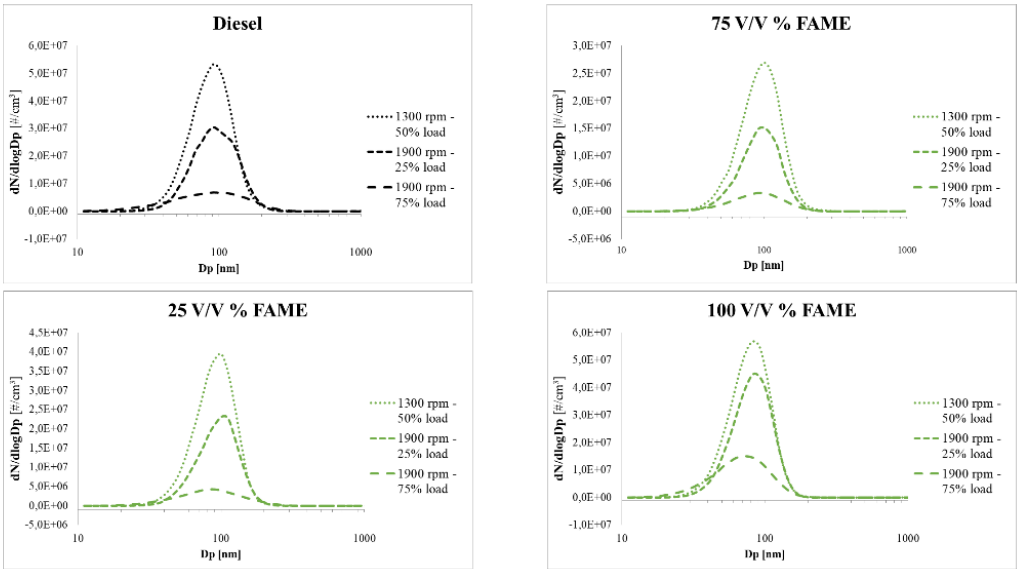
Thesis 3: Relates to the relationship between the number of particulates emitted by the engine and the engine operation conditions and the engine itself.

3.a. There is no linear relationship between the total number of particulates in the range of 10 nm to 1000 nm electrical mobility diameter emitted by the Diesel-engine running on diesel and renewable fuels (standardized FAME and non-standardized TBK) and the power of the engine. The total particulate number varies depending on engine power (the three tested engine operating point: 1300 rpm – 50% load; 1900 rpm – 25% load; 1900 rpm – 75% load). However, the change in engine torque has a clear effect on the emitted particulates, so with the increase in engine torque (load), the total number of particulates decreasing. (the two engine operating point tested: 1900 rpm – 25% load; 1900 rpm – 75% load). Torque change - all particle number change relationship exists for all the fuels tested (unmixed fuels and blended fuels). Measurements have been carried out at three steady state points of engine, while each point were with the same level of engine power for fuels tested (Chapter 5.2.4., [TP 3]).



3. Figure Thesis 3.a. – Function between engine operating conditions and total particulate number emitted by the engine

3.b. With measurements at three steady state operating points the particulate size-number distribution of emitted particulates has been recorded and characterized regarding a 25-year-old Diesel-engine with EURO II classification in the electrical mobility diameter range of 10 nm – 1000 nm of particulates emitted. In this range, the calculated mean diameter, so the size to which the largest particle number belongs, is around 100 nm for each of the fuels tested and the engine. (maximum deviation: + 8 nm and – 17 nm). Based on these statements, I conclude that particle emissions with a scale of nm but below 1 µm are not only a feature of modern engines. However, the number of particles of this size range is only set out first as a requirement in the EURO VI (2014) emission type approval regulation of engines of road heavy duty vehicles [106]. (Chapter 5.2.3., [TP 3])



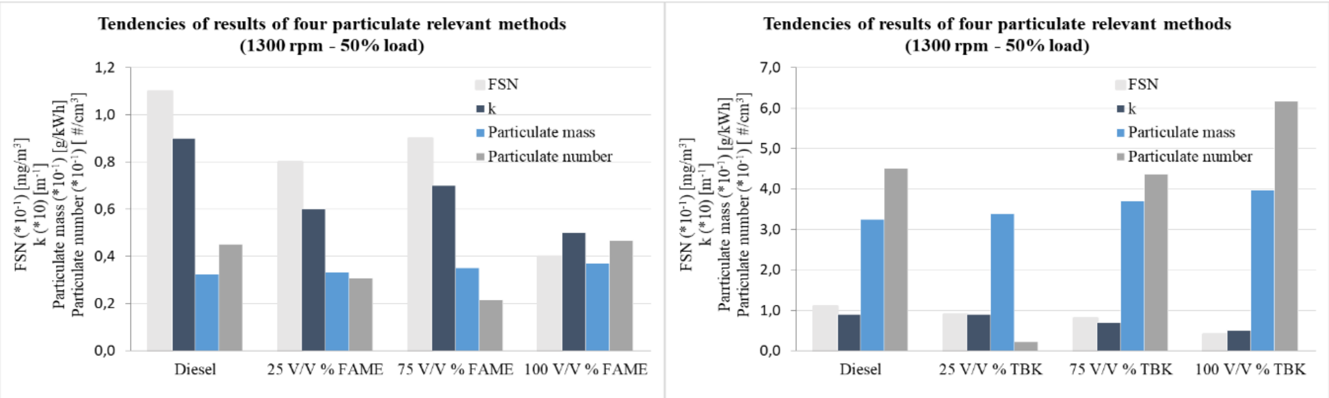
4. Figure Thesis 3.b. – Particulate emission of the engine in range of 10 nm – 1000 nm of electrical mobility diameter

<u>Thesis 4:</u> The results of the particulate relevant emission measurement methods (FSN, opacity, particulate mass, particulate number) of the tested Diesel-engine show contradictory tendencies by increasing the renewable content of the tested fuels.

4.a. Based on the results obtained at the same power level for each tested fuel at the three steady state operating points of the engine, that with increasing blending ratio of renewable fuels (standardized FAME and non-standardized TBK) to the fossil in the fuel tested, the engine particulate relevant emissions vary significantly. The results of the particulate relevant pollutant emissions of the tested engine are measured by four different, widely used measurement methods show contradictory tendencies while the bio-derived part of the tested fuel increasing (FSN decreases, opacity decreases, particulate mass increases, particulate number changes). Because of this:

4.b. On the basis of the results obtained at the same power level of engine for each of the tested fuels at the three steady state operating points tested, I determine, that the particulate matter emission of the tested compression ignition engine cannot be clearly assessed by the applied measurement procedures. Therefore, in order to examine the particulate emission of Diesel-engines (i), several different methods of measurement have to be always used when comparing diesel and renewable fuels to avoid the mistake of increasing or decreasing particle emissions. (Chapters 5.2.1.-5.2.4., [TP 3])

4.c. Or (ii) new procedure or procedures for the determination of particulate emissions from Diesel-engines have to be developed, which more clearly indicates that the amounts of particulates emitted by the engine when the bio rate increases in the tested fossil-renewable blend. Such a method may be the counting the particles up to a limit of 10 μm. This expanded size range is also expected to include particles that play a role in mass measurement (causing "mass effect"). I also recommend testing the toxicity of the emitted particles. The determination of the mass or number of particles is important itself, but this can be further increased by examining social significance, eg. by toxicity. Social significance, I mean the negative impact of the particle on the living being or on the built environment as well. (Chapters 5.2.1.-5.2.5., [TP 3])



5. Figure Thesis 4. – Tendencies of particulate relevant emission measurement methods

Thesis 5: **Based on an economic analysis of air pollutant emissions from the Diesel-engine being tested renewable fuels are less economically viable than fossil diesel because of their higher emissions of air pollutants.**

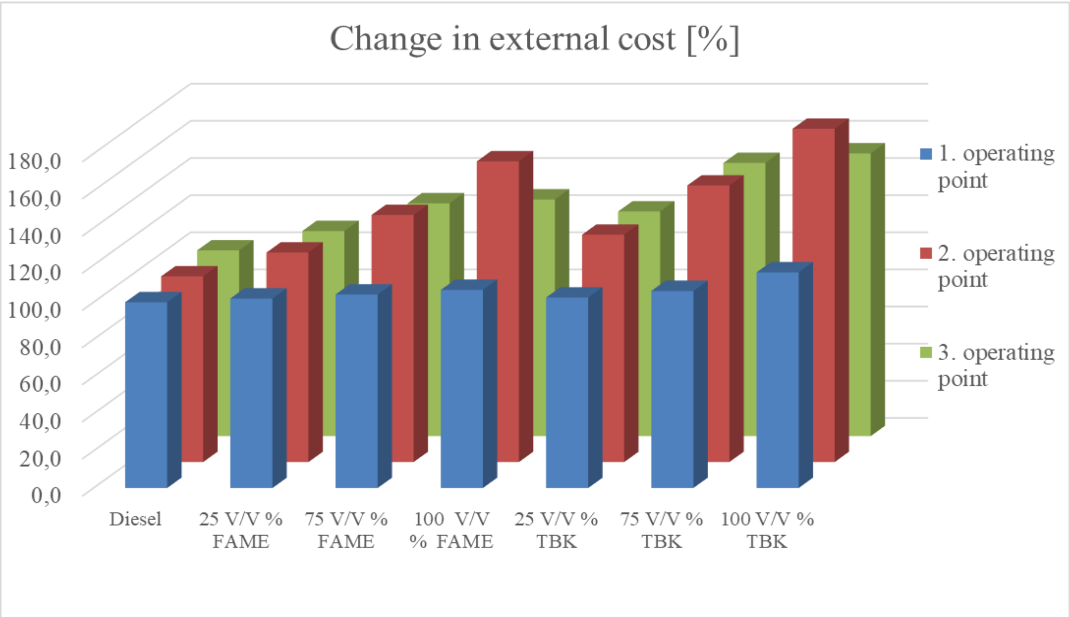
At the three steady state operating points of the engine tested, the air pollutant emissions obtained at the same performance level for each tested fuel at the same level of performance I have developed a costing model described in the following formula:

$$C_{j,k} = \sum_i (E_{i,j,k} \cdot \frac{H_{akt.tüa}}{3,6} \cdot B_t \cdot \eta_{(eff)j,k} \cdot u \cdot \frac{f_i}{10^6})$$

where:

- $C_{j,k}$: is the external cost [Ft] of the sum of the harm values of the measured pollutant components per engine operating point (j) and the blending ratio (k);
- $E_{i,j,k}$: measured emission values [g/kWh] per pollutant (i), per engine operating point (j) and blending ratio (k);
- $H_{akt.tüa.}$: the heating value of the currently tested fuel for diesel, FAME and TBK and proportional to the mixing ratios in case of blends [MJ/dm^3];
- B_t: the specific fuel consumption of the vehicle with the fuel tested (t) [dm^3/100km];
- $\eta_{(eff)\ j,k}$: effective efficiency of the tested engine per engine operating point (j) and blending ratio (k);
- u: total lifetime mileage for buses [km];
- f_i: specific external cost factor per pollutant (i) [Ft/t].

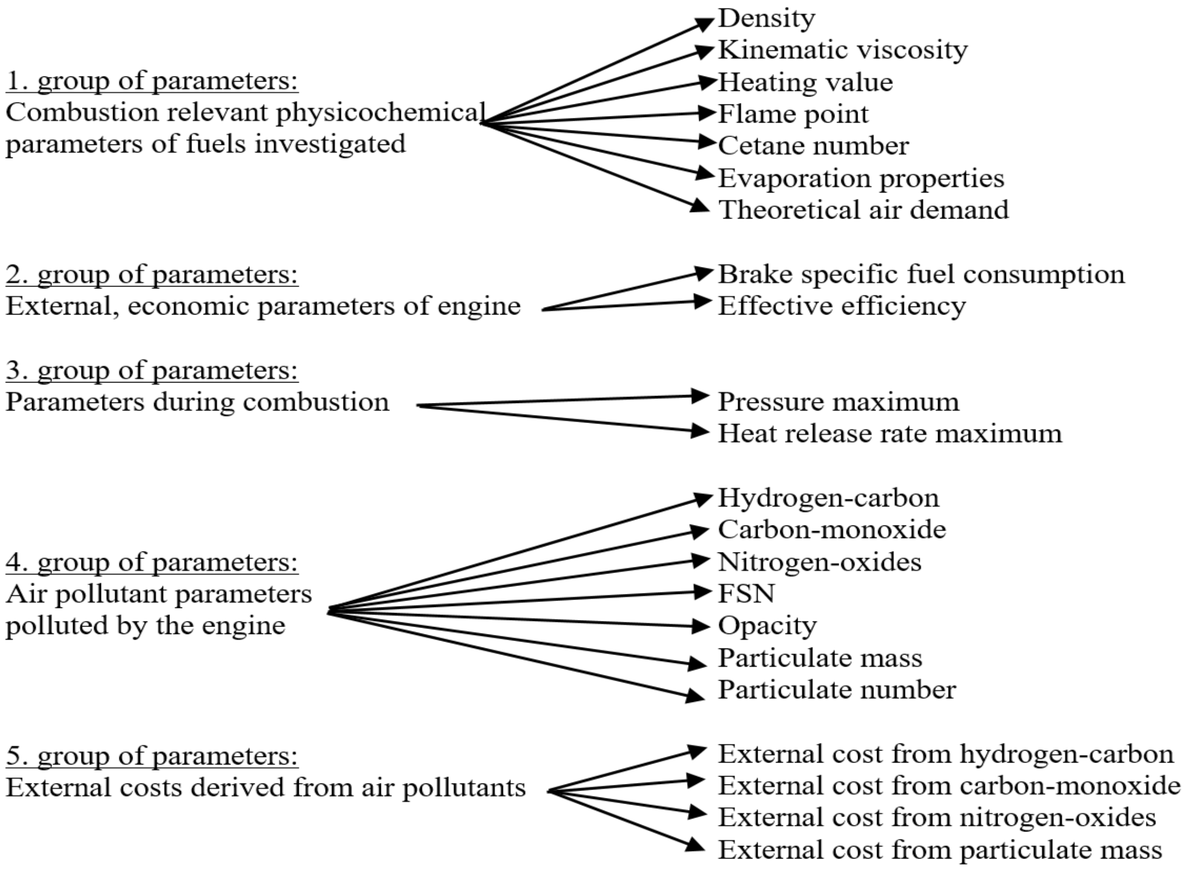
Using the formula, cost factors associated with the engine's air pollutant components I also analyzed the use of the tested renewable fuels in diesel engines from an economic point of view. By the results, I have found that the use of renewable fuels - from the point of view of external (external) costs resulting from the use - is unfavorable, it is economically disadvantageous to use renewable fuels compared to conventional diesel. (Chapter 6, [TP 1])



6. Figure Thesis 5. – Results of external cost calculation

<u>Thesis 6:</u> According to a comprehensive, complex assessment method for the use of the tested renewable fuels (standardized FAME and non-standardized TBK) in the tested Diesel-engine when comparing fuels in a Diesel-engine, at least five parameter groups and several parameters within a parameter group should be considered.

I have set up an evaluation system based on the results of the tested renewable fuels (standardized FAME and non-standardized TBK) in the tested Diesel-engine. Bio-derived fuels can be evaluated as favourable for some parameters and unfavourable for another paramters. Therefore, for the complex evaluation of the use of different fuels in Diesel-engines, it is appropriate and necessary to have at least the five parameter groups presented in the thesis (1. physico-chemical properties of fuels, 2. external parameters of the engine, 3. combustion pressure and heat release rate, 4. emission, 5. economics), so that several parameters are examined in a parameter group. It follows that the results of only one – any – parameter group or of only one – any – parameter tests may give false information about the advantages or disadvantages of fuels when comparing them. (Chapter 7, [TP 2])



7. Figure Thesis 6. – Scheme of complex evaluation method

Thesis 7: According to the results of a comprehensive, complex assessment of the use of the tested renewable fuels (standardized FAME and non-standardized TBK) in the tested Diesel-engine the use of the tested renewable fuels in Diesel-engines is less favorable than the use of the original fuel of the engine, which is the fossil diesel.

7.a. The result of the assessment using the assessment method presented in Thesis 6 shows that for all the renewable fuels (standardized FAME and non-standardized TBK), compared to fossil diesel, among the evaluated parameters unfavorables are more than favorable and neutral. As a result, the focus of the overall assessment is shifted in the unfavourable direction. So, based on the result of the complex evaluation method developed for the application the use of the tested renewable fuels in diesel engines is less favourable, as the engine's original fuel, which is the fossil-derived diesel. (Chapter 7, [TP 2])

7.b. Despite the benefits of the new type TBK-biodiesel fuel in its production technology [3, 33], it has no advantages without additive in the field of use in the Diesel-engine tested compared to the conventional standardized vegetable oil methyl-ester and to the original standardized diesel. (Chapters 3., 4., 5., 6., [TP 1 – TP 15])

3. Table Thesis 7. – Result of complex evaluation

Group of parameters	Parameter	Evaluation of renewable fuel against fossil diesel	Weighing factor	Weighted result
1. group of parameters: Combustion relevant physicochemical parameters of fuels investigated	Density	unfavourable	1	1 unfavourable
	Kinematic viscosity	unfavourable	1	1 unfavourable
	Heating value	unfavourable	1	1 unfavourable
	Flame point	unfavourable	0	0
	Cetane number	neutral	1	1 neutral
	Evaporation properties	unfavourable	1	1 unfavourable
	Theoretical air demand	favourable	0	0
2. group of parameters: External, economic parameters of engine	Brake specific fuel consumption	unfavourable	1	1 unfavourable
	Effective efficiency	neutral	0	0
3. group of parameters: Parameters during combustion	Pressure maximum	favourable	0	0
	Heat release rate maximum	favourable	0	0
4. group of parameters: Air pollutant parameters polluted by the engine	Hydrogen-carbon	favourable	1	1 favourable
	Carbon-monoxide	neutral	1	1 neutral
	Nitrogen-oxides	favourable	1	1 favourable
	FSN	favourable	1	1 favourable
	Opacity	favourable	1	1 favourable
	Particulate mass	unfavourable	1	1 unfavourable
	Particulate number	unfavourable	1	1 unfavourable
5. group of parameters: External costs derived from air pollutants	External cost from hydrogen-carbon	favourable	1	1 favourable
	External cost from carbon-monoxide	neutral	1	1 neutral
	External cost from nitrogen-oxides	unfavourable	1	1 unfavourable
	External cost from particulate mass	unfavourable	1	1 unfavourable
Number of parameter groups investigated: 5	**Number of parameters investigated: 22**	**Result:** **unfavourable: 10** **favourable: 8** **neutral: 4**		**Weighted result:** **unfavourable: 9** **favourable: 5** **neutral: 4**

8. Publications related to the thesis

[TP 1] *Szabados, G., Bereczky, Á.* (2019): **Economic Evaluation of Renewable Fuels through Pollutants Derived from Internal Combustion Engine.** Periodica Polytechnica Mechanical Engineering, 63(1), 33-38. DOI: 10.3311/PPme.12521

[TP 2] *Szabados, Gy., Bereczky, Á.* (2018): **Use of biofuels in a compression-ignition engine - comprehensive technical and economical analysis**. European Kones 2018. 44th International Scientific Congress on Powertrain and Transport Means. **23-26 September 2018. Czeztochowa, Poland.** DOI: 10.5604/01.3001.0012.2505

[TP 3] *Szabados, G., Bereczky, Á., Ajtai, T., & Bozóki, Z. (2018)*: **Evaluation analysis of particulate relevant emission of a diesel engine running on fossil diesel and different biofuels.** Energy, 161, pp. 1139-1153. DOI: 10.1016/j.energy.2018.07.154

[TP 4] *Szabados, Gy., Bereczky, Á.* (2018): **Experimental investigation of physicochemical properties of diesel, biodiesel and TBK-biodiesel fuels and combustion and emission analysis in CI internal combustion engine.** Renewable Energy, 121, pp. 568-578. DOI: 10.1016/j.renene.2018.01.048

[TP 5] *Szabados, G., Bereczky, Á.* (2015): **Comparison tests of diesel, biodiesel and TBK-biodiesel.** Periodica Polytechnica. Mechanical Engineering, 59(3), pp. 120-125. DOI: 10.3311/PPme.7989

[TP 6] *Szabados, G., Merétei, T.* (2015): **Comparison Tests of Fossil Diesel Fuel and TBK-Biofuel.** Periodica Polytechnica. Transportation Engineering, 43(4), 218. pp. 218-224. DOI: 10.3311/PPtr.7963

[TP 7] *Szabados György, Dr. Bereczky Ákos*: **Megújuló tüzelőanyagok összehasonlító vizsgálatai**. ENERGIAGAZDÁLKODÁS, 55. évfolyam (2014), 5-6. szám, pp. 26-29. ISSN: 0021-0757

[TP 8] *Szabados György, Lovas Máté*: **Gázolaj és biodízel tüzelőanyagok Diesel-motorban történő égési folyamatának szimulációja az AVL FIRE CFD szoftver segítségével/Combustion Simulation of Diesel Fuel and Biofuel by the Help of AVL FIRE CFD software.** Műszaki Szemle, 2015:18.66, pp. 35-40.

[TP 9] *Dr. Bereczky Ákos, Szabados György, Lukács Kristóf*: **Összehasonlító vizsgálatok a fosszilis gázolaj és a TBK-Biodízel tüzelőanyagokkal a kompressziógyújtású motorban való üzemelés tekintetében**. A JÖVŐ JÁRMŰVE, 2013:1-2, pp. 68-71. ISSN: 1788-2699

[TP 10] *Dr. Merétei Tamás, Szabados György*: **Magyar találmány - A TBK-Biodízel tüzelőanyag: Az új típusú tüzelőanyag elsősorban emisszió szempontú motorüzemi vizsgálata**. A JÖVŐ JÁRMŰVE, 2012:1-2, pp. 82-86. ISSN: 1788-2699

[TP 11] *Szabados György, Dr. Kerekes Zsuzsanna, Bácskai István, Dr. Bereczky Ákos*: **Biotüzelőanyagok motorikus szempontból releváns tulajdonságainak meghatározása és összehasonlítása**. ENERGETIKA-ELEKTROTECHNIKA KONFERENCIA – ENELKO, 2014.10.9-12., Székelyudvarhely. pp. 88-93. ISSN 1842-4546

[TP 12] *Szabados, Gy., Lovas, M.* (2015): **Combustion simulation of diesel fuel and biofuel by the help of AVL's multi-purpose thermo-fluid CFD software**. 12th International Conference on HEAT ENGINES AND ENVIRONMENTAL PROTECTION, 2015.05.27-29., Pécs. pp. 51-56. ISBN 978-963-313-217-3

[TP 13] *Szabados, Gy., Lukács, K.* (2013): **Comparative investigations of operating conditions of a C.I. engine running on fossil diesel and TBK-Biodiesel fuels.** 11th International Conference on HEAT

ENGINES AND ENVIRONMENTAL PROTECTION, 2013.06.03-05., Balatonfüred. pp. 31-37. ISBN: 978-963-313-091-9

[TP 14] *Merétei, T.,* *Szabados, Gy.* (2012): **Investigations of TBK-biofuel in CI engine**. Gépészet 2012 - EIGHTH INTERNATIONAL CONFERENCE ON MECHANICAL ENGINEERING. 2012.05.24-25., Budapest, (BME GMK)., Paper 45., pp. 348-354. ISBN: 978-963-313-055-1

[TP 15] *Lukács, K.,* *Szabados, Gy., Bereczky, Á.* (2015): **Developing the model for the investigation of combustion process of renewable fuel in AVL FIRE program**. 11th International Conference on HEAT ENGINES AND ENVIRONMENTAL PROTECTION, 2013.06.03-05., Balatonfüred. pp. 323-328. ISBN: 978-963-313-091-9