energies
MDPI

Article

Particulate Matter and Gaseous Emission of Hydrous Ethanol Gasoline Blends Fuel in a Port Injection Gasoline Engine

Maji Luo [1,2,*], Musaab O. El-Faroug [1,2,3], Fuwu Yan [1,2] and Yinan Wang [1,2]

1 Hubei Key Laboratory of Advanced Technology for Automotive Components, Wuhan University of Technology, Wuhan 430070, China; musaabgaffar@whut.edu.cn (M.O.E.-F.); yanfw@whut.edu.cn (F.Y.); wangyinan94@whut.edu.cn (Y.W.)
2 Hubei Collaborative Innovation Center for Automotive Components Technology, Wuhan University of Technology, Wuhan 430070, China
3 Mechanical Engineering Department, Faculty of Engineering, Elimam Elmahdi University, Kosti 11588, Sudan
* Correspondence: mjluo@whut.edu.cn; Tel.: +86-27-8785-8033

Received: 19 July 2017; Accepted: 21 August 2017; Published: 25 August 2017

Abstract: The industrialization that increases day by day needs more and more power/fuel sources that are commonly available, abundant, renewable, and environmentally friendly. Recently, nearly all of the cities in China (PRC) have been influenced by haze. However, the pollutants from automobiles have always been seriously considered to be the main contamination causes of the haze and that influence human health. This study concerns the impact of hydrous ethanol on in-cylinder pressure, particulate matter (PM), and gaseous emissions (oxides of nitrogen (NO_x) and unburned hydrocarbon (HC)) from a port fuel injection (PFI) gasoline engine. Tests were conducted on a four-cylinder port injection gasoline engine at different engine loads at an engine speed of 2000 rev/min for commercial gasoline, hydrous ethanol-gasoline blends (10% and 20% hydrous ethanol by volume), and an anhydrous ethanol-gasoline blend (20% anhydrous ethanol by volume). The results show that the peak in-cylinder pressure with the use of gasoline was the highest compared with the hydrous ethanol and anhydrous ethanol blends. Compared with the anhydrous ethanol blend, the hydrous ethanol blends performed well at a high load condition, equivalent to a low load. In addition, the total particulate number (PN) declines with an increase in engine operating loads for all of the fuels tested. The outcome of this study is an important reduction in PM number, mass emissions, and mean diameters of particles as the use of hydrous ethanol blends increases, while the form of the particulate size distribution remains the same. Furthermore, the NO_x emission is raised with a rise in engine load, and NO_x and HC emissions are reduced with the use of hydrous ethanol and anhydrous ethanol blend as equated with pure gasoline. Moreover, the correlation between the total particle number against NO_x and HC has been found; the number of particles increases when the NO_x emission decreases, and the opposite trend is exhibited for the HC emission. Therefore, it can be concluded that hydrous ethanol blends look to be a good selection for PM, NO_x, and HC reduction for gasoline engines.

Keywords: port injection gasoline engine; hydrous ethanol; in-cylinder pressure; particulate matter; gaseous emission

1. Introduction

A significant task that people must take seriously is to decrease greenhouse-effect gas emissions caused by various human activities and reduce the reliance on crude oils. A major contributor to the greenhouse effect is the transport section due to weighty and enlarging traffic grades. Thus, study activities have been concentrated on the investigation of substitute energy sources for the sustainable progression of society and the global economy [1]. The burning of fuels, such as gasoline and diesel, are among the contributors to the emission of hazardous gases, such as particulate matter (PM), the oxides of nitrogen (NO_x), unburned hydrocarbon (HC), and carbon monoxide into the atmosphere. The optimum candidate biofuels to replace gasoline are alcohols, which can be used in a neat form or mixed with gasoline in both optimized spark-ignition (SI) engines. One optional is already in popular use around the world, namely ethanol. First-generation ethanol is produced from wheat, sugar cane, corn, etc., and is very contentious since there is a food consumption risk [2]. In addition, second-generation ethanol is manufactured from wood chips, agricultural wastes, and grass; hence, it has shown to be less controversial [2].

Ethanol has various benefits over gasoline to become an attractive substitute fuel. Ethanol is a renewable fuel with a high-octane number, high oxygen content, is less toxic, has a low carbon/hydrogen ratio, and the higher latent heat of vaporization of ethanol raises its volumetric efficiency [3,4]. A disadvantage of ethanol is the decreased lower heating value, which leads to an increase in fuel consumption [4]. The manufacture of anhydrous ethanol (water content that is <1%) is a costly, and an important amount of energy is needed throughout the dehydration and distillation of ethanol. Some authors have suggested that 37% of the energy manufacture of neat ethanol is connected with water dehydration and distillation (see Figure 1) [5,6]. Thus, the use of hydrous ethanol as a fuel would consequently enhance the overall energy efficiency, making it a good choice as a fuel source [3].

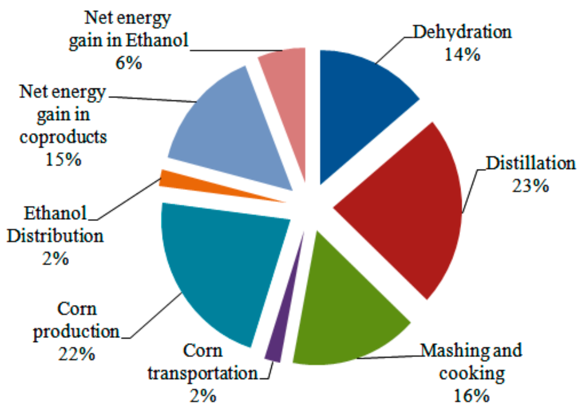


Figure 1. Net energy balance for various stages of corn ethanol manufacture [5,6].

Many empirical reports have investigated the appropriateness of alcohols in general [7–10] and hydrous ethanol in particular as fuels for internal combustion engines. Readers may refer to our review paper for further details [3], which concludes, as briefly discussed here, that mixing hydrous ethanol in gasoline yields an increase in combustion efficiency [11,12], cylinder pressure [11,13–15], heat release rate [13], engine torque [12,16–20], engine power [11,12,16–20], engine thermal efficiency [12,17,18,21,22], brake mean effective pressure [11,17,18,23], and fuel consumption [11,16,17,19,20]. On the other hand, it decreases nitrogen oxide (NO_x) emissions [11,12,14,22,24–28], carbon monoxide (CO) emissions [13,14,17,19,21,25,29], carbon dioxide (CO_2) emissions [13,19,24], and hydrocarbon (HC) emissions [12–14,17,19,25,28,29]. Furthermore, a number of investigations [27,30] have stated that HC emissions slightly rise due to the rise the percentage of water in an ethanol blend. A limited number of studies [14,16,30] have indicated that the aldehyde (formaldehyde and acetaldehyde) emissions from hydrous ethanol fuel are raised compared to gasoline. From the literature, no information can be gained on the impact of hydrous ethanol gasoline blends on particulate matter emissions from a port injection gasoline engine. Several investigations have studied the effects of hydrous ethanol fuel on PM emissions from diesel engines [31–33], and they found that hydrous ethanol was effective in reducing PM emissions from diesel engines. Hence, research on PM emissions for the hydrous ethanol gasoline blends is needed.

Particulate matter emissions are now of considerable importance because results from medical studies have shown that even moderate-to-low-level exposure from internal combustion (IC) engines causes a negative impact on people's health [34–39]. The health effects are found to correlate more with the size of PM and less with the mass [40]. The smaller particles discharged from engines fueled by gasoline could have more severe effects on the human respiratory system than the bigger particles from engines fueled by diesel [41]. According to EURO 6c and China 6a, the number of particle emissions discharged from engines must kept below 6.0×10^{11} particles/km. The principal sources of PM are fuel, air, and material breakdown and lubricating oil [42]. Fuel properties have important effects on PM emissions.

A number of researchers [43–49] have made a significant reduction in engine-out PM emissions from gasoline engines by using anhydrous ethanol. Price et al. [43] reported that anhydrous ethanol blends E85 and E30 showed the lowest PM emissions, followed by methanol blends M85 and M30 for lean fuel–air mixtures. Another investigation issued by Chen et al. [44] detected a reduction of PM emissions when running E10 over gasoline under cold conditions by a coolant temperature of 20 °C. Muralidharan et al. [45] noticed that the addition of anhydrous ethanol in gasoline had decreased the particle number in both steady speed and transient conditions. Catapano et al. [46] found that the distribution of particle size is strongly affected by fuel composition and operating conditions. At 2000 rpm and a full load condition, the anhydrous ethanol addition reduced the PN concentration. They also reported that at a 4000 rpm partial-load condition, a significant increase of PN is observed for the E50 and E85 fuels. Storey et al. [47] conducted an experimental investigation on a direct injection (DI) gasoline vehicle working on E0, E10, and E20 fuels. It was found that anhydrous ethanol blends decreased the particulate matter number and mass concentration emissions for both steady state and transient cycles. Vuk and Vander [48] found that anhydrous ethanol blends showed significant PM reductions compared to the base fuel. They also noticed that E30 and E85 with low aromatic gasoline fractions were the cleanest fuels tested from a PM emission.

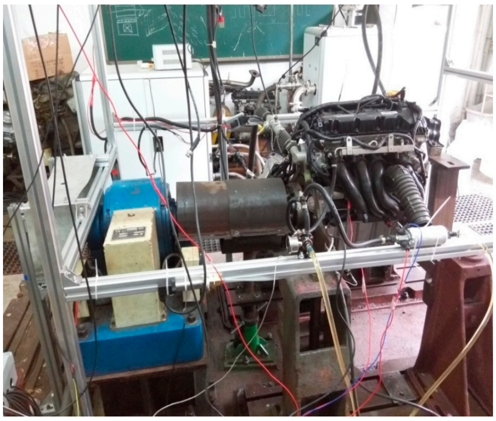
Many of the considered studies have reported conflicting results on this topic. Chen et al. [50] investigated the effect of anhydrous ethanol gasoline blends in different blending percentages ranging from 0% to 85% by volume of anhydrous ethanol on PM emission at a stoichiometric condition and speed of 1500 rev/min. The outcomes showed that the anhydrous ethanol addition caused a rise in both particle mass and number over the size variety of 23–700 nm. Bielaczyc et al. investigated the effect of anhydrous gasoline blends (E5, E10, E25, and E50) on PM emission discharged from an SI engine. The results showed that the PM emissions varied depending on the fuel blend employed. The E25 fuel was the best fuel with regard to PM emission, with the lowest PM mass emissions and the second-lowest PM number emissions [51]. Therefore, research on PM emissions for the anhydrous gasoline blends is needed to identify these odd trends.

Considering the production cost of hydrous ethanol compared with anhydrous ethanol, the absence of experimental data means that there is a clear need to investigate the effect of hydrous ethanol additions in gasoline on PM emission, and also considering that the smaller size of the particles discharged from port fuel injection (PFI) gasoline engines have a greater health impact than the bigger particulates discharged from diesel engines. Therefore, researchers have used different strategies to decrease the PM emissions from PFI and DI gasoline engines [52–56]. Moreover, the properties of Chinese fuel are highly different, typified by higher emissions and lower engine performance [54]; thereby, the China 6a legislation has applied a particulate number limit to all engines (PFI, DI, and compression ignition (CI)) .Therefore, the purpose of this investigation is to comprehensively elucidate the effects of fuel type and blend concentration for hydrous ethanol and anhydrous ethanol gasoline blends (HE0, HE10, HE20, and E20) on the in-cylinder pressure, particulate matter emissions (size distribution, particle number, mass concentrations, and count median diameter of particles), and gaseous emissions (NO_x and HC) from a port-injected gasoline engine at a speed of 2000 rev/min and various load conditions to find a correlation between PM emissions and gaseous emissions.

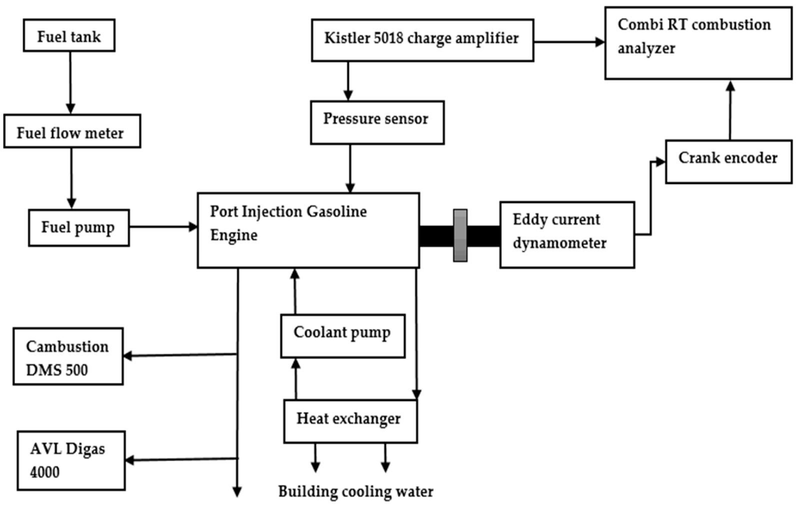
2. Materials and Methods

2.1. Research Engine and Fuels

The research engine and diagram of the experimental setup are displayed in Figure 2. The experiments were conducted on a four-cylinder, water-cooled, PFI, and SI gasoline engine. Table 1 shows the main specifications of the research engine. The research engine was conjugated to an eddy-current dynamometer to control the engine's torque and speed, and the accuracies of the speed and torque were 1 rev/min and 1 Nm, respectively. The coolant and oil temperatures were measured by the sensors with accuracy of ±0.1 K. A piezoelectric pressure sensor (type 6117BFD17, KISTLER, Switzerland) with a resolution of ±0.5% was placed to substitute for the spark plug in the first cylinder of the engine. The sensor of pressure was used with a charge amplifier (type 5018, KISTLER, Switzerland) and a shaft encoder to obtain the cylinder pressure data. The pressure data were recorded and computed by a combustion analyzer, Model Combi RT (S-N: 0087) (SMETEC, Germany). To detect the PM emissions, we used a fast particulate spectrometer (DMS 500) (CAMBUSTION, United Kingdom). The DMS 500 gave a number/size spectrum for particulates among 5 nm and 1000 nm and the response time of 200 milliseconds. A cyclone separator removed particulates over 1000 nm to decrease the cleaning required. A comprehensive characterization of its operational principle can be found at another place in the literature [51]. The gaseous emissions (HC and NO_x) were analyzed using an exhaust gas analyzer, Model AVL Digas 4000 (AVL, Austria), with an accuracy of 1 ppm.



(**a**)



(**b**)

Figure 2. (**a**) The research engine; (**b**) schematic of the experimental setup.

Table 1. Details of the experimental gasoline engine.

Cylinders	Four in a Row
Injection type	Aspirate port fuel injection
Bore × stroke	75.0 × 84.8 (mm)
Connecting road length	143.70 (mm)
Compression ratio	10.50:1
Work order	1-3-4-2
Rated power	78/600(kW/(rev min^{-1}))
Rated torque	135/4500 (Nm/(rev min^{-1}))
Intake valve opening	353 (°CA ATDC)
Intake valve closing	−141 (°CA ATDC)
Exhaust valve opening	135 (°CA ATDC)
Exhaust valve closing	−349 (°CA ATDC)
Ambient temperature	25 ± 3 (°C)
Lambda	1
Spark timing @ 2000 rev/min	31.3 (°CA BTDC)
Intake fuel pressure @ 2000 rev/min	3.09 (bar)
Intake air pressure @ 2000 rev/min	0.38 (bar)

Four experimental fuels (HE0, HE10, HE20, and E20) were used in this research. One hundred percent commercial gasoline was applied as the reference fuel for all of the blends, identified as HE0, and two hydrous ethanol (containing 5% water)-gasoline splash blends containing 10% (HE10) and 20% (HE20) hydrous ethanol by volume in gasoline. One fuel containing 20% (E20) anhydrous ethanol (containing 0% water) was prepared from the base fuel. The main chemical and physical properties of the gasoline, anhydrous ethanol, and hydrous ethanol are shown in Table 2. The excellent burning of fuel in an internal combustion engine depends on the fuel's chemical and physical properties [3]. It is well-known that ethanol contains oxygen, and that the chemical and physical properties of ethanol change the properties of blends to which it is added in terms of characteristics such as density, boiling curve, octane number, volatility, heating value, and enthalpy of combustion. Thereby, it directly influences the engine's performance characteristics, combustion, and the level of exhaust emissions [7].

Table 2. Properties of gasoline, anhydrous, and hydrous ethanol fuels [3].

Property	Gasoline	Anhydrous Ethanol	Hydrous Ethanol
Water content (vol/vol %)	0	0	4.0–5.0
Latent heat of vaporization (kJ/kg)	380–500	900–920	948
LHV (MJ/kg)	42.7–43.4	26.8	24.76–25.235
Stoichiometric–A/F ratio (w/w)	14.7	9	8.7–8.8
RON	88–100	108.6	111.1
MON	80–90	89.7	91.8–103.3
Carbon content (mass %)	87.4	52.2	50.59–50.7
Hydrogen content (mass %)	12.6	13	12.89–13
Oxygen content (mass %)	0	34.7	36.3–36.42
H/C (atom ratio)	1.795	3	3
O/C (atom ratio)	0	0.5	0.53
Sulphur content (ppm)	9	0	0

2.2. Methods and Operating Settings

In this research, the engine was initially run with gasoline to warm up until the coolant and lubricating temperatures have arrived at stable values, and then the data were measured. During all of the operating conditions, the temperature of water cooling was maintained between 80 °C and 85 °C, and the temperature of the lubricating oil was kept between 85 °C and 90 °C, relating to the engine loads. However, before the engine was run with a new fuel, it was run for several minutes to make sure no previous fuel remained. The investigations were done by test fuels at five various engine loads: 10 Nm, 20 Nm, 30 Nm, 40 Nm, and 50 Nm at an engine speed of 2000 rev/min. The engine speed of 2000 rev/min was selected alternatively to the urban-way mode, because there are further PM emissions and gaseous emissions emitted from an engine fueled by gasoline when the engine works on the urban-way mode [57]. To evaluate the combustion, the cylinder pressure was averaged over 200 cycles to decrease the impact of the cyclic variability. The tests for PM emissions were measured constantly for one minute at the engine exhaust emissions pipe of the port fuel injection engine, and after that the data were averaged. However, this spectrometer (DMS500) has a fully integrated two-stage dilution system. The primary dilution stage is purposed to avoid agglomeration and condensation matters (sampling gases diluted by warm air up to 150 °C and the dilution ratio is 5:1). The type of secondary diluter is a rotating disc, given a precise dilution ratio at all periods, which has high ratio dilution (12:1–500:1) that is aimed to let investigators sample from a very large range of PM concentrations. However, the optimum dilution ratio was monitored by a personal computer and the measured PM emissions are corrected for the all of the used dilution ratios. For the gaseous emissions, the experiments were repeated thrice to ensure the accuracy of the measurement, and their average was used. The primary uncertainty in the measurements have been determined using the method of root mean square error. The percentage uncertainties of particulate number concentration and count median diameter were ±3.9% and ±0.55%, respectively, and those of NO_x and HC were around ±1%. It can be found that the uncertainty of the experimental setup and the repeatability of the experimental data is acceptable.

3. Results and Discussion

3.1. In-Cylinder Pressure

The in-cylinder pressure statistic was averaged over 200 cycles to decrease the impact of cyclic variability. Figure 3 shows the comparisons of cylinder pressures for the fuels (HE0, HE10, HE20, and E20) at the engine speed of 2000 rpm for the engine loads of 20 Nm and 50 Nm. It was detected that the peak in-cylinder pressure with the use of HE0 was the highest compared with hydrous ethanol and anhydrous ethanol blends at both engine loads; this result may be attributed to the lower pressure in the intake manifold when ethanol is used as fuel, and the heat of vaporization of HE10, HE20, and E20 decreases the gas temperature in the cylinder, leading to a lower peak of in-cylinder pressure. Compared with E20, HE20 showed a lower peak of in-cylinder pressure in the case of low load due to a higher heat of evaporation. However, at a high load condition, HE20 performed better equated to low load, most likely due to the existence of water involved in hydrous ethanol that led to a flame propagation and an improved combustion process due to the raised amount of H, O, and OH radicals from water dissociation [13,58,59]. In addition, the test results announced by Rahman et al. [60] revealed that a faster combustion was achieved by adding a small amount of water in ethanol. In addition, under low equivalence ratio conditions, the flame speed for hydrous ethanol was higher than that of anhydrous ethanol. Otherwise, under high equivalence ratio conditions, the flame speed of anhydrous ethanol stayed higher [61]. In summary, the in-cylinder pressure was strongly affected by engine load. In addition, hydrous ethanol gasoline blends carried out well at high load condition equated to low load.

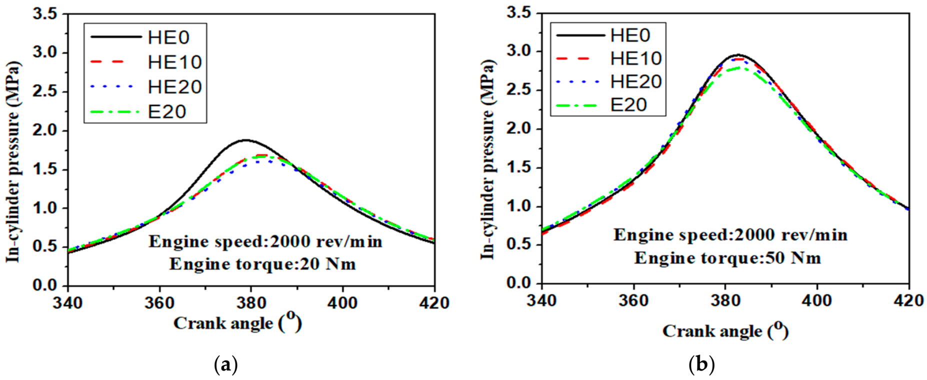


Figure 3. Impact of hydrous ethanol gasoline blends on in-cylinder pressure at an engine speed of 2000 rev/min and engine loads of (**a**) 20 Nm and (**b**) 50 Nm.

3.2. PM Emission Characteristics

The exhaust PN and size distributions for the four various fuels with respect to engine load at the speed of 2000 rev/min have been reported. Figure 4 shows the impact of the various experiment fuels on particle size and number distribution. The instrument DMS 500 that measures the PM emission in the size range of 5–1000 nm was used. As displayed in Figure 4, it is obviously indicated that the particle size and number distribution are reliant on the engine load condition and fuel used, as the majority of the particles are smaller than 10 nm in diameter. However, particles with sizes larger than 20 nm reduced importantly, and the biggest particulates emissions discharged by HE0 in important numbers were less than 100 nm in diameter. In addition, the concentration of nucleation particles is higher in comparison to accumulation mode particles at all engine loads. Figure 4 also shows that the concentration of nucleation mode particles reduces with engine load for all of the fuels tested. When the engine is working at the same load, a significant reduction of the PN distribution of the particles can be observed for the ethanol blends equated to gasoline (HE0). The results here are consistent with the PN distribution results reported in previous publications [43–49,62]. There are many causes leading to a decrease of the PN in the ethanol blends; compared with gasoline fuel, hydrous ethanol and anhydrous ethanol have no aromatic content, a higher laminar flame propagation speed, and a higher percentage of oxygen content. Thereby, these properties explain the decrease of PN in the blended fuels. The influence of hydrous ethanol compared to the pure ethanol is visible, and the presence of water included in the hydrous ethanol that led to a decrease of PM emissions due to the chemical effect of water. Roberts et al. [63] found that water could reduce the soot by chemical, thermal, or physical effects. In addition, Rao et al. [64] stated that with increased water concentration, the soot emission reduced from the flame. Further interesting research was issued by Andrews et al. [65], who observed that the reduction in particulate emissions increased as water percentage increased.

Figure 5 shows the total PN concentration of the particles at 2000 rev/min and various loads from 10 Nm to 50 Nm. As shown in Figure 5, in all cases, the concentration of the total PN decreases with an increase in engine operating loads. The reason behind it is the trend of the decrease of fuel burned with the rise in engine load that is not reported here, which is consistent with previously stated studies [14,66–68]. In addition, the lower particle concentration obtained with hydrous ethanol and anhydrous ethanol blends in comparison to gasoline due to the higher hydrogen to carbon ratio, higher volatility, higher percentage of oxygen content in the fuel, and no sulfur and aromatics in ethanol also favored the repression of PM formation inside the cylinder [69]. Another mechanism for the remarked decrease is the oxidation of PM emission by OH radicals from ethanol [70], and by H, O, and OH radicals from water dissociation [13,71,72]. According to chemical kinetics model results published by Zhang et al. [59], the addition of water in fuel encourages the formation of free radicals O, H, and OH, which encourages the oxidation of emissions. Anyhow, the impact of water on PM emission and combustion is not totally understood. Additional research on explaining the chemical kinetic role of water on emissions and combustion in internal combustion engines is still in progress.

In addition, Nour et al. [73] stated that the water contained in hydrous ethanol achieves longer ignition delays equated to pure ethanol, which makes the mixing between air and fuel more homogenous, thereby reducing the PN emissions. Moreover, when working, a gasoline engine with hydrous ethanol led to a decrease in PN concentration due to the chemical effect of water. The PN concentrations are reduced by 96.73%, 99.12%, and 74.51% in average for HE10, HE20, and E20, respectively. In summary, the hydrous ethanol gasoline blends showed the highest reduction of the concentration of total PN compared with the anhydrous ethanol gasoline blend and gasoline.

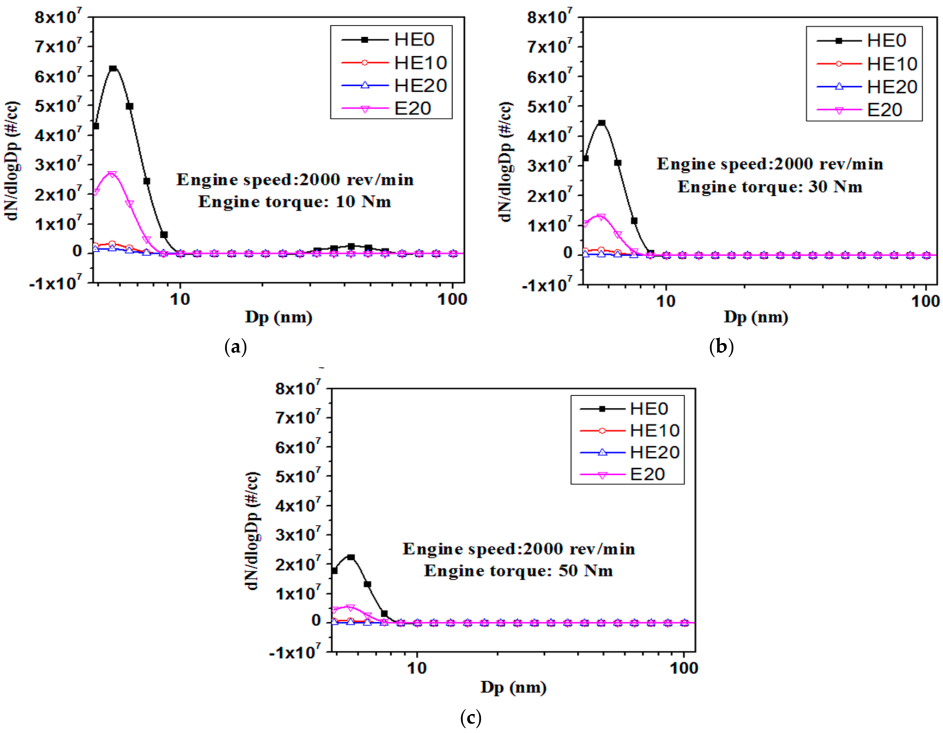


Figure 4. Size distribution of particles for ethanol blends at a 2000 rev/min engine speed and (**a**) 10 Nm; (**b**) 30 Nm; (**c**) 50 Nm engine loads.

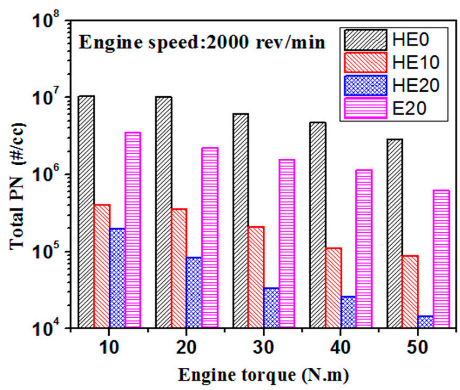


Figure 5. Difference of total particulate number (PN) concentration with engine load.

The PM emissions from the DI gasoline engine can be characterized based on size spectra as: nucleation mode particles (5 nm < *Dp* ≤ 30 nm), accumulation mode particles (30 nm < *Dp* < 100 nm) [52], and coarse mode particles (*Dp* > 1000 nm). To deeply investigate the reduction in total PN emissions, nucleation and accumulation mode particles are estimated in Figure 6. The smaller particles are much more hazardous than the bigger particles [52]. It is observed from Figure 6 that the concentration of nucleation particles is higher in comparison to that of accumulation particles at all engine loads. Figure 6 also reveals that the concentration of nucleation mode particles reduces with engine load, while in general the concentration of accumulation mode particles also decreases with engine load. The significant reduction in the concentration of nucleation and accumulation size particulates for the ethanol blends are consistent with a previously reported study [46].

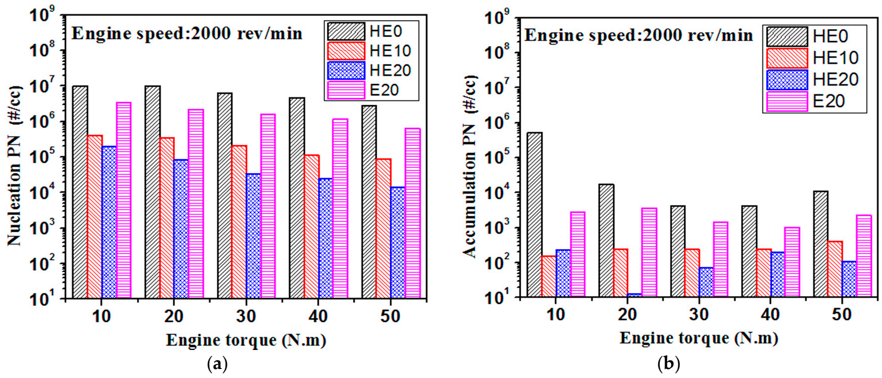


Figure 6. Variation of (**a**) nucleation mode; (**b**) accumulation mode number particles with engine load.

The mass concentration of PM has been computed by taking a limiting hypothesis that the particles are spherical and have a density of 1000 kg/m^3. However, density and particle fractal size are subject to engine operating conditions and particle diameters [74]; therefore, these values are nominal for comparison. However, Figure 7 shows the changes of the concentration of the mass particles with engine load for HE0, HE10, HE20, and E20. The outcomes of this investigation display that there is an important reduction in the concentration of mass particulates for the blended fuels. The PM mass concentrations are decreased by 48.87%, 83.09%, and 32.89% on average for HE10, HE20, and E20, respectively. The identical explanations which lead to a decrease of total PN for the blended fuels will also lead to a decrease in the total PM mass. The reduced amount of gasoline fuel burned inside cylinder helps to decrease the mass of carbon. Furthermore, ethanol has short C–C chemical bonds and has no sulfur; thereby, there is a decrease in PM formation. It can also be noticed that the larger reduction in the mass of the particles was found at higher hydrous ethanol blends. In general, it is observed from Figure 8 that the concentration of nucleation mode particulates reduces with engine operating load. In addition, the concentrations of nucleation and accumulation mode particles are lower for the HE20 blends at all engine loads.

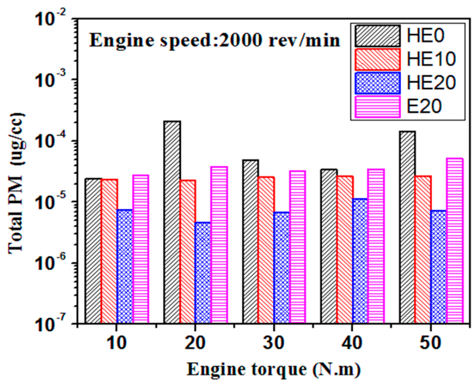


Figure 7. Difference of total particle mass with engine load.

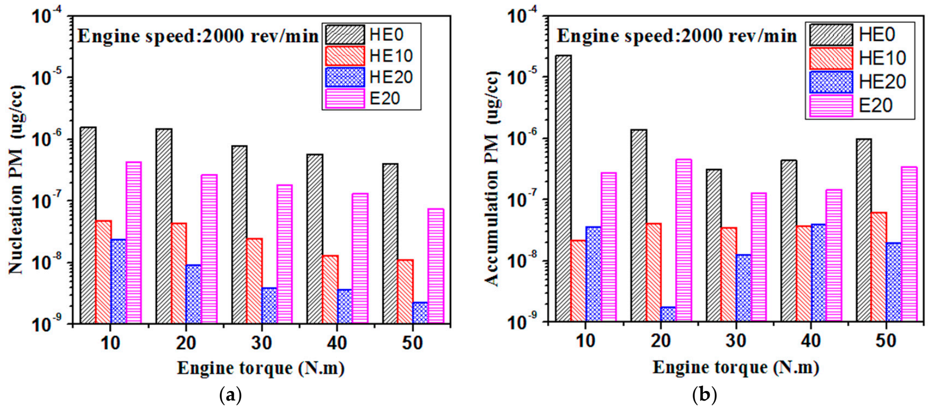


Figure 8. Variation of (**a**) nucleation mode; (**b**) accumulation mode mass particles with engine load.

Figure 9 shows the count median diameter (CMD) of the distributions of the tested fuels versus engine loads. For the computation of the CMD, all of the particulate sizes ranging from 5 nm to 1000 nm were calculated. In Figure 9, the CMD reduces with engine operating load. In addition, the HE20 emissions ensued in a smaller particles size equated to the HE0 case: the CMD ranged from 5.7 nm to 6.2 nm. The CMD distributions are reduced by 3.11%, 4.0%, and 3.02% on average HE10, HE20, and E20, respectively.

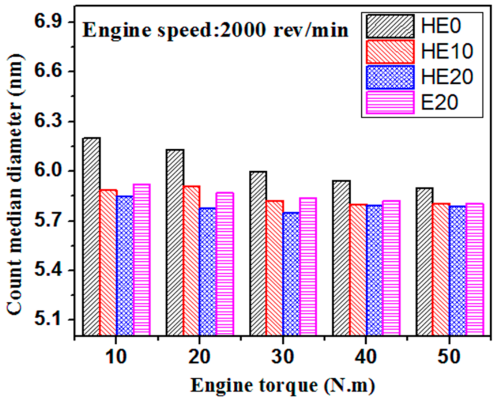


Figure 9. Variation of count median diameter with engine load.

3.3. Gaseous Emission Characteristics

For the four different fuels, the NO_x emissions for varying engine loads at the speed of 2000 rev/min are demonstrated in Figure 10. The rate of NO_x formation is a highly temperature-dependent phenomenon. It is obvious from Figure 10 that the NO_x emission is raised with a rise in engine load. This is due to a raised combustion temperature when the engine load increases, which outcomes in further NO_x formation in the engine cylinder. It is also clear that the NO_x emission is reduced with the use of hydrous ethanol and anhydrous ethanol blend as equated with pure gasoline. This result may be attributed to water present in the hydrous ethanol, and a higher latent heat of evaporation of the ethanol blends, which ensues in a lower combustion temperature and slows down the procedure of NO_x formation [19]. The NO_x emissions are decreased by 9.58%, 33.05%, and 7.09% on average for HE10, HE20, and E20, respectively. The outcomes obtained are consistent with the NO_x results stated in previous publications [11,12,14,22,24–27].

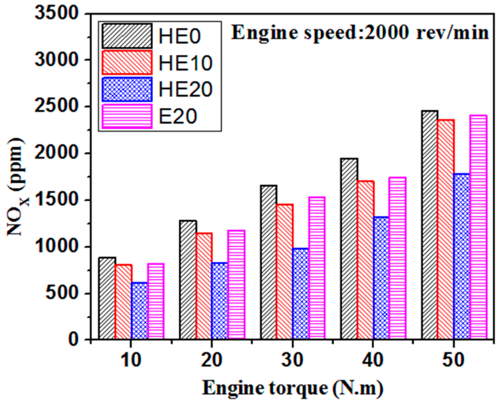


Figure 10. Difference of NO_x emission with engine load.

However, the HC emission is the result of incomplete combustion from the hydrocarbon fuel. The HC emission trends are highly changeable because they depend on combustion chamber design, charge heterogeneity, flame quenching, etc. [3]. The HC emissions are mainly a consequence of engine configuration, fuel composition, residence time, and oxygen availability [7]. As displayed in Figure 11, the HC emission for the tested fuels decreases with the increasing of engine load. At conditions of high load, higher combustion temperatures elevated the change rates, consequently decreasing the HC emission contrasted to the low load condition. HE20 also looks to be a favorable choice for HC emissions reduction, because HE20 has a lower ratio of carbon to hydrogen equated to HE0. Furthermore, hydrous ethanol fuel has oxygen content in it, which encourages combustion efficiency and decreases emissions of HC. The results achieved are in line with previous publications recorded in [12–14,17,19,25,29]. Compared with HE20, E20 indicated slightly lower HC emissions at low engine load conditions due to the best volatility of anhydrous ethanol fuel, leading to an enhancement of the air–fuel mixing, and thereby promoting combustion and encouraging the oxidization of HC. With the rise of engine load, the gas temperature in the cylinder rises, which leads to an increased number of O, H, and OH radicals from water dissociation in hydrous ethanol, which promotes combustion and therefore decreases HC emission. The HC emissions are decreased by 18.23%, 32.69%, and 27.97% on average for HE10, HE20, and E20, respectively.

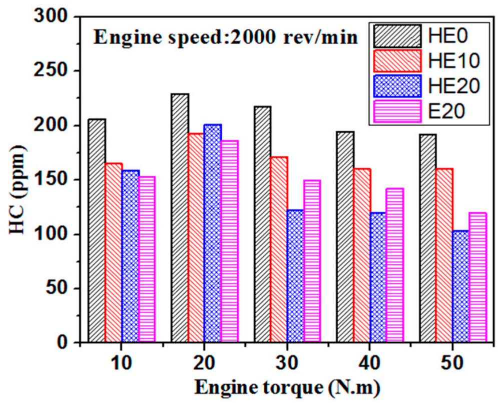


Figure 11. Variation of HC emission with engine load.

3.4. Correlations between PN-NO_x and PN-HC

Figure 12a shows the total PN emissions versus NO_x emissions for tested fuels at different operating conditions. As expected, the PN is inversely proportional to NO_x emission. The outcomes achieved are consistent with previous issues announced in [32,75]. Nabi et al. [75] found that the

PN was oppositely relative to NO, with a very high correlation coefficient. Hydrous ethanol blends showed the lowest PN concentration and the lowest NO_x than those of the anhydrous ethanol blend and gasoline. Tse et al. [76] stated simultaneous decreases in PN and NO_x emissions by increasing ethanol content from 0% to 20%. The significant parameter for PM and NO_x reduction and formation is in-cylinder gas temperature. However, the cylinder temperature increases when the engine load increases, leading to lower particulate numbers and higher NO_x emissions. Figure 12b displays the total PN for all of the experiment's operating conditions against HC emissions. The link reflects clearly that the lower the particulates number, the lower the HC emissions. The fuel properties had a more important impact on the PM emission's formation and HC emissions discharged. Ethanol blends have high oxygen content in fuel, no aromatic content, low carbon/hydrogen ratio, etc., which lead to a decrease in HC emissions and a decline in PM formation. The PM formation and HC emissions reduction also depends on the in-cylinder gas temperature. As mentioned above, the in-cylinder gas temperature raises with the raise of engine loads, leading to a decrease in particulate formation and also leading to an increase in the conversion rate of HC emissions.

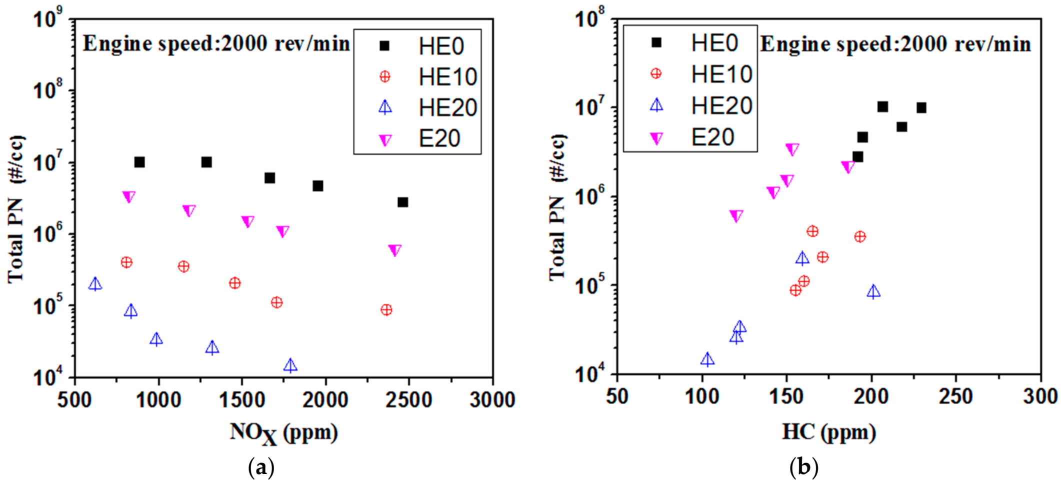


Figure 12. Correlation between total PN and (**a**) NO_x emission; (**b**) HC emission.

4. Conclusions

The in-cylinder pressure, particulate matter emission, and gaseous emissions of a PFI gasoline engine have been evaluated when commercial gasoline and hydrous ethanol gasoline blends are used at different operating conditions. However, the subsequent outcomes can be achieved from the experimental analysis. The operating conditions and fuel composition had an important impact on the engine's emission characteristics. The nucleation particle and accumulation particle concentrations reduce with engine load for all fuels. Overall, the particulate number and mass concentration decrease with an increase in engine operating loads. In addition, the lowest total PM number, total PM mass, and count median diameter were achieved with the hydrous ethanol gasoline blends in comparison to the anhydrous ethanol blend and gasoline. The exhaust NO_x emissions from the engine were increased with the increasing of engine load. The use of hydrous ethanol gasoline blends decreases NO_x and HC emissions when compared to gasoline. From the outcomes, it can be determined that HE20 fuel appears to be a good option for particulate matter and gaseous emissions reduction for gasoline engines.

Acknowledgments: This research was funded by the Fundamental Research Funds for Central Universities WUT grant No. (2015III040) and 111 project grant No. (B17034). Musaab O. El-Faroug would like to express his appreciation to the Chinese Scholarship Council and the Sudanese Government for financial encouragement for his Ph.D. studies.

Author Contributions: Maji Luo and Fuwu Yan conceived and designed the tests; Musaab O. El-Faroug and Yinan Wang performed the experiments and analyzed the data; all the experiment equipment included in this manuscript are provided by Professor Maji Luo; Musaab O. El-Faroug wrote the manuscript, Maji Luo help to revise this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chandra, R.; Takeuchi, H.; Hasegawa, T. Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1462–1476. [CrossRef]
2. Ghadikolaei, M.A. Effect of alcohol blend and fumigation on regulated and unregulated emissions of IC engines—A review. *Renew. Sustain. Energy Rev.* **2016**, *57*, 1440–1495. [CrossRef]
3. El-Faroug, M.; Yan, F.; Luo, M.; Fiifi Turkson, R. Spark ignition engine combustion, performance and emission products from hydrous ethanol and its blends with gasoline. *Energies* **2016**, *9*, 984. [CrossRef]
4. Masum, B.; Masjuki, H.; Kalam, M.; Fattah, I.R.; Palash, S.; Abedin, M. Effect of ethanol-gasoline blend on NO_x emission in SI engine. *Renew. Sustain. Energy Rev.* **2013**, *24*, 209–222. [CrossRef]
5. Saxena, S.; Schneider, S.; Aceves, S.; Dibble, R. Wet ethanol in HCCI engines with exhaust heat recovery to improve the energy balance of ethanol fuels. *Appl. Energy* **2012**, *98*, 448–457. [CrossRef]
6. Martinez-Frias, J.; Aceves, S.M.; Flowers, D.L. Improving ethanol life cycle energy efficiency by direct utilization of wet ethanol in HCCI engines. *J. Energy Resour. Technol.* **2007**, *129*, 332–337. [CrossRef]
7. Meng, L.; Zeng, C.; Li, Y.; Nithyanandan, K.; Lee, T.H.; Lee, C.-F. An experimental study on the potential usage of acetone as an oxygenate additive in PFI SI engines. *Energies* **2016**, *9*, 256. [CrossRef]
8. Al-lwayzy, S.H.; Yusaf, T. Combustion of microalgae oil and ethanol blended with diesel fuel. *Energies* **2015**, *8*, 13985–13995. [CrossRef]
9. Sharudin, H.; Abdullah, N.R.; Najafi, G.; Mamat, R.; Masjuki, H. Investigation of the effects of iso-butanol additives on spark ignition engine fuelled with methanol-gasoline blends. *Appl. Therm. Eng.* **2017**, *114*, 593–600. [CrossRef]
10. Li, Y.; Gong, J.; Deng, Y.; Yuan, W.; Fu, J.; Zhang, B. Experimental comparative study on combustion, performance and emissions characteristics of methanol, ethanol and butanol in a spark ignition engine. *Appl. Therm. Eng.* **2017**, *115*, 53–63. [CrossRef]
11. Schifter, I.; Diaz, L.; Gómez, J.; Gonzalez, U. Combustion characterization in a single cylinder engine with mid-level hydrated ethanol-gasoline blended fuels. *Fuel* **2013**, *103*, 292–298. [CrossRef]
12. Venugopal, T.; Sharma, A.; Satapathy, S.; Ramesh, A.; Gajendra Babu, M. Experimental study of hydrous ethanol gasoline blend (E10) in a four stroke port fuel-injected spark ignition engine. *Int. J. Energy Res.* **2013**, *37*, 638–644. [CrossRef]
13. Wang, X.; Chen, Z.; Ni, J.; Liu, S.; Zhou, H. The effects of hydrous ethanol gasoline on combustion and emission characteristics of a port injection gasoline engine. *Case Stud. Therm. Eng.* **2015**, *6*, 147–154. [CrossRef]
14. De Melo, T.C.C.; Machado, G.B.; Belchior, C.R.; Colaço, M.J.; Barros, J.E.; de Oliveira, E.J.; de Oliveira, D.G. Hydrous ethanol-Gasoline blends-Combustion and emission investigations on a flex-fuel engine. *Fuel* **2012**, *97*, 796–804. [CrossRef]
15. Augoye, A.; Aleiferis, P. *Characterization of Flame Development with Hydrous and Anhydrous Ethanol Fuels in a Spark-Ignition Engine with Direct Injection and Port Injection Systems*; SAE Technical Paper, 2014-01-2623; SAE International: Warrendale, PA, USA, 2014.
16. Clemente, R.C.; Werninghaus, E.; Coelho, E.P.; Ferraz, L.A.S. *Development of an Internal Combustion Alcohol Fueled Engine*; SAE Technical Paper, 2001-01-3917; SAE International: Warrendale, PA, USA, 2001.
17. Costa, R.C.; Sodré, J.R. Hydrous ethanol vs. Gasoline-ethanol blend: Engine performance and emissions. *Fuel* **2010**, *89*, 287–293. [CrossRef]
18. Costa, R.C.; Sodré, J.R. Compression ratio effects on an ethanol/gasoline fuelled engine performance. *Appl. Therm. Eng.* **2011**, *31*, 278–283. [CrossRef]
19. Kyriakides, A.; Dimas, V.; Lymperopoulou, E.; Karonis, D.; Lois, E. Evaluation of gasoline-ethanol-water ternary mixtures used as a fuel for an Otto engine. *Fuel* **2013**, *108*, 208–215. [CrossRef]

20. Amorim, R.J.; Baeta, J.G.C.; Valle, R.M.; Barros, J.; Carvalho, R. Analysis of an Otto cycle engine performance regarding alcohol concentration in gasoline and CNG usage. In Proceedings of the XVIII International Congress of Mechanical Engineering, Ouro Preto, Brazil, 6–11 November 2005.
21. Olberding, J.; Beyerlein, D.C.S.; Steciak, J.; Cherry, M. *Dynamometer Testing of an Ethanol-Water Fueled Transit Van*; SAE Technical Paper, 2005-01-3706; SAE International: Warrendale, PA, USA, 2005.
22. De Melo, T.C.C.; Machado, G.B.; de Oliveira, E.J.; Belchior, C.R.P.; Jos, M.; de Oliveira, D.G. *Different Hydrous Ethanol-Gasoline Blends-Ftir Emissions of a Flex-Fuel Engine and Chemical Properties of the Fuels*; SAE Technical Paper, 2011-36-0080; SAE International: Warrendale, PA, USA, 2011.
23. Lanzanova, T.D.; Vielmo, H.A.; Sari, R.L.; Dornelles, H.M.; Tatsch, G.A.; Martins, M.E.; Michels, L. *Performance Analysis of a Spark Ignited Engine Running on Different Water-in-Ethanol Mixtures*; SAE Technical Paper, 2013-36-0202; SAE International: Warrendale, PA, USA, 2013.
24. Chen, R.-H.; Chiang, L.-B.; Wu, M.-H.; Lin, T.-H. Gasoline displacement and NO_x reduction in an SI engine by aqueous alcohol injection. *Fuel* **2010**, *89*, 604–610. [CrossRef]
25. Liu, S.-H.; Shen, L.-Z.; Ye, N.-Y.; Bi, Y.-H.; Luo, X. Research on effects of E10 hydrous ethanol gasoline blend on performance and emissions of gasoline engine. *Chin. Intern. Combust. Engine Eng.* **2012**, *33*, 46–51. (In Chinese)
26. Suarez-Bertoa, R.; Zardini, A.; Keuken, H.; Astorga, C. Impact of ethanol containing gasoline blends on emissions from a flex-fuel vehicle tested over the worldwide harmonized light duty test cycle (WLTC). *Fuel* **2015**, *143*, 173–182. [CrossRef]
27. Brewster, S.; Railton, D.; Maisey, M.; Frew, R. *The Effect of e100 Water Content on High Load Performance of a Spray Guide Direct Injection Boosted Engine*; SAE Technical Paper, 2007-01-2648; SAE International: Warrendale, PA, USA, 2007.
28. El-Faroug, M.O.; Luo, M.-J.; Yan, F.-W.; Liu, Y.-P.; Destech Publicat, I. Experimental investigation on the stability of hydrous ethanol gasoline blends and emission products from SI engine. In Proceedings of the 2016 International Conference on Energy Development and Environmental Protection (Edep 2016), Beijing, China, 11–12 June 2016.
29. Hu, J.; Yan, W.-S.; Liu, L.-D.; Xu, Y.-F.; Wang, Q.-F.; Liu, X.; Zhang, W.; Liang, X.-Y. Experiment study of E10 hydrous ethanol/gasoline blends on gasoline engine. *Int. Combust. Engine Powerpl.* **2007**, *1*, 001. (In Chinese)
30. Munsin, R.; Laoonual, Y.; Jugjai, S.; Imai, Y. An experimental study on performance and emissions of a small SI engine generator set fuelled by hydrous ethanol with high water contents up to 40%. *Fuel* **2013**, *106*, 586–592. [CrossRef]
31. Ruiz, F.A.; Cadrazco, M.; López, A.F.; Sanchez-Valdepeñas, J.; Agudelo, J.R. Impact of dual-fuel combustion with n-butanol or hydrous ethanol on the oxidation reactivity and nanostructure of diesel particulate matter. *Fuel* **2015**, *161*, 18–25. [CrossRef]
32. López, A.F.; Cadrazco, M.; Agudelo, A.F.; Corredor, L.A.; Vélez, J.A.; Agudelo, J.R. Impact of n-butanol and hydrous ethanol fumigation on the performance and pollutant emissions of an automotive diesel engine. *Fuel* **2015**, *153*, 483–491. [CrossRef]
33. Hwang, J.T.; Northrop, W.F. *Gas and Particle Emissions from a Diesel Engine Operating in a Dual-Fuel Mode Using High Water Content Hydrous Ethanol*; ASME Paper No. ICEF2014–5460; ASME: New York, NY, USA, 2014.
34. Pope III, C.A.; Ezzati, M.; Dockery, D.W. Fine-particulate air pollution and life expectancy in the United States. *N. Engl. J. Med.* **2009**, *2009*, 376–386. [CrossRef] [PubMed]
35. Brook, R.D.; Rajagopalan, S.; Pope, C.A.; Brook, J.R.; Bhatnagar, A.; Diez-Roux, A.V.; Holguin, F.; Hong, Y.; Luepker, R.V.; Mittleman, M.A. Particulate matter air pollution and cardiovascular disease. *Circulation* **2010**, *121*, 2331–2378. [CrossRef] [PubMed]
36. Goldberg, S.V. Cancer Tip: Nanoparticles Can Damage DNA, Increase Cancer Risk. Press Release. 2007. Available online: https://www.sciencedaily.com/releases/2007/04/070417154357.htm (accessed on 24 August 2017).
37. United States Environmental Protection Agency. Particulate Matter. Available online: http://cfpub.Epa.Gov/airnow/index.Cfm?Action=aqibasics.Particle (accessed on 10 August 2017).
38. Myung, C.-L.; Ko, A.; Lim, Y.; Kim, S.; Lee, J.; Choi, K.; Park, S. Mobile source air toxic emissions from direct injection spark ignition gasoline and LPG passenger car under various in-use vehicle driving modes in Korea. *Fuel Process. Technol.* **2014**, *119*, 19–31. [CrossRef]

39. Fang, S.C.; Cassidy, A.; Christiani, D.C. A systematic review of occupational exposure to particulate matter and cardiovascular disease. *Int. J. Environ. Res. Public Health* **2010**, *7*, 1773–1806. [CrossRef] [PubMed]
40. Valavanidis, A.; Fiotakis, K.; Vlachogianni, T. Airborne particulate matter and human health: Toxicological assessment and importance of size and composition of particles for oxidative damage and carcinogenic mechanisms. *J. Environ. Sci. Health Part C* **2008**, *26*, 339–362. [CrossRef] [PubMed]
41. Samuel, S.; Hassaneen, A.; Morrey, D.; Gonzalez-Oropeza, R. *The Effect of Gasoline Additives on Combustion Generated Nano-Scale Particulates*; SAE Technical Paper, 2009-01-1823; SAE International: Warrendale, PA, USA, 2009.
42. Attar, M.A.; Xu, H. Experimental investigation of impacts of engine hardware, operating parameters and combustion performance on particulate emissions in a DISI engine. *Appl. Energy* **2016**, *177*, 703–715. [CrossRef]
43. Price, P.; Twiney, B.; Stone, R.; Kar, K.; Walmsley, H. *Particulate and Hydrocarbon Emissions from a Spray Guided Direct Injection Spark Ignition Engine with Oxygenate Fuel Blends*; SAE Technical Paper, 2007-01-0472; SAE International: Warrendale, PA, USA, 2007.
44. Chen, L.; Stone, R.; Richardson, D. Effect of the valve timing and the coolant temperature on particulate emissions from a gasoline direct-injection engine fuelled with gasoline and with a gasoline-ethanol blend. *Proc. Inst. of Mech. Eng. Part D J. Automob. Eng.* **2012**, *226*, 1419–1430. [CrossRef]
45. Muralidharan, M.; Subramanian, M.; Kanal, P.; Malhotra, R. *Characterisation of Particulates with Different Blends of Ethanol-Gasoline in Two Wheelers*; SAE Technical Paper, 2009-01-0686; SAE International: Warrendale, PA, USA, 2009.
46. Catapano, F.; Di Iorio, S.; Lazzaro, M.; Sementa, P.; Vaglieco, B.M. *Characterization of Ethanol Blends Combustion Processes and Soot Formation in a Gdi Optical Engine*; SAE Technical Paper, 2013-01-1316; SAE International: Warrendale, PA, USA, 2013.
47. Storey, J.M.; Barone, T.; Norman, K.; Lewis, S. Ethanol blend effects on direct injection spark-ignition gasoline vehicle particulate matter emissions. *SAE Int. J. Fuels Lubr.* **2010**, *3*, 650–659. [CrossRef]
48. Vuk, C.; Vander Griend, S.J. *Fuel Property Effects on Particulates in Spark Ignition Engines*; SAE Technical Paper, 2013-01-1124; SAE International: Warrendale, PA, USA, 2013.
49. Maricq, M.M.; Szente, J.J.; Jahr, K. The impact of ethanol fuel blends on PM emissions from a light-duty GDI vehicle. *Aerosol Sci. Technol.* **2012**, *46*, 576–583. [CrossRef]
50. Chen, L.; Stone, R.; Richardson, D. A study of mixture preparation and PM emissions using a direct injection engine fuelled with stoichiometric gasoline/ethanol blends. *Fuel* **2012**, *96*, 120–130. [CrossRef]
51. Bielaczyc, P.; Woodburn, J.; Klimkiewicz, D.; Pajdowski, P.; Szczotka, A. An examination of the effect of ethanol-gasoline blends' physicochemical properties on emissions from a light-duty spark ignition engine. *Fuel Process. Technol.* **2013**, *107*, 50–63. [CrossRef]
52. Geng, P.; Zhang, H.; Yang, S. Experimental investigation on the combustion and particulate matter (PM) emissions from a port-fuel injection (PFI) gasoline engine fueled with methanol-ultralow sulfur gasoline blends. *Fuel* **2015**, *145*, 221–227. [CrossRef]
53. Bahreini, R.; Xue, J.; Johnson, K.; Durbin, T.; Quiros, D.; Hu, S.; Huai, T.; Ayala, A.; Jung, H. Characterizing emissions and optical properties of particulate matter from PFI and GDI light-duty gasoline vehicles. *J. Aerosol Sci.* **2015**, *90*, 144–153. [CrossRef]
54. Xing, J.; Shao, L.; Zheng, R.; Peng, J.; Wang, W.; Guo, Q.; Wang, Y.; Qin, Y.; Shuai, S.; Hu, M. Individual particles emitted from gasoline engines: Impact of engine types, engine loads and fuel components. *J. Clean. Prod.* **2017**, *149*, 461–471. [CrossRef]
55. Karavalakis, G.; Short, D.; Chen, V.; Espinoza, C.; Berte, T.; Durbin, T.; Asa-Awuku, A.; Jung, H.; Ntziachristos, L.; Amanatidis, S. *Evaluating Particulate Emissions from a Flexible Fuel Vehicle with Direct Injection when Operated on Ethanol and Iso-Butanol Blends*; SAE Technical Paper, 2014-01-2768; SAE International: Warrendale, PA, USA, 2014.
56. Zhu, R.; Hu, J.; Bao, X.; He, L.; Lai, Y.; Zu, L.; Li, Y.; Su, S. Tailpipe emissions from gasoline direct injection (GDI) and port fuel injection (PFI) vehicles at both low and high ambient temperatures. *Environ. Pollut.* **2016**, *216*, 223–234. [CrossRef] [PubMed]
57. Geng, P.; Zhang, H. Combustion and emission characteristics of a direct-injection gasoline engine using the MMT fuel additive gasoline. *Fuel* **2015**, *144*, 380–387. [CrossRef]

58. Dryer, F. Water addition to practical combustion systems—Concepts and applications. *Symp. Int. Combust.* **1977**, *16*, 279–295. [CrossRef]
59. Zhang, W.; Shu, G.; Chen, Z.; Shen, Y.; Weng, J. Chemical kinetics of ignition timing of diesel engine fueled with water emulsion diesel. *Trans. Chin. Soc. Agric. Eng.* **2012**, *28*, 59–66. (In Chinese)
60. Rahman, K.M.; Kawahara, N.; Tsuboi, K.; Tomita, E. Combustion characteristics of wet ethanol ignited using a focused Q-switched Nd: YAG nanosecond laser. *Fuel* **2016**, *165*, 331–340. [CrossRef]
61. Bradley, D.; Lawes, M.; Liao, S.; Saat, A. Laminar mass burning and entrainment velocities and flame instabilities of i-octane, ethanol and hydrous ethanol/air aerosols. *Combust. Flame* **2014**, *161*, 1620–1632. [CrossRef]
62. Liu, H.; Wang, Z.; Long, Y.; Xiang, S.; Wang, J.; Fatouraie, M. Comparative study on alcohol-gasoline and gasoline-alcohol dual-fuel spark ignition (DFSI) combustion for engine particle number (PN) reduction. *Fuel* **2015**, *159*, 250–258. [CrossRef]
63. Roberts, C.E.; Naegeli, D.; Chadwell, C. *The Effect of Water on Soot Formation Chemistry*; SAE Technical Paper, 2005-01-3850; SAE International: Warrendale, PA, USA, 2005.
64. Rao, V.; Bardon, M. The effect of water on gas phase soot formation in laminar diffusion flames. *Combust. Flame* **1984**, *55*, 73–78. [CrossRef]
65. Andrews, G.; Bartle, K.; Pang, S.; Nurein, A.; Williams, P. *The Reduction in Diesel Particulate Emissions Using Emulsified Fuels*; SAE Technical Paper, 880348; SAE International: Warrendale, PA, USA, 1988.
66. Huang, J.; Wang, Y.; Li, S.; Roskilly, A.P.; Yu, H.; Li, H. Experimental investigation on the performance and emissions of a diesel engine fuelled with ethanol-diesel blends. *Appl. Therm. Eng.* **2009**, *29*, 2484–2490. [CrossRef]
67. Qi, D.; Bae, C.; Feng, Y.; Jia, C.; Bian, Y. Combustion and emission characteristics of a direct injection compression ignition engine using rapeseed oil based micro-emulsions. *Fuel* **2013**, *107*, 570–577. [CrossRef]
68. Agarwal, A.K. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Prog. Energy Combust. Sci.* **2007**, *33*, 233–271. [CrossRef]
69. Rahman, M.M.; Stevanovic, S.; Brown, R.; Ristovski, Z. Influence of different alternative fuels on particle emission from a turbocharged common-rail diesel engine. *Procedia Eng.* **2013**, *56*, 381–386. [CrossRef]
70. Surawski, N.C.; Miljevic, B.; Roberts, B.A.; Modini, R.L.; Situ, R.; Brown, R.J.; Bottle, S.E.; Ristovski, Z.D. Particle emissions, volatility, and toxicity from an ethanol fumigated compression ignition engine. *Environ. Sci. Technol.* **2009**, *44*, 229–235. [CrossRef] [PubMed]
71. Rajan, S. Water-ethanol-gasoline blends—Physical properties, power, and pollution characteristics. *J. Eng. Gas Turbines Power* **1984**, *106*, 841–848. [CrossRef]
72. Li, Y.; Nithyanandan, K.; Lee, T.H.; Donahue, R.M.; Lin, Y.; Lee, C.-F.; Liao, S. Effect of water-containing acetone-butanol-ethanol gasoline blends on combustion, performance, and emissions characteristics of a spark-ignition engine. *Energy Convers. Manag.* **2016**, *117*, 21–30. [CrossRef]
73. Nour, M.; Kosaka, H.; Sato, S.; Bady, M.; Abdel-Rahman, A.K.; Uchida, K. Effect of ethanol/water blends addition on diesel fuel combustion in RCM and DI diesel engine. *Energy Convers. Manag.* **2017**, *149*, 228–243. [CrossRef]
74. Virtanen, A.; Ristimäki, J.; Marjamäki, M.; Vaaraslahti, K.; Keskinen, J.; Lappi, M. *Effective Density of Diesel Exhaust Particles as a Function of Size*; SAE Technical Paper, 2002-01-0056; SAE International: Warrendale, PA, USA, 2002.
75. Nabi, M.N.; Zare, A.; Hossain, F.M.; Rahman, M.M.; Bodisco, T.A.; Ristovski, Z.D.; Brown, R.J. Influence of fuel-borne oxygen on european stationary cycle: Diesel engine performance and emissions with a special emphasis on particulate and no emissions. *Energy Convers. Manag.* **2016**, *127*, 187–198. [CrossRef]
76. Tse, H.; Leung, C.; Cheung, C. Investigation on the combustion characteristics and particulate emissions from a diesel engine fueled with diesel-biodiesel-ethanol blends. *Energy* **2015**, *83*, 343–350. [CrossRef]