Scientia Iranica B (2014) 21(1), 171–180

SCIENTIA IRANICA

Sharif University of Technology
Scientia Iranica
Transactions B: Mechanical Engineering
www.scientiairanica.com

Effect of speed and load on exergy recovery in a water-cooled two stroke gasoline-ethanol engine for bsfc reduction purposes

M. Ghazikhani, M. Hatami[*,1] **and B. Safari**

Department of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, P.O. Box 91775-1111, Iran.

Received 14 April 2012; received in revised form 14 January 2013; accepted 15 July 2013

KEYWORDS
Exergy;
Irreversibility;
Two stroke engine;
Ethanol;
bsfc.

Abstract. The most important part of the second law of thermodynamics is described as determining the value and source of wasted exergy in processes, and suggests concepts for reducing those losses in order to enhance efficiency. So, the main purpose of this paper is to study the effect of alcoholic additives, load and engine speed on combustion irreversibilities and second law efficiency. The mentioned alcoholic fuel is ethanol, which is combined with gasoline in different percentages of 5, 10 and 15%. The experiments have been done for 2500, 3000, 3500 and 4500 rpm, and 25%, 50% and 75% full load. The results show that, mostly, when alcoholic fuel is used, the combustion internal irreversibility increases and second law efficiency decreases, which is due to the increase in temperature difference between burned combustion products and unburned mixtures, but, an increase in load and engine speeds increases second law efficiency. Another important outcome of the present study is in demonstrating brake specific fuel consumption (bsfc) reduction, due to using recovered exergy from water, whose average value is 14.1%.

1. Introduction

Exergy or availability can be defined as: the maximum useful work that can be produced through system interaction with the environment when it reaches thermo mechanical and chemical equilibrium [1]. The most important objectives of second-law application in internal combustion engines can be classified as:

- Evaluating all processes and devices, and calculating their ability to produce useful work;
- Identifying exergy losses and detecting their sources;
- Proposing methods to exploit these sources to reduce losses and increase efficiency [2].

Since 1868, many people have worked on exergy concepts. Rakopoulos and Giakoumis [2] and Caton [3] reviewed all these works. Recently, Amjad et al. [4] investigated the exergy analysis of HCCI combustion when a blended fuel, consisting of n-heptane and natural gas, is used. They found that when the mass percentage of natural gas increases, exergy destruction is decreased, thus increasing second-law efficiency. In recent years, much research has been published concerning exergy in alternative and alcoholic fuels. For example, Alasfour [5] conducted an experimental work about exergy in a butanol-gasoline blend. He used a single cylinder, SI engine, and showed that 50.6% of fuel energy can be utilized for useful work (34.28% from indicated power, 12.48% from the exhaust, and only 3.84% from the cooling water), and

1. *Present address: Department of Mechanical Engineering, Esfarayen University, Esfarayen, North Khorasan, Iran.*
*. *Corresponding author. Tel.: +98 511 8815100(209); Fax: +98 511 8763304; Mobile: +98 915 7186374*
E-mail addresses: m.hatami2010@gmail.com (M. Hatami); m_ghazikhani@yahoo.com (M. Ghazikhani); behruoz.safari@gmail.com (B. Safari)

the available energy unaccounted for represents 49.4% of total available energy. The second-law efficiency of the gasoline-butanol blend showed a 7% decrease compared to the pure gasoline engine, and, from the viewpoint of the second law of thermodynamics, was unsuitable and unfavorable.

Because ethanol or ethylic alcohol (C_2H_5OH) can be produced from herbaceous seeds, beets and potatoes, it can be a suitable alternative fuel for oil category fuels [6]. Ethanol has been blended with gasoline for increasing the octane number and its non-detonation properties. Eyidogan et al. [7] investigated the effect of ethanol-gasoline (E5, E10) and methanol-gasoline (M5, M10) fuel blends on performance and combustion characteristics of a SI engine. They showed that using ethanol made an increase in bsfc and octane number. These results were expected because the heating values of the alcohols were 37-53% lower than that of pure gasoline. Li et al. [8] used ethanol fuel in a two strike diesel engine with EGR, because of its low cetane number, and it was shown that ethanol makes lower soot and NOx, and also causes 2-3% increase in thermal efficiency.

As Rakopoulos and Giakoumis [2] revealed, most previous work concerning exergy balance with alcoholic fuels has been done on four stroke and diesel engines, and the effect of load and engine speeds on exergy balance has not been widely investigated due to its complexity. Thus, this experimental work aims to investigate the effect of ethanol additives on exergy balance in a two stroke gasoline engine, and the effect of load and speed on second law efficiency is discussed. Furthermore, bsfc reduction, due to using recovered exergy from water, is calculated. The experimental setup is shown in Figure 1.

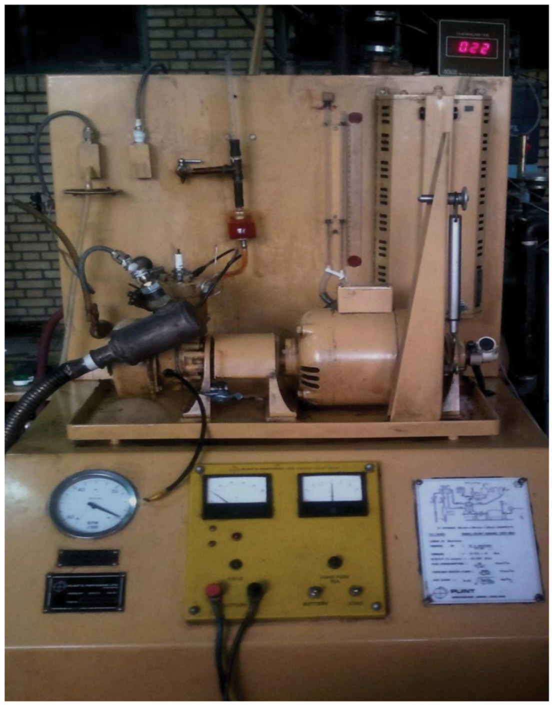

Figure 1. Test bed in laboratory.

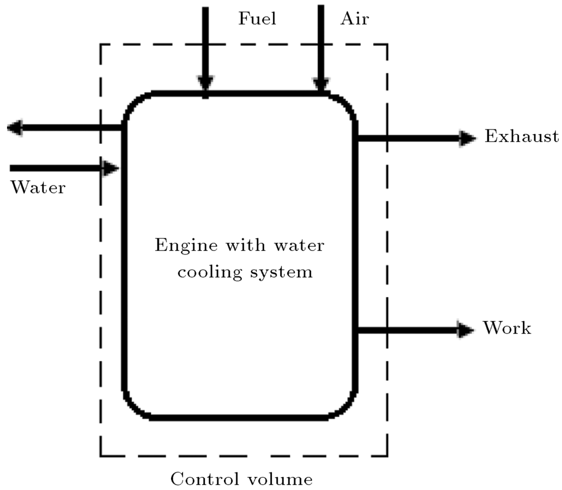

Figure 2. Control volume.

2. Exergy analysis and governing equation

In this work, for exergy analysis, the control volume is considered as in Figure 2. As seen, air, fuel and cooling water enter the control volume, and water, exhaust and work exit from it. The exergy balance for this control volume can be written as [9]:

$$\frac{d\Phi_{cv}}{dt} = \Sigma\dot{\Phi}_Q + \Sigma\dot{m}_i\psi_i - \Sigma\dot{m}_e\psi_e + \dot{W}_{\text{act}} - \dot{I}_{\text{total}}. \quad (1)$$

Since the non-flow exergy term (left side of Eq. (1)) and exergy transfer term to ambient is zero, the exergy balance will be:

$$\dot{I}_{\text{total}} = \Sigma\dot{m}_i\psi_i - \Sigma\dot{m}_e\psi_e + \dot{W}_{\text{act}} = \dot{m}_f a_{\text{fch}} - \dot{m}_{\text{Ech}}\psi_{\text{Ech}} - \dot{m}_{\text{water}}\Delta\psi_{\text{water}} + \dot{W}_{\text{act}}, \quad (2)$$

where exhaust mass flow is the sum of the inlet air and fuel mass flow.

$$\dot{m}_{\text{Exh}} = \dot{m}_a + \dot{m}_f. \quad (3)$$

Availability changes are calculated from Eq. (4), when entropy and enthalpy changes are obtained from Eqs. (6) and (7), and thermodynamic tables for exhaust and cooling water flow, respectively:

$$\Delta\psi = \Delta h - T_0\Delta S. \quad (4)$$

As mentioned for exhaust flow, C_p can be given as a function of temperature. Due to the exhaust temperature range (130-330°C), Eq. (5) can be a suitable temperature-dependent equation for all cases in this experiment [10].

$$C_p = 28.11 + 0.1967 \times 10^{-2} T + 0.4802 \times 10^{-5} T^2 - 1.966 \times 10^{-9} T^3. \quad (5)$$

By integrating Eq. (5), Eqs. (6) and (7) for exhaust flow were obtained as follows:

$$dh = C_p dT \Rightarrow \int_{h_0}^{h_{\mathrm{Exh}}} dh = \int_{T_0}^{T_{\mathrm{Exh}}} C_p dT \Rightarrow h_{\mathrm{Exh}} - h_0 = \frac{1}{28.9}[28.11(T_{\mathrm{Exh}} - T_0) + 0.9835 \times 10^{-3}(T_{\mathrm{Exh}}^{-2} - T_0^{-2}) + 0.16 \times 10^{-5}(T_{\mathrm{Exh}}^{-3} - T_0^{-3}) - 0.49 \times 10^{-9}(T_{\mathrm{Exh}}^{-4} - T_0^{-4})]. \quad (6)$$

For entropy changes,

$$TdS = dh - vdp \Rightarrow TdS = C_p dT - \frac{RT}{p}dp \Rightarrow dS = \frac{C_p dT}{T} - RLn(\frac{p_{\mathrm{Exh}}}{p_0}),$$

$$\Delta S_{\mathrm{Exh}} = \int_{T_0}^{T_{\mathrm{Exh}}} ds = \int_{T_0}^{T_{\mathrm{Exh}}} \frac{C_p dT}{T} - RLn(\frac{p_{\mathrm{Exh}}}{p_0}) = \frac{1}{28.9}[28.11 Ln\left(\frac{T_{\mathrm{Exh}}}{T_0}\right) + 0.1967 \times 10^{-2}(T_{\mathrm{Exh}} - T_0) + 0.2401 \times 10^{-5}(T_{\mathrm{Exh}}^2 - T_0^2) - 0.655 \times 10^{-9}(T_{\mathrm{Exh}}^3 - T_0^3)] - RLn(\frac{p_{Exh}}{p_0}). \quad (7)$$

By substituting Eqs. (6) and (7) into Eq. (4), exhaust exergy changes will be calculated. For calculating irreversibility, due to heat transfer between cooling water and in-cylinder gases, the following equation can be used [9]:

$$I_Q = T_0 Q(\frac{1}{T_{\mathrm{water}}} - \frac{1}{T_{\mathrm{comb}}}), \quad (8)$$

where Q represents the heat transfer between cooling water and in-cylinder combustion products, and can be calculated as follows:

$$Q = \dot{m}_{\mathrm{water}} C_{\mathrm{water}}(T_e - T_i). \quad (9)$$

In an internal combustion engine, by assuming use of the exhaust and cooling water exergy, second-law efficiency can be defined as:

$$\varepsilon = \frac{\text{output exergy}}{\text{input exergy}} = \frac{\text{water exergy + exhaust exergy + work}}{\text{fuel exergy}}. \quad (10)$$

2.1. Fuels exergy

For hydrocarbon fuels of the type $C_z H_y$, chemical exergy is often approximated by:

$$a_{\mathrm{fch}} = \mathrm{LHV}(1.04224 + 0.011925\frac{y}{z} - \frac{0.042}{z}), \quad (11)$$

where, LHV is the lower heating value of the fuel. Styrylska [11], Rodriguez [12] and Stepanov [13] represented various approximations for the chemical exergy of fuel. One approximation for liquid fuel of the general type $C_z H_y O_p S_q$ can be found in [13], based on the work of Szargut and Styrylska [11]:

$$a_{\mathrm{fch}} = \mathrm{LHV}[1.0401 + 0.01728\frac{y}{z} + 0.0432\frac{p}{z} + 0.2196\frac{q}{z}(1 - 2.0628\frac{y}{z})]. \quad (12)$$

The stoichiometric combustion equation for fuels of the general type $\mathrm{C}_x\mathrm{H}_y\mathrm{O}_z$ is [9]:

$$\mathrm{C}_x\mathrm{H}_y\mathrm{O}_z + (x + \frac{y}{4} - \frac{z}{2})(\mathrm{O}_2 + 3.76\mathrm{N}_2) \Rightarrow x\mathrm{CO}_2 + \frac{y}{2}\mathrm{H}_2\mathrm{O} + 3.76(x + \frac{y}{4} - \frac{z}{2})\mathrm{N}_2. \quad (13)$$

In a two stroke engine, because of the scavenging process, determining the air to fuel ratio using the exhaust gas analyzer and stoichiometric air to fuel is better and exquisite [14]. For this reason, we have endeavored to use Eqs. (12) and (13) for determining the air to fuel ratio.

2.2. Corrected factor and bsfc

The standard condition is defined $P_a = 736$ mmHg, $P_v = 9.65$ mmHg and $\phi = 0.31$ at $T_a = 29.4$°C but the thermo-dynamical condition in the experimental laboratory is different. So, the corrected factor is used to develop the real experimental condition to a standard condition. For this reason, the corrected brake power factor is defined as in the following equation [1];

$$C_f = \frac{P_{bs}}{P_{bm}} = \frac{\dot{m}_{as}}{\dot{m}_{am}} = \frac{P_{sd}}{P_m - P_{vm}}\sqrt{\frac{T_m}{T_s}}. \quad (14)$$

With assumptions $P_{sd} = 736.6$ mmHg and $T_s = 29.4$°C, the corrected brake power factor is calculated and the amount of P_{bs} is defined as follows:

$$P_{bs} = C_f P_{bm} = C_f(2\pi N\tau). \quad (15)$$

Brake specific fuel consumption (bsfc) in internal combustion engines is defined as the ratio of fuel flow rate to engine brake power. If it is possible to use the whole recovered exergy, bsfc can be calculated by the following:

$$\mathrm{bsfc} = \frac{\dot{m}f}{P_b} = \frac{\dot{m}f}{2\pi N\tau + \text{recovered exergy from water}}. \quad (16)$$

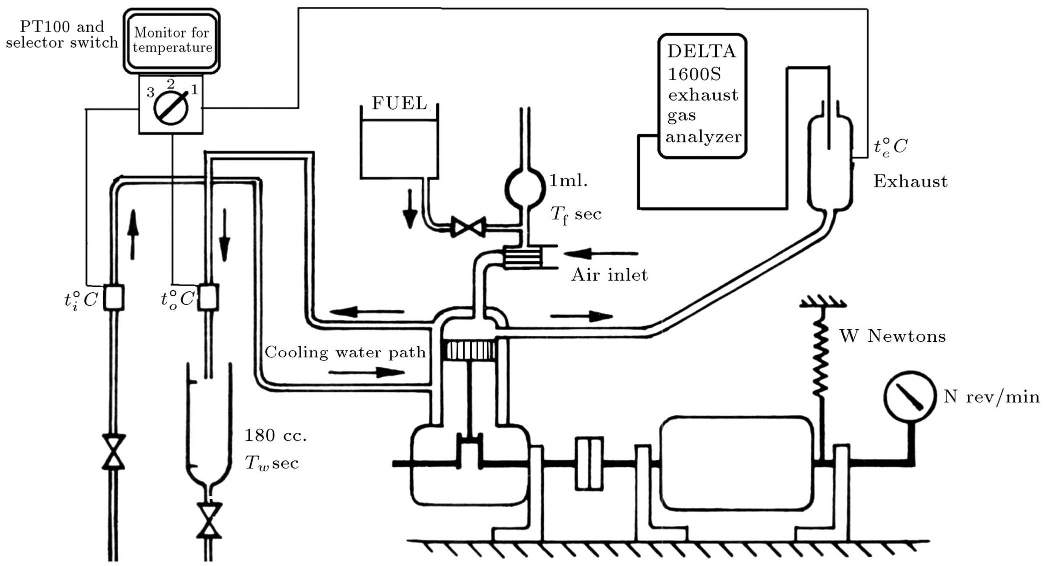

Figure 3. Schematic of the experimental set up.

Table 1. Specifications of the test engine.

Engine model	2-stroke JAP-J34
Bore	35 mm
Number of cylinder	1
Stroke	35 mm
Displacement volume	34 ml
Compression ratio	6
Nominal output power	0.5 k (W , 4000 rev/min
Maximum speed	6000 rev/min
Corporation	Plint & Partners LTD

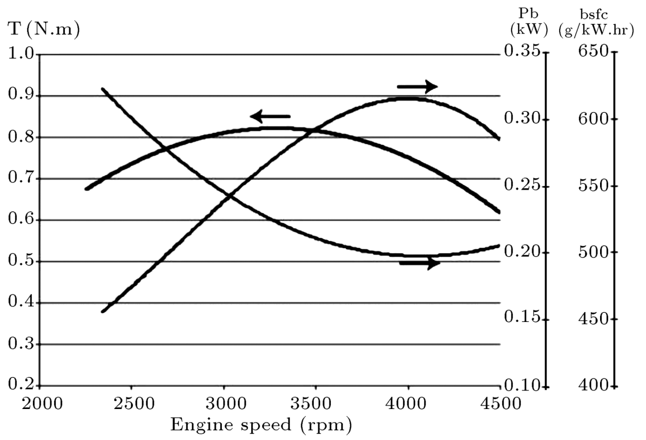

Figure 4. Performance map of test engine.

3. Experimental apparatus

The experimental set up consists of a two stroke, one cylinder SI engine, an engine test bed and an exhaust analyzer. The schematic of the experimental set up is shown in Figure 3. The engine model is JAP-J34 and the cooling fluid is water. Specifications of the engine are given in Table 1. The torque meter has an accuracy of $\pm 0.5\%$. For measuring fuel consumption, the time of 1cc fuel consumption was measured with a digital chronometer with a definition rate of $\pm$ 0.01 s. The exhaust temperature, inlet and outlet cooling water temperature were measured with high accuracy PT100 sensors, whose values were shown on a screen.

4. Tests procedure

All the tests were done in three general steps. First, obtaining the performance map, second, determining the specification of blended fuels, and finally, running the engine at various speeds with using blended fuels. For obtaining the performance map, the engine is started with gasoline, and stabilized awhile to reach a stable state. In this state, the engine is set to full throttle and maximum power applied to it. All experiments are done for 2500, 3000, 3500 and 4500 rpm, and 1 cc fuel consumption time and torque are recorded. After calculating output power and bsfc, the performance map can be obtained as in Figure 4.

Experiments were performed with four different fuels at 25%, 50% and 75% of full load. The fuels were pure gasoline 95% gasoline+5% ethanol 90% gasoline+10% ethanol and 85% gasoline+15% ethanol. Some properties of these fuels are shown in Table 2. The testing procedure is as follows.

As mentioned, experiments were performed with four different fuels at 25%, 50% and 75% of full load, and 2500, 3000, 3500 and 4500 rpm. After completion of a standard warm up procedure, the engine speed was increased from 2500 to 4500 rpm. At each point, the engine was stabilized for 2 minutes, and then, the measurement parameters (temperatures, exhaust gases, water mass flow, fuel consumption time, torque

Table 2. Some properties of the test fuels.

Properties	**Gasoline**	**Ethanol**	**Gasoline with 5% ethanol**	**Gasoline with 10% ethanol**	**Gasoline with 15% ethanol**
Typical formula	$C_{7.93}H_{14.83}$	C_2H_5OH	$C_{7.63}H_{14.39}O_{0.05}$	$C_{7.34}H_{13.95}O_{0.1}$	$C_{7.04}H_{13.51}O_{0.15}$
Density (kg/lit)	0.7378	0.7987	0.7408	0.7439	0.7469
Heating value (MJ/kg)	44.4	26.8	43.45	42.51	41.58
Molecular weight	110	46	106.75	103.63	100.39
Fuel exergy (kJ/kg)	47030	29842	46620	45635	44664
Stoichiometric air/fuel	14.5	8.97	14.43	14.31	14.17

and speed) were recorded. For verifying the recorded data, these were checked three times at each step on the running engine.

5. Results and discussion

5.1. *Effect of ethanol percentages on exergy balance*

Using ethanol in combustion engines has two different aspects, one is positive and the other is negative. Having a lower heating value is the negative aspect and having lower flash point and lower ignition delay can be the positive one. Exergy analysis charts are shown in Figure 5. As seen in Figure 5(a), by using ethanol additives, water exergy decreased. This is due to reduction in combustion temperature and lower heat transfer to cooling water. When ethanol was added to gasoline (for 10% and 15%), most combustion energy was consumed for equilibrating burned and unburned gas temperatures, and caused an increase in irreversibility, as shown in Figure 5(c). As mentioned above and using Eq. (10), blending 10 and 15% ethanol caused a reduction in second law efficiency, but, for 5% ethanol, a positive aspect dominated and second law efficiency generally increased.

For better perception, pie and bar charts were used to describe exergy balance. Figures 6 and 7 show pie charts for 2500 rpm and 3000 rpm, respectively. As seen in these figures, using 10 and 15% ethanol causes 5 and 10% increase in control volume irreversibility (I_{cv}), respectively. This is due to the different evaporation speeds of gasoline and ethanol, where most combustion energy is consumed for equilibrating these different temperatures. But, for 5% ethanol, I_{cv} has been reduced up to 12%, and a 1-4% increase in work exergy is observed. For all percentages of ethanol, a reduction in water exergy, due to reduction in combustion temperature, is seen. Bar charts in Figure 8 compare second law efficiency for fuels at four speeds. As seen, for all speeds except 3500 rpm, second law efficiency

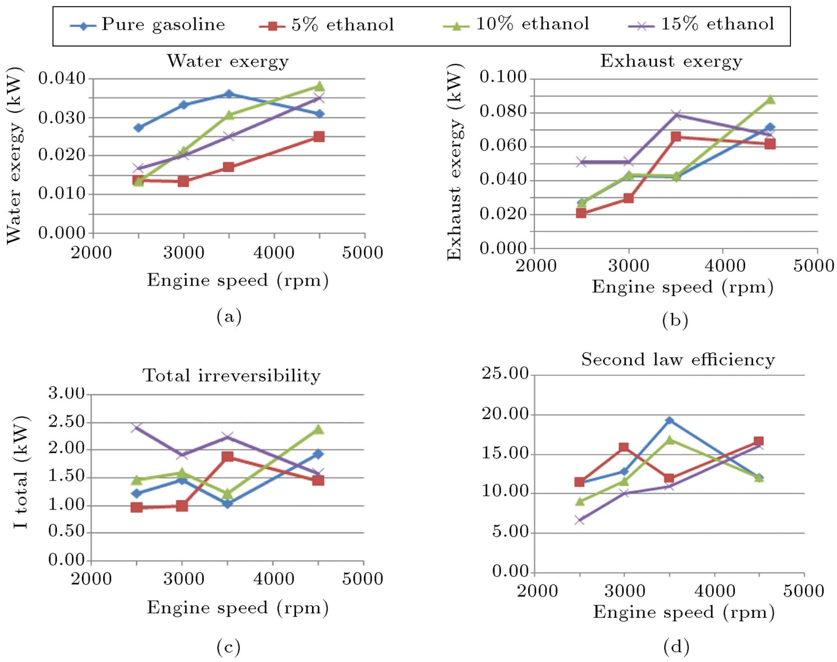

Figure 5. Exergy analysis charts.

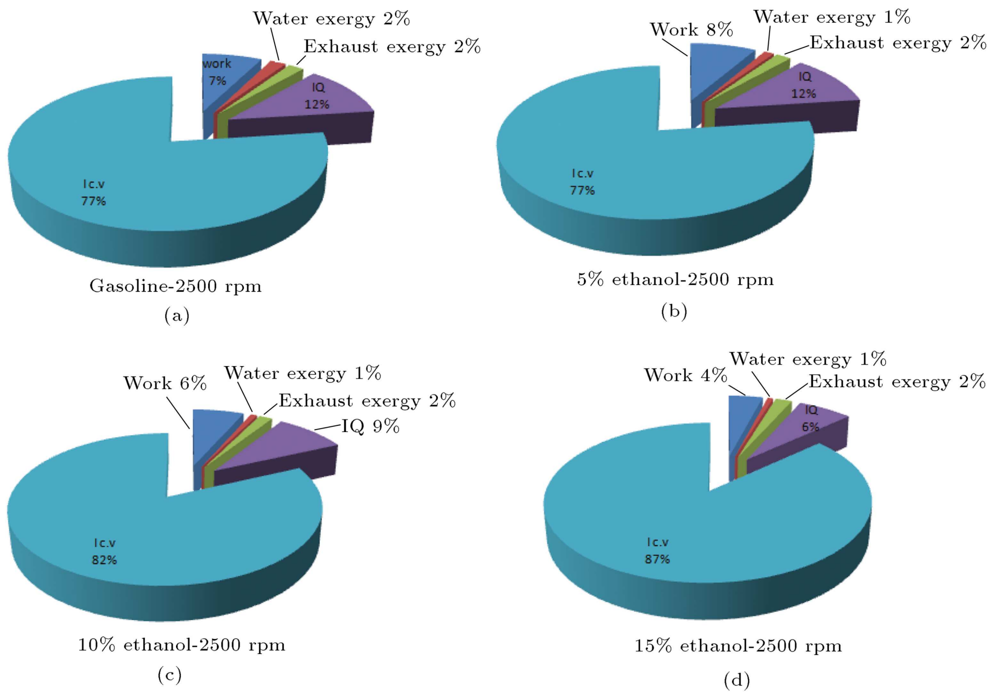

Figure 6. Exergy balance for 2500 rpm and four different fuels.

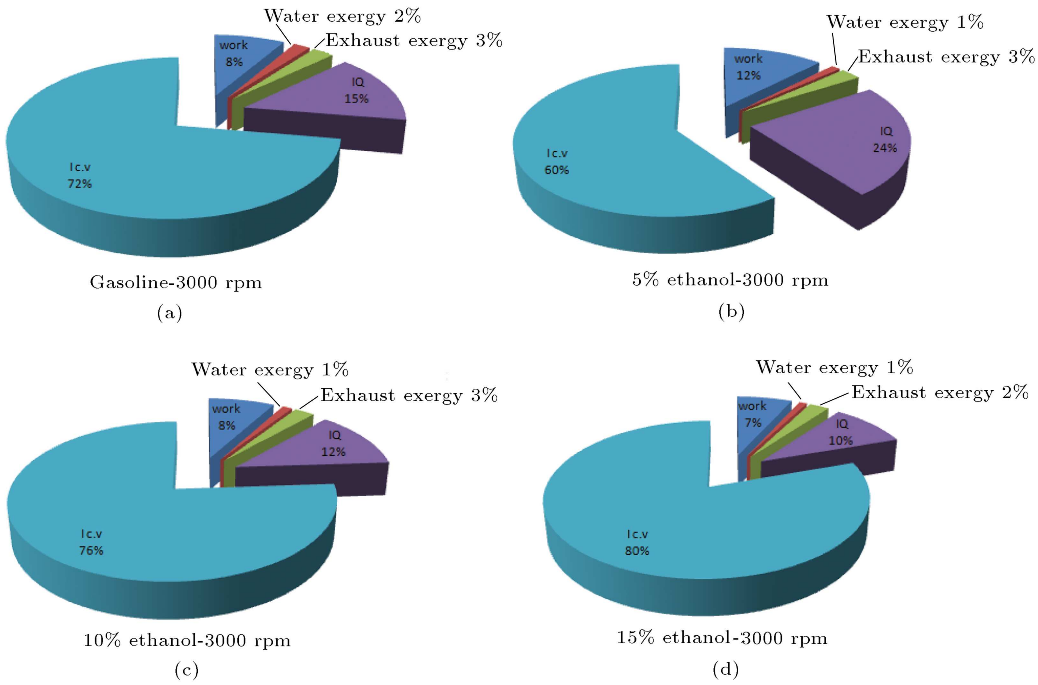

Figure 7. Exergy balance for 3000 rpm and four different fuels.

for 5% ethanol is 2-5% higher than for pure gasoline, and for 10 and 15% ethanol, second law efficiency is 3-5% lower than pure gasoline. At 3500 rpm, for all percentages of ethanol blended with gasoline, second law efficiency has been decreased by 3-5%. As seen in this figure, the maximum of second law efficiency occurred at 4500 rpm with 5% ethanol, whose value is approximately 17%.

5.2. Effect of load and engine speed on the second law efficiency

The effect of engine speed and torque on exergy balance and irreversibility is very complex [15]. Generally, however, when torque increases, an increase in pressure and temperature in the cylinder is caused. This makes an increase in exhaust gas availability and a reduction in combustion irreversibility. Figure 9

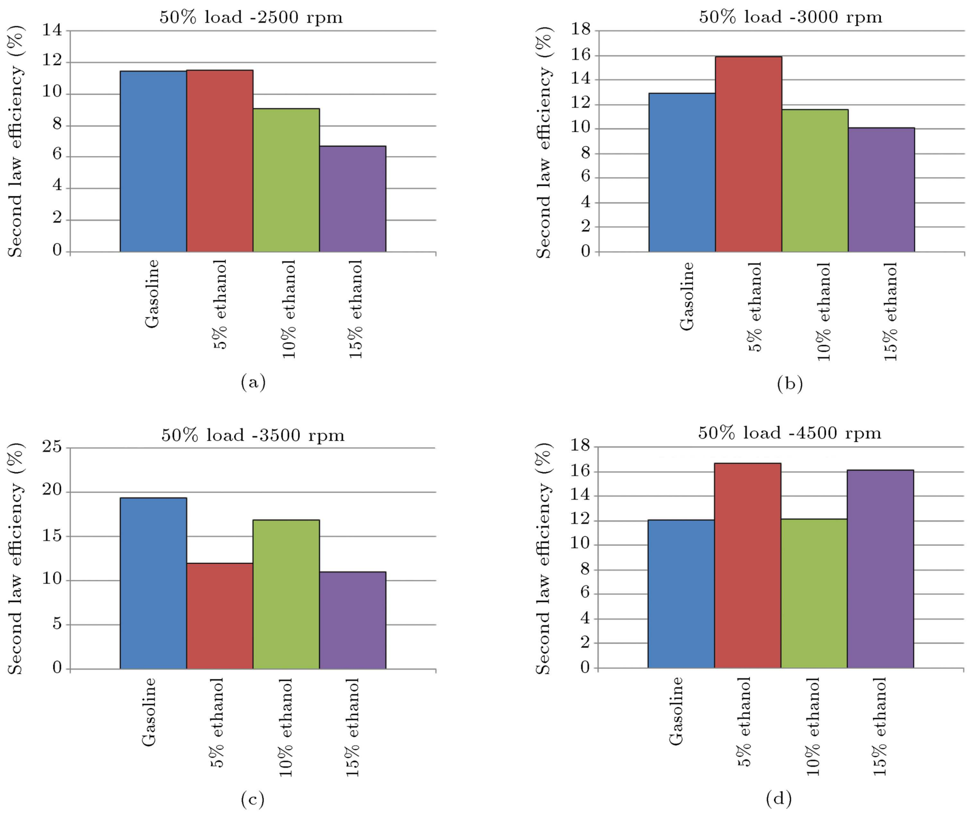

Figure 8. Comparison of second law efficiency for fuels in four speeds.

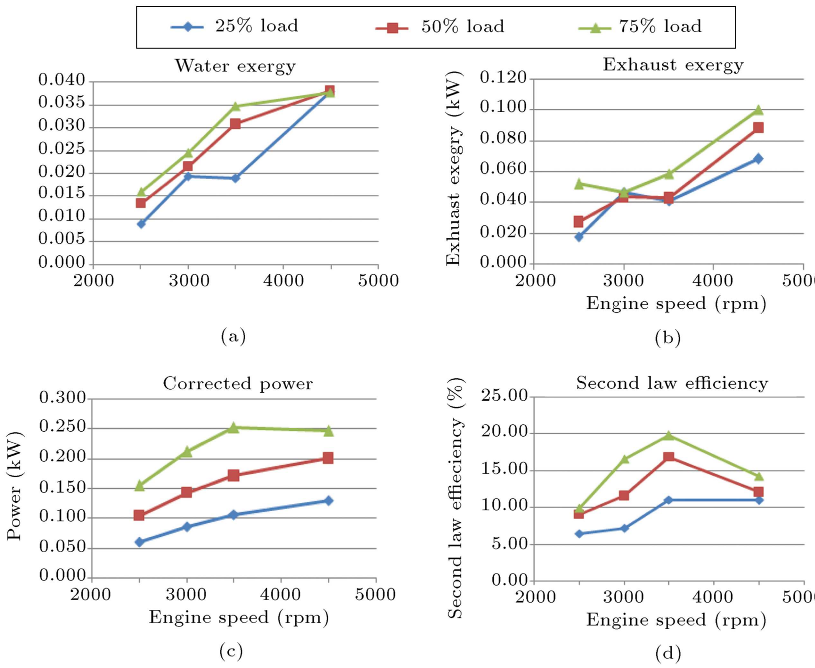

Figure 9. Effect of load and engine speed on exergy balance terms for 10% ethanol.

confirms this truth. Increasing the second law efficiency in Figure 9(d) is due to increasing the exergy terms in Figure 9(a), (b) and (c) (see Eq. (10)). When speed is increased, an increase in friction, combustion irreversibility and exhaust gas exergy occurs. Also, an increase in speed causes a decrease in cylinder heat loss, due to the less available time for heat transactions. The effect of engine speed on exergy terms is depicted in Figure 10. As seen, by increasing engine speed, internal irreversibility decreases, which is

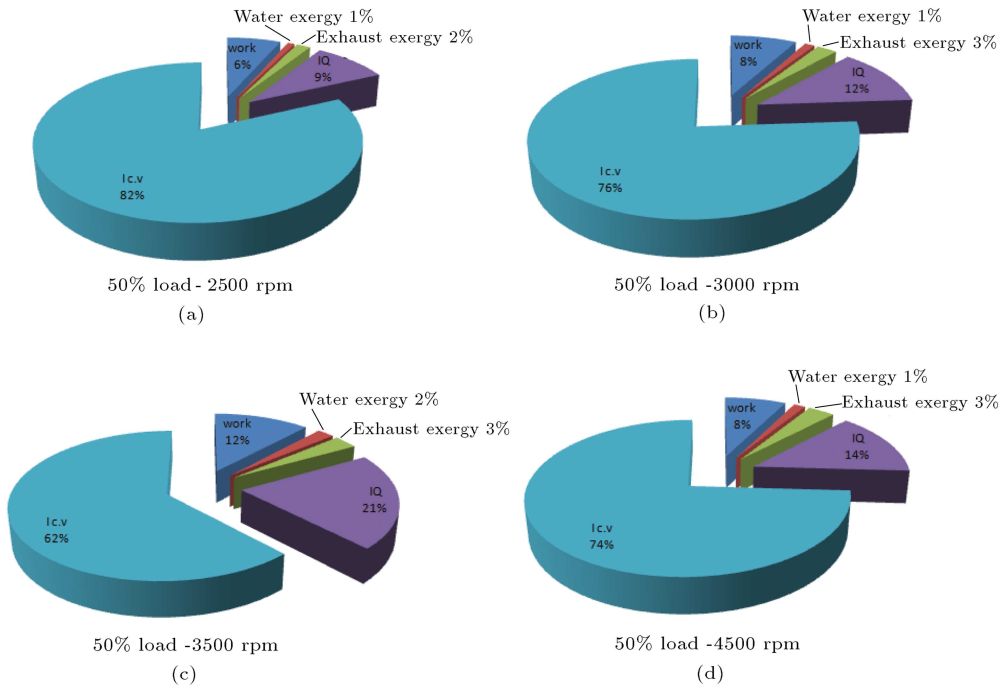

Figure 10. Effect of engine speed on exergy balance for 50% full load and 10% ethanol.

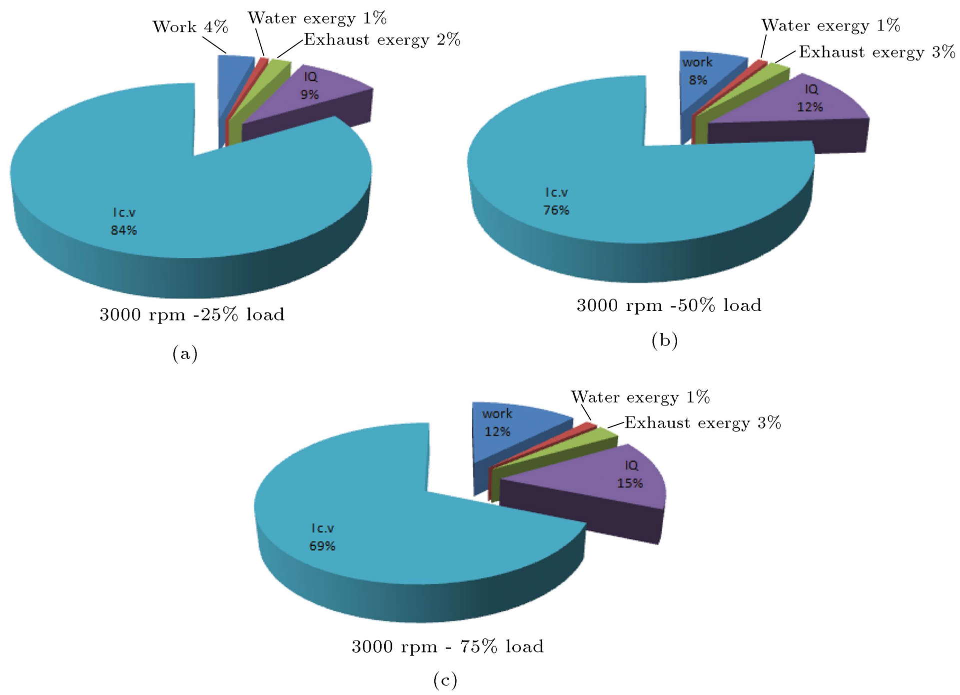

Figure 11. Effect of engine torque (% of full load) on exergy balance terms in 3000 rpm and 10% ethanol.

due to higher combustion temperature at high speeds. Also, by increasing engine speed, exhaust exergy and output work is increased. Figure 11 shows the engine load in exergy terms. An increase in load makes an increase in output work, and exergy terms, and a decrease in internal irreversibility, which is due to higher combustion temperature under these conditions. The effect of load and engine speed on second law efficiency is depicted in Figure 12 for 10% ethanol. By increasing the speed and load, second law efficiency can be increased generally.

5.3. bsfc reduction due to using the exergy recovery from water

As mentioned in Subsection 5.1, using ethanol has two different aspects, which are in front of each other.

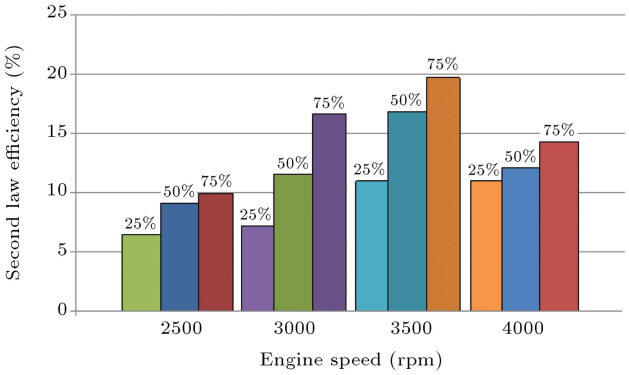

Figure 12. Second law efficiency in different load and speeds (for 10% ethanol).

When using 10% and 15% ethanol, the negative aspect has dominated to the positive and bsfc has increased, but, for 5% ethanol, the positive aspect has dominated and bsfc has been reduced, which is an advantage for this state. It is assumed that all the recovered exergy from the water-cooled system can be usable as an input power. Then, using Eq. (16), bsfc will be decreased significantly. Figure 13(a) and (b), which is for 5% and 10% ethanol, respectively, compares the bsfc before and after using recovered exergy. Table 3 demonstrates that the percentage of bsfc when using 10% ethanol is, on average, 14.1% reduced.

6. Conclusion

In this paper, we endeavored to blend ethanol with gasoline in three different percentages: 5, 10 and 15%.

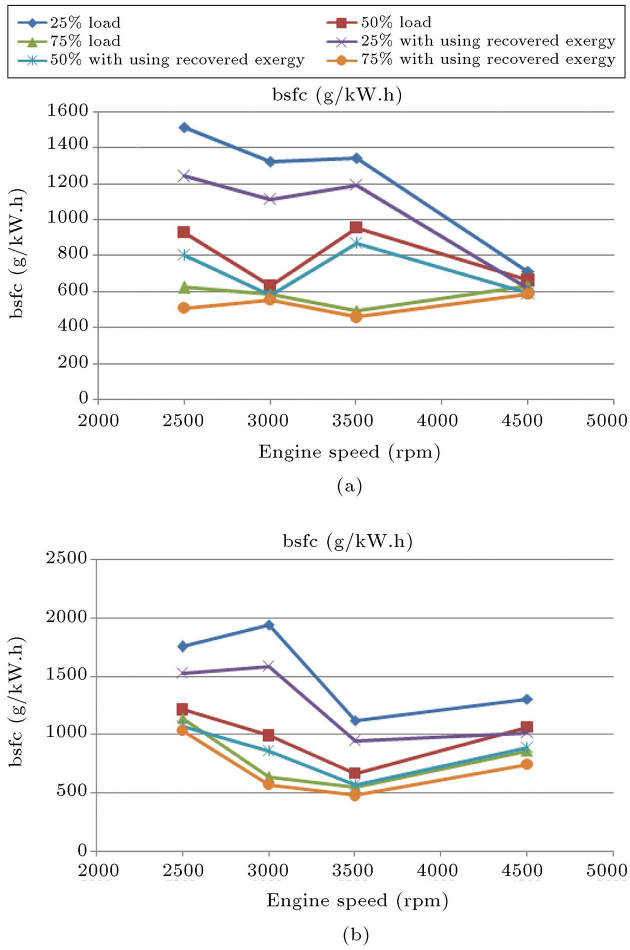

Figure 13. Effect of exergy recovery from water in bsfc reduction: (a) 5% ethanol; and (b) 10% ethanol.

Table 3. bsfc reduction percentage due to using exergy recovery for 10% ethanol.

Torque (% of full load)	Speed (rpm)	bsfc (g/kW.h)	bsfc with using recovered exergy (g/kW.h)	% of bsfc reduction
	2500	1752.969	1528.346	12.81386
	3000	1941.985	1586.225	18.3194
25%	3500	1119.610	949.9509	15.15341
	4500	1306.129	1011.424	22.56324
	2500	1210.687	1072.678	11.39923
	3000	991.059	861.3905	13.08383
50%	3500	669.570	567.7576	15.20564
	4500	1060.039	891.6959	15.88084
	2500	1141.926	1035.383	9.330114
	3000	633.959	568.328	10.35256
75%	3500	546.510	480.5454	12.07015
	4500	860.657	746.4277	13.27234

This paper investigates the effects of ethanol additives, load and engine speed on the exergy balance terms, and bsfc. The following main conclusions can be drawn from the current work:

- Using ethanol created an increase in bsfc. This result was expected, as the heating values of the alcohols are approximately 60% lower than that of pure gasoline. For increasing bsfc, recovered exergy from the cooling water can be used.
- Ethanol additives create a lower temperature for combustion. For this reason, transfer of exergy to the cooling decreases, and, so, second law efficiency decreases.
- The effect of engine speed and torque on exergy balance and irreversibility reveals that when torque or speed increases, an increase in pressure and temperature is caused in the cylinder. This makes an increase in exhaust gas availability and a decrease in internal irreversibilities.

References

1. Heywood, J., *Internal Combustion Engine Fundamentals*, McGraw-Hill Education (1988).
2. Rakopoulos, C.D. and Giakoumis, E.G. "Second law analyses applied to internal combustion engines operation", *Prog. Energy Combust. Sci.*, **32**, pp. 2-47 (2006).
3. Caton, J.A. "A review of investigations using the second law of thermodynamics to study internal-combustion engines", SAE paper no. 2000-01-1081. Warrendale, PA: Society of Automotive Engineers Inc. (2000).
4. Amjad, A.K., Khoshbakhi Saray, R., Mahmoudi, S.M.S. and Rahimi, A. "Availability analysis of n-heptane and natural gas blends combustion in HCCI engines", *Energy*, **36**, pp. 6900-6909 (2011).
5. Alasfour, F.N. "Butanol a single-cylinder engine study: Availability analysis", *Appl. Therm. Eng.*, **17**(5), pp. 37-49 (1997).
6. Demirbas, A., *A Realistic Fuel Alternative for Diesel Engines*, London: Springer (2008).
7. Eyidogan, M., Ozsezen, A.N., Canakci, M. and Turkcan, A. "Impact of alcohol-gasoline fuel blends on the performance and combustion characteristics of an SI engine", *Fuel*, **89**(10), pp. 2713-2720 (2010).
8. Li, X., Qiao, X., Zhang, L., Fang, J., Huang, Z. and Xia, H. "Combustion and emission characteristics of a two-stroke diesel engine operating on alcohol", *Renew. Energy*, **30**, pp. 2075-2084 (2005).
9. Wark, K. *Advanced Thermodynamics for Engineering*, McGraw-Hill, Inc. (1995).
10. Rosen, M.A. "Clarifying thermodynamic efficiencies and losses via exergy", *Exergy, An Int. J.*, **2**, pp. 3-5 (2002).
11. Szargut, J. and Styrylska Angena, T. "rhte bestimmung der exergie von brennstoffen. Brennst-Wa" rme-Kraft, **16**, pp. 589-96 (1964).
12. Rodriguez, L. "Calculation of available-energy quantities", in: Gaggioli RA, editor. *Thermodynamics: Second Law Analysis*. Washington, DC: American Chemical Society Symposium, pp. 39-59 (1980).
13. Stepanov, VS. "Chemical energies and exergies of fuels", *Energy*, **20**(2), pp. 35-42 (1995).
14. Heywood, J.B. and Sher, E., *The Two-Stroke Cycle Engine*, Taylor & Francis, Philadelphia (1999).
15. Rakopoulos, C.D. and Giakoumis, EG. "Speed and load effects on the availability balances and irreversibilities production in a multicylinder turbocharged diesel engine", *Appl. Therm. Eng.*, **17**, pp. 299-313 (1997).

Biographies

Mohsen Ghazikhani received his PhD degree, in 1993, from Leeds University, England, and is currently Associate Professor of Mechanical Engineering at Ferdowsi University of Mashhad, Iran. His main research interests include internal combustion engines, combustion, thermodynamics and exergy analysis in engineering applications.

Mohammad Hatami was born in 1987 in Iran. He received BS and MS degrees in Mechanical Engineering from Ferdowsi University of Mashhad, Iran, in 2009 and 2011, respectively, and is currently a PhD degree student of Energy Conversion at Babol University of Technology, Iran. His main research interests are internal combustion engines, CFD modeling and analytical solutions for nonlinear problems .

Behrouz Safari received his MS degree, in 2012, in Aerospace Engineering from Ferdowsi University of Mashhad, Iran. His research interests are ventilation systems design with Career software, internal combustion engines and propulsions.