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Article

Speed Effects on the Performance of a Gasoline Engine Using a Mixture of Gasoline-Ethanol Fuels

Hamed Asghari and Amin Farzin*

Department of Mechanical Engineering, Islamic Azad University, Langarud Branch, Guilan, Iran
* Correspondence: Amin Farzin (amin.farzin@iau.ac.ir)

Abstract: In recent years, to quantify the quality, energy called "exergy" has been widely used in designs, simulations, and evaluation of the performance of various thermal-chemical systems. The main goal of this project is to evaluate the quality of gasoline engines and the efficiency of a gasoline engine using a mixture of gasoline and ethanol. Furthermore, the effects of 2500 rpm and 4500 rpm on analyzing the second law of thermodynamics were investigated with different fuels. The methods examined in this research include efficiency through heat transfer, irreversibility, total efficiency, and efficiency of burned fuel. The results showed that the performance parameters for gasoline and different ethanol compounds increase until the combustion stage then decrease with the beginning of the expansion phase. For fuel E85, 32.323% of the input energy is converted into indicative exergy and this value for E0, E20, E40, and E60 fuels was 26.27%, 28.5%, 30.3%, and 31.8% respectively. By increasing the amount of ethanol, the efficiency of the second law of thermodynamics increases. The second law efficiency at 4500 rpm for E0, E20, E40, E60, and E85 fuels was, 32%, 35.7% 39.8%, 42.8%, and 50% respectively. Furthermore, by reducing the speed to 2500 rpm, the efficiency for E0, E20, E40, E60, and E85 fuels reduced to 26.7%, 30.4%, 31%, 34%, and 36%, respectively.

Keywords: Fuels, Gasoline Motor, Mixture of Gasoline-Ethanol, Performance, Speed Effects

1. Introduction

Internal combustion engines play an important role in human life and are designed according to environmental limitations and economic efficiency [1]. In 1923, tetraethyl lead was first used as an additive in America. Tetraethyl lead is being removed from gasoline over time due to its toxic and carcinogenic effects [2]. This made the research about other additives with fewer pollution effects and increased engine power become very important. Currently, scientists have turned to using plant-based fuels as additives in fossil fuels, such as bioethanol [2]–[4]. Energy analysis in different systems, such as internal combustion engines, uses the first law of thermodynamics [5]. Furthermore, the second law of thermodynamics is dependent on the quality of energy and when the quality of energy decreases in processes, it provides the possibility of improving the quality by producing entropy [6]. Using the analysis of the second law of thermodynamics (exergy) along with the first law of thermodynamics (energy analysis) is more efficient in the analysis of internal combustion engines [4], [5], [7]. Therefore, the main goal of this project is to evaluate the quality of gasoline engines and the efficiency of a gasoline engine using a mixture of gasoline and ethanol.

Amer et al. undertook study on internal combustion engine performance using gas-gasoline fuels. The results revealed that heat loss for gasoline and gas fuels causes the energy and exergy increase; so, the exergy efficiency increases somewhat more than the corresponding energy efficiency when engine speed increases [6]. In another study, the effect of changes in fuel density ratio, variable specific heat on energy efficiency, exergy of methanol, ethanol, isooctane, and liquid petroleum gas was investigated in the SI engine model. While the specific heat of all fuels increases from condensation to combustion and reduces when leaving the exhaust, the findings of this study revealed that irreversibility in the state of combustion, internal heat transfer, and exhaust gases decreases with increasing compression ratios for all kinds of fuels [8]. In 2012, Rezapoor performed a research study to analyze a bi-fuel SI engine model for improving ITS performance [9].

The model successfully solved the differential equations associated with the compression, combustion, and expansion stages. [9]. A group of scientists analyzed the energy and exergy in gasoline engines and evaluated the potential for recovery and improvement of heat loss and exergy efficiency of gasoline engines through exergy analysis [10]. The results of their efforts showed that at high speed, the energy of the exhaust gas is greater than the energy of the cooling water. Furthermore, the exergy efficiency of the exhaust gas is higher at high speeds. In addition, by recovering and improving heat loss, their research demonstrated that gasoline engine fuel efficiency could be increased by 21% [10].

2. Materials and Methods

Given that utilizing the primary law of thermodynamics, there comes about of demonstrated by the test comes about of Kiani et al., is reliable, in this inquiry about, exergy investigation on gasoline and ethanol powers (E0, E20, E40, E60, and E85 (at 2500 rpm and 4500 rpm). The gasoline motor was inspected.

Fig. 1 Expectation of the chamber weight interior of the barrel as it appears to be fuel at 4500 rpm. Fig. 1, Essentially comes about Exploratory with the comes about gotten from the show for E20 fills. E40, E60 and E85 have great compatibility. Fig. 2 shows the anticipated values of the temperature of the combustion chamber at each degree of the wrench point at 4500 rpm for diverse combinations of gasoline and ethanol. The fuel temperature of E0 is higher than other fills with diverse rates of ethanol. The reason for that is more the calorific esteem of the fuel is E0 compared to other powers. The specialized determinations of this motor are given in Table 1. To begin with, the governing equations utilized within the internal processes of the engine are said. The fundamental equation utilized within the modeling stages is the vitality preservation equation [11], [12].

$$\delta Q - \delta W = dE \tag{1}$$

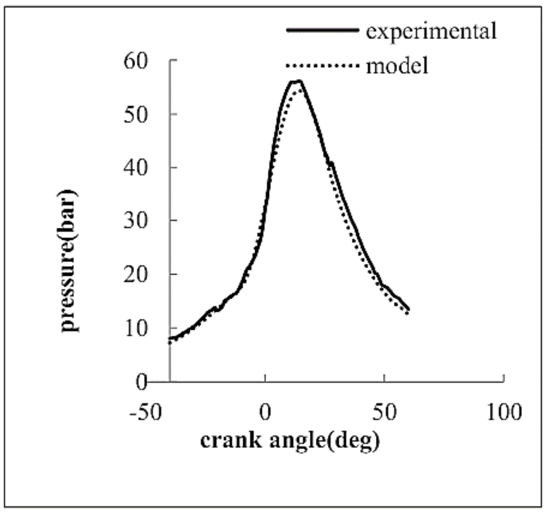

Figure 1. Comparison of experimental and model in-cylinder pressure for petrol fuel.

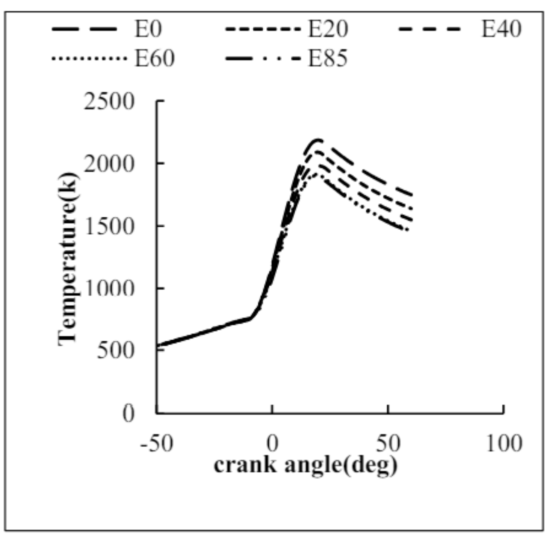

Figure 2. A schematic diagram of in-cylinder temperature.

Table1. The SI engine's technical specifications.

Engine Specifications	Content	Unit
Connecting rod length	133.8	mm
Stroke	87	mm
Cylinder bore	79.6	mm
Cylinders (n)	4	….
Compression factor	10	….

The Heat Transfer

The heat transfer rate between the cylinder wall and the outside environment is calculated based on Newton's displacement heat transfer equation [13], [14].

$$\frac{dQ_w}{d\theta} = \frac{h_g(\theta)A_w(\theta)\left[T_g(\theta) - T_w\right]}{N} \tag{2}$$

dQ_w, the heat transfer rate between the cylinder walls and the outside environment is in J. h_g heat transfer coefficient displacement, A_W (θ) effective surface of the cylinder wall according to m^2, Tg(θ) gas temperature in the combustion chamber, T_w, the temperature of the cylinder wall is in Kelvin, and *N* is the engine speed. Equation 3 can be used to calculate the indicator value [15].

$$\delta w = \frac{1}{2}(P_2 + P_1)(V_2 - V_1) \tag{3}$$

In this regard, P_1 and V_1 are pressure and volume, respectively, at the start of the step; P_2 and V_2 are the pressure and volume at the end of the step.

Cosine Function

In the combustion process, the method known as the cosine function (The Current study) was used to calculate the combustion rate of the mixture inside the cylinder in the spark ignition engine [16].

$$X_b = 0.5\left(1 - \cos\left[\pi\frac{(\theta - \theta_s)}{\theta_b}\right]\right) \tag{4}$$

In this regard, θ_s is the start of sexual intercourse and θ_b is the duration of intercourse [17].

Exergy Analysis

The investigation strategy of the primary law of thermodynamics alone isn't able to completely analyze the compelling parameters, and to check the productivity of the motor, which needs to respect the irreversibility of different forms, the analysis of the moment law of thermodynamics ought to be utilized. Within the investigation of the moment law, the key parameter is proficiency. Effectiveness is also called exergy. Efficiency is the greatest hypothetical work that the framework can do [18]. When a system's internal and external temperatures are both maintained in harmony, we say that there is a thermomechanical balance. If only thermomechanical equilibrium is established between the system and its surroundings, it is said that the system is in a limited dead state. The terms thermal exergy and mechanical exergy are collectively called thermomechanical exergy.

Chemical exergy is defined as the ability of the system to function as a result of the reversible chemical reaction between the system components and the environment or as a result of the reversible transition of the system components to the environmental conditions and mixing with the environment until reaching the dead state of the range to the (real) dead state. This parameter is studied separately from thermomechanical exergy [19].

Engine Performance Balance

Exergy balance can be done in the engine cylinder expressed as equation 5.

$$\frac{dA}{d\theta} = \frac{dA_Q}{d\theta} - \frac{dA_W}{d\theta} + \frac{dA_F}{d\theta} - \frac{dI}{d\theta} + \sum m_{in}^{i} b_{\text{in}} - \sum \dot{m}_{\text{out}} b_{\text{out}} \quad (5)$$

In this regard, da/dθ the rate of total exergy changes inside the engine cylinder, $\sum \dot{m}_{\text{out}} b_{\text{out}}$ and $\sum m_{in}^{i} b_{\text{in}}$ are the energy transfer terms with input masses, and the output is that if you encounter this closed system, Semesters are deleted. b exergy of the input mass flow to the cylinder or the output from it, in the form of an equation (6) is defined [20].

$$\mathrm{b} = \mathrm{h} - T_0 S - \sum m_i \mu_i^0 \quad (6)$$

In the above equation, S is the entropy of the gases inside the cylinder, and the index zero is related to the ambient conditions. dAq/dθ , The efficiency rate through heat transfer is in terms of crank degree and is calculated from equations (7) [20], [21].

$$\frac{dA_Q}{d\theta}\left(1 - \frac{T_0}{T_{cycl}}\right)\frac{dQ_W}{d\theta} = 0 \quad (7)$$

Transferred heat rate = DqW/dθ, the instantaneous temperature of the cylinder = T cycle, the ambient temperature = T0, dAw/dθ the efficiency ratio is calculated through formula 8. P0= environmental pressure=25°c and P Cycle = Instantaneous cylinder pressure [9], [16], [22].

$$\frac{dA_w}{d\theta} = \left(P_{cycl} - P_0\right)\frac{dv}{d\theta} \quad (8)$$

$$\frac{dV}{d\theta} = \frac{V_d}{2}\sin\theta\left[1 + \cos\theta\left(R^2 - \sin^2\theta\right)^{\frac{1}{2}}\right] \quad (9)$$

mf and m, respectively, the fuel mass and the total mass inside the cylinder, $x d$b/dθ, the burning rate at each moment of the crankshaft rotation d which is obtained from equation (4). In addition, a_{fch}, the chemical exergy of the fuel obtained from equation (10) or (11) (For the fuel $C\alpha H\beta$, α is the number of carbons, β is the number of hydrogen and LHV is the low calorific value of the fuel).

$$\frac{a_{fch}}{LHV} = 1.033 + 0.0169\frac{\beta}{\alpha} - \frac{0.0698}{\alpha} \quad \text{(for Gas)} \quad (10)$$

$$\frac{a_{fch}}{LHV} = 1.04224 + 0.011925\frac{\beta}{\alpha} - \frac{0.042}{\alpha} \quad \text{(for liquid)} \quad (11)$$

For liquid fuels with the $C_Z H_Y O_P S_q$ formula (z=number of carbon, H = number of hydrogen, P = number of oxygen, and q = Number of sulfur) the chemical exergy is obtained from equation 12 [21]–[23].

$$a_{fch} = \mathrm{LHV}\left[1.0401 + 0.01728\frac{y}{z} + 0.0432\frac{\frac{p}{2}}{z} + 0.2169\frac{q}{z}\left(1 - 2.0628\frac{1}{z}\right)\right] \quad (12)$$

Chemical Exergy

The system can still move around in its environment while in a restricted dead state, but it won't react chemically with anything around it. Equation 13 then defines chemical efficiency for an ideal gas composition [9], [21].

$$A_{fch}\left(\mu_{i,0} - \mu_i^0\right) m_i T_0 \sum \mathrm{R_i m_i Ln} \sum \frac{\mathrm{x_i}}{\mathrm{x_i^0}} \quad (13)$$

μ_i^0 is the chemical potential of component i in the real dead state, x_i is the mole fraction of component i in the mixture in the limited dead state, and x^0 is the mole fraction of component i in the dead state, x_i^0 represents the ambient temperature, and R are the global gas constants.

Thermomechanical Exergy

Thermomechanical exergy, defined as the greatest theoretical work that a system is capable of achieving when its internal and external temperatures and pressures are in balance, is determined using Equation 14 [24].

$$\bar{A}_{tm,i} - \bar{h}_i - \bar{h}_{i,0} - T_0\left(\bar{s}_i - \bar{s}_{i,0}\right) \quad (14)$$

$\bar{h}_{i,0}$=enthalpy of formation of component i, $\bar{h}_{i,0}$= Enthalpy of formation of component i in ambient conditions, s_i = Entropy of component i, $\bar{s}_{i,0}$ is the Entropy of component i in standard mode, T_0 = environment temperature. Equation 15 can be used to calculate the entropy in the standard state of each component in the mixture. The u coefficients in equation 15 for each component are extracted from JANAF thermodynamic tables [13].

$$s_i^0 = \tilde{R}_i\left(u_{i1}\,\mathrm{Ln}\,T + u_{i2}T + \frac{u_{i3}}{2}T^2 + \frac{u_{i4}}{3}T^3 + \frac{u_{i5}}{4}T^4 + u_{i7}\right) \quad (15)$$

For step-by-step calculation of specific heat and enthalpy of formation of gasoline and bioethanol in fuel, equations 16 and 17 are used [12].

$$h_G(T) = u_{G_1} + u_{G_2}\frac{t^2}{2} + u_{G_3}\frac{t^3}{3} + u_{G_4}\frac{t^4}{4} - \frac{u_{G_3}}{t} + u_{G_6} + u_{G_8} \quad (16)$$

$$h_E(T) = u_{E_1} + u_{E_2}\frac{t^2}{2} + u_{E_3}\frac{t^3}{3} + u_{E_4}\frac{t^4}{4} - \frac{u_{E_5}}{t} + u_{E_6} + u_{E_8} \quad (17)$$

The entropy of the standard state is calculated at P0 pressure, i.e., atmospheric pressure, which is a function of temperature; therefore, to calculate entropy at different pressures, equation 18 should be used [21].

Si0 = Standard state entropy, R_i = Global gas constant, Kj/Kgk= 8.314 = Mole fraction of component *i*.

$$s_i = s_i^0 - \tilde{R}_i \,\mathrm{Ln}\left(\frac{x_i}{p_0} p\right) \tag{18}$$

To calculate the total entropy of the mixture

$$\mathrm{S} = \sum n_i s_i \tag{19}$$

n_i is the number of moles of each component.

Irreversibility

Irreversibility in a cylinder is calculated from equation 21 [16], [21].

$$I = T_0 * S_{\mathrm{gen}} \tag{20}$$

S_{gen}' is the entropy produced and T0 is the initial temperature of the environment.

Entropy Produced

Equation 21is used to determine the entropy produced

$$S_{gen} = -\sum \frac{Q_w}{T_{....}} + \Delta S \tag{21}$$

ΔS is the transferred heat, Qw is the temperature of the cylinder wall, *w* is the entropy change in the cylinder [8] [25].

Total Exergy

Thermomechanical efficiency plus chemical efficiency is equal to the exergy of the whole system [20].

$$\mathrm{A} = A^{tm} + A^{ch} \tag{22}$$

Energy Efficiency and Exergy

According to the first law of thermodynamics, energy efficiency (Ƞ1) is defined as work indicative of the thermal energy of the burned fuel. In short, the efficiency of the first law is the ratio of heat that has been converted into mechanical work. Of course, in the engine, instead of assuming heat, fuel combustion is considered [9], [16], [25].

$$\eta_I = \frac{\text{Energy}_{\text{ out}}\text{ (work)}}{\text{Energy}_{\text{ in}}} = \frac{W}{m_f Q_{\mathrm{LHV}}} \tag{23}$$

According to formula (24), the exergy efficiency is defined as the work transfer on the amount of fuel burned in the specific chemical exergy of the fuel.

A_w = Efficiency through work transfer, a*fch* = Chemical exergy of fuel

$$\eta_{II} = \frac{\text{Energy}_{\text{ out}}\text{ (work)}}{\text{Energy}_{\text{ in}}} = \frac{A_W}{m_f a_{fch}} \tag{24}$$

3. Results and Discussion

The presented model was done for the spark ignition engine of the Ford model (418 MVH). Therefore, the exergy analysis of the effect of the fuel mixture on the performance parameters will be investigated.

Comparison Of Performance Parameters

Figs. 3 to 6 show the comparison of performance parameters for the different fuel combinations they provide. Total exergy increases with increasing engine speed for all fuels (E0, E20, E40, E60, and E85), as shown in Fig. 3. Both the chemical and thermomechanical exergy of fuel, which contribute to overall efficiency, grow as engine speed rises. Here is an explanation for this reason: The amount of gasoline entering the cylinder and the maximum pressure inside it are both increased as the engine speed rises. [26]. As a result, the thermomechanical exergy is caused by the increase in pressure, and the chemical exergy is caused by the increase in fuel input into the cylinder. On the other hand, according to Fig. 3, the total exergy of fuel E0 is higher compared to E20 and compared to E40, E60, and E85 due to the high calorific value of fuel. Sezer et al. conducted research on exergy parameters in spark ignition engines, which are consistent with these results [16].

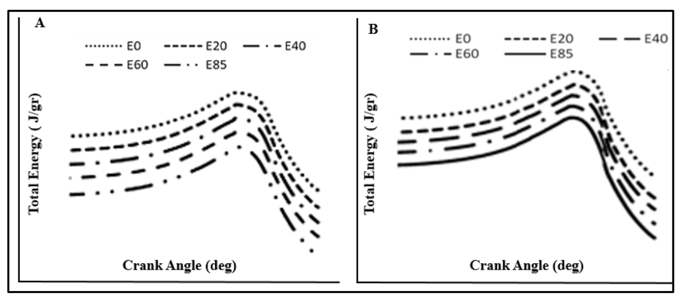

Figure 3. Figures show the whole exergy term in (a) 4500 rpm, (b) 2500 rpm.

Exergy parameters on a gasoline engine with speeds between 1200 rpm and 2400 rpm, the results of this research showed that combustion is the most important cause of system inefficiency, and almost all performance parameters increase with increasing engine speed [7]. Figure 4 shows that for E0, E20, E40, E60, and E85 fuels, the exergy due to heat transfer (aQ) decreases as engine speed increases. Actually, the exergy through heat transfer is minimal because the amount of time for heat transfer from the cylinder gases to the wall decreases with increasing engine speed [27]. According to Fig. 4, exergy occurs through heat transfer in all stages of a cycle. The compression stroke causes an increase in heat transmission because the gases within the cylinder heat up. The maximum heat transfer occurs in the combustion phase. Therefore, combustion has the largest share in the loss of efficiency due to heat transfer, so the exergy due to heat transfer decreases

[18]. This parameter for E0, and E20 fuels compared to E40, E60 and E85 are more and have a big difference with E85.

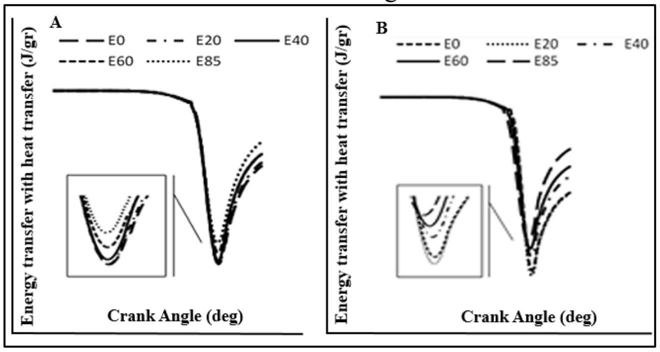

Figure 4. Exergy parameter through heat transfer in (a) 4500 rpm, (b) 2500 rpm.

The reason for this is the higher heat value of E0 compared to E20 and compared to E40, and finally, E60 is higher than E85. In Fig. 5, the irreversibility parameter (i) decreases with increasing engine speed for all fuels; in other words, with increasing engine speed, the amount of heat transfer inside the combustion chamber decreases. Nevertheless, reducing the irreversibility value of production in the combustion stage is caused by the decrease in the temperature of the combustion stage [16], [28], [29].

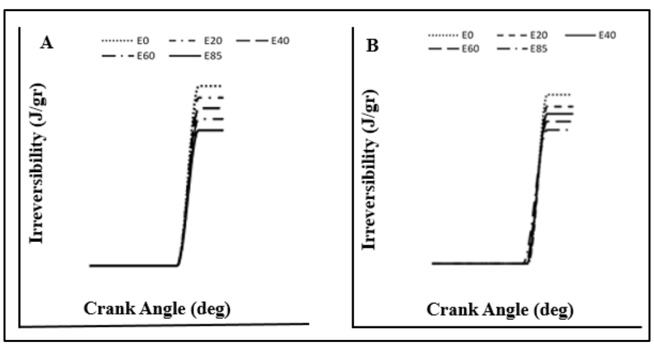

Figure 5. Irreversibility parameter in (a) 4500 rpm, (b) 2500 rpm.

In fact, in the condensation stage, because the temperature and the amount of heat transfer are low, then the irreversibility is zero. But gradually, with the beginning of the combustion stage, the temperature and pressure increase, and as a result, the amount of heat transfer increases. Conversely, the most crucial irreversibility factor is self-combustion; about eighty percent of combustion irreversibility results from the heat transfer between the reacting gases and the gases not yet burned. Finally, after the start of combustion, the irreversibility increases, and after that, the irreversibility decreases due to the decrease in entropy and the decrease in enthalpy caused by the decrease in pressure and temperature. Finally, in the expansion phase, the rate of irreversibility remains constant [29].

It can also be seen that the irreversibility of E0 fuel was higher than that of E20 and E20 compared to other fuels. The reason for this is the increase in the heat transfer rate of E0 and E20 compared to E40, E60, and E85 due to the lower calorific value of fuels. According to Fig. 6, the exergy of the burned fuel increases with increasing engine speed for all fuels. Furthermore, the engine speed increases the amount of fuel entering the cylinder [26]. The exergy of the burned fuel was zero before the combustion stage because the contents inside the cylinder did not react, and no fuel was consumed. At the beginning of the combustion phase, the chemical reaction is carried out, and the fuel is burned. Therefore, with the end of the combustion stage (the end of the chemical reaction), the functionality of the burned fuel remains constant [30]. Furthermore, the results from Fig. 6 show that because the E0 fuel has a higher calorific value, the burned fuel had the highest exergy compared to other fuels.

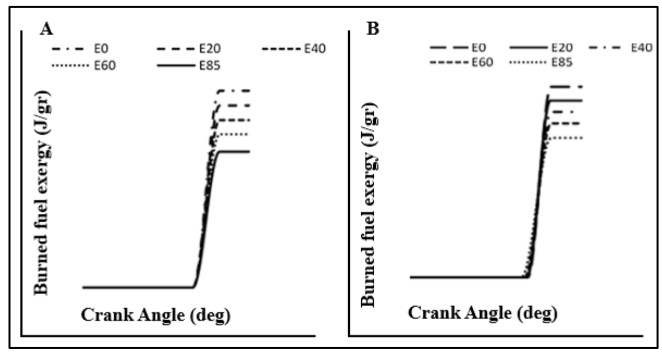

Figure 6. Exergy parameter of burned fuel in (a) 4500 rpm, (b) 2500 rpm.

In Fig. 7, for E85 fuel, 23.32% of input exergy is converted into indicative work exergy. This amount is for E0, E20, E40 and E60 fuels, respectively. 37.26, 5.28, 3.30, and 8.31 percent The reason for that is the higher oxygen content and, as a result, the improvement of the combustion process at E85 compared to other fuels. This causes the efficiency of the second law to be higher for E85 fuel compared to E0, E20, E40, and E60 fuels. Stated differently, the density of the ethanol-gasoline combination and the volumetric efficiency rise as the volume percentage of ethanol rises, thereby producing more complete combustion and hence the efficiency of the second law rises as well [30]. As the volume % of ethanol grows, the efficiency of the first law of thermodynamics also increases. The increase in the indicator work is greater for the E0, E20, E40, E60, and E85, 34, 8.36, 4.40, and 32.5%, respectively. Furthermore, the results from Fig. 7 show that a greater percentage of the input exergy for E85 fuel is spent on exergy through heat transfer and exergy through work transfer, which is the reason for the increase in the share of ethanol in the Fuel mixture, which increases the octane number and, in other words, lengthens the ignition delay time and increases the mass of fuel consumed in the combustion chamber. Ethanol has a higher evaporation rate than gasoline (three times), which causes faster and better combustion of mixtures with an increase in the percentage of ethanol. An increase in the combustion rate causes a greater amount of energy to be released near the top dead center, and as a result, the pressure increases [26].

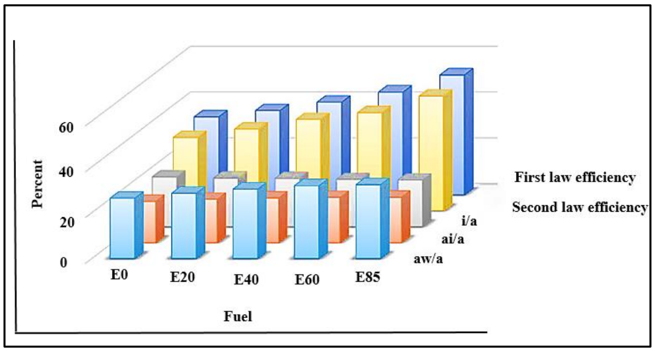

Figure 7. The evaluation of the first and second law efficiency at 4500 rpm.

According to Fig. 8, the efficiency of the first law of thermodynamics increased with the increase in ethanol volume percentage at 2500 rpm for fuels E0, E20, E40, E60, and E85, respectively, 8.36, 34, 40.44, and 32.52%. Other results show that 25.8% of the input exergy is converted into an indicative work exergy (85%). It is 7/2500 rpm because of the transmission. The heat is higher compared to 4500 rpm, and the percentage of exergy transfer through heat transfer compared to the input exergy for E0, E20, E40, E60, and E85 fuels is about 6.25%, 26%, 5.26%, 2.27%, and 28%. These values, relative to rpm 4500, have increased. Garhghani et al. [27] analyzed the second law analysis on a gasoline engine with dual fuel (gasoline and natural gas). The results showed that the efficiency of the second law at 2500 rpm was 23% compared to 4500 rpm, which has increased to 4500. In his research, Rezapour investigated the exergy parameters in a spark ignition engine (natural gas and gasoline) [9], [14]. The results of this study showed that the efficiency of the second law of thermodynamics at rpm is 33% at 4500 rpm and 31% at 2500 rpm.

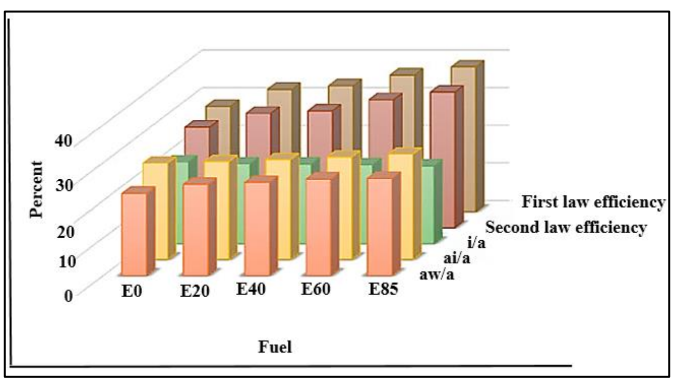

Figure 8. The evaluation of the first and second law efficiency at 2500 rpm.

4. Conclusion

The influence of engine speed and fuel type on a spark ignition engine was explored in this work. First, the conceptual foundations for an exergy analysis of the system with a definition, the expression of exergy, the expression of associated exergy equations and their application for closed systems are established. This study reveals that the combustion process is the main contributor of irreversibility to the engine; hence, the chemical efficiency of fuel rises with higher engine speed. Exergy lowers by heat transfer when ethanol content in the fuel composition rises. Moreover, the second law of thermodynamics enhances efficiency by raising ethanol concentration. Furthermore, the efficiency reduces via heat transfer as the engine speed rises.

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Conflicts of Interest: The authors declare no conflict of interest.

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