COMPARATIVE STUDY OF THE EFFECTS OF USING TEL AND ETHANOL AS FUEL ADDITIVES FOR SI ENGINE

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ABSTRACT

The effects of tetra-ethyl lead (TEL) and ethanol additive to pure lead-free gasoline on both engine performance and exhaust gas pollutants on a fixed compression ratio spark-ignited engine were investigated experimentally. The fuel blends were leaded gasoline and ethanol-gasoline blends with different compositions. It was found that the addition of TEL to gasoline leads to an increase of CO emission, but the addition of ethanol to the fuel, significantly decreases the CO emission. The results showed that the use of 10 % ethanol-gasoline fuel blend (Gasohol) is the most suitable blend to be used as an alternative to TEL additive at a rate of 1.5 g/US gallon without loss in power and octane rating. Further increase of ethanol concentration has lead to a reduction in engine performance.

INTRODUCTION

Nowadays, there is a growing interest from governments and nations all-over the world in reducing air pollution caused by vehicles' exhaust gas emission. Cars and commercial vehicles are responsible for more than 60% of air pollutants [1]. In its race with time, the state of California sets its first " Pure Air Act", which aims at having ideal clean air by the year 2010. One of the best solutions to this problem is the use of clean energy resources. Hydrogen has been investigated as an automotive fuel because of its potential for efficient combustion and low exhaust emissions [2,3]. Methanol has also received attention as an alternate fuel for the dwindling supply of petroleum based fuels because it can be synthesized from coal, oil shale, tar sands, and renewable resources [4].

Gasoline and diesel fuel additives that help reducing exhaust gas pollutants have been also investigated. Exhaust emission were significantly lowered in the range of 45 to 93 % for a fleet of 50, 1986-1987 model year cars designed for unleaded gasoline over a corresponding fleet of leaded fueled cars of 1980 model year average [5].

McCall et al, [6], concluded that an automobile could not be operated solely on dissociated or steam reformed methanol over the entire required power range and that the use of reformed methanol, compared to liquid methanol, may result in a small improvement in thermal efficiency even-though dissociated methanol is a better fuel than steam reformed methanol for use in spark ignition engine. Also, they found that the use of dissociated or steam reformed methanol may result in lower exhaust emissions compared to liquid methanol.

In a comparison study, Kaneko et al, [7], obtained that the maximum methanol and propane engine output is higher by approximately 20% and 8% respectively than the gasoline engine. they also concluded that the brake thermal efficiency of the methanol and propane engine is better than the base gasoline engine and the engine exhaust emission levels of methanol fuel are lower than gasoline, especially for NO_x and HC and this was not the case with propane.

Alcohols have certain advantages as fuels, particularly in countries without oil resources, or where there are sources of renewable raw materials for producing methanol (CH_3OH) or ethanol (C_2H_5OH). Car manufactures have extensive programs for developing alcohol-fueled vehicles (FORD(1982)). Alcohols can also be blended with oil-derived fuels and this improves the octane rating. Both alcohols have high Octane rating [ethanol has a RON (research method) of 106, Ref.[8]] and high enthalpy of vaporization; this can cause starting problems for cold ambient conditions, and therefore it may be necessary to start engines with petrol. The other main disadvantages are the lower heating value (about half that of petrol for methanol and two-thirds for ethanol), and the miscibility with water [9].

The aim of the present work is to study the effect of adding tetra-ethyl lead and ethanol to lead-free gasoline (This gasoline has been especially prepared for the purpose of doing this research work. It is not a commercial gasoline and it is not available in the market. The composition of this gasoline is 64 % Rheniformate ,11 % low straight run naphtha and 25 % pentane) on engine performance as well as engine emissions. Ethanol has been selected over methanol because ethanol have higher heating value , lower density , higher Octane number, and needs higher air to fuel ratio [10]. Also the commercial Alcohol contains 86.4 % of ethanol [11]. More-over, ethanol and higher alcohols dissolve more readily in hydrocarbons [12].

EXPERIMENTAL SET-UP

The experimental set up consists of an Opel 4-cylinder engine type 12-0074440 (more engine specifications are available in Appendix A), movable engine dynamometer and the following measuring instrumentations.

- Thepra instrumentations panel for measuring engine torque with control of load and hydraulic pressure connections.
- Bosch Mot 501 motor tester, which is capable to measure the following:-
  * Engine idling measurements (idle speed, battery voltage, primary current, and oil temperature)
  * Engine ignition system measurements (no-load speed, ignition angle, vacuum pressure)
  * Exhaust gas measurements (carbon monoxide, carbon dioxide,and unburned hydrocarbons); the instrument model is Bosch ETT 8.33.

The accuracy of the instrument used are given in Appendix B.

TEST PROCEDURE

The experiments of this investigation have been performed on five fuel samples representing:

a- Premium gasoline with 1.5 gram of tetra-ethyl lead (TEL) per US gallon and density of 743.2 kg/m^3.
b- Lead free gasoline prepared and composed of the following constituents: 64 % Rheniformate, 11 % low straight run naphtha, and 25 % pentane.
c- Unleaded gasoline with 10 % pure ethanol (C_2H_5OH).
d- Unleaded gasoline with 20 % pure ethanol.
e- Unleaded gasoline with 30 % pure ethanol.

The above fuel blend was prepared and kept in a sealed glass container. No separation have been noticed after a week period. However, a fresh sample fuel blend was prepared just before doing the experiment.

The purpose of these five samples of fuel blend prepared is:-

1- To study the effect of adding TEL to gasoline on the exhaust gas emissions.
2- To study the effect of adding ethanol to gasoline on both engine performance and engine emissions for a fixed compression ratio.

In all experiments, the following procedures were carried out:

a- Preparation of fuel blend sample and filling the fuel tank.
b- Running the engine with fully-opened throttle (WOT) and maximum resisting torque applied to the engine dynamometer until we reach the minimum possible speed .
c- Varying the engine load (speed) by decreasing the resisting torque gradually through an eddy current hydraulic engine dynamometer.

At every single specified speed the following measurements are recorded: RPM, engine intake air flow rate, engine brake power, unburned hydrocarbon, carbon monoxide, and carbon dioxide. Unfortunately , the instrument was not capable to measure NO_x, which considered one of the main pollutants.

RESULTS AND DISCUSSION

A selected sample of the experimental results are given in Table (1) and plotted in Figures (1) and (2). Figure (1) shows the effect of TEL addition to pure gasoline at rate of 1.5 gram per US gallon (not as the commercial case, where, usually chlorine & bromine are added with TEL [10]) on engine torque, power, specific fuel consumption and engine emissions.

It is clear from Figures (1-a) and (1-b) that there is almost no difference in engine output power and torque between the leaded premium gasoline with 95 octane number and the unleaded gasoline with 87.4 octane number for this fixed compression ratio engine. This excludes the speed range over 4000 RPM which gives better performance for the leaded gasoline over the unleaded one. This may be explained as, in the speed rang lower than 4000 RPM, the octane requirement for this engine (compression ratio 7.5) is just 87.5. This octane number requirement is covered by both leaded and unleaded gasoline. In the speed range over 4000 RPM , by increasing the speed, less time for heat transfer between the gases inside the cylinder and the cooling water will be available for each cycle. This will leads to an increase of the average gases temperature, which in turn increases the possibility of detonation, which will affect more the fuel with less octane number. Therefore the fuel with higher octane number (in our case the leaded one, since Tetraethyl lead improve the octane rating of the fuel by modifying the chain reactions [13]) will perform better at higher speeds.

Figure (1-c) shows that there is a little improvement in engine brake specific fuel consumption on using unleaded gasoline over the leaded premium gasoline by about 6 %. The reason may concern the combustion process of both fuels, as Figure (1-e) shows less Co is produced with lead-free gasoline, which means more complete combustion, i.e. TEL reduce the rate of reaction in combustion process.

The effect of adding TEL to pure gasoline on exhaust gas emissions is shown in Figures (1-d) to (1-f). In Figure (1-d) the unburned hydrocarbons versus engine speed is plotted for both pure lead-free gasoline and leaded premium gasoline. It can be noticed that the leaded gasoline gives less unburned hydrocarbons emission by an average value of 7 % of that given by unleaded gasoline. This is because the leaded gasoline gives better combustion, in turn better mixing and more turbulence. It is well known that as the level of turbulence increase the HC emission decrease [10], therefore leaded gasoline gives less unburned hydrocarbons.

Figure (1-e) shows the effect of TEL addition to pure gasoline on engine carbon monoxide emission. During the operational range of speed of 2000 RPM and above, the leaded fuel gives more carbon monoxide emission by about 0.5- 1 % than the lead-free one. This results in a decrease of engine carbon dioxide emission as indicated in Figure (1-f). This can be attributed to the same reason stated before, which is adding TEL reduces the reaction rate.

Table 1. Experimental results

RPM	BkW	bsfc g/kWh	Torque N.m	HC ppm	CO%	CO_2%	
1720	11.70	269.0	65.0	268	5.45	10.9	
2010	14.20	258.0	67.5	248	5.24	11.5	unleaded
2500	17.90	293.0	68.5	197	3.17	13.0	gasoline
3000	22.00	262.0	70.0	196	2.73	12.6	octane No.
4010	28.30	305.8	67.5	171	3.20	13.3	87.4
4500	30.60	308.5	65.0	126	3.30	13.4	density
5010	30.20	321.3	57.5	122	3.48	12.6	728.4 kg/m^3
5510	31.70	331.0	55.0	111	2.91	12.7	
1600	10.47	276.0	62.5	253	4.71	10.7	
2000	13.61	314.5	65.0	222	4.93	11.7	Leaded
2500	17.67	302.8	67.5	207	3.82	12.3	gasoline
3000	22.00	267.6	70.0	187	3.06	13.1	octane No.
3970	28.06	324.2	67.5	129	3.32	12.6	95
4510	30.70	322.5	65.0	133	3.81	12.6	density
5000	32.72	370.7	62.5	128	4.52	12.2	743.2 kg/m^3
5480	33.00	350.1	57.5	99	3.52	13.1	
2140	15.00	317.5	67.0	195	3.13	12.5	90 % gasoline
2500	17.80	312.0	68.0	184	1.57	13.0	10 % ethanol
3000	22.00	288.6	70.0	174	2.41	13.1	octane No.
4020	28.40	326.0	67.5	154	2.93	12.7	91.8
4510	30.70	310.0	65.0	125	2.00	13.0	density
5020	31.50	302.0	60.0	110	2.45	13.0	734.86 kg/m^3
5480	33.00	320.7	57.5	79	1.06	13.3	
2020	13.75	310.5	65.0	196	2.98	12.3	80 % gasoline
2510	17.74	331.0	67.5	165	0.95	13.1	20 % ethanol
3000	21.20	314.0	67.5	153	0.94	13.2	octane No.
4040	27.50	330.0	65.0	140	2.06	13.1	96.3
4510	29.30	346.0	62.0	106	1.16	13.5	density
5010	30.16	336.0	57.5	92	1.49	13.5	741.32 kg/m^3
5530	31.85	352.0	55.0	72	0.81	13.6	
1660	11.30	333.5	65.0	247	1.48	9.1	
2140	14.80	327.4	66.0	209	1.25	13.1	70 % gasoline
2510	17.74	333.8	67.5	199	1.09	13.1	30 % ethanol
3000	22.00	318.1	70.0	179	0.51	13.2	octane No.
4010	27.30	335.3	65.0	116	0.61	13.5	99.33
4570	28.70	375.2	60.0	80	0.58	13.5	density
4990	30.00	358.9	57.5	62	0.46	13.6	747.78 kg/m^3
5550	30.80	384.6	53.0	47	0.27	13.7	

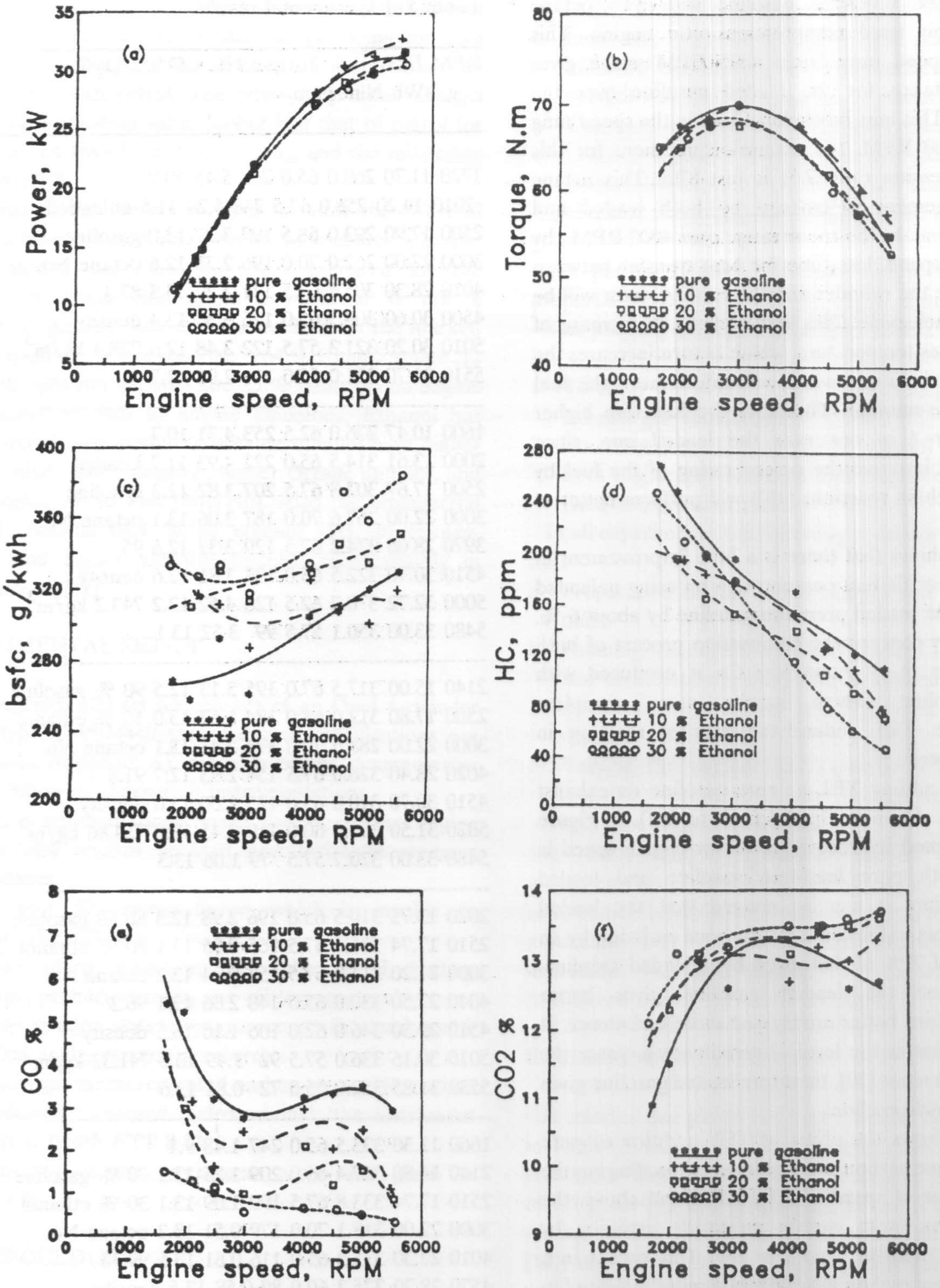

Figure 1. Effect of tel additive to pure gasoline on:
a- engine output power b- engine torque c- engine bsfa d- HC emission e- CO emission f- CO emission.

To Figure out the effect of ethanol-gasoline fuel blend with different percentages on the engine performance and exhaust gas emissions, a set of experiments were carried out using four different fuel blends of 0 %, 10 %, 20 %, and 30 % ethanol with pure lead-free gasoline. The results are plotted in Figure (2).

Figure (2-a) shows the effect of ethanol addition with different percentage on engine output power. It is clear that there is almost no difference up to engine speed of 4000 RPM, over which 10 % ethanol fuel blend gives the relatively highest output power. Any additional increase in ethanol percentage results in decreasing engine power. This can be attributed to the fact that, adding ethanol to gasoline, has two effects on the fuel blend properties, the first is an increase of the octane number (see Table 1), since ethanol latent heat of evaporation is much greater than that of gasoline and accordingly ethanol additive helps delaying chain reactions of end gas [14]. The second is,it decreases the heating value. Both effects have opposite direction on engine performance. When the engine speed becomes high, higher temperature for gases inside the cylinder will be attained, this will increase the tendency of detonation. At this situation the importance of the first effect start to become valuable. This explain why 10 % ethanol fuel blend performs better at high speed. By increasing the percentage of ethanol in the fuel blend, the second effect starts to be pronounced, resulting less power output. This explain why as the percentage of ethanol increases, less power output produced.

The effect of ethanol percentage variation in a fuel blend with gasoline on engine driving torque is shown in figure (2-b). The figure illustrates that all fuel blend samples almost give the maximum torque at 3000 RPM, beyond which 10 % ethanol-gasoline fuel blend gives the best engine output driving torque. This can be explained with the same reasons indicated above.

Figure (2-c) shows the effect of ethanol addition to gasoline on engine bsfc. The figure declares that lead free gasoline gives lower bsfc up to engine speed of 4000 RPM, after which 10 % ethanol fuel blend starts to give less bsfc. The reasons behind that are the higher heating value the pure lead-free gasoline has, as well as minimum density among the different fuel blends makes the pure gasoline superior in bsfc. During the full load range of engine speed, the 10 % ethanol fuel blend improves the combustion process in addition to the engine increased level of turbulence by over-speeding. With this improved combustion process, less fuel consumption is expected. If the percentage of ethanol is increased over 10 %, the effect of higher density fuel blend resulted from ethanol addition to gasoline fuel blend starts to increase the bsfc.

Figure (2-d) shows the effect of ethanol addition on engine exhaust unburned hydrocarbons. The highest unburned hydrocarbons emitted occur with pure gasoline without any additive (0 % ethanol) for all engine loading conditions. Near full load condition (over 3500 RPM), the minimum unburned hydrocarbon emission occurs with the highest percentage of ethanol in its blend with gasoline (i.e., 30%). At lower speed range (less than 3500 RPM), the 30 % ethanol-gasoline fuel blend gives higher values of HC emissions than corresponding ones (10 % and 20 %.). This phenomenon can be explained as follows: there are two factors which reduce HC, the first is increasing turbulence through speeding of the engine, and the second is by increasing the ethanol percentage in the fuel blend, improve combustion process by increasing the octane number and increasing the level of the flame temperature. Generally the former is more effective than the later, that is why 30 % ethanol-gasoline fuel blend is the lowest in HC emission among all fuel blends at high speed.

Figure (2-e) shows the effect of ethanol addition to gasoline on carbon monoxide emitted in engine exhaust gases. It can be noticed that as the ethanol percentage in gasoline increases less percentage of carbon monoxide in exhaust gases will be detected. This will lead to a reduction in CO emission level from an average value of 4 % for pure lead-free gasoline fuel blend to a value less than 1 % for 30 % ethanol-gasoline fuel blend . That can be attributed to the improvement in combustion process with the increase of ethanol percentage added to gasoline.

The expected result and conclusion of Figure(2-e) is shown in Figure (2-f). This figure shows the increase in carbon dioxide emitted in engine exhaust gasses with the percentage increase of ethanol in gasoline fuel blend. A result that supports the approaching of combustion process to normal complete combustion by increasing ethanol percentage in gasoline fuel blend. This increase results in a total decrease of carbon atoms in the fuel blend of ethanol and gasoline and in improving the air fuel ratio and combustion efficiency.

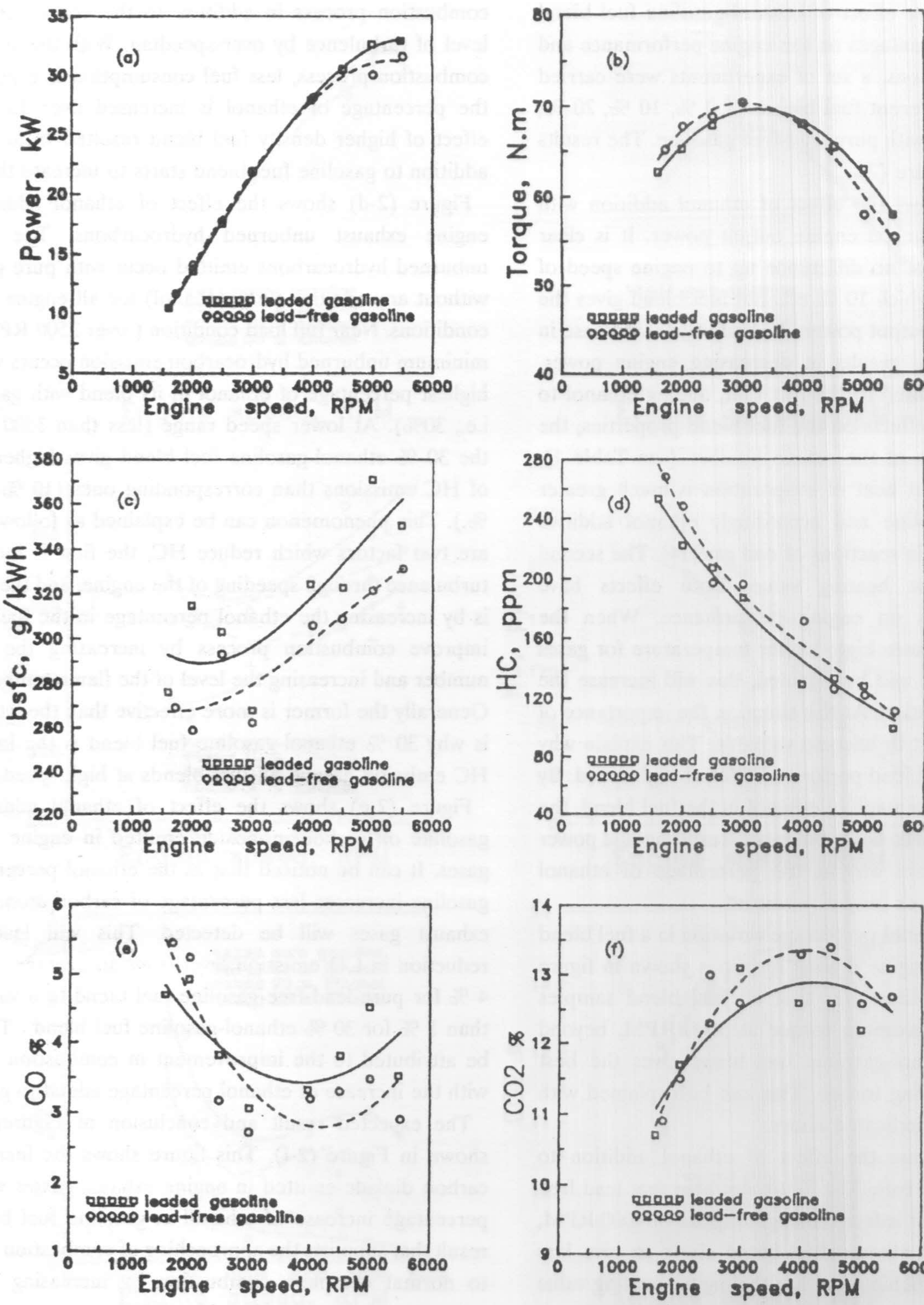

Figure 1. Effect of tel additive to pure gasoline on:
a- engine output power b- engine torque c- engine bsfa d- HC emission e- CO emission f- CO emission

From the previous discussion the two questions that may arise are; first, which is better to use for all-ready designed car engines, leaded gasoline or unleaded one ?; second, what percentage of ethanol in a fuel blend with gasoline is recommended to be used in the same designed car engine for the engine power output?. The answer for the first question is that if the designed engine can work with unleaded gasoline without detonation (i.e., its compression ratio needs only octane number around 87.4), it is not recommended at all to use leaded gasoline. This also depends on the quality of petroleum oil distilled in the oil refinery and the manufacturing method and mixing process of petroleum base gasoline which affect its octane rating.

The answer for the second question is that 10 % of ethanol in a fuel blend with pure lead-free gasoline (i.e., 91.8 RON) may be considered the best percentage of ethanol additive to a blend of fuel for the following reasons:-

1- It gives the highest engine power output among the blends, which is equivalent to the corresponding one of premium gasoline with 1.5 grams of TEL for each US gallon.
2- Its bsfc is very close to the minimum value of pure lead-free gasoline.
3- It reduces CO emission within 37.5 % of its value corresponded to pure lead-free gasoline.

CONCLUSIONS

The effects of TEL and Ethanol additive to pure lead-free gasoline on both engine performance and exhaust gas pollutants on a fixed compression ratio spark-ignited engine were investigated under the conditions of operating engine speed range and full load. The following are the conclusions of the investigations:

1- For leaded and unleaded gasoline, there is no difference noticed for engine output power and torque curves.
2- Using unleaded gasoline resulted in lowering the bsfc by an average value of about 6 % over the corresponding bsfc given by using leaded gasoline.
3- Adding TEL to pure gasoline decreases HC emission, increases CO emission and decreases CO_2 in addition to lead oxides showed up which is harmful to brain cells and youngsters. Therefore, it is not recommended to use large amount of TEL as octane improve ng additive to gasoline.
4- The 10 % ethanol-gasoline fuel blend gives the same output power and torque as the leaded gasoline with 1.5 gram TEL for each US gallon.
5- The engine bsfc will increase by increasing the percentage of ethanol addition in gasoline fuel blend. This increase could reach 25 % over that corresponding value given by pure lead-free gasoline.
6- The unburned hydrocarbons decrease with the increase in the percentage of ethanol addition in its blend with gasoline.
7- Increasing the ethanol percentage in the blend leads to an increase of carbon monoxide emission in the engine exhaust gas with a minimum average value of 0.8 % at 30 % ethanol fuel blend and a maximum average value of 3.8 at zero percent ethanol.
8- The carbon dioxide percentage in exhaust gas emission increases with the increase of ethanol percentage in gasoline fuel blend.

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APPENDIX A

The Opel engine specifications are as follows:

Engine Type	12-0074440
Pistons Displacement	1200 Cubic centimeters
Maximum Power	38 kilowatts @ 5300 RPM
Maximum Torque	72 Newton-meter @ 3000 RPM
Inlet Valve opens @	30° BTDC
Exit Valve closes @	60° ATDC
Firing order	1-3-4-2
Compression Ratio	7.5
Octane Requirement	87.5

APPENDIX B

The accuracy of the instrument used as given by its manufactural

Engine rotational speed	± 10 RPM
Ignition angle	± 0.1
Vacuum pressure	± 1 mbar
Carbon Monoxide CO (% Vol.)	± 0.01 %
Carbon Dioxide CO_2 (% Vol.)	± 0.1 %
Hydrocarbons HC (ppm)	± 2 ppm