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To cite this article: Setia Abikusna and Bambang Sugiarto 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **753** 012004

IOP Conf. Series: Earth and Environmental Science **753** (2021) 012004 doi:10.1088/1755-1315/753/1/012004

Study on the utilization of low-grade bioethanol on SI gasoline engine as a mixture of pure gasoline fuel or with the addition of oxygenated additives to improve performance and reduce emissions

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Abstract. Utilization Currently, bioethanol has developed into additional fuel or substitute fuel for motorcars as a renewable energy source. Although Indonesia has great potential for developing bioethanol, its utilization continues to be very low. In certain areas in Indonesia, bioethanol is produced on a tiny low scale grade (hydrous) and is barely used as a drink; therefore research and development of the utilization of bioethanol in motorcars are needed, where the grade must be higher (anhydrous). Hydrous bioethanol has slightly different characteristics compared to anhydrous bioethanol. Octane is lower, heating value is lower, the heat energy of vaporization is higher, and the oxygen content is higher. However, the precise values for every characteristic rely on the mixture content and therefore the water content contained so a separate test of the hydrous bioethanol is required. This study could be a study of the utilization of hydrous bioethanol produced from low-grade bioethanol which is converted to high- grade bioethanol through a distillation process using motorcycle exhaust gas as a heat source which is applied to a compact-distillation system consisting of an evaporator, separator, and condenser to distil low-grade bioethanol (around 30%) becomes high-grade bioethanol (> 90%). Followed by testing the utilization of anhydrous bioethanol mixed with gasoline in SI gasoline engines, the composition of the mixture E0, E5, E10, and E15 and therefore the composition of the mixture with the addition of oxygenated additives (cyclohexanol) as secondary alcohols to further improve performance and reduce gas emissions throw it away.

1. Introduction

The use of fossil energy if used continuously and does not decrease, can cause oil reserves to run out. To beat this problem, we would like to develop alternative renewable energy, from green plants, and are available from nature. One in all of them is biomass energy derived from organic matter. Biomass energy sources can come from agricultural or agricultural products, wood, agriculture or maybe waste. Biomass energy will be accustomed to produce heat, make fuel and produce electricity [1]. Biomass energy utilization technology has been developed which consists of direct combustion and conversion of biomass into fuel. The results of this conversion can include biomass gas, bioethanol, biodiesel, and liquid fuels [2, 3].

In its development, ethanol as a fuel has been utilized in Brazil since 1970, both with the mixture E20-E25 (anhydrous) or E100 (hydrous), the employment of ethanol in flex-fuel engines, in fact with different engine specifications with gasoline engines naturally. The employment of ethanol fuel has successfully suppressed CO_2 emissions in Brazil between 1997 and 2010 [4, 5]. Technically, the employment of ethanol must listen to many things like compatibility/suitability with metal materials (corrosion), compatibility/suitability with plastic or rubber materials (chemical losses), high fuel consumption (low energy content), loss of driveability (changes in air ratio/fuel), cold engine start conditions (low vapour pressure) specifically for areas with shallow temperatures (even below 0°C). The conditions mentioned above are all very enthusiastic about the amount of ethanol mixed with gasoline, the specifications and quality of ethanol fuel, further because of the technology of the engine itself.

Experimental research has been conducted to judge the consequences of ethanol and gasoline performance, emissions, and fuel combustion on fuel engine spots when operating with a lean air-fuel mixture (lambda 0.9 - 1.6). Combustion parameters like combustion duration, ignition delay, temperature and pressure within the cylinder, and warmth release level are analysed and accustomed understand the behaviour of fuel consumption and emission of thin combustion mode compared to stoichiometric conditions. The experimental results show that combustion instability occurs after lambda 1.4. This causes a rise in fuel consumption. The instability is additionally because of a decrease in combustion temperature, with high heat release and low combustion temperatures in an exceedingly thin mixture. In general, ethanol produces greater combustion efficiency [6], besides the employment of ethanol may improve the emissions produced, directly proportional to the vehicle [7, 8].

In contrast to the employment of ethanol in Indonesia to become fuel continues to be classified as very low. However, it is different from the assembly of low-grade ethanol as a kind of beverage consumed by specific communities, both traditional and industrial scale, found in Indonesia. Ethanol which might be used as an engine fuel is typically anhydrous ethanol with a 99.5% (fuel grade). If it has used entirely as fuel, engine modification is required, but engine modification is not needed [9]. Anhydrous ethanol used has little or no water content and may even be said to be pure so when mixed directly with gasoline, it can directly enter the combustion chamber. While hydrous ethanol has low concentration and still has water content in it (4.9% - 5%) so it cannot be directly mixed with gasoline. To be used as a combination with gasoline the most water content is 7.4%. Therefore, we would like an easy technique that will accommodate low-grade ethanol produced by the community to be converted into high-grade ethanol and also the results will be directly applied as a combination of fuel within the engine. Hydrous ethanol has slightly different characteristics compared to anhydrous ethanol [10]. Octane is lower, and the heating value is lower, the heat of vaporization is higher, and the oxygen content is higher. However, the precise values for every characteristic rely upon the mixture content and also the water content contained, so a separate test of hydrous ethanol is required.

This research is to determine how high-grade ethanol as a result of distillation from low-grade ethanol is employed as a fuel mixture in gasoline engines, and with the addition of additives to create the mixture more homogeneous and to check its utilization on performance and emissions. As one of the components that can affect performance and emissions is the cyclic variation that occurs. If the cyclic variation is too considerable the result is very influential on torque fluctuation which in turn can reduce the driveability of the engine.

2. Method

Evaporator a part of the compact-distillatory is mounted on to the exhaust to take advantage of the warmth from the exhaust gas for heating distillation and therefore the installation is installed to take advantage of the space within the dynamic fuel engine by not changing the physical appearance condition of the motor so that it is possible to try and do a tryout. The procedure of testing a compact-distillatory by exploiting the exhaust gas that passes through the muffler is going to be wont to heat the distillatory unit occupied by the distillation material with low ethanol content. Due to the warmth from the combustion gases the warmth conduction occurs on the surface of the muffler to be an evaporator. As a result, the evaporator will convert the ethanol phase into steam. Then the valve is attached to the evaporator bypass which is controlled by a choke on the motor handle. When the warmth has reached 80°C, it will be seen within the temperature controller connected to the probe within the evaporator, choking to the lower mitt handle to shut the exhaust heat flow to the evaporator employing a valve. The new flow of flue gas will flow to chop. As a result, the warmth of the evaporator will be retained and does not increase significantly. Steam distillate material in high levels of ethanol will flow to the separator; with the separator mechanism, it has expected that the evaporated vapour is going to be separated from ethanol vapour. Distilled ethanol vapour will flow into the condenser (heat exchanger). Within the condenser, ethanol vapour is going to be converted into liquid. It will be an extra fuel in high-level ethanol. A Gate valve is employed to manage the new exhaust gas from the exhaust. A gate valve is installed for the manifold to become an evaporator and bypass the manifold. Under normal conditions, the gate valve within the bypass manifold will close but the evaporator manifold will open. However, when the thermocouple is attached to the evaporator, it sends a proof to the temperature control which is that the temperature condition within the evaporator has reached the bioethanol heating point. Therefore, the faucet on the gate valve is going to be turned manually and therefore the heat flow will taste the bypass, but the valve gate on the evaporator type is going to be closed. Then the manifold that connects the evaporator to the separator and the warmth exchanger, uses an insulated copper pipe, which suggests stopping convection from releasing calories.

The engine employed in this study is an SI Honda engine type AFX12U21C07 one cylinder 125 cc SOHC with an electronically controlled mechanical system. The fuel used is seven forms of gasoline and ethanol mixture prepared supported variable mixing ratio from RON 88 to RON 96, ethanol quality by volume, with a mix of E5, E10, and E15, still because of the addition of cyclohexane ($C_6H_{12}O$) and cyclohexanol ($C_7H_{14}O$) additives, with a composition of 0.5% vol/vol in each fuel mixture. The fuel mixture is mixed within the fuel tank and manifold inlet. That the level of premix is sort of high and almost constant, therefore the mass rate will be measured and controlled directly. To complete the character of the fuel, each fuel mixture is tested for its characteristics. The cylinder combustion pressure is measured employing a Kistler 6617B piezo-electric sensor (maximum pressure up to 200 bar) and recorded by the LabVIEW acquisition system. Crank position angles (up to 720 crank angles) are obtained with the encoder shaft; the order is adjusted to synchronize the cylinder combustion pressure signal with the crankshaft angle. Type K thermocouples are accustomed to monitor the temperature of exhaust gases, fuels, lubricants, and spark plugs. This machine is connected to a dynamometer for BHP, torque, and SFC analysis, and is connected to QROTECH-401 (4/5 gas analyser) to live the content in exhaust gases like CO, CO_2, O_2 and HC. The air-fuel ratio analysis is completed by installing a lambda sensor (oxygen sensor) within the manifold.

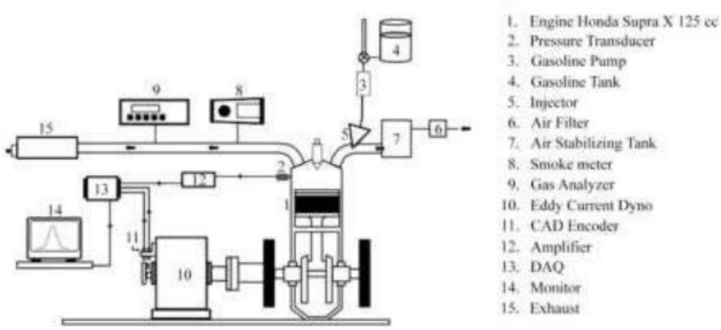

Figure 1 Experimental Set-Up [11]

The picture above shows the experimental chart on a 125 cc SI engine connected to other supporting components. One in each of them could be a pressure transducer that attaches on to the sparking plug. In the SI engine operation, the height combustion pressure varies greatly reckoning on engine operating conditions. Combustion pressure variations within the cylinder occur from one cycle to the subsequent, called cyclic variations. In contrast, the utilization of a thinner mixture and exhaust gas recirculation, and increased operation occurs thanks to various conditions when idling and when it stops. Cyclic variations in SI engines are identified as fundamental combustion conditions. This cyclic variation can cause torque fluctuations, which successively leads to low computer operation. By reducing cyclic variations, engine output can increase by up to 10% under identical fuel consumption conditions and might reduce engine noise and vibration [12]. The combustion pressure within the cylinder is a critical indicator of cyclic variation (COV), is measured in each cycle at each crankshaft rotation angle. Some critical parameters associated with pressure on the cylinder are; peak pressure within the cylinder (P_{max}), the angle of the crankshaft where the height pressure (CA P_{max}) occurs and also the indicated adequate average pressure (IMEP) in one cycle. Pmax could be a measure of the amount of pressure that increases thanks to combustion. If combustion is quicker, a better level of pressure increase will occur. The P_{max} shown depends on the change within the combustion phase and the combustion rate. The number of variation depends on whether the combustion is quicker or slower. Faster combustion will lead to higher P_{max}. P_{max} will tend to occur closer to TDC, whereas slower combustion cycles will have lower Pmax and Pmax CA removed from TDC. This test experiment meted out as many as 800 cycles for every mixture of gasoline and ethanol, after running the engine until it reaches a stable condition. The oil temperature and cooling water are at 50°C. The accelerator opening is maintained at 100%, and ignition timing is controlled per the mechanism which is controlled by the mechanical system. As for variations in engine speed at 4.000 rpm 8.500 rpm with engine speed increasing every 500 rpm. This engine speed variation is to determine conditions from the low, medium, to high speed.

3. Results and Discussions

The Influence of exploiting exhaust gas to heat distillatory relies on fuel consumption and emission gas. An Experiment was done to gasoline Otto engine in an exceedingly very variety torque by exploiting exhaust gas to distillation heater.

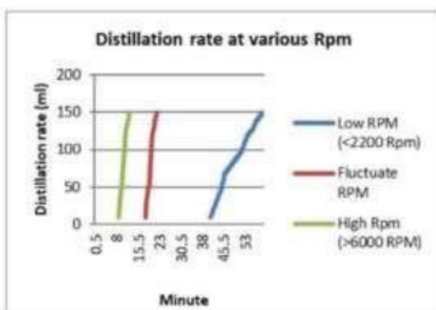

Figure 2 Distillation Rate at Various RPM

From the chart above are visiting be seen that top engine speed (> 6.000 rpm) can produce the fastest distillation rate and in low speed refers to wish long duration to produce distillation. From obtained data, the duration is required to distillate low-grade ethanol to be high- grade ethanol, and therefore the distillation volume rate is comparable undeviating to engine speed accustomed test compact-distillatory apparatus. It shows that heat exhaust gas is employed as a distillation energy source influenced by engine speed. The upper engine speed, the upper heat within the muffler, and therefore the effect of evaporating distillation low-grade ethanol within the evaporator is higher. Increasing the best temperature from the exhaust gas is unexpected because it will influence faster evaporating distillation and water grade in distillation also will evaporate and so it'll influence high-grade ethanol produced.

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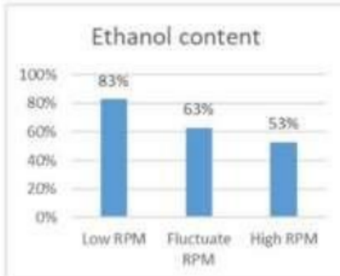

Figure 3 Ethanol Content at Various RPM

From the chart above, it has known that alcohol concentration means of each speed, whereas the very best alcohol concentration is reached by the low speed with a percentage equals to 83%, in low speed produces higher alcohol concentration due to low water speed that has distilled its phase unchanging thoroughly, whereas alcohol has changed its phase so most of the lead to compact-distillatory is alcohol. It is because of exhaust gas that has resulted in low-speed relative constant so heat that has generated within the muffler indicating increase slowly then it will significantly influence to a unit that may be distilled to compact-distillatory. Whereas in fluctuate speed and high speed is in relative low-grade because H_2O has changed its phase and distilled with alcohol so it produces a lower level. It has caused by a rise in temperature to significant exhaust gas due to combustion within the combustion chamber. Because there is no temperature setting toward the header pipe that has used as a compact-distillatory energy source so all heats are visiting be accustomed heat distillate within the evaporator compact-distillatory.

Coefficient of Variation (COV) combustion in SI engines is a crucial subject studied extensively because it limits the engine operating range. Much research has been done to look at the causes of cyclic variations within the combustion process, resulting in cyclic variations in engine output performance. Cyclic variations will be observed and characterized by the combustion pressure within the cylinder measured experimentally. The cylinder pressure resulting from engine combustion from 4.000 rpm, 6.00 rpm, and 8.500 rpm rotation for each fuel mixture from E0, E5, E10, and E15, could also be seen within the picture below. Each fuel mixture produces a superior combustion pressure in each cycle.

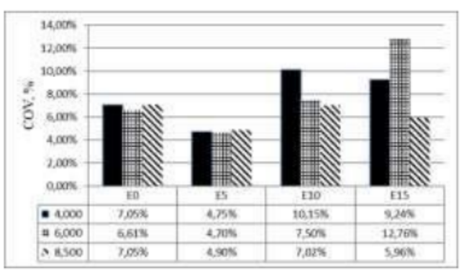

Figure 4 COV on Fuel Mixture Variation (uncertainty + 0.15)

From the results of the graph above, it has found that the E5 mixture at each engine speed condition produces all-time low COV in comparison to other fuel mixtures including even when put next to the E0 mixture. The bottom COV E5 corresponds to the tiniest variation in combustion pressure as previously described. If you take a look at the fuel mixture graph from E0 to E15, the cylinder pressure graph at E5 is that the most optimum, the cyclic variation is that the least in each engine speed variation, but there is a difference within the maximum cylinder pressure produced. It is different from the mixture E0, E10, and E15 in each variation of engine speed, where there is a difference within the combustion

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cycle from one cycle to the subsequent. The addition of 5% ethanol to gasoline can reduce the force per unit area of 9.8 kPa (20%), where the effect of fuel force per unit area on engine conditions is when the engine is running at low environmental temperatures, hot and high ambient temperatures, and through engine acceleration. If the combustion occurs earlier this may cause the maximum cylinder pressure to also occur at the crankshaft angle which is closer to TDC, as within the previous explanation that if the combustion occurs too early, it will cause a rise in pressure before the tip of the compression stroke and therefore the engine output power will decrease. Thus, the rise in work during the compression stroke is more significant than the rise in work done on the piston during the work stroke. Also, with earlier combustion, the height pressures and temperatures may cause knocking. Conversely, if the ignition timing vs crank angle is late, then whether or not the piston moves during the compression stroke and therefore the effort stroke, the pressure will decrease. Besides, there is a risk of combustion occurring before the valve opens at the top of the trouble stroke, and this might cause the valve to overheat.

Ethanol includes a high affinity for water because it contains a particular amount of water in it. This cannot be a controversy if you merely use ethanol as fuel because it has thoroughly mixed with water, where the ethanol has polar properties that dissolve quickly with water. However, but some serious problems can arise when the gasoline-ethanol mixture is employed. Phase separation can occur during this mixture because gasoline and ethanol do not seem to be thoroughly mixed homogeneously [13]. This problem is often prevented by using solvents that are semi-polar (solubility improvement). The oxygenate additives added to every fuel mixture E5, E10, and E15 are cyclohexane ($C_6H_{12}O$) and cyclohexanol ($C_7H_{12}O$) with a volume of 5% vol/vol. Both of those additives belong to a secondary alcohol, which are cyclic organic compounds with carbon C-6 and C-7 and an OH group (alcohol), respectively. Because the carbon chain length increases, and within the presence of the OH group, the influence of the polar hydroxyl on the molecular properties tends to decrease. Therefore, this additive is semi-polar. This becomes a binder between gasoline and ethanol so that the mixture of the two may be more homogeneous.

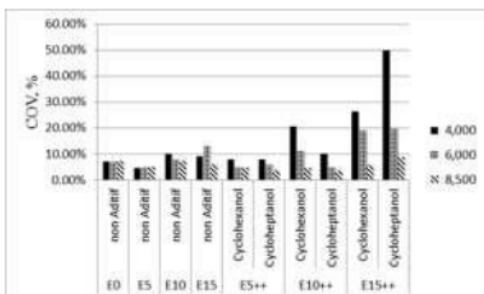

Figure 5 COV on Fuel Mixture Variation with Oxygenated Additives (uncertainty + 0.15)

From the figure above, it has found that the mixture of E10 ++ with the oxygenate cyclohexanol additive produces rock bottom COV, namely 3.42% at 8.500 rpm engine speed when put next to other fuel mixtures. The bottom COV E10 ++ corresponds to the littlest variation in combustion pressure.

To keep the Air Fuel Ration (AFR) near the theoretical AFR level, the ECU corrects the injection duration supported by the oxygen sensor (this is named closed-loop operation). If the ECU compares the voltage signals sent from the oxygen sensor with a better signal voltage than the required, the ECU sets a richer AFR than the theoretical AFR. It reduces the number of fuel injected to the right value. The correction of ignition timing and injection duration for every fuel mixture is shown within the figure below. In general, the ignition timing will advance when the engine speed increases. This can be because, at higher engine speed, the time available is brief enough to finish the combustion in one cycle. This combustion that happens becomes faster so that the ignition timing must be advanced earlier, related to this also the speed of propagation of fireplace is extremely necessary. Ethanol contains a

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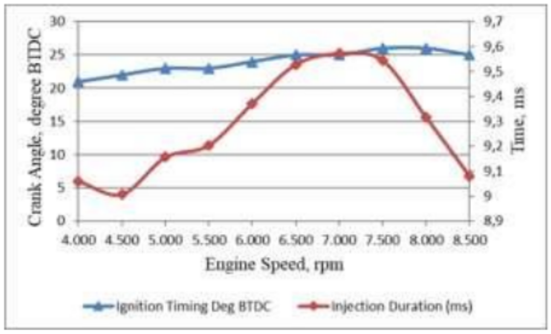
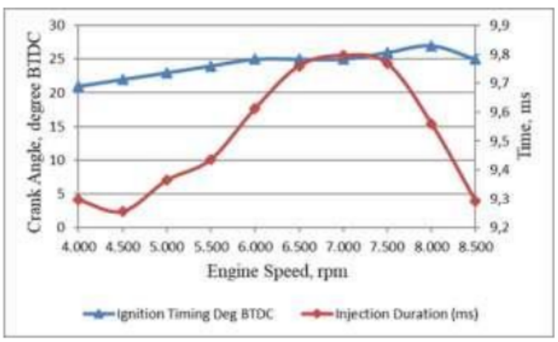
higher laminar flame speed (0.42 m/s) so the speed of flame propagation also increases, and possibly reduces engine knock, except the results of the high-octane value of ethanol. While the injection duration will increase in line with the rise in engine speed, and eventually decrease slowly (fuel cut off), to avoid over-running and maintain the AFR.



(a)



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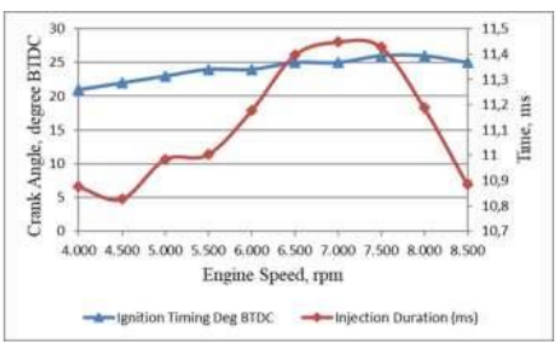

(c)

Figure 6 Ignition Timing Correction at (a) E5, (b) E10, and (c) E15

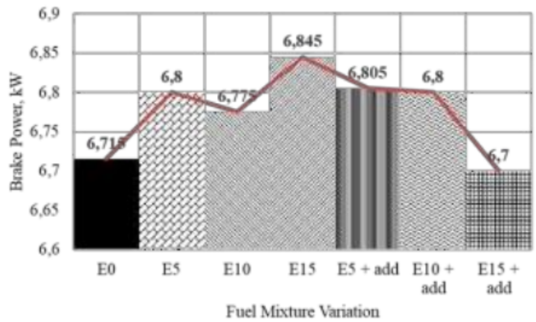

Figure 7 Maximum Power Comparison (uncertainty + 1.09)

The picture above shows that the foremost effective Brake Horse Power (BHP) is produced by E15 with the resulting value of 6.845 kW, a rise of 1.94% from the BHP produced by pure gasoline (E0). Moreover, the smallest BHP is found within the E15 ++ fuel variation, a decrease of 0.27% from pure gasoline. E15 ++ fuel has the very best octane value, this affects the ignition timing, which ends within the engine losing the facility it can produce. Additionally, the addition of additives to the E15 mixture makes the oxygen content increase so that the air and fuel ratio conditions become lean (lean). The beneficial effect of ethanol as a fuel is that its hydrogen bridge formation contains oxygen (34.7% by weight) which allows for more complete combustion. Additionally, the density of ethanol (809.9 kg/m^3) is over gasoline (750.8 kg/m^3), which causes more fuel within the same volume. At last, the heat of its evaporation (725.4 kJ/L) is more than gasoline (223.2 kJ/L), thereby giving the manifold a lower temperature and increasing its volumetric efficiency, which ends in a rise in BHP. At a better engine speed, the combustion that happens faster with the speed of the ignition time, the time available is brief enough to complete the combustion in one cycle, within which case the speed of flame propagation is essential. Ethanol incorporates a higher laminar flame speed (0.42 m/s) so that the speed of flame propagation also increases, and possibly reduces engine knock, except the results of the high-octane value of ethanol.

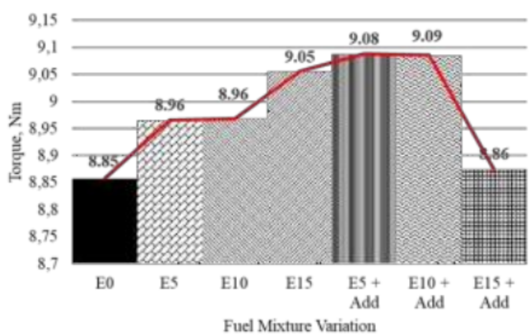

Figure 8 Maximum Torque Ratio (uncertainty + 0.89)

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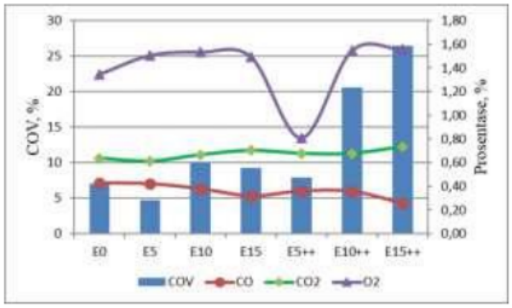
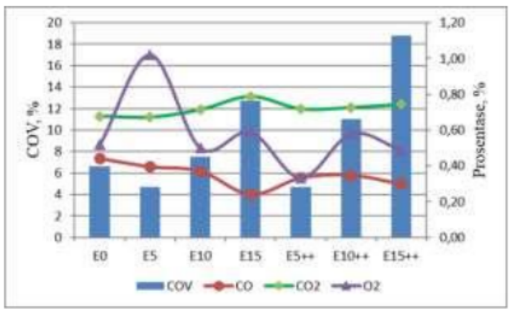


(a)



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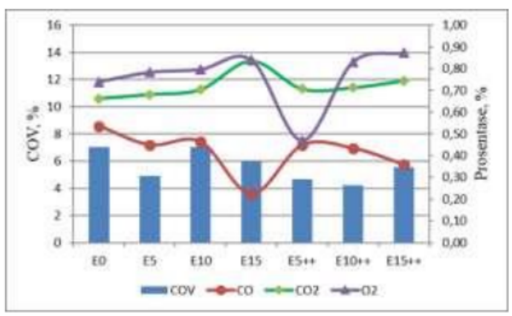

(c)

Figure 7. COV vs. CO, CO2, and O2 in Fuel Mixture Variation
(a) At 4.000 rpm, (b) at 6.000 rpm, and (c) at 8.500 rpm

Figure 8 shows that with the addition of ethanol to the fuel, the torque generated by the engine test also will be higher. In some fuel mixtures with cyclohexane, it can even increase the torque. The foremost optimal fuel mixture in producing torque is within the E10++ (5% vol/vol) fuel mixture. The torque value produced during this optimum mixture is 9.09 Nm. While the bottom torque produced by pure gasoline (E0) is 8.85 Nm, it is seen that the resulting torque increase is 2.7%. However, it was found that when using cyclohexane, together with the addition of ethanol, the most torque decreases. With relation to torque, COV is incredibly influential especially at 8.500 rpm. This is often the case with E10 ++ mixtures with COV at 4.24%. The torque increases significantly compared to other blends. As within the previous explanation, with ethanol which contains a higher octane value compared to

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gasoline, it can make combustion more complete. With the addition of cyclohexane, it is semi-polar, which has the mixture to bind stronger so on make the mixture between gasoline and ethanol more homogeneous.

The image above (Fig. 9) can show the effect of the COV of every fuel mixture on engine speed variations on the CO, CO_2, and O_2 produced. The yield of CO gas with the addition of cyclohexane leads to comparisons with other fuel variations. The addition of cyclohexane to numerous fuels with a percentage of ethanol can reduce the resulting CO gas emissions. The effect of adding ethanol on the emission of additive CO and non-additive CO, this is often a product of incomplete combustion because of insufficient oxygen within the air-fuel mixture or sufficient combustion time in one cycle. The concentration of CO emissions is additionally highly obsessed with engine operating conditions and also the air-fuel ratio. Some CO always appears within the exhaust, even in lean mixtures, but the concentration decreases with decreasing combustion temperature.

4. Conclusions

With shorter tray spacing, compact-distillatory produces lower grade alcohol, but distillation rate is higher. The lower feed volume produced higher-grade alcohol, distillation speed is higher, but thermal efficiency is lower. Based on distillation rate parameter and alcohol grade produced, compact-distillatory with tray spacing 100 mm, volume 800 ml, engine speed 5.400 rpm produces the best work, namely distillation rate 274.3 ml/hr and alcohol grade 88.97%.

A smaller COV will have a positive impact on the engine, namely that the torque fluctuation does not occur so that the engine driveability will be further increased. With the addition of ethanol, lower COV obtained from this study was the E5 mixture at 6.000 rpm, which was 4.70% compared to pure gasoline alone (E0 = 6.61%), there was a decrease of about 29%. The rise in ethanol content had a positive impact on COV, not just for the E5 mixture, E10 and E15 mixtures were also relatively less than the E0 mixture, especially at a better engine speed of 8.500 rpm. This can be because ethanol has an octane value, oxygen contains, heat energy which is beyond gasoline, so it can improve combustion within the cylinder.

COV will be corrected even less when the fuel mixture of gasoline and ethanol is added with oxygenated additives. When mixed with cyclohexane (0.5% vol/vol), lower COV occurs within the E10 ++ mixture at an engine speed of 8.500 rpm, which is 4.24%, there is a decrease of about 36%, and when mixed with cyclohexanol (0.5% vol/vol) all-time low COV also occurred within the E10 ++ mixture, still, at an engine speed of 8.500 rpm, namely 3.42%, there was a decrease of about 48% compared to pure gasoline (E0).

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