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Application of Alcohol Fuel Properties in Spark Ignition Engine: A Review

(Perlaksanaan Sifat-Sifat Minyak Alkohol dalam Sistem Gasoline Enjin: Tinjauan)

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ABSTRACT

Rapid depletion of petroleum resources had raised the awareness of reducing the dependency on the fossil fuels by means of alternative fuels. Alcohols had emerged as the most competitive candidate among the well-known alternative fuels because it can be produced from renewable resources such as waste material. Some of the examples of alcohols are methanol, ethanol, and butanol. Each of these alcohols has the capability for its utilization in vehicles due to its cheap price than the other alcohol and has similar chemical properties to gasoline and diesel. Currently, only few research papers had discussed the alcohol fuel properties in the collective form of information including adverse effect of alcohol fuel usages and its responses in spark ignition engine performance and emissions. Therefore, this paper is focusing on the physical and chemical properties of alcohol fuels with recent literature data specifically for spark ignition engines. In addition, the usages on the properties of alcohol fuel to the current available spark ignition engine will also be review in this paper. Advantages and disadvantages of alcohol fuel usages are also summarized. This review indicates that continuous research and development still need to be done especially on alcohol fuel properties as it will give greater engine performance and better emissions.

Keywords: Alcohol Fuel Properties; Engine Performance; Emission; Spark Ignition Engine

ABSTRAK

Penurunan pesat sumber petroleum telah meningkatkan kesedaran untuk mengurangkan kebergantungan kepada bahan api fosil melalui bahan api alternatif. Alkohol telah muncul sebagai calon paling kompetitif di kalangan bahan api alternatif yang terkenal kerana ia boleh dihasilkan dari sumber yang boleh diperbaharui seperti bahan buangan. Antara contoh alkohol adalah methanol, etanol, dan butanol. Setiap alkohol ini mempunyai keupayaan untuk penggunaannya di dalam kenderaan kerana harganya yang murah daripada alkohol yang lain dan mempunyai sifat kimia yang sama untuk petrol dan diesel. Pada masa ini, hanya beberapa kertas penyelidikan yang membincangkan sifat-sifat bahan api alkohol dalam bentuk maklumat kolektif termasuk kesan sampingan penggunaan bahan api alkohol dan tindak balasnya dalam prestasi pencucuhan enjin pencucuhan dan pelepasan. Oleh itu, makalah ini memberi tumpuan kepada sifat fizikal dan kimia bahan api alkohol dengan data sastera baru-baru ini khusus untuk spark pencucuhan mesin. Di samping itu, penggunaan bahan api alkohol ke enjin pencucuk api semasa yang ada juga akan dikaji semula dalam kertas ini. Kelebihan dan kekurangan penggunaan bahan api alkohol juga diringkaskan. Kajian ini menunjukkan bahawa penyelidikan dan pembangunan yang berterusan masih perlu dilakukan terutama pada sifat bahan api alkohol kerana ia akan memberikan prestasi enjin yang lebih besar dan pelepasan yang lebih baik.

Kata kunci: Sifat-sifat Bahan Api Alkohol; Prestasi Enjin; Pelepasan; Enjin Pencucuhan Percikan

INTRODUCTION

It is known that combustible material which is fuel such as coal, wood, oil, or gas, often used to control fire in order to create heat or power. In a self-sustaining exothermic reaction, the combustible material will reacts easily with oxygen. Study on the characteristics of the fuels is important to understand the combustion phenomenon and engine performance. In addition, characteristics of the fuel also have influence on the engine power efficiency, the fuel consumption, the emissions and specifically on the durability and the reliability of the engine (Gupta 2006; Salvi et al. 2013). There are several requirements that needed to be satisfied to determine the characteristics of the fuels which are:

1. The fuel must be completely vaporized, atomized, vaporized and completely mixed together with the air in order to have fast combustion process (Gupta 2006).
2. Swift during starting the engine and reliable at any ambient condition.
3. The surface of the combustion chamber should remain free from carbon and other deposits to achieve smooth combustion process.
4. The cylinder face, the piston and the piston rings should be free from excessive wear and corrosion.
5. In the combustion process, the fuel must stay free from thermal stresses especially the engine due to the development of the temperature gradient.
6. No emissions of harmful exhaust gases during completion of combustion stages.

Generally, fuels are separated by its sources and phases. In terms of its sources, fuel is divided into two which is natural and artificial. For phases, fuel is classified into three phases known as solid (coal, wood etc.), liquid (petroleum products, alcohol, bio-fuel etc.), and gas (methane, butane, hydrogen, biogas etc.) (Houghton-Alico 1982). For the application of the fuel on engine operation, the selection is mainly governed by 1) type of the equipment required to store and supply the fuel in the engine, 2) the calorific value per unit volume of the fuel, and 3) the cost of the fuel at the site of the engine (Gupta 2006). Nowadays, increasingly strict regulation enforcements on the pollutant produced by automotive engines together with volatile price of gasoline has increased the needs for alternative fuel with good engine performance, efficient fuel economy and lower emission pollutants. Some of the criteria for the alternative fuels is that it should be from renewable sources and abundant, cheap to compete with conventional fuels and capable to be blended directly with current available gasoline engine without major modifications. Due to these reasons, alcohol has been an attractive option of alternative fuel to be used commercially and also alcohol characteristics met the requirements stated earlier. Currently, Brazil, China and United States are among of the countries that widely used alcohol fuel as an additive or alternative fuel (Jin et al. 2011). Also there is a lot of research on the effect of alcohol operation with gasoline and diesel in internal combustion engine (Bergthorson & Thomson 2015; Masum et al. 2015). However, the reason and explanation on how the properties of alcohol fuel affect the engine performance and exhaust emissions still not clear. Thus in this review, detail description will be presented on alcohol fuel properties and its effect on engine performance and exhaust emissions. Besides that, comprehensive review of alcohol fuels by previous researchers is presented in this paper. Finally, discussion will be done on important qualities of fuel that should be performed to give better engine performance and lower exhaust emissions.

APPLICATION OF ALCOHOL FUEL PROPERTIES

Fundamental knowledge on the alcohol fuel characterization is essential in order to understand the combustion phenomenon occurs in the gasoline engine. The knowledge of the fuel properties is very important because its helps consumer to use the fuel efficiently and selecting the suitable fuel for the right purpose (H. H. M. B.M. Masum et al. 2014; Surisetty et al. 2011). In addition, having knowledge on characteristic of the alcohol fuel will have influence on the efficiency, design, durability and the reliability of the engine. Utilization of alcohol fuel in the engine also one of the contributing factors of the environment pollution due to the alcohol fuel properties. For the alcohol fuel properties, it can be related with chemical and physical properties such as density, flash point, lower heating energy, viscosity, vapor pressure, temperature control, chemical formula, and etc. (Houghton-Alico 1982). Each of these characteristic of the alcohol fuel have its own advantages and disadvantages to the engine operation and pollutant emissions. In order to have a consistent composition and quality as well as reliable engine operation, the properties of alcohol fuel must follow the limitation of available standards in the world (EN, DIN, ATSM, etc). In the following, explanation on some of the main fuel properties that directly relates to the alcohol fuel and its effect on spark ignition engine operation will be described. Table 1 shows the fuel properties of gasoline and several alcohol fuels.

TABLE 1. Properties of methanol, ethanol, propanol, and butanol (Balki & Sayin 2014a; Sarathy et al. 2014; Surisetty et al. 2011)

Properties	Gasoline	Methanol	Ethanol	Propanol	Butanol
Chemical formula	C_8H_{18}	CH_3OH	C_2H_5OH	C_3H_7OH	C_4H_9OH
Molecular weight	114	32.04	46.06	60.09	74.11
Density (Kg/m³)	736.8	792.0	794.3	789.4	806
Net lower heating value (MJ/kg)	43.919	20.10	27.00	32.95	35.69
Stoichiometric A/F ratio	15.05	6.40	9.00	10.33	11.17
Oxygen content, mass %	0	49.90	34.70	26.60	21.60
HoV (kJ/kg)	349	1178	923	761	683
Reid Vapor Pressure (at 37.8°C) (kPa)	63.9	31.72	19.1	13.8	6.6
Research Octane Number	95	108.7	107.4	112.5	105.1

RESEARCH OCTANE NUMBER

In general, octane number is a quantitative measurement where the fuel is being utilized in an engine without taking account the abnormal phenomenon where air-fuel mixture is "knocking" or self-igniting. There are two types of octane numbers that is used to determine the quality performance of the fuel and there are; 1) Research Octane Number (RON) where it simulates fuel performance under lower engine operation; 2) Motor Octane Number (MON) simulates at high engine operation to determines its fuel performance. Eventually, the octane numbers of a fuel is calculated as the average of reserach and motor octane number.

Spark ignition engine combustion related both to the engine design and also the quality of the fuel. Under ideal conditions, the combustion take places as the spark plug produce spark that initiate the flame that burns all the fuel across the combustion chamber. However, the knocking phenomenon happened when the part of gasoline-air mixture also known as end gas zone undergo pre-flame reaction caused by the pressure increases at the end gas zone. Highly temperature sensitive peroxides are the among the products from the main pre-flame reaction which will spontaneously ignite when peroxides although the flame front from the spark plug not yet arrived at the end gas zone. This pehnomenon causes detonation or knocking (Sangeeta et al. 2014). Figure 1 shows the common combustion phenomenon that takes place in the engine operations. The combustion is said to be a normal combustion when the flame spreads through the cylinder until the end of the combustion process without any distraction changes from the shape and the speed (Gupta 2006). As shown in Figure 1, auto-ignition or pre-ignition will happen when the mixture is ignited and burns before the flame reaches it. Meanwhile, detonation causes engine knocking that occurs when there is a sudden rise in the reaction rate and an increment in pressure that form pressure waves (Gupta 2006).

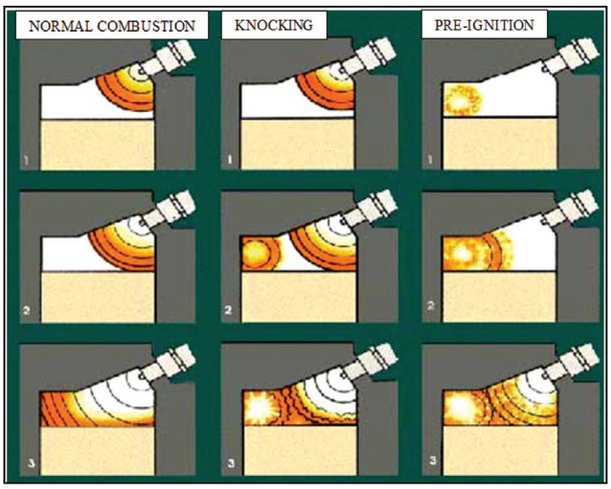

FIGURE 1. Combustion phenomenon in the engine operations (Gupta 2006)

Addition of alcohol in gasoline blends will increase the octane number which will improve the antiknock behavior and allowed more advanced timing that produced higher combustion pressure and higher torque (Ioannis Gravalos 2011). Figure 2 indicates that the higher molecular weight of alcohol the larger amount of volume fraction in the blends in order to have the same amount of oxygen content with the lower molecular weight of alcohols. The presence of oxygen content (wt%) in the blends has caused alcohol fuels to have higher octane number. The increase in octane number will reduce the knock in the engine.

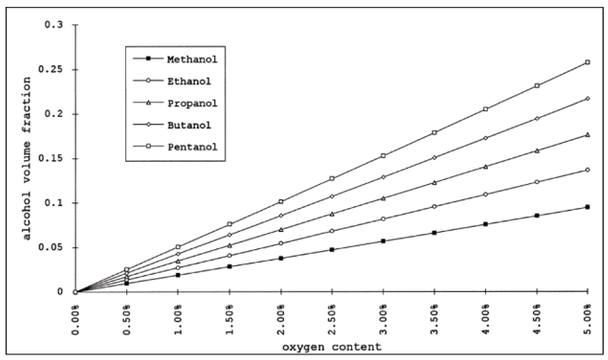

FIGURE 2. Volume fraction of alcohol-gasoline blends ($C_1 – C_5$) with oxygen content (Yacoub, Bata & Gautam 1998)

In addition, spark ignition engine able to operate at higher compression ratio without knocking due to increase in octane number of fuels which give in lower propensity for ignition. Besides improving the antiknock behavior, increases in octane number will results in more advance timing that produces higher combustion pressure and higher torque (Altun et al. 2013). Recent research by Eyidogan et al. (2010) shows that methanol contain higher oxygen rate than the ethanol, more oxygen produces better combustion efficiency and consequently reduces the bsfc. Besides that, brake thermal efficiency increases with the increasing of vehicle speeds because of the decreases in fuel consumption. The higher the oxygen rate, the better of the combustion and thus increases the thermal efficiency. Investigation also has been done on the effects of methanol fuel on the spark ignition engine performance and exhaust emissions (Çay et al. 2013). Results obtained proved that methanol fuel did lowered the emission characteristics compared to gasoline fuels. Zhend et al. (2013) theoretically investigated spark ignition methanol engine in a high compression ratio with knocking combustion under various engine operating conditions. The results demonstrated that engine knock cannot be solve by only retarding the spark timing. The knock intensity was found to be reduced and the peak pressure was to be greatly suppressed due to increase of EGR (exhaust gas recirculation) and high compresstion ratio.

HEATING VALUE

Another term for heating value is calorific value. It is defined as heat released by the fuel when it is completely burnt and measured at constant volume or constant pressure, and the hot gas is cooled back to its the initial temperature (ASTM D240-17). Heating value can be divided into higher heating value (HHV) and lower heating value (LHV). For alcohol fuels, the lower heating value increases as carbon atom number is increasing in the blends. In another words, the increase in carbon and hydrogen content is related with the increase in molecular weight of alcohol fuels and corresponds to the decrease of oxygen content. For example, methanol with one carbon atom and ethanol with two carbon atoms have lower LHV than gasoline. This will leads to higher fuel consumption as the engine need to double up the engine power to have the same power output from gasoline. This has been proved by the result shown that the usage of alcohol fuels in gasoline engine will have twice of fuel consumption compared to gasoline in order to have same engine power output (Agarwal et al. 2014; Balki et al. 2014b). This situation has leads to the increase in fuel consumption and reducing fuel economy. In order to overcome this problem, there has been approached by the researchers to use alcohol with four or more carbon atoms in order to achieve lower heating value that is closer to gasoline. Previous research done also shows that the fuel consumption reduced and able to obtained better mileage (Elfasakhany 2014; Masum et al. 2014).

LATENT HEAT OF VAPORIZATION

Define as the amount of heat (KJ/kg) required to convert one unit mass of a liquid at its boiling point into a one unit mass of vapor without any increase in temperature. Alcohol fuel with higher heat of vaporization have better fuel conversion efficiency compared to gasoline. Alcohol fuel will lowered down the temperature of the air entering into engine and increase the volumetric efficiency with the engine power output. Moreover, alcohol fuels are easier to vaporize in the compression stroke due to high heat of vaporization. This is because as the fuel absorbs heat from the cylinder during vaporization, the air fuel mixture is compressed more easily, thus improving thermal efficiency for alcohol-gasoline blend than that of gasoline. However, higher heat of vaporization of alcohol fuels also has negative impacts especially in its ability to start the engine during cold conditions. Current advance in fuel delivery system and usages of higher molecular weight alcohols seems to be the solution to overcome cold start condition. Recent research by Hsieh et al. (Hsieh, Chen, Wu & Lin 2002) studied different percentages blends of ethanol–gasoline blends in an spark ignition engine. The author concludes that, the engine torque and fuel consumption slightly improved compared to the gasoline when using ethanol–gasoline blends. Having higher latent heat of vaporization has leads to the enhanced engine torque. This can be explain that having higher heat of vaporization will lessened the intake temperature due to alcohol fuel easily vaporizes and evaporates in the intake manifold. The same result was also obtain by other researchers (Feng et al. 2013; Schifter et al. 2011)

DENSITY

Density of a fuel is an important parameter especially for gasoline engine performance. For an example, fuel that having higher density will affect the engine power output because of the injected fuel mass in the engine as it is measured by the fuel injection system (Alptekin & Canakci 2008). In addition, density of a fuel also have an influence in evaluating engine ignition quality and quantity calculations which will have an effect on engine operation (Sera et al. 2009). Some of the significance effect on the performance of engine is the combustion characteristic and fuel efficiency of fuel atomization. Masum et al. (2014) asserted that the density of the gasoline and alcohol blends can be calculated by using Equation (1), where v_i is a volumetric concentration of the density in the blend.

$$Density_{blend} = \sum_{i=1}^{n} v_i \times Density \tag{1}$$

Generally, density increases with aromatic content which means that high content of ocatane gasoline will have higher density. Nevertheless, adding oxygenated products such as alcohol fuels into the gasoline will result the octane rating increases but will not affect the current density. The sources of raw material used to produce fuel in the production process also could affect the density of a fuel (Atabani et al. 2012; Xue et al. 2011). Thus, it can be explained that the density of the blended fuel is increases due to the rise of the alcohol content in the blend mixture. Choosing an acceptable range of density for an engine operation is necessary especially in designing inlet fuel system and suitable flowrates of vehicle for various components in the vehicle (Guibet 1990).

REID VAPOR PRESSURE

Reid Vapor Pressure is the relative pressure (pressure difference based on atmospheric pressure) which to measure how quickly fuels to evaporate (Guibet 1990). Reid vapor pressure (RVP) also refers as vapor pressure which measure by following standard procedure measurement at 37.8^{o}C in a chamber with a vapor/liquid volume ratio 4:1. In another words, it also known as volatility or saturation pressure where how quickly the fuel to evaporate as it will contribute more to ozone layer which will affect surrounding environment. The volatility of the fuel is represented by one or several characteristics, such as distillation curve, vaporization enthalpy, and vapour pressure. As shown in Figure 3, volatility of alcohol fuels is decreased with the increase in carbon atom number. Ethanol with two carbon atoms has the highest vapour pressure at 20% alcohol concentration compared to other alcohols (Masum et al. 2014). This means that alcohol with more than four carbon atoms will have fewer tendencies on vapour lock and cavitation problem. Note that blending alcohols with gasoline, especially shorter

chain alcohols (methanol and ethanol); the blends exhibited reductions in distillation temperatures and did not behave like an ideal mixture due to the formation of a near azeotropic mixture. Thus, the fuels must be adequately volatile in order to have easy engine start and sufficient vaporization for fuel distribution between the cylinders. A study conducted by Pumphrey et al. (2000) showed that vapour pressure of gasoline was initially increased with the addition of alcohols, then the value was lowered as the proportion of alcohol was increased. The total elevation and the composition of the peak further affected the characteristic of the additive where it influenced the performance of engine and had an impact on the environment

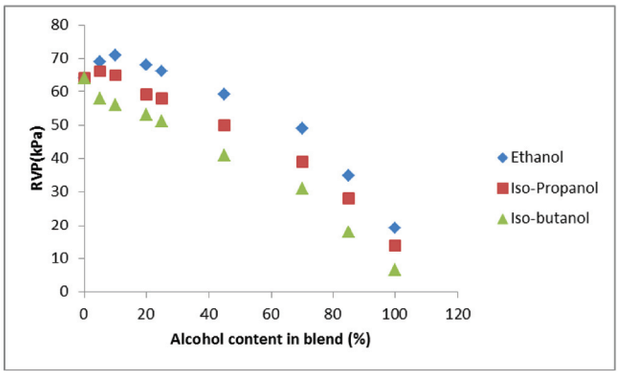

FIGURE 3. Estimated RVP values with alcohol concentration in alcohol-gasoline blends (H. H. M. B.M. Masum, M.A. Kalam, S.M. Palash, M.A. Wakil, S. Imtenan 2014)

VISCOSITY

Viscosity is a measurement of resistance to the flow of a liquid due to the internal friction of one part of a fluid moving over another and it is based on its temperature and molecular structure (Knothe et al. 2005). Viscosity is one of the important properties because it affects the behavior of fuel injection. Accurate amount of fuel is needed for injection in order to have better efficiency. Tesfa et al. (2010) measured experimentally the correlation between density and viscosity of a fuel blends and prediction model has been developed relating viscosity as a function of density as shown in Equation (2).

$$\ln(\eta) = 0.0357\rho - 29.02 \qquad (2)$$

Where η is the kinematic viscosity of the fuel blends in mm^2/s at a given temperature and ρ is the density of the fuel blends at a given temperature. By having a density value of a fuel blends, the kinematic viscosity of the fuel blends can be estimated by using the prediction model. The results also show that about 0.37 of maximum absolute error for the values from predicting model and experimental values. In terms of its application, the kinematic viscosity prediction model can be used in predicting air-fuel phenomenon, combustion characteristics and investigation of fuel pump systems (Tesfa et al. 2010). Generally, higher viscosity can leads to poorer fuel atomization that can produce poorer vaporization, cause narrower injection spray angle and greater in-cylinder of the fuel spray (Ejim et al. 2007; Haşimoğlu et al. 2008; Pandey et al. 2012). All these effects can lead to increased oil dilution, overall poorer combustion, and greater emissions. Fuel that having too high kinematic viscosity may cause poor atomization during fuel spraying and result in engine deposits and wear on the fuel system where it leads to more energy required for deliver the fuel into the engine (Muñoz et al. 2011; Utlu & Koçak 2008). Accordingly, the viscosity of the alcohols increases as the carbon chains becomes longer. This means that higher molecular weight alcohol have higher viscosity compare lower alcohol content. For example, butanol with four carbon atoms is used as an alternative compared to ethanol (two carbon atoms) and methanol (one carbon atoms) when more viscous blend is required in the blend. In addition, the kinematic viscosity of butanol is several times higher than gasoline and has closely similar level with diesel fuel. Nonetheless, the presence of higher viscosity of alcohol in diesel engine will not cause wear problems, especially in fuel pump systems, due to insufficient lubricity (Jin et al. 2011).

OXYGEN CONTENT

The total oxygen content in the fuel blends is determined by referring to the overall contents of fuels, including carbon, hydrogen, nitrogen, and oxygen. Gasoline has a composition that can affect the emission of organic compounds. Besides that, high proportions of aromatic hydrocarbons, such as toluene, benzene, and olefins, produce large amount of reactive hydrocarbons (Dasilva et al. 2005). Due to these reasons, blending oxygenated compounds, such as alcohol with gasoline, reduces the amount of aromatic compounds. Generally, the oxygen content of an alcohol decreases with longer carbon chains. Butanol is a four-carbon alcohol, doubling the carbon of ethanol and containing 25% less than oxygen content (Jin et al. 2011). Using oxygen content in alcohol-gasoline blends, which is known as oxygenates fuels, makes the combustion better (homogeneous combustion) and reduces CO with HC emissions. Previous research also showed that as the higher alcohol fuel was blended with gasoline, larger amounts of fuel had been needed in order to match with the oxygen contents of lower alcohols (Yacoub et al. 1998). Ahmed (2013) showed that specific fuel consumption decreased as the percentage of methanol addition increased at a constant load. It is because; the addition of methanol generated more oxygen to complete the combustion in the combustion chamber. The specific fuel consumption, in addition, decreased with the increasing loads. It is inversely proportional to the thermal efficiency of the engine.

FLASH POINT

The flash point of a fuel is the lowest or minimum temperature at which the fuel can be heated so that the vapour gives off flashes momentarily when an open flame is passed over it under specific conditions. In term of its usage in the testing,

flashpoint is a parameter that can predict the possible fire hazards during transportation, handling, and storage of a fuel (Sangeeta et al. 2014). For an example, butanol is much safer fuel to use in high temperature compare to other alcohol fuels because it has a high flash point and lower vapor pressure.

ENGINE PERFORMANCE AND EMISSIONS TEST

For the past few years, many researchers and scientist had done experiments on engine testing using pure alcohol or blended with gasoline in order to study alcohol effect on engine operation. Some of the researches done are explained as per follows (Liu e al. 2007; Szybist et al. 2010; Yanju et al. 2008). The results obtained from each researcher differ from each other due to the varied test conditions and engine technologies used in the experiments. For example, Liu et al. (2007) used gasoline and methanol–gasoline blends as fuels on a three-cylinder experiment engine. They added methanol at the volumetric rates of 10%, 15%, 20%, 25%, and 30% to gasoline. Based on the obtained experimental results, increment of methanol ratio in the gasoline decreased engine torque and power, but it increased BTE. This is due to the methanol has a higher laminar flame speed which will make combustion process finish earlier and improve BTE. Meanwhile, as for emission results, it was determined that the first study pertaining to emissions (HC, and CO) had decreased significantly. This can be explained that as the blend contains more oxygen when methanol is added into gasoline, which will reduces HC and CO emissions.

Investigation also was performed on the effects of optimal injection and ignition timings upon performance and emissions from the usages of methanol in a high compression direct injection stratified charge spark ignition methanol engine (Li et al. 2010). The results showed that maximum in-cylinder pressure and maximum heat release rate were obtained in the optimal injection and ignition timings with an engine speed at 1600 rpm and full load condition. This is due to the usage of stratified charge spark ignition engine, which controlled the ignition process with spark plug that directly injected fuel into the combustion chamber as it mixed with air and ignited the fuel. Thus, the methanol engine is able to achieve the highest indicated thermal efficiency, the smallest cycle of variation, and the shortest ignition delay. On the other hand, an investigation carried out by Agarwal et al. (Agarwal et al. 2014) applied 10% and 20% methanol blended with gasoline in spark ignition transportation engine and the results were further compared with base gasoline. The results showed only minor difference in cylinder pressure and heat release rate started late for gasohol blends with peaks of heat release rate wider compared to those for gasoline. This can be explained as gasoline has numerous hydrocarbons with different boiling points, while methanol contains a single boiling point with one hydrocarbon. Moreover, methanol has oxygen in its molecular structure.

Williams et al. (2009) performed an experimental investigation by using gasoline and different types of alcohol-gasoline blends under a specified engine test condition. One of the results obtained showed that the addition of butanol to gasoline under hot testing had only little impact on the combustion behaviour, the thermal efficiency, and the exhaust emissions. The author also suggested that using fuel with high-octane bio-component together with downsized lean boosting engine would able to reduce the CO_2 emissions (Williams et al. 2009). On the other hand, butanol-gasoline blends with maximum 35% volume of butanol were investigated for engine performance and emissions by Yang et al. (2009). By advancing the spark timing, the power of engine was recovered based on the obtained results. Interestingly, the butanol-gasoline blends further improved the combustion process, besides reducing the unburned hydrocarbon in the engine and carbon monoxide emissions. This is attributed to butanol as it is an oxygenated fuel with lower stoichiometric air-fuel ratio, and thus, has the ability to give leaner combustion (Sharudin et al. 2017).

An experimental study used the blend of iso-butanol and diesel to study the performance and emissions on a low speed light duty diesel engine (Gu et al. 2013). In addition, using various combinations of the exhaust gas recirculation and the injection timing with a fixed low speed engine; the effect of the molecular structure difference on soot emission had been determined. The results showed that iso-butanol blends gave shorter ignition delay compared to n-butanol diesel blends. It also showed that iso-butanol had high peak cylinder pressure and a higher premixed heat release rate than n-butanol. In terms of its soot emission, it decreased when diesel fuel was added to butanol. Nevertheless, n-butanol-diesel blends gave lower soot emissions compared to iso-butanol-diesel blends. Moreover, it had been proven that the use of exhaust gas recirculation and retarding the injection timing are practical approaches to decrease emission of nitrogen oxides.

Furthermore, a study had looked into blending only low alcohol content (methanol) with gasoline to investigate its effect on spark ignition engine performance and exhaust emission (Ahmed et al. 2013; Yanju et al. 2008). The results showed that as the volume percentage of blending was increased, the emitted regulated emission decreased, especially on carbon monoxide (CO) and Oxides of Nitrogen (NO_x). This is mainly due to larger heat capacity of triatomic molecules and higher latent heat that reduce the combustion temperature and eventually reduces the NO_x emissions. By increasing the percentage of methanol in the blends, the brake power and the brake thermal efficiency were also increased due to propagation of laminar flame speed of methanol is higher than gasoline. On top of that, Eyidogan et al. (2010) experimentally analyzed the effects of unleaded gasoline, ethanol–gasoline, and methanol–gasoline blends at low ratios on engine performance, combustion characteristics, and exhaust emissions. Based on the results obtained, it was observed that the usage of blend fuel increased the BSFC, while the cylinder gas pressure (CGP) and the heat release rate (HRR) began to rise earlier. It had been determined that with the usage of alcohol mixtures, the CO and HC emissions also decreased. The main reason for the decrease in emissions

was the presence of oxygen in the blend that improved the combustion process.

Cay et al. (2013) theoretically investigated the effects of methanol fuel on the performance of engine and exhaust emissions. The results showed that the CO and HC emission characteristics improved with the use of methanol compared to gasoline. This is due to the high evaporation heat of methanol when it entered engine cylinders, which significantly reduces the CO and HC emissions compared to gasoline. Meanwhile, the experiment conducted by Ioannis et al. (2011) showed that methanol gasoline blended fuels resulted in lower brake power and brake torque, but higher BSFC than gasoline. The performance characteristics of methanol-gasoline blended fuels had been worse than for ethanol due to the influence of the combustion-related properties. In terms of exhaust emissions, NO_x emissions decreased as the methanol exhibited higher heat of vaporization, which caused the combustion temperature to decrease.

QUALITY OF ALCOHOLS FUELS FOR SPARK IGNITION ENGINE

In order to ensure a smooth operation of spark ignition engine, the alcohol fuels must posses some of the basic qualities. Firstly is the volatility of fuels which defines as the main characteristic to determine its suitability on SI engine. Volatility depends on the fractional composition as it is a mixture of different hydrocarbons. Usual method of measuring volatility of fuel is by using distillation of the fuel in a special device at atmospheric pressure and in the presence of its own vapor pressure. As per mention earlier, the gasoline mainly must have adequate volatility to give easy starting, rapid warm up and sufficient vaporization for proper distribution between the cylinders (Sangeeta et al. 2014). At the same time, the gasoline must not be not so volatile or excessive that leads to form vapor lock which will impede the flow of gasoline to the carburetor (Astbury 2008).

Secondly is starting and warm up of the engine. A fuel should be vaporizing at the room temperature in order to have easy starting of the engine. Low distillation temperature is needed based on the distillation curve with the range of 0-10% boiled off, which will results in having the temperature gradually increase to the operating temperature as the engine warms up. Thirdly is the operating range performance of the engine. Again, it is desired to have low distillation temperatures for the range of engine operation in order to obtain good vaporization of the gasoline. It is intended to have more uniform delivery of fuel to the cylinder and better acceleration characteristics by reducing the quantity of liquid droplets in the intake manifold (Ganesan 2012). Next is the vapor lock characteristic of the fuels. Defines as the ability to restrict the fuel supply to the engine caused by overload or rapid formation of vapor in fuel supply system or carburetor. Thus, it will affect the reduction of fuel flow into the engine and cause loss in power of the engine. Two critical factors to probably increase the vapor lock are exposure of the fuel to high temperature or low pressure in the fuel system and highly volatile fuels related to the front-end volatility (Gupta 2006).

Besides that, antiknock quality of fuel also determines its quality. Each fuel has its tendency in resisting to produce detonation which depends largely on chemical composition and molecular structure of the fuel or relates with self-ignition characteristics. For example, having higher power output and thermal efficiency, while allowing the use of higher compression ratios is the results of fuels with high anti-knock property. Lastly is the gum deposits and Sulphur content from the usage of fuels. In general, fuels with reactive hydrocarbon and impurities that had being stored for a long time have a tendency to form gum. It will cause operating difficulties for instance carbon deposits on the engine, and gum deposits in the manifold which will reduce the volumetric efficiency greatly (Gupta 2006). Due to its corrosiveness, sulphur content present in the fuels can directly corrode fuel lines and injection pumps when water is available at low temperature. Besides that, sulphur also can promote knocking in the SI engine due to its low ignition temperature. Due to this negative effect, it is necessary to have a limit for the presence of gum and sulphur content in order to avoid problem stated above problems.

ADVANTAGES AND DISADVANTAGES OF ALCOHOL FUEL PROPERTIES

In the present automobile industry, ethanol and methanol are the most common alcohol fuels used as additives with gasoline in spark ignition engines. It is because they are in a fluid state, besides possessing several physical and combustion properties similar to those of gasoline. In addition, ethanol and methanol have higher octane number, oxygen ratio, flammability limit, low carbon to hydrogen ratio, and higher heat of vaporization, which offer fuel conversion efficiency compared to gasoline. Moreover, some properties, such as high heat of vaporization, in methanol and ethanol allow cool air to enter into the engine, which offers higher power output and increased volumetric efficiency. In terms of the production, ethanol and methanol can be produced from fermenting, distilling starch crops such as corns and natural gas through the gasification of coal, woods, most biomasses, and even combustible trash (Atsumi et al. 2008). In fact, a new method of production had also been introduced, such as gasification by partial oxidation from carbohydrates, to produce methanol and thus, making it possible to be produced from biofuel sources, such as rice husks, rice bran, and sawdust (Atsumi et al. 2008).

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. While higher molecular weight alcohols such as butanol and pentanol often used as additive in alcohol gasoline blends. At present, methanol is made from natural gas, but it can also be made from a variety of renewable sources, such as wood, coal, waste paper, and biomass. Production of methanol is in liquid form and usually, it is handled and stored like gasoline. Generally,

methanol can be divided into two types, which are directly used as a blending agent with gasoline or diesel; and indirect use that acts as an ingredient in the production of biodiesel and hydrogen for use in vehicles with fuel cells (Turner et al. 2013). In the application of spark ignition engine, alcohol fuels has its own advantages and disadvantages (Masum et al. 2015; Pearson & Turner 2014; Surisetty et al. 2011; Turner et al. 2013).

Methanol (CH_3OH) has received public attention in the transportation and power generation sectors due to its low-polluting future fuels and it has been considered as highly efficient with its lean operating ability (Hu, Wei, Liu & Zhou 2007). Moreover, the presence of oxygen in alcohol fuel allows soot-free combustion with a low particulate level (Sharudin, Abdullah, Mamat, Ali & Mamat 2015). Methanol also has a high octane number, which can reduce engine knocking. Furthermore, methanol has high heat vaporization that offers fuel conversion efficiency, which cools the air entering into the engine and increases the volumetric efficiency with the power output compared to gasoline (Sharudin et al. 2015). However, cold start problem occurs when pure methanol is used and it fails to provide ignitable vapour to the engine due to its lacking on highly volatile compounds (Abdullah et al. 2015). Methanol also will bring corrosion problems along the fuel passages and fuel pump due to its corrosive. This corrosive issue will leads to the water contamination problems. Modification on the engine need to be done so that it is compatible with the engine operation and allows for higher concentration. More volatile compounds (iso-butanol, and propanol) are recommended to be added to methanol in order to overcome the problems (Jin et al. 2011).

For higher molecular alcohol such as iso-butanol (C_4H_9OH), it has higher LHV than methanol as the LHV of alcohol rises with increase of its carbon atom number. Therefore, fuel consumption will reduce and a better mileage can be obtained when using iso-butanol fuels compared to methanol. Meanwhile, the volatility of alcohols decreases with the increase of carbon atom number. This means iso-butanol with four carbon atom has much less problems towards vapor lock and cavitation that can eliminate the need for special blends during summer and winter months. In addition, alcohol molecules contain alkyl and hydroxyl, which shows that the more carbon of alcohol molecule contains, the easier the alcohol can be blended into gasoline fuel. This further illustrates that iso-butanol has very good solubility with gasoline without any additive and it can also blend with diesel very well. Other than that, iso-butanol is less prone to water contamination compared to ethanol which allows it to be transported and distributed using the existing fuel supply infrastructure (Szwaja & Naber 2010). Iso-butanol also has a very high flashpoint and low vapour pressure, whereby it is a safer fuel to use in a high temperature condition (Ali et al. 2010). Meanwhile, due to better toleration in water contamination and less corrosive than ethanol, butanol is suitable for the existing pipelines without any modification. Alcohol fuels cause excessive engine wear and damage the internal part of the engine. Carbon deposits also will present on piston and engine head. Due to the presence of oxygen which having high atomic weight, energy density of the alcohol is lower than base gasoline. One major drawback of butanol is the cost of production. Cost to produce butanol is significantly higher than ethanol (Tsao 2008).

CONCLUSION

This review paper objective is to summarize the important aspects of alcohol fuel properties that give direct impact on spark ignition engine operation. Latent heat of vaporization, lower heating value, and research octane number are some of the alcohol fuel properties that effect engine performance, combustion characteristics and emissions. Based on the past research done using alcohol-gasoline blends in spark ignition engine, the result shows improvement in overall engine performance and emission. In addition, this review also shows that the qualities in alcohol fuel is better than base gasoline. Advantages and disadvantages of alcohol fuels shows that careful selection need to be made and further investigation should be done before it is operated with spark ignition engine. Currently, interest in varying the alcohol fuel properties is increasing rapidly, driven by three major factors which are environment, economy and reliability. In terms of environment, it is minimizing flaring effect in fuel utilization. The economy uses the waste gas streams in the plant/source for increased profitability such as end flash gas or heavy hydrocarbons. While reliability improves availability by avoiding complex and expensive fuel treatment equipment. The demand for operation with varying alcohol fuel properties is already here and interest is expected to increase more. For environmental, economic and reliability reasons it will be necessary to stretch the approved fuel properties and to have the flexibility to utilize different sources. Finally, further research in alcohol fuels could contribute to a new scientific knowledge in automotive industries especially in energy efficient vehicles (EEVs) as it meets the demand of Malaysian Government's National Automotive Policy (NAP).

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