IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 6 Ver. I (Nov. - Dec. 2015), PP 72-79
www.iosrjournals.org

The impact of engine operating variables on emitted PM and Pb for an SIE fueled with variable ethanol-Iraqi gasoline blends

Miqdam T Chaichan
Mechanical Engineering Dept., University of Technology, Baghdad, Iraq

Abstract: *The replacement of gasoline with ethanol is increased worldwide indicating the need to understand the air quality impacts of this exchanging. In the recent study, variable experimental tests conducted to evaluate the impacts of several ethanol-gasoline blends (E20, E50, and E80) on particulate matter (PM) and lead (Pb) concentrations emitted from a four-stroke, single cylinder, water-cooled spark-ignition (SI) engine. PM and Pb exhaust emissions measured and analyzed at variable engine operation parameters.*

The emitted PM emissions reduced with increase concentration of ethanol in the blend. Compared to the baseline gasoline (E0), E20 gave relatively lower reductions in PM emissions, while E50 and E80 both reduced PM emissions under the conditions studied. Ethanol was observed to impact Pb emissions depending on the ethanol share in the blend.

Keywords:- *Ethanol-gasoline blends, gasoline engine, PM, Pb, emissions.*

I. Introduction

Many valuable epidemiological studies estimated the health impacts of ambient PM and showed the associations between the various health endpoint measures and the ambient concentrations of PM mass. Epidemiological studies of long-term and short-term found associations between $PM_{2.5}$ and PM_{10} and increments in all stroke-related deaths, cause mortality, and respiratory disease-related deaths [1, 2 & 3].

Many regulations lay out to force vehicle manufacturers to make new cleaner vehicles; these steps managed to reduce the emitted emissions even though the fuel use rates grow dramatically [4]. Previous works have shown that there is a close relationship between fuel quality and vehicle emissions [4, 5 & 6]. Gasoline quality includes octane, Reid vapor pressure, lead content, sulfur content, and shares of olefins, aromatics, and oxygenates [7]. Air pollution constituted of particulate matter (PM) suspended in air as solid and liquid particles [8]. The particulate matter (PM) formation is constantly changing both in the motor vehicle exhaust stream and in the ambient air. PM exhaust emissions from gasoline-powered cars have changed significantly over the past 25 years [9 & 10]. The reformulation of fuels resulted in these changes, especially the removal of lead additives, the broad application of exhaust gas treatment in gasoline-powered passenger cars and trucks, and changes in engine design and operation [11].

Lead, which was the major PM component in gasoline vehicle exhaust, was virtually eliminated with the introduction of unleaded gasoline mandated in the United States for the 1975 model year vehicles and the later phase-out of lead in all automotive gasoline. Lead (Pb) is a ubiquitous and versatile metal that is non-essential to human uptake, unlike other heavy metals that required nutrients such as chromium, manganese, molybdenum, nickel and selenium. Pb linked with blood poisoning and anemia [12], and exposure to excessive levels leads to damage of almost all organs and organs systems especially the central nervous system and kidneys. There is no safe blood lead level by which children are not affected [13 & 14].

The production of biofuels and encouraging its wide use is a significant approach to reducing the dependence on fossil fuels. Biofuels combustion results in significant reductions in emitted greenhouse gasses compared to fossil fuels [15]. Many researchers indicated a crucial reduction in emitted PM concentrations from diesel engines fueled with biodiesels [16]. However, the biofuels (as bio-ethanol) impact on petrol engine’s PM is rather controversial [17 & 18]. Ericsson et al., 2008, studied the tailpipe particulate emissions from the port and direct-injected vehicles with E5 and E85 fuels. They found lower PMs and total mass by using biofuels [19]. Czerwinski investigated the emitted nanoparticles emissions from two-stroke scooters fueled with ethanol blends [20]. The study results show that the addition of ethanol led to little effects on the emitted nanoparticles emissions. Muralidharan studied the characterization of particulates with different blends of ethanol-gasoline in scooters. The increase of ethanol percentage in gasoline from 5 to 30 percent did not affect the average PM concentration [21]. Until today, there is a necessity for more studies to reveal the influences of biofuels on the emitted PM emissions from SIE.

Many countries as United States, Canada, and European adopted E85 (85% ethanol and 15% gasoline) as the highest using blend in current and future flex-fuel vehicles. In the US, ethanol production from corn approached about a half billion gallons, this quantity managed the production of over 10.5 billion gallons. Ethanol use rose since the mid-1980, because of this huge production [22]. In Iraq, there are excellent opportunities for producing bio-ethanol from rice, corn and palms. Nowadays ethanol produced in Iraq as an alcoholic drink called Araq [23].

Until recently there has been less interest in the analogous question of ethanol's influence on gasoline vehicle emissions. As long as the soot is naturally low from the stoichiometric combustion that occurs in spark ignition engines [24]. There are few studies of ethanol effects on engine PM emissions to date. Studies by Chen [25] and Price [26] report PM reductions for E20 blends (20% ethanol), but their results for E10 are mixed. Chen [25] found that particle emissions can be increased or decreased depending on fuel injection timing, which they attribute to competing influences of fuel vaporization and oxygen content. Chaichan studied the effect of single cylinder engine variables on PM and Pb concentrations. The study demonstrated that PM concentration increased with increasing equivalence ratio and engine speed and torque. Also, it confirmed that engine variables have no effect on emitted Pb concentrations, and these concentrations depend only on leaded gasoline quantity burned [23].

The evaluation of the effect of many engine variables on PM and Pb concentrations is the primary objective of this study. The engine fueled with variable ethanol-Iraqi conventional gasoline blends. The study answers whether it is possible to substitute Iraqi gasoline with a green fuel.

II. Expermintal Setup

2.1. Experimental apparatuses

The experimental tests performed using petrol engine, type (PRODIT GR306/0001). The engine is a single cylinder, and water cooled spark ignition of four strokes and variable compression ratio. Fig. 1 shows the general arrangement of the experimental rig while Table-1 lists the engine specifications. The engine connected to an air tank used to damp out the air pressure fluctuations before it enters the carburetor. The air drawn into the cylinder volume measurement calculated from the pressure drop across an orifice utilizing a manometer. The engine supplied fuel flows from the main fuel tank across a graduated measuring fuel gauge (burette). A hydraulic dynameter used to measure the engine output torque. Exhaust gas temperatures measured using type K thermocouples at the beginning of the exhaust tube. All the devices mentioned above calibrated in the laboratory by comparing its readings with that of a set of calibrated ones.

Table1 Engines pacifications

Manufacturer	PRODIT	No load speed range	500-3600 rpm (Otto cycle)
Cycle	OTTO or DIESEL, four strokes	Load speed range	1200-3600 rpm (Otto cycle)
Number of cylinder	1 vertical	Intake star	54^{o} before T.D.C
Diameter	90mm	Intake end	22^{o} after T.D.C
Stroke	85mm	Exhaust start	22^{o} before T.D.C
Compression ratio	4-17.5	Exhaust end	54^{o} after T.D.C
Max .power	4 kWat 2800 rpm	Fixed spark advance	10^{o} (spark ignition)
Max .torque	28 Nm at 1600 rpm	Swept volume	541cm^3

Fig. 1, single cylinder Prodet spark ignition engine

Fig. 2, drawing air equipment to collect PM type Sniffer

Fig. 2 represents "Sniffer L-30" that is the low volume air sampler used to collect emitted PMs. Micro-filters type Whatmann-glass used to collect PMs. The used filters weighted before and after the end of sampling process that extend to one hour. The used filter temporarily kept in a plastic bag to the end of collecting samples process until weighed and analyzing the results. The following equation determines the particulate matters (PMs) concentrations [28]:

$$PM \ \ in \ (\mu g / m^3) = \frac{w_2 - w_1}{Vt} \times 10^6$$

- *Vt* calculated by the equation:

$$Vt = Q_t \cdot t$$

Fig. 3 represents the luminous microscope (Eclipse model ME600) built by Nicon company/Japan used to study the air particulates specifications. Fig. 4 shows the atomic spectrum absorption system manufactured by Shimadzu company type (AA-6200) made in Japan used to evaluate the lead concentrations in particles samples.

Fig. 3, light microscope used to study PM specifications

Fig. 4, the system used in evaluating of Pb concentrations in particulates (the atomic spectrum absorption system)

Combustion tests carried out using the Iraqi gasoline with octane number (ON=82) produced by Al Doura refinery/Baghdad. Iraqi gasoline characterized by its low octane number and high lead content. Gasoline properties checked in the Fuel Laboratory in the Mechanical Engineering Department, University of Technology. Table-2 reveals the gasoline and ethanol typical properties. Ethanol (99.7% purity) used in this work. It was distillated from Iraqi drink named (Araq) for several times to purify it from any residuals. Ethanol–gasoline blended fuel was prepared by mixing the ethanol (20, 50 & 80% by volume); these blends were named E20, E50 & E80.

2.3. Test procedure

The tests were carried out under steady-state conditions. The engine was allowed to run until it reached steady-state conditions, and then, the data were collected subsequently. The engine was firstly warmed up with the coolant and lubricating temperatures stabilized.

The experimental tests started with neat gasoline (E0) at a compression ratio (CR= 8:1) which is the higher useful compression ratio for gasoline fuel. The second set of tests was conducted this compression ratio for each ethanol-gasoline blend. All tests carried out at optimum spark timing. The following round of tests performed to evaluate equivalence ratio effects on PM and Pb concentration at optimum spark timing. The next tests carried out at a stoichiometric air-fuel ratio to assess the effect of engine torque, speed and spark timing on PM and Pb concentrations.

Engine speed impact studies at different speeds, starting by 1250 till 2500 rpm. The torque fixed constant at (15 Nm) and engine speed varied (1250, 1500, 1750, 2000 and 2500 rpm). In the other set of experiments, the engine speed fixed at (1500 rpm) and engine torque changed (10, 15, 20, 22.5 and 25 Nm). The last set of tests: the experiments conducted on the engine with changing spark timing from 5°BTDC to 50°BTDC to estimate its effects on PM and Pb concentrations.

Table 2 Properties of typical gasoline and ethanol

Property	Gasoline	Ethanol
Chemical formula	various	C_2H_5OH
Oxygen content by mass [%]	0	34.8
Density at NTP [kg/l]	0.74	0.79
Lower heating value [MJ/kg]	42.9	26.95
Volumetric energy content [MJ/l]	31.7	21.3
Stoichiometric AFR [kg/kg]	14.7	9
Energy per unit mass of air [MJ/kg]	2.95	3.01
Research octane number	89-95	109
Motor octane number	85	89.7
Boiling point at I bar [ºC]	25-215	79
Heat of vaporization [kJ/kg]	180-350	838
Reid vapor pressure [psi]	7	2.3
Flammability limits in air [λ]	0.26-1.6	0.28-1.99
Laminar flame speed at NTP, Ø=1 [cm/s]	28	40
Adiabatic flame temperature [ºC]	2002	1920
Specific CO_2 emissions [g/MJ]	73.95	70.99

III. Results And Discussion

3.1. Equivalence ratio effect

Fig. 5 shows the impact of operating the engine at a broad range of equivalence ratios on PM concentration when the engine fueled with the tested fuels. Neat gasoline emitted the maximum PM concentrations for all tested equivalence ratios.

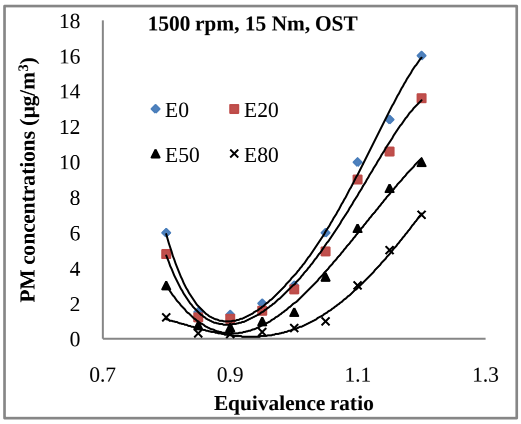

Fig. 5, Equivalence ratio effect on PM concentrations at 1500 rpm, 15 Nm and optimum spark timing

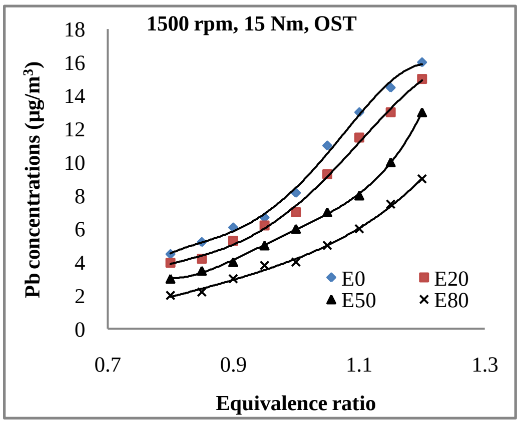

Fig. 6, Equivalence ratio effect on Pb concentrations at 1500 rpm, 15 Nm and optimum spark timing

E80 emitted the lowest concentrations for all tested blends. Increasing ethanol portion in the blend means increasing the oxygen content of it. All researchers agreed that oxygen presence improves combustion efficiency and reduces emitted pollutions. The minimum PM concentrations exist on the lean side near stoichiometric equivalence ratio (Ø=0.9-1.0). PM concentrations reduced by 14.67, 39.65 and 67.77% for E20, E50 and E80 respectively compared with E0. The results show that PM concentrations reduce with adding ethanol to gasoline, but the reduction percentage did not equalize addition ethanol percentage. The homogeneity and turbulence of air-fuel mixture inside the combustion chamber are the cause for this result.

There is no effect of equivalence ratio on Pb concentrations as Fig. 6 represents, but it clarifies that adding ethanol to gasoline reduces these concentrations highly. Increasing ethanol portion on gasoline account reduces lead concentration in the blend. So, as a result, Pb concentrations reduced in exhaust gasses. The reductions measured in these concentrations were 11.39, 30.13 and 50.09% for E20, E50 and E80 respectively compared to E0. Again, the reduction percentages did not equalize the ethanol percentage in the blends. The aggregation of a part of burned lead on valves and piston rings and crevices is the cause of this result.

3.2. Engine torque effect

PM concentrations increased at very low torques and high torques, also, as Fig. 7 manifests. At low torques, the combustion chamber temperature is low, and a part of the fuel burns partially or condenses on combustion chamber walls, causing high PM concentrations. At high torques, the engine has to thrust more fuel to the combustion chamber to preserve the required speed causing higher PM concentrations. Adding ethanol reduced these concentrations by 5.61, 25.9 and 47.44% for E20, E50, and E80 respectively compared with E0. Engine operation with E20 resulted in a low reduction of PM concentration while fueling the engine with E80 resulted in a high reduction of these concentrations.

Torque has no effect on Pb concentrations as Fig. 8 reveals. Adding ethanol caused a high reduction in these concentrations. The reductions were 18.99, 40.625 and 65.5 % for E20, E50 and E80 respectively compared with E0. Pb concentrations affected by its weight in the fuel as References [23 & 29] concluded. Ethanol (with no lead in its structure) addition reduced Pb concentration with ratio approximately close to its percentage in the blend. The differences are due to sticking of part of lead compounds on walls and valves of the combustion chamber as mentioned above.

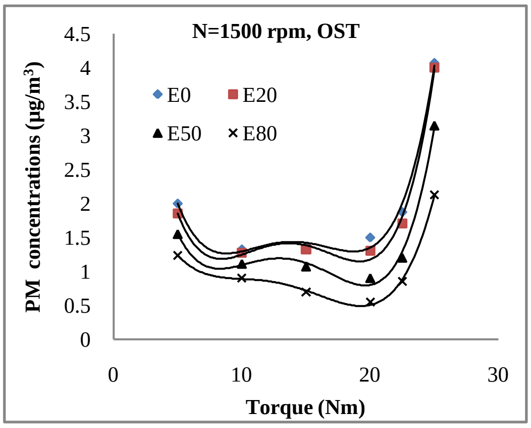

Fig. 7, Engine torque effect on PM concentrations at 1500 rpm, 15 Nm and optimum spark timing

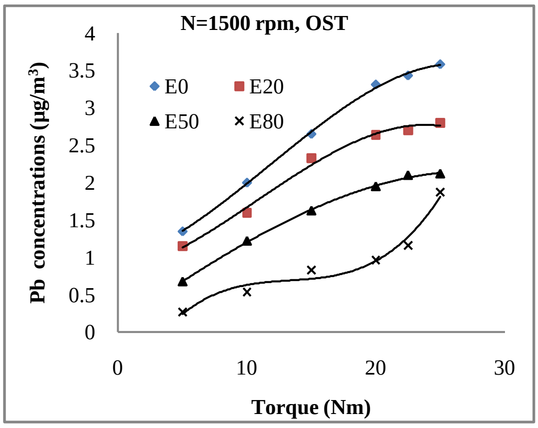

Fig. 8, Engine torque effect on Pb concentrations at 1500 rpm, 15 Nm and optimum spark timing

3.3. Engine speed effect

PM concentrations relatively high at low engine speed and very high at high engine speeds, as Fig. 9 represents. The minimum values of PM concentrations are at moderate speeds. At low speed, the combustion chamber temperature is low causing condensation of molecules of high weights and partially burned. In the other hand running the engine at high speeds need more fuel to be burned to achieve the required speed at specific load causing higher PM concentrations. Adding ethanol reduced these emissions by 5, 21.1 and 42.857% for E20, E50, and E80 respectively compared with E0. Fueling the engine with E20 resulted in a limited reduction in PM concentrations.

Pb concentrations increased with increasing engine speed, as Fig. 10 clarifies. Adding ethanol reduced these concentrations with about 17.08, 41.77 and 65.189% for E20, E50, and E80 respectively compared with E0. The figure shows that at high engine speeds, higher reductions achieved. The increments in temperature and turbulence inside combustion chamber resulted in better reactions that throw out higher lead compounds concentrations compared to low speeds.

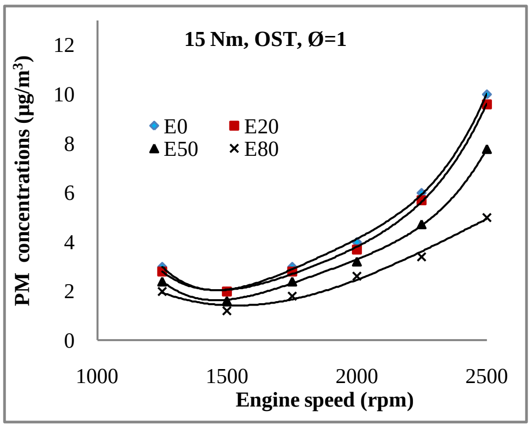

Fig. 9, Engine speed effect on PM concentrations at 15 Nm and optimum spark timing and stoichiometric equivalence ratio

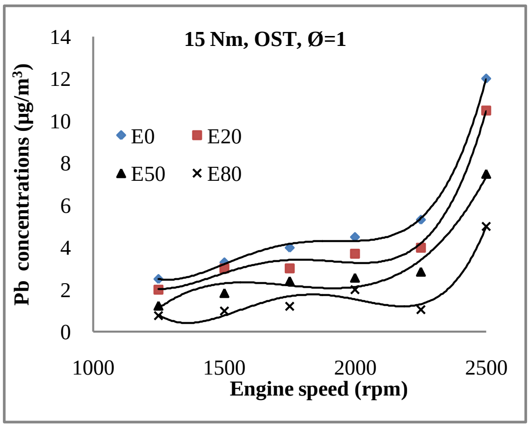

Fig. 10, Engine speed effect on Pb concentrations at 15 Nm and optimum spark timing and stoichiometric equivalence ratio

3.4. Spark timing effect

PM concentrations increased at spark timing far away from optimum one, as Fig. 11 demonstrates. At engine timings near optimum spark timings, PM concentrations reached its minimum values. The engine temperature and pressure inside combustion chamber reduce due to retarding spark timing away from the optimum timing. Also, it reduces preparation time for complete combustion resulting in higher PM concentrations. Severe spark timing advancing caused engine knock that caused a disturbance in combustion operation resulted in higher PM concentrations.

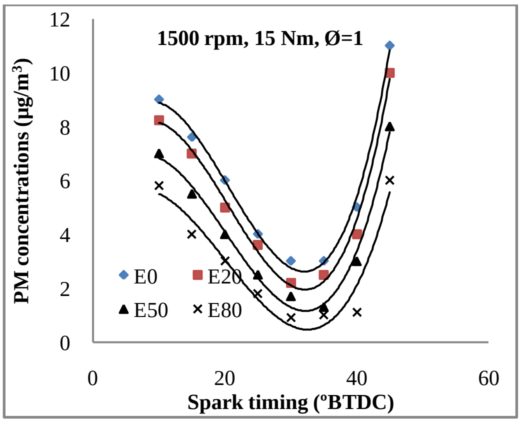

Fig. 11, Spark timing effect on PM concentrations at 1500 rpm, 15 Nm and stoichiometric equivalence ratio

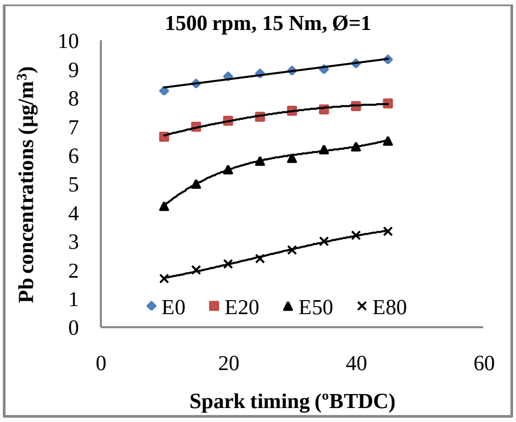

Fig. 12, Engine torque effect on Pb concentrations at 1500 rpm, 15 Nm and stoichiometric equivalence ratio

As ethanol has higher flame propagation than gasoline, the optimum spark timing of E50 and E80 were less than OST of E0 and E20. Ethanol addition continued to reduce PM concentrations. The reductions were 12.44, 32 and 51.44% for E20, E50 and E80 respectively compared with E0. Iraqi gasoline characterized by its high lead contents and large molecules with weights, these two parameters prevented ethanol from reducing PM concentrations more than the measured values. Improving gasoline by reducing lead and sulfur contents accompanied by the reduction of high weights molecules produced better PM concentrations when ethanol added.

Pb concentration seems to be not affected by spark timing variation, as Fig. 12 illustrates. There is a little increment in Pb concentrations at advanced timings compared with retarded ones. Advancing spark timing resulted in increasing temperature and pressure inside the combustion chamber, causing better reactions for the lead. As a consequence, Pb concentrations increased a little. Adding ethanol reduced Pb concentrations due to a reduction in its weight in the blend where ethanol has zero lead content. The reductions in Pb concentrations were 16.92, 35.87 and 71% for E20, E50 and E80 respectively compared with E0.

All the results demonstrated that adding ethanol to gasoline reduced Pb concentrations in higher rates compared to PM reductions. Lead compounds in exhaust gasses are mainly a part of PM compounds but not all these compounds. Hence reducing Pb concentration reduces PM concentration but not necessarily at the same rate. PM concentrations depend not only on lead compounds but also on sulfur and the aromatic compound in gasoline.

IV. Conclusions

Ethanol added to Iraqi conventional gasoline to evaluate the effect of this addition on PM and Pb concentrations in the exhaust gas. The effect of equivalence ratio, engine torque, speed and spark timing variation on theses concentrations also studied. The following conclusions summarize the results:

1. Increasing ethanol portion in the blend means increasing the oxygen content of it resulting in PM concentrations reduction. This decrease happened in different ratios with changing engine parameters like equivalence ratio, torque, speed and spark timing.
2. The minimum PM concentrations exist on the lean side near stoichiometric equivalence ratio (Ø=0.9-1.0).
3. The reduction in the temperature and turbulence inside combustion chamber caused higher PM concentrations at low torques and speeds.
4. Increasing the inner fuel quantity increased PM concentrations at high torques and speeds.
5. PM concentrations increased at spark timing far away from optimum one.
6. Pb concentrations reduction was proportional to ethanol rate in the blend. Although the reduction was not equivalent to the ethanol addition, it was relatively close to it.
7. There is no effect of equivalence ratio, torque, speed or spark timing on Pb concentrations. The only effect was for lead weight in gasoline.
8. Adding ethanol to Iraqi gasoline increases its octane number, besides, to extricate it from dangerous lead content.

Referances

[1] F Laden, J. Schwartz, F. E. Speizer and D. W. Dockery, Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities study, Am J Respir Crit Care Med, 173(6), 2006, 667-672.

[2] C A Pope, M. Ezzati and D. W. Dockery, Fine-particulate air pollution and life expectancy in the United States, N Engl J Med, 360(4), 2009, 376-386.

[3] A. Zanobetti and J. Schwartz, The effect of fine and coarse particulate air pollution on mortality: a national analysis, Environmental health perspectives, 117(6), 2009, 898-903.

[4] F Yan, E. Winijkul, S. Jung, T. C. Bond and D. G. Streets, Global emission projections of particulate matter: I. Exhaust emissions from on-road vehicles, Atmospheric Environment, 45 (28), 2011, 4830-4844.

[5] K Kar, Measurement of vapor pressures and enthalpies of vaporization of gasoline and ethanol blends and their effects on mixture preparation in an SI engine, SAE paper No. 2008- 01-0317, 2008.

[6] T. Johansen and J. Schramm, Low-temperature miscibility of ethanol-gasoline-water blends in flex fuel applications, Energy Sources, Part A, 31, 2009, 1634-1645.

[7] L F Chen, The Influence of ethanol blends on particulate matter emissions from gasoline direct injection engines, SAE paper No. 2010-01-0793, 2010.

[8] J Symonds and et. al., Density of particles emitted from a gasoline direct injection engine, In 12th ETH Conference on Combustion Generated Nanoparticles, Zurich, 2008.

[9] L Chen and R. Stone, Measurement of enthalpies of vaporization of isooctane and ethanol blends and their effects on PM emissions from a GDI engine, Energy Fuels, 25, 2011, 1254–1259.

[10] R M Balabin and et al., Molar enthalpy of vaporization of ethanol gasoline mixtures and their colloid state, Fuel, 86, 2007, 323–327.

[11] J. Symonds and et al., Diesel soot mass calculation in real-time with a differential mobility spectrometer, J. Aerosol Sci., 38, 2007, 52–68.

[12] G C Fang, Y. L. Huang and J. H. Huang, Study of atmospheric metallic elements pollution in Asia during 2000-2007, Journal of Hazardous Materials, 180, 2010, 115-121.

[13] U Franck, S. Odeh, A. Wiedensohler, B. Wehner and O. Herbarth, The effect of particle size on cardiovascular disorders-The smaller the worse, Science of Total Environment, 409, 2011, 4217-4221.

[14] J S Devera, Chemical characterization of $PM_{2.5}$ air pollution in Dhaka and Noakhali, Bangladesh, MSc Thesis, Faculty of San Diego State University, USA, 2012.

[15] M Wang, M. Wu and H. Huo, Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types, Environmental Research Letters, 2, 2007, 1-13.

[16] X He, J. C. Ireland, B. T. Zigler, M. A. Ratcliff, K. E. Knoll, T. L. Alleman and J. T. Tester, The impacts of mid-level biofuel content in gasoline on SIDI engine-out and tailpipe particulate matter emissions, Presented at the SAE 2010 Power-trains, Fuels and Lubricants Meeting, San Diego, California, 2010.

[17] L Chen, M. Braisher, R. Stone and D. Richardson, The influence of ethanol blends on particulate matter emissions from a gasoline direct injection engine, SAE 2010-01-0793, 2010.

[18] K S Varde, Characterization of exhaust emissions in a SI engine using E85 and cooled EGR, SAE 2009-01-1952, 2009.

[19] P Ericsson, M. Holmstrom, A. Amberntsson-Carlsson, C. Ohlson, M. Skoglundh, B. Andersson and P. A. Carlsson, Characterization of particulate emissions and methodology for oxidation of particulates from non-diesel combustion Systems, SAE 2008-01-1746, 2008.

[20] J Czerwinski, P. Comte, F. Reutimann and M. Makkee, Emissions of 2-stroke scooters with ethanol blends, SAE 2009-24-0143, 2009.

[21] M Muralidharan, S. Muthan, P. C. Kanal and R. Malhotra, Characterization of particulates with different blends of ethanol-gasoline in two wheelers, SAE 2009-01-0686, 2009.

[22] U. Nopmongcol, W. M. Griffinb, D. Yarwood, A. M. Dunkerc, H. L. MacLeand, G. Mansell, J. Grant, Impact of dedicated E85 vehicle use on ozone and particulate matter in the US, Atmospheric Environment, 45, 2011, 7330-7340.

[23] M. T. Chaichan, Practical measurements of laminar burning velocities and Markstein Numbers for Iraqi diesel-oxygenates blends, The Iraqi Journal for Mechanical and Material Engineering, 13(2), 2013, 289-306.

[24] M M Maricq, Soot formation in ethanol/gasoline fuel blend diffusion flames, Combustion and Flame, 159, 2012, 170–180.

[25] L. Chen, R. Stone, D. Richardson, A study of mixture preparation and PM emissions using a direct injection engine fuelled with stoichiometric gasoline/ethanol blends, Fuel, 96, 2012, 120–130.

[26] P Price, B. Twiney, R. Stone, Particulate and hydrocarbon emissions from a spray guided direct injection spark ignition engine with oxygenate fuel blends, SAE paper No. 2007-01-0472, 2007.

[27] M T Chaichan, Experimental evaluation of the effect of some engine variables on emitted PM and Pb for single cylinder SIE, Association of Arab Universities Journal of Engineering Science, 2(20), 2013, 1-13.

[28] L McWilliam and T. Megaritis, Experimental investigation of the effect of combined hydrogen and diesel combustion on the particulate size distribution from a HSDI diesel engine, International Journal of Vehicle Design, 5 (1), 2008, 107-117.

[29] V Jeroen & V. Sebastian, Modeling the combustion of light alcohols in SI engine s: a preliminary study, Ghent University, Belgium, F2010-SC-O-04, 2010.

NOMENCLATURE

^{o}BTDC	Degree before top dead centre
CA	Crank angle
HUCR	Higher useful compression ratio
OST	Optimum spark timing
SIE	Spark ignition engine
Ø	Equivalence ratio
PM	Particulate matters concentration in (µg/m^3).
Pb	Lead
E0	Gasoline
E20	20% ethanol + 80% gasoline
E50	50% ethanol + 50% gasoline
E80	80% ethanol + 20% gasoline
w_1	The filter weight before sampling operation in (g).
w_2	The filter weight after sampling operation in (g).
Vt	The drawn air total volume (m^3)
Q_t	Elementary and final air flow rate through the device (m^3/sec).
t	The sampling time in (min).