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Research Paper

The effect of ethanol-gasoline blends on performance and exhaust emissions of a spark ignition engine through exergy analysis

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HIGHLIGHTS

- Examining the performance of ethanol-gasoline blend.
- Evaluation of the exhaust emissions.
- Energy and exergy analysis.
- Calculation of irreversibility from cooling system and the exhaust resulting.

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ABSTRACT

Ethanol which is considered as an environmentally cleaner alternative to fossil fuels is used on its own or blended with other fuels in different ratios. In this study, ethanol which has high octane rating, low exhaust emission, and which is easily obtained from agricultural products has been used in fuels prepared by blending it with gasoline in various ratios (E0, E10, E20, and E30). Ethanol-gasoline blends have been used in a four-cylinder four-stroke spark ignition engine for performance and emission analysis under full load. In the experimental studies, engine torque, fuel and cooling water flow rates, and exhaust and engine surface temperature have been measured. Engine energy distribution, irreversible processes in the cooling system and the exhaust, and the exergy distribution have been calculated using the experimental data and the formulas for the first and second laws of thermodynamics. Experiments and theoretical calculations showed that ethanol added fuels show reduction in carbon monoxide (CO), carbon dioxide (CO_2) and nitrogen oxide (NO_X) emissions without significant loss of power compared to gasoline. But it was measured that the reduction of the temperature inside the cylinder increases the hydrocarbon (HC) emission.

1. Introduction

Internal combustion engines using fossil-based fuels are generally used in today's vehicles. The increase in the environmental problems and the decrease in the fossil-based fuel reserves accelerated the search for alternative energy sources. In recent years, alcohol-based fuels containing methanol or ethanol are preferred as alternative energy sources for internal combustion engines [1,2]. Ethanol which is a renewable energy source that can be easily obtained from agricultural biomass products like corn and sugarcane with low cost can be used in spark ignition engines on its own or blended with gasoline [3,4]. Ethanol's physical and thermal properties show similarities with those of gasoline [5]. Its low greenhouse effect, lower harmful exhaust emission into the atmosphere, ability to blend with gasoline homogenously, and high octane rating have been popularizing ethanol usage in recent years. On the other hand, its lower heat of combustion compared to gasoline, the need for modifications on internal combustion engines to be able to use it as fuel, and its being obtained from products requiring large fertile agricultural lands are the disadvantages of ethanol [6].

Ethanol's structural formula is CH_3CH_2OH, and the abbreviated chemical formulas C_2H_5OH and C_2H_6O are often used. Ethanol's octane rating and oxygen ration are higher than gasoline (C_8H_{18}) despite its lower carbon and hydrogen ratio [7]. In internal combustion engines, the temperature and the pressure of the mixture inside the cylinder vary according to the compression ratios. Increasing the compression ratio in order to obtain more power from the engine also increases the temperature and the pressure

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Nomenclature

be	specific fuel consumption (g/kWh)
C_8H_{18}	gasoline
C_2H_6O	ethanol
CO	carbon monoxide
CO_2	carbon dioxide
Cp_c	specific heat of coolant
Cp_{cal}	specific heat of water calorimeter
E_{fuel}	energy of fuel
E_0	100% gasoline
E_{10}	10% ethanol and 90% gasoline blend
E_{20}	20% ethanol and 80% gasoline blend
E_{30}	30% ethanol and 70% gasoline blend
E_{100}	100% ethanol
F	force (N)
h_{in}	input enthalpy
h_{out}	output enthalpy
HC	hydrocarbon
H_2O	water
N_2	nitrogen
NO_x	nitrogen oxide
M	torque
m_{in}	mass of inlet
m_c	mass of cooling water
m_{cal}	cooling water flow calorimeter
m_{fuel}	mass of fuel (kg/s)
m_{out}	mass of outlet
n	engine speed (rpm)
P_e	effective engine power
O_2	oxygen
Q	heat transfer
Q_{ci}	heat transfer with cooling water inlet
Q_e	the heat energy removed by the exhaust gas
Q_{in}	heat transfer inlet
Q_{out}	heat transfer outlet
Q_{LVH}	lower thermal value of the fuel
Q_{rad}	radiation heat transfer
R	gas constant
rpm	revolutions per minute
T	temperature
T_{engine}	temperature
T_0	temperature of environment
$T_{cal,1}$	calorimeters cooling water inlet temperature
$T_{cal,2}$	calorimeters cooling water outlet temperature
T_{cia}	the average inlet and outlet temperatures of the cooling water
$T_{ci,1}$	temperature of cooling water inlet
$T_{ci,2}$	temperature of cooling water outlet
$T_{e,1}$	exhaust gas temperature in the exhaust manifold outlet
$T_{e,2}$	calorimetry transition temperature of the exhaust gas
$T_{e,3}$	outlet temperature of the exhaust gas calorimeter
X	exergy
X_{ci}	exergy of cooling water
$X_{destroyed}$	destroyed exergy
X_{heat}	heat with said exergy
X_{rad}	radiation with the exergy
X_{work}	work with the exergy
W	work

Greek symbols

ρ	density
η	efficiency
η_e	effective efficiency
μ	gas viscosity
ω	angular velocity
ψ	fuel exergy factor
ψ_{in}	exergy fuel input factor
ψ_{out}	output fuel exergy factor

inside the cylinder, thereby causing a risk of engine knock. Using ethanol, which has a high octane rating, as fuel in spark ignition engines causes fewer engine knock problems [8].

Ethanol may be used in spark ignition engines on its own or by blending it with gasoline in different ratios. Alcohols are generally used in internal combustion engines either by blending them with fuels in certain ratios or by injecting into the inlet manifold. Recently the third method is also available as a direct injection in cylinder [9–14]. Ethanol's ignition speed and its heat of evaporation are higher than gasoline. For this reason, engines using ethanol have higher efficiency due to quicker combustion [15,16].

Internal combustion engines harmful emissions into the atmosphere cause air pollution. Combustion products harmful to the environment such as CO, CO_2, NO_X, and HC are released into the environment in different rates depending on the fuel type and fuel/air mixture ratio. As a general rule, because of the lower thermal values of ethanol compared to gasoline, specific fuel consumption increases and harmful NO_X emissions decrease [17–19]. But tests in spark ignition engines show that increasing the ethanol ratio lowers the engine output power and torque values [20,21].

Increasing the compression ratio in gasoline engines increases the thermal efficiency but it accelerates HC the creation of emissions because it also increases the surface/volume ratio. Also, the increase of temperature due to higher compression ratio also increases NO_X emission [22,23]. Energy and exergy analyses may be carried out using the performance results obtained in experiments on internal combustion engines [24]. With these analyses, after the determination of the optimum working intervals of the engine, new designs can be developed in order to increase thermal efficiency [25,26].

When using ethanol-gasoline blends as fuel in gasoline engines, the optimum working interval can be determined by identifying the energy distribution and the energy lost through cooling, exhaust, and radiation. Because the irreversible processes in the engine increase the energy loss, it decreases the exergy [27,28]. The usability of alternative fuels in an engine depending on the load and velocity changes in gasoline engines can be determined using exergy and energy analyses [29]. Performance and exhaust emissions in various working conditions have been studied after the addition of various ratios of alcohols into the fuel in gasoline engines. Literature review shows that ethanol-gasoline blends significantly lower HC and CO emissions until the 20% ratio limit. But when the ethanol ratio in the blend surpasses 40%, engine speed shows unbalances due to poor fuel/air mixture [20,30]. For this reason, it was determined that the best ethanol blend ratio in ethanol-gasoline blends for the best emission values is between 20% and 30% [31,32].

Literature review shows that many experimental studies have been conducted on the engine performance and emissions when using different ratios of blends between E0 and E100 in spark ignition engines [33,34]. But there is only a limited number of studies that contain thermodynamic analyses expressing energy distribution and irreversible processes. In this study, E0, E10, E20, and E30 fuel blends have been tested in various engine speeds in order