



Experimental Investigation on the Effect of Adding Butanone to Gasoline in SI Engine Emissions and Performance

Abed Al-Khadhim M. Hassan *, Sadeq A. Jassam

Mechanical Engineering Dept., University of Technology, Baghdad-Iraq, Alsina'a street, 10066 Baghdad, Iraq.

*Corresponding author Email: Abdulkadhim.m.hadi@uotechnology.edu.iq

HIGHLIGHTS

- Adding of ketones affect the physical properties of gasoline.
- the density changed from (710 kg/m³) for net gasoline to (724 kg/m³) for butanone at adding ratio of (9%).
- The addition of ketones improves the emissions characteristic of engine. The best reduction of (UHC, CO₂, CO and NO_x) was (47.51, 24.9, 27.35 and 35.91%) recorded by butanone addition at ratio of (9%).

ARTICLE INFO

Handling editor: Muhsin J. Jweeg

Keywords:

Ketone
Butanone
Emissions
Performance
Gasoline

ABSTRACT

This research is performed to study and investigate the influence of adding some ketone compounds on performance, emissions, and heat balance of spark ignition engine. The compound used in this study is butanone (C₄H₈O). The importance of the research lies in increasing the octane number by adding specific percentages of butanone and showing its impact on improving the combustion process, performance and reducing pollutants. This ketone has been added to the basic fuel (gasoline) with three concentration ranges (3, 6 and 9%), respectively. All experimental tests were carried out on gasoline engine type (Nissan QG18DE), four cylinders, and 4-stroke. The acquired results showed that adding of ketones affects the physical properties of gasoline, where the density changed from (710 kg/m³) for net gasoline to (724 kg/m³) for butanone at an adding ratio of (9%). The octane number also increased for all types of ketones compared with pure fuel, and it will be improved from (86) for pure gasoline to (93.1) for butanone at an adding ratio of (9%). While the calorific value will be decreased from (43000 kJ/kg) for gasoline to (41665.44) for butanone at an adding ratio of (9%). The addition of ketones improves the emissions characteristic of the engine. The best reductions of (UHC, CO₂, CO and NO_x) were (47.51, 24.9, 27.35 and 35.91%), respectively recorded by butanone addition at a ratio of (9%). In the case of performance, the best increments of brake power, brake thermal efficiency and volumetric efficiency were (14.5, 7, 14.94 and 11.64%), respectively, which is achieved by adding (9%) of butanone.

1. Introduction

The importance of the research lies in increasing the octane number by adding specific percentages of butanone and showing its impact on improving the combustion process, performance and reducing pollutants. The performance levels of any engine depend on some key factors, among which is to focus on the performance of brake power, brake specific fuel consumption, brake thermal efficiency, air to fuel ratio, and engine speed. Most importantly is the type of the fuel used, which is considered to be one of the most important indicators that affect the engine's performance [1, 2]. Also, the enormous increase in environmental pollution caused by combustion processes makes it essential that solutions are required for their reduction. This problem is caused by the exhaust emission from the internal-combustion engines and other combustion systems. The reactions that occur in the engine's combustion process not only produce substances such as CO₂, H₂O and N₂, but also produce various pollutants which are found in the engine exhaust. The three main pollutants which are subject to exhaust emission legislation are carbon monoxide (CO), unburned hydrocarbons (HC) and nitrogen oxides (NO_x) [3, 4]. With the aim of improving the quality of the fuel in order to obtain its best performance levels and also decrease the emissions, there must be a focus on the improvements of the Octane number which can be improved by adding especial additives. The fuel additives are chemicals added to fuel in small quantities in order to enhance its performance or to add properties that were not present in the base fuel. One of fuel additive types which can be used is ketones [5]. Raid Rashid Jasper et al. [6] investigated the effect of traditional additive fuel on the performance of spark ignition engine. Three types of fuel additives were used, these additives are (gasoline additive, Gema and T-max) that were added to pure fuel as a volumetric ratio (1/6, 1/7.1 and 1/8), respectively. The results showed that the engine performance increases by using the traditional additive, where the brake power increases by

(23%, 18%, and 12.6%) by using gasoline blending, also it increases the brake thermal efficiency, where the maximum for (T-max) was approximately (8%) and the minimum for (gasoline additive) was about (3.7%). The study showed that enhancement in the brake specific fuel consumption for (T-max, Gema, and gasoline additive) was by (5%, 2%, and 1%), respectively compared to pure fuel. Ashraf Elsakany, [7] formed new blended fuels by adding (3–10 vol. %) of acetone into a regular gasoline. The blended fuels were tested for their energy efficiencies and pollutant emissions using SI (spark-ignition) engine with single-cylinder and 4-stroke. The engine was operated with each blend at (2600–3500) r/min. Experimental results showed that the AC3 (3 vol. % acetone + 97 vol. % gasoline) blended fuel has an advantage over the neat gasoline in exhaust gases temperature, in-cylinder pressure, brake power, torque and volumetric efficiency by about (0.8%, 2.3%, 1.3%, 0.45% and 0.9%), respectively. Ashraf Elfasakhany [8] mixed and examined renewable bioethanol and bio-acetone as new fuel for the SI engine for the first time. Three different blend rates were applied (3, 7, and 10 vol% of dual bio-acetone and bioethanol in gasoline) and compared with each other and the pure gasoline. The results showed a rate of (10 vol% of bioethanol and bioacetone in gasoline) introduced the greatest volumetric efficiency, brake power, output torque, and the lowest CO and UHC emissions, compared to other fuel blends and pure gasoline. Besides, all fuel blends showed higher performance and lower emissions compared to the pure gasoline.

Qijun Tang et al. (2020) [9] firstly mixed the acetone, butanol and ethanol (ABE) with the pure gasoline to make the different sample fuels (referred to as ABE10, ABE20, and ABE30). The results indicated that the high-speed SI engine fuelled with ABE30 boasted the largest power, and followed by ABE20 and ABE10, while the pure gasoline generated the lowest output power.

Yuanxu Li [10] used various acetone-gasoline blends such as A10, A20, and A19.5W0.5 (19.5 vol.% acetone and 0.5 vol.% water and 80 vol.% gasoline) and A19W1 (19 vol.% acetone and 1 vol.% water and 80 vol.% gasoline) as fuels in a port-fuel injection (PFI) spark ignition (SI) engine. The performance of the tested fuels was compared with that of G100 (gasoline) under various equivalence ratios (ϕ) from 0.83 to 1.25 and at engine loads of 3 and 5 bar (bmep). The results showed that A19W1 generally had higher brake thermal efficiency, and lower carbon monoxide (CO), nitrogen oxide (NO_x) and BTEX (Benzene, Toluene, Methylbenzene, and Xylene) than those of other test fuels. Therefore, water containing acetone-gasoline blends could be used as a good alternative fuel due to the improvement of engine performance and reduction of emissions.

2. Experimental apparatuses

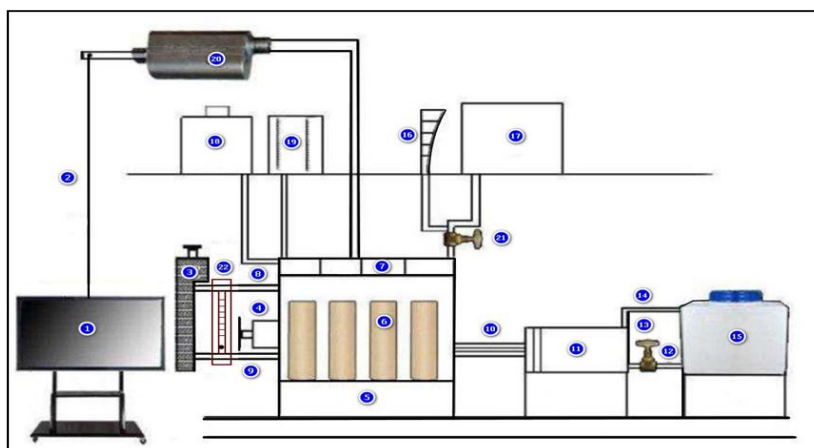
A study is conducted to understand the influence of adding butanone to gasoline fuel on both engine performance and emission characteristics. We studied the way by which butanone is blended with gasoline in addition to the type of machine used in this experiment as well as the test procedure using three concentrations of (3, 6, and 9%). The engine used in the experimental tests is Nissan QG18DE gasoline engine, four cylinders, 4-stroke, direct injection, natural aspirated in-line, closed water-cooled cycle with a displacement volume of (1.8 L) and fitted with a hydraulic dynamometer. The engine has a cast-iron cylinder block, cylinder bore is (80.0 mm) and the piston stroke is (88.0 mm). All experimental tests were conducted in the University of Technology (The Mechanical Engineering Department). The test engine with its equipment are shown in Figure 1. The specifications of the test engine are given in Table 1. The schematic diagram of the experimental set up is shown in Figure 2 and the definition of the parts of the system is shown in Table 2. The properties of pure and blended fuel were all examined and the results were listed in Table 3.



Figure 1: The test engine

Table 1: Tested engine specifications [11]

Manufacture	Nissan (Aguascalientes, Yokohama, Atusta Plant)
Mark	QG18DE
Fuel type	Gasoline
Fuel system	Multi point fuel injection (MFI)
Cylinder alloy	Cast iron
Engine type	Four stroke, Inline-4 (straight-4)
Displacement	1.8 liter
Engine oil capacity	2.7 L
Power	85.3 – 94 kW
Torque moment	163-176 Nm (at 2800 rpm)
Cylinder bore	80mm
Piston stroke	88mm
Compression ratio	9.5:1
Intake valve	30.2mm
Exhaust valve diameter	25.2mm
Number of main bearing	5

**Figure 2:** Schematic diagram of the experimental set up**Table 2:** Definition of the parts of the system in the figure above

1	Gas analyzer	12	Inlet water to the dynamometer
2	Prop of gas analyzer	13	The valve of water tank
3	Radiator	14	outlet water from dynamometer
4	Engine fan	15	Water tank
5	The test engine	16	Fuel consumption meter
6	Cylinders of engine	17	Fuel tank
7	Cylinder head	18	Air surge tank
8	outlet water from engine	19	Manometer
9	Inlet water to engine	20	Silencer
10	cop lent link	21	The valve of the fuel tank
11	Hydraulic dynamometer	22	Flow meter

Table 3: Physical properties of blends (ketone + fuel)

Sample name	Calorific value(kJ/kg)	Density (kg/m ³)	Viscosity mpa.s	Octane number at 16.5 C ⁰
Gasoline (pure fuel)	43000	710	0.551	86
3% butanone+ 97% gasoline	42535.64	714.949	0.548	90.5
6% butanone+ 94% gasoline	42091.228	719.5	0.587	93.1
9% butanone+ 91% gasoline	41665.44	724	0.554	95.6

3. Results and Discussion

3.1 Physical properties of fuel

3.1.1 Density

The effect of types of butanone and doses level on the density of gasoline fuel is shown in Figure 3. The figure shows that the density of gasoline fuel increases with increasing the doses level of butanone for all cases, where the highest increase was at (9%). Because the dose density is higher than that of pure fuel.

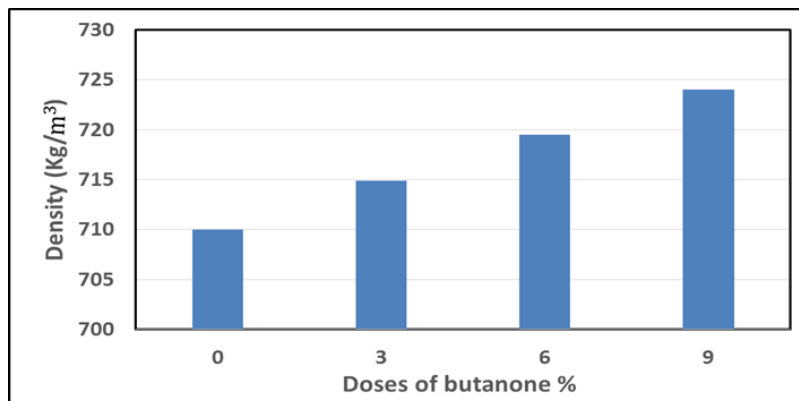


Figure 3: Variation of density with butanone doses

3.1.2 Calorific value

The influence of the types of butanone and doses level on the calorific value of gasoline fuel is shown in Figure 4. The figure reveals that the calorific value of gasoline fuel decrease with increasing the dosing level of butanone for this type.

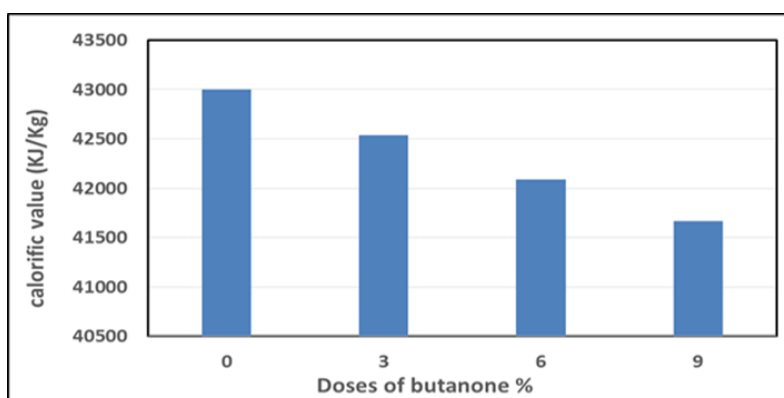


Figure 4: Variation of calorific value with butanone doses

3.1.3 Viscosity

The effect of the types of butanone and doses level on the viscosity of gasoline fuel is shown in Figure 5. The figure shows that the viscosity of gasoline fuel increases with increasing the doses level of butanone. The maximum value of viscosity for the other dose with butanone at (6%) is (0.587 mPa.s).

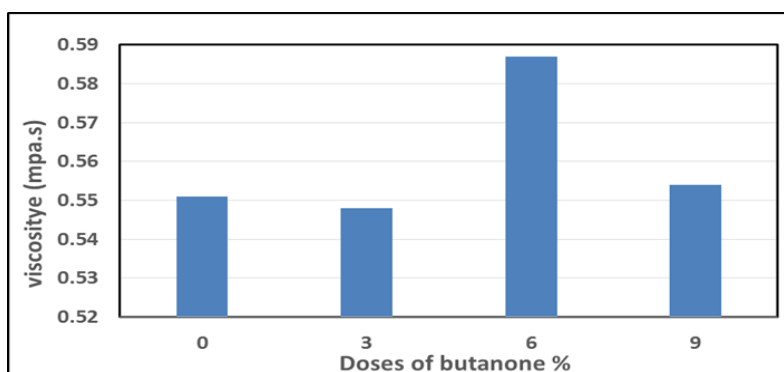


Figure 5: Variation of viscosity with butanone doses

3.1.4 Octane number

The effect of butanone type with different doses levels on the octane number of gasoline fuel is shown in Figure 6. The octane number of gasoline fuel increases with increasing the doses level of butanone for this type. The increase of the octane number becomes very clear at a dosage of (9%). Because of this dose, the characteristics of fuel improved more than other dosages.

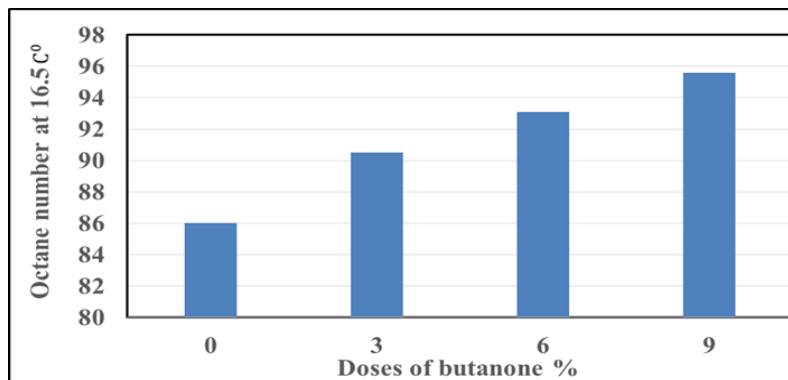


Figure 6: Variation of octane number with butanone doses

3.2 Performance of the engine

3.2.1 Brake power (B.p)

Brake power can be defined as the power available at the crankshaft. Therefore, it does depend mainly on engine speed, as it increases with increasing this speed. Figure 7 shows this relationship between engine speed and brake power for pure fuel and for butanone blends with three doses of (3, 6, and 9%), whereas it's clear that the increase is almost linear with respect to the brake power. Also, it was noticed that the addition of butanone to the pure fuel leads to increase the value of brake power, where the percentage of average value of brake power increased by (8.74, 11.87 and 14.5%) for three doses of (3, 6 and 9%), respectively. This increase is due to several reasons, including increasing the hydrogen and oxygen levels in blends, which will lead to increase the combustion process speed. This, in turn, will ensure more efficient burning of the blend fuel. Also, with blends (butanone + gasoline), the octane number will be increased and this means that there is more pressure that the fuel withstands before detonating.

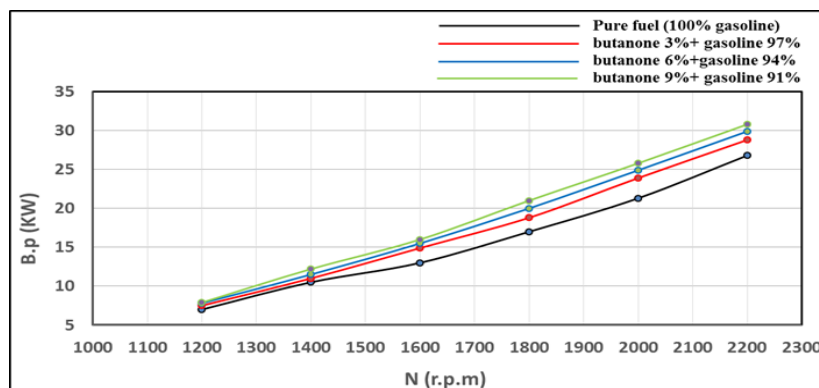


Figure 7: Variation of brake power with engine speed

3.2.2 Brake specific fuel consumption (b.s.f.c)

The (b.s.f.c) is fuel amount consumed for obtaining of unit power. It is one of the most important performance parameters that can be used for performance comparisons of different fuels. Figure 8 shows the brake specific fuel consumption with variable speeds of engine at pure fuel and at various additive concentrations of butanone. It was noticed that the values of (b.s.f.c) will be decreased by (5.1, 6.7 and 7.4%) at the addition of butanone for different doses. This is due to the increase in the rates of oxygen that leads to maximum utilization of the calorific value and the energy released.

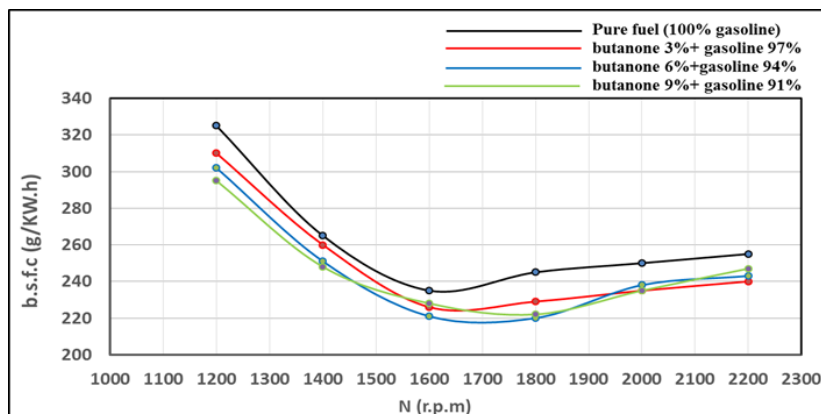


Figure 8: Variation of (b.s.f.c) with engine speed

3.2.3 Brake thermal efficiency ($\eta_{B.Th.}$)

Brake thermal efficiency with several speeds of engine at different mixtures of cyclohexane is presented in Figure 9. It is observed that the brake thermal efficiency improved when using butanone and increased by (2.7, 4.9 and 7%) with increasing dose ranging, respectively. This is related to the improvement in combustion due to the oxygen content in the molecules of butanone and also to the octane raising associated with the increase in percentage of butanone addition.

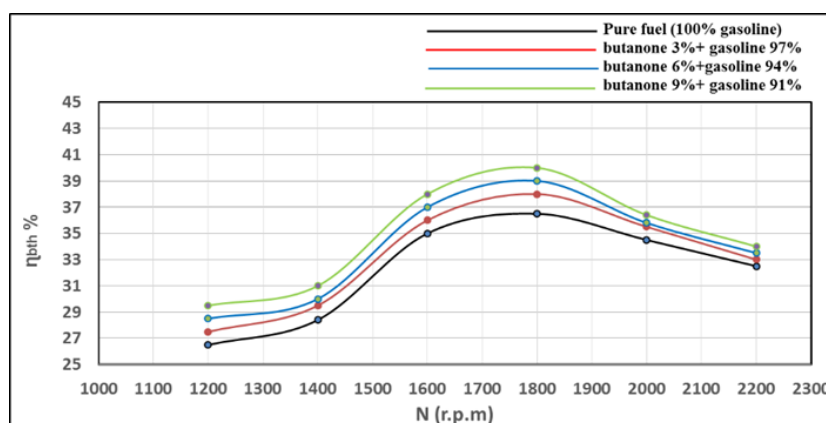


Figure 9: Variation of brake thermal efficiency with engine speed

3.2.4 Volumetric efficiency (η_v)

Volumetric efficiency is one of the most important factors of an internal combustion engine' performance because of its direct effect on combustion quality. Figure 10 shows an increase in volumetric efficiency in each mixture of butanone. The percentage average value will be increased by (3.76, 6.95 and 11.64%) by adding (3, 6 and 9%) from butanone. This is due to higher evaporation possessed by this butanone. The cooling effect of evaporation of this butanone causes the temperature at the intake manifold to be low and it increases volumetric efficiency due to increasing the inlet air density. We stated that this butanone has a higher combustion temperature than that of gasoline, and this means more evaporation heat than that of gasoline causes the intake manifold temperature to be lower and it increases volumetric efficiency.

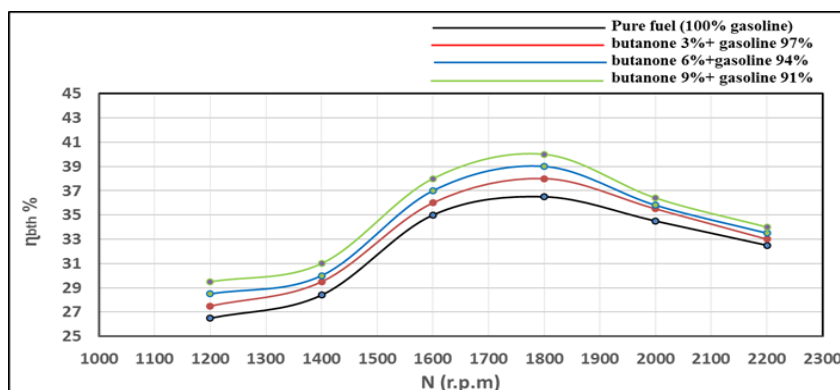


Figure 10: Variation of volumetric efficiency with engine speed

3.2.5 Brake mean effective pressure (b.m.e.p)

Figure 11 shows the increase of brake mean effective pressure when the engine speed increases for pure fuel and when adding the butanone. The behavior of these curves is similar to those in brake power because the mean effective pressure is depending on brake power, and it increases when brake power increases. The brake means effective pressure of butanone increased by (9, 12.12 and 14.94%) for (3, 6 and 9%), respectively.

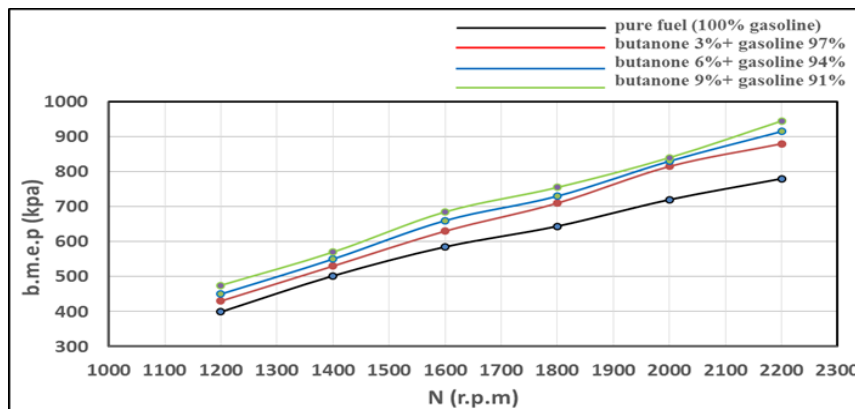


Figure 11: Variation of (b.m.e.p) with engine speed

3.3 Emissions

3.3.1 Carbone dioxin (CO_2)

Figure 12 shows the percentage average value of (CO_2) for butanone and how it is increased when the engine speed increases, but it decreases when the concentration of butanone increases. The rates of (CO_2) for three concentrations of butanone will be decreased by (37.72, 29.59 and 24.9%) by adding (3, 6 and 9%) of butanone, respectively. In the case of engine speed, the increase happens in the rated (CO_2) because the increase of temperature and pressure will lead to more rate of oxidation of blends. While there is a decrease in the average percentage of (CO_2) when using butanone, and the reason is due to complete combustion of blends because of the high content in the amount of oxygen in butanone, and this will lead to consume less amount of fuel.

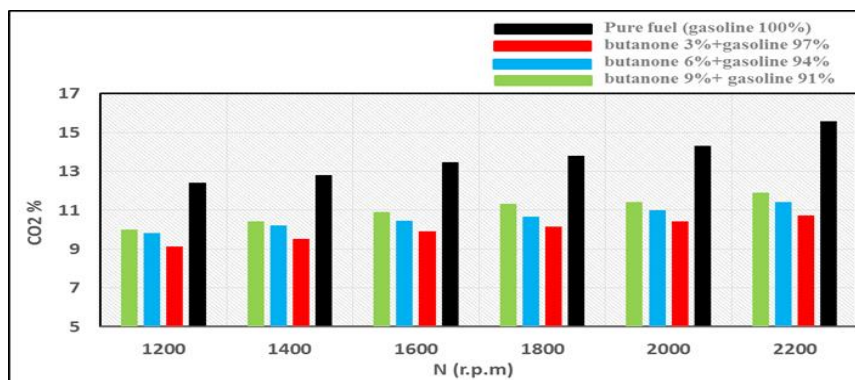


Figure 12: Variation of CO_2 emission with engine speed

3.3.2 Carbon monoxide (CO) and unborn hydrogen (UHC)

CO emission occurs due to incomplete combustion or insufficient oxygen during combustion or due dissociation of CO_2 , while the (UHC) will be formed due to unequal ratios between fuel and air and also because of incomplete combustion. Figures 13 and 14 show the (CO) and (UHC) emissions change with speed, respectively. We will record those high values noticed at low and medium speeds and it starts decreasing again at high speed. This is due to increasing the temperature of combustion chamber, leading to increase oxidation and decrease (CO) and (UHC). In addition, the decomposition of hydrocarbon in high temperature leads to decrease the (CO). In the case of blends, for butanone and when the concentration of butanone increases, the percentage average value of these emissions will be decreased. For (CO), the rates of carbon monoxide will be decreased by (14.49, 18.3 and 27.35%) for butanone. While (UHC) will be decreased by (24.45, 32.92 and 47.51%) for butanone at (3, 6 and 9%) of butanone, respectively. This reduction when using butanone is due to high rates of oxygen content in butanone compared to pure fuel and this leads to make the combustion process more complete.

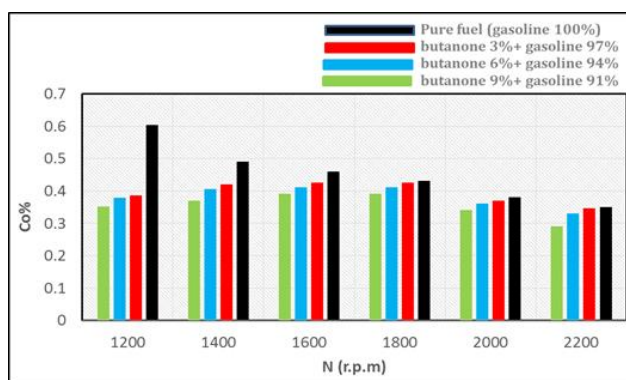


Figure 13: Variation of CO emission with engine speed

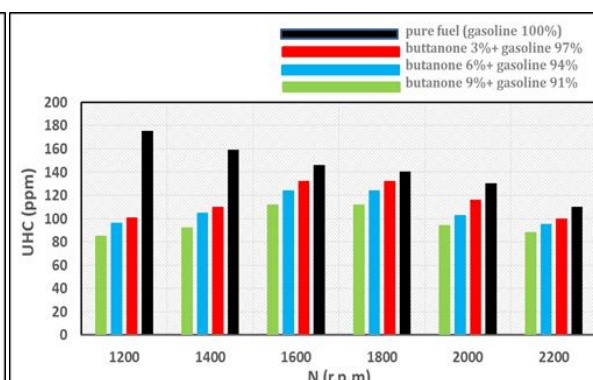


Figure 14: Variation of UHC emission with engine speed

3.3.3 Nitrogen Oxides (NO_x)

It is a compound of oxygen and nitrogen that is formed by reacting with each other during combustion at high temperatures. Figure 15 presents the variation of (NO_x) with the engine speed for the tested gasoline fuels. The largest amount of (NO_x) is usually found at a high speed of (2200 r.p.m), at which the temperature and pressure are the highest. In the case of fuel blends, the rate of (NO_x) will be decreased by (10.61, 12.54 and 35.91%) at doses (3, 6 and 9%) for butanone. This reduction rate is due to complete combustion of the blended fuel, which consumes the most oxygen in the combustion zone and reduces the chance of NO_x formation despite the temperature rise.

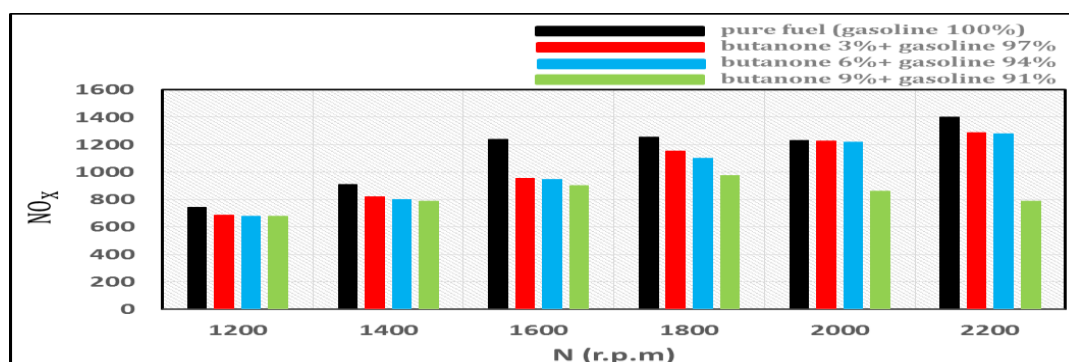


Figure 15: Variation of NO_x emission with engine speed

3.4 Heat balance

It is the distribution of the heat energy supplied to a thermo-mechanical system among the various drains, including both useful output and losses. The results of useful output and losses of heat which are obtained from the experimental test will be displayed and discussed for each butanone in the next paragraph as follows:

- Figures 16, 17A, 17B and 17C show that the heat balances beside brake power are resulted due to the combustion process for cyclohexane with concentrations of (3, 6 and 9%). It was noticed that the value of total energy supplied (Q_r) will be increased with the increase of engine speed, and the reason for this is due to increasing the rate of fuel consumption ($\dot{m}_f$) and this makes the most utilization of calorific value. In the case of blends, the (Q_r) will be increased by (5.06, 5.59 and 6.59%) when adding cyclohexane butanone.
- In the case of heat rejected to cooling water (Q_w), they will also be increased when engine speed increases due to increase the mass flow rate of water ($\dot{m}_w$) and also increase the temperature of water, which enters and exits from the engine. For the blends, the (Q_w) will be increased by (2.44 and 0.97%) for ratios of (3 and 9%) and decreased by (1.91%) for a ratio of (6%) when adding butanone.
- The heat loss to exhaust (Q_{exh}) also depends directly on engine speed. The increment rate of (Q_{exh}) returns to the increase of mass flow rate of air ($\dot{m}_a$) and mass flow rate of fuel ($\dot{m}_f$), and also due to increase the exhaust temperature. For the blends, the (Q_{exh}) will be increased by (1.79 and 1.69%) for ratios of (3 and 9%) and decreased by (1.11%) for a ratio of (6%) for butanone. Because of the increase in the exhaust temperature.
- The unaccountable heat loss (Q_{un}), which is considered as a heat loss due to heat transfer, friction power, and operation of axillary devices (Q_t), will increase with increasing the engine speed. It will be increased by (5.57, 17.85 and 2.07%) for ratios of (3, 6 and 9%) of butanone.

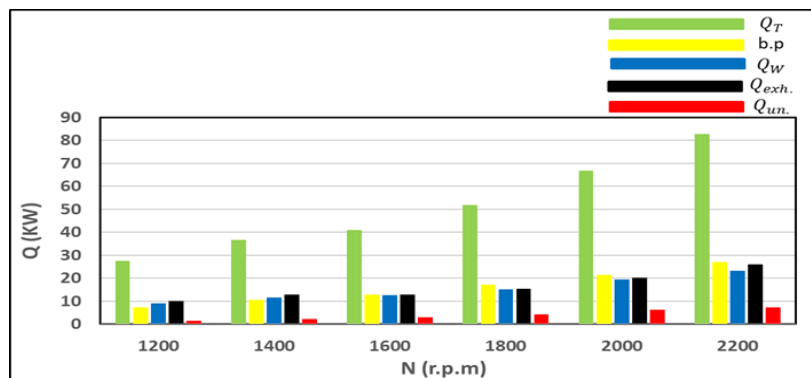
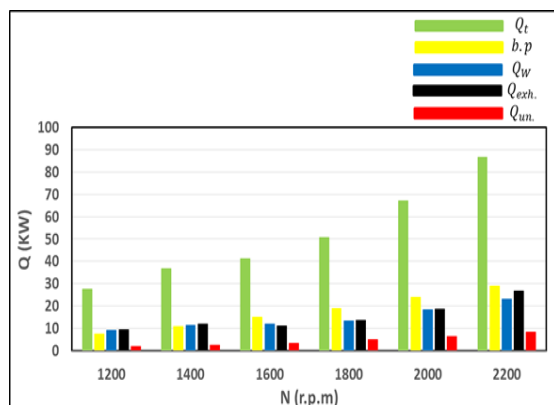
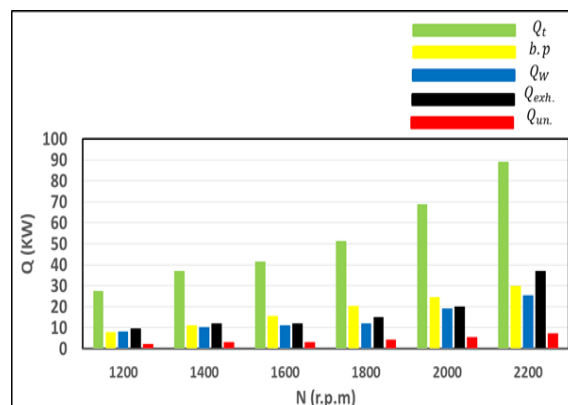


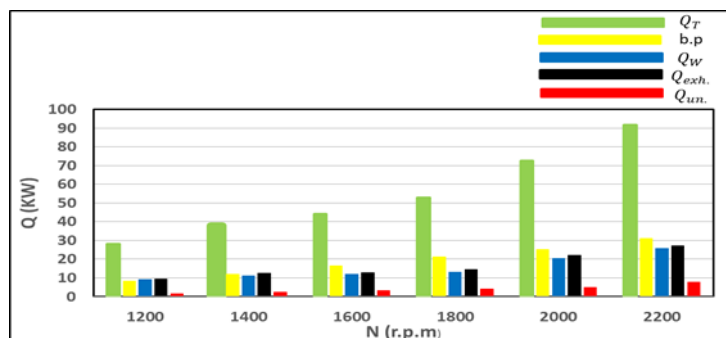
Figure 16: Variation of heat balance with engine speed for pure fuel



(A) (3%) butanone



(B) (6%) butanone



(C) (9%) butanone

Figure 17: Variation of heat balance with engine speed for butanone

3.5 Exhaust gas temperature

Figure 18 shows the variation of exhaust gas temperature with the engine speed for the tested gasoline fuels and blends for butanone type for the whole range of engine speed. The results demonstrated that the exhaust gas temperatures increased with increasing the engine speeds for pure fuel and also for blends. From the results, it was noticed that the exhaust temperature for blends will be higher compared with pure fuel. It will be increased by (4.92, 11.79 and 23.63%) for butanone at (3, 6 and 9%), respectively. This is due to the increase in the octane number of the blended fuels which lead to more efficient combustion associated with rising of combustion temperature. The increment in exhaust temperature is also due to the enhancement in the combustion process and increases in the oxidation process of carbon and oxygen.

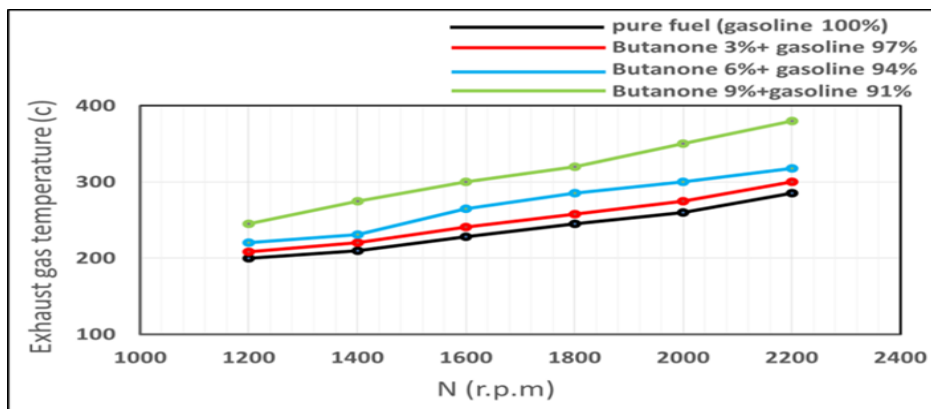


Figure 18: Variation of exhaust temperature with engine speed

4. Conclusions

Researchers proposed several alternatives for replacing gasoline fuel in spark ignition engines. In this work, a systematic study aiming to compare and evaluate the performance and environmental behavior of these alternatives was conducted to help recommending the next generation of alternatives in automobiles. This study focused on the effect of using fuel additives (butanone) on the performance and emissions of the SI engine. The butanone with three concentrations of (3, 6 and 9%) were used to improve the engine performance, reduce the emissions resulted from the combustion process and enhance the physical properties of gasoline fuel. The engine performance is evaluated by a lump of different factors, among which is to focus on the performance of brake power, brake specific fuel consumption, brake thermal efficiency, air to fuel ratio, and engine speed, e.g ,1200/2200 r/min, while the pollutant emissions are evaluated by CO, UHC, CO₂ and NO_x. Results showed the lowest CO, UHC, and NO_x, while CO₂ IS increases when the engine speed increases but decreases when the concentration of butanone increases. It could be concluded that the (9%) percent blend of butanone with pure gasoline fuel can be observed as the best blend in regard to performance and exhaust emission characteristics as compared to all other blends.

Author contribution

All authors contributed equally to this work.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

- [1] D. U. Lawal, Performance of spark ignition engine using gasoline-91 and gasoline-95, *International Journal of Innovative Science, Engineering and Technology*, 1 (2014).
- [2] A. A. Abdel-Rahman, on the emissions from internal-combustion engines: a review, *International Journal of Energy Research*, 22 (1998) 483-513.
- [3] T.T. Falloon, Effect of fuel additives in a natural gas and gasoline engine, *The Doctoral dissertation, Colorado State University*.
- [4] M. Mart, Effect of Gasoline Fuel Additives on Combustion and Engine Performance, *Diss. UCL (University College London)*, (2015).
- [5] M. V. Kumar, The impacts on combustion, performance and emissions of biodiesel by using additives in direct injection diesel engine, *Alexandria Engineering Journal*, 57 (2018) 509-516.
- [6] R. R. Jaseem, An Experimental Investigation of the Effect of Traditional Enhancement on Spark Ignition Engine Performance, *Kirkuk University Journal-Scientific Studies*, 6 (2011) 1-14.

- [7] E. Ashra,. Investigations on performance and pollutant emissions of spark-ignition engines fueled with n-butanol-, isobutanol-, ethanol-, methanol-, and acetone-gasoline blends: A comparative study, *Renewable and sustainable energy reviews*, 71(2017) 404-413.
- [8] E. Ashraf, Gasoline engine fueled with bioethanol-bio-acetone-gasoline blends: Performance and emissions exploration, 274 (2020) 117825.
- [9] Q. Tang, Experimental study the effects of acetone-butanol-ethanol (ABE), spark timing and lambda on the performance and emissions characteristics of a high-speed SI engine, 279 (2020) 118499.
- [10] Y. L. Nithyanandan, Experimental study on combustion and emission performance of a spark-ignition engine fueled with water containing acetone-gasoline blends *Fuel*, 210 (2017) 133-144.
- [11] <https://www.engine-specs.net/nissan/qg18de.html>