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Investigation of Effects of Diesel and Biodiesel Fuels on Energy and Exergy Analysis in Diesel Engines

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Abstract

In this study, energy and exergy analyses were applied to experimental data obtained from a four stroke, four cylinders, naturally aspirated, having 1800 rpm direct-injected diesel engine in case of using various fuels. Air and fuel flow rates, engine speed, emissions and relevant temperatures are taken into consideration to be able to perform the first and second law of thermodynamics. With the help of these data obtained from the experiments, balances of energy and exergy rates for the control volume by means of 1st and 2nd law (energy and exergy) efficiencies of thermodynamics associated with the quantity and quality were obtained for various fuels such as diesel fuels, cotton and soybean biodiesel. All results were compared with each other to determine fuel effects on energetic and exergetic performance in diesel engines. As a result, it was concluded that diesel fuel showed better energetic and exergetic performance than those of biodiesels of cotton and soybean.

Keywords: Energy, Exergy, Internal combustion engines, Alternative fuels.

Dizel Motorlarda Enerji ve Ekserji Analizleri Üzerine Dizel ve Biyodizel Yakıt Etkisinin Araştırılması

Özet

Bu çalışmada, farklı yakıtların kullanıldığı 4 zamanlı, 4 silindirli, doğal emişli, 1800 devir/dakika'daki direk enjeksiyonlu bir dizel motorundan elde edilen datalara, enerji ve ekserji analizleri uygulanmıştır. Termodinamiğin birinci ve ikinci yasa analizlerini uygulayabilmek için hava ve yakıt debileri, motor hızı, emisyonlar ve ilgili sıcaklıklar hesaplamalara dâhil edilmiştir. Deneysel çalışma sonucunda elde edilen veriler yardımıyla, termodinamiğin miktar ve kalite ile ilgili olan 1. ve 2. yasa verimleri kullanılarak dizel yakıtı, pamuk ve soya biyodizeli için enerji, ekserji denge denklemleri elde edilmiştir. Dizel motorlarda enerji ve ekserji performansı üzerine çeşitli yakıtların etkilerini belirleyebilmek için sonuçlar birbirleriyle karşılaştırılmıştır. Sonuç olarak, dizel yakıtının pamuk ve soya biyodizelinden daha iyi enerji ve ekserji performansına sahip olduğu tespit edilmiştir.

Anahtar Kelimeler: Enerji, Ekserji, İçten yanmalı motorlar, Alternatif yakıtlar

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1. INTRODUCTION

The idea of using alternative fuels has been widely spreading for many years as a replacement for fossil fuels. The importance of this idea came from the large scale of utilization of fossil fuels in mechanical power generation in various sectors, like agriculture, commercial, domestic, and transport sectors, and also the fact of the continuous rise in fuels cost and their eventual disappearance[1].

The consciousness of cleaner production technology is increasing globally. The need for an alternative to fossil fuels has engendered extensive research in recent years. Fossil fuels are non-renewable sources of energy which generate pollutants and are linked to global warming, climate change and even some incurable diseases. The impending challenges and the environmental implications of fossil fuels have been reviewed widely. Due to the increase in the price of the petroleum and the environmental concerns about pollution coming from the car gases, biodiesel is becoming a developing area of high concern [2]. Biodiesel has been identified as one of the notable options for at least complementing conventional fuels. Its production from renewable biological sources such as vegetable oils and fats has been reviewed widely; its advantages over petroleum diesel cannot be overemphasized: it is safe, renewable, non-toxic, and biodegradable; it contains no sulphur; and it is a better lubricant. In addition, its use engenders numerous societal benefits: rural revitalization, creation of new jobs, and reduced global warming its physical properties has been reviewed widely as well and some of which are dependent on the feedstock employed for its production. The flash point of biodiesel is significantly higher than that of petroleum diesel or gasoline, thus making it one of the safest fuels available. However, the calorific value of biodiesel is about 9% lower than that of the regular petroleum diesel. The variations in the biodiesel energy density are more dependent on the fatty raw materials used than the production process [3].

The use of vegetable oils and their derivatives was found to be one of the reasonable solutions. However, the direct use of vegetable oils in diesel engines was found impractical due to several factors, such as the high viscosity, acid composition, and free fatty acid content. Accordingly, they require further modifications for effective use undergoing transesterification reaction is the most favorable for decreasing oil's viscosity and producing so-called "biodiesel fuel".

Biodiesels are monoalkylesters of long chain fatty acid derived from renewable lipid feedstock. The interest of this alternative energy resource is that the fatty acid methyl esters, known as biodiesel, have similar characteristics of petro diesel oil which allows its use in compression motors without any engine modification. However, using vegetable oil to replace fuel caused the food versus fuel issue all over the world. So, the idea of using waste vegetable oil (WVO) has been introduced as an economical solution which also gives a waste management solution [1].

In recent years, the energy and exergy analysis has become widely used in the design, simulation and performance assessment of thermal systems. Researchers have conducted several studies of where losses occur in engines and methods to increase performance based on the second law of thermodynamics [4-9].

Exergy is defined as the maximum theoretical work that can be obtained from a system as it comes to equilibrium with a reference environment. The exergy content of a natural material input can be interpreted as a measure of its quality or potential usefulness, i.e., its ability to perform 'useful' work.

Exergy analysis has been widely used in the design, simulation and performance evaluation of energy system [7]. Renewable energy sources can be a good substitute of the fossil fuels which are being terminated fast. Nowadays, biomass and biofuels are considered because of their environment friendly characteristics and their ability of supplying much more energy. An alternative means to select the most efficient and convenient biomass, is exergy analysis [10]. Sayin et. al. [11] presented comparative energy and exergy analyses of a four-cylinder, four-stroke spark-ignition engine using gasoline fuels of three different research octane numbers (RONs), namely 91, 93 and 95.3. Each fuel test was performed by varying the engine speed between 1200 and 2400 rpm while keeping the engine torque at 20 and 40 Nm. Then, using the steady-state data along with energy and exergy rate balance equations, various performance parameters of the engine were evaluated for each fuel case. It was found that the gasoline of 91-RON, the design octane rating of the test engine, yielded better energetic and exergetic performance, while the exergetic performance parameters were slightly lower than the corresponding energetic ones. Furthermore, this study revealed that the combustion was the most important contributor to the system inefficiency, and almost all performance parameters increased with increasing engine speed. Tosun [5] studied assessment of energy and exergy analysis applied to experimental data obtained from a four stroke, four cylinders, naturally aspirated, direct-injected diesel engine by using different fuels.

Sezer and Bilgin [9] investigated the effects of the air–fuel mixture (charge) properties on the exergy balance in Spark ignition engines. The results obtained by Sezer and Bilgin [9] showed that increasing fuel-air equivalence ratio caused an increase in irreversibility’s and also exergy losses with heat transfer and exhaust gases, but enriching the air–fuel mixture beyond the stoichiometric ratio makes no significant contribution to the exergy transfer with work transfer. A slightly lean mixture also gives the best first and second law efficiencies. It is observed that there is a linear relation between the residual gas fraction and the exergetic variables. An increase in the residual gas fraction decreases the irreversibility’s and exergy losses aside from the exergy transfer with work transfer. However, increasing the residual gas fraction positively affects the first and second law efficiencies because of the diluting of the charge. Increase of initial charge temperature creates a reduction in the irreversibility’s and the exergy losses and, it also results in a lower exergy output by work transfer. Further, increase of initial charge temperature negatively influences the first and second law efficiencies.

Depletion of fossil fuels directed researchers to search alternative fuels. In this regard, various biofuels are being tested to see feasibility of usage by scientists. Beside usage of energy, its effective usage is crucial. Exergy analysis can be used to design and assess the system thermodynamically to define inefficiencies of the system.

After analysis, system inefficiencies can be signed and try to find ways of reducing these inefficiencies. In this study, energy and exergy analysis were applied to the experimental data of a diesel engine fueled with various fuels such as cotton and soybean biodiesel and they were compared with respect to standard diesel fuel.

2. MATERIAL AND METHOD

In this study, the experimental study was conducted in Petroleum Research and Automotive Engineering Laboratories of the Department of Automotive Engineering at Cukurova University. Experiments were performed on a Mitsubishi Canter 4D34-2A with four stroke, four cylinders, and naturally aspirated direct-injected diesel engine with 1800 rpm. Specifications of the engine are presented in Table 1. Schematic representation of experimental setup is given in Figure 1.

A hydraulic dynamometer was used for determination of torque and power output. Table 2 shows technical specifications of the dynamometer.

TESTO 350 XL gas analyzer was also used to measure exhaust emissions. Emission data was collected using a computer program. Accuracy of the gas analyzer is ±10 ppm for CO, 1% for CO_2 and ±1 ppm for NO_x. The fuel quality measurements were done according to TS EN 14214 and EN 590.

Table 1. Technical specifications of the test engine

Brand	Mitsubishi Canter
Model	4D34-2A
Configuration	Inline 4
Type	Direct injection diesel with glow plug
Displacement	3907cc
Bore	104mm
Stroke	115mm
Power	89kW @ 3200rpm
Torque	295Nm @ 1800rpm
Cooling System	Water cooled
Weight	325kg

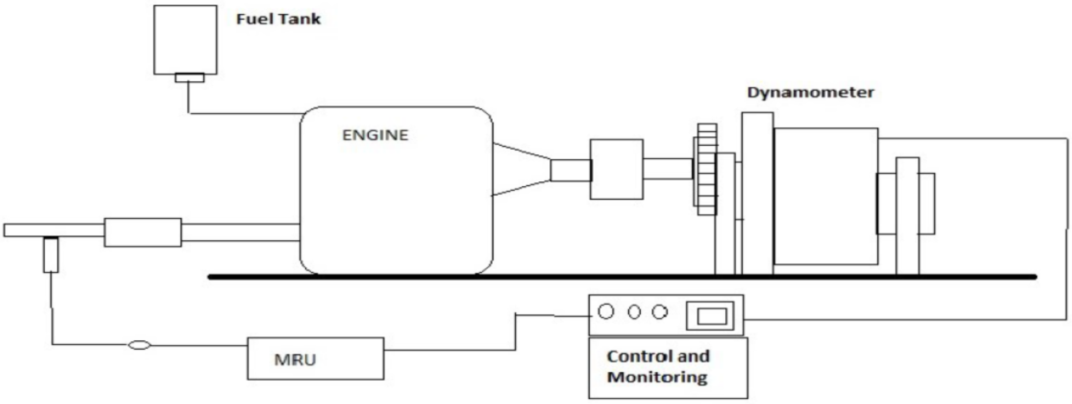

Figure 1. A schematic representation of experimental setup

Table 1. Technical specifications of thedynamometer

Torque Range	0-1700 Nm
Speed Range	0-7500 rpm
Body Weight	45 kgf
Total Weight	110 kgf
Body Diameter	350 mm
Torque Arm Length	350 mm

2.1. Transesterification Method of Vegetables Oils

In the transesterification of different types of oils, triglycerides react with an alcohol, generally methanol or ethanol, to produce esters and glycerin. To make it possible, a catalyst is added to the reaction. The overall process is normally a sequence of three consecutive steps, which are reversible reactions. In the first step, diglyceride is obtained from triglycerides, monoglyceride is produced from diglyceride and in the last step, and glycerin is obtained via monoglycerides. In all these reactions esters are produced. The stochiometric relation between alcohol and the oil is 3:1. However, an excess of alcohol is usually more appropriate to improve the reaction towards the desired product. Flow diagram of biodiesel production process is shown in Figure 2.

2.2. Exergy and Energy Analysis

From the thermodynamics point of view, exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. Unlike energy, exergy is not subject to a conservation law (except for ideal, or reversible, process). Rather, exergy is consumed or destroyed, due to irreversibilities in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with the process.

Here, Table 3 clearly compares the concepts of energy and exergy form different perspectives.

Exergy analysis is a method that uses the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the analysis, design and improvement of energy and other systems. The exergy method is a useful tool for furthering the goal of more efficient energy-resource usage. It enables the locations, types, and true magnitudes of wastes and losses to be determined. In general, more meaningful efficiencies are evaluated with exergy analysis rather than energy analysis due to the fact that exergy efficiencies are always a measure of the approach to the ideal. Therefore, exergy analysis can reveal whether or not and how possible to design more efficient energy systems by reducing the inefficiencies in existing systems. Many engineers and scientists suggest that the thermodynamic performance of a process is best evaluated by performing an exergy analysis in addition to or in place of conventional energy analysis because exergy analysis appears more meaningful and to be more useful in efficiency improvement than energy analysis. Further discussions of exergy analysis for a large number of processes and systems are given elsewhere. It is extremely important that for exergy analysis, the state of the reference environment, or the reference state, must be specified completely for the exergy analysis. This is commonly conducted by specifying the temperature, pressure and chemical composition of the reference environment. The results of exergy analysis are relative to the specified reference environment, which in most applications is modeled after the actual local environment.

2.3. Exergy Equations

Energy can neither be created nor be destroyed. Energy appears in many forms and different qualities and the quality of energy can increase locally or be destroyed. When using energy, we utilize the energy conversions along its way towards heat at environmental temperature. The necessity to determine the available part of the energy, or the similar amount of mechanical work that could be extracted from it has crucial role. Exergy is a measure of how far a certain system deviates from equilibrium with its environment and therefore, the following expressions can be written for the exergy contained in a system equation, $Ex = T_0\left(\mathrm{S}_{\mathrm{t,eq}} - \mathrm{S}_{\mathrm{t}}\right)$ here T_0 is the temperature of the environment and $\left(\mathrm{S}_{\mathrm{t,eq}} - \mathrm{S}_{\mathrm{t}}\right)$is the deviation from equilibrium of the negentropy (=minus the entropy) of the system and its environment, i.e., the total system. (‘*eq*’ denotes equilibrium with the environment).

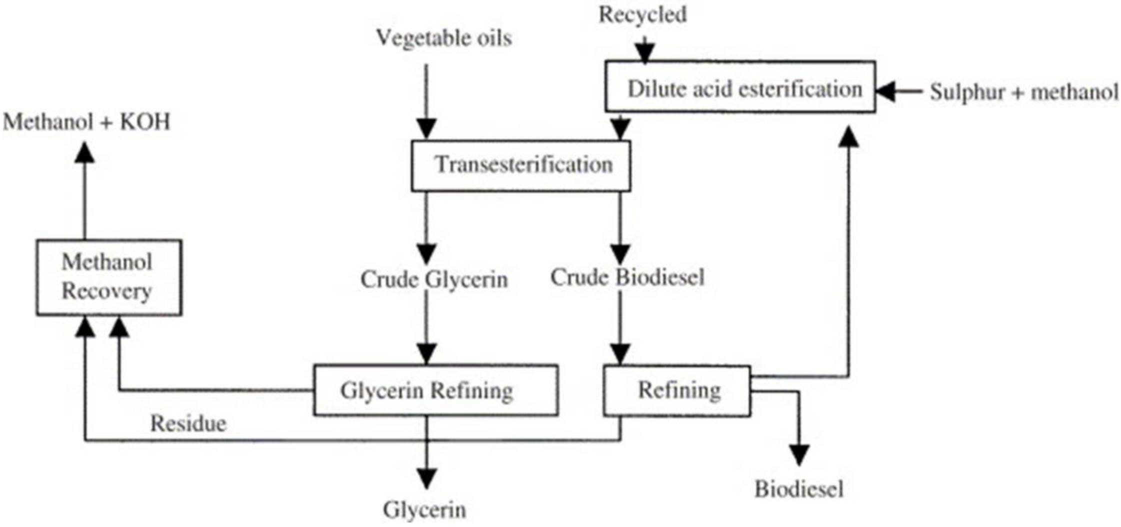

Figure 2. Basic scheme for biodiesel production [2]

Table 3. The main differences between energy and exergy

Energy	Exergy
is dependent on the parameters of matter or energy flow only, and independent of the environment parameters.	is dependent both on the parameters of matter or energy flow and on the environment parameters.
has values different from zero (equal to mc^2 in accordance with Einstein's equation).	is equal to zero (in a dead state by equilibrium with the environment).
is guided by the first law of thermodynamics for all the processes.	is guided by the first law of thermodynamics for reversible processes only (in irreversible processes it is destroyed partly or completely).
is limited by the second law of thermodynamics for all processes (incl. reversible ones).	is not limited for reversible processes due to the second law of thermodynamics.
is motion or ability to produce motion.	is work or ability to produce work.
is always conserved in a process, so can neither be destroyed nor produced.	is always conserved in a reversible process, but is always consumed in an irreversible process.
is a measure of quantity.	is a measure of quantity and quality due to entropy.

$$Ex = U + P_0V - T_0S - \sum i\mu_{i0}\, n_i \quad (1)$$

where U, V, S, and n_i denote extensive parameters of the system (energy, volume, entropy, and the number of moles of different chemical components) and P_0, T_0, and μ_{i0} are intensive parameters of the environment (pressure, temperature, and chemical potential which may also include gravitational and electromagnetic potentials, etc.). The subscript '0' denotes conditions of the reference environment. It is evident from this equation that the exergy of a system is zero when it is in equilibrium with the reference environment (i.e.,when $T=T_0$, $P=P_0$, and $\mu_k=\mu_{k0}$ for all k).

$$Ex = \left(U - U_{eq}\right) + P_0\left(V - V_{eq}\right) - T_0\left(S - S_{eq}\right) - \sum_i \mu_{i0}\left(n_i - n_{ieq}\right) \quad (2)$$

where on the right hand side easily determined quantities appear. Therefore, it is an easy task to determine the exergy content of a given system in a given environment. The following relation for a substance which has an exergy content deriving only from its concentration can be expressed as;

$$Ex = RT_0 n\, ln(c/c_0) \quad (3)$$

where n is the number of moles of the substance, R is the gas constant, T_0 is the temperature of the environment, c is the concentration of the substance in the material considered, and c_0 is the concentration of the substance in the environment.

This concept of exergy is applicable for materials like inert gases or other not chemically active materials. The chemically reacting materials receive an additional exergy contribution from the change in the chemical potential. The exergy content in a material can be summarized by the following formula:

$$Ex = n[\mu - \mu_0 + RT_0 \ln(c/c_0)] \quad (4)$$

Where μ_0 is chemical potential for the material in its reference state, i.e., in equilibrium with the environment.

2.4. Calculations for Energy and Exergy Analysis

All equations needed for performing energy and exergy analysis were given in this chapter. Calculations to obtain energetic and exergetic efficiencies were shown only for diesel fuel here. Some of the data obtained from engine test and other needed information of fuels for equations are given in Table 4.

2.4.1. Energy Input Rate

$$E_{fuel} =((0{,}00197013)(44524))=87{,}72 \text{ kW} \quad (5)$$

2.4.2. Total HeatLosses

$$\dot{Q}_{loss} = (87{,}72) - (29{,}54407) = 58{,}175\text{W} \quad (6)$$

2.4.3. Energy Efficiency

$$\eta_I = (29{,}54407) / (87{,}72) = 0{,}336\ (33{,}67\%) \quad (7)$$

Mass fraction ratios of the elements in the fuels were given in Table 5.

2.4.4. Input Exergy Rate

$$\varphi = 1{,}0401+0{,}1728(0{,}148810)+0{,}0432(0)+0{,}2169(0)(1-2{,}0628(0{,}148810) \quad (8)$$

$$\varphi = 1{,}065814368$$

$$\varepsilon_{fuel} =(44524)(1{,}065814386)=47454{,}31972 \text{ kJ/kg} \quad (9)$$

$$\dot{Ex}_{in} =(0{,}00306852)(45808{,}698)=140{,}56 \text{ kW} \quad (10)$$

2.4.5. Output Exergy Rate

The output (exhaust) exergy rate consists of both thermo-mechanical and chemical exergy of the exhaust gases.

Table 2. Data obtained from engine test

Fuels	Lower heating value (kJ/kg)	Engine speed(rpm)	Work (kW)	Mass flow rate of fuel (kg/s)	Mass flow rate of air (kg/s)
Diesel	44524	1800	29,54407	0,00197013	0,10279675
Cotton	39728,87	1800	25,58633	0,00186519	0,10211456
Soybean	39824,84	1800	26,12452	0,00188913	0,10203432

Table 3. Mass fraction ratios of the elements in the fuels

Fuels	Chemical formula	h/c	O/C	a/C
Diesel	$C_{14}H_{25}$	0,148810	0	0
Cotton	$C_{18.}H_{34.}O_2$	0,157407	0,148148	0
Soybean	$C_{15.}H_{25.}O_2$	0,138889	0,177778	0

Both thermo-mechanical and chemical exergy values of each of the exhaust gases are calculated. Then the total of these two exergy values of each exhaust component were multiplied with their own mass flow rate. All of the mass flow rates of the exhaust gases were calculated from the mass balance.

$$\dot{m}_{air} + \dot{m}_{fuel} = \dot{m}_{exhaust} \tag{11}$$

Heywood [12] suggested a formula for the mass flow rate of air. It can be calculated as follows:

$$\dot{m}_{air} = \frac{\rho_{air} V_d N}{2.60} \tag{12}$$

In the formula of air mass flow rate, ρ_{air} represents density of air (kg/m^3),V_d, cylinder volume (m^3), N, engine speed (rpm). Calculations of the mass flow rates are given in Table 6.

Product results of fuels were also given in Table 7.

With the help of the data given in Table 6 and Table 7, we can determine the coefficients of given emission data below (d, e, f, g, h).

$$\mathrm{aC_xH_yO_z + b(O_2 + 3{,}76N_2) \rightarrow CO_2 + dCO + eCO_2 + fNO + gNO_2 + hN_2 + jH_2O} \tag{13}$$

Rest of the unknown coefficients (a, b, c, j) can be found with conservation of mass principle for carbon (C), oxygen (O), hydrogen (H) and nitrogen (N). All of the coefficients are given in Table 8.

By means of reaction coefficients, mass fraction of each emission was obtained. Finally, mass flow rate of each exhaust gases were determined separately as shown in Table 9.

In order to calculate thermo-mechanical exergy of exhaust gases we need enthalpy and entropy values of the gases at related temperatures (Dead state temperature and exhaust gas temperature).

Table 10 also shows the enthalpy and entropy values at stated temperatures.

Table 11 presents specific thermo-mechanical exergy, specific chemical exergy and the total output (exhaust) exergy values for diesel fuel.

Table 4. Calculations of the mass flow rates

	Cylinder volume (0.0009769m^3)			**Air density** (1.225kg/m^3)	
	Engine speed (rpm)	Air mass flow rate (kg/s) (1 cylinder)	Air mass flow rate (kg/s) (4 cylinder)	Mass flow rate of fuel (kg/s) ($\dot{m}_f$ was experimentally determined)	Mass flow rate of exhaust gases (kg/s) (total)
Diesel	1800	0,025699	0,102796	0,00197013	0,1058645
Cotton	1800	0,025876	0,103941	0,00186519	0,10580619
Soybean	1800	0,025	0,104321	0,00188913	0,10581720

Table 5. Product results of fuels

Products	**Diesel**	**Cotton**	**Soybean**
(%)	9,87	10,96	10,99
CO (ppm)	593	283	287
CO_2 (%)	6,02	5,69	5,59
NO (ppm)	987	1054	960
NO_2 (ppm)	214	328	315

Table 6. Reaction coefficients

Coefficient	**Diesel**	**Cotton**	**Soybean**
a	1,05171E-05	9,86214E-06	9,98767E-06
b	0,000541	0,000565	0,000546
c	3,27E0-04	3,63E-04	3,65E-04
d	2,24E-06	1,07E-06	1,09E-06
e	3,48E-06	1,37E-04	1,29E-04
f	3,48E-06	3,72E-06	3,67E-6
g	4,93E-07	7,55E-07	3,12E-7
h	0,002032	0,002115	0,002543
j	0,0001314	0,0001277	0,0001321

Table 7. Mass flow rates of each product gas emissions

Product mass flow rates (kg/s)	**Diesel**	**Cotton**	**Soybean**
O_2	0,010464	0,1462281	0,1534321
CO	6,27E-05	3,77E-04	3,87E-05
CO_2	0,00638	0,07583514	0,00342
NO	0,0001044	0,00140488	0,00010783
NO_2	5,69E-02	4,37E-04	5,72E-04
N_2	0,05690982	0,077355	0,077463
H_2O	0,00236636	0,02793367	0,00321145

Table 8. Enthalpy and entropy values of product gases for diesel fuel

Products	**T_{ex}= 800 K (Exhaust gas temperature)**			**T_0 = 298 K (Dead state temperature)**		
	$h-h_0$(kJ/kmol)	$h-h_0$ (kJ/kg)	s (kJ/kmol,K)	s_0 (kJ/kmol,K)	$s-s_0$ (kJ/kmol,K)	$s-s_0$ (kJ/kg,K)
O_2	15840	495	235,82	205,03	30,79	0,962
CO	15170	541,79	227,17	197,54	29,63	1,058
CO_2	22810	518,41	257,42	213,73	43,69	0,993
NO	15550	518,33	240,99	210,64	30,35	1,012
NO_2	22140	481,30	282,41	239,91	42,5	0,924
N_2	15040	537,14	220,92	191,5	29,42	1,051
H_2O	18000	1000	223,72	188,71	35,01	1,945

Table 9. Specific thermo-mechanical exergy, specific chemical exergy and the total output exergy values for diesel fuel

Products	**Mass flow rate (kg/s)**	**Specific thermo-mechanical exergy (kJ/kg)**	**Specific chemical exergy (kJ/kg)**	**The total specific output (exhaust) exergy (kJ/kg) (thermo-mechanical + chemical exergy)**	**The total output (exhaust) exergy (kW)**
O_2	0,0148613	208,3	123,27	331,57	4,93
CO	3,55068E-5	226,47	1050,34	1276,81	0,05
CO_2	0,0086189	222,51	448,91	671,42	5,79
NO	0,00013544	216,86	-	216,86	0,03
NO_2	7,1873E-6	205,98	-	205,98	0,0014
N_2	0,07903829	224,03	24,67	248,7	19,66
H_2O	0,00316855	420,39	481,31	901,7	2,86

Both thermo-mechanical and chemical exergy output values of each exhaust gases can totally be calculated as shown below:

$$\dot{E}x_{out} = \sum \dot{m}_i (\varepsilon_{tm} + \varepsilon_{chem})_i = 33.30 \text{ kW} \quad (14)$$

2.4.6. Work Exergy Rate

Net exergy work is equal to the net energy work:

$$\dot{E}x_{work} = \dot{W} = 29{,}54407 \text{ kW} \quad (15)$$

2.4.7. Exergy Rate Related with Heat Transfer

Heat transfer exergy rate from the cooling water to the environment is defined as:

$$\dot{Q}_{cw} = 87{,}72 – [29{,}440 – (0{,}0148613)(495) + (3{,}55068E\text{-}5)(541{,}7857) + (0{,}0086189)(518{,}4091) + (0{,}00013544)(518{,}3333) + (7{,}1873E\text{-}6)(481{,}3043) + (0{,}07903829)(537{,}1429) + (0{,}00316855)(1000)] \quad (16)$$

$\dot{Q}_{cw}$ = 19,89 kW
$T_{cw,inlet}$ = 324,71 K
$T_{cw,outlet}$ = 361,73 K
T_{cw} =(324,71+361,73) / 2 = 343,22 K (17)
T_0 = 298 K (dead state temperature)

$$\dot{E}x_{heat} = (1 – 298/343{,}22)(19.89) = 2{,}62 \text{ kW} \quad (18)$$

2.4.8. Exergy Destruction

Exergy destruction value can be determined as follows:

$$\dot{E}x_{dest} = 140{,}5649 – [33{,}30462 + 2{,}62 + 29{,}54407] = 75{,}1 \text{ kW} \quad (19)$$

2.4.9. Exergy Efficiency

Exergy efficiency *(Ψ)* of the control volume can be expressed as the ratio of the exergy work rate to the fuel exergy input rate:

$$\psi = (29{,}54407k) / (140{,}5649) = 0{,}210 \ (21\%) \quad (20)$$

3. RESULTS AND DISCUSSIONS

In the experiments, diesel fuel and cotton and soybean biodiesel are used as fuel. The results from energy (first law) analysis are given both in Table 12 and in Figures 3-4.

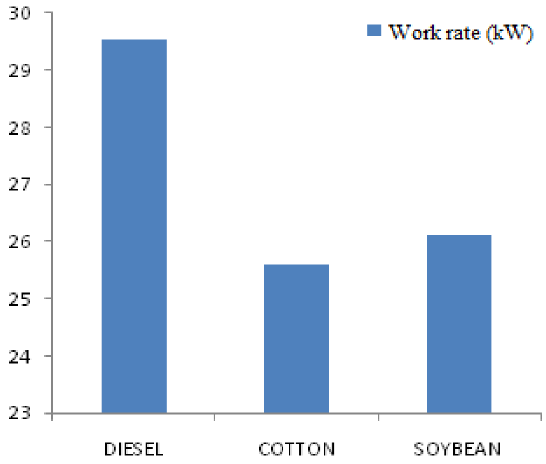

Figure 3. Work rate values of diesel fuel and biodiesels

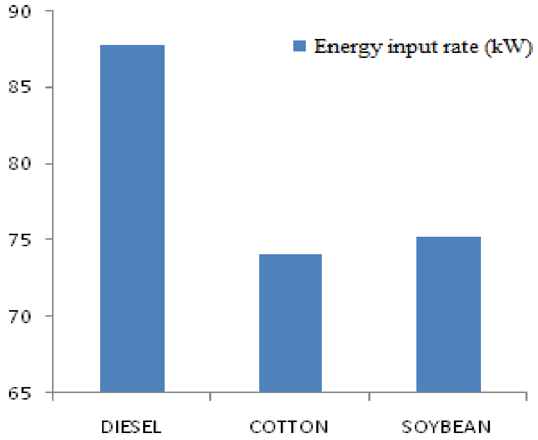

Figure 4. Energy input rates (fuel energy) of diesel fuel and biodiesel

It can be seen from the Figure 3 that work rate of biodiesel of cotton and soybean is lower than diesel fuel. For cotton and soybean biodiesel, power loss at the same engine speed can be

Table 12. Energy analysis results of the fuels used in engine

Fuel	Engine speed	Work rate (kW)	Energy input rate(kW)	Total heat loss (kW)	Energy efficiency (%)
Diesel	1800	29,54407	87,72	58,175	33,67
Cotton	1800	25,58633	74,10	48,53367	49,10548
Soybean	1800	26,12452	75,23	34,5	34,726

explained by its lower heating values and also poor atomization can be caused by high viscosity and density.

The energy supplying to the engine is known as energy input rate which contains heat loss and work rate and calculated by using mass flow rate and lower heating value of fuel as shown in Figure 4. Supplied energy to the control volume is direct proportional with lower heating value fuel; heating of value of diesel fuel is higher than those of the cotton and soybean due to the higher input rate.

Figure 5 presents the energy input rates of diesel fuel and biodiesel. Heat loss can be calculated by subtracting the useful work rate from supplied energy by fuel energy input rate. Biodiesels have more oxygen content than diesel fuel. This means better combustion and obtaining higher temperature in cylinder.

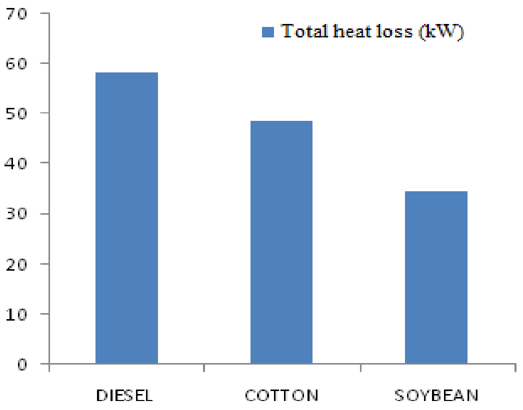

Figure 5. Total heat loss values of diesel fuel and biodiesels

Figure 6 shows energetic efficiencies (thermal efficiency or 1st law efficiency) of engine by using various fuels at a certain engine speed comparatively. Thermal efficiency is the measure of how efficiently energy input is converted to useful work in engine. This means that the ratio of work rate to energy input rate gives energetic efficiency. As can be seen from the Figure 6, more efficient conversion occurs in engine with diesel fuel usage.

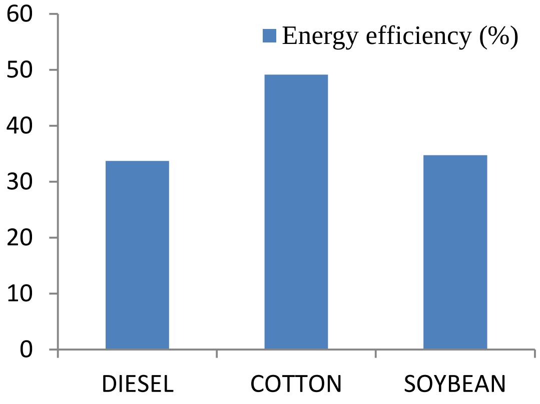

Figure 6. Energy efficiencies of diesel fuel and biodiesels

The results obtained from exergy (second law) analysis are given both in Table 13.

Figure 7 shows input exergy rates of fuels (fuel exergy) at a certain engine speed comparatively. Since specific flow exergy in input exergy rate contains lower heating value of fuel, similar trend with energy input rates of fuels was obtained as expected. Cotton and soybean biodiesels has1,23% and lower input exergy rate value than that of diesel fuel.

Table 13. Results of second law analysis for various fuels

Fuel	Engine speed (rpm)	Input exergy rate (kW)	Output exergy rate (kW)	Work exergy rate (kW)	Exergy rate related with heat transfer (kW)	Exergy Destruction (kW)	Exergy efficiency (%)
Diesel	1800	93,49	32,01	29,5440	2,046	29,89	31,6
Cotton	1800	87,3	33,46	25,5863	2,66	52,6	29,3
Soybean	1800	78,9	34,1	26,12452	2,97	49,8	29,7

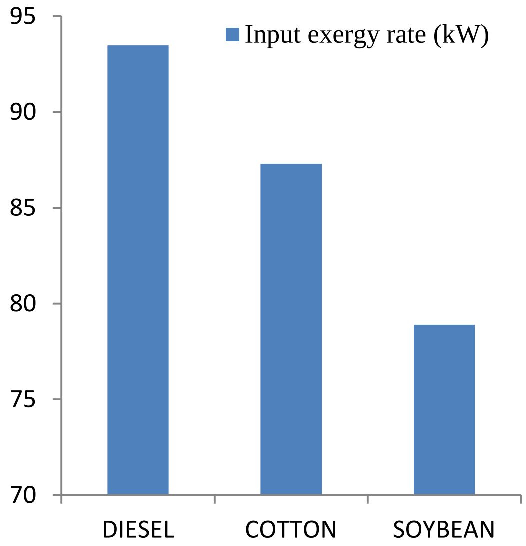

Figure 7. Input exergy rate values of diesel fuel and biodiesels

Figure 8 gives the output exergy rates of fuels at a certain engine speed. Output exergy contains all of the output exergy of exhaust gases (both thermo-mechanical and chemical) and consists of notable amount of input exergy (i.e. 23,69% of input exergy for diesel fuel).

Work exergy rate values of diesel fuel and biodiesels are given in Figure 9. The exergy is defined as the maximum extractable work potential; exergy work rate can be defined as work rate.

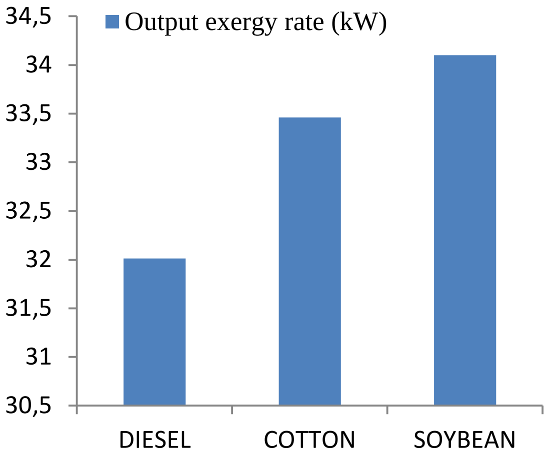

Figure 8. Output exergy rate values of diesel fuel and biodiesels

Therefore, similar graph was given here as showed previously for work rate in exergy analysis.

Figure 10 shows work exergy rate values of diesel fuel and biodiesels. Exergy rate associated with heat transfer is function of ambient temperature (dead state temperature), cooling water temperature (inlet and outlet) and heat transfer rate through cooling water.

The highest heat loss exergy was obtained in soybean biodiesel due to cooling water effect. Exergy destruction values were shown in Figure 11.

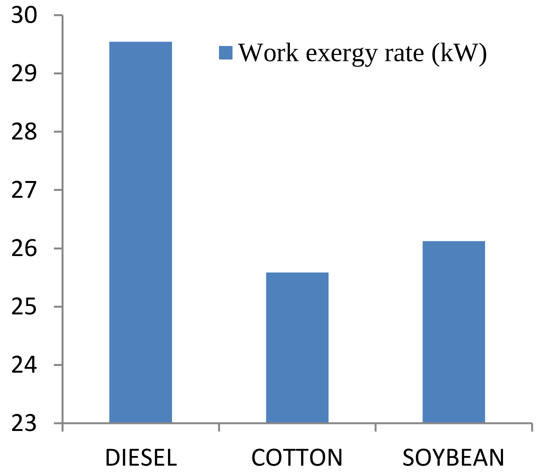

Figure 9. Work exergy rate values of diesel fuel and biodiesels

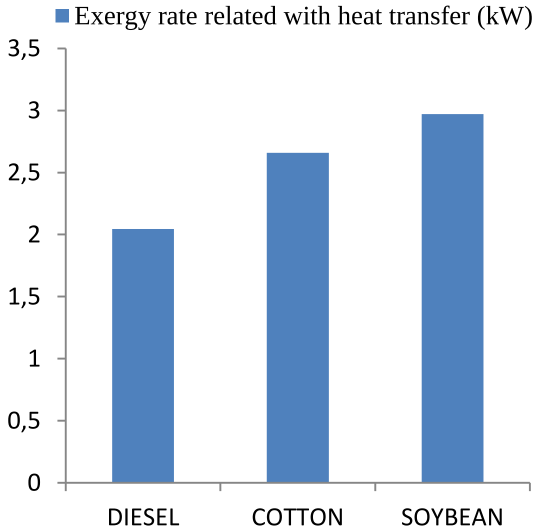

Figure 10. Exergy rate related with heat transfer values of diesel fuel and biodiesels

In an internal combustion engine; heat transfer, friction, mixing and combustion itself cause destroying of usable, available energy which is named as exergy. This all irreversible processes in internal combustion engine destroy notable amount of input exergy of the fuels. This part of exergy can't be converted any useful work. Exergy destruction can be found by subtracting output exergy values from the input exergy values. This difference gives us destroyed part of exergy. Moreover, it can be calculated by multiplying dead state temperature (298 K) with generated entropy [13]. This means exergy destruction is directly proportional with generated entropy. High temperature in engine means increasing of entropy. Containing more oxygen content of biodiesel causes the high temperature than that of diesel fuel in cylinder. Therefore, exergy destruction rates of biodiesel are bigger than that of diesel fuel.

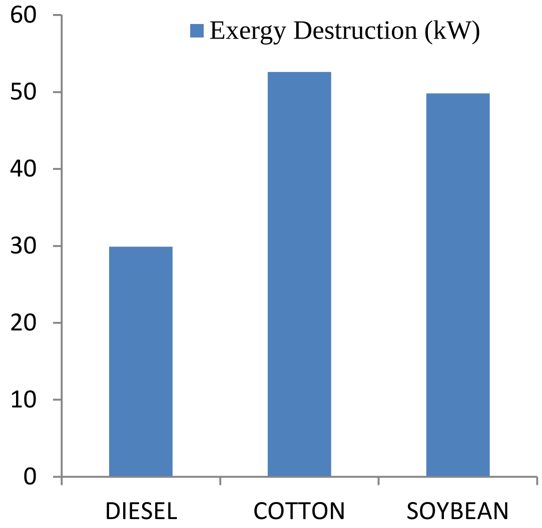

Figure 11. Exergy destruction values of diesel fuel and biodiesels

Exergetic efficiencies (2nd law efficiency) of engine by using various fuels at a certain engine speed are given in Figure 12 comparatively. Exergy efficiency can be found as the ratio of the exergy work rate to the fuel energy input rate. Exergy efficiency of the cotton and soybean biodiesels is 24,9% lower than diesel fuel. There is an opposite trend between exergy destruction and exergetic efficiency. When the amount of exergy destruction increases exergetic efficiency decreases as expected. So, they are inversely proportional.

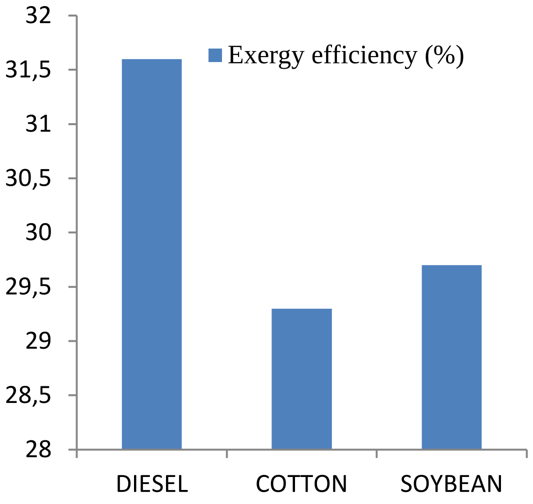

Figure 12. Exergy efficiency values of diesel fuel and biodiesels

Figures13-15 shows the breakdown of fuel exergy by percent of each fuel. It can be clearly seen and it gives considerable important information about the conversion of given input fuel exergy to other exergy forms. Output exergy rate, exergy rate related with heat transfer and exergy destruction values of cotton and soybean biodiesels are higher than those of diesel fuel.

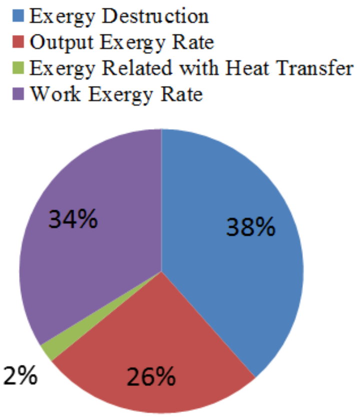

Figure 13. Distribution of exergy for diesel

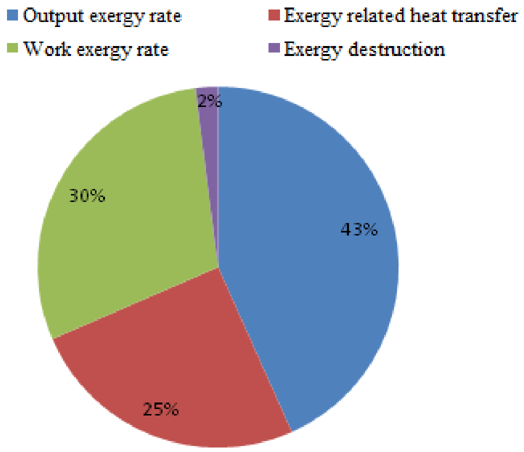

Figure 14. Distribution of exergy for cotton Biodiesel

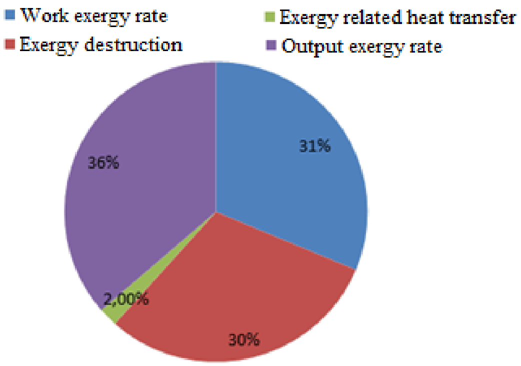

Figure 15. Distribution of exergy for soybean biodiesel

4. CONCLUSIONS

Exergy is a way to a sustainable development. In this regard, exergy analysis is a very useful tool, which can be successfully used for the performance evaluation of and all energy-related systems. It is an effective method using the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the design and analysis of energy systems.

In this study, emissions results of diesel engine fueled with various fuels were used in order to perform energy and exergy analysis. Some fuels such as diesel, cotton and soybean were compared with respect to their energetic and energetic performance. In conclusion, diesel fuel was the best energetic and energetic efficiency than biodiesels of cotton and soybean. Comparing two biodiesels of cotton and soybean for in case of energetic and exegetic performance, there was a little difference. These analyses can also be applied to the other fuels.

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