EFFECTS OF GASOLINE ETHANOL BLENDS ON PERFORMANCE OF SI ENGINE: A TECHNICAL REVIEW

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ABSTRACT

A review on effect of ethanol blend on performance of SI engine emphasis on correct blending percentage with gasoline for maximizing engine performance and minimizing emission from engine. In present scenario the dependency on fossil fuel is increasing day by day for different operations like transpiration, electricity production and transportation etc. but limited quantity of fossil fuel may be problem in future energy needs which may be compensate with renewable energy source for transpiration. Alcohol may be used as gasoline fuel for clean emission with good combustion properties with some limitation. In present review author focused on effect of ethanol blend on SI engine in place of neat gasoline fuel.

1.Introduction

Day to day fuel economy of engines is getting improved and it will continue to improve. Increments in number of transportation vehicles have started dictating the demand for fuel which will increase the price of gasoline in near future. The huge problem with gasoline fuel is the engine emission like CO, CO2 and hydro carbons (HC) which increase day by day due to increasing of transportation vehicles [1]. With increasing demand and depletion in fossil fuels reserves, alternative fuel will become more common in coming decades. The alternative fuel like alcohol, hydrogen, etc. has physicochemical properties similar to gasoline but has clean emission as compared to gasoline for same engine output power. Most of the researchers found that use of alternative fuel separately in SI engines is less effective in terms of engine emission and engine performance both. But blending with gasoline enhances the effect on performance of engine and reduced level of emission. Only one drawback in most of alternative fuels is emission of nitrogen oxide through engine is increasing as compared to gasoline engine. The reason is face of high combustion temperature ached during combustion process. It will reduce by blending with gasoline engine. This is the lead found by author by reviewing the number of literature on renewable energy source and fuels. Some researchers found that use of alcohol blend for light duty SI engine without any modification. But heavy duty SI engine needs a lot of change in injection system of fuel and design of combustion chamber. Ethanol is oxygenated fuel which reduces emission of CO and CO2 complete combustion but the high latent heat of vaporization reduces the emission temperature which is the cause of emission of hydrocarbon which is not favorable case for SI engine. As per different country emission standards the limited emission HC, CO and CO2 allowed for any type of engine which draw attention of researchers that alternative fuel blending with optimum range comes within the permissible range of emission through SI engine or not.After reviewing various papers on effect of alcohol blends with gasoline for SI engine we found that the limiting or optimum blending of ethanol with gasoline is scope of research for direct fuel injection or port fuel

injection system for SI engine. Ethanol blend has high flame speed as compared to gasoline so that no longer delay period for spark ignition is required and due to this the chance of incomplete combustion at higher speed of engine is reduced. The purpose of direct injection for ethanol and port injection of gasoline is that high vapor pressure of alcohol as compared to gasoline which means direct injected ethanol converted into vapor by compression pressure in combustion chamber which does not properly happen in port fuel injection system which opens a topic of research area on design of injection system in spark ignition engine for better performance. By energy consumption comparison it was found that ethanol was more efficient than gasoline[14] combustion efficiency, is also better than gasoline [6-16] but the neat ethanol produces high combustion pressure and temperature due to which there is greater chance of damage in piston head and combustion chamber wall and high percentage of ethanol also reduces the vaporization rate and due to this cooling effect observed [13] over the exhaust port which reduced the mean effective pressure and reduces engine power, so that ethanol should blend with correct percentage with gasoline for better engine performance. By reviewing it was observed that 25% to 50% by volume of gasoline which is denoted like (E25 to E50) produced desired output in terms of emission and engine performance.[6,7,9,15,16].

2.Ethanol Fundamental

Ethanol has high octane number, high latent heat of vaporization, high flame speed, low sulphur content, has less calorific value which means high fuel air ratio required for complete combustion. Ethanol is most promising fuel for SI engine.[25-28] Ethanol is renewable source because it is derived from fermentation of food stock and also derived from fermentation of cellulose stock like rice straw, corn stalks and sugar cane which are examples of sugar containing feed stock.[24]

Table 1: Ethanol physicochemical properties

Parameter	Ethanol	Gasoline
Chemical formula	C_2H_5OH	C_2-C_{14}
H/C ratio	3	1.795
O/C ratio	0.5	0
Molecular weight	46.07	110
LHV (MJ/l)	21.3	31.9
Research Octane Number	106	91
Density @ 20°C	790.9	744.6
Gravimetric Oxygen Content %	34.78	0
Stoichimetric A/F ratio	9:1	14.71:1
Enthalpy of vaporization (KJ/ kg)	840	373

Boiling Point (°C)	78.4	32.8

2.1 Knock Tendency: Knocking is an important parameter in any SI engine because higher tendency of knock reduces the engine performance and also damages the piston head and cylinder wall [45]. Knocking happens in SI engine due to improper combustion and uncertain combustion rate. In past 10 years researchers found that alcohol has lots of similarity with gasoline and it is more effective as compared to gasoline [16,15,5]. M. Bahattin Celik found that for small compression ratio gasoline has less tendency for knock but for high compression ration like 10:1 gasoline has high tendency of knock but ethanol blending has less tendency.[16] In this series Yuan Zhuang et. al. also examined and found that direct injection of ethanol in SI engine promotes fast laminar flame speed, wide flammability and low emission temperature which improve anti knocking.[17]. Hui Liu et.al. examined and found that alcohol blend with gasoline suppress the knock and ethanol has highest anti-knock tendency for direct injection system among all alcohols.[21]

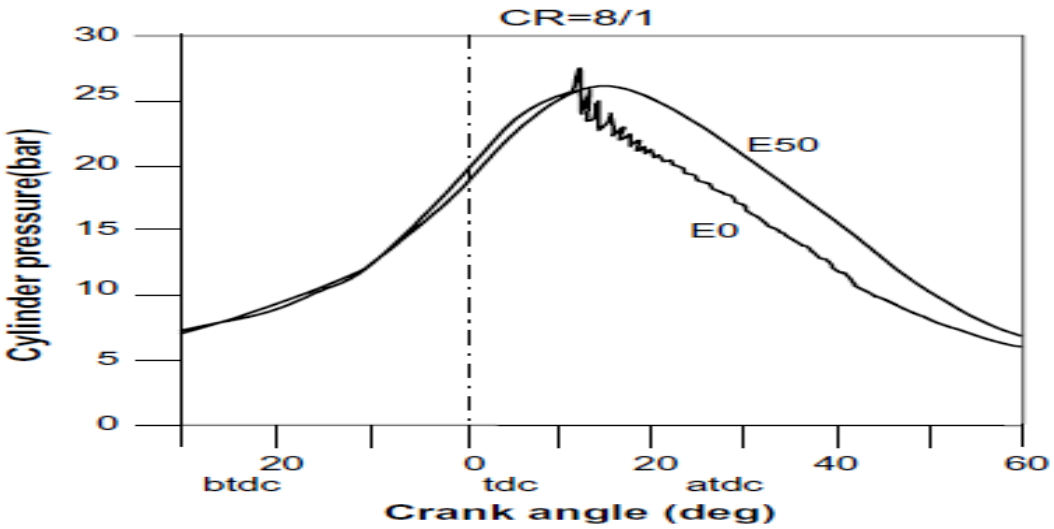

Figure 1: knocking tendency of gasoline and blended fuel (E0, E50) at 2000 rpm and 8:1 CR [16]

2.2 Flame speed:

Flame speed of ethanol is highest among all alcohols[14]. Because the ethanol is oxygenated fuel with O/C ratio 0.5 and zero for gasoline fuel which means less air is required for burning. (TABLE 1) and high vapor pressure enhances turbulence in combustion chamber so that flame speed is high.[15] Yuan Zhuang et. al. found that direct injection of ethanol in SI engine promotes fast laminar flame speed, wide flammability[17] P.G. Aleiferis et.al. stated that ethanol blend had faster flame growth in compression of butanol, iso-octane, methane and gasoline fuel by direct injection through center located injector [18] Gasoline Marshall et. el found that on decreasing equivalence ratio from 1 to 0.8 the laminar flame speed decreases 28 to 16 cm/s at 1 bar and at 5 bar 41 to 26 cm/s.[29] flame speed of ethanol increases by increasing the temperature of engine body which is because more evaporation of ethanol creates more thermal energy and increases the speed of combustion.[30].

2.3 Exhaust temperature: Ethanol blend reduces the emission temperature because of high heat of evaporation most of heat absorbed by thanol droplet at exhaust port and reducing emission temperature but increasing NOX and this trend is parallel to increased percentage of ethanol.[23, 10,12]. And also investigating that there is some

optimal limit of ethanol by which cooling effect increased is E0 to E58.[12] the decrement in exhaust temperature promotes the decrement in HC, CO.

3. Engine Emission: With the use of ethanol in gasoline clean emission observed by author after reviewing the papers. Refer table 1, it is clear that O/C percentage is more than gasoline which means the proper combustion takes place and reduces the CO but at the same time NOX emission increases due to fact that at higher combustion temperature nitrogen present in air gets converted into oxides but reducing the emission temperature which is reducing effect in global warming[1,6] Emission of particulate matter is calculated by number called PN and measured by optical spectroscopy with infra red light.[5,7,8] formaldehyde is also a emission product of SI engine but the main constituent of emission through SI engine are.

3.1 Effect on NO_x emission: Due to high oxygen content in ethanol fuel and low exhaust temperature increase the NO_x emission. M.A. Costaglio et.al. found that E85 blend reduce NOX emission by 15% but at same time 3.5 times higher carbonylic emission which is unhealthy for human and environment.[6] Simeon Ilive found by simulation technique on 1-D SI engine that on increasing percentage of ethanol E0 to E50 the nitrogen oxides emission decreasing when using blend percentage more than 30% .[9] Mustafa Kemal Balki et.el found that SI engine with compression ratio 9, 2400 rpm and fuel injection timing 20 º CA optimum condition achieved by Tuguchi method has less break specific NOX.[13] M. Bahattin Celik investigated by experiment on SI engine for effect of suitable blends of ethanol with gasoline fuel at high compression ratio and full load condition. For this investigation a SI engine was selected with compression ratio 6:1 with 2000 rpm engine speed for constant load with E0, E25, E75 and E100 blend of ethanol. An interesting result was found by experiment which were: E50 blend produced less NOX emission, decrease by 19% [16] Yuhan Huang et. al. investigated the effect of injection timing on mixture formation and combustion for EDI plus GDI engine and found that mixture near spark plug leaner and distribution of equivalence ratio was uneven when reducing the direct injection timing of ethanol and due to late direct ethanol injection local over cooling and over rich mixture was observed. The combustion speed and temperature was reduced by reducing direct injection timing and reducing [23].

3.2 Effect on CO emission: Carbon emission through SI engine is due to incomplete combustion and less air volume [1a]. Ethanol is a oxygenated fuel which means due to availability of oxygen less air is required for combustion and complete combustion reduces the chance of CO emission [32,33]. Maria Antonietta Costagliola et. al. investigating the performance and emission through four stroke motorcycle of euro 3 emission standard fuelled with bioethanol blend (5% to 30% by volume) with gasoline found that particulate number and CO emission reduced [22] By energy consumption compression it was found that ethanol had more efficient combustion than gasoline due to high oxygen content and low boiling point which enhance the vaporization rate but the lower energy consumption enhanced the air fuel mixing for proper combustion and in was noted that ethanol has less emission of CO[14] Jaeho Cho et. al. investigated the effect of ethanol blend on PM emission from 2359 cc, 11:1 compression ratio, emission through catalytic convertor 2.4 L inline four cylinder , wall guided spark ignition direct injection (SIDI) engine. The observation for blend of E0 to E20 was that PN concentration decreased by 96% which analyzed by differential mobility spectrometer. E10 blend had

undesirable property investigated through this experiment that for fuel pressure varied from 45 bar to 75 bar the PN concentration decreases due to fact that at cold start condition ethanol blend needs more temperature for vaporization and required more fuel so that at starting PN concentration increases but for more percentage of blend of ethanol problem resolved[11] Yung-Chen Yao et.al. investigated the effect of emission from smaller SI engine like motorcycle. Here consider two motorcycles- one equipped with carburetor and other equipped with fuel injector and rest of design of engine is same as ordinary small engine of 50 to 125 cc capacity. For investigation select two fuels E15 and other convention gasoline. After experiment it was observed that motorcycle with carbonator emitted 32% less CO and for second motorcycle with fuel injector emitted 10% less CO as compared to gasoline [8]

3.3 Effect on CO2 emission: Pioter Bielaczyc et al. tested and examined the physicochemical properties of ethanol-gasoline blend from E5 to E50 over the old unmodified European car and New European driving cycle with unregulated exhaust compound in laboratory and found that with the change in percentage of ethanol in gasoline blend the partial number change linearly because of improved combustion [3] Carbon dioxide is greenhouse gas and it increases by using unleaded gasoline and ethanol blend with four stroke and SI engine [35] Ceviz and Yüksel et.al. investigating the effect of ethanol blend on SI engine emission and cycle variability found increment in CO2 concentration while CO concentration decreased when using E10.[36] The European Union is trying to enhance the percentage of ethanol blend in gasoline by 10% by 2020 and to reduce the fuel life cycle greenhouse emission [37,38,39].Al- Hasan examined the effect of ethanol blend on SI engine emission with three fourth throttle opening with variable engine speed and found that 7.5% CO2 emission increased and Hsieh et.al. also found that with use of ethanol blend in SI engine CO2 emission increased by 5-25% more.[41,41]

3.4 Effect on HC emission: Hydrocarbon are also reduced by ethanol blend, similarly CO because of oxygen content in ethanol enhances combustion and reduces improper combustion. Pioter Bielaczyc et el reported that in urban driving condition with E50 blend reduce HC.[3] I. Gravalos et al found that lower molecule alcohol gasoline blend reduces 20.4% more HC as compared to gasoline and also observed that at high engine speed engine hydrocarbon decreases[4]. The emission through SI engine is dependent on engine speed, design of combustion chamber, air fuel ratio and ignition system design. M. Clairotte et al examined that high ethanol fuel contains less HC but -7ºC (low temperature the HC increases due to insufficient combustion.[5] M.A. Costaglio et al found that ethanol with 85% by volume of gasoline reduces polycyclic aromatic hydrocarbon which is the main cause of carcinogenic to human being.[6] Yung-Chen Yao et.al. investigated effect of ethanol bled in SI engine with carburetor with E15 blend and found that THC concentration is same as gasoline but with direct injection THC reduced by 10%.[8] M. Bahattin Celik investigating the effect of E50 on SI engine HC emission found 12% reduction.[16]

4. Engine Performance: Ethanol increases the engine performance by increasing volumetric efficiency, thermal efficiency but specific fuel consumption increases because ethanol has less calorific value as compared to gasoline (ref Table1) so that more ethanol is required for burning which enhances density of ethanol in combustion chamber, volumetric efficiency increase and due to oxygenated fuel high flame speed produces

rapid combustion without knock even in higher compression ratio enhance the thermal efficiency but air-fuel ratio decreases so more fuel is required.[1, 2,4,5,6,10].

4.1 Break specific fuel consumption (bsfc): Break specific fuel consumption means quantity of fuel required to produce 1 KWh power. Ethanol is low calorific value fuel even half of gasoline so that more fuel is required for producing power as compared to gasoline. Mustafa Canakci et el investigated the engine performance characteristics of 4 cylinder, 4 stroke multi point fuel injector SI engine with ethanol (E5, E10) and methanol blend (M5, M10) for 80km/hr and 100 km/hr vehicle speed and investigated the break specific fuel consumption and found that on increasing ethanol blend BSFC increase for ethanol this increment is 2.8% and 3.6% of E5 and E10 as compared to gasoline.[7]. M. Bahattin Celik investigated suitable ethanol blend for high compression ratio SI engine and found that with E50 blend SFC was reduced by 3% as compare to gasoline.[16]

4.2 Volumetric Efficiency: Many researchers found that with ethanol blend in SI engine volumetric efficiency increases.[10,11,12] Ethanol is high latent heat of vaporization due to which cooler intake in combustion chamber increases density of charge and improves volumetric efficiency for more power production. Yuhan Huang investigated the effect of ethanol blend in DISI engine and found that evaporation rate was reduced by addition of ethanol in gasoline from 94.3% to 92% for E0 to E80 fuel.[12] Ashrof Elfasakhany investigated the effect of ethanol blend in volumetric efficiency and found that on increasing the ethanol blend percentage the volumetric efficiency increases from 0.275 to 0.411 for 3400 rpm with E0 to E10 blend [10]

4.3 Mean Effective Pressure: Ethanol improves combustion efficiency by increasing percentage of ethanol and high mean effective pressure achieve which is parallel with engine power.[12] but S. Ilive investigated over 1D engine model for ethanol blend for engine performance and found that on increasing percentage of ethanol blend reduced engine break power due to low heating value of ethanol[42,43].

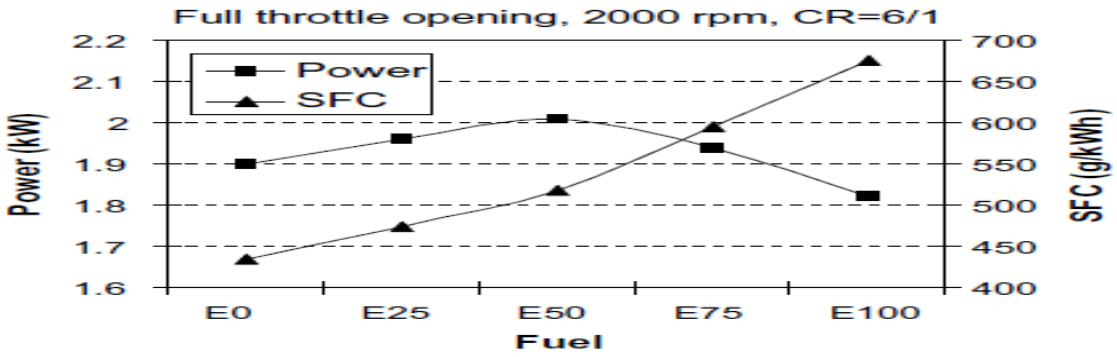

Figure 2: Effect of Ethanol bled over power and SFC [16]

Researchers also found that the combustion and thermal efficiency improved after blending with ethanol because of high octane number and high flame speed.

3.Conclusion

To meet the future requirement of gasoline fuel for transportation is going to create a big problem in front of us and will create a need to find out the alternative fuel for better emission ,reducing PN number with good thermal efficiency and alcohol has a great opportunity to researchers for selecting as alternative fuel but both methanol

and ethanol have lots of good properties like high octane number , low emission of carbon dioxide gas and reduced harmful emission of gases but at the same time it is a difficult to be as a alternative fuel. Alcohol has a high latent heat of vaporization and corrosive effect over metal and plastic etc. so that only alcohol is not suitable fuel for SI engines and we need to blend this with gasoline and also bi and tri blending i.e methanol-gasoline (MG), ethanol –gasoline(EG) and ethanol-methanol-gasoline (GEM) and use of these fuel as alternative problem the difficulties of selection of alternative fuel alone is almost removed and thermal efficiency, higher compression ratio and low emission achieved. After reviewing the literature gaps were found which are:-

- There is little attention of researchers over effect on ethanol over material inside combustion chamber after long period of use.
- The effect of atmospheric condition directly affected the ethanol blend fuel which was reported but there is less research over optimum percentage of alcohol at the very cold conditions and very warm condition

4.References

[1]. Hui Liu, Zhi Wang, Yan Long, Shouzhi Xiang, Jianxin Wang, Mohammad Fatouraie "Comparative study on alcohol–gasoline and gasoline–alcohol Dual-Fuel Spark Ignition (DFSI) combustion for engine particle number (PN) reduction" Fuel 159 (2015) 250–258.

[2]. J.W.G. Turner, R.J. Pearson, E. Dekker, B. Iosefa, K. Johansson, K. ac Bergström "Extending the role of alcohols as transport fuels using iso-stoichiometric ternary blends of gasoline, ethanol and methanol" Applied Energy 102 (2013) 72–86.

[3]. Piotr Bielaczyc, Joseph Woodburn, Dariusz Klimkiewicz, Piotr Pajdowski, A Szczotka "An examination of the effect of ethanol–gasoline blends physicochemical properties on emissions from a light-duty spark ignition engine" Fuel Processing Technology 107 (2013) 50–63

[4]. I. Gravalos , D. Moshou , Th. Gialamas , P. Xyradakis , D. Kateris , Z. Tsiropoulos "Emissions characteristics of spark ignition engine operating on lowerehigher molecular mass alcohol blended gasoline fuels" Renewable Energy 50 (2013) 27-32.

[5]. M. Clairotte , T.W. Adam , A.A. Zardini , U. Manfredi , G. Martini , A. Krasenbrink , A. Vicet , E. Tournié , C. Astorga "Effects of low temperature on the cold start gaseous emissions from light duty vehicles fuelled by ethanol-blended gasoline" Applied Energy 102 (2013) 44–54.

[6]. M.A. Costagliola, L. De Simio, S. Iannaccone, M.V. Prati "Combustion efficiency and engine out emissions of a S.I. engine fuelled with alcohol/gasoline blends" Applied Energy 111 (2013) 1162–1171.

[7]. Mustafa Canakci , Ahmet Necati Ozsezen , Ertan Alptekin , Muharrem Eyidogan "Impact of alcoholegasoline fuel blends on the exhaust emission of an SI engine" Renewable Energy 52 (2013) 111e117.

[8]. Yung-Chen Yao , Jiun-Horng Tsai , I-Ting Wang "Emissions of gaseous pollutant from motorcycle powered by ethanol–gasoline blend" Applied Energy 102 (2013) 93–100.

[9]. Simeon Iliev "A Comparison of Ethanol and Methanol Blending with Gasoline Using a 1- D Engine Model" 25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014, Procedia Engineering 100 (2015) 1013 – 1022.

[10]. Ashraf Elfasakhany "Investigations on the effects of ethanol-methanol-gasoline blends in a spark-ignition engine: Performance and emissions analysis" Engineering Science and Technology, an International Journal 18 (2015) 713-719.

[11]. Jaeho Cho, Woosung Si, Wonwook Jang, Dongyoung Jin, Cha-Lee Myung, Simsoo Park "Impact of intermediate ethanol blends on particulate matter emission from a spark ignition direct injection (SIDI) engine" Applied Energy 160 (2015) 592–602.

[12]. Yuhan Huang , Guang Hong , Ronghua Huang "Investigation to charge cooling effect and combustion characteristics of ethanol direct injection in a gasoline port injection engine" Applied Energy 160 (2015)244–254.

[13]. Mustafa Kemal Balki , Cenk Sayin , Murat Sarıkaya "Optimization of the operating parameters based on Taguchi method in an SI engine used pure gasoline, ethanol and methanol" Fuel 180 (2016) 630–637.

[14]. F. Catapano , S. Di Iorio , A. Magno , P. Sementa , B.M. Vaglieco "A comprehensive analysis of the effect of ethanol, methane and methane-hydrogen blend on the combustion process in a PFI (port fuel injection) engine" Energy 88 (2015) 101-110.

[15]. Hakan Bayraktar "Theoretical investigation of flame propagation process in an SI engine running on gasoline–ethanol blends" Renewable Energy 32 (2007) 758–771.

[16]. M. Bahattin Celik "Experimental determination of suitable ethanol–gasoline blend rate at high compression ratio for gasoline engine" Applied Thermal Engineering 28 (2008) 396 404.

[17]. Yuan Zhuang, Guang Hong "Effects of direct injection timing of ethanol fuel on engine knock and lean burn in a port injection gasoline engine" Fuel 135 (2014) 27–37.

[18]. P.G. Aleiferis , J.Serras-Pereira , D.Richardson "Characterisation of flame development with ethanol, butanol, iso-octane, gasoline and methane in a direct-injection spark ignition engine" Fuel 109 (2013) 256–278.

[19]. Michael Storch , Florian Hinrichsen , Michael Wensing , Stefan Will , Lars Zigan " The effect of ethanol blending on mixture formation, combustion and soot emission studied in an optical DISI engine" Applied Energy 156 (2015) 783–792.

[20]. Yueqi Luo, Lei Zhu, Junhua Fang, Zhuyue Zhuang, Chun Guan, Chen Xia, Xiaomin Xie, Zhen Huang "Size distribution, chemical composition and oxidation reactivity of particulate matter from gasoline direct injection (GDI) engine fueled with ethanol-gasoline fuel" Applied Thermal Engineering 89 (2015) 647-655.

[21]. Hui Liu, Zhi Wang, Yan Long, Jianxin Wang "Dual-Fuel Spark Ignition (DFSI) combustion fuelled with different alcohols and gasoline for fuel efficiency" Fuel 157 (2015) 255–260.

[22]. Maria Antonietta Costagliola , Maria Vittoria Prati , Salvatore Florio , Pietro Scorletti , Daniele Terna , Paolo Iodice , Dario Buono , Adolfo Senatore "Performances and emissions of a stroke motorcycle fuelled with ethanol/gasoline blends" Fuel 183 (2016) 470–477.

[23]. Yuhan Huang , Guang Hong , Ronghua Huang "Effect of injection timing on mixture formation and combustion in an ethanol direct injection plus gasoline port injection (EDI+GPI) engine" Energy 111 (2016) 92-103.

[24]. M. Balat, "Current alternative engine fuels", Energy Sources 27 (6) (2005) 569–577.

[25]. Cooney CP, Worm YJ, Naber JD. "Combustion characterization in an internal combustion engine with ethanole gasoline blended fuels varying compression ratios and ignition timing". Energy Fuels 2009;23(5):2319-24.

[26]. Schifter L, Diaz R, Rodriguez JP, G_omez Gonzalez U." Combustion and emissions behavior for ethanole gasoline blends in a single cylinder engine. Fuel 2011;90:3586-92.

[27]. Celik MB. Experimental determination of suitable ethanolegasoline blend rate at high compression ratio for gasoline engine. Appl Therm Eng 2008;28: 396-404.

[28]. Hsieh WD, Chen RH, Wu TL, Lin TH. Engine performance and pollutant emission of an SI engine using ethanolegasoline blended fuels. Atmos Environ 2002;36:403-10.

[29]. Marshall SP, Taylor S, Stone CR, Davies TJ, Cracknell RF. Laminar burning velocity measurements of liquid fuels at elevated pressures and temperatures with combustion residuals. Combust Flame2011;158:1920–32.

[30]. Bradley D, Lawes M, Mansour MS. Explosion bomb measurements of ethanol- air laminar gaseous flame characteristics at pressures up to 1.4 MPa. Combust Flame 2009;156:1462–70.

[31]. Wang Zhi, Liu Hui, Long Yan, Wang Jianxin, He Xin. Comparative study on alcohols gasoline and gasoline–alcohols dual-fuel spark ignition (DFSI) combustion for high load extension and high fuel efficiency. Energy 2015;82:395–405.

[32]. Bielaczyc, A. Szczotka, M. Wojnarowicz, The alternative fuels powertrain technology evolution, in: Polish Society of Combustion Engines Conference paper PTNSS–2009–SC–162, 2009

[33]. H. Bayraktar, Experimental and theoretical investigation of using gasoline–ethanol blends in spark-ignition engines, Renewable Energy (30) (2005) 1733–1747.

[34]. Al-Hasan M. Effect of ethanoleunleaded gasoline blends on engine performance and exhaust emission.Energy Conversion and Management 2002;44: 1547-61.

[35]. Ceviz MA, Yüksel F. Effects of ethanoleunleaded gasoline blends on cyclic variability and emissions in an SI engine. Applied Thermal Engineering 2005; 25:917-25.

[36]. European Commission. Directive 2003/30/EC of the European parliament and the council – 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. Off J Eur Communities; 2003.

[37]. European Commission. Directive 2009/28/EC of the European parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/ 77/EC and 2003/30/EC. Off J Eur Communities L140/16; 2009.

[38]. European Commission. Directive 2009/30/EC of the European parliament and of the council of 23 April 2009 amending directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending council directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing directive 93/12/EEC. Off J Eur Communities L140/88; 2009.

[39]. Al-Hasan M. Effect of ethanol-unleaded gasoline blends on engine performance and exhaust emission. Energy Convers Manage 2003;44:1547-61.

[40]. Hsieh WD, Chen RH, Wu TL, Lin TH. Engine performance and pollutant emission of an SI engine using ethanolegasoline blended fuels. Atmos Environ 2002;36:403-10.

