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Evaluation of the Energy Balance of a Gasoline Engine Using Ethanol and n-Butanol as Additives

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ABSTRACT

Energy supply is one of the most important current issues in the world. The most uses of fossil fuels are for providing power to internal combustion engines. The increase in the global price of fossil fuels and the environmental concerns have made researchers to look for alternate sources of energies, such as biofuels. The main disadvantage of biofuels is their low heating values. However, they can be used as gasoline additives. The aim of this study was to evaluate the energy balance of a four-cylinder gasoline engine with ethanol and n-butanol alcohols in different volume percentages at three different engine speed of 1000, 1500, 2000 rpm. The results showed that the engine brake power increased in fuel blends that contain bio-alcohols compared to pure gasoline fuel. Also, by increasing the engine speed, the engine brake power of the fuel blends increased so that at 2000 rpm, the G70E15B15 fuel blend had the highest brake power of 47.1 kW. Also, the exhaust heat loss in fuel blends containing ethanol and n-butanol increased compared to pure gasoline, and also increased with the increase in engine speed. The lowest exhaust heat loss of 3.98 kW related to pure gasoline at 1000 rpm and the highest exhaust heat loss of 6.38 kW for G70E15B15 fuel blend at 2000 rpm were obtained. Pure gasoline fuel had lower heat loss of cooling system than other fuel blends. Heat loss of cooling system decreased with increasing speed from 1000 to 2000 rpm. Therefore, the G70E15B15 fuel blend with 11.01 kW and pure gasoline with 2.89 kW had the highest and lowest heat loss of cooling system, respectively.

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INTRODUCTION

Energy supply is one of the most important issues in the world nowadays. A large amount of this energy is used by fossil fuel-powered machinery and transportation vehicles. As of 2018, there were 1.42 billion cars and light trucks worldwide. By 2050, it is predicted that there will be more than 2 billion cars on the road (Shadidi et al., 2021). The increase in the global price of fossil fuels and the increase in environmental warnings worldwide have made researchers looking for renewable sources for these types of fuels (Khoshkname et al., 2022; Shadidi et al., 2017). Researchers have experimented with several techniques to increase the efficiency of biofuel-consuming engines in order to use alternative fuels. Several combinations of the primary fuel with ethanol, methanol, and butanol were used in these techniques (Lapuerta et al., 2017; Shirazi et al., 2020). Recently, researchers studying automotive have focused on three forms of alcohol: butanol, ethanol, and methanol (Masum et al., 2014; Uyumaz, 2015). Butanol, which belongs to the alcohol family, is made up of four carbon chains with the formula $C_4H_{10}O$. Butanol isomers come in four different varieties, which are: 1. Butanol, also known as n-butanol, a) iso-butanol, b) tert-butanol, c) sec-butanol (Vairamuthua et al., 2015). The combination of butanol with gasoline fuels is more appropriate since it is more similar to gasoline fuel than methanol and ethanol in terms of the heating value, octane number, air-fuel stoichiometric ratio, and auto-ignition temperature (Khoobbakht et al., 2016).

Butanol is very similar to gasoline fuel in terms of heating value, stoichiometric ratio of air to fuel, and octane number, so its combination with gasoline fuels is more suitable. So, butanol has been suggested as the next generation of biofuels as an alternative to conventional fuels (Yusri et al., 2016). The energy balance of an internal combustion engine is the analysis of the first law of thermodynamics, which is also called the thermal balance (Shadidi et al., 2017). The basis of this method is according to the first law of thermodynamics, by selecting the control volume on the engine, the amount of energy input to the engine by fuel combustion can be obtained. It is also possible to obtain the output energy from the engine, part of which is in the form of net output power, and the rest is in the form of cooling heat energy, exhaust heat energy, and unaccounted heat loss that covers mainly the convection and radiation heat losses (N Shirvan et al., 2022). A common way to evaluate a physical or chemical process in terms of energy is to write an energy balance based on the first law of thermodynamics, which can be used to reduce heat loss or increase heat recovery. In order to improve the efficiency of the engine, the ways of heat loss should be identified and the amount of heat lost from these ways should be obtained. To obtain these losses, it is necessary to check the heat or energy balance of the engine. Energy balance actually includes consideration of useful work, cooling system heat loss, exhaust heat loss, lubrication system heat loss, etc (Yüksel & Ceviz, 2003).

Researchers have been studying the use of alcohols as an additive to monitor the energy balance of the engine in recent years. In a study, 2-butanol-gasoline fuel blends in three different ratios (5, 10, and 15) were investigated and compared with pure gasoline. By analyzing the energy balance, they concluded that the engine power, cooling energy, and exhaust output energy have improved by an average of 3.3, 0.8, and 2.3%, respectively, for the 15% 2-butanol fuel blends compared to the pure gasoline fuel (Yusri et al., 2016). In another study, an experimental four-cylinder four-stroke engine was tested with ethanol and gasoline fuels with proportions of 0, 5, 10, 15 and 20%. The results showed that by increasing the percentage of ethanol in gasoline-ethanol fuel blends, the percentage of useful work increased, while cooling heat loss and exhaust heat loss decreased compared to the performance of the pure gasoline (Kiani Deh Kiani et al., 2012). In another research, the energy balance of a four-stroke single-cylinder engine with biofuels including pure ethanol (E100), 15% ethanol (E15) and 85% ethanol (E85) was investigated. The results showed that with the increase in the percentage of ethanol in the fuel, the ratio of exhaust loss to thermal loss increased (Qasemian et al., 2021). The effects of the levels of biodiesel-ethanol-diesel fuel blends on energy balance of a DI diesel engine was also investigated. The average work production and overall energy loss rates were shown to be 41.22 kW and 71.36 kW, respectively, in the results. Merely 37% of the input energy was transformed into mechanical energy, with the remaining 63% being lost through various means from the control volume (Khoobbakht et al., 2016).

The use of the alcohols as an alternative for fossil fuels has been considered in recent years. However, investigating the effects of alcohol on the engine seems necessary. Therefore, in this study, the energy balance of a water-cooled, four-cylinder gasoline engine using a gasoline-ethanol- n-butanol fuel blends (G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15) at three different speeds (1000, 1500 and 2000 rpm) was investigated.

MATERIALS AND METHODS

Fuel Preparation

The gasoline required for this experiment was obtained from one of the gas stations located in Hamedan, Iran. The required ethanol and n-butanol were obtained from Merck-Germany with a purity of 99.6%. After preparing gasoline fuel, ethanol and n-butanol alcohols, fuel blends were combined according to specified volume percentages. In Table 1, the composition ratio of prepared fuels is presented.

Table 1. Fuel blends

Fuel blends	Gasoline %	Ethanol%	n-Butanol%
G100	100	0	0
G85E5B10	85	5	10
G85E10B5	85	10	5
G75E15B10	75	15	10
G75E10B15	75	10	15
G70E15B15	70	15	15

Engine Test Setup

A water-cooled, four-cylinder gasoline engine coupled to a dynamometer available in the Thermodynamics Laboratory of the Technical Engineering Faculty of Bu-Ali Sina University was used to conduct experiments (Figure 1). To measure the torque, inlet and outlet water temperature and exhaust temperature, a PLINT dynamometer coupled to biofuels, the engine manufactured by the Ford factory in Germany was used.

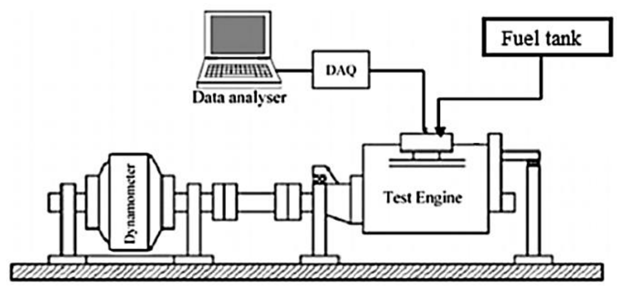

Fig 1. Schematic diagram of engine set up

Energy balance calculation

In order to determine the energy balance in the engine, a control volume around it must be taken into account. The steady flow for this control volume, as per the first law of thermodynamics, is as follows (Shadidi et al., 2017):

$$Q_s = P_b + Q_w + Q_{exh} + Q_{un} \quad (1)$$

where Q_s is the fuel's energy supply. It's clarified by:

$$Q_s = \dot{m}_f + Q_{LHV} \quad (2)$$

where $\dot{m}_f$ and Q_{LHV} stand for the fuel's mass flow rate and lower calorific value, respectively and P_b is the brake power, which can be computed using:

$$P_b = \frac{2*\pi*N\left(\frac{\text{rev}}{\text{s}}\right)*T(N.m)}{10^3} \quad (3)$$

where T and N stand for the torque and speed of the engine, respectively.

The following formula can be used to calculate Q_w, or the rate of heat transfer to the cooling system:

$$Q_w = \dot{m}_w \times C_w \times (T_2 - T_1) \quad (4)$$

where $(T_2 - T_1)$ is the temperature differential between the cooling water input and output, and $\dot{m}_w$ and C_w are the mass flow rate and specific heat of the cooling water, respectively.

The heat loss from exhaust is Q_{exh}. It is computed by taking into account the amount of heat required to raise the temperature of the entire mass (fuel + air) from ambient circumstances (T_a) to exhaust temperature (T_g). The mean specific heat of the exhaust gases (C_e), which is the specific heat of air at the mean exhaust gas temperature in this instance, must be calculated. The following formula is used to calculate exhaust heat loss:

$$Q_{exh} = (\dot{m}_f + \dot{m}_w) \times C_e \times (T_g - T_a) \quad (5)$$

Q_{un} is the unaccounted heat loss, which includes radiation and convection from the engine's external surface along with any heat rejected into the oil (if applicable). The subtraction rule can be used to determine the unaccounted heat loss:

$$Q_{un} = Q_s - (P_b + Q_w + Q_{exh}) \quad (6)$$

RESULTS AND DISCUSSION

Calculations related to engine energy balance including braking power, heat transfer to cooling system, exhaust heat loss and unaccounted heat loss were performed on gasoline engine at three speeds of 1000, 1500 and 2000.

The engine brake power of various fuel blends at various engine speeds is displayed in Figure 2. At 1000, 1500, and 2000 rpm, Figure 2 demonstrates that the engine brake power increased when bio-alcohols were added to the fuel blends in comparison to pure gasoline. The greatest value of 47.1 kW was attained at 2000 rpm with G70E15B15 fuel. It can also be concluded that by increasing the engine speed in fuel blends, the engine brake power has increased significantly. Khoshkname et al. (2022) have shown that the increase in braking power in fuel blends can be attributed to the presence of excess oxygen molecules in ethanol and butanol alcohols, which causes complete combustion of the fuel inside the cylinder.

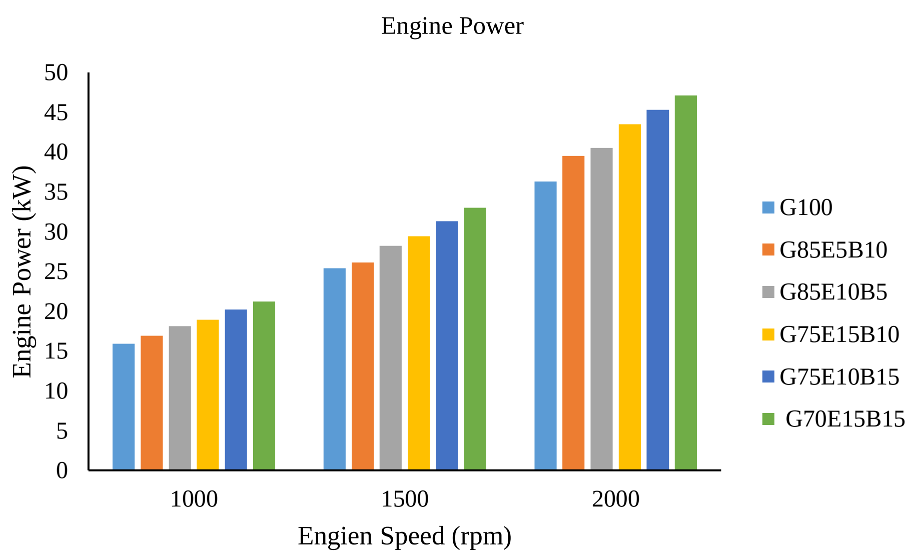

Fig 2. Engine power

Figure 3 shows the heat transfer to the engine cooling system. According to the figure3, pure gasoline fuel had lower heat transfer to the cooling system than other fuel blends, and cooling system heat loss increased with increasing engine speed from 1000 to 2000 rpm. On the other hand, it can be concluded that the amount of heat loss of the cooling system of the gasoline-ethanol-n-butanol fuel blends increased significantly with the increase in engine speed, and the highest was the G70E15B15 fuel at 1000 rpm. This increase can be considered due to the increase in the temperature of the combustion chamber at higher engine speeds, which causes a higher temperature in the cylinder, and the impact of the cooling air on the engine causes its temperature to rise and the cooling loss to increase compared to the low speeds of the engine (Shadidi et al., 2017).

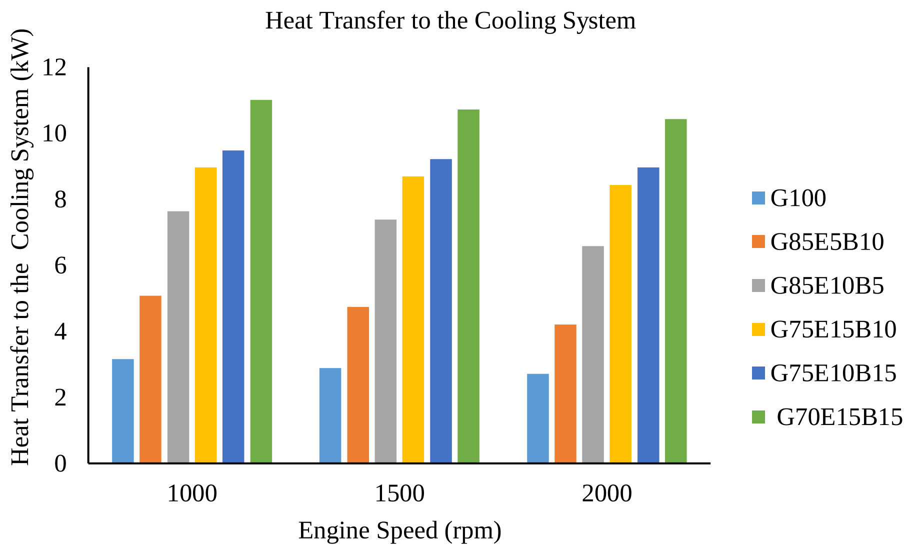

Fig 3. Heat transfer to the cooling system

According to Figure 4, pure gasoline at a speed of 1000 rpm had the lowest amount of exhaust heat loss compared to other fuel blends. As the engine speed increased, the exhaust heat loss increased. G70E15B15 fuel had more exhaust heat loss than other fuel blends. This loss naturally increased with increasing engine speed and reached its highest level at 2000 rpm. An increase in the temperature of the combustion chamber at higher speeds, as well as the presence of more ethanol and n-butanol in the fuel mixture can increase exhaust heat losses (Gnanamoorthi & Devaradjane, 2015; Shadidi et al., 2017).

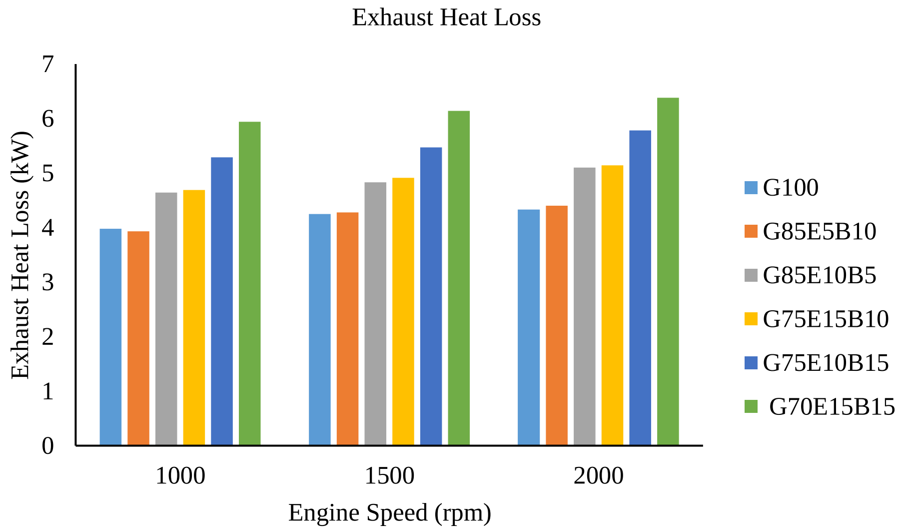

Fig 4. Exhaust Heat Loss

Figure 5 shows that the amount of unaccounted heat loss in pure gasoline fuel decreased with increasing engine speed, and it had the highest value at 1000 rpm. Also, in other fuel blends, as the engine speed increased, according to equation 6, with the increase of brake power, heat transfer to the cooling system and exhaust heat loss, the unaccounted heat loss of all fuel blends decreased and reached the lowest level in fuel G70E15B15 fuel blend (1.99 kW).

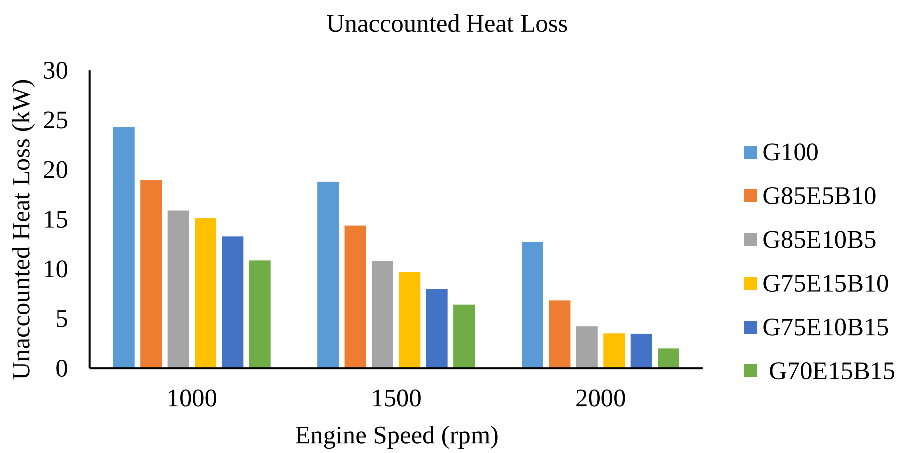

Fig 5. Unaccounted heat loss

Figures 6 to 8 show the energy balance of the engine at the three different engine speed using the gasoline-ethanol-n-butanol fuel blends.

According to Figure 6, it can be seen that at a speed of 1000 rpm, the engine brake power of the engine increased with the increase in the percentage of ethanol and n-butanol alcohols and reached the highest value in G70E15B15 fuel blend that the amount of alcohol used was the maximum, and pure gasoline had the lowest engine brake power at engine speed of 1000 rpm. The fuel blends G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 had 15.9, 16.7, 18, 18.8, 20.1 and 21.3 kW engine brake power at 1000 rpm, respectively. Heat transfer to the engine cooling system at 1000 rpm for pure gasoline was 3.16 kW, which was lower than other fuel blends, that means, the presence of alcohols in the fuel blend increases the heat transfers to system cooling. The heat transfers to cooling system in G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 fuels were 5.08, 7.64, 8.96, 9.48 and 11.01 kW, respectively. The exhaust heat loss increased with the addition of bio-alcohols in the fuel blends, the reason for this can be the increase in the presence of hydrocarbons in the structure of alcohols (the heat of combustion of each alcohol depends on the number of hydrocarbons in the molecular formula of the alcohol molecule. The higher the number of hydrocarbons per alcohol molecule, the higher is the heat of combustion), and the highest amount of exhaust heat loss was reported in G70E15B15 fuel blend, which was 5.94 kW. The unaccounted heat loss decreased at engine speed of 1000 rpm. The presence of alcohols in fuel blends causes the reduction of unaccounted heat loss. G70E15B15 fuel with the highest amount of alcohol had the lowest unaccounted heat loss amounting to 10.81 kW, and G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 fuel blends had 23.44, 19.21, 16.24, 15.21, 13.48 and 10.81 kW respectively.

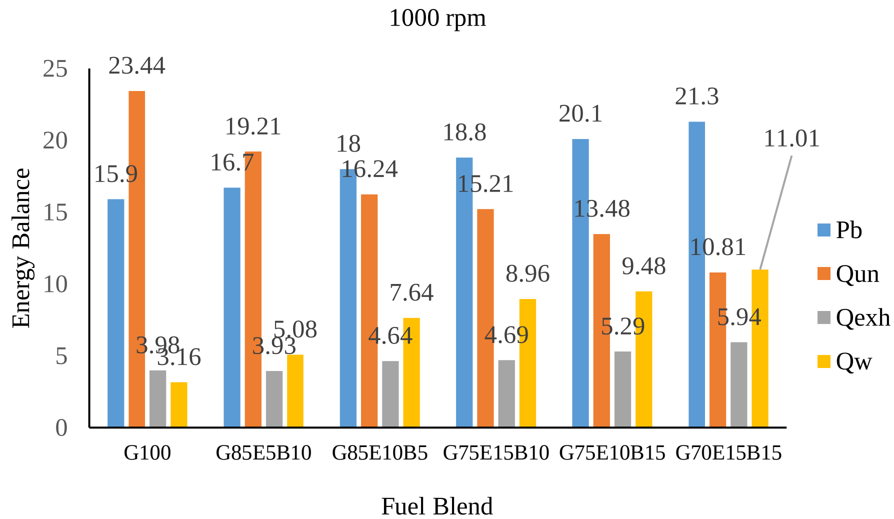

Fig 6. Engine energy balance at 1000 rpm

The engine brake power at engine speed of 1500 rpm for pure gasoline was 25.1 kW, and by increasing the percentage of ethanol and n-butanol in the fuel blends, the brake power increased, and G70E15B15 had the highest engine brake power (Figure 7). The engine brake power of G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 fuel blends was 25.1, 26.2, 28.2, 29.6, 31.4 and 33 kW, respectively. Heat transfer to the engine cooling system at engine speed of 1500 rpm in pure gasoline fuel was 3.16 kW, which had the lowest value compared to other fuel blends. According to Figure 7, the fuel blend G70E15B15, which had the highest amount of alcohol, had the highest heat transfer to the cooling system, and for the fuel blends G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15, was reported 2.89, 4.74, 7.38, 8.69, 9.22 and 10.72 kW respectively. By increasing the amount of alcohol in the fuel blends at the speed of 1500 rpm, the exhaust heat loss increased. The amount of exhaust heat loss at 1500 rpm for G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 fuel blends was 4.25, 4.28, 4.83, 4.91, 5.47, 6.14 kW, respectively. The amount of unaccounted heat loss in pure gasoline fuel had the highest value compared to other fuel blends, and with the addition of ethanol and n-butanol to gasoline, the unaccounted heat loss has increased.

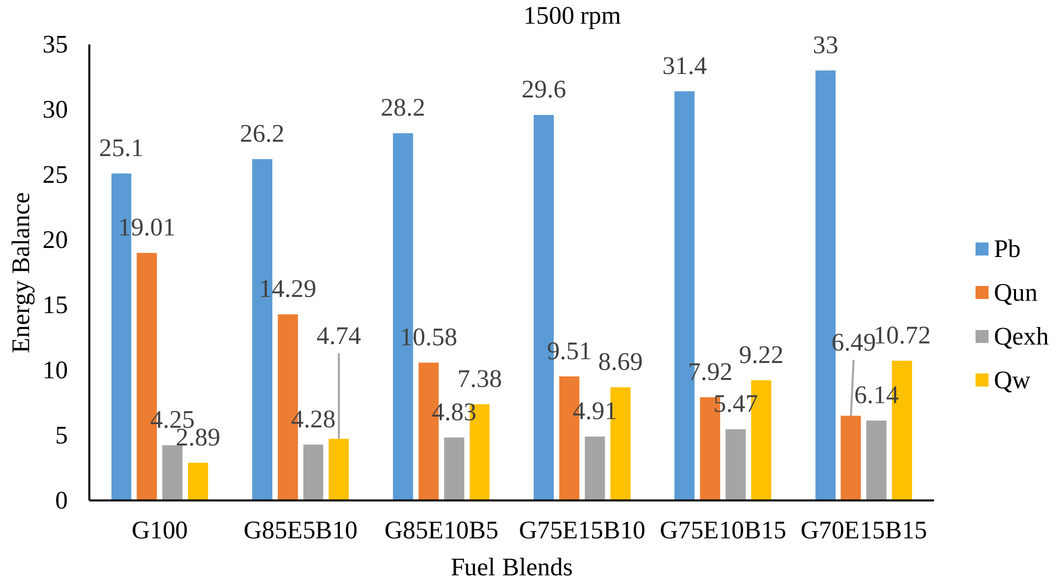

Fig 7. Engine energy balance at 1500 rpm

Figure 8 shows that the engine brake power of G70E15B15 fuel blend had the highest engine brake power of 47.2 kW. Engine brake power in fuel blends G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 was reported as 36.5, 39.3, 40.7, 43.5, 45.4, 47.2 kW respectively. By increasing the percentage of alcohols in fuel blends, heat transfer to the engine cooling system increased. Heat transfer to the cooling system for G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 fuel blends was reported as 2.89, 3.21, 6.58, 8.43, 8.96 and 10.43 kW, respectively. G100 fuel had the lowest amount of exhaust heat loss compared to other fuel blends. The increase of alcohol in the fuel blends caused the increase in exhaust heat loss. The amount of exhaust heat loss at 2000 rpm for G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 fuels was 4.33, 4.4, 5.1, 5.41, 5.78 and 6.38 kW, respectively. The unaccounted heat loss in the engine decreased with the increase of bio-alcohols in gasoline according to Figure 8. The unaccounted heat loss in pure gasoline fuel has the highest rate compared to other fuel blends, and the lowest unaccounted loss was related to G70E15B15 fuel blend (1.72 kW). The unaccounted heat loss of G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15 fuel blends was reported 12.3, 7.03, 4.01, 3.25, 2.28, 1.72 kW, respectively.

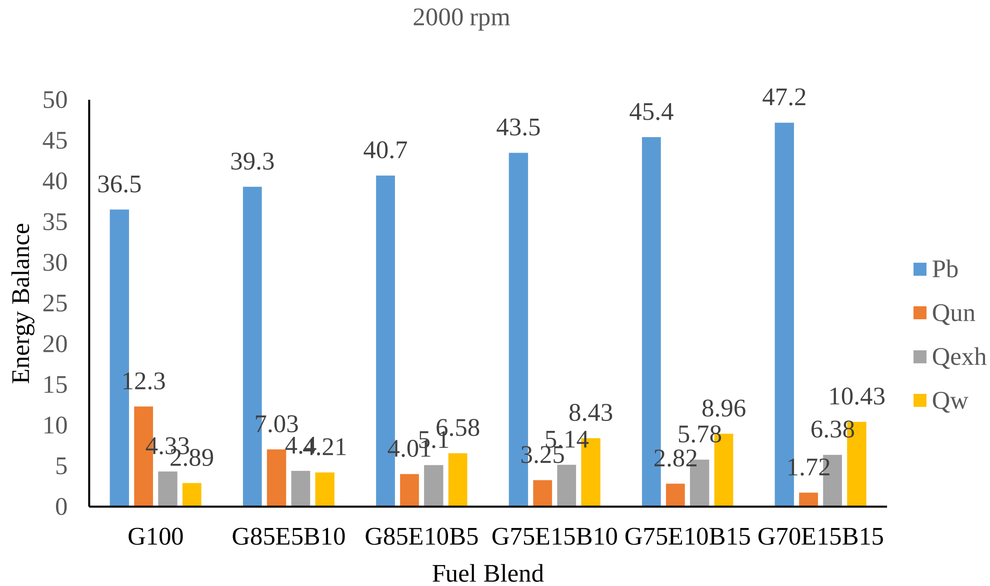

Fig 8. Engine energy balance at 2000 rpm

CONCLUSION

In this research, the energy balance of a water-cooled, four-cylinder gasoline engine using gasoline-ethanol-n-butanol fuel blends (G100, G85E5B10, G85E10B5, G75E15B10, G75E10B15 and G70E15B15) at engine speeds of 1000, 1500 and 2000 rpm was investigated and the following results were obtained:

1- The engine brake power increased with the increase in the percentage of alcohols in the fuel blends. The highest brake power was related to G70E15B15 fuel blend, which was obtained at 1.47 kW at 2000 rpm. Increasing the engine speed from 1000 to 2000 rpm increased the engine brake power. The increase in engine brake power in fuel blends containing alcohol can be attributed to the presence of additional oxygen molecules in ethanol and n-butanol.

2- As the engine speed increased, the amount of exhaust heat loss increased, and G70E15B15 fuel had the highest exhaust heat loss. The presence of ethanol and n-butanol in the fuel increased exhaust heat loss.

3- Heat transfer to the cooling system increased with increasing engine speed from 1000 to 2000 rpm. Also, the presence of ethanol and n-butanol alcohols caused an increase in heat loss of cooling system, and the highest amount related to G70E15B15 fuel blend was 11.01 kW at 1000 rpm. Due to the increase in temperature in the combustion chamber, heat loss of cooling system increased.

4- The unaccounted heat loss decreased by increasing the engine speed and by adding bio-alcohols to the fuel blends and reached its lowest level (1.99 kW) in G70E15B15 fuel blend at 2000 rpm.

REFERENCES

Gnanamoorthi, V., & Devaradjane, G. (2015). Effect of compression ratio on the performance, combustion and emission of DI diesel engine fueled with ethanol–Diesel blend. *Journal of the energy institute*, *88*(1), 19-26. https://doi.org/10.1016/j.joei.2014.06.001

Khoobbakht, G., Akram, A., Karimi, M., & Najafi, G. (2016). Exergy and energy analysis of combustion of blended levels of biodiesel, ethanol and diesel fuel in a DI diesel engine. *Applied Thermal Engineering*, *99*, 720-729. https://doi.org/10.1016/j.applthermaleng.2016.01.022

Khoshkname, D., Haji Agha Alizade, H., & Shadidi, B. (2022). Investigating the Effect of Using of Different Alcohols as Gasoline Additives on an Engine Emitted Pollutants. *Biomechanism and Bioenergy Research*, *1*(2), 21-25. 10.22103/BBR.2022.20415.1018

Kiani Deh Kiani, M., Ghobadian, B., Ommi, F., Najafi, G., & Yusaf, T. (2012). Artificial neural networks approach for the prediction of thermal balance of SI engine using ethanol-gasoline blends. Multidisciplinary Research and Practice for Information Systems: IFIP WG 8.4, 8.9/TC 5 International Cross-Domain Conference and Workshop on Availability, Reliability, and Security, CD-ARES 2012, Prague, Czech Republic, August 20-24, 2012. Proceedings 7, https://doi.org/10.1007/978-3-642-32498-7_3

Lapuerta, M., Ballesteros, R., & Barba, J. (2017). Strategies to introduce n-butanol in gasoline blends. *Sustainability*, *9*(4), 589. https://doi.org/10.3390/su9040589

Masum, B., Masjuki, H., Kalam, M., Palash, S., Wakil, M., & Imtenan, S. (2014). Tailoring the key fuel properties using different alcohols (C2–C6) and their evaluation in gasoline engine. *Energy Conversion and Management*, *88*, 382-390. https://doi.org/10.1016/j.enconman.2014.08.050

N Shirvan, H., Chitsaz, I., Amani, E., Abdolmaleki, S., & Parivar, A. (2022). Energy balance on a three-cylinder engine with turbocharger. *Engine Research*, *49*(49), 29-38.

Qasemian, A., Haghparast, S. J., Azarikhah, P., & Babaie, M. (2021). Effects of compression ratio of bio-fueled SI engines on the thermal balance and waste heat recovery potential. *Sustainability*, *13*(11), 5921. https://doi.org/10.3390/su13115921

Shadidi, B., Haji Agha Alizade, H., & Ghobadian, B. (2017). The effect of a novel hybrid nano-catalyst in diesel-biodiesel fuel blends on the energy balance of a diesel engine. *Energy Equipment and Systems*, *5*(1), 59-69. https://doi.org/10.22059/EES.2017.24720

Shadidi, B., Najafi, G., & Yusaf, T. (2021). A Review of Hydrogen as a Fuel in Internal Combustion Engines. Energies 2021, 14, 6209. In: s Note: MDPI stays neutral with regard to jurisdictional claims in published ….https://doi.org/10.3390/en14196209

Shirazi, S. A., Foust, T. D., & Reardon, K. F. (2020). Identification of Promising Alternative Mono-Alcohol Fuel Blend Components for Spark Ignition Engines. *Energies*, *13*(8), 1955. https://doi.org/10.3390/en13081955

Uyumaz, A. (2015). An experimental investigation into combustion and performance characteristics of an HCCI gasoline engine fueled with n-heptane, isopropanol and n-butanol fuel blends at different inlet air temperatures. *Energy Conversion and Management*, *98*, 199-207. https://doi.org/10.1016/j.enconman.2015.03.043

Vairamuthua, G., Kailasanathana, S. S. C., & Thangagiric, B. (2015). Investigation on the Effects of nanocerium oxide on the performance of CalophyllumInophyllum (punnai) biodiesel in a DI diesel engine. *Journal of Chemical and Pharmaceutical Sciences www. jchps. com ISSN*, *974*, 2115.

Yüksel, F., & Ceviz, M. (2003). Thermal balance of a four stroke SI engine operating on hydrogen as a supplementary fuel. *Energy*, *28*(11), 1069-1080. https://doi.org/10.1016/S0360-5442(03)00090-2

Yusri, I., Mamat, R., Azmi, W., Najafi, G., Sidik, N., & Awad, O. I. (2016). Experimental investigation of combustion, emissions and thermal balance of secondary butyl alcohol-gasoline blends in a spark ignition engine. *Energy Conversion and Management*, *123*, 1-14. https://doi.org/10.1016/j.enconman.2016.05.082