Journal of Applied Mechanical Engineering and Green Technology, Vol. 1, No. 1 (2019) 35-40

Journal of Applied Mechanical Engineering and Green Technology

Journal homepage: http://ojs.pnb.ac.id/index.php/JAMETECH
p-ISSN: 2655-9145; e-ISSN: 0000-0000

Effects of water content in a-zeotropic ethanol to the power, specific fuel consumption and thermal efficiency of an SI engine

I.M. Suarta[a1], I. P. G. Sopan Rahtika[a], P.W. Sunu[a],·K. Bangse[a], and I.N. Darma Susila[a]

[a]*Mechanical Engineering Department, Politeknik Negeri Bali, Campus Street Bukit Jimbaran, Kuta Selatan, Bali 80364, Indonesia*

Abstract

In this research, the effect of water content in a-zeotropic ethanol to the power produced, specific fuel consumption, and the thermal efficiency of an SI engine was observed. Tests carried out on anhydrous ethanol fuel (99.7% v) and a-zeotropic ethanol fuel (95.5% v). The test was carried out using the engine brake power indicator load cell type TD 800PM. The amount of power produced, specific fuel consumption and engine thermal efficiency were tested for varying load on four stroke one-cylinder engine. The amount of power, specific fuel consumption was observed, also the thermal efficiency produced by both of the fuels was calculated. The amount of power, specific fuel consumption and thermal efficiency using both types of fuel compared. The results showed that the amount of power produced by a-zeotropic ethanol fuel was higher than anhydrous ethanol fuel. The need for specific fuels when uses a-zeotropic ethanol slightly higher than anhydrous ethanol. Engine thermal efficiency produced by a-zeotropic ethanol is lower than anhydrous ethanol.

Keywords: ethanol; anhydrous; a-zeotropic; fuel; efficiency

1. Introduction

Energy saving, global warming and air pollution are the main reasons for the use of renewable alternative energy and environment friendly [1, 2, 3, 4, 5]. Ethanol can be used directly as a fuel, or mixed with gasoline in a SI engine [4, 6]. The use of anhydrous ethanol as fuel requires very high energy in its purification process. One of several ways to make ethanol more competitive as fuel is to use it with a higher water content [7, 8]. A-zeotropic ethanol is ethanol with a concentration of 95.5% v. A-zeotropic ethanol can be produced by distillation without molecular sieves. The combustion speed and flammability limit (ER) of a-zeotropic ethanol are also better than anhydrous ethanol [9, 10]. Testing of short chain alcohol fuels such as methanol, ethanol and butanol has been carried out a lot to reduce fossil fuel uses, improve the emissions quality and reduce toxic exhaust gases. Differences in property of alcohol fuels cause variations in consumption, performance and emissions of gasoline and diesel engines [2, 11].

The research uses a fuel mixture of gasoline with ethanol is also done by [12]. In their study tested engine performance and exhaust emissions produced. His research claims that addition of ethanol increases engine power, this can be related to the presence of hydroxyl radicals in ethanol, which contribute to complement combustion enhancer. Extra oxygen in the molecular structure of ethanol caused more release of chemical energy as result of combustion of fuel converted to thermal energy. BSFC of the engine is increases by 22.81% with the addition of 10% ethanol to gasoline as shown in Figure 1.

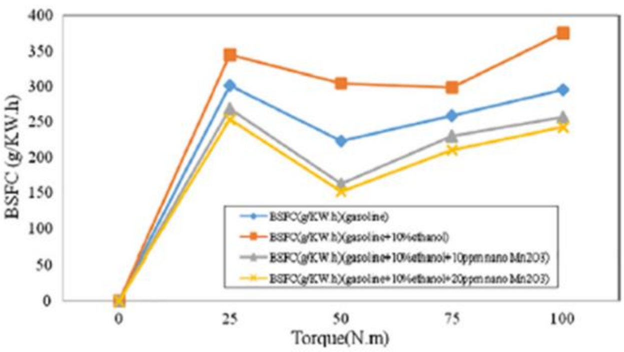

Figure 1. Effect of gasoline blends with ethanol and Mn_2O_3 on BSFC

Engine performance test using ethanol fuel is also done by [13]. The test concluded that ethanol with 5%v of water content was operated at engine with constant speed 3,600 rpm, stoichiometric mixture showed a load effect on BSFC and efficiency. By increasing the generator load from 10% to 100%, overall efficiency increased by 18%, while BSFC

[1]Corresponding author. Tel.: +6281236455857; Fax: +62361702811
E-mail address: madesuarta@pnb.ac.id

Nomenclature

SI	Spark ignition	TDV	Total displacement volume (m^3)
BSFC	Brake specific fuel consumption		

decreased by around 76%. A decreasing trend of BSFC when increasing load also indicated by [14]. The emissions are very low. The results of the study can be seen in Figure 2.

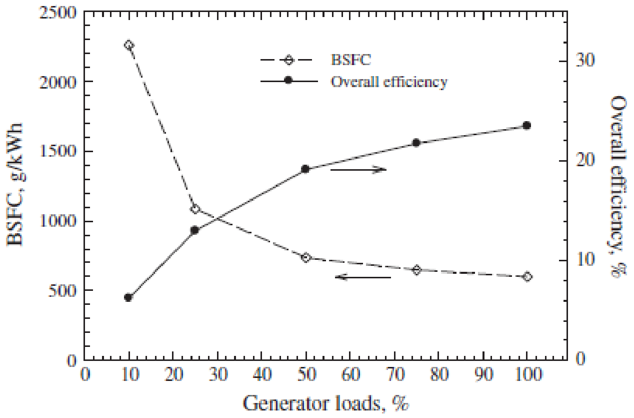

Figure 2. Effect of load on BSFC and efficiency when using ethanol fuel 95% v

Iodice et al. [4] showed, with the addition of anhydrous ethanol in blend, torque and brake power also increase owing the heat of evaporation of ethanol (around 910 kJ / kg) is twice higher than gasoline. So, during the evaporation of ethanol / gasoline mixture under of hot operating conditions, the flow of fuel tends to absorb more cylinder heat than gasoline. In this condition, the charge and intake manifold temperatures decreases, thus increasing volumetric efficiency.

Deng et al. [3] do a research on pure gasoline and the mixture with hydrous ethanol 95,5%v. Compared to using pure gasoline, thermal brake efficiency is obtained higher when using a mixture of hydrous ethanol gasoline on the engine tested. It is caused by hydroxyl radicals (-OH) produced by ethanol, which improves the combustion and flame propagation speed. The results of the research are shown in Figure 3

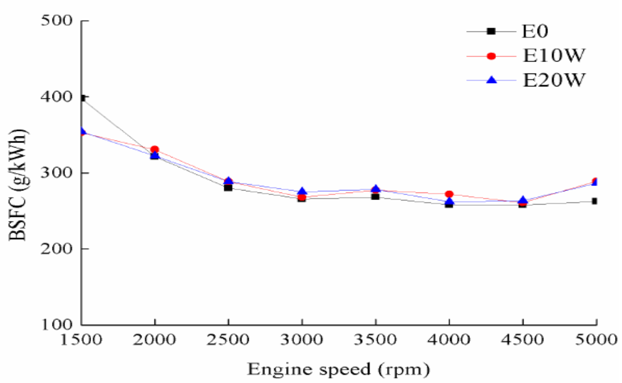

Figure 3. Effect of engine speed to BSFC using gasoline and its mixture with ethanol

Because of, a shorter combustion period the results is lower heat loss to the cylinder wall, which promotes the thermal brake efficiency. Also compared between E10W and E20W; E20W produces higher thermal brakes efficiency on the tested machine. It caused by presence of oxygen is higher at E20W, which helps increase combustion.

Costa and Sodré [15] found that it was consumed more hydrous ethanol to get the same power compared to gasoline ethanol mixture. For both types of fuel, it is operated at equivalence ratio 1.12, and the stoichiometric air/fuel ratio is 13.1 for the gasoline-ethanol blend and 8.7 for hydrous ethanol. BSFC for hydrous ethanol is up to 54% higher than that of gasoline-ethanol blend, as a consequence of the lower heating value of hydrous ethanol with respect to that of the ethanol-gasoline blend. Improved fuel economy using hydrous ethanol instead of the ethanol gasoline blend, could only be possible with engine modifications, especially in the compression ratio

Chuepeng et al. [16] stated that in stoichiometric air-fuel mixture the rate of consumption of hydrous ethanol fuel is higher than anhydrous ethanol and gasoline around 9% and 194%. The greater fuel consumption for hE100 than that of the E100 is correspondent to the lower heating value of hE100 which is lesser by approx. 5% than that of the E100.

Based on the results of previous studies that the speed of flame and better quality emissions from hydrous ethanol, the current study compares ethanol fuel (a-zeotropic 95.5% v) with anhydrous ethanol fuel (99.7% v). Tests are carried out using varying of loads on the both type of fuel.

2. Methods

The research was conducted by laboratory test methods. The first step, for anhydrous ethanol fuel is use absolute ethanol for analysis from Merck. Furthermore, the anhydrous ethanol was diluted to hydrous ethanol (a-zeotropic) at (95.5% v) water content at the analytical laboratory. For testing of power, specific fuel consumption and thermal efficiency, was tasted out on engine brake power indicator TD 800PM load cell type with a test set-up as shown in Figure 4. By processing the test data, the results of calculations are obtained as in Tables 1 and 2.

3. Results and Discussion

By using the preliminary data engine with speed of 3500 rpm, the load increases every 1 kg, 15 mm orifice diameter, 200 mm load arm length. With the use of (Torque)

$$\tau = F.r, \quad (1)$$

Fuel consumption Q_{mf} (kg/s) where:

$$Q_{mf} = Q_v . \rho_f , \quad (2)$$

Power produced can be calculated by using equation (3):

$$(P) = \frac{2\pi Frn}{60} \text{ in kW} \quad (3)$$

The air flow rate through the orifice plate is calculated by equation (4):

$$Q_{va} = \frac{Q_{ma}}{\rho_a} = \alpha\varepsilon\frac{\pi d^2}{4}\sqrt{\frac{2\Delta p}{\rho_a}} \qquad (4)$$

and consumption of specific fuel is calculated as below:

$$B_{sfc} = \frac{Q_{mf}\left(^{kg}/_{s}\right)}{P(kW)} \qquad (5)$$

Volume of combustion chamber:

$$Q_{th} = \text{engine TDV x } \frac{n}{2 \times 60}\left(\frac{m^3}{s}\right), \qquad (6)$$

with volumetric efficiency:

$$\eta_v = \frac{Q_{va}}{Q_{th}} \times 100\%; \qquad (7)$$

Thermal Efficiency:

$$\eta_{bt} = \frac{P(kW)}{Q_f} = \frac{P(kW)}{Q_{mf}.LHV} \qquad (8)$$

So that the results of calculations are obtained as presented in Tables 1 and 2.

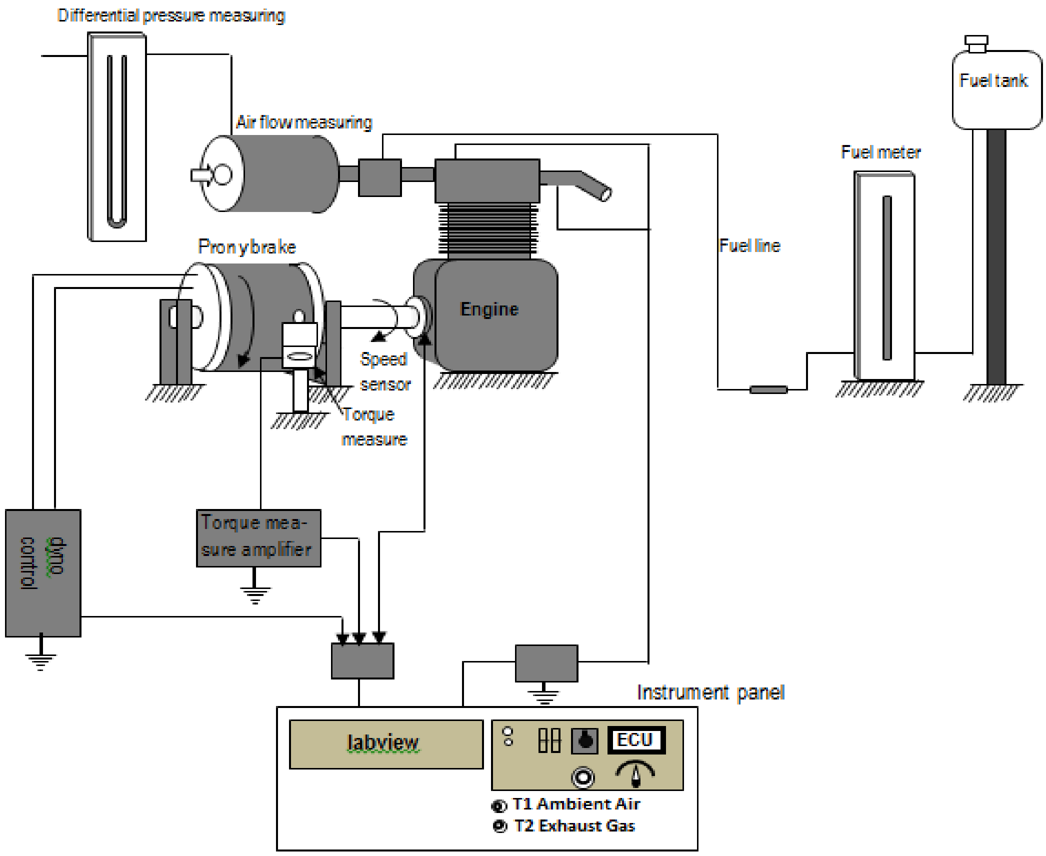

Figure 4. Set-up experimental

Table 1. Results of calculation of ethanol anhydrous data

TD 800PM SINGLE-CYLINDER ENGINE TEST-BED, Mechanical Absorber

Room temperatur : 29
Atmospheric pressure : 105,2 kPa
Opening position of throttle valve : -

Engine type : ....
Fuel type : anhydrous ethanol
Specific gravity : ....

Tested by : ....
Date :5/7/2018
Air box / Orifice diameter : 300/15
Manometer slope : 1:5
Manometer reading for zero air flow :

n rpm	Net Force kg	τ (N.m)	Fuel Consumtion					Air flow rate						A/F ratio	Temperatur (°C)		P kW	B_{sfc} kg/kWh	η_{bt} %
			Graduated cylinder			Indicator Q_f kW	Q_{mf} kg/s	Air box				Indicator Q_{va} m^3/s	Q_{ma} kg/s		Engine Inlet air T1	Exhaust gas T2			
			Volume ml	Time s	Q_{vf} (l/s)			Manometer Reading mm H2O			Q_{th} (m^3/s)								
								Left	Right	Net									
3500	0	0	5	17.62	0.00028	5.96311	0.00022418	285	115	170	0.0057	0.00161	0.0019	8.4004	28	281	0	#DIV/0!	0
3136	1	1.96	5	18.01	0.00028	5.83398	0.00021932	285	115	170	0.0051	0.00161	0.0019	8.5863	28	300	0.6443	1.22541	11.044
3100	2	3.92	5	19.11	0.00026	5.49817	0.0002067	285	115	170	0.0051	0.00161	0.0019	9.1108	28	281	1.2739	0.58414	23.169
3000	3	5.88	5	19.45	0.00026	5.40206	0.00020308	280	120	160	0.0049	0.001561	0.0018	8.996	28	282	1.8491	0.39538	34.23
2600	4	7.84	5	20.15	0.00025	5.21439	0.00019603	270	130	140	0.0042	0.001461	0.0017	8.7178	28	261	2.1368	0.33027	40.979
2313	5	9.8	5	21.18	0.00024	4.96081	0.0001865	270	130	140	0.0038	0.001461	0.0017	9.1635	28	247	2.3761	0.28255	47.898

Table 2. Results of a-zeotropic ethanol data calculation

TD 800PM SINGLE-CYLINDER ENGINE TEST-BED, Mechanical Absorber

Room temperatur : 29
Atmospheric pressure : 105,2 kPa
Opening position of throttle valve : -

Engine type : ....
Fuel type : azeotropik ethanol 95,5%v
Specific gravity : ....

Tested by : .... Date : 5/7/2018
Air box / Orifice diameter : 300/15
Manometer slope : 1:5
Manometer reading for zero air flow :

n rpm	Net Force kg	τ (N.m)	Fuel Consumtion					Air flow rate						A/F ratio	Temperatur (°C)		P kW	B_{sfc} kg/kWh	η_{bt} %
			Graduated cylinder			Indicator Q_f kW	Q_{mf} kg/s	Air box				Indicator Q_{va} m^3/s	Q_{ma} kg/s		Engine Inlet air T1	Exhaust gas T2			
			Volume ml	Time s	Q_{vf} (l/s)			Manometer Reading mm H2O			Q_{th} (m^3/s)								
								Left	Right	Net									
3500	0	0	5	10.34	0.00048	9.93772	0.00038685	370	30	340	0.0057	0.002276	0.0027	6.8844	28	320	0	#DIV/0!	0
3321	1	1.96	5	10.97	0.00046	9.367	0.00036463	365	30	335	0.0054	0.002259	0.0026	7.25	29	332	0.6823	1.9238	7.2844
3244	2	3.92	5	11.23	0.00045	9.15013	0.00035619	360	30	330	0.0053	0.002243	0.0026	7.3662	29	334	1.333	0.96193	14.568
3221	3	5.88	5	11.65	0.00043	8.82026	0.00034335	360	30	330	0.0053	0.002243	0.0026	7.6417	29	337	1.9854	0.62258	22.509
3147	4	7.84	5	12.06	0.00041	8.5204	0.00033167	360	40	320	0.0051	0.002208	0.0026	7.7899	29	323	2.5863	0.46167	30.355
2575	5	9.8	5	12.94	0.00039	7.94096	0.00030912	335	55	280	0.0042	0.002066	0.0024	7.8184	29	334	2.6453	0.42068	33.312

3.1 Power

The power produced by a-zeotropic ethanol is higher than that of anhydrous ethanol at the same load. Difference increases power proportional with increased load as shown in Figure 5. Engine power performance is significantly dependent on the physical and chemical properties of the fuel used. The latent heat of a-zeotropic ethanol evaporation is lower than ethanol anhydrous. It caused by the structure of a-zeotropic ethanol molecules is shorter so it is easier to evaporate than ethanol anhydrous [7]. Therefore, produce more power in engine operation but will consume more fuel, which leads to higher volumetric efficiency. Furthermore, a-zeotropic ethanol has a centralized oxygen molecule that benefits the combustion process so that it produces more perfect combustion, and increases combustion efficiency.

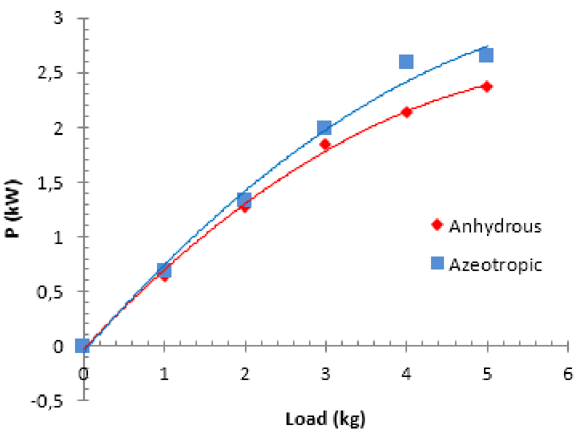

Figure 5. Comparison of the power produced by ethanol a-zeotropic with ethanol anhydrous at the same load.

A-zeotropic ethanol combustion speed higher than anhydrous ethanol causes the generated power is also higher. Seeing these factors affect engine power performance to be consideration in the use of a-zeotropic ethanol into fuel.

3.2 Specific fuel consumption

The latent heat evaporation of a-zeotropic ethanol is lower than anhydrous ethanol causes a-zeotropic ethanol to evaporate more easily in the engine operation process. The result is more fuel goes into the combustion chamber resulting in greater power. Lower heat value causes the need of more amount of fuel to produce the same power. This result consistent with [13,14]. Comparison of specific fuel consumption shown in Figure 6.

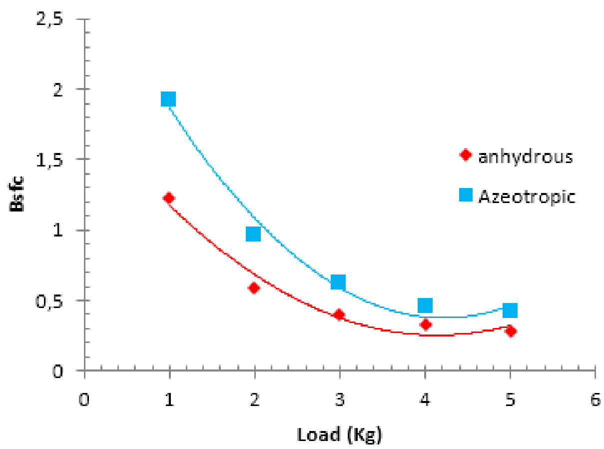

Figure 6. Comparison of specific fuel consumption using a-zeotropic ethanol and anhydrous ethanol

Hydrogen bonds in O and H atoms in ethanol and water molecules cause molecules to group with strong bonds. Thus in the process of evaporation in the carburetor the distance between fuel molecules becomes closer which implies occupying a narrower space so that more fuel enters the combustion chamber. Bigger combustion velocity of a-zeotropic ethanol is also a cause of bigger combustion power and better emission quality [3]. This is also in accordance with the results of Phuangwongtrakul's research [17]. The higher of ethanol levels BSFC is increasing.

3.3 Thermal efficiency

A-zeotropic Ethanol thermal efficiency is lower than anhydrous ethanol this caused more fuel needs to produce the same power as anhydrous ethanol. The combustion efficiency is influenced by the amount of fuel needed per cycle, the temperature in the cylinder and the homogeneity of the mixture. Because more fuel is supplied (load increases), there is an increase in reactant stratification at higher loads. Load stratification occurs and causes over rich zona formation. So the tendency of the difference in combustion efficiency is greater according to the increase in load. This is the same as [18], the thinner the mixture the combustion efficiency increases. The increase of power when the use of a-zeotropic ethanol is smaller than the fuel consumption of each power produced. So that thermal efficiency decreases when using ethanol a-zeotropic fuel. Graphs comparing between thermal efficiency of a-zeotropic fuel and anhydrous ethanol are shown in Figure 7.

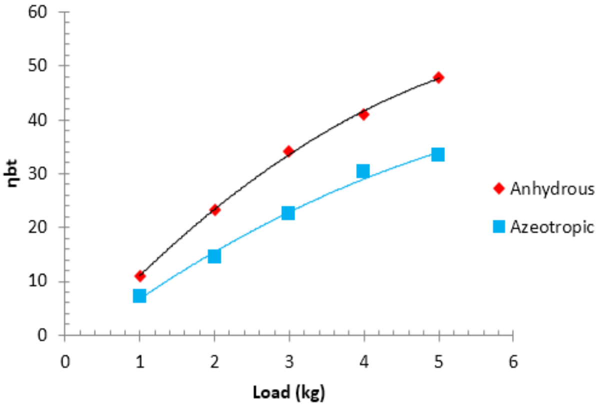

Figure 7. Comparison of thermal efficiency using a-zeotropic ethanol fuel and anhydrous ethanol

4. Conclusions

Using a-zeotropic ethanol fuel produced greater power than anhydrous ethanol at the same load. The higher the load the higher difference in power will produced. The amount of power produced depends on the characteristics of combustion such as combustion speed and volumetric efficiency of fuel.

Fuel consumption use a-zeotropic fuel higher than anhydrous ethanol fuel. This is due to the a-zeotropic ethanol fuel heating value is smaller than anhydrous ethanol or to produce the same power, consumption more amount of a-zeotropic ethanol fuel than a-zeotropic ethanol fuel.

The thermal efficiency of a-zeotropic ethanol is smaller than anhydrous ethanol at the same load. The difference in efficiency increases in proportion to the increase in load.

References

[1] I. Awad Omar, R. Mamat, M. Ali Obed, N.A.C. Sidik, T. Yusaf, K. Kadirgama and M. Kettner, "Alcohol and ether as alternative fuels in spark ignition engine", *Renewable and Sustainable Energy Review,* http://dx.doi.org/10.1016/j.rser.2017.09.074

[2] I.M. Suarta, I.N.G. Baliarta, I.P.G. Sopan Rahtika and P.W. Sunu, "The Role of Hydrogen Bonds Of The Azeotropic Hydrous Ethanol Fuel Composition To The Exhaust Emissions", *Journal of Physics*: Conf. Series 953 2018 *J. Phys.: Conf. Ser.* **953** 012070

[3] X. Deng, Z. Chen, X. Wang, H. Zhen, and R. Xie, "Exhaust noise, performance and emission characteristics of spark ignition engine fuelled withpure gasoline and hydrous ethanol gasoline blends", *Case Studies in Thermal Engineering. https://doi.org/10.1016/j.csite.2018.02.004*

[4] P. Iodice, G. Langella, A. Amoresano, "Ethanol In Gasoline Fuel Blends: Effect On Fuel Consumption and Engine Out Emissions Of Si Engines In Cold Operating", conditions. *https://doi.org/10.1016/j.applthermaleng.2017.11.090*

[5] P. Sakthivel, K.A. Subramanian, R. Mathai, "Indian scenario of ethanol fuel and its utilization in automotive transportation sector", Resources, Conservation & Recycling, 132, 2018, pp. 102–120

[6] S. Chuepeng; S. Srisuwan and M. Tongroon, "Lean hydrous and anhydrous bioethanol combustion in spark ignition engine at idle", Energy Conversion and Management 128, 2016, pp. 1–11

[7] I.M. Suarta, I.N.G. Wardana, H. Nurkholis and W. Widya, "The Role of Molecule Clustering by Hydrogen Bond in Hydrous Ethanol on Laminar Burning Velocity", *Journal of Combustion.* Article ID 5127682, 9 pages. http://dx.doi.org/10.1155/2016/5127682.

[8] J.L.S. Fagundez, R.L. Sari, F.D. Mayer, M.E.S. Martins, and N.P.G. Salau, "Determination of optimal wet ethanol composition as a fuel in spark ignition engine", *Applied Thermal Engineering* http://dx.doi.org/10.1016/j.applthermaleng.2016.10.099

[9] I.M. Suarta, I.N.G. Wardana, H. Nurkholis and W. Widya,."The Role of Hydrogen Bonding on Laminar Burning Velocity of Hydrous and Anhydrous Ethanol Fuel with Small Addition of n-Heptane", *Journal of Combustion* Volume 2016, Article ID 9093428, 8 pages http://dx.doi.org/10.1155/2016/9093428

[10] B. Baine and S. Acharya, "The effect of elevated water content on swirl-stabilized ethanol/air flames", *Fuel*, 105, 2013, pp. 90–102.

[11] I. M. Yusria, R. Mamat, G. Najafi, A. Razman, Omar I. Awad, W.H. Azmi, W. F. W. Ishak, A.I.M. Shaiful, "Alcohol based automotive fuels from first four alcohol family incompression and spark ignition engine: A review on engine performanceand exhaust emissions", *Renewable and Sustainable Energy Reviews*, 77, 2017, 169–181.

[12] M. Amirabedi; S. Jafarmadar, S. Khalilarya, "Experimental investigation the effect of Mn_2O_3 nanoparticle on theperformance and emission of SI gasoline fueled with mixture of ethanol and gasoline", Applied Thermal Engineering, 149, 2019, pp. 512–519

[13] R. Munsin, Y. Laoonual, S. Jugjai, Y. Imai, "An experimental study on performance and emissions of a small SI enginegenerator set fuelled by hydrous ethanol with high water contents up to 40%", Fuel, 106, 2013, pp. 586–592

[14] R. Salvador, C. Bringhenti, J.T. Tomita, “Characterization of an ethanol fueled heavy-duty engine powering a generator set”, http://dx.doi.org/10.1016/j.applthermaleng.2016.03.107

[15] R.C. Costa, and J.R. Sodré, “Hydrous ethanol vs. gasoline-ethanol blend: Engine performance and emissions”, Fuel, 89, 2010, pp. 287–293.

[16] S. Chuepeng, S. Srisuwan, and M. Tongroon, “Lean hydrous and anhydrous bioethanol combustion in spark ignition engine at idle”, Energy Conversion and Management, 128, 2016, pp. 1-11.

[17] S. Phuangwongtrakul, W. Wechsatol, T. Sethaput, K. Suktang, S. Wongwises, “Experimental study on sparking ignition engine performance for optimal mixing ratio of ethanol-gasoline blended”, Fuels. *http://dx.doi.org/doi: 10.1016/j.applthermaleng.2016.02.084*

[18] T. Diórdinis, M. Lanzanova, M. D. Nora and H. Zhao, “Performance and economic analysis of a direct injection spark ignitionengine fueled with wet ethanol”, *Applied Energy*, 169, 2016, pp. 230–239