UTILIZATION OF WASTE FRYING OILS FOR TRANSPORT FUEL EXTENDER – BENEFICIAL TO THE ENVIRONMENT

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Abstract: University of Szeged, Faculty of Engineering carried out research on behalf of Tisza Volán Company (integrated in Centre for South Great Plain Transport Plc.) which takes great care of environmental protection and sustainable management. So the fundamental objective of this research is to analyse utilization possibilities of used vegetable oils (waste frying oils derived from food production, food preparation) as fuels mixed into diesel fuel. This paper summarized the application possibilities, limitations, environmental impacts and difficulties of waste frying oils as fuels. The research points out that all action of different sizes of companies and behaviour of member of society are welcomed and they contribute to sustainable use of environment. This paper helps to expand the knowledge about the utilization of waste frying oils as fuels.

Keywords: waste frying oils, fuel, transport

Introduction

One of the key objective of the European Union developments is energetics, particularly regarding the transport sector: in the energy supply of transport the usage of fossil fuels must be reduced. The 'Resilient Energy Union with a forward-looking climate change' means making energy more secure, affordable and sustainable for citizens and businesses. So the possibility of alternative solutions is coming into view such as the more efficient production and utilization of renewable energy. The energy security, environmental and economic challenges can be managed together by the increase of energy efficiency. For public utilization of the achieved results the foundation of European Energy Union also takes place among the energy policy approaches. These intentions are confirmed and served by the fact that among the Social Challenges priority topics of Horizon 2020 Framework Programme appears the establishment of an intelligent, environmentally friendly and integrated transport. This way an energy-efficient and modern transport reduces the dependence on fossil fuels for transport. Furthermore the protection of the natural resources can be facilitated (Horizon 2020). But important principle is that the implement of 'immature' technologies does not serve the fulfilment of objectives but it might induce the opposite effects.

1. The necessity of utilization and the criterions of applicability

According to the EU regulations it is also a Hungarian objective to increase the rate of bio-components in both diesel and petrol fuels (42/2005 (10 March); 138/2009 (30 June)).

The current biofuel-rate is 4.8V% that is induced by increasingly stringent environmental regulations, continuous fluctuations of crude oil price, long-term energy policy intentions and last but not least different social and agricultural expectations (Act CXVII of 2010), because the EU has accepted some directives (HTTP1) to facilitate the spread of biofuels. Some of them are important directives about the promotion of the use of renewable sources (2009/28/EC) and also a directive (2009/30/EC) regards about the introducing mechanism to monitor and reduce greenhouse gas emissions particularly regarding the transport services and furthermore, a directive on the promotion of clean and energy-efficient road transport vehicles (2009/33/EC). These directives establish a common framework for the production and promotion of energy from renewable sources and organic wastes and other sources. The CARS 21 work-group has determined in its annual report (in 2012) that

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the harmonized alternative fuel-infrastructure is insufficient in EU and it impedes the introduction of alternative fuelled vehicles to the market and delays their favourable environmental effects (CARS 2020). This way an EU regulation was formed with the recommendations of the work-group about the establishment of Connecting Europe Facility (No 1316/2013) and also a directive on the deployment and building of the necessary infrastructure (2014/94/EU).

From the end of the 70's (but the first papers were published in '86/87) intensive experiments were started in the USA and in many European countries (such as Hungary) aiming for the operation of diesel engines with vegetable oil and during them it was confirmed that vegetable oils are suitable for the operation of heavy marine engines and also for lubricating oil (Emőd et al. 1995; MAN 2004; Balog 2005; Carranca 2005; Losoncz et al. 2006; Demirbas et al. 2007; Enweremadu et al. 2009, 2010; Parekh et al. 2012; Naima et al. 2013). Vegetable oils can only be used as diesel engine fuels if they are purified and resin-free. After it such a question was posed whether vegetable oil – that appear in food production – as waste can be utilized for energy purposes. Nowadays frying in vegetable oil is widespread both in the industry and in the households. The Act CXXVII of 2003 contains regulations about the special rules of how to distribute excised products and levy excise tax on petroleum products with waste frying oils used as fuels. According to the Section 50 (2) the petroleum means those products that are produced, offered, sold or used as fuels or additives for fuels or diluent. So according to the Point f) of Section 52 (2) the tax rate can be determined by the tax rate of the closest petroleum regarding its production, supply, import, offer, sale, or usage as a fuel. Keeping in mind this regulation, *during the research answers were sought for the opportunities of waste frying oils (used vegetable oils) utilised as fuels and in this respect the physical and chemical properties of some waste frying oils were measured and after it bench tests (engine brake tests) and emission tests were carried out – applied different mixing ratios for fuels – on stable diesel engines and on a city bus.*

2. The physical and chemical examination of waste frying oils

Thermal and oxidative processes are occurring in the oil during frying at high temperature complex, so the physical and chemical properties of the oil are changing, its colour is becoming darker, its viscosity is getting higher and it tends to foam. In the close past there were some research (Demirbas et al. 1997; Gertz 2000; Aladedunye et al. 2009; Sanli et al. 2011) in order to observe and describe these changes: as a result of polymerization the viscosity increases because of the greater mass of the extended molecules and also acid number, density increases, however, iodine content reduces, peroxide number increases to the limit and then reduces.

The main physical and chemical parameters of the refined sunflower oil and the commercially available diesel fuel according to the standards and product sheet (MSZ EN 590; HTTP2) that are in Table 1. It can be observed that in the case of some parameter (viscosity, flash point) there are significant differences that have impact on the applicability as a fuel.

2 types of frying oils were examined, the samples (control, before and after filtration) can be seen in Figure 1.

Table 1. Important physical and chemical parameters

Substance	**Density [kg/litre]**	**Heating value [MJ/kg]**	**Viscosity at 40 ºC [mm²/s]**	**Cetane number [-]**	**Flash point (open cup) [ºC]**
Diesel fuel	0.81-0.85	40.6-44.4	2-4.5	>51	>55
Sunflower oil	0.93	37.1	32.9	38	293

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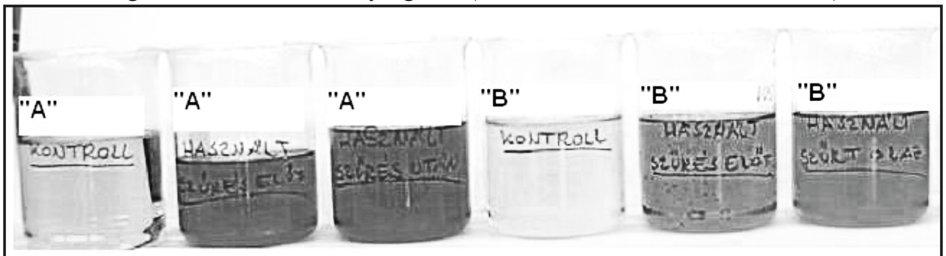
The samples main features:

- *Sample "A"*: sunflower oil (was used for one day to fry meat in breadcrumbs)
- *Sample "B"*: sunflower oil (was used for one day to fry meat in breadcrumbs, vegetable and potato)

Figure 1: "A" and "B" frying oils (control, before and after filtration)



The parameters of the control and used frying oils were measured based on the relevant standards in laboratories at University of Szeged, Faculty of Engineering. The collected waste frying oil samples were first filtered to remove food residues (using 15 µm diameter filter). The filter time (it depends on the composition and viscosity) of 500 ml oil in the case of sample "A": 24 sec/500 ml of sample "B": 22 sec/500 ml.

During the examination of special physical and chemical properties of samples (waste vegetable oils) the main features (Table 2) of each sample were determined – according to the relevant standards – such as density, dynamic viscosity (AND VS vibration viscometer), kinematic viscosity (20 ºC), acid number, moisture content, peroxide number. The results were evaluated and compared according to the quality standards and claims made on diesel engine fuels. These important general requirements are low volatility, easy pumpability, appropriate viscosity, high resistance to temperature, chemical resistance, easy ignition, proper combustion parameters (cetane number>50), good flow properties at low temperatures, and to be available in a relatively constant quality. *It is expected of fuels to contain components to provide good quality, to be environmental friendly and to have high energy in order to protect the engine and environment.*

The properties of normal diesel fuel were considered during the evaluation of results. So this way it has been determined that the examined filtrated frying oils do not have any significant negative impacts – that would make more difficult their application as a fuel mixed into the normal diesel fuel – compared to diesel fuel.

The filtrated waste oil sample regarding the determined physical/chemical properties there were no significant differences compared to each other. One of the most important parameters is the higher viscosity of vegetable oils. The increase of viscosity is not dangerous

Table 2. The physical and chemical properties of the samples

Samples	Moisture content	Dyn. visc. [Pas]	Density [kg/m^3]	Kin. visc. [mm^2/s]	Peroxide number
"A" control	0.012	0.05473	919.6	59.52	13.53
"A" waste, unfiltered	0.025	0.07835	924.6	84.74	48.26
"A" waste, filtered	-	0.08976	925.3	97.01	45.31
"B" control	0,002	0.05947	919.6	64.67	26.84
"B" waste, unfiltered	0.012	0.06876	922.3	74.55	45.85
"B" waste, filtered	-	0.07723	922.4	83.73	25.83

if the frying oil is dense and viscosity improver processes (polymerization, resinification) are not caused by it. Furthermore, normal diesel fuel reduces the great molecular weight of vegetable oils that is relevant to start combustion and to prevent subsidence in the engine. It must be mentioned here that it is needed to make an analysis (basic combustion parameters) about all waste frying oil before utilization. However, considering the fact that the properties of filtrated frying oil differ from the properties of normal diesel fuel, their combustion properties differ as well and therefore their utilization is limited concerning the conventional diesel engines that were not really designed to be operated with vegetable oil.

3. The properties of fuels mixed with waste frying oils

According to the research objective the utilization of waste frying oils as a fuel of internal combustion engines is made by mixing them with normal diesel fuel and therefore the determination of fuel properties produced by different mixing ratios is needed (Table 3). The mixing was carried out by 1/2 part of “A” frying oil and 1/2 part of “B” frying oil. The experimental mixing ratios were the following regarding filtrated frying oils and normal diesel fuels: 0:100; 1:99; 2:98; 5:95; 10:90; 20:80; 100:0.

Table 3. Density, kinematic viscosity of experimental samples (at 20 °C)

Mixing ratio [%]	Density [kg/m^3]	Kinematic viscosity [mm^2/s]
0	835.3	3.663
1	837.7	3.736
2	836.0	3.816
5	839.4	4.217
10	843.6	4.943
20	851.4	6.225
100	921.9	69.855

Viscosity increases exponentially (very close correlation) with the mixing of used oil. As viscosity stays under the specified value of 5 mm^2/s until the used oil content of 10% it can be determined that the filtrated waste frying oil mixed with normal diesel fuel up to a ratio of 10% is applicable as a fuel for vehicles with diesel engines. It can also be mentioned that the examined fuel mixtures do not have any significant negative effects compared to normal diesel fuel and therefore they can be mixed with normal diesel fuels in conventional diesel engines without any problem. The engine brake test (bench test) and operational test justify the hypothesis.

4. Results of the engine brake test

As the composition and quality of fuels play a significant role in the operation of heat engines beside the construction design, so it is need to carry out engine brake tests. The tests take place at the University of Szeged where the stable experimental diesel engine is available and their main parts are: conventional VW 1.9 D diesel engine (4-cylinder, cylinder capacity 1896 cm^3, max power 47 kW, compression ratio 22:1, swirl-chamber engine, indirect injection), control, indicating and data collection system, emission measurement system.

The objective of the tests was to determine the effect of normal diesel fuels with a content of 5% and 10% frying oil on the operation of diesel engines compared to the normal diesel fuelled.

Brake tests were carried out according to the ECE R49 standard and the parameters of the engine were determined in relation to engine speed (revolution per minute). The tests contain the full potential operating range. The

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engine parameters were determined at different measuring point (ranging from 850-2000 rpm) and then sketched the engine performance curves (power, torque, consumption) (Nagy 2015). Measured properties (exhaust gas temperature, absolute and specific fuel consumption, performance and torque values) were either slightly better or the same as the control samples. Based on the exhaust gas temperatures in relation to engine speed it can be determined that the mixed filtrated waste oils do not influence the temperature conditions of engines. The temperature of exhaust gas was in the range of 250-650 °C in all cases (it should be mentioned that there were lower values at the beginning of the measure). In the range of normal operating engine speed (1000-1800 rpm) the temperature range shrinks and the typical temperatures are 600-650 °C. Operating with normal diesel fuel with a ratio of 5% and 10% waste oil in the range of 850-2000 rpm can interpret almost the same power as in the case of normal diesel fuel. In the case of all the fuels at the engine speed of 1850 rpm the maximum effective power value can be measured.

During the evaluation of torque data it was concluded that the waste frying oil slightly increases the engine torque but the change is not significant. However, this also means that there is not a negative effect on engine dynamics.

Furthermore it can be seen that in the engine speed range of 1400-1800 rpm the specific consumption is nearly constant (260 g/kWh) in the case of all the fuels.

Based on the discussed results the utilization of normal diesel fuels with a maximum ratio of 10% waste oil in internal combustion engines – despite the higher viscosity values – is not difficult and does not cause engine operating problems. According to the previous ones it can be determined that the waste frying oil with a maximum mixing ratio of 10% will change significantly neither the fuel consumption nor the dynamic properties of the engine so it can be applied under operating conditions. Here it is noted that during operation the engine oil tests need to be performed in order to know the engine oil properties.

5. Emission studies on a stable diesel engine

Based on the physical and chemical properties of mixed engine fuels and also the results of engine brake tests the right quality fuels can be selected in the aspect of engine operation and then fuel tests can be carried out under operating conditions. The tests were carried out with a mixing ratio of 10% waste oil and the goal was to find out what kind of impact has the applied fuel on emission with special emphasis on exhaust fumes. The environmental protection is an important factor in terms of the applicability of fuels with different composition in course of internal combustion engine.

Engine start problems did not occur and the engine ran smoothly during the whole test. Properties of normal diesel fuel were not modified by the mixing of 10%, also smoke and soot were influenced favourably. The operation with mixed fuel in 'cold' conditions causes a 50% reduction and in 'warm' conditions a 30% reduction regarding smoke compared to the normal diesel fuel operation. A similar trend can be observed during the evaluation of soot where reduction is 50% at the speed of 870 rpm and 30% at the speed of 4000 rpm. These benefits occurred because there is more oxygen in the mixed fuel and the presence of fuel oxygen allows the fuel to burn 'more completely', so it can be realized fewer unburned fuel emissions. This way it can be verified that an alternative fuel can be produced from waste frying oil that meets the environmental requirements.

6. Trial operation on a city bus, particularly regarding the environmental aspects

Tisza Volán Company runs about 400 city and interurban buses and coaches to its scheduled

Table 4. Fumigation

	Engine speed [rpm]	Fume [%]	K [m^{-1}]
Measurement I*	2110	29.5	0.81
Measurement II**	2050	23.2	0.61

Note: *100% normal diesel fuel; **mixture of 92% diesel fuel and 8% waste frying oil

public transport activity. The purchase of significant amount of fuel consumed by vehicles is quite important economic and environmental factor for the company. Therefore the reduction of consumed fuel is a priority task for the company.

University of Szeged and Tisza Volán Company made a research contract to test how the utilization of a mixture of waste frying oil and commercially available diesel fuel oil influences the operation of an internal combustion engine (Final Report 2011).

The selected bus engine specifications: IKARUS 280.40A (year 1998), RÁBA D10UTSLL190, Euro-II environmental class diesel engine, 10350 cm^3, cylinder capacity, in-line 6 cylinders, turbo-charged, air-recooling, maximum power 190 kW (at 1900 rpm), maximum torque 1130 Nm (at 930-1300 rpm). Used equipments: HFP-100 vehicle testing test bench, BOSCH BEA 85 exhaust gas analyser, AVL DICOM 4000 fumigation measurer.

The trial operation took place at Tisza Volán Company. The nominal capacity of the fuel tank of the bus is 250 litres this way the mixed fuel contained 20 litres of frying oil and 230 litres of normal diesel fuel so the mixing ratio was 8%. The measured values are engine force, power, average fuel consumption and diesel engine exhaust emissions (commonly known as 'diesel fumes'. The soot content (or carbon particle) values depend on the fuel used and the type of engine. Most of the contaminants are adsorbed onto the soot. (So the petrol engines produce more carbon monoxide but much less soot than diesel engines.) Same engine performance, better consumption and substantially better fumigation values were registered during the measurement of mixing normal diesel fuel with waste frying oil compared to diesel fuelled. The effects of applied fuels on fumigation can be seen in Table 4.

The utilization of mixed filtrated frying oils in road traffic does not influence noticeably the startup and the driving dynamics of the bus, the visible fumigation of the bus is moderate.

Summary

In the recent years the relations and interactions among environment, economy and society have come to the fore. The applicability tests of alternative fuels such as the recycling of used frying oil can open new possibilities for transport and environmental protection. And it means new challenges for the engineers. But there is an important aspect that the utilization of waste frying oil is only competitive with the conventional fuels if it is considered with its complex advantages. Also the competitiveness of application is assisted by the fact that the mixing does not require engine construction modifications therefore a new option is provided for transport. The advantages of application are the favourable environmental impact and the reduction of energy-dependency. The results of engine tests verify that the filtrated waste oils can be combusted in conventional diesel engines if they are mixed with normal diesel fuel.

It can be the objective of the further research to determine special combustion parameters of other waste frying oils, to observe buses operation and their driving dynamics in public transport under different weather circumstances, and to analyze the impact of mixed fuels on the engine oil parameters.

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No 1316/2013 Regulation (EU) – Establishing the Connecting Europe Facility

2014/94/EU Directive on the deployment of alternative fuels infrastructure

HTTP1: http://ec.europa.eu/legislation/index_en.htm (regulations, directives, decisions)

HTTP2:http://mol.hu/images/pdf/Vallalatiugyfeleknek/Uzemanyagok/Dizel_termeklap 2011.pdf

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