Investigation of DISI Engine Particle Emissions

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Abstract

The reduction of particle emissions is nowadays an important issue with respect to emissions from gasoline powered motor vehicle. Using new development technologies and renewable oxygenated fuels are considered the most suitable solution for sustainable future. This is a part of an ongoing research focused on the comparison of particle emissions from gasoline and ethanol DISI (Direct Injection Spark Ignition) engine. Amount of particle emissions would be reduced by using ethanol DISI engine. In addition, physical structure of particle emissions emitted from gasoline and diesel diffusion flames were investigated by using a Scanning Electron Microscopy (SEM) and a Transmission Electron Microscopy (TEM). The DISI engine was tested on engine dynamometer with different loads and injection behaviors, with homogenous and stratified charge. Then, the particle emissions were sampled by smoke meter in order to investigate physical structure and measure the amount of particle emissions. The results showed that particle emissions emitted from ethanol are lower than gasoline. The average primary size of gasoline and diesel fuels particle emissions are approximately 25-60 nm and 50-60 nm, respectively. The accumulated sizes of gasoline and diesel fuels particle emissions are approximately 100-360 nm and 100-500 nm, respectively. The findings of this study can serve as guidance for the reduction particle emissions from gasoline DISI engines by using ethanol.

Keywords: Particle Emissions, Ethanol, DISI Engine

1. Introduction

Nowadays, the fuel consumption in transportation field is one of the main reasons to both realize the depleting fossil fuel and increasing amount of emissions. In particular, the limitations of new emission standards have set the emission levels further to reduce both spark ignition and diesel engines such as euro 6.

It is imperative, then, to find out alternative fuels instead of using fossil fuels. Ethanol is one of the most suitable alternative fuels for spark ignition engines because of the advantages of ethanol, e.g. better knock limit range due to higher octane number of ethanol, higher volumetric efficiency due to cooling effect of higher heat of vaporization and also reduced particle emissions due to more complete combustion from oxygen atom inside ethanol molecule.

The development of new clean spark ignition engines, such as direct injection spark ignition (DISI) engines is important because of the advantages of DISI engines, e.g. higher thermal efficiency due to direct fuel injection, higher power output than conventional homogeneous charge port injection spark ignition (PSI) engines and lower fuel consumption due to an ultra-lean combustion in stratified charge operating mode [1].

The use of ethanol in direct injection spark ignition engines is to reduce regulated pollutant emissions produced by internal combustion engines, as well as to reduce the greenhouse effect impact of transportation. Needless to say, NOx and HC emissions [2] are prejudicial effects on the environment and human health.

In addition to engine combustion, diffusion flame in stratified charge operation of DISI engine is similar to compression ignition (CI) engine that causes particle emissions consisting of a solid fraction (SOL) and a soluble organic fraction (SOF). Primary particles, composed of carbon and metallic ash, are coated with SOF and sulphate. A primary soot particle has two distinct parts: an inner core located at the central region of the primary particle and outer shell. The composition of particle emissions may vary widely depending on the operating conditions and fuel composition [3-7].

The objectives of this research are to characterize and measure amount of gasoline and ethanol DISI particle emissions. The advantage of ethanol is discussed in the view point of particle emissions.

2. Experimental Apparatuses

2.1 Fuels

The use of ethanol in the experiment was considered due to the reduction of particle emissions and fossil fuel consumption in automotive. The domestic production can reduce amount of transportation activities of gasoline fuels. Higher octane number than gasoline can perform a better anti-knock for increased compression ratio and performance subsequently. Since ethanol has a higher heat of vaporization, higher densities in the intake can increase the volumetric efficiency. Moreover, ethanol is an oxygenated fuel, a fuel that contains oxygen molecule, therefore excess air can react with CO in residual emissions. However, a lower heating value of ethanol, compared with gasoline, governs ethanol to be injected more than gasoline to achieve the same amount of total energy. Fuels properties are shown in Table 1.

Table 1. Fuels properties [8]

Fuel properties	Ethanol	Gasoline
Formula	C_2H_5OH	C_4 to C_{12}
Molecular weight [g/mol]	46.70	100-105
Carbon [mass%]	52.20	85-88
Hydrogen [mass%]	13.10	12-15
Oxygen [mass%]	34.70	2.70
Density, kg/l, 15/15ºC	0.79	0.72-0.77
Boling point, ºC	78	27-225
Vapor pres., kPa at 38ºC	15.90	48-103
Specific heat, kJkg-1K-1	2.40	2
Viscosity, mPa s at 20	1.19	0.37-0.44
Low, heating val., 103 kJ/l	21.10	30-33
Auto ignition temp.,	423	257
Research octane number	108.60	98
Motor octane number	92	87
(R+M)/2	100	92.50
Cetane number	-	5-20
Flammability lim., Vol%	4.30/19	1.40/7.60
Water Tolerance, Vol%	Compl.miscible	Negligible
Stoichiometric air/fuel ratio	9	14.70
Carbonyl [ppm] as C-O	567	-
Carbonyl [ppm] as acetone	1117	-
Carbonyl [ppm] as acetaldehyde	893	-
Sulphur [mg/kg]	<0.80	10
Copper [mg/kg]	<0.10	-

2.2 Engine

A direct injection spark ignition (DISI) engine, inline 4 cylinders, 4 strokes, 1834 cm^3 displacement, was used in the experiment as the source of emissions, with the engine specification shown in Table 2. An increased fuel efficiency and high power output [4], by increased compression ratio, are the main advantages of DISI engines. In addition, the cooling effect of the injected fuel and the more evenly dispersed mixtures allow for more aggressive ignition timing curves [9]. Emissions levels can also be more accurately controlled with the DISI system. The cited gains are achieved by the precise control over amount of fuel and injection timings, which are varied according to the load conditions.

In addition, there are no throttling losses in some DISI engines, when compared to a conventional fuel injected or carburetor engines, which would greatly improve efficiency in engines without a throttle plate [10].

Table 2. Engine specification

Model	4G93 GDI
Type	In-line OHV, DOHC
Number of cylinders	4
Combustion chamber	Pentroof type
Displacement	1.834 Liter
Bore	81.0 mm
Stroke	89.0 mm
Compression ratio	12 : 1
Maximum output	96 kW @ 6000 rpm
Maximum torque	177 Nm @ 3750 rpm

2.3 Engine Dynamometer

An engine dynamometer was used in the experiment (Model: Tokyo Plant 150 PS, as shown in Fig.1) to measure force, moment of force (torque), or power, as well as control engine speeds and loads. The power produced by an engine can be calculated by simultaneously torque measuring and rotational speed (RPM) of engine.

Fig.1. Engine dynamometer

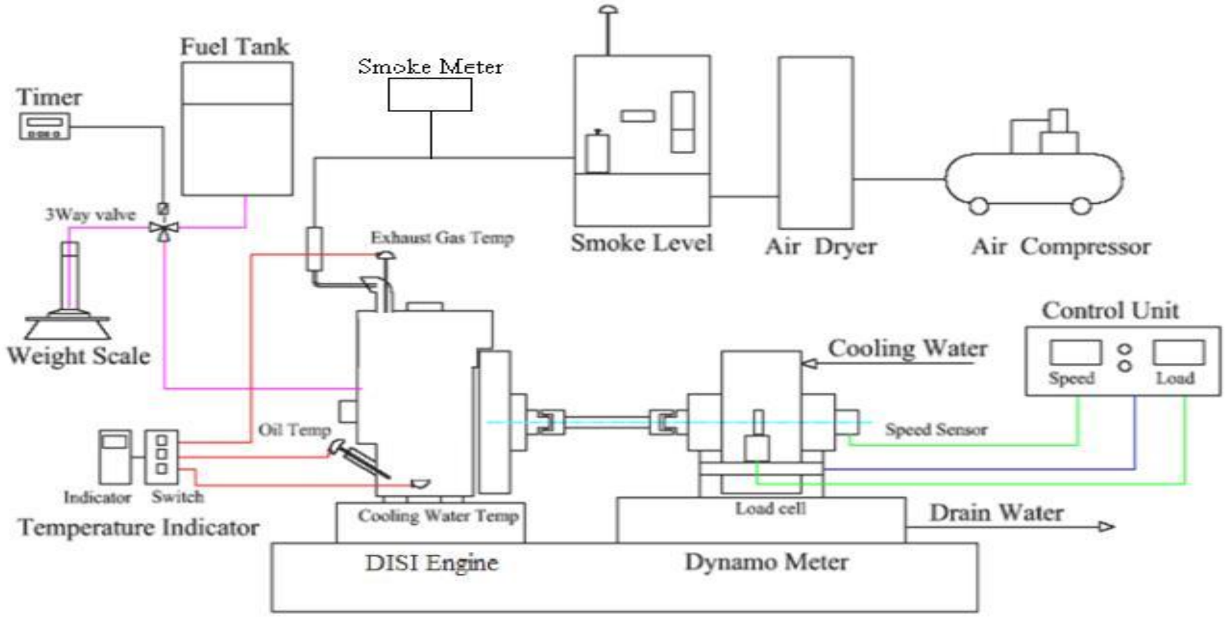


Fig.2 Schematic diagram of experimental setup

3. Research Methodology and Procedures

A direct injection spark ignition (DISI) engine, inline 4 cylinders, 4 strokes, 1834 cm^3 displacement was measured emissions at 1000 rpm idle and 1500 rpm under 10, 20% loads, using gasoline and ethanol, respectively. The 1000 rpm idle condition was selected to study a critical condition, in terms of stability, for DISI engine, and the 1500 rpm under 10, 20% loads were chosen as representative points for urban driving conditions. The injection behaviors were controlled for both homogenous and stratified charges. All the conditions investigated were carried out at λ=1. Particle emissions were sampled directly from the exhaust pipe, and then measured for concentration of particle emissions with smoke meter, as shown in Fig.2. On the other hand, gasoline and diesel diffusion flame particle emissions were generated by gasoline and diesel lamps in order to investigate the primary and accumulated particle emissions size by SEM, TEM and image analysis method, summation of longest and shortest lengths divided by two. In addition TEM and SEM images of ethanol particle emissions generated by lamp are in the progress.

4. Results and Discussions

4.1 Structure of Particle Emissions

Fig.3 shows gasoline and ethanol diffusion flames by Schlieren method image. The core of ethanol diffusion flame was lighter than that of gasoline, where particle emissions are formed at the center of diffusion flame. Similarly, Fig.4 shows gasoline and ethanol diffusion flames by optical image. The length of ethanol diffusion flame was shorter than that of gasoline due to ethanol contains less carbon content than gasoline and ethanol also contains oxygen atoms that promote more complete combustion.

Gasoline and diesel particle emissions images were taken in SEM and TEM method in order to verify primary and accumulated size and formation of particle emissions. Gasoline and diesel particle emissions were generated by fuel lamp. Figs.5(a) and 5(b) shows SEM image of gasoline and diesel accumulated particle emissions, respectively. Accumulated sizes of gasoline were slightly smaller than that of diesel, 100-360 nm vs. 100-500 nm.

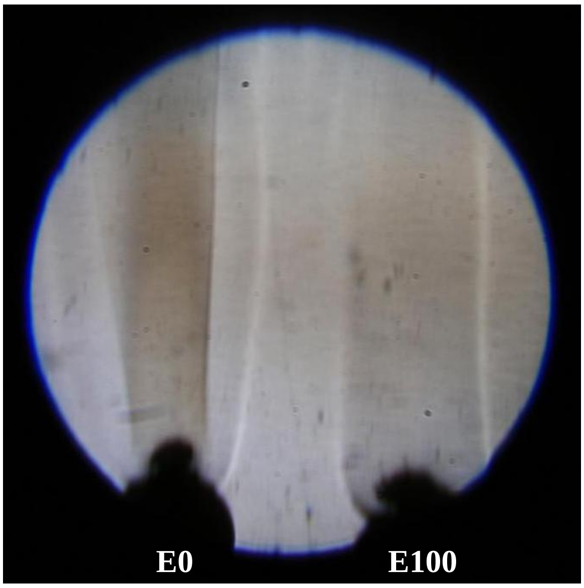
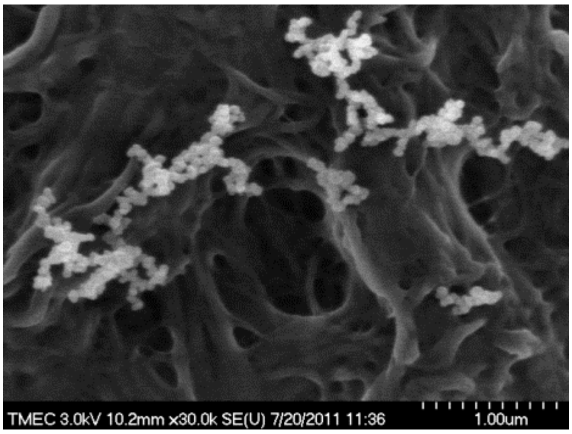
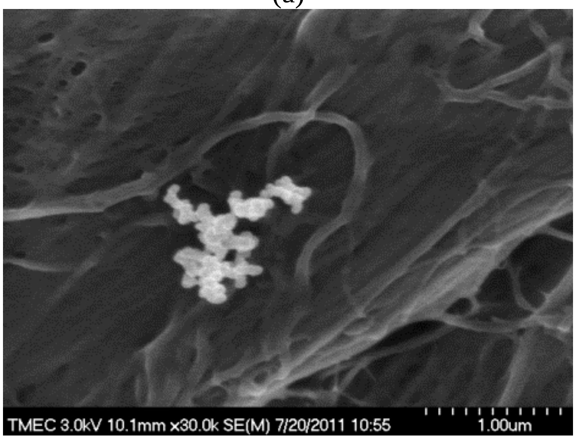


Fig.3 Gasoline (left) and ethanol (right) diffusion flames captured by Schlieren method

Fig.4 Gasoline (left) and ethanol (right) diffusion flames captured by conventional digital camera

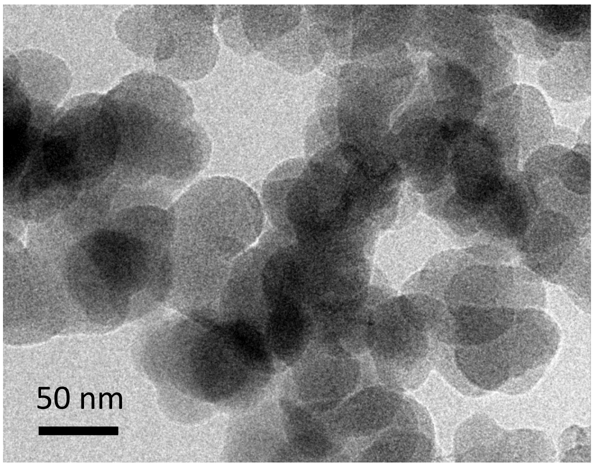


(a)

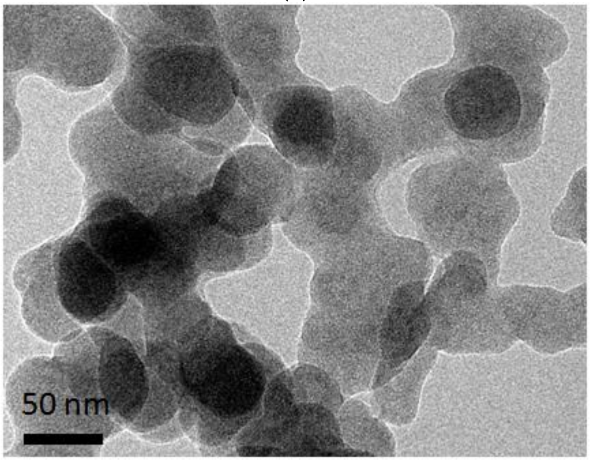


(b)

Fig.5 SEM image of (a) gasoline and (b) diesel particle emissions



(a)



(b)

Fig.6 TEM image of (a) gasoline and (b) diesel particle emissions [11]

However, the primary size of particle emissions is very difficult to measure by SEM image because surface of particle emissions were cover by unburned hydrocarbon. Then, primary size of particle emissions was measured later by TEM image. Primary size of gasoline and diesel particle emissions was shown in Fig.6(a) and Fig.6(b), respectively. TEM image was used to verify primary size because they were not covered by unburned hydrocarbon. Primary size of gasoline is slightly smaller than that of diesel, 25-60 nm vs. 50-60 nm.

4.2 Particle Emissions Concentration

The particle emissions were formed in the rich fuel region in the combustion chamber. The exhaust gas was emitted in the exhaust pipe. The remaining particle emissions of gasoline and ethanol were trapped by using a paper filter, as showed in Fig.7, directly from the exhaust pipe. Subsequently, smoke meter was applied to measure the concentration of trapped particle emissions on the paper filter by light opacity method. The zero and 100 percentages of black smoke means no and full of particle emissions on the filter paper, respectively.

Fig.8 shows the black smoke percentage of gasoline and ethanol under no load condition when varying engine speeds and injection behaviors. The results showed that the percentage of black smoke of gasoline was higher than that of ethanol for all cases. The maximum percentage of black smoke was 1000 rpm, stratified and gasoline condition. Fig.9 shows the black smoke percentage of gasoline and ethanol at 1500 rpm varying engine speeds, injection behaviors and loads. The results showed that the percentage of black smoke of gasoline was higher than that of ethanol for all cases. The maximum percentage of black smoke was 1500 rpm, stratified charge mode, 20% load and gasoline.

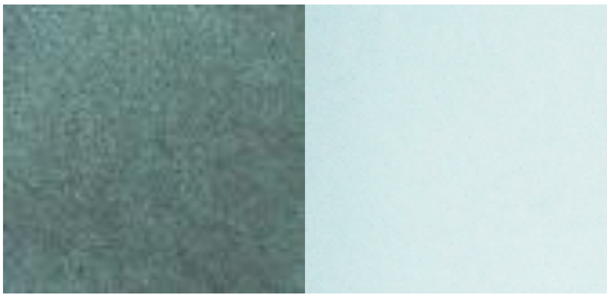


Fig.7 Tested paper of gasoline (left) and ethanol (right) particle emissions

Hence, gasoline particle emissions formation was higher than ethanol. This could be explained that more particle emissions were remained in gasoline combustion than those of ethanol. Since ethanol contains oxygen molecules, ethanol is readily oxidized with the available oxygen in the flame zone.

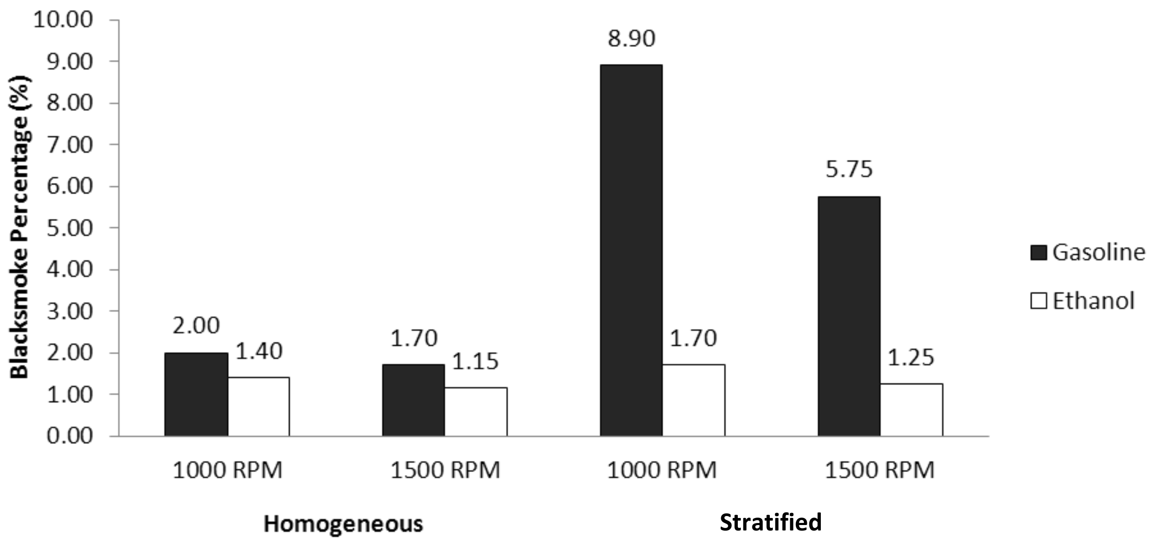


Fig.8 Quantities of gasoline and ethanol DISI particle emissions under no load condition

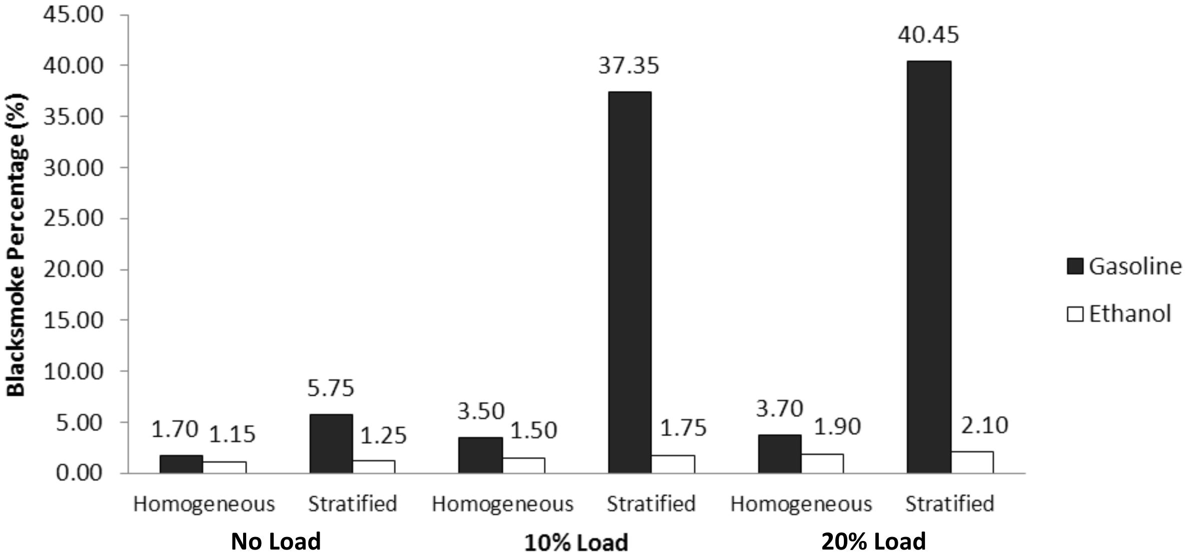


Fig.9 Quantities of gasoline and ethanol DISI particle emissions under 1500 rpm varying loads condition

5. Conclusions

The investigation of DISI engine fuelled gasoline and ethanol in this study shows the particle emissions concentration of gasoline and ethanol under varying engine speeds, loads and injection behavior. Particle emissions were analyzed by smoke meter. In addition, SEM and TEM images of gasoline and ethanol particle emissions from diffusion flame were used to verify the primary and accumulated particle emissions size. The main conclusions can be summarized as follows:

1 The primary and accumulated sizes of gasoline are homologous with that of diesel. The similarities of characteristic can be explained that particle emissions of any hydrocarbon by diffusion flame such as spray combustion are similar. That means gasoline can be the cause of particle emissions as diesel, and also cause of global gas emitting and environmental concern. Hence, the investigation of particle emissions of gasoline is as important as diesel

2 The remaining particle emissions of gasoline is higher than that of ethanol due to ethanol is the oxygenated fuel so oxygen molecules in ethanol can improve more complete combustion of the engine

3 The remaining particle emissions at engine speed 1000 rpm is lower than that at 1500 rpm since higher engine speed relates to higher tumble intensity that causes better mixing formation in combustion chamber.

4 The remaining particle emissions of 20% loads operating is higher than that of either 10% or no load due to much amount of fuel injected, rich fuel, causing particle emissions.

5 The remaining particle emissions under stratified charge operating mode is higher than homogeneous charge operating mode since the late injection made less fuel propagation than homogeneous charge operating mode. The rich fuel region around spark plug is the cause of particle emissions under stratified charge operating mode.

6 Since oxygenated fuel has a strong effect on particle emissions of combustion, using ethanol instead of gasoline may reduce emissions and pollutions from internal combustion engine.

7 Although the use of light opacity method in order to measure particle emissions concentration is an indirect measurement and that can cause some error in results, the method shows significant in the results which lead to good conclusions as well as mass measurement.

6. Acknowledgment

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