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## **Normal Butanol Additive in Methanol-Gasoline Blends Fired in a Spark Ignition Single Cylinder Engine : Effects on Combustion and Emission Characteristics**

The effect of firing n-butanol additives in methanol-gasoline blends is compared with that of methanol-gasoline blends of total alcohol volume of 10 to 90 % in gasoline fuel (GF). The comparison was based on combustion and regulated emission characteristics. Tests were carried out on a BASF octane rating engine. Higher volatility and lower energy content of methanol-gasoline blends used were improved by the addition of n-butanol to the blends. Additives of n-butanol was recommended for the shortening combustion duration; reducing engine-out oxygen a benefit for downsizing the intake manifold and raising the heating value of fuel mixture. *Bibl. 17, Fig. 9, Table 2.*

**Key words:** bioalcohols, combustion, emission, spark-ignition engine.

### **Introduction**

Researcher's efforts world-wide are directed to finding cleaner fuels than fossil fuels in internal combustion engines. The goal is to replace or reduce the use of fossil fuel. Conventional fuels such as gasoline degrade the environment. Use of Petroleum oil in trans portation greatly contributes to the deterioration of the environment through the emission of regulated emissions such as nitric oxides (NO<sub>x</sub>), unburned hydrocarbon (UHC), carbon monoxide (CO), particulate matter (PM), and carbon dioxide (CO<sub>2</sub>). These pollutants accumulating into the atmosphere contribute to the greenhouse effect, adverse effect on public health and climate change. Alcohols are oxygenates which have emerged as alternatives for improving the octane number and oxygen content in gasoline [9], which improves combustion process.

Researchers have investigated the effect of mainly single alcohol-gasoline blends on engine parameters such as ignition delay, emission behavior and fuel consumption. Regardless of the positive impact of emission reduction afforded by alcohol blends, they present certain problems that need to be dealt with if satisfactory performance is to be guaranteed in engines.

A substantial amount of studies [7, 8, 14] has focused on the use of single alcohol/gasoline blends (%) taking the advantages of oxygenates and their potential status to reduce regulated emissions. Their advantages over gasoline include better anti-knock characteristics and reduction of CO and UHC emissions [6, 9, 14, 18]. Alcohols such as ethanol, methanol, and butanol have a higher octane rating than gasoline fuel (GF) and therefore can be used in high compression ratio (CR) engines with high power. The higher heat of evaporation of the alcohols (3-5 times) than GF, cools down the incoming fuel-air charge making it denser and thereby improving the power output. On the other hand, the high auto-ignition temperature of alcohols makes them safer to handle than GF [5]. The most popularly studied alcohol used as a fuel additive in spark ignition engines is ethanol [11, 23]. In recent years interest by researchers in n-butanol as a transportation fuel has risen [24]. In Ref [21] experiments were conducted on a single cylinder, spark ignition, Cooperative Fuel Research (CFR) engine. The author's finding is that the ignition delay for n-butanol/gasoline blends decreases when the shared volume of n-butanol to GF was increased and the burning duration for the n-butanol/gasoline blends or 100 % n-butanol is similar to that of GF. Blends

of n-butanol, 0 % (GF), 20 %, 60 %, and 100 % were studied, and compression ratios, (CR) of 8:1 and 10:1 were examined. Besides, n-butanol and blends develop higher in-cylinder pressures than GF.

Lubrication problems are usually encountered by conventional fuel injection systems [20] due to the lower viscosity of alcohol fuels, which lead to the wearing of the engine parts. During combustion, an alcohol blended fuel produces acids that are responsible for wearing of engine parts. Neutralizers such as Zinc dialkyldithiophosphates and calcium sulfonates are added in lubricating oil to neutralize these acids and improve lubrication. Shorter intervals of lubricant oil change reduce corrosive wear significantly. All alcohols are highly corrosive, which is a function of water content; but the higher the molecular weight of the alcohol the less corrosive it is [17].

Another drawback of single alcohols with low carbon hydrogen (C/H) ratio alcohol such as ethanol and methanol is the reduction in energy content. Anhydrous ethanol is soluble in gasoline [15]. The properties of n-butanol are such that n-butanol has the potential to overcome the drawback of lower-carbon alcohols [22].

The emission of toxic organic compounds such as aldehydes increases with the increase of alcohol content in the fuel mixture. However the minimum emissions of aldehydes correspond to the stoichiometric composition of the fuel mixture and increase when it is leaned or enriched with fuel. These can be reduced by adding to the fuel mixture small proportions of aniline and pre-heating the air before entering the engine [10].

Although fewer works [7, 21], have appeared in the literature involving combustion characteristics of isomers of butanol and methanol, n-butanol has several advantages over methanol and ethanol. These include: high tolerance to water contamination [8]; use in existing fuel distribution pipelines, less corrosive to aluminum or polymer components in fuel system, has ability to blend in gasoline or diesel at higher shared volume without modifying vehicles and results in better fuel economy due to its higher energy density. The impacts that widely used alcohols (ethanol and methanol) as additives in traditional fuels have on the mixture properties are summarized as follows:

- Improve combustion efficiency due to intermolecular oxygen between the molecules of the alcohol.

- Reduce the theoretical air-to-fuel ratio and leans the fuel mixture with GF.

**Table 1. Properties of Gasoline, Methanol and n-Butanol**

Property	Gasoline	Methanol	n-Butanol
Chemical formula	C <sub>8</sub> H <sub>15</sub>	CH <sub>3</sub> OH	C <sub>4</sub> H <sub>9</sub> OH
Molecular weight [kg/kmol]	111	32	74
Oxygen cont. [mass. %]*	0	50	22
Net Lower Heating Value [MJ/kg]	43.5	20.1	33.3
Stoichiometric A/F ratio [-]	14.6	6.4	11.1
Specific Gravity [-]	0.72	0.79	0.81
Octane Number [-]	91–97	107	113
Vapor Pressure at the 23.5 °C [kPa]	60–90	32	2.3
Latent heat [kJ/kg]	305	1103	581.4

\* Ref. [1, 18].

- Have reduced energy content measured by lower heating value (LHV) which causes higher brake specific fuel consumption (BSFC).

A comparison of the properties of the alcohols is shown in Table 1.

Single lower alcohol(methanol)-gasoline blends that are mostly used in engines emit high evaporative emissions during cold starting of engines [2]. Increasing the shared volume of methanol to gasoline fuel has limited application due to the loss of brake power caused by the reduced energy content of alcohol blends. The methanol-gasoline blends used in engines cause vapor lock in fuel delivery systems due to their higher volatility, which is measured indirectly by vapor pressure (VP). However, the addition of higher alcohols such as propanol, n-butanol, and pentanol to the methanol-gasoline blends eliminates or reduces vapor lock due to the lower volatility of the higher alcohols [2].

Methanol-gasoline blends raise the vapor pressure (VP) [13] measured by the Reid method [4] and depresses the distillation curves [3]. The lower carbon to hydrogen ratio (C/H) alcohols (methanol and ethanol) causes the most dramatic increase in VP and the largest depression of the distillation curve. The addition of the higher alcohols to single alcohol blends moderates the VP of the fuel mixture and curbs the effect on the distillation curves. The cited authors demonstrated the improvement caused by dual alcohols such as n-butanol or other higher alcohol admixed to single alcohol blends during the cold starting of the engines. However, they did not evaluate the effects of the proposed dual alcohols on combustion and regulated emission characteristics of steady state engine operation.

The aim of this study was to determine the advantages of firing n-butanol added to methanol-gasoline blends on a single cylinder spark ignition engine operating at steady state. The combustion and regulated emission characteristics of the blends were compared with the single methanol-gasoline

blends. The dual alcohol blends were specially selected to match the vapor pressure of GF.

### Methods and materials

It is known that the amount of alcohol which one can add to the conventional fuels (so called shared volume) has certain limits due to the physical/chemical differences between alcohols and conventional fuels. The author's hypothesis is that it is possible to increase the alcohol shared volume in gasoline fuel (GF) beyond the known limits by using two alcohols (instead of one). These two alcohols have to be selected in such a way that the physical properties of the resulting mixture will not hinder the performance characteristics in internal combustion engines.

In this study two alcohols: methanol and n-butanol were blended into GF in proportion that increases the volume of alcohol % (v/v) in the blend to higher than 30 %. The additive of n-butanol to methanol-gasoline blends dual alcohol

**Table 2. Methanol and n-butanol to admix the gasoline fuel for experimental evaluation**

Bore [mm]	65
Stroke [mm]	100
Displacement [ccm]	332
Maximum power at full load and 600 RPM [kW]	0.6
Maximum fuel consumption [ml/h]	400
Orifice diameter [mm]	0.6
Spark plug	W145T1
Mixture Heater [W]	70
Compression ratio changeable from Type	4:1 to 11:1 BASF

**Table 3. Test engine parameters**

Methanol-gasoline blends (SAG)							
Blend #	1	2	3	4	5	6	7
Methanol	10	15	20	25	30	40	80
C <sub>tot</sub>	10	15	20	25	30	40	80
Gasoline	90	85	80	75	70	60	20
Identification	M10	M15	M20	M25	M30	M40	M80
n-Butanol additive (DAG)							
Blend #	8	9	10	11	12	13	14
Methanol	10	15	20	25	30	40	80
n-Butanol	20	25	30	35	20	20	10
C <sub>tot</sub>	30	40	50	60	50	60	90
Gasoline	70	60	50	40	50	40	10
Identification M-nB	10:20	15:25	20:30	25:35	30:20	40:20	80:10

**Table 4. Accuracy of measuring instruments**

Analyzer	Range	Accuracy
Carbon monoxide (CO)	0–15 % (v/v)	± 0.011 %
Carbon dioxide (CO <sub>2</sub> )	0–16 % (v/v)	± 0.336 %
Unburned Hydrocarbon (UHC)	0–5000 ppm	± 10.5 ppm
Nitrogen oxides (NO <sub>x</sub> )	0–5000 ppm	± 42 ppm

gasoline (DAG) blends were prepared by a method to optimize them in the function of the VP as proposed in Ref. [2].

Fourteen blends were used as shown in Table 2 (M0 not shown, represents the reference (ref) fuel, that is, GF with octane number 95). The DAG blends were selected with proportions of methanol and n-butanol % (v/v) in gasoline fuel so that the final mixture had the same VP as GF meeting the VP requirement for fuels. The basic engine parameters are shown in Table 3. The engine was made to run for 20 minutes to warm up. The blends were evaluated in terms of indicated pressure and heat release as a function of crank angle degrees; emission characteristics as a function of the excess air ratio ( $\lambda$ ) at a constant speed of 600 RPM. The experiments were conducted on a BASF (Badische Anilin- und Soda Fabrik) octane rating engine as shown in Figure 1. The heat release rate (HRR) was calculated using the indicated pressure data from the engine runs and a computer program [12, 19].

The fuel n-butanol was manufactured by VWR Prolabo (BDH), purity 99.99, a density of 0.809 g/cm<sup>3</sup> (20 °C), molecular formula CH<sub>3</sub>-(CH<sub>2</sub>)<sub>3</sub>-CH<sub>2</sub>OH, molecular weight (MW) 74.12 kg/kmol, boiling point 118 °C (at 1013 kPa), melting point -89.8 °C, flash point: 30 °C. Methanol was purity 99.9 % manufactured by Molar chemicals KFT; specific gravity 0.790, water content 0.028 %, evaporation residual 0.0008 %. Gasoline of specification EN-95 was manufactured by MOL.

Speed was kept constant at 600 RPM and compression ratio of 7.3:1. The accuracy of the analyzers is shown in Table 4. The pre-sampler and measuring equipment, a Horiba 8120F analyzer module, is shown in Figure 1. The module was equipped with two infrared gas analyzers of the type: Horiba Model AIA-23 used to measure CO and CO<sub>2</sub> components. A hydrocarbon heated flame ionization detector type: Horiba FID-FIA-22 was used to measure UHC; whereas a chemiluminescence detector type: CLD-53M NO/NO<sub>x</sub> measured NO<sub>x</sub> in the range: 0 to 5000 ppm. The pressure transducer of the Type: Kistler 6005 was used to measure the pressure in the combustion chamber; and a sensor type: Hengstler RI 32-0/1024.ER.14KA optical encoder was used to determine the Top dead center (TDC) and speed [19].

### Results and discussions

The aim of this study was to determine (by engine experiments) the superior qualities of dual alcohols over single alcohol gasoline blends. The

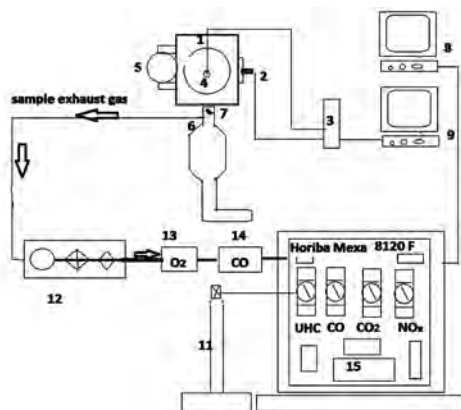


Figure 1. Schematic arrangement of test engine and gas analyzers: (1) Single piston BASF engine, (2) crank angle encoder, (3) charge amplifier, (4) piezoelectric pressure transducer (inside cylinder), (5) carburetor, (6) three way catalytic converter, (7) thermocouple, (8) data acquisition PC to measure emissions, (9) PC to measure indicated pressure, (11) H<sub>2</sub>-He cylinder, (12) heated pre-sampler system, (13) Paramagnetic-analyzer (O<sub>2</sub>), (14) carbon monoxide gas analyzer, (15) Horiba Mexa 8120F analyzers.

problems of vapor lock and deterioration of the lower heating value of the fuel mixture caused by single alcohol blends are compensated with the addition of n-butanol to the methanol-gasoline (SAG) blends [2]. However, it was necessary to determine the effect of burning the DAG blends on combustion and emission characteristics at steady state engine operation.

Figure 2 (a) shows the effect of blends: M10, M15, M20, M30, M40, and M80 on unburned hydrocarbon concentration. Because meth-

anol has lower energy content than GF; an increased dose of methanol-gasoline blend is supplied to produce the same output of brake power as GF. This causes emission of UHC to increase. However, the greater oxygen content of the methanol-gasoline blends than GF causes the emission of UHC to be reduced during the combustion process. Consequently methanol-gasoline blends recorded a lower UHC emission concentration than GF. The emission of UHC was further reduced as the shared volume of methanol to GF was increased above 40 % (v/v).

In Figure 2 (b) similarly there is a small increased dosage of the blend M-nB 40:20 (40 % methanol, 20 % n-butanol, and 40 % gasoline by volume (v/v)) supplied relative to M-nB 25:35 (with the same total alcohol content) in order to maintain the same brake power output. As before the net effect is that the blend of M-nB 40:20 recorded less emission of UHC than that of M-nB 25:35; because as is indicated in Table 2.0, methanol, which has twice the amount of oxygen than n-butanol oxidizes UHC more than does n-butanol. Similarly, M-nB 20:30 had a lower UHC emission reduced relative to GF than M-nB 30:20 (arbitrarily chosen). But the net effect of the two blends was almost the same (from  $\lambda = 1.12$  to 1.29).

In Figure 3 (a) effect of blend M-nB 10:30 and M30 emissions on UHC were compared. The blend M-nB 10:30 reduced emission of UHC by 9.2 % (relative to GF) and M30 by 20 % at  $\lambda = 1.1$  with a total alcohol content of 30 % (v/v). In Figure 3 (b) effects of the blends: M-nB 15:25 and M40

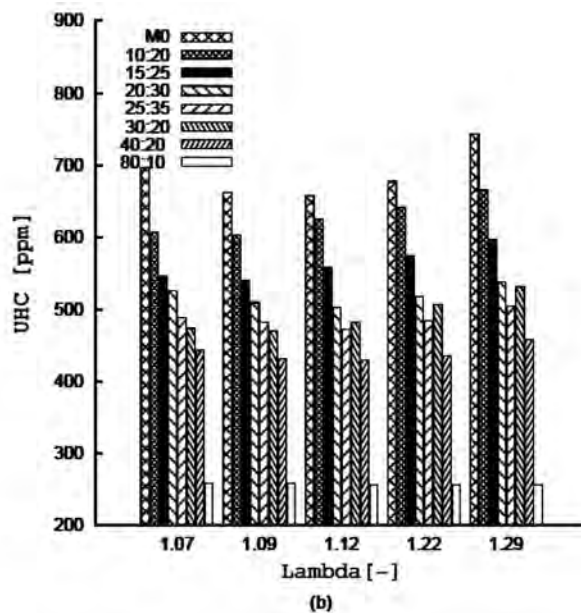
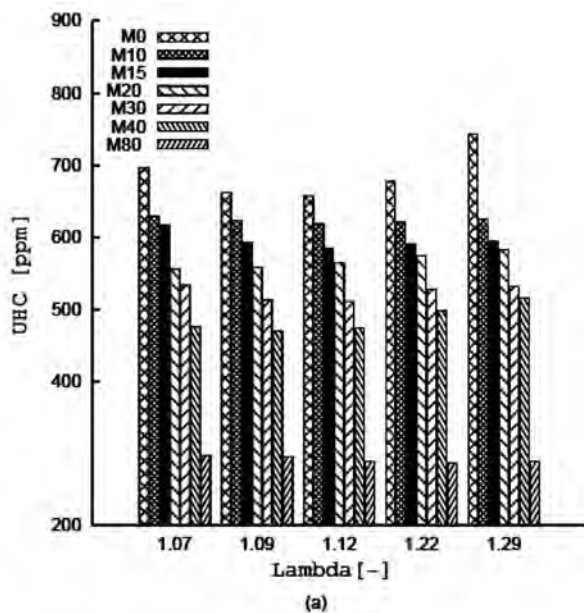


Figure 2. Unburned hydrocarbon emission vs  $\lambda$  for (a) methanol and (b) n-butanol-methanol-gasoline blends.



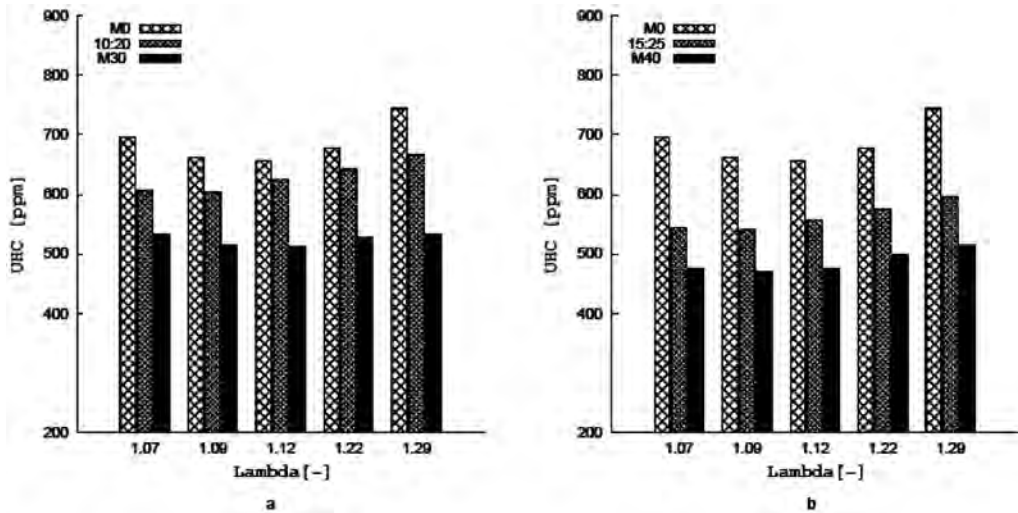


Figure 3. Comparing the effect of (a) M30 with M-nB 10:20 and (b) M40 with M-nB 15:25 blends on UHC emission vs  $\lambda$ .

on UHC emissions were compared. M-nB 15:25 reduced emission of UHC by approximately 16.9 %; whereas M40 by 26.9 % at  $\lambda = 1.1$  relative to GF with a total alcohol content of 40 % (v/v). The reasons for this behavior are discussed in the section of Figure 2.

In Figure 4 (a) the test blends: M30, M40, M-nB 10:20 and M-nB15:25 had similar indicated peak pressure and reduced with increasing excess air ratio ( $\lambda$ ) due to the so called leaning effect of the alcohols added to GF. It is desirable for the engine to operate with blended fuel near  $\lambda = 1.09$

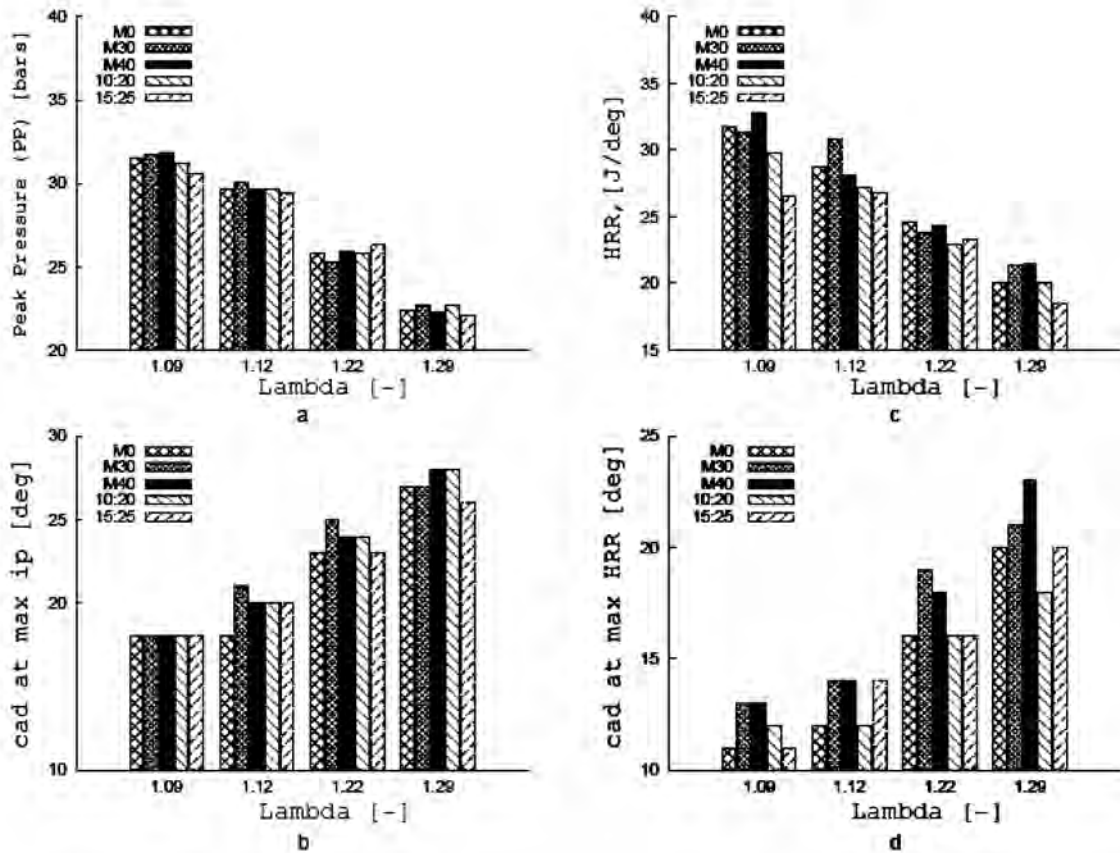


Figure 4. The relationship between maximum indicated pressure (ip) and HRR and corresponding (CA) ATDC vs  $\lambda$ .

to maintain effective pressure. Figure 4 (b) shows that the leaner the fuel mixture is ( $\lambda > 1.2$ ) the location crank angle degree after top dead centre (CA ATDC) of the peak indicated pressure is

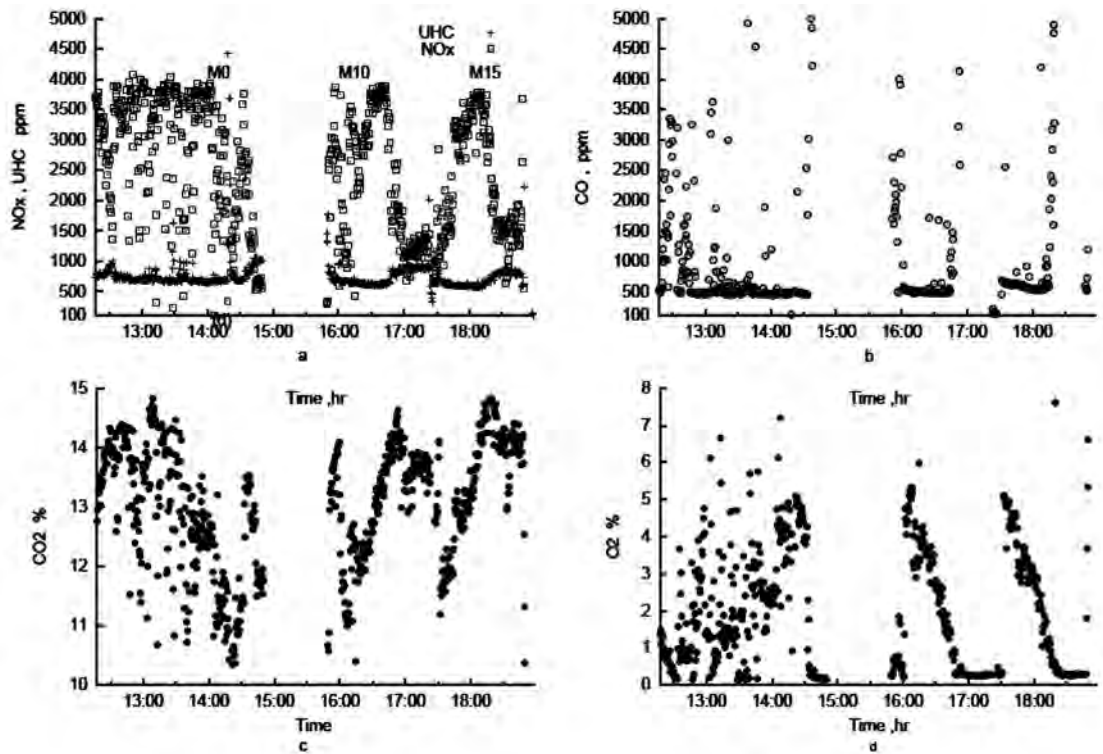


Figure 5. Emission characteristics of fuel: ref fuel, blends: M10 and M15 vs real time.

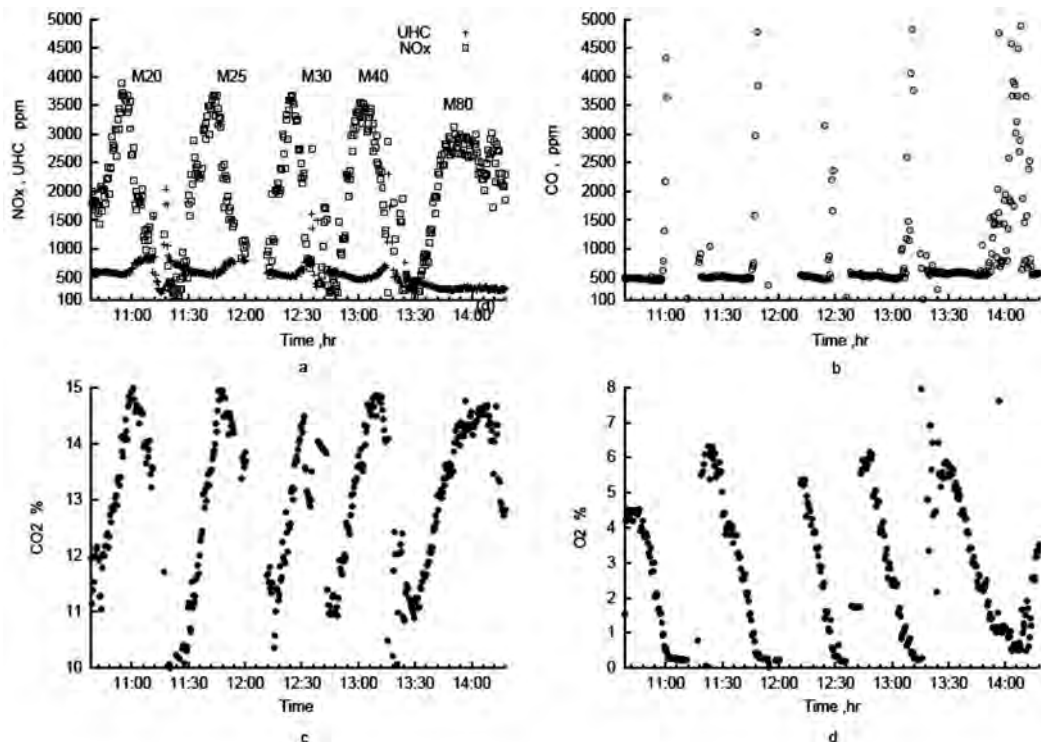


Figure 6. Emission characteristics of methanol-gasoline blended fuel vs real time.

more into the expansion stroke than when  $\lambda = 1.09$ . The maximum HRR observed with fuel blend M30 and M40 is higher than that of blends M-nB 10:20 and M-nB 15:25 respectively (see Figure 4 (c)). However, the greater leaning effect of the methanol-gasoline blends for the same brake power output than the DAG blends is undesirable for good engine performance. The DAG blends moderate the leaning effect and also shortens combustion duration (Figure 4 (d)) due to the improved heating value compared with methanol-gasoline blends.

Figure 5 shows the effect of test fuels: M0, M10 and M15 on regulated emissions. When  $\text{NO}_x$  emission was maximum implying high temperatures, CO and UHC were minimized (at real time: 16:00 to 17:00 hrs – see Figure 5 (a) and Figure 5 (b)). Emissions of UHC rose about 17:00 hrs in Figure 5 (a) whereas  $\text{NO}_x$  emission dropped significantly indicating low temperatures, which are characteristic of alcohol blends. This trend was also observed beyond real time 18:00 hrs in Figure 5 (a). Emission of  $\text{CO}_2$  was high (peak) depicting complete combustion of the fuels with a high oxidation of CO (comparing Figure 5 (b) with Figure 5 (c)). Emission of CO by all the test fuels was mostly identical

around the value of 500 ppm in real time; but quite high at the beginning of experiments due to the effects of the gasoline fuel during engine warm-up (Figure 5 (b)). Engine-out oxygen varied between 2 and 5 % (Figure 5 (d)) at minimum CO emission whereas the oxygen-out with M0 depended on operating conditions such as engine warm up.

Figure 6 (a-c) shows the regulated emission for five blends: M20, M25, M30, M40, and M80. There was a slight fall in the  $\text{NO}_x$  emission when the alcohol content in GF was increased (see also Figure 5 (a)) due to the fall in temperature introduced by the blends which have a higher latent heat than GF (see Table 1). Emissions of UHC were at minimum concentration when  $\text{NO}_x$  (Figure 6 (a)) was at its maximum level and vice versa. Emission of  $\text{NO}_x$  reduced slightly relative to GF with the addition of methanol or both methanol and n-butanol fractions into gasoline fuel (Figures: 5 (a), 6 (a), 7 (a)). Theoretically thermal  $\text{NO}_x$  is a by-product of combustion and its formation rate has exponential dependence on temperature. Its formation, which is well studied and understood [16] depends on the residence time and higher temperatures.

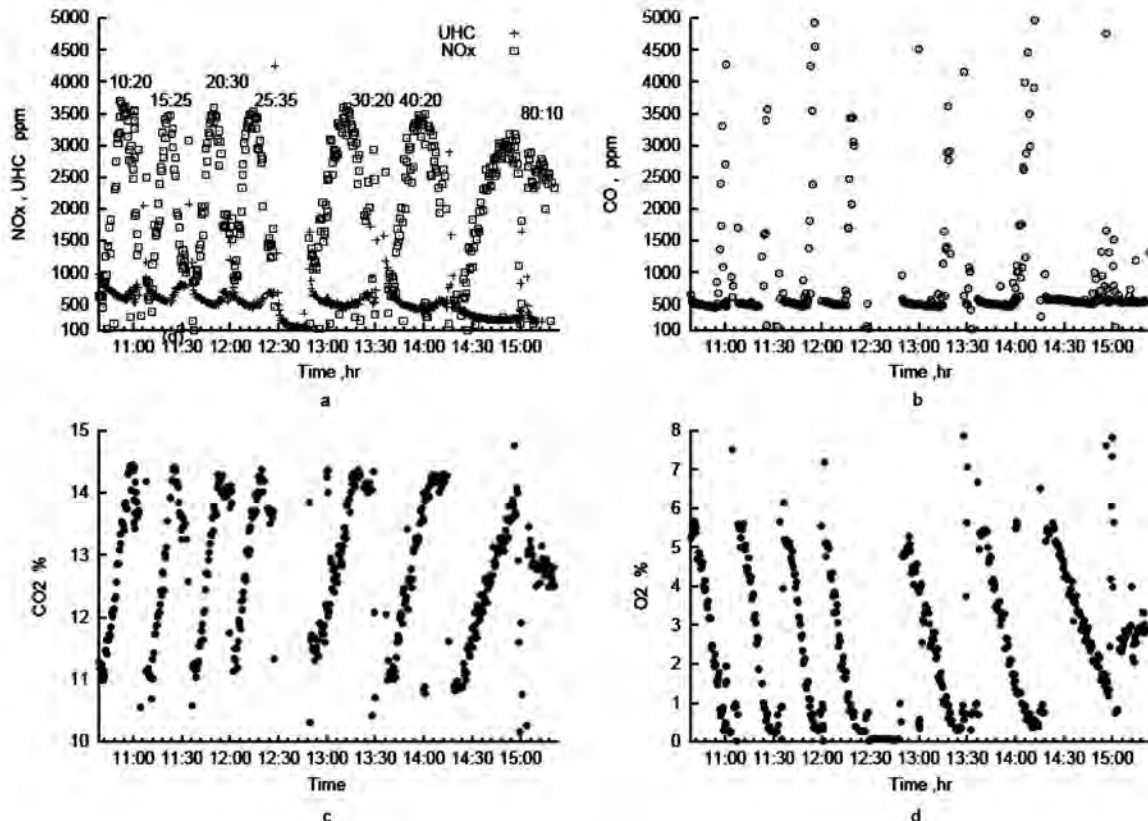


Figure 7. Emission characteristics of n-butanol additive blended fuel vs real time.



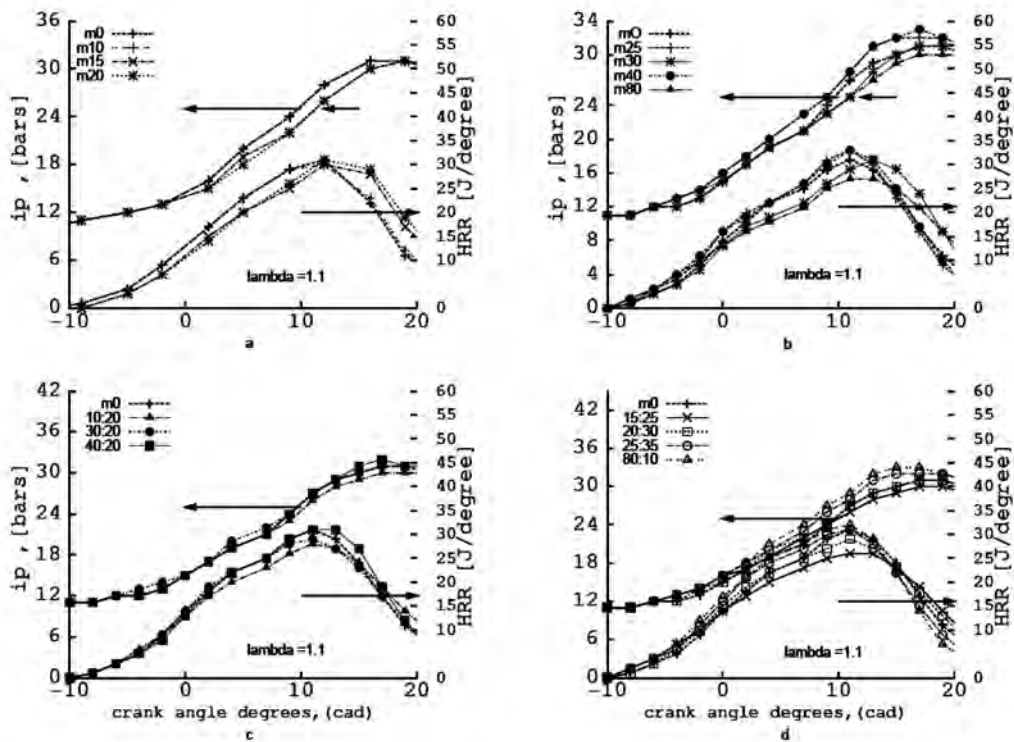


Figure 8: (a, b) Effect of methanol-gasoline and (c, d) dual alcohol blends on indicated pressure (ip) and heat release rate (HRR) at  $\lambda = 1.1$ .

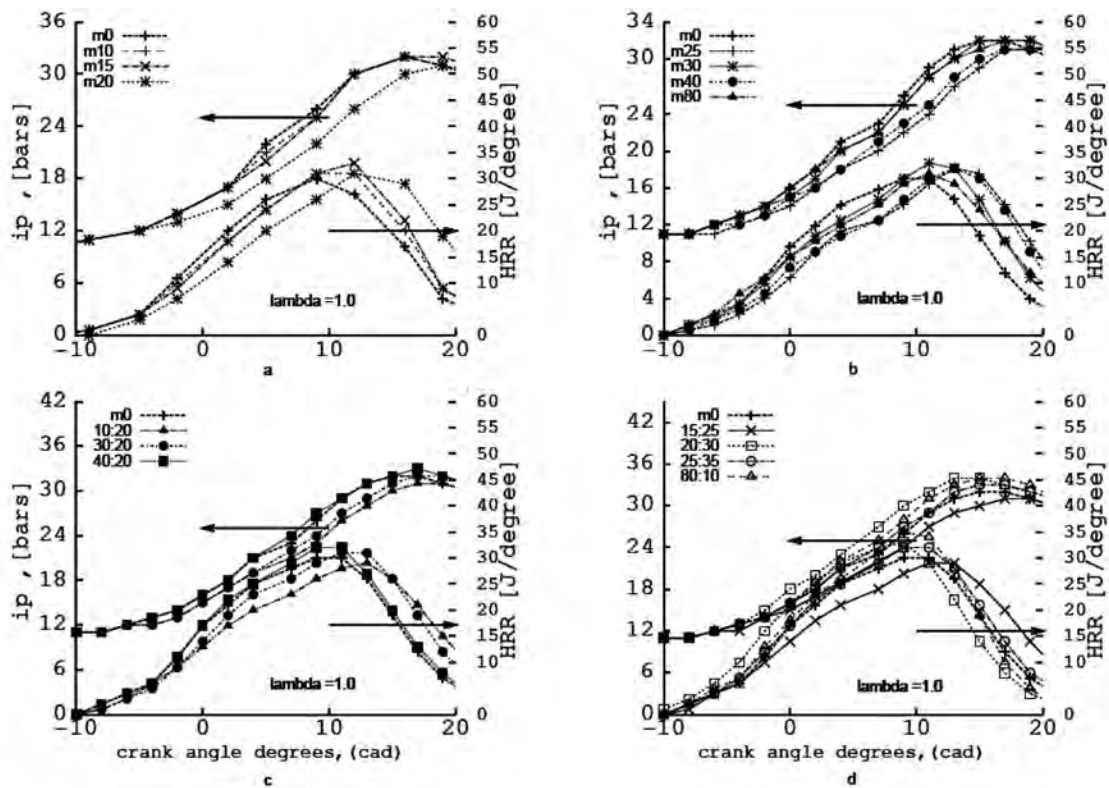


Figure 9: (a, b) Effect of methanol-gasoline and (c, d) dual alcohol blends on indicated pressure (ip) and heat release rate (HRR) at  $\lambda = 1.0$ .



As indicated before the minimum and level emission of CO (Figure 6 (b)) implied that sufficient oxidation of the pollutant occurred in high temperature environment; in contrast the emission of CO<sub>2</sub> (Figure 6 (c)) correlating with that of NO<sub>x</sub> (Figure 6 (a)) was high as expected. However, engine-out oxygen Figure 6 (d) varied between 2 and 6.5 % when CO emission was at minimum concentration.

Figure 7 shows the effect of DAG blends: from M-nB10:20 to M-nB 80:10 on emissions. The results are similar to single alcohols described in the section of Figure 6. However, the engine-out oxygen is significantly reduced (1.0 to 2.5 %, see Figure 7 (d)) at minimizing emission of CO indicating their superior quality of combustion. Besides a reduced oxygen-out is a benefit for downsizing the intake manifold.

In Figure 8 (a-d), the heat release rate (HRR) of M10 (see Figure 8 (a)) and M-nB 30:20 (Figure 8 (c)) blends had the same combustion duration in (CAD) as GF. Both blends had the same indicated peak pressure. However, blends: M25, M40, M-nB 40:20, M-nB 25:35 and M-nB 80:10 had a shortened combustion duration; whereas blends: M15, M20, M30, M80, M-nB 10:20, M-nB 15:25 and M-nB 20:30 had a slightly prolonged combustion duration. Consequently the effect of increased n-butanol fraction on the combustion duration was to shorten it; that is when the shared volume of both n-butanol and methanol in GF was increased. However, combustion duration was prolonged in the case of methanol only-gasoline blends. The effect of n-butanol was to improve the combustion efficiency due to its higher heating value than methanol.

Figure 9 shows the effect of blends on HRR for stoichiometric mixtures for both the n-butanol additive and methanol-gasoline blends. The combustion duration was prolonged more substantially for both blends compared with their effects in Figure 8.

### Conclusions

The shared volume (% v/v) of alcohol used in conventional fuels such as gasoline is limited by the lower energy content of the alcohol. However, when another alcohol such as n-butanol is added in the methanol-gasoline blend, the energy content of the fuel mixture is improved. The lower volatility of n-butanol is reported [2] to reduce the problems of the fuel delivery system caused by the higher volatility of methanol-gasoline blends used. The aim of this study was to determine the advantages of firing additives of n-butanol in methanol-gasoline (DAG) blends

over methanol-gasoline (SAG) blends. This was done on a spark ignition single cylinder engine at steady state operation. Regulated emissions and combustion characteristics of the two types of blends were compared.

A greater reduced emission of UHC with the SAG blends was observed than DAG blends (constrained to the same total alcohol content). The emission of UHC reduced by 9.2 % (relative to gasoline fuel-GF) using blend: M-nB 10:30 (10 % methanol, 30 % n-butanol, and 60 % gasoline) and by 20 % using M30 blend at  $\lambda = 1.1$ . Blend M-nB 15:25 reduced by approximately 16.9 % whereas M40 reduced by 26.9 % at  $\lambda = 1.1$ . Emission of UHC for the blends was at minimum when NO<sub>x</sub> was at its maximum and vice versa.

There was a slight fall in the NO<sub>x</sub> emission when the alcohol content in GF was increased.

Emission of CO by all the test fuels was generally around the value of 500 ppm in real time but quite high at the beginning of experiments due to the effects of the gasoline fuel during engine warm-up.

A shortening of the combustion duration was observed with DAG blends when the total shared volume of methanol and n-butanol to GF was increased. Besides these type of blends reduced the leaning effect promoted by single alcohol (methanol) gasoline blends. The methanol-gasoline blends caused the combustion duration to be prolonged as the methanol shared volume to GF was increased. Blends operating at stoichiometric mixtures further prolonged combustion duration than when operating at  $\lambda = 1.1$ .

To compensate for the poor emission of UHC reduced by DAG blends the total alcohol content can be raised to greater than 40 % (v/v) needing no engine modification.

The engine-out oxygen was significantly reduced using DAG blends indicating the superior quality of combustion of the DAG blends. Besides a reduced engine oxygen-out is a benefit for downsizing the intake manifold.

The authors recommended the use of DAG blends due to their effect of shortening combustion duration and their higher energy content than SAG blends.

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### Nomenclature

ATDC	–	after top dead center
ASTM	–	American society for testing and materials
BTDC	–	before top dead center
C/H	–	carbon to hydrogen ratio
CAD	–	crank angle degrees
CR	–	compression ratio
DAG	–	dual alcohol gasoline
FID	–	flame ionization detection
GF	–	gasoline fuel
HRR	–	heat release rate
IP	–	Indicated Pressure [bars]
LHV	–	lower heating value [MJ/kg]
Mx	–	% methanol in gasoline fuel
RVP	–	vapor pressure [kPa, psi] by Reid Method
SAG	–	single alcohol gasoline
TDC	–	top dead center
UHC	–	unburned hydrocarbon
VP	–	vapor pressure
$\lambda$	–	excess air ratio

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**Добавление нормального бутанола к метанол-бензиновым  
смесям, сжигаемым в одноцилиндровом двигателе с  
искровым зажиганием : Влияние на характеристики  
горения и образование вредных веществ**

Добавление дозированной спиртовой добавки, которая используется в стандартных бензиновых топливах, ограничивается в связи с пониженной энергией (теплотой сгорания) спирта, однако энергия топлива возрастает при использовании в метанол-бензиновой смеси, помимо имеющейся, другой спиртовой добавки — н-бутанола. При этом благодаря пониженной летучести н-бутанола ослабляются проблемы с топливной системой двигателя, обусловленные повышенной летучестью метанол-бензиновых смесей. Цель работы состояла в определении преимуществ использования двойных спиртовых смесей с бензином (DAG) по сравнению с односпиртовыми смесями (SAG). Содержание спиртов в смеси превышало 30 % (об.). Воздействие горючих спиртовых добавок н-бутанола к метанол-бензиновым смесям (DAG) сравнивается с таковым при использовании метанол-бензиновых смесей (SAG) для случаев содержания спиртов от 10 до 90 % (об.) в бензиновом топливе. Сравнение основывалось на характеристиках горения по степени приближения к регламентируемым показателям вредных выбросов: NO<sub>x</sub>, CO, UHC (несгоревшие углеводороды). Испытания проводились на двигателе фирмы BASF с пересчетом мощности (по октану). Установлено, что выбросы UHC сокращались в большей степени при работе с SAG, чем при использовании DAG. Повышение доли спирта в бензиновом топливе сопровождается незначительным уменьшением выбросов NO<sub>x</sub>. При этом выбросы UHC для смесей минимальны, когда содержание NO<sub>x</sub> максимально, и наоборот. Установлено, что рост NO<sub>x</sub> → (NO<sub>x</sub>)<sub>max</sub> при высоких температурах сопровождается минимизацией выбросов CO и UHC. Рекомендуется добавление н-бутанола для сокращения продолжительности горения и снижения содержания кислорода на выходе из двигателя как основа сокращения габаритов впускного (всасывающего) трубопровода и повышения теплоты сгорания топливной смеси. *Библ. 17, рис. 9, табл. 2.*

**Ключевые слова:** бензино-спиртовое топливо, биоспирты, вредные выбросы (NO<sub>x</sub>, CO, UHC), горение, двигатель с искровым зажиганием.

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## **Додавання нормального бутанола до метанол-бензиновим сумішей, що спалюються в одноциліндровому двигуні з іскровим запаленням : Вплив на характеристики горіння та утворення шкідливих речовин**

Додавання дозованої спиртової домішки, яка використовується у стандартних бензинових паливах, обмежується у зв'язку зі зниженою енергією (теплотою згорання) спирту, проте енергія палива зростає при використанні у метанол-бензиновій суміші, окрім тієї, що є, іншої спиртової домішки — н-бутанола. При цьому завдяки зниженій летючості н-бутанола ослаблюються проблеми з паливною системою двигуна, зумовлені підвищеною летючістю метанол-бензинових сумішей. Мета роботи полягала у визначенні переваг використання подвійних спиртових сумішей з бензином (DAG) у порівнянні з односпиртовими сумішами (SAG). Вміст спиртів у суміші перевищував 30 % (об.). Дія горючих спиртових домішок н-бутанола до метанол-бензинових сумішей (DAG) порівнюється з такою при використанні метанол-бензинових сумішей (SAG) для випадків вмісту спиртів від 10 до 90 % (об.) у бензиновому паливі. Порівняння ґрунтувалося на характеристиках горіння за мірою наближення до регламентованих показників шкідливих викидів:  $\text{NO}_x$ , CO, УНС (незгорілі вуглеводні). Випробування проводилися на двигуні фірми BASF з перерахунком потужності (за октаном). Встановлено, що викиди УНС скорочувалися більшою мірою при роботі з SAG, ніж при використанні DAG. Підвищення долі спирту у бензиновому паливі супроводжується незначним зменшенням викидів  $\text{NO}_x$ . При цьому викиди УНС для сумішей мінімальні, коли вміст  $\text{NO}_x$  максимальний, та навпаки. Встановлено, що зростання  $\text{NO}_x \rightarrow (\text{NO}_x)_{\max}$  при високих температурах супроводжується мінімізацією викидів CO та УНС. Рекомендовано додавання н-бутанола для скорочення тривалості горіння та зниження вмісту кисню на виході з двигуна як основа скорочення габаритів впускного (всмоктуючого) трубопроводу та підвищення теплоти згорання паливної суміші. *Бібл. 17, рис. 9, табл. 2.*

**Ключові слова:** бензино-спиртове паливо, біоспирти, шкідливі викиди ( $\text{NO}_x$ , CO, УНС), горіння, двигун з іскровим запаленням.