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An Overview Of Spark Ignition Engine Operating On Lower-Higher Molecular Mass Alcohol Blended Gasoline Fuels

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Graphical abstract

No	Author	Type of SI Engine (Cylinder/Stroke)			Type of Alcohols			Data Acquisition & Analysis (Performance and Exhaust Emission)								
								Performance					Emission			
		Single Cylinder	Four Cylinder	Four Stroke	Methanol	Ethanol	Butanol	Brake Power	Torque	BSFC	Brake Thermal Efficiency	Volumetric Efficiency	CO	CO_2	UHC	NO_x
1	[13]	X			X					X	X		X		X	X
2	[20]	X			X	X				X	X		X		X	X
3	[11]		X	X	X	X				X	X					
4	[21]	X			X			X		X	X		X	X		X
5	[14]		X	X	X	X		X	X	X			X		X	X
6	[22]	*	*	X			X			X			X			X
7	[23]	*	*	*			X					X				
8	[18]	X		X			X		X	X				X		X
9	[9]		X	X	X	X				X	X		X	X	X	
10	[24]		X	X	X	X	X		X	X	X		X		X	X

Abstract

This paper reviews the utilization of lower and higher molecular weight alcohols as fuel for spark ignition engine. As an alternative fuel for spark ignition engine, alcohol is widely accepted as comparable to gasolin. It is due to its ability that can be produced from biological matter through the current available and new processes. Moreover, alcohol is also considered as fuel additive due to its physical and chemical properties compatible with the requirements of modern engines. The objective of this paper is to provide an overview of these fuels by highlighting on the fuel properties and spark ignition engine responses. The first part of this review explains the important of alcohol fuel properties related to the engine performance and emissions, and the difference of these properties for each type of alcohol. The second part discusses recent advancements in research involving lower and higher molecular weight alcohols mainly responses from spark ignition engine.

Keywords: Engine performance, emission, methanol, butanol, spark ignition engine

1.0 INTRODUCTION

Lifestyle development and the growth of world population increased worldwide energy consumption. One of the top energy consumers is transportation, where the demand of fossil fuels such as gasoline and diesel increases. Moreover, burning of these fossil fuels for transport vehicles causes global warming that have direct impact on human health [1, 2]. Rising demands of fossil fuels and negative effects of the emission have driven the researchers and scientists to find alternative fuels. Thus, alcohol fuel is being introduced and has attracted many interests from the market. Its ability to be produced from renewable resources and capability to deliver better engine performance with clear emission are some of the main attractions [3].Generally, there are two types of alcohol fuels, which are lower and higher molecular weight alcohols. Lower molecular weight alcohols such as ethanol and methanol have been used as fuel boosters by mixing them with gasoline. Ethanol is produced from starch and sugar cane by fermentation. On the other hand, methanol is produced from coal, natural gas and biomass. Higher molecular weight alcohols often used as additive in alcohol gasoline blends. Most higher alcohols such as propanol, butanol and pentanol are produced from coal derived syngas.Thus, the aim of this review paper is twofold; first to summarise the important properties of using alcohol fuel as an alternative fuel to gasoline. Secondly, to determine the responses on engine performance and emissions of spark ignition engines based on previous research studies until now.

2.0 IMPORTANT PROPERTIES OF ALCOHOL FUELS

Alcohols have a large and diverse family of chemical compounds. It is a hydroxyl derivatives of hydrocarbons recognized by its unique arrangement of carbon, hydrogen, and oxygen atoms. Having oxygen enables alcohol to combust more completely which increases the combustion efficiency and reduces air pollution [4, 5]. The physical and chemical properties of several alcohol are presented in Table 1. Knowledge on alcohol characterization is vital for customer satisfaction, legislative requirements and the preservation of industry standards. First, increase in molecular weight of alcohol fuels correspond to the decrease of oxygen content (wt%). Using 10% of ethanol blended with gasoline able to reduce greenhouse gas emission with the presence of oxygen [6]. Morever, lower heating value (LHV) also increases with the increase of carbon and hydrogen content of the alcohol. Alcohol that have four or more carbon usually have LHV closer to gasoline, which is beneficial for improving fuel economy. Second is the volatility of alcohol, which decreases with the increase of carbon atom number. This shows that higher molecular mass alcohol has less tendency towards cavitation and vapor lock problem compare to lower molecular mass alcohol.

Alcohols usually have higher latent heat of vaporization which cools the air entering into combustion chamber of the engine that can influence the mixture temperature. Due to this reason, the temperature at the intake manifold drops and this increases the volumetric efficiency of gasoline engine [7]. Besides that, alcohols ignition propensity is the most attractive feature for internal combustion engine application. Having high octane rating corresponds with lower propensity for ignition, allows SI engine to operate at higher compression ratio without knocking.

In terms of intersolubility, the presence of alkyl and hydroxyl enable alcohol to blend with gasoline and diesel fuel. The more carbon an alcohol molecule contains, the easier the alcohol can be blended into gasoline and diesel fuel. Besides that, the longer carbon chains of alcohols will increase its viscosity. For this reason, a higher molecular weight alcohol normally will be used when a more viscous solvent is required. For an example, the kinematic viscosity of butanol is several times higher than that of gasoline, so it will not cause potential wear problems on the fuel pump designs caused by insufficient lubricity [8]. Regarding with the handling and distribution, high molecular mass alcohol is more favourable because it can tolerate water contamination and less corrosive which make it suitable for transportation through existing pipelines [8].

Table 1 Properties of methanol, ethanol, propanol, butanol and pentanol [6, 9]

Properties	Methanol	Ethanol	Propanol	Butanol	Pentanol
Chemical formula	CH_3OH	C_2H_5OH	C_3H_7OH	C_4H_9OH	$C_5H_{11}OH$
Molecular weight	32.04	46.06	60.09	74.11	88.14
Net lower heating value (MJ/kg)	20.10	27.00	32.95	35.69	37.62
Stoichiometric A/F ratio	6.40	9.00	10.33	11.17	11.74
Oxygen content, mass %	49.90	34.70	26.60	21.60	18.1
Boiling Point (°C)	64.70	78.00	97.00	98.00	138.00
Specific Gravity at 20°C	0.792	0.794	0.804	0.81	0.816

3.0 ALCOHOLS FUELS RESPONSES ON ENGINE PERFORMANCE AND EMISSION

It is not surprise that alcohols continue to be attractive fuels for today’s modern internal combustion engine based on their favorable physical-chemical properties. Table 2 shows the recent research studies done on alcohols for the past five years. Listed is the data acquisition on performance and emission, type of engine and fuel used for the experimental work. Based on Table 2, several rigorous investigation and significant findings had being done on the effects of alcohol with gasoline blends to the performance and emission of spark ignition engine.

Investigation done by J. Li *et al*. [10] on the effects of optimal injection and ignition timing on performance and emission using direct injection spark ignition engine fueled with methanol. The result shows that good combustion and low emissions was achieved for the overall mode range by using optimal injection and ignition timings compared with non-optimized injection with ignition timings. Improvement of BSFC more than 10% was recorded in the overall load range due to the formation of ideal stratified mixture distribution in the cylinder under different loads for optimal injection timing and ignition timing. The effects of methanol-diesel and ethanol-diesel fuel blends on the performance and exhaust emission using single cylinder naturally aspirated diesel engine was investigated by C. Sayin [11]. The result given shows that reduction was recorded on brake thermal efficiency, smoke opacity, emission of THC and CO with methanol-diesel and ethanol-diesel fuel blends. Meanwhile there is an increase in the BSFC and NO_x emissions due to lower energy content and higher oxygen concentration in the alcohol blend. Studies on the effects of ethanol and methanol addition to unleaded gasoline to the performance and emissions of spark ignition engine were carried out. [12]. The results showed that ethanol gasoline blends are better than methanol-gasoline blends for the performance charts due to the effect of the combustion related properties. Significance reduction on the exhaust emissions was recorded for both methanol and ethanol gasoline blends due to high ratio usages of ethanol and methanol B.M. Masum *et al*. [13] investigated the different ratios of multiple alcohols(C2 to C6) compared to the conventional ethanol gasoline blend (E15) using four cylinder gasoline engine at specified test condition. Three type of different blend ratio have being identified which are maximum heating value (MaxH), maximum research octane number (MaxR) and maximum petroleum displacement (MaxD) in order to have an optimum blend. The result showed that the entire optimum blend gave higher torque and brake thermal efficiency (BTE) but lower BSFC compared to E15. In terms of exhaust emissions, all optimum blend and E15 give lower CO and HC emission but higher NO_x emission than gasoline.

Table 2 Previous research on alcohol fuel for past five years

No	Author	Type of SI Engine (Cylinder/Stroke)			Type of Alcohols			Data Acquisition & Analysis (Performance and Exhaust Emission)								
								Performance					Emission			
		Single Cylinder	Four Cylinder	Four Stroke	Methanol	Ethanol	Butanol	Brake Power	Torque	BSFC	Brake Thermal Efficiency	Volumetric Efficiency	CO	CO_2	UHC	NO_x
1	[10]	X			X					X	X		X		X	X
2	[11]	X			X	X				X	X		X		X	X
3	[14]		X	X	X	X				X	X					
4	[15]	X			X			X		X	X		X	X		X
5	[12]		X	X	X	X		X	X	X			X		X	X
6	[16]	*	*	X			X			X			X			X
7	[17]	*	*	*			X					X				
8	[18]	X		X			X		X	X				X		X
9	[19]		X	X	X	X				X	X		X	X	X	
10	[13]		X	X	X	X	X		X	X	X		X		X	X

*Using other than indicated engine.

Based on recent research studies, only few researchers investigated the effect of both lower and higher alcohol with its effect on engine performance and emissions [13, 20-22]. Nevertheless, there is still lack of research on blending the lower and higher molecular mass alcohol with gasoline specifically by identifying type and percentages of alcohol addition with improvement on the overall fuel properties. Besides that, knowledge on the application of alcohol to gasoline fuel and their effect on engine combustion, performance and emissions are also necessary in order to relate with the improvement of fuel properties and percentage addition of alcohol. Thus, next sub-topic on this will be focus on explaining the effect of each lower and higher molecular mass alcohol on spark ignition engine performance and emissions.

3.1 Lower Molecular Weight Alcohols

Normally, lower mass alcohol provides octane enhancement which established bigger fraction of the alcohol-gasoline blends mixture. Interestingly, methanol is one of the favorite selections due to its excellent combustion properties and high octane number. However, methanol blends will consume large amount of fuel for supplying the same amount of energy due to its LHV [4, 14, 19, 23]. It's high heat of vaporization cools the inlet air which leads to increased fuel conversion efficiency. Furthermore, it results in improved volumetric efficiency resulting in increase of the engine power output compared to gasoline [19]. Moreover, presence of oxygen in methanol able to produce a soot-free combustion with a low particulate level [24]. Application of methanol in spark ignition engine also able to reduce emission of carbon monoxide (CO) and unburned hydrocarbon (UHC) due to leaning effect [7, 10, 12, 14, 18, 21, 22, 25]. Leaning effect is defined as enhancement of oxygen content in fuel to improve combustion efficiency in cylinder [7] . Unfortunately, emissions of nitrogen oxides (NOx) increases at a very lean operation condition. This relates to higher cylinder temperature of alcohol gasoline blends compared to base gasoline. The other factors on the formation of NOx are related with rate of combustion inside the chamber and higher oxygen concentration [22]. Methanol also has high volatility which will cause phase separation and increase in Reid Vapor Pressure. This will result in high in-cylinder combustion temperature and cause drivability problems such as vapor lock [26].

3.2 Higher Molecular Weight Alcohols

Defined as higher carbon number alcohols that have higher octane number, energy content and able to displace more gasoline than that of ethanol. Due to its greater physical and chemical characteristics in terms of volatility and adaptability to the existing fuel storage with distribution infrasturcture,butanol has been proposed as the next-generation biofuel for transportation to replace gasoline [27, 28]. Among the research done on iso-butanol is investigation on the fuel conversion efficiency of gasoline-isobutanol blends by Adrian Irimescu [17, 29]. Compared with gasoline, slight improvement is shown on the full load conversion efficiency when the engine running below 50% of butanol blends while usage of pure butanol decrease up to 9%. While for the part load efficiency shows various drop depending on loads and blends ratio, during 50 % butanol blend with very light load was noticed having maximum of 12% efficiency drop. By ranging the air-fuel mixture temperature and engine efficiency, incomplete fuel evaporation was determined as the major factor for fuel conversion efficiency. Iso-butanol also received attention from other engine researchers who studied performed of SI engine [30, 31]. In another study done by Wigg *et al*. [5] which focused on the emission properties of neat butanol in a port-injected spark ignition engine, it showed that butanol produced three times of UHC as compared to gasoline. The UHC emissions kept increasing with the further increa in amount of butanol which supports the general trend and it is suspected due to poor atomizing of butanol. Nevertheless, CO emission for butanol gives 12% reduction and NO_x emission of butanol are 17% lower than gasoline at stoichiometry. The decrease of CO emissions can be attributed to the extra oxygen in the alcohol fuel. While the decrease in NO_x emissions relates with the higher UHC emissions earlier which lead to a lower heat release resulting in lower combustion temperature. The research team also examined the molecular structure impact on the combustion of butanol and suggested that iso-butanol is the best "trade-off" for emissions [32].

4.0 CONCLUSION

This review paper gathers knowledge of lower and higher molecular weight alcohol which allows better understanding of its responses on engine performance and emission. It can be summarized that lower molecular weight alcohols received public attention due to its low-polluting properties and high efficiency through their lean operating ability. Meanwhile, the higher molecular weight alcohols provide better water tolerance, volatility control, solving phase separation and lower Reid Vapor Pressure (RVP) of the blends. In terms of emissions, both lower and higher molecular weight alcohol will give lower emission for CO and UHC due to presence of oxygen that assist in complete combustion. However, details studies need to be done, especially by blending both lower and higher alcohols with gasoline on engine performance and emissions. Thus, as a final conclusion from this review, both alcohols are suitable to operate the spark ignition engines with better engine performance and emit lower pollutants compared to gasoline fuel.

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