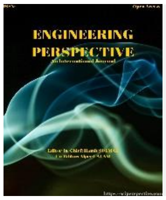

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Research Paper

An Experimental Study of the Influences of Lacquer Thinner Addition to Gasoline on Performance and Emissions of a Spark Ignition Engine

Ahmet Uyumaz[1], Ali Batuhan Kilmen[1*], Murat Kaş[1]

[1] *Mechanical Engineering Department, Faculty of Engineering and Architecture, Burdur Mehmet Akif Ersoy University, Burdur, 15030, Turkey*

ABSTRACT

In this study, lacquer thinner (LT) has been utilized as an addition to pure gasoline in a single cylinder SI engine for increasing performance and reducing emissions. The tests were done at wide open throttle condition and 2400, 2700, 3000, 3300, 3600 and 3900 rpm engine speeds. The influences of lacquer thinner were observed on the engine torque, thermal efficiency, specific fuel consumption (SFC) and HC, CO and CO_2 emissions. The findings demonstrated that with the addition of the lacquer thinner caused engine torque and power output values to decrease as the amount of lacquer thinner increased. SFC was increased by about 4.36%, 9.13% and 11.64% with LT10, LT20 and LT30 compared to full gasoline at 2700 rpm respectively. But fairly noticeable reductions were observed at CO and HC emissions as lacquer thinner added to the gasoline. HC decreased by 3.4%, 5.6% and 12.13% with LT10, LT20 and LT30 according to gasoline at 3900 rpm respectively. Similarly, CO has decreased by 1.09%, 2.18% and 3.56% with LT10, LT20 and LT30 according to gasoline at 3900 rpm respectively. Lacquer thinner showed positive and impressive results compared to pure gasoline on exhaust emissions. However thermal efficiency decreased, and SFC has increased with lacquer thinner addition to gasoline, but the reduction in engine torque and power can be acceptable considering the drastic improvements at emission levels. Also, it has been observed that lacquer thinner can be used as a gasoline additive without any modifications in spark ignition engines. Still further research is needed on Lacquer thinner on SI engines.

Keywords: Engine Performance; Emissions; Lacquer Thinner; Spark Ignition Engine

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Author Contacts
**Corresponding Author*
e-mail addresses : auyumaz@mehmetakif.edu.tr a.batuhan392@hotmail.com, muratkas585@gmail.com,

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1. Introduction

Alternative fuels or fuel additives are being searched by the researchers due to the reasons such as depletion of oil reserves and the harmful influences of the fossil fuels on the environment. Because spark ignition engines have lower emission rates compared to diesel engines, they are more prefer-able despite having lower thermal efficiencies and lower compression ratios. These circumstances can be further made better with the usage fuel additives in SI engines. Lacquer thinner, also known as cellulose thinner (LT) has drawn attention to improve spark ignition performance and emissions. LT is a ubiquitous and cheap substance that is used for thinning paints and is a powerful solvent that is used for cleaning painting equipment such as brushes. LT is produced from toluene, acetone and methanol. It also has high volatility characteristics which makes it suitable to mix with gasoline as an additive. Since LT is in liquid form it can be easily mixed with gasoline and other types of liquid fuels. Considering these facts LT can be used as an ignition improver to achieve higher thermal efficiencies. When the literature was examined, it was realized that there are not many detailed studies on the effects of LT in SI engines. Awad et al. [1] has reviewed the usage of alcohols and ethers such as ethanol and methanol as fuels in SI engines. They have found that lesser CO and NO_x emissions, but specific fuel consumption (SFC) has increased. Chivu et al. [2] compared commercial diesel blends with turpentine obtained from pine trees they have found that 7.9% increase in torque at 15T85D mixture and 9% power increase at low speed and 5% power increase at high speeds with 30T70D mixture but it had a negative effect on NO_x emissions. Rao et al. [3] has found that with increasing toluene concentrations there was a consistent reduction of the HC, CO and NO_x. Eng et al. [4] tested n-octane/toluene and iso-octane/toluene blends to observe the influences. Kinetic interactions were realized between fuel species. Iqbal et al. [5] has developed ID correlation to guess knock for a toluene reference mixture. Nematizade et al. [6] compared an ethanol-gasoline blend and a G-series fuel of GS1 and GS2. They have found that torque and power of the engine decreases (not significantly) and SFC increases but, HC reduces about 8% and CO reduces about 47%. Zhou et al. [7] commentated the performance of both lignin and cellulose derivatives. They have found that cetane number (CN) has higher effect than oxygen content. Machado et al. [8] looked on the influence of separate components and the amount of fuel on performance and combustion in SI engines. They have found that toluene and isooctane are important components because of their high-octane ratings also higher compression ratios are better for engines in operating conditions susceptible for knocking. Shahgholi et al. [9] investigated a gasoline engine's performance changes and emissions by gasoline mixtures and ethanol and thinner additives. They have found that addition of the thinner and ethanol increased SFC and reduced CO emissions also, increasing the amount of thinner and ethanol additives has reduced the vibration of the engine. Because SI engines present lower thermal efficiency compared to CI engines because of the lower CR. Gonca et al. [10] tested the impacts of dual mixtures on the theoretical performance characteristics of an SI engine. They have found that maximum decrease ratio of thermal efficiency is 29.71% with the combustion of 50% of methanol. Gonca et al. [11] has tested the effects of petroleum based liquid fuels and alcohols. They have found that fuel type considerably affects the brake power, brake thermal efficiency and NO formation. Ibrahim [12] researched the effects of diethyl ether in diesel engine. 15% diethyl ether showed the 7.2% increase on maximum brake thermal efficiency and 6.7% decrease on brake specific fuel consumption. Since fossil fuels are harmful to the environment and their reserves are getting depleted each day [13] it is crucial to search for alternative fuel sources or additives that are more readily available, cheap and more sustainable. Taking these facts into consideration lacquer thinner can be a good additive to gasoline since they have similar chemical compositions, and they mix well without any modification. In the current study, it was aimed to observe the influences of LT in terms of engine performance and exhaust emissions (HC, CO and CO_2) in a single cylinder four stroke spark ignition engines. For this purpose, the test engine was operated at wide opening throttle and different engine speeds between 2400 and 3900 rpm with the intervals of 300 rpm.

2. Material and Method

The experiments were conducted at Burdur Mehmet Akif Ersoy University, High Vocational School of Technical Sciences Automotive Laboratory. Figure 1 shows the schematic of the view of the test engine setup. Internal Combustion Engines (ICE) are critical machines in various applications from automotive to the industrial machinery. Understanding the effects of the LT on the performance and emissions as an additive to the gasoline in different conditions is essential. For that reason, six different engine speeds have been chosen and experiments were performed at full engine load condition (wide-open throttle), the selected engine speeds are 2400, 2700, 3000, 3300, 3600 and 3900 rpm. A torque sensor was coupled between the dynamometer and test engine shown in the Figure 1 Properties of the test engine were exhibited in the Table 1. Engine block temperature and oil temperature were held constant to prevent measurement differences. Engine was warmed up and then data was collected for each test. Honda GX 160, a single cylinder SI engine was fixed with an AC dynamometer for loading. When test engine started running dynamometer started to produce electricity, then using a potentiometer and a rheostat were precisely adjusted and engine speed was manipulated. Lastly fuel consumption was determined with digital precision scale with 0.5 gr accuracy.

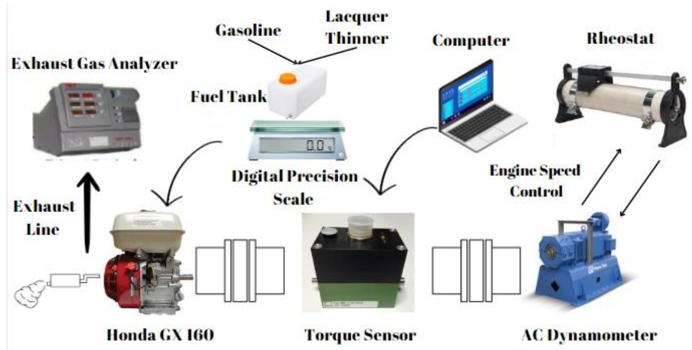

Figure 1. Schematic engine test setup

Table 1. Properties of the test engine

Model	Honda GX160
Bore x stroke [mm]	68x45
CR	8.5:1
Cylinder volume [cm³]	163
Power output [kW] HP@3600rpm	Max. 5.5
Torque [Nm]@2500 rpm	Max.10.78

Lacquer Thinner was used as additive to gasoline in this work. Properties of the gasoline and LT is given side by side in Table 2. Gasoline was the base reference fuel. For the preparation of the test fuels LT and gasoline was measured volumetrically and then combined to acquire 500 ml of test fuel in the end. At the end of each experiment amount of test fuel left was measured and then more gasoline and LT was added to the blend to achieve 500 ml again. LT is added to the gasoline at the rates of 10%, 20% and 30% to obtain test fuels. Test fuels have been named as LT10 (10 % Lacquer thinner + 90 % gasoline), LT20 (20% Lacquer thinner+ 80% gasoline), LT30 (30% Lacquer thinner+70% gasoline).

Table 2. Properties of the test fuels [10-16]

	Gasoline	Lacquer Thinner
Density [kg/m^3]	746	870
Latent heat of vaporization [kJ/kg]	331.6	-
Calorific value [kJ/kg]	43594	41030
Flash point [°C]	-43	-7
Octane number	96.47	-
Boiling point [°C]	30-225	110,6 – 111,6
Auto ignition temperature [°C]	257.2	536

Engine torque was determined concurrently according to the engine speed. Engine torque and speed values were delivered to the computer. Technical specifications of the torque sensor are given in Table 3.

Table 3. Specifications of the torque sensor

Model	Burster 8661
Nominal supply voltage range [V DC]	10-30
-3 dB cutoff frequency [Hz]	200
Insulation resistance [MΩ]	> 5
Fluctuation [mV]	<50
Rated torque output voltage [V]	+10
Driver signal (K pin) [V DC]	10…30

HC, CO and CO_2 emissions were determined by using an exhaust gas analyzer. Technical properties of the emission analyzer are shown in the Table 4.

Table 4. Properties of the exhaust gas analyzer

	Operating Range	Accuracy
HC	0- 9999 ppm	1 ppm
CO_2	0-18 %	0.1 %
NO_x	0- 5000 ppm	1 ppm
O_2	0-25 %	0.01 %
CO	0- 14 %	0.001 %
λ	0-4	0.001

2.1. Data Reduction

The engine torque is a measured value versus on the engine speed. With engine speed and torque values engine power can be calculated using the Eq. (1).

$$N_e = \frac{M_e . n_e}{9549} \quad (1)$$

N_e stands for engine power, M_e stands for engine torque and n_e stands for engine rpm. After engine power is calculated SFC can be calculated using Eq. (2) [16].

$$SFC = \frac{m_f}{N_e} \quad (2)$$

m_f denotes the fuel consumption and SFC determines the engine fuel economy. Thermal efficiency has been calculated using the Eq. (3) [16].

$$\eta_T = \frac{N_e}{m_f . Q_{LHV}} \quad (3)$$

Here η_T shows the thermal efficiency and Q_{LHV} stands for the calorific value of the fuel [16].

3. Results and discussions

The changes of the engine torque can be viewed in the Figure 2. Maximum torque was reached at 2400 rpm for each test fuel and engine torque started to decrease as the engine speed increased. Heat losses and gas leakages increase with the rise of engine speed. Engine torque has decreased as the amount of LT raised in the blend. LT30 presented the lowest amount of torque. This is because LT has lower calorific value than gasoline. Engine torque has decreased about 4.66% at 2400 rpm. There is not significant difference between gasoline and LT fuel mixtures. This phenomenon is attributed to the lack of oxygen and oxidation reactions slow down with the additive of LT in the fuel mixture.

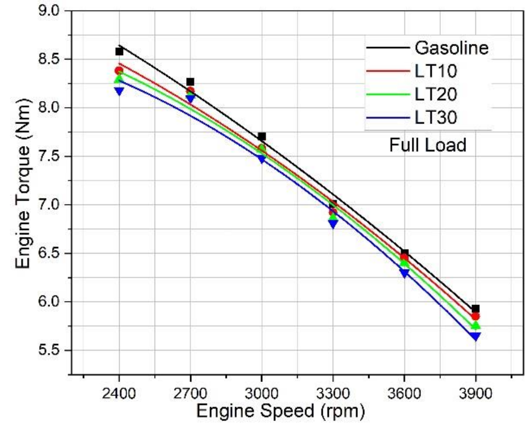

Figure 2. Engine torque

Power output of the engine rises with the rise of engine speed. Figure 3 exhibits the effect of LT on power output. Maximum effective power is computed at 3600 rpm for each test fuels. Volumetric efficiency is deteriorated at high engine speeds. Sufficient oxygen could not be delivered into the cylinder resulting in worse oxidation reactions. In addition, flow losses increase, and mechanical efficiency declines with the rise of engine speed. Hence, produced power decreases at high engine speed. Similarly to engine torque, power output decreases as the amount of LT increases in the blend. The highest power output was determined at 3600 rpm for all test fuels. Power output decreased 0.77%, 1.55% and 3.06% at LT10, LT20 and LT30 respectively at 3600 rpm. Kocakulak et al [14]. has found that with the addition of hexane to the gasoline reduced the engine torque in an SI engine.

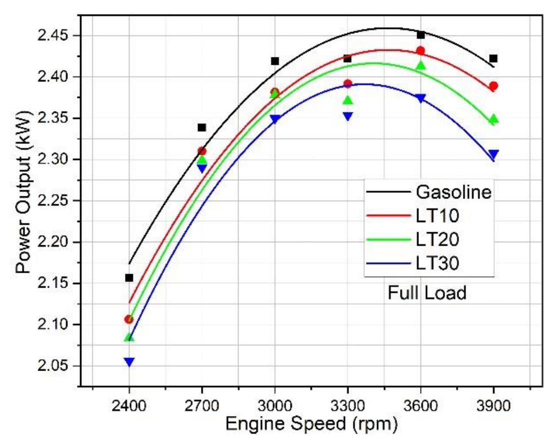

Figure 3. Power output

Figure 4 reflects the effects of LT on SFC. SFC is an important aspect of performance evaluations in internal combustion engines. When engine speed is too high or too low SFC increases as depicted in Figure 4. The lowest SFC data were calculated for 2700 rpm for all test fuels. And as expected increase of LT in the blend increased the SFC owing to LT having lower calorific value than gasoline and higher density. The increase of LT fraction in the fuel mixtures caused to increase of test fuel density. More charge mixture is taken into the cylinder by mass. So, higher fuel consumption is observed to obtain same power in comparison with pure gasoline. The highest SFC value is calculated with LT30 blend. SFC increased by about 4.36%, 9.13% and 11.64% with LT10, LT20 and LT30 respectively at 2700 rpm. So, more LT is required to achieve required fuel energy to reach same power output.

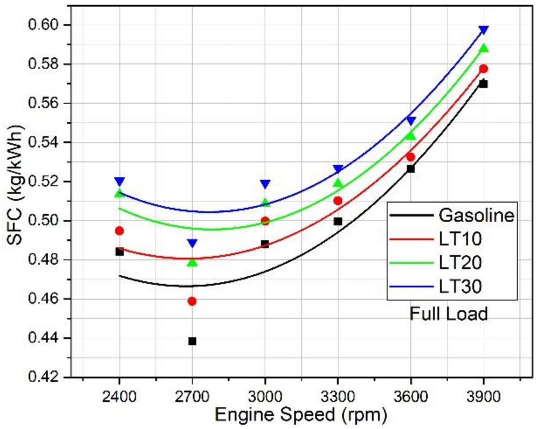

Figure 4. Effects of LT on SFC at various engine speeds

Thermal efficiency shows the produced net work depending on the obtained energy by ignition of the fuel. Calorific energy that is one of the most important factors affecting the thermal efficiency. The addition of LT leads to decrease thermal efficiency as seen in Figure 5. The lowest thermal efficiency was obtained using LT30. Thermal efficiency that is significant variable reflects the produced power output from obtained heat energy. Maximum thermal efficiency was determined at 2700 rpm for all test fuels. Figure 5 depicts the variations of thermal efficiency. Like SFC best thermal efficiency values are obtained at middle engine speed values. Maximum thermal efficiency values were also calculated at 2700 rpm. Thermal efficiency decreased by 3.69%, 6.90% and 8.15% at LT10, LT20 and LT30 respectively compared to gasoline.

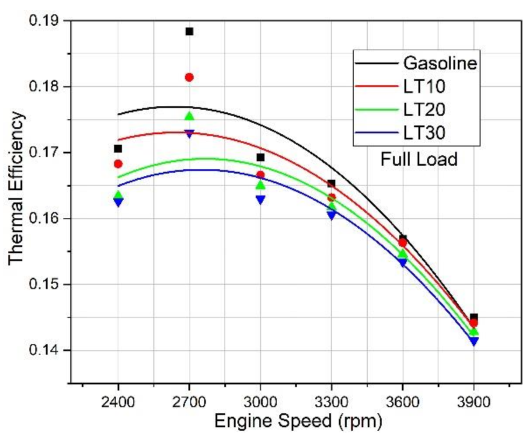

Figure 5. Effects of LT on thermal efficiency

Figure 6 shows the effects of LT on CO emissions. Incomplete combustion caused to obtain CO emissions. CO is generated due to lower cylinder temperature and lack of oxygen in combustion. As it can be seen in the Figure 6, with the addition of LT CO emission is reduced and lowest value is calculated with LT30 blend. At 3900 rpm measured CO values reduced by about 1.09%, 2.18% and 3.56% with LT10, LT20 and LT30 respectively. So, with the addition of LT it can be said that the combustion is improved, and CO formation is decreased. Uyumaz [15] has found that with the addition of diethyl ether to the gasoline in an SI engine CO and HC emissions have reduced and as the amount of diethyl ether increased in the blend CO and HC emissions continued to reduce further.

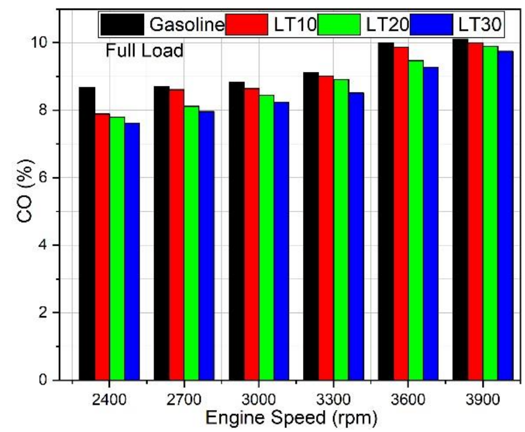

Figure 6. Effects of LT on CO emission

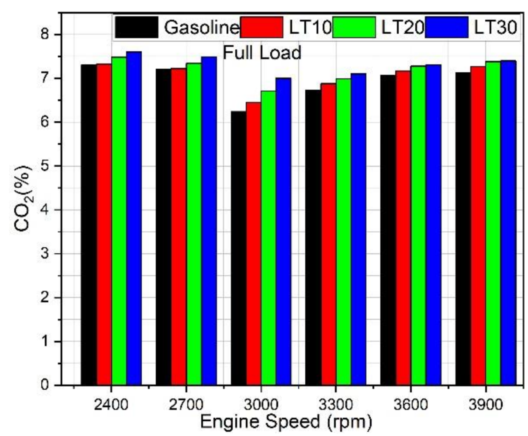

Figure 7. Effects of LT on CO_2 emission

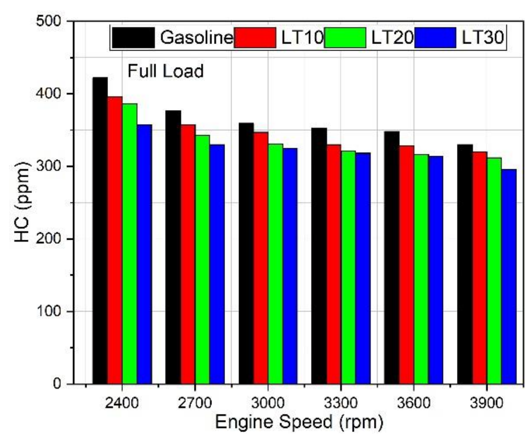

Figure 8. Effects of LT on HC emission

Figure 7 shows the changes of CO_2 emission. There is an inverse relationship between CO_2 and CO. So, as CO decreased CO_2 is increased with the addition of LT. The highest CO_2 like CO was determined at 3900 rpm for all test fuels. Highest CO_2

increase was 3.79% with LT30 blend. Higher density of LT caused to increase released heat and the temperature at the end of combustion. This situation helps to trigger the oxidation reactions. Hence, CO_2 formation is strengthened. It can be also stated that lower flash point of LT improves the combustion reactions resulting in more CO_2 generation. Lastly, values of determined HC emissions are given in Figure 8. At lower speeds the mixture cannot be properly ignited in the combustion chamber because of weak turbulence so HC formation is increased. As it can be seen here with the addition of LT HC emission is reduced significantly about by 3.4%, 5.46% and 12.13% with LT10, LT20 and LT30 respectively at 3900 rpm. Because of its high volatility, LT resulted lower unburned hydrocarbons.

4. Conclusions

The purpose of this experiment was to observe the influences of LT on engine performance and emissions as an addition to gasoline. The findings presented that with the addition of LT engine torque and power output is reduced but not that high of an amount that would render LT unusable as an additive to gasoline. Also, SFC is increased but this would be the case for any additive to gasoline that has lower calorific value than gasoline. The positive effects of LT as an additive lie on the emission side of the experiment. Harmful emissions such as CO and HC were reduced significantly with the addition of LT to the gasoline. HC reduced by 3.4%, 5.6% and 12.13% with LT10, LT20 and LT30 compared to gasoline at 3900 rpm respectively. CO has decreased by 1.09%, 2.18% and 3.56% with LT10, LT20 and LT30 compared to gasoline at 3900 rpm respectively. With these data, it can be said that lacquer thinner is a viable option to use as an additive to gasoline and can be used as without any modification whatsoever. Still further research is needed on the influences of LT on engine performance and emissions.

Nomenclature

AC	Alternative current
CI	Compression ignition
CN	Cetane number
CR	Compression ratio
CO	Carbon monoxide
CO_2	Carbon dioxide
DC	Direct current
HC	Hydrocarbon
HP	Horsepower
ID	Ignition delay
LT	Lacquer thinner
SFC	Specific fuel consumption
SI	Spark ignition
m_f	Consumed fuel
M_e	Engine torque
N_e	Effective power
NO_x	Nitrogen oxide
Q_{LHV}	Lower heating value

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Ahmet Uyumaz: Conceptualization, Supervision, Writing-review & editing
Ali Batuhan Kilmen: Conceptualization, Writing-original draft, Validation, Investigation
Murat Kaş: Methodology, Data curation, Formal analysis.

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