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REVIEW ON THE USE OF BIOETHANOL / BIOMETHANOL – GASOLINE BLENDS IN SPARK IGNITION ENGINE

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Abstract: *Increased environmental awareness and depletion of fossil petroleum resources are driving the automotive industry to seek out and use alternative fuels. For instance, the biofuel is a major renewable energy source to supplement declining fossil fuel resources. In particular, alcohols are an important category of bio-fuels, bio-ethanol and bio-methanol being a feasible alternative to gasoline. A very important thing is that alcohols use does not require major spark ignition engine (SIE) modifications.*
This review paper covers the potential of alcohols from biomass as alternative fuels for automotive SIE application. The presented literature review focused mainly on the relative advantages and drawbacks of these alternative fuels for application to internal combustion engine (ICE).

Keywords: fuels, bio-ethanol, bio-methanol, gasoline, spark ignition engine

INTRODUCTION

From the road transport standpoint, today, there are three major problems facing humanity: (1) concerns about greenhouse gas (GHG) emissions and global climate change; (2) a desire for renewable/sustainable energy sources; and (3) an interest in developing domestic and more secure fuel supplies, in other words, energy security. These issues have led to intense debate within international organizations and among political leaders on the impacts of the increased use of biofuel.
The EU objective is to achieve an overall 80%–95% reduction in CO2 emissions by the year 2050, with respect to the 1990 level. Decarbonization of transport and the substitution of oil as transport fuel therefore have both the same time horizon of 2050. Thus, the European "Renewable Energy Directive" 2009/28/EC includes a binding target of 10 percent renewable fuels in transport in 2020 [1- 5].
H.K. Rashedul et al. in [6] reported that world primary energy demand is projected to expand 5by almost 60% from 2002 to 2030. This means that the average yearly increase is about 1.7%. Under these circumstances, it is estimated that, fossil fuels will continue to dominate global energy use. They will account for around 85% of the increase in world primary demand over 2002–2030. Hence, considering the fact that the fossil fuels resources are depleting in a very fast rate, researchers are looking for environment friendly renewable fuel sources.
In the context of the same ideas, Choongsik Bae et al in [7], reports that even up to 2040, the major portion (up to 90%) of transportation propulsion will still rely on the internal combustion engine (ICE). They say that the global demand for transportation fuels is expected to grow continuously at between 1.2% and 1.4% per annum and discussions on the current state and the future of transportation fuel are important. An early discussion on future options for alternative fuels already took place during the 1980s. These attempts were made not only to seek alternative solutions to energy security and sustainability, but also to seek benefits that alternative fuels can provide to engine efficiency improvement and emission reduction.
S. K. Thangavelu et al. in [8] support the idea the most eminent alternative fuels for replacing fossil fuels in internal combustion engines are biofuels (biodiesel and bioethanol).

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Regarding the emission of greenhouse gases (GHG), Choongsik Bae et al say in [7] that gradual penetration of biofuels and natural gas, is expected to contribute to lowering greenhouse gas emission in the long term. They sustain also, that the use of fossil fuels is a major contributor to CO2 emissions, where human activities generate about 25 billion tons of CO2 annually. They showed that the biofuels derived from vegetable oil, as well as ethanol from corn and wheat when they are produced using biomass as a primary energy source, would cut GHG emissions on a well-to-wheel (WTW) basis to about half of that of fossil fuels. Advanced technologies in the manufacturing process of biofuels has the potential to decrease GHG emission compared to fossil fuels on a well-to-wheel basis.
S. Iliev in [9] sustains too, that among the various alcohols, ethanol and methanol are known as the most suitable fuels for spark ignited (SI) engines and the use of oxygenated fuel additives provides more oxygen in the combustion chamber and has a great potential to reduce emissions from SI engines.
Ethanol and methanol has higher oxygen in basis as compared to mineral fuels that help internal combustion (IC) engine to achieve higher complete combustion. More oxygen in fuels means more complete combustion to be achieved [10 - 15].
In [7], Choongsik Bae et al say that due to technical and economic reasons, methanol and ethanol were successfully introduced as alternative fuels for conventional spark ignition engines in the form of fuel additives, blend fuels and bi-fuels
H.K. Rashedul et al. in [6] say, too, that among the current available biofuels, bioethanol appears to be a likely renewable and alternative automotive fuel as it has properties that would allow its use in current engines with minor modifications, besides improving the engine performance and reducing the emission of the pollutants.
In [8], S. K. Thangavelu et al. sustain too, that bioethanol is one of the most important biofuels produced from bioenergy crops and biomass. It is considered as clean, renewable and green combustible fuel alternative to gasoline because of its physicochemical properties like: high octane number, high heat of vaporization, and low vapor pressure. Furthermore, ethanol is easily miscible and used as oxygenated portion in gasoline for cleaner emission.

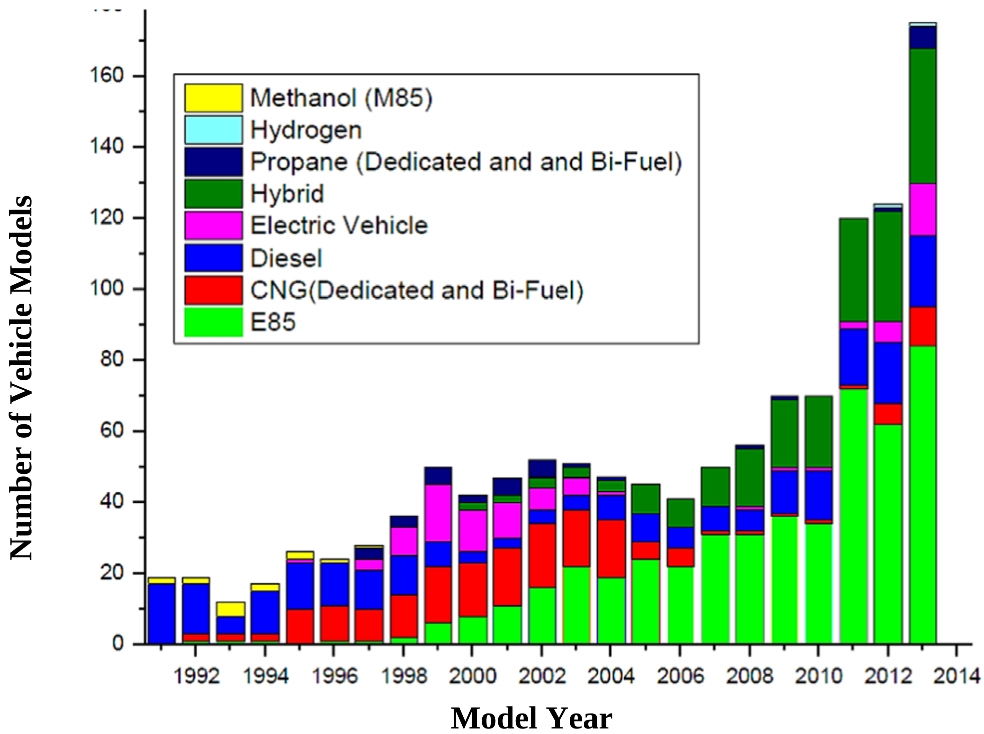

Figure 1. Number of vehicle models using different types of fuel [16]

In Figure 1 M. A. Ghadikolaei in his review [16] shows the number of vehicle models using different types of fuel. It is noticed in the last few years, ethanol is used frequently, especially ethanol - gasoline blends in high percentages.

BIO-ETHANOL / BIO-METHANOL PRODUCTION

Alcohol has accompanied the history of mankind from ancient civilization to the present. Through the industrial revolution in the 19th and early 20th centuries, alcohol began to gain attention as an automotive fuel. Production of ethanol has two major industrial production pathways. One pathway is the reaction of ethane with steam, while the other pathway is alcoholic fermentation from renewable bio-organic materials [7].

S. K. Thangavelu et al. in their review paper [8] in which cite 140 references, show the raw material used to produce bioethanol. Thus, the main categories are:

- Agriculture residues reported between 2010 and 2014 from 18 references: wheat straw, rice straw, sweet sorghum bagasse, sugar cane bagasse, rice hulls, rape straw, barley straw, Miscanthus (grass), corn stove, hazelnut shell, sugar cane tops, and horticulture waste;
- Woody biomass, reported from 9 references: industrial hemp, yellow poplar, construction and demolition (C&D) wood waste. S. K. Thangavelu says that yellow poplar and C&D wood waste are more suitable for high yield commercial ethanol production worldwide;
- Algae biomass, reported from 6 references: Chlamydomonas reinhardtii, microalgae, red seaweed gracilaria sp. and macroalgae (Eucheuma cottonii) were recently utilized for bioethanol production. In summary, S. K. Thangavelu says that C. reinhardtii, microalgae and red seaweed gracilaria sp. are having high ethanol yield (greater than 20% yield) capable for commercial scale bioethanol production;
- Herbaceous, industrial and municipal solid waste. The wastes from food and starch processing industries, soft drinks and brewery industries, fruit peel waste, food waste and waste from herbaceous crops. Saravana Kannan Thangavelu concludes from 29 references, recent bioethanol production studies mostly focus on utilizing herbaceous, industrial and municipal solid waste (MSW). The energy requirement of the pre-treatment and hydrolysis of MSW was very less compared to agriculture residues.

In their critical review [17, 18], H.B. Aditiya et al. and Jan Baeyens et al. talk about the raw material for ethanol dividing it into two categories, first and second generation. The feedstock used of first generation bioethanol production is restricted due to its edibleness since it would clash the feeding purpose. Second generation bioethanol production eliminate the shortcomings of the first generation since it employs non-edible feedstock sourced from agriculture and forestry wastes. Lignocellulosic and starchy materials in them are convertible to fermentable sugars that are able to be further processed, resulting anhydrous bioethanol as the end product. Also, they showed the existing variants of second generation bioethanol production methodologies, namely pre-treatment, hydrolysis, fermentation and distillation, as well as the worth of second generation production for future.

Choongsik Bae in [7] says that methanol can be manufactured by coal, natural gas, coke-oven gas, hydrogen and biomass. However, most methanol is produced by synthesis gas, which is composed of carbon monoxide and hydrogen.

In Figure 2 Choongsik Bae shows the manufacturing paths of fossil and regenerative fuels.

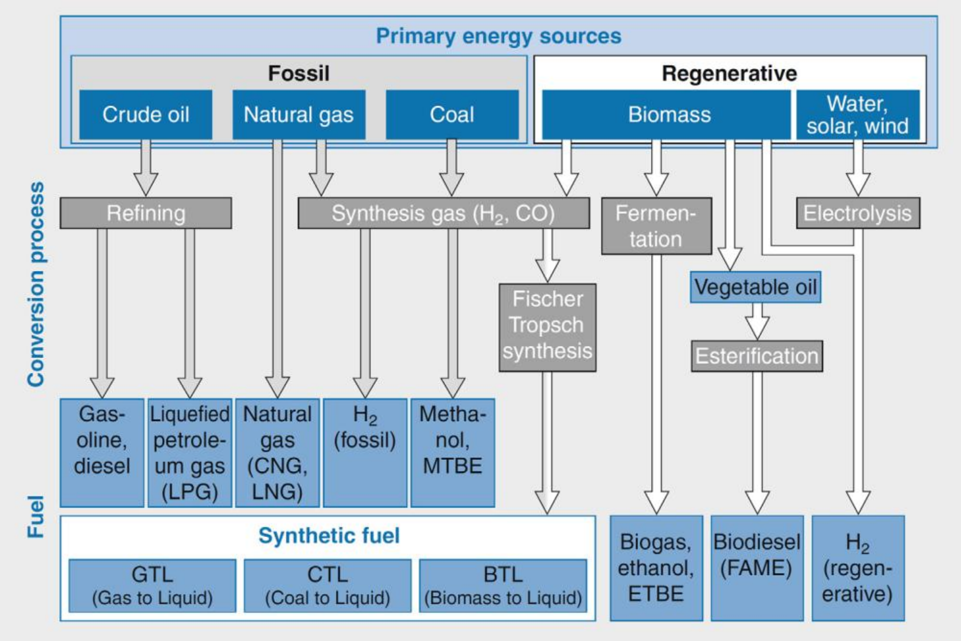

Figure 2. Manufacturing paths of fossil and regenerative fuels [7]

BIO-ETHANOL / BIO-METHANOL PHISICO-CHEMICAL PROPERTIES

Methanol and ethanol are oxygenated liquid hydro-carbon fuels. The hydroxyl moiety makes methanol and ethanol hydrophilic, and has a dipole moment. This polarization by dipole moment affects the inter-molecular interactions, and makes them hydrophilic and behave close to an azeotrope when blended with gasoline [7]. An azeotrope or a constant boiling mixture is a mixture of two or more liquids whose proportions cannot be altered by simple distillation. This happens because when an azeotrope is boiled, the vapour has the same proportions of constituents as the unboiled mixture. Table 1 shows the physical properties values of gasoline, ethanol and methanol [6, 7, 18 - 24, 26, 27, 28].

Evaporation characteristics influence the spray structure and affect the preparation of air–fuel mixture under different engine load conditions. The volatility characteristics are described by using the vapor pressure and distillation curve which are affected by intermolecular interactions. Changes of the Reid vapor pressure and distillation properties do not show a linear correlation as a function of the ethanol blend ratio [7].
The vapor pressure of gasoline is higher and the boiling point is lower than those of ethanol between the temperature ranges of 300 – 410 K (table1). Therefore, under cold-start condition, engine operating on ethanol has stability and emission problems.
Under high temperature condition, the ethanol spray showed faster diffusion and evaporation. Therefore, Choongsik B. [7] suggested that the injection timing of ethanol blended fuel could be retarded close to top dead center (TDC) as the ethanol content increased. Also, he says that various ratios of ethanol - gasoline blended fuels the spray liquid length decreases and the spray angle increases as the ethanol contents increase at low ambient pressure. Also, methanol and methanol blended with gasoline exhibit slightly distinct behaviour under high temperature condition.

The heating value of fuel is one of its most important physical properties, and is used for the design and numerical simulation of combustion processes within internal combustion (IC) engines. Recently, there has been a significant increase in the use of dual fuel and blended fuels in CIE and SIE. In these conditions, it is necessary to develop prediction models which

evaluate the heating value depending on the nature of the mixture [25].
The heating value of fuel can be defined in two ways: a) the higher heating value (HHV) which is determined by bringing all the products of combustion back to the original pre-combustion temperature, and in particular condensing any vapour produced to liquid water, or gross calorific value; b) the lower heating value (LHV), or net calorific value which is determined by subtracting the heat of vaporization of the water vapour from the HHV. The lower heating value (LHV) of methanol and ethanol are significantly lower than that of gasoline.
Octane number is a measure of a gasoline's ability to resist auto-ignition; auto-ignition can cause engine knock, which can severely damage engines. Two laboratory test methods are used to measure octane: a) Research Octane Number (RON) correlates best with low speed, mild-knocking conditions; b) Motor Octane Number (MON) correlates with high-temperature knocking conditions and with part-throttle operation. RON values are typically higher than MON, and the difference between these values is the sensitivity, which should not exceed 10 [19]. The alcohol fuels show higher octane numbers, which is favourable to achieve higher thermal efficiency. Choongsik B. [7] cites studies on the fuel consumption behaviour considering connection between increased compression ratio and octane number, which showed that an octane number increment of approximately 4–6 was required per unit increase in compression ratio.
Alcohol fuels have higher ***latent heats of vaporization*** (Lhv) than that of gasoline; therefore, enhanced charge cooling effects can be expected. The cooling effect itself can also contribute to increased knock tolerance and volumetric efficiency.
The increase of droplet size after the injection event is attributed to the higher ***kinematic viscosity*** and ***surface tension*** of the ethanol [7].

Table1. Physical properties values of gasoline, ethanol, methanol [6, 7, 18 - 24, 26, 27, 28]

Item	Gasoline	Methanol	Ethanol
Molecular weight [kg/kmol]	111[6]	32[7]	46[6]
Density@20^{0}C [kg/m^3]	(0.72–0.78) [6,7]	0.792 [7]	0.785 [7] (0.80–0.82) [6]
Lower heating value [MJ/kg]	(41.0-44.0) [6,7,26,27]	19.9[7]	(26.4-26.9) [6,7,18,26,27]
Octane number (RON)	(92-98) [6,7]	109[7]	(107-110) [6,7,26]
Cetane number	8[6]		11[6]
Stoichiometric air–fuel ratio (A/F)	(14.4-14.7) [6,7,26]	6.5[7]	9.0[6,7] 8.96[26]
Latent heat of vaporization [kJ/kg]	305[7] ; 300[26] 349[27]	1168[7]	840[7, 26] 837[27]
Boiling point [°C]	(27–225) [6,7]	64.7[7]	78 [6,7,18,26]
Flame speed [m/s]	(0.37–0.43) [7]	-	0.39 [7]
Specific heat [kJ/kg K]	2.0 [6]	1.44 [28]	2.4 [6]
Vapour pressure@20^{0}C, [KPa]	(45-105) [19,26]	12,9 [20]	5.9 [21,26]
Kinematic viscosity@20^{0}C [cSt]	0.74[24]	0.759[23]	1.481[22]
Flash point	42.77 [28]	11,1 [28]	16.45 [18] 17.2[28]
Auto-ignition temperature	(246-280) [28]	470 [28]	424.85 [18] 365 [28]

COMBUSTION CHARACTERISTICS OF BIO-ETHANOL FUEL IN SIE

From a technical point of view, the wide use of renewable biofuels or alternative fuels can contribute to improvements in engine performance and emission characteristics. The combustion properties directly determine whether or not the given alternative fuels are suitable for engine operation [7].

S. K. Thangavelu et al. [8] in summary from 16 references, the blended ethanol fuel (E5 toE85) and pure ethanol (E100) in SI engines increase the combustion efficiency, in-cylinder pressure, in-cylinder temperature. Moreover, ethanol blended gasoline and pure ethanol decrease the combustion duration, combustion speed, combustion temperature and heat release rate (HRR). In addition, engine knocking increase and cold start SI engines problem appears when ethanol was used.

H.K. Rashedul et al. [6] reported the performance characteristics of spark ignition engine using ethanol as fuel at different operating conditions, such as:

In-cylinder pressure

As shown in Figure 3 [6], the in-cylinder pressure of different ethanol-gasoline blends fuels (E30, E50, E80 and E100) are higher than that of pure gasoline (E0) at the beginning of the combustion process (until its peak values). This is because of the earlier spark timing and faster burning rate of ethanol. Also, it can see that at the end of combustion, the in-cylinder pressure for pure gasoline (E0) is slightly higher due to longer combustion duration.

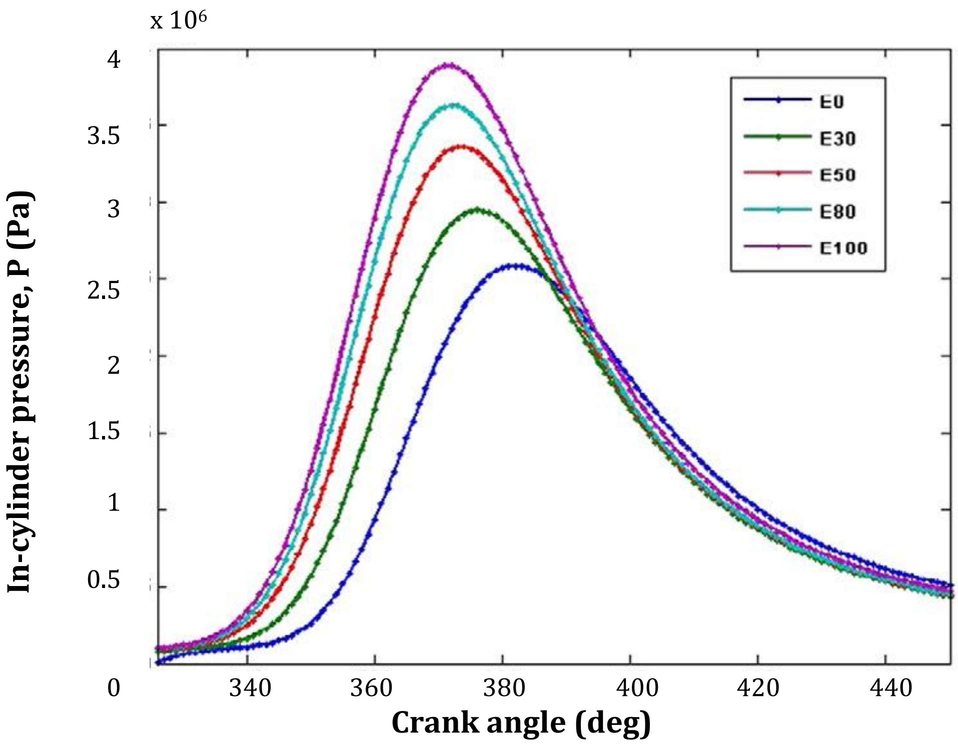

Figure 3. In-cylinder pressure against the crank angle for different ethanol-gasoline blends [6]

In-cylinder temperature

Higher peak in-cylinder temperature indicates higher engine thermal efficiency. As shown in Figure 4, H.K. Rashedul et al. [6] demonstrated that increasing ethanol content in the blended fuels, the peak in-cylinder temperature also increases at the beginning of combustion, until its peak values. After the peak value, for pure gasoline (E0) experiences shows [6] a higher in-cylinder temperature than that of pure ethanol (E100). This is also caused by the longer combustion duration of gasoline.

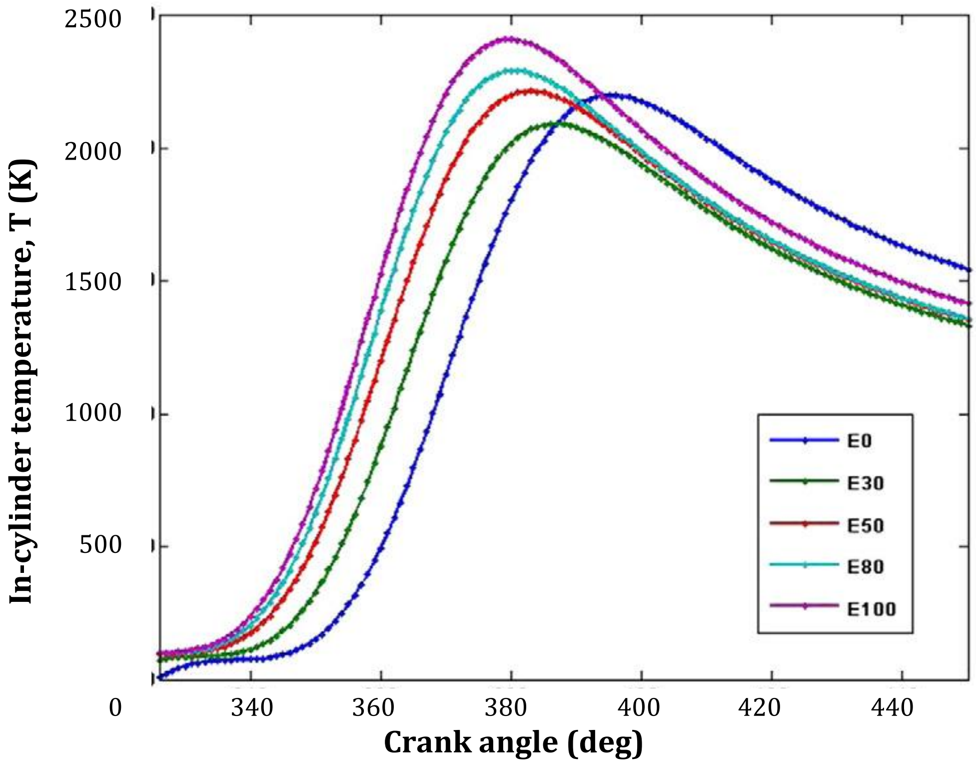

Figure 4. In-cylinder temperature against the crank angle for different ethanol-gasoline blends [6]

Mass burned fraction. Longer combustion duration means less combustion efficiency and this reduces the engine efficiency. From the graph, in Figure 5. H.K. Rashedul et al. [6] concluded that the combustion duration for gasoline is longer than for ethanol as a result of increased lower heating value of gasoline. Besides, decreasing the combustion duration, the graph also shows that the addition of oxygenated ethanol to gasoline results in earlier spark timing. Therefore, the combustion starts earlier with the presence of ethanol.
Increasing oxygen contain fuel burns at a faster rate, and reach the maximum rate earlier than gasoline due to more complete combustion. This better combustion efficiency suggests that using more amount of ethanol in fuel blends can prevent the premature combustion, and thus improve the anti-knock characteristics.

Coefficient of heat transfer. The performances of spark ignition engine depend strongly on the in-cylinder heat transfer from the combustion fuel to the wall in the combustion chamber. This process is especially the convective heat transfer. The engine heat transfer influences the engine efficiency, exhaust emissions and component thermal stresses.
Coefficient of convective heat transfer increases with increasing ethanol content in ethanol-gasoline mixture, so the heat transfer by convection in the cylinder is higher, but only at the beginning of the combustion process until its peak values (see Figure 6) [6].

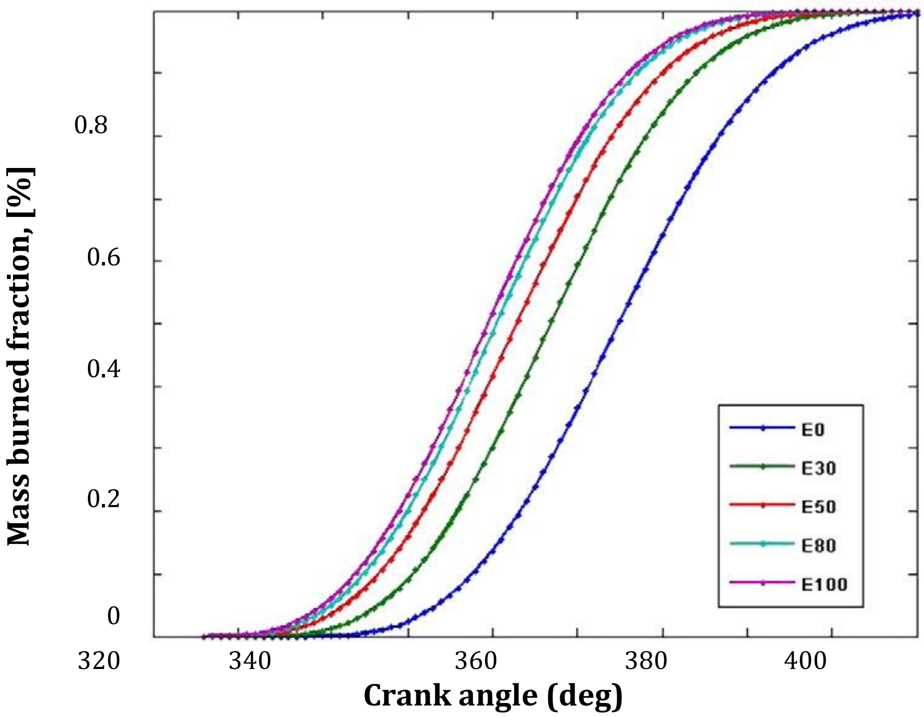

Figure 5. Mass burned fraction vs. crank angle for different ethanol-gasoline blends [6]

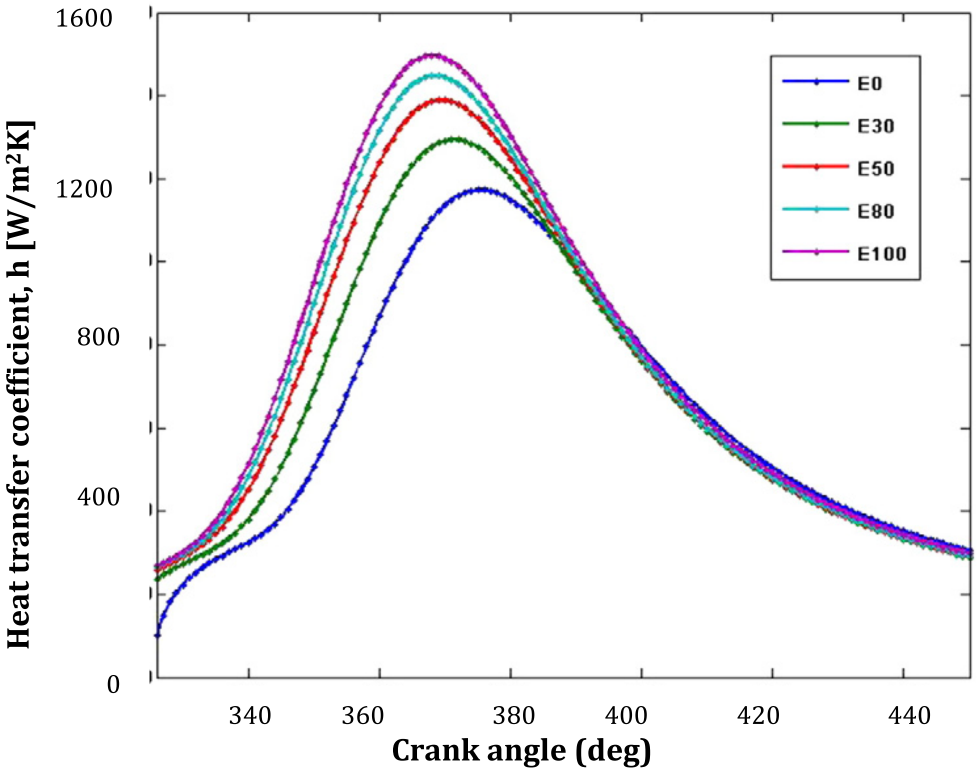

Figure 6. Coefficient of heat transfer vs. crank angle for different ethanol–gasoline blends [6]

ENGINE PERFORMANCE PARAMETERS

Engine torque and brake mean effective pressure (BMEP)

S. K. Thangavelu et al. in [8] says that about 93% researches from 29 references reported that adding ethanol fuel in SI engine slightly increased the engine torque. Up to 5% increment in the engine torque for ethanol fuel was observed in most of these studies.

H.K. Rashedul et al in [6] concluded that adding 5–15% ethanol to the blends led to an increase in engine torque. Consequently, BMEP increases, as well. In fact, in the review paper [8], the authors concluded that most of the cited researches reported that BMEP increased for ethanol fuel in SI engine.

Brake power

In [8] the authors confirmed that, there is a slight increment in brake power for lower content of ethanol in blends (up to 60% content of ethanol). When ethanol content is raised to more than 60% the brake power decreases. When running with neat ethanol (E100) fuel, it was seen that 4% decrease in power occurs in comparison with neat gasoline (E0).

S. Iliev in [9] considers that, when the ethanol content in the blended fuel was increased the engine brake power decreased for all engine speeds. The brake power of gasoline was higher than those of E5-E50 for all engine speeds. When the methanol content in the blended fuel was increased (M5 and M10), the engine brake power slightly increased. This can be explained by the fact that oxygenated fuels have a better combustion efficiency. When the methanol content in the blended fuel was increased (M30 and M50), the engine brake power decreased for all engine speeds. The brake power of gasoline was higher than those of M50 for all engine speeds.

H.K. Rashedul et al in [6] concluded that adding 5–15% ethanol to the blends led to an increase in the engine brake power.

Brake specific fuel consumption (BSFC)

Brake specific fuel consumption is defined as the amount of fuel consumed for each unit of brake power developed per hour. In review [8], authors concluded that all the cited studies reported only a slight decrement compared to gasoline. However, this can only be feasible for lower ethanol blends. There is no evidence of BSFC decrease for higher ethanol blends (E60 to E100) from literatures. H.K. Rashedul et al in [6] concluded that adding 5–15% ethanol to the blends decreases the brake specific fuel consumption. S. Iliev in [9] says the BSFC increased as the ethanol percentage increased. The reason is that the heating value and stoichiometric air-fuel ratio are the smallest for this fuel, which means that for specific air-fuel equivalence ratio, more fuel is needed. He declares that the highest specific fuel consumption is obtained at E50 (M50) blended fuel. Also, a slight difference exists between the BSFC when using gasoline and when using ethanol and methanol gasoline blended fuels E5 (M5), E10 (M10) and E20 (M20)). The lower energy content of ethanol gasoline blended fuels causes some increment in BSFC of the engine when it is used without any modification.

Volumetric efficiency (VE)

In [8] the authors concluded that the volumetric efficiency (VE) increased for ethanol fuel in SI engines. H.K. Rashedul et al in [2] concluded that adding 5–15% ethanol to the blends led to an increase in the engine volumetric efficiency.

For a small sized engine equipped with a carburetor and fuelled with different bioethanol blends which is used in small agricultural machinery, in [2], the authors claim that the volumetric efficiency is strongly increased, thanks to the evaporation and cooling effect of the bioethanol: using E80 it is possible to elaborate up to 20% more air than with gasoline.

EMISSION CHARACTERISTICS

Carbon monoxide (CO)

Many researches cited in [8] (88.6% of 36 references) reported that blended ethanol fuel in SI engine decreased the carbon monoxide (CO) emissions. Some researchers reported only a slight reduction in CO which is up to 10%. Many cited studies reported that more than 30% CO reduction was noticed in higher level ethanol blends.

In [9, 26] the authors say that when ethanol and methanol percentage increases, the CO concentration decreases resulting from improved combustion efficiency. This can be explained by the amount of oxygen due to the ethanol and methanol. So, an increase in the proportion of oxygen will promote the further oxidation of CO during the engine exhaust process. Another important reason for this reduction is that ethanol (C2H5OH) and methanol (CH3OH) has less carbon than gasoline (C8H18). The lowest CO emissions are obtained with blended fuel containing methanol (M50).

Regarding emissions of CO over the New European Driving Cycle (NEDC) test, the change was still relatively modest, slight decrease when amount of ethanol increase, say Piotr Bielaczyc et al. in [29]

In [16], authors sustain CO emission was increased with using alcohol fuels in fumigation mode compared to fossil fuels; however, that was decreased with using alcohol fuels in blended mode in most cases.

Nitrogen Oxides (NOx)

As seen in [8], maximum of 58% cited studies reported that the NOx emission decreased while adding ethanol in SIE. Among them, some of the literatures reported only a slight reduction in NOx emission up to 10%. The same trend was not seen in others of the literatures.

In summary [8], there is no consistency for NOx emission for different SIE fuelled with varied ethanol blend. In this area, a very important conclusion is that use of hydrous-ethanol can reduce the NOx emission significantly. Moreover, premixed water content in ethanol is more favorable than separate water injection.

S. Iliev shows in Figure 7 [9] the effect of ethanol and methanol gasoline blends on NOx emissions for different engine speeds.

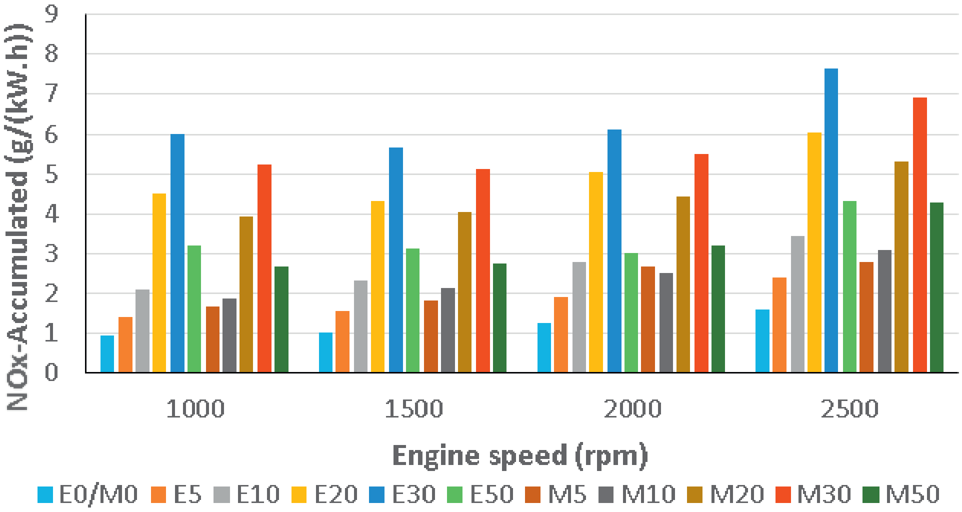

Figure 7. *Continued ...*

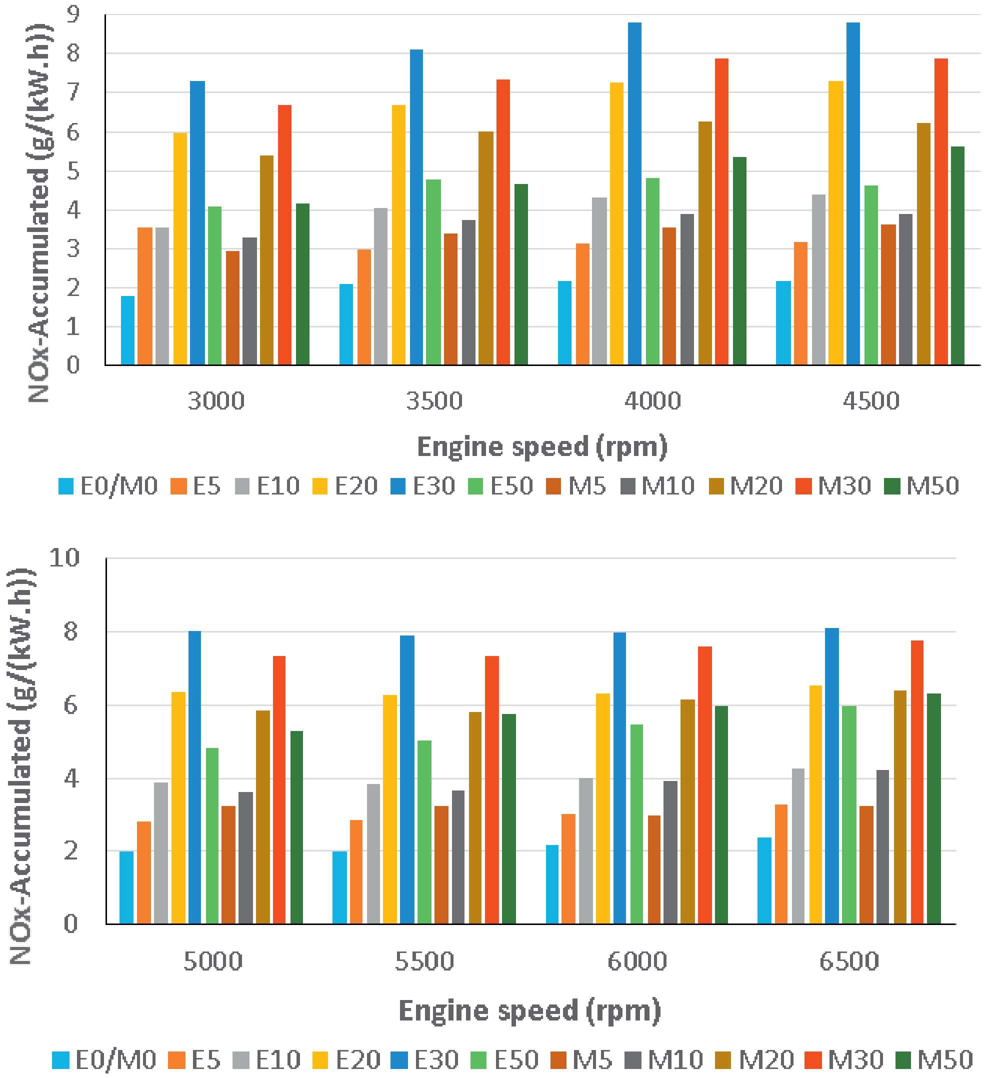

Figure 7. Influence of ethanol and methanol gasoline blended fuels on NOx emissions. [9]

It can be seen, when ethanol and methanol percentage increases up to 30% E30 (M30), the NOx concentration increases after which it decreases with increasing the ethanol (methanol) percentage. This can be explained by the increased in-cylinder temperature. The higher percentage of ethanol (methanol) in gasoline reduces the in-cylinder temperature. Emissions of NOx varied relatively little from one blend to another, a very slight increase was in fact observed for percent over 25%, notice Piotr Bielaczyc et al. in [29]. Increasing amount of alcohol, similar or reduced levels of NOx emissions was determinate in [26].

In [27] Alasdair Cairns et al. studied the effects of combining Early Inlet Valve Closing (EIVC) strategy with internal Exhaust Gas Recirculation (EGR) during port fuel injection of various alcohol blended fuels in a thermodynamic single cylinder research engine. In the case of warm idle engine conditions, they concluded that the use of high ethanol content fuels enabled moderate reductions (up to 20%) in NOx, which was primarily associated with significant increase in the residual mass tolerated. Also, in case of moderate speed and load conditions (2000 rpm/6 bar Indicated Mean Effective Pressure IMEPn), they concluded that for maximum NOx reduction, VVT-only operation proved to offer the highest benefit, regardless of the type of alcohol blended in the fuel at up to 25% volume.

Heat transfer has a strong influence on exhaust emissions because temperature has a strong effect on emissions. H.K. Rashedul et al. in [6] give an example, the formation of NOx has an exponential dependence on temperature. A reduction in the peak combustion temperature of 25–50 degrees can halve the NOx emissions. Furthermore, the wall temperature is important for emissions because in spark ignition engines, NOx emissions increase significantly with increasing surface temperatures.

Carbon dioxide (CO2)

S. K. Thangavelu et al. in [8] noticed that the findings of cited studies (140 references) are contradictory in terms of CO2 emissions. About 60% researches observed that the carbon dioxide (CO2) increased for adding fuel ethanol in SI engines. About 40% of literatures mentioned that CO2 emission decreased for ethanol fuel in SI engines. In summary, use of hydrous-ethanol in SI engines slightly decrease the CO2 emission compared to gasoline. Piotr Bielaczyc et al. in say [29] about emissions of CO2 over the NEDC that a very slight decrease for E50 was observed. CO2 emission was decreased with using alcohol fuels in fumigation mode compared to fossil fuels; however that was increased with using alcohol fuels in blended mode in significant tests [16].

Unburned hydrocarbon (HC)

S. K. Thangavelu et al. in [8] noticed that 94% of the cited researches, found unburned hydrocarbon (HC) emission decrease with ethanol fuel blends in SI engine compared to gasoline. However, few studies reported about slight reduction in HC due to the use of hydrous ethanol and lower blends. Few studies reported a slight increase in HC when adding ethanol.

Simeon Iliev shows in [9] the effect of the ethanol and methanol gasoline blends on HC emissions for different engine speeds. He demonstrated that, when ethanol and methanol percentage increases, the HC concentration decreases. He also says that the comparison of decrease of HC emissions among the blended fuels indicates that methanol is more effective than ethanol. The lowest HC emissions are obtained with blended fuel containing methanol (M50). Also, the low in-cylinder temperature can lead to an increment in the unburned combustion product.

Emissions of HC over the NEDC [29] decrease when amount of ethanol increase. HC emission was increased with using alcohol fuels in fumigation mode compared to fossil fuels; but that was decreased with using alcohol fuels in blended mode in major cases [16].

Particulate matter (PM) and particulate number (PN) emissions

The main component of the PM (soot) is the carbon that has formed in the combustion process of the fuel. The spark-ignition engines with direct injection, PM occur at high burning temperatures in areas with rich mixture.

Storch M. Et al. treat in their works [30, 31] issues related to the soot formation and particulate emission in spark-ignition engines running with various blends of gasoline and ethanol.

They cite several research studies showing that, for engines with direct injection (DISI) PM emissions can be reduced by increasing the ethanol content in gasoline. Other studies also show that a lower content of ethanol (eg, E10, E20) can be advantageous in terms of particulate emissions, obviously by decreasing of these.

M. Storch cites Maricq declaring that blends up to 20% get small benefits on concentration of PM. PM significant reductions relate to blends above 30%.

Contradictory results concerning the behavior of ethanol in terms of PM emissions is attributed to physico-chemical properties of ethanol and ethanol-gasoline blends. The ethanol changes the evaporation characteristics of the mixture, enthalpy of evaporation, which lead to

the tendency for an increase in the soot formation.
Generally, particulate emission decreases with increasing ethanol content. But, during special regimes of engine operation, eg for the catalyst heating operation point, there were higher concentrations of PM at E20 in comparation with isooctane.
This contradictory behaviour can be explained given the physico-chemical properties of ethanol, gasoline and ethanol-gasoline mixture. In [31] studies were performed on engines with direct injection. The work demonstrated that under specific conditions, a mixture about 20% of ethanol requires optimization of injection strategy, improving mixture formation in order to achieve the aspirations regarding emissions of PM.
Choongsik Bae et al. in [7] say that it is generally accepted that ethanol blended fuel exhibited higher PM and PN emissions than that of gasoline, mainly due to the lower evaporation characteristics of ethanol at ambient temperature below 300 K. However, the PM emission shows controversial results under warm-up conditions. The authors claim that the total PM emission with E85 showed eight times more than that of gasoline fueld engine. It was reported that the higher enthalpy of vaporization and deteriorated spray break-up lead to increase of the PM emission.
PM and smoke emissions were decreased with using alcohol fuels in both modes (fumigation and blended modes) compared to fossil fuels in all cases [16].

Other unregulated emissions
Unregulated emission compounds such as cet-aldehyde, form-aldehyde, aromatics, ethylene, and particulate emissions from ethanol fuel in SIE were also observed by some researchers as reported by S. K. Thangavelu et al. in [8]. Many of the researches reported that a cet-aldehyde and form aldehyde emissions from ethanol fuel increased compared to gasoline. However, Yao et al. cited by S. K. Thangavelu et al. in [8] reported that benzene, toluene, ethyl-benzene and xylene decreased about 53%, 29%, 76% and 13% for E15 compared to E0 in 1C engine, respectively.

CONCLUSION AND RECOMMENDATIONS

General results concluded from this study can be summarized as follows:

- The significance of using alternative fuels can be attributed to the following aspects: (1) pursuing energy sustainability through the extended usage of those alternative fuels derived from renewable energy sources and mitigating the concerns of limited fossil fuel energy; (2) improving engine efficiency and engine-out emissions with the aid of superior physical or chemical properties of alternative fuels compared to those of fossil fuels; (3) relieving the unbalanced usage of fossil fuels.
- Alcohols are an important category of bio-fuels. The ethanol and methanol have been good candidates as alternative fuels for the vehicles because they are liquid and have several physical and combustion properties like gasoline and can be used directly without requiring any major changes in the design of the engine;
- About the combustion characteristics of bio-ethanol fuel in SIE, we can conclude that in-cylinder pressure, in-cylinder temperature, mass burned fraction, coefficient of heat transfer of different ethanol-gasoline blends fuels is higher than that of pure gasoline, but only at the beginning of the combustion process, until its peak values. After this, the trend is not the same;
- Regarding the engine performance parameters, we can conclude the following: engine torque slightly increase adding ethanol; there is a slight increment in brake power for lower content of ethanol or methanol in blends; brake thermal efficiency (or BSFC), volumetric efficiency increase when adding ethanol; brake specific fuel consumption

decreases for lower ethanol, methanol blends, but, there are some studies which claim that brake specific fuel consumption increases when ethanol/methanol amount increases; brake mean effective pressure increases for ethanol fuel in SIE;

- Regarding emission characteristics we can conclude the following: CO emissions decrease when ethanol and methanol percentage increases; for NOx it can be concluded that only a slight reduction was reported when ethanol and methanol are adding, but a very important conclusion is that use of hydrous-ethanol can reduce the NOx emission significantly more than separate water injection; use of hydrous-ethanol in SIE slightly decrease the CO2 emission compared to gasoline; slight reduction in HC when amount of ethanol/methanol increases; about the PM emission, the results are contradictory and the level of emissions are related to engine operating conditions; there was no significant reduction of unregulated emissions, such as aromatics, acetaldehyde, and carbonyls.

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