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A study of the stabilities, microstructures and fuel characteristics of tri-fuel (diesel-biodiesel-ethanol) using various fuel preparation methods

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Abstract. In this study, the work was carried out to investigate the effects of ethanol proportions on the stabilities and physicochemical characteristics of tri-fuel (Diesel-Biodiesel-Ethanol). For the first time, tri-fuel emulsions and blended were compared side by side. The experiment was done with composition having 5%, 10%, 15%, 20% and 25 % of ethanol with fixed 10% of biodiesel from palm oil origin on a volume basis into diesel. The results indicated that the phase stabilities of the emulsified fuels were higher compared to the blended fuels. In addition, tri-fuel composition with higher proportion of ethanol were found unstable with high tendency to form layer separation. It was found that tri-fuel emulsion with 5% ethanol content (D85B10E5) was of the best in stability with little separation. Furthermore, tri-fuel with lowest ethanol proportion indicated convincing physicochemical characteristics compared to others. Physicochemical characteristics of tri-fuel blending yield almost similar results to tri-fuel emulsion but degrading as more proportion ethanol content added. Emulsion category had cloudy look but on temporarily basis. Under the microscope, tri-fuel emulsion and blending droplet were similar for its active moving about micro-bubble but distinct in term of detection of collision, average disperse micro-bubble size, the spread and organization of the microstructure.

1. Introduction

Owing to their excellent drivability and fuel economy, diesel engine has been utilized in most of the sector including transportation and agricultural industry [1]. Meanwhile, the level of air pollution and greenhouse gases emission are now a wide concern. Indirectly, diesel engine contributed via incomplete combustion that release polluted hazardous gases, including carbon monoxide (CO), carbon dioxide (CO₂), nitrogen dioxide (NO₂), unburned hydrocarbon (HC) and particulate matter (PM). In the same way, this is a serious risk to the environment and could affect human health eventually. Thus, the research and development of alternative fuels for transportation are preferable niche area [2]. In addition, studies on the applicability of clean energy technologies continue to receive attention [3]. Mixing biodiesel, alcohol and diesel are one of the latest attempt as part of renewable alternative energy sources solution with environmentally friendly characteristics in contrast to fossil fuels [2, 4]. Tri-fuel new lineup includes the possibility of secondary atomization attribute capability [5]. The work has started but is at preliminary stage. Good news is that biodiesel and ethanol are under oxygenated fuel categories and many believe that oxygenated fuel into diesel could improve the combustion efficiency [6-8]. Also, the interest in tri-fuel category is mainly driven by the potential



reduction of exhausted CI engine gas emission namely carbon monoxides, hydrocarbon and particulate matter [9]. Besides, air-fuel mixture formation could be improved by the influence mechanism of ethanol [10]. And the best part is, no minor or major engine modification needed [11].

Unfortunately, the solubility of diesel with ethanol would be the problem considering ethanol immiscibility nature and water content [1, 12]. It was reported that ethanol is not completely miscible in the composition and only with 5% of ethanol demonstrate complete miscibility in diesel [11]. Fortunately, biodiesel could be the solution to the phase separation problem of diesel-ethanol [13]. Beside economically viable [14], biodiesel could increase the solubility of ethanol in diesel [15]. Compatibly and suggested in the literature, phase separation of diesel-ethanol could be prevented by emulsifier [16]. It was not until recently, Hagos et al. [15] initiated the concern towards the distinction between tri-fuel emulsions and blending in the review article last year. In other word, to date, little research has been done to compare tri-fuel under blending and emulsions category side by side. For commercialization, it is imperative to ensure the fuel stability to be consistent. The fuel sit in a tank for extended period is likely give chance for the gravity to do the work. Destabilization of the fuel during operation or storage may cause engine failure [17]. Few minutes operation of variable fuels due to the phase separation in the engine could do the damage and may trigger costly engine repair. In addition, stability study is necessary to determine if additional mixing or additive is required besides the main component in the composition [18]. Bottom line, understanding the physicochemical properties of tri-fuel is essential as basis to rationalize the formulation potential. The propensity to downgrade the properties with time due to phase separation is not something to be taken for granted. Potential degradation may appear as the alteration of cetane number, viscosity and density. As an example, consequently, density degradation alone with the effect on the injection timing could promote engine deficiency and unwanted emission [18].

The main objective of this work was to evaluate diesel-biodiesel-ethanol as tri-fuel and compared blended against emulsions category with biodiesel constant volume percentage from the stability and physicochemical characteristics viewpoint. Concurrently, microstructures of both tri-fuel categories were immediately observed upon prepared and compared.

2. Design of experiment

Diesel, biodiesel and ethanol were the main ingredient to form tri-fuel composition. The study was carried out in three stages. Firstly, to acknowledge the effect of ethanol on the stability and physicochemical characteristics of tri-fuel blended. Next, the effect of ethanol on the stability and physicochemical characteristics on tri-fuel emulsions type. Finally, under the microscope, the comparison between the two-mixing strategy; droplet of blended versus emulsions were outlined and discussed.

3. Preparation of tri-fuel blends and emulsions

Diesel, ethanol and biodiesel from palm oil origin were obtained from nearby convenient supplier. Tri-fuel emulsions were compounded using Hielscher Ultrasonic Processor UP400S Emulsifier with 0.7% cycle and 40% amplitude maintaining the temperature between 30°C to 40°C for 5 minutes. Approximately 100 ml on a beaker per samples were prepared. Temperature was monitored throughout the exercise with infrared thermometer. For blending, magnetic stirring has been used for 30 minutes. Again, the temperature was monitored consistently the entire time. The use of magnetic stirrer meant no physical contact of the sample with the blade. Stirring hotplate brand FAVORITE with variable control on temperature and magnetic stirrer speed was the selected apparatus to do the job. The increase temperature can be controlled from 90°C to 525°C. The embedded heating mechanism were switched off in this case. The intensity level of magnetic stirring can be adjusted from 1 to 9. For the experiment, the level 5 speed was utilized. According to the model specification, maximum speed of the stirrer could reach up to 1000 rpm. For the sake of argument, it is fair to approximate level 5 speed stirring speed to represent range of output between 500 to 600 rpm. For blended tri-fuels, regardless of percentage ethanol content, it was found that the temperature of the composition remains under room temperature the entire time. Ethanol content were varied from 5%, 10% ,15%, 20% and 25% with biodiesel remain 10%. The experiments began with the preparation of

the composition. The volume of each fuel was measured and mixed according to the decided proportion. 10 samples of tri-fuel were tested for the stability and fuel characteristics. The proportions were varied as shown in Table 1.

Table 1. Proportion of fuel for each of the sample

Sample	Diesel (%)	Biodiesel (%)	Ethanol (%)	Purpose
1	85	10	5	Blending
2	80	10	10	Blending
3	75	10	15	Blending
4	70	10	20	Blending
5	65	10	25	Blending
6	85	10	5	Emulsification
7	80	10	10	Emulsification
8	75	10	15	Emulsification
9	70	10	20	Emulsification
10	65	10	25	Emulsification

The stability behavior tests were conducted at room temperature for approximately one month. All the data on the stability behavior was done by visual inspection of the blends physical appearance every day for 35 days. Subsequently, there were four types of testing conducted mainly density, calorific value, viscosity and flash point for each of the tri-fuel emulsions following diesel standard test. Besides that, the microstructure of the tri-fuels was also observed to differentiate between blended and emulsion categories.

4. Experimental procedure

4.1. Stability behavior

The stability test method in this experiment is widely known as gravitational stability [17, 19]. The stability of the fuels was observed for 1 month under room temperature. The blended fuels and emulsified fuels are being filled into 10 test tubes respectively as shown in Figure 1. The sample can be differentiated by comparing the layer of separation during the stability process. Photos were taken every 2 hours on the first day. For the following 7 days, the photos were set to be taken once a day. Subsequently, the photos were taken continuously each week for 4 weeks.

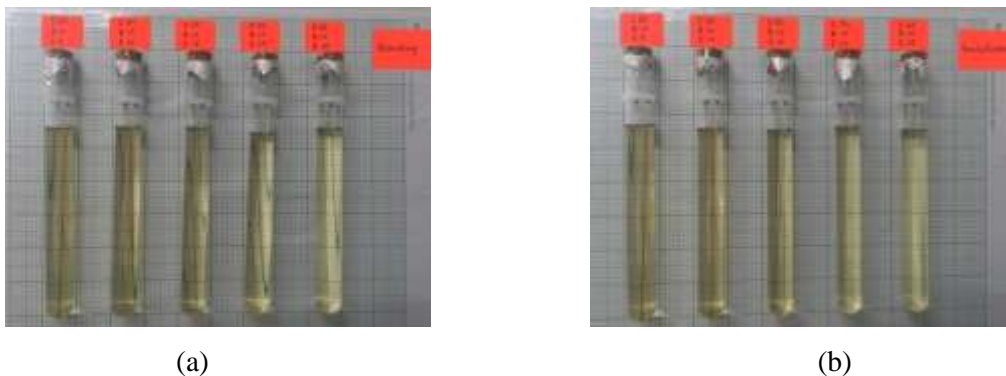


Figure 1. The samples which are undergo blending process (a) and emulsification process (b).

4.2. Microstructure

Digital microscope brand Dolomite Calestron was used to observe the microstructure of the samples. Microstructure of the tri-fuel blends and emulsion fuels were observed to differentiate between blended fuels and emulsified fuels. Immediate inspections (within the same day of the fuel preparation) were done to spot the significant different between blending and emulsions. Each of the tri-fuels were taken 3 times for convincing result. 40x objective lens was used and the total magnification of the images was up to 400x. On top of that, all the images were additionally analyzed using image processing software called Image J (automatic particle sizing).

4.3. Physicochemical properties – density, calorific value, viscosity and flash point

The density reading was not obtained directly from hydrometer instrumentation but was calculated from separated volume and mass measurement. The density was obtained applying weight measurement technique. Weight measurements machine was required to measure the weights of the fuels and calibrated beforehand. The volumes of the fuels were measured by using a 10 ml syringe. To be specific, 10 ml of fuel is taken by using a syringe. Then, every 2 ml of fuel is weighted and the weight is recorded. The experiment was conducted at room temperature and repeated for three times. An average reading was taken before the densities of tri-fuel blended and tri-fuel emulsified were calculated with the equations below:

$$\rho = \frac{m}{V} \quad (1)$$

where m = mass of the sample
 V = volume of the sample
 ρ = density

Research indicate that comparable calorific value of blending fuel to diesel meant almost similar thermodynamic parameters for engine can be expected [5]. The calorific value of the tri-fuels was measured with Bomb Calorimeter and Model 6772 Calorimetric Thermometer in accordance to diesel international standard procedure ASTM-D240. The dynamic viscosity was measured using Brookfield Viscometer Model DV-III ULTRA Programmable Rheometer. The reading should be accepted within the equivalent percentage of torque, ranging between 10% to 100% for any combination of spindle rotation. Kinematic viscosity was calculated by the equations below:

$$\nu = \frac{\mu}{\rho} \quad (2)$$

where ν = kinematic viscosity
 ρ = density
 μ = dynamic viscosity

The measurement was in accordance to diesel international standard procedure ASTM-D7042. Tri-fuel flashpoint was evaluated using Koehler model K16591, rapid flash point tester. Flash point is widely known as the lowest temperature of the fuel when it starts to burn or ignite. Slightly differ than autoignition reading as flash point is the lowest temperature to ignite without the influence of ignition source. In this experiment, there were five samples which contain different ethanol proportion tested. The measurement was in accordance to diesel international standard procedure ASTM D93.

5. Results and discussion

5.1. Stability behaviour

The stabilities of all the samples were observed for more than a month at room temperature. Center of attention was on any detected separation layer in centimeter with observation conducted every 2 hours on the first day. Subsequently, once a day till day seven. Onward, observation was taken every once a week till the fifth week. In term of appearance, under tri-fuel emulsions categories, it was prominently translucent but that was only last for a short while. The cloudy looking was noticeable only applied to emulsions category and not on blending type. Best bet the cause of this could be because the intensive disruption effect of ultrasonic emulsifier to the composition. As for blending mixtures, it appeared transparent all along from the beginning. Overall, all categories presented itself with clear look eventually. Table 2 shows the separated layer of tri-fuel blend and emulsion for 35 days via visual observation. The blended fuels were observed more profound to encounter phase separation compared to emulsified fuels. From Figure 2, D65B10E25 with the highest ethanol content, separated layer of blended fuel was observed higher than the emulsified category. Whereas in Figure 3, the emulsified fuel which contained the lowest ethanol content (D85B10E5) was found to be the best in stability with no separated layer detected.

Table 2. Separated layer of tri-fuel blend and emulsion within one month.

Duration	Separated layer (cm)									
	Blended fuels					Emulsified fuels				
	D85	D80	D75	D70	D65	D85	D80	D75	D70	D65
	B10	B10	B10	B10	B10	B10	B10	B10	B10	B10
	E5	E10	E15	E20	E25	E5	E10	E15	E20	E25
2 hours	0	0	0	0	0	0	0	0	0	0
4 hours	0	0	0	0	0	0	0	0	0	0
6 hours	0	0	0	0	0.3	0	0	0	0	0.2
8 hours	0	0	0	0	0.3	0	0	0	0	0.2
10 hours	0	0	0	0	0.4	0	0	0	0	0.2
12 hours	0	0	0	0	0.4	0	0	0	0	0.2
2 days	0	0	0	0	0.5	0	0	0	0.4	0.4
3 days	0	0	0	0	0.5	0	0	0	0.4	0.4
4 days	0	0	0	0	0.6	0	0	0	0.4	0.5
5 days	0	0	0	0	0.7	0	0	0	0.4	0.5
6 days	0	0	0	0	0.7	0	0	0.2	0.5	0.6
7 days	0	0	0	0.2	0.8	0	0	0.2	0.6	0.7
14 days	0	0	0.2	0.4	0.8	0	0.2	0.3	0.6	0.8
21 days	0	0.2	0.4	0.5	1	0	0.2	0.3	0.7	0.8
28days	0.1	0.3	0.4	0.6	1.1	0	0.2	0.3	0.7	0.8
35 days	0.2	0.4	0.5	0.7	1.2	0	0.2	0.3	0.7	0.8

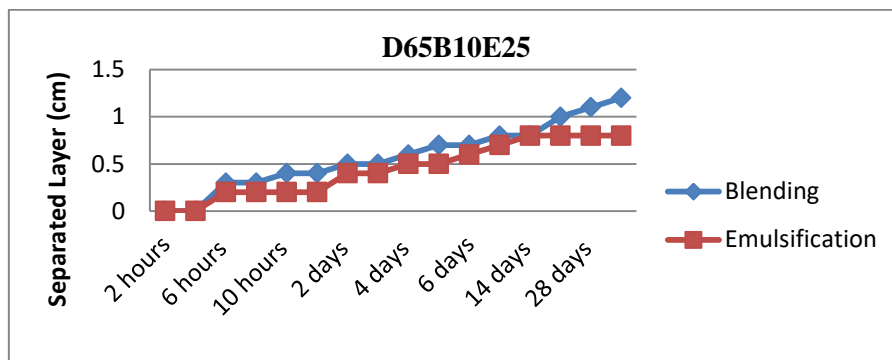


Figure 2. Comparison of tri-fuel (D65B10E25) blend and emulsion.

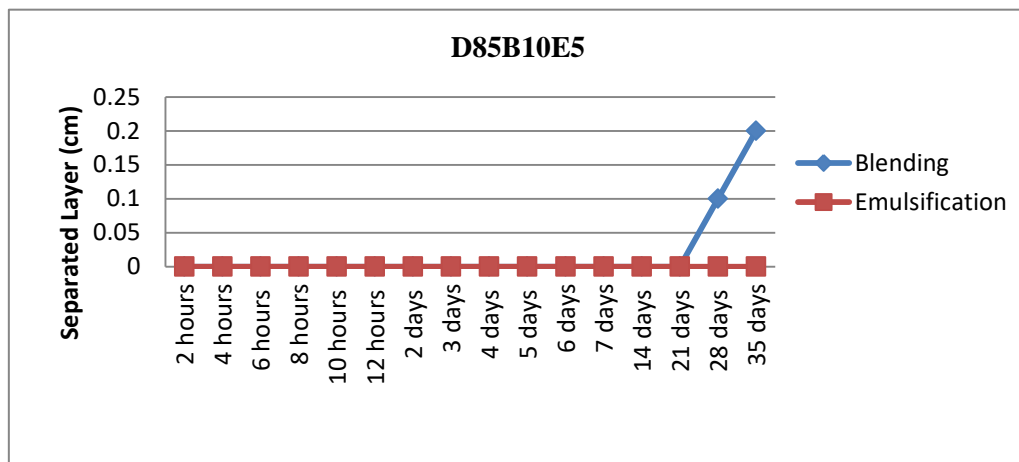


Figure 3. Comparison of tri-fuel (D85B10E5) blend and emulsion.

The effect of ethanol proportion on phase stability for tri-fuel blends and emulsions were studied at room temperature. Figure 4 and 5 depicted the effect of ethanol proportion on the stability of tri-fuel blends and emulsions. More ethanol content in the composition depicted faster phase separation. Nevertheless, notice that, ethanol content with the exact same proportion or more than biodiesel had cause phase separation. Tri-fuel emulsions with 2:1 ratio between biodiesel and ethanol was found effective with none phase separation detected for more than a month. As for the blending, phase separation on day 21, likely the interpretation was that during mixing process, the addition of biodiesel did not really perform its trade in the mixture. It was understood in the theory that the miscibility was possible reflecting biodiesel acted as an amphiphile (surface active agent) which contained nonpolar tails and polar heads [20]. The basis was that, the polar head in a biodiesel molecule oriented itself to the ethanol and the nonpolar tail oriented to the diesel [3]. Thus, figure 4 and 5 are tide back to the previous study reigniting the debate on whether can biodiesel really act as surfactant or just a source for string of setback. However, the skepticism on the basic entitlement that biodiesel did not act as surfactant was not however relevant in this case. It was important to acknowledge under D85B10E5 both blended and emulsions category, biodiesel was seen did contributed to the delay of phase separation and to one extend preventing the phase but not at all cost. The trend revealed that constant volume of biodiesel into each of the composition as per the experiment design could not keep up with the increment of higher ethanol content. Thus, argument on constant volume of biodiesel with weak miscible propensity tolerance in the tri-fuel mixture cannot stands in one row with the previous dispute by Kwanchareon et al. [1] on biodiesel inability to accommodate solubility.

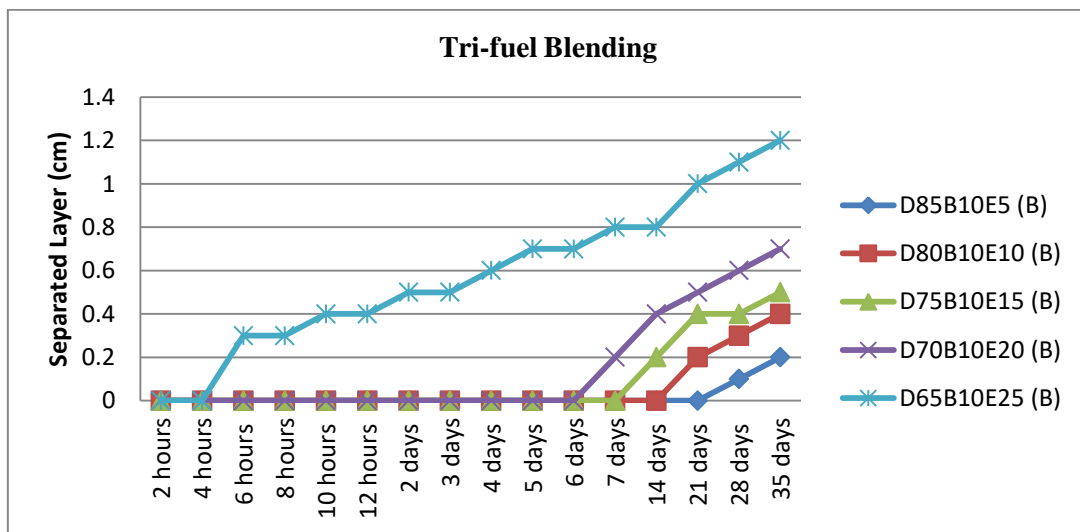


Figure 4. The effect of ethanol proportion on the stability in tri-fuel blend.

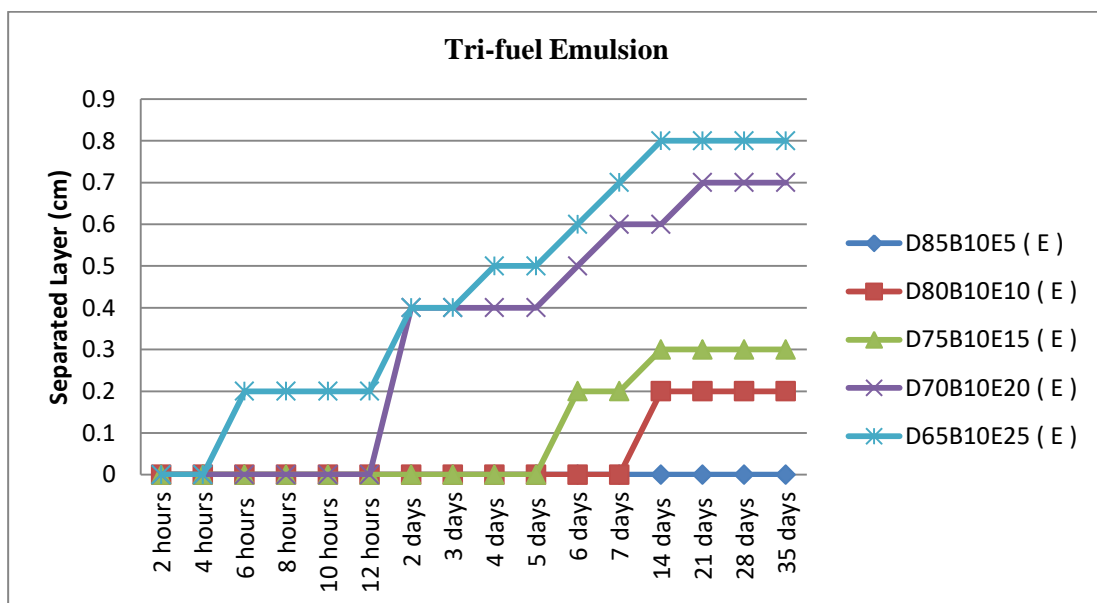


Figure 5. The effect of ethanol proportion on the stability in tri-fuel emulsion.

Furthermore, something in common between the two figures and quite noticeable was that the pattern indicated the delay of the separation phase per different mixing strategy. What it suggests was that, underestimating mixing procedure and the assumption that improper mixing strategy carry no weight has been significantly proven wrong here. Unexpectedly, half an hour blending approach beat 5 minutes emulsification technique. 5 days variant on D70B10E20 between blending and emulsification approach remark the substantial distinction upon the cost for miscibility. The reversing news was unprecedented but recall back on the mentioned momentarily translucent look upon 5 minutes emulsification process, the bafflement was somehow cured and self-explained. The temporarily cloudy phenomenon on the composition noticed under emulsification category deserved to be given a second look seriously in the future to get better understanding. One idea is to increase emulsification time or perhaps be more creative in seeking for better results. After all, the quick 5 minutes emulsification time was proven inadequate to substantiate desire outcome. Hence, another suggestion would be to try on a mix mood approach. The rational to the urge on being creative to get the solution is based on the

revealed stability period of the blended category yield better than emulsions plus the desire microstructure characteristics that will be explained in the next section. Anyhow, as expected, both mixing categories with the highest ethanol contain were the most unstable composition and easily prone to separate. The highest separated layer could be seen on the sample with the highest percentage of ethanol (D65B10E25). Meanwhile, the lowest separated layer could be seen on the sample with the lowest percentage of ethanol (D85B10E5). When the ethanol contents increased in the tri-fuel blends and emulsions, the instability were seen more noticeable and formed separated layer in a brief period. Although the scenario was a sign of failure, lesson to be learned here is the basic to be grabbed.

5.2. Microstructure

The microscopic images of tri-fuels were used to be further analyzed by using software called Image J as shown in Figure 6. The particle size of the blended fuels and emulsified fuels are depicted in Table 3.

Table 3. The particle size of the blended fuels and emulsified fuels.

Slice	Count	Total area (μm^2)	Ave size (μm)	Area (%)	Mean grey value
D75B10E15 (B)	1183	1045041	883.382	21.261	255
D75B10E15 (E)	5751	802083	139.468	16.318	255
D80B10E10 (B)	1608	968467	602.28	19.704	255
D80B10E10 (E)	6455	716168	110.948	14.57	255
D85B10E5 (B)	2114	941134	445.191	19.147	255
D85B10E5 (E)	8863	588155	66.361	11.966	255

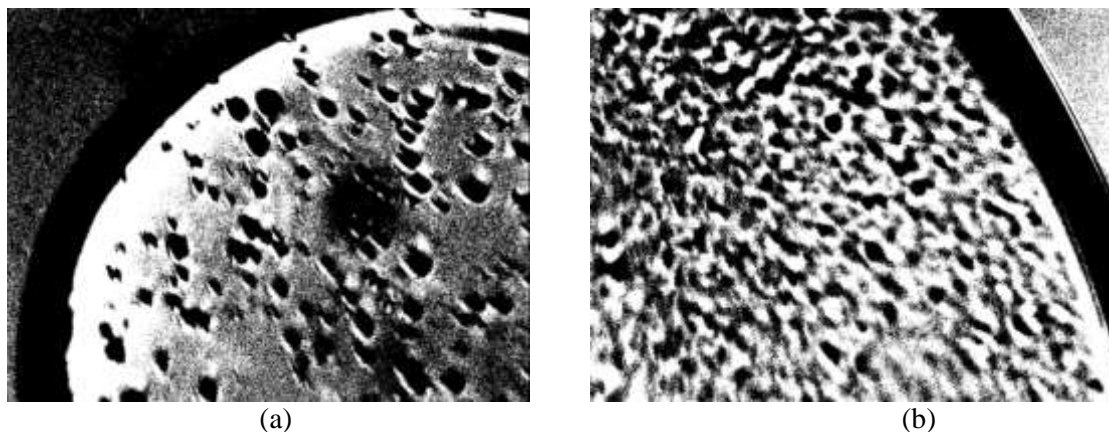


Figure 6. Microscopic image of (D75B10E15) tri-fuel blend (a) and emulsion (b).

Under the microscope, the significant difference between the two mixing categories were apparent. Emulsions spreading micro bubble dispersant were found incontestable compared to blending category. 30 minutes stirring period, as suspected, tri-fuel blending category appeared with non-uniform size micro-bubble. Furthermore, there were many active micro-bubbles detected in the tri-fuel emulsion droplet. The blended fuels show higher average particle size than the emulsified fuels. In addition, it was observed that the micro-bubbles were constantly moving and active. Somehow the movement was more synchronized compared to blending category. The question rises quickly whether this was due to the mixing strategy or due to other circumstances such as unconscious normal handling quivering, surrounding wind interaction or liquid density energy. Again, it not a bad idea to explore the reason behind this behavior in the future.

It was convincingly demonstrated that effective meant of dispersing through emulsification approach were needed to obtain evenly distributed micro size bubble in the droplet as in Figure 7 and

not on figure 8. It was also observed that tri-fuel emulsions appeared with particle size smaller than the blended fuels. Agglomeration behavior detected in blending category could be the root cause of this. From Figure 9, the agglomeration, attraction and interaction between the active micro bubble in the droplet was detected microscopically. As mentioned earlier, random movement of the micro-bubble under the tri-fuel emulsion droplet were more organized and so non-collide or sticking into one another was detected as found in the blending droplet. Whether this was due to the effectiveness of emulsification or not remain unanswered. The undesired collision was observed on blending category but not on tri-fuel emulsions as shown in Figure 10. When this distinction came, it is important to go back checking on the quality of the composition mixing procedure seriously before conducting any engine test in the future. Last, but not least, it is worth point taking that blending category demonstrate ineffective dispersing via just magnetic stirring mechanism.



Figure 7. D65B10E25 emulsion category.

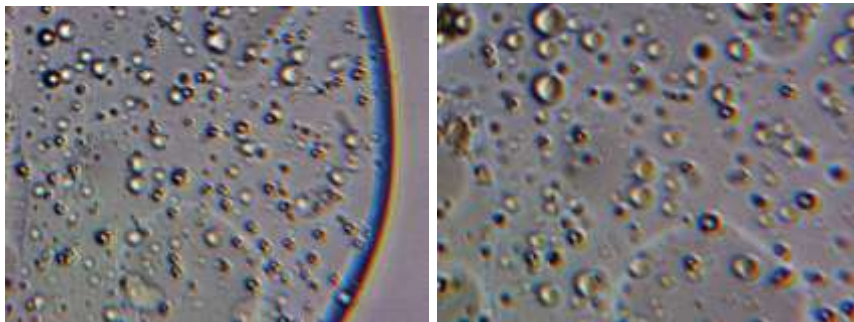


Figure 8: D80B10E10 blending category.

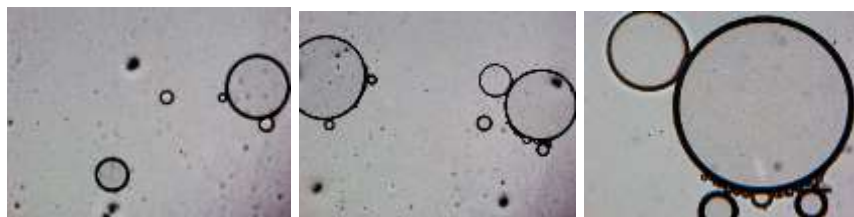


Figure 9. D75B10E15 blending category with bridging interaction between particle.



Figure 10. D75B10E15 emulsion category with no interaction between particle

As mentioned in the previous section, it is reasonable to pause and discuss what not many recognize, the merit of droplet with uniform, active and eventually disburst of micro-bubble. What embedded inside the narrative appearance of the microscopic image may or may not signal the contribution of the composition to the combustion behavior. But it is wise to acknowledge the droplet microstructure as a tool to unlock, connect and compensate the limited knowledge on tri-fuel secondary atomization attribute with microstructure identity of each of tri-fuel composition setting. Adapting knowledge from the study of micro-explosion phenomenon on water in diesel, the eventually distributed disperser of the liquid in micro-scale would be a desired appearance that should tip the scales in favor of the tri-fuel study relative to secondary atomization as subject matter. No research so far testified that the quality of tri-fuel mixing prepared in favor or otherwise to the micro-explosion phenomenon theory. The reason this is important to note is that through this, the appreciation on the signature of secondary atomization can be appreciated and the phenomenon can be predicted based on the identity of the droplet microstructure uniqueness. It is not enough to assume or just swallow that now. The idea is to take this argument seriously as the essence to explore the composition and proceed with further discovery. Moreover, this sentiment was not just synthesized from the outcome of the experiment but also extracted and integrated from previous work related to puffing and micro-explosion phenomenon study of tri-fuel.

5.3. Physicochemical properties

5.3.1. Density

Table 4 shows the density of tri-fuel blend and emulsion at different ratios of diesel, biodiesel and ethanol. Plotted on graph, Figure 11 depicted the variation of density reading for all categories. It can be observed that the density of the blended fuels and emulsified fuels decreased with an increasing of the percentage of ethanol content. Density reading of blended fuels were found almost like emulsified fuels in view of both had the same proportion. Perhaps, mixing strategy has no significant influence on the density of the composition. Measured separately as individual component, biodiesel showed the highest density reading followed by diesel. Ethanol has lower density and as such lowered the density of the mixture. Tri-fuel which contained 5% of ethanol content (D85B10E5) showed highest density value while tri-fuel which contained 25% of ethanol content (D65B10E25) showed the lowest density value. Biodiesel clearly compensated the drop trend caused by ethanol. Comparing the density drop trend of all proportion and category to diesel as the base guideline, 20% ethanol in the composition can be considered too much with unacceptable density reading. Nonetheless, it is worth to note that higher density reading means higher energy content could be expected.

Table 4. Density of tri-fuel blend and emulsion.

Sample fuel	Density (g/ml)	
	Blending	Emulsification
D85B10E5	0.8505	0.8347
D80B10E10	0.838	0.8273
D75B10E15	0.8298	0.8153
D70B10E20	0.7859	0.7995
D65B10E25	0.7753	0.7854

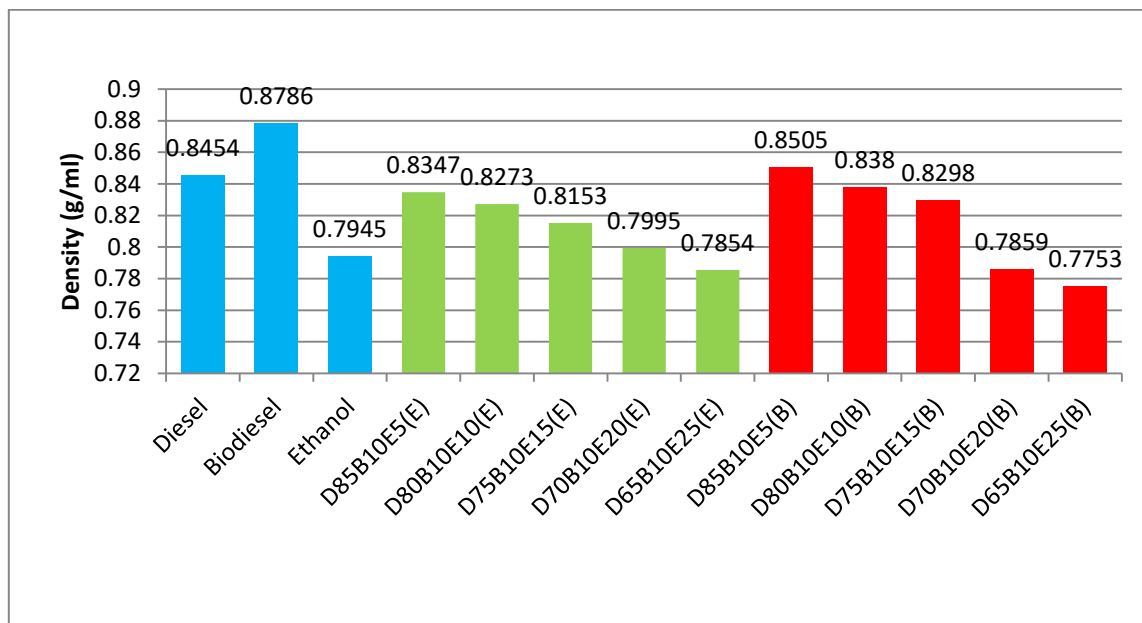


Figure 11. The variation of density of tri-fuel blends and emulsions.

5.3.2. Calorific value

Table 5 shows the calorific value of tri-fuel blends and emulsions at different ratios of diesel, ethanol but constant biodiesel proportion. Plotted on graph as shown in Figure 12, the calorific value of the blended fuels and emulsified fuels decreased with an increasing of the percentage of ethanol content. Side by side plotted on graph, all the calorific values of the blended fuels were found almost indistinguishable to the emulsified fuels considering both had the same proportion of tri-fuel. The variation however was not significant and small. In other word, emulsification or blending, mixing strategy did not tailored the calorific value as seen on the density reading. On the other hand, the calorific value of the mixture reduced with the increasing of ethanol content. This is seemingly familiar case in bi-fuel study with biodiesel into diesel. As more biodiesel into diesel resultant in reduction of calorific value [21]. The tri-fuel which contained highest percentage of ethanol (D65B10E25) had the lowest calorific value. Because fundamentally, lower calorific value means lower heat of combustion, subsequently, lower heating value of the tri-fuel may affect the power output of the engine. The highest calorific value could be seen at the tri-fuel blend which contained 5% of ethanol (D85B10E5) and it was almost the same as the calorific value of pure diesel. Thus, it makes sense to include oxygenation fuel with the purpose of obtaining better combustion via realizing more oxygen is added. Nevertheless, to gamble by adding too much, the impact will be on deterioration of calorific value which in turn could also disturb the combustion efficiency. It is therefore advisable to stay right in between the two extreme values. The argument on calorific value decrement pattern versus increasing trend of oxygenated content due to ethanol and biodiesel in tri-fuel however have not much received attention in the literature. To sum up, it is crucial to recognize the balance in between the conflicting decision that one must go through when dealing with tri-fuel because of these two key physicochemical properties.

Table 5. Calorific value of tri-fuel blend and emulsion.

Sample fuel	Calorific value (MJ/kg)	
	Blending	Emulsification
D85B10E5	48.1567	47.7769
D80B10E10	45.901	45.7008
D75B10E15	44.7689	44.4648
D70B10E20	41.9735	42.6654

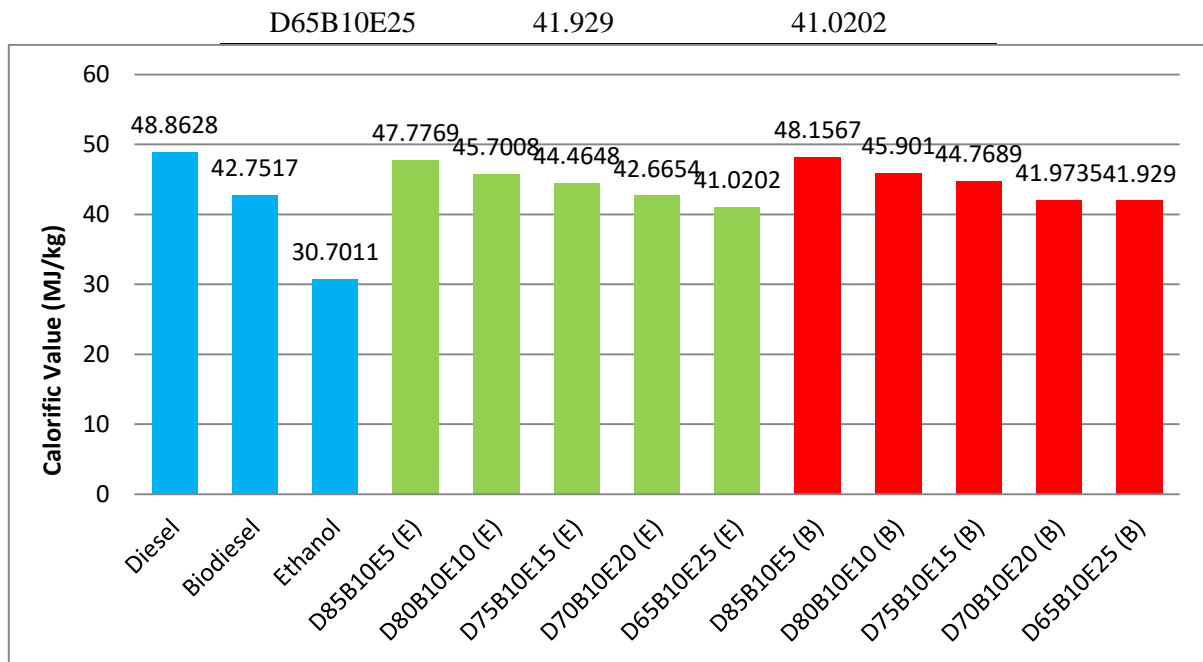


Figure 12. The variation of calorific value of tri-fuel blends and emulsions.

5.3.3. Kinematic viscosity

Figure 13 illustrates the kinematic viscosities of the blended fuels were almost on the same track as emulsified fuels perhaps because both had the identical component proportion. Again, it was safe to say that mixing strategy has no significant impact on the kinematic viscosity of the composition. However, it is widely accepted that the increase in temperature affected the molecular structure of the tri-fuel. Theoretically, as the temperature increased, the molecules started to get excited. Because of the overwhelm inner molecules gross motion, bond of the molecules got loosen. Hence, the tri-fuel decrease its viscosity. Figure 14 and 15 show the effect of ethanol proportions on kinematic viscosities in tri-fuel at various temperatures. Overall, the kinematic viscosities of the tri-fuel decreased with the increase of the ethanol contents. Nonetheless, the kinematic viscosities reading obtained can be considered compatible with diesel grade No 2-D with normal range between 1.9 to 4.1. It is reasonable to discuss the constraint subject to closer to the peak and closer to the lower level of acceptable viscosity. Too high viscosity would cause high pumping load requirement. In addition, the limitation will be on flow characteristics of the fuel in the nozzle and spray. Furthermore, micro-explosion attribute is almost impossible with high viscosity fuel. On the other hand, tendency towards too low viscosity level would be the dilution. Possible leaking into the cylindrical wall of combustion chamber and lubrication issue are the two-main problem.

Table 6. Kinematic viscosity of tri-fuel blend and emulsion at various temperatures.

Sample fuel	Kinematic viscosity					
	30°C (Cst)		40°C (Cst)		50°C (Cst)	
	Blending	Emulsification	Blending	Emulsification	Blending	Emulsification
D85B10E5	4.3483	4.4306	3.4973	3.5635	2.8189	2.8723
D80B10E10	4.0286	4.0807	3.2648	3.307	2.4953	2.5276
D75B10E15	3.6678	3.733	3.0998	3.155	2.4346	2.4779
D70B10E20	3.6773	3.6148	3.0883	3.0358	2.4673	2.4254
D65B10E25	3.5363	3.4908	2.9287	2.891	2.2844	2.255

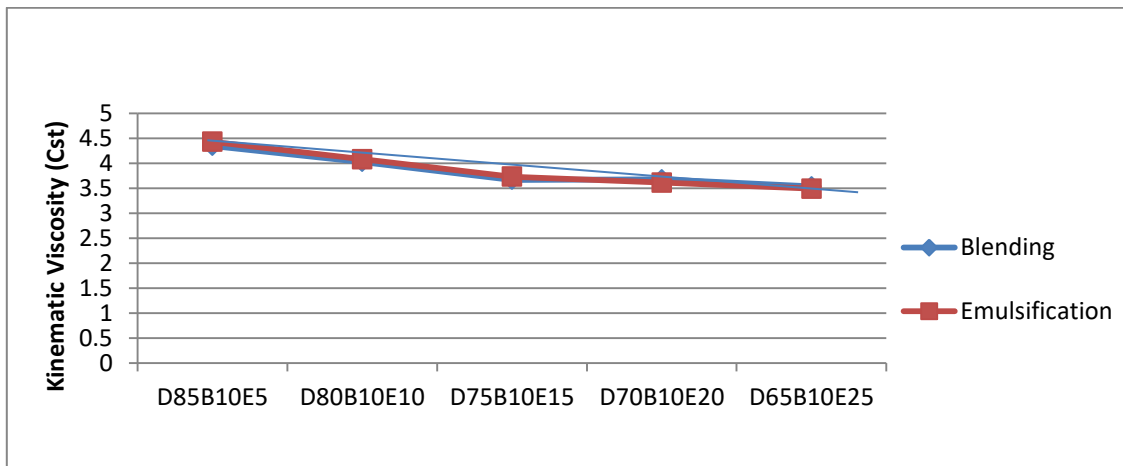


Figure 13. The variation of kinematic viscosity of tri-fuel blend and emulsion at 30°C.

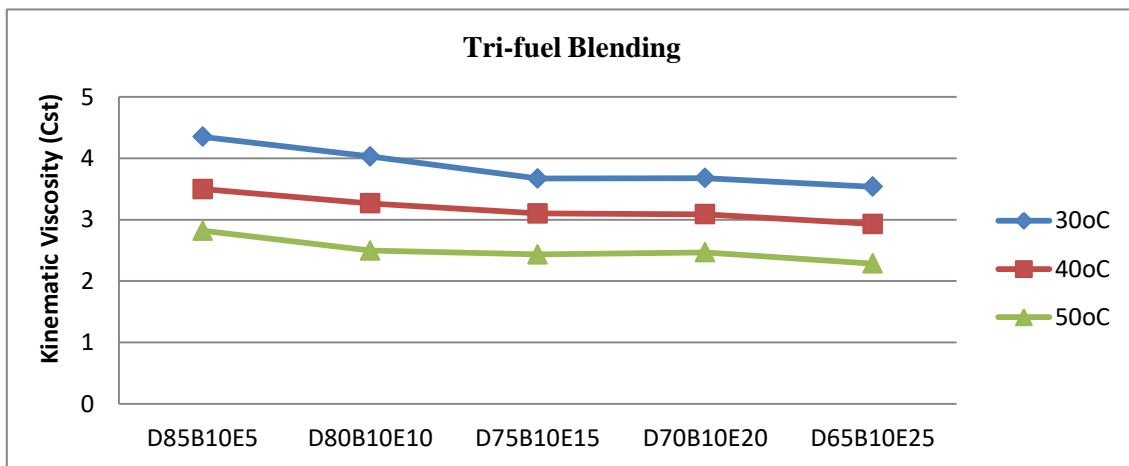


Figure 14. The effect of ethanol proportion on kinematic viscosity in tri-fuel blend at various temperatures.

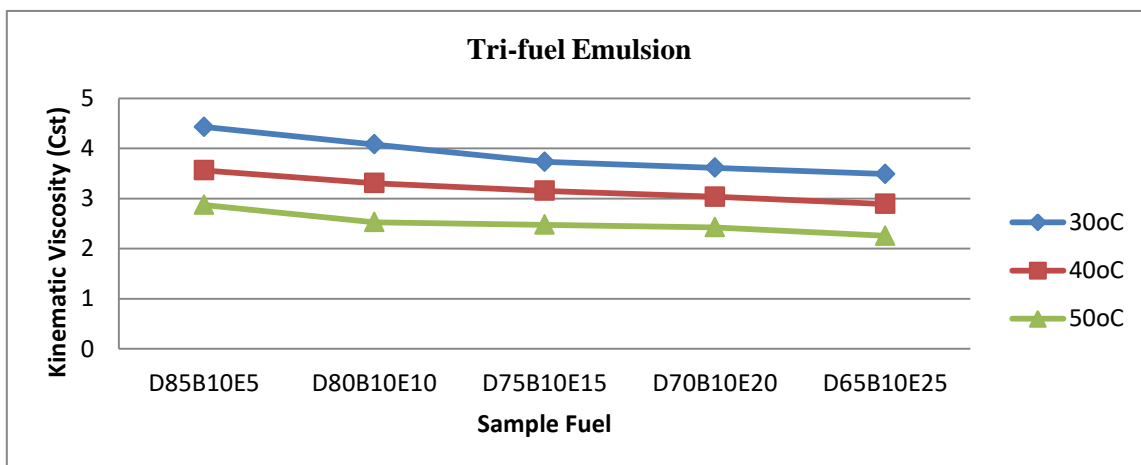


Figure 15. The effect of ethanol proportion on kinematic viscosity in tri-fuel emulsion at various temperatures.

5.3.4. Flash Point of tri-fuel Blends and emulsions

The concern on flash point limit is the handling and safety issue. Because the composition involved three different type of fuels, flash point reading presented in range is not a surprise. Dynamic behavior of the flash point is seen relatively closer to each other, approximately 5°C. Not to be confused with the temperature of autoignition, similar or higher reading of flash point from conventional diesel is desirable. The ethanol contents in the mixtures affected the flash points of the mixtures. Table 7 shows that the flash points of the tri-fuels gradual decreased with the increase of ethanol proportions. Tri-fuel blends and emulsions, both category had the same values of flash points. In other word, no impact of blending or emulsion, either way, the study confirms the flash point reading was identical. Instead, the impact is coming from the type and level of content of the composition. From the previous study, tri-fuel which contained higher flash point were relatively safe for transportation and distribution in current fuel systems [22]. Eyes on the acceptable limit of at least 60oC or above, D70B10E20 and D65B10E25 can be regarded as highly flammable composition for both category and should be avoided.

Table 7. Flash point of tri-fuel blend and emulsion.

Sample fuel	Flash point (°C)
D85B10E5	110°C – 115°C
D80B10E10	85°C – 90°C
D75B10E15	65°C – 70°C
D70B10E20	50°C – 55°C
D65B10E25	45°C – 50°C

6. Conclusions and recommendations

Comparative study of tri-fuel between blending strategy and emulsions under one roof had never been done before. The pattern on period taken for phase separation between different proportion likely been driven by way the compositions were prepared beforehand. Temporarily translucent alike detected on tri-fuel emulsions category should have been given the fair attention. Calorific value and density decline trend as more ethanol content was a complementary outcome. In the sense that degradation in-term of calorific value because of ethanol content could be complemented by the decreasing trend of density. This was so because as a result of density decrease, wider spread of fuel spray in combustion chamber and better atomization behavior could be expected. The emulsified fuel with lower ethanol content was the most stable and had better fuel characterization compared to others. Thus, the emulsion of 85% diesel, 10% biodiesel and 5% ethanol were suggested to be the optimum choice as an alternative fuel. Tri-fuel emulsions and blending had support from science, but the level of acceptance on the stability with time remain a questionable drawback. More experiment needs to be conducted with diverse ways of preparing the emulsions and blending. Perhaps, additive could be included in the future direction on tri-fuel blending or emulsions comparative study. Nonetheless, it was established that, blending or emulsification could not directly tailor the reading of density, flashpoint, viscosity or calorific value but different proportion could. What's clear was that, different mixing strategy could influence the stability against time and phase separation could potentially promote variable reading of physicochemical properties. Tri-fuel emulsification identity was on the more uniform dispersed micro-bubbled compared to blending. On the other hand, non-uniform in size, collision and interaction between micro-bubble were the signature of blending category under the microscope. Both categories with active consistent interrupted behavior. It is believed that the motion is essential in delaying the phase separation and encourage miscibility. To maintain the desire disruption influence, in the storage it is wiser to consider stabilizer mechanism by maintaining mild stirring force in the storage tank. Perhaps, In the future, to sustain evenly distributed droplet size, further study to explore the potential of stabilizer additive on top of biodiesel into tri-fuel should be proposed. The bottom line is that, the microstructure study may give an insight for future researchers to address the lack of continuity found

between the study of tri-fuel with different category, micro-explosion phenomenon and engine combustion outcome. This study is only small portion of the equation and more needs to be done. Perhaps, next, surface tension study could be done with the same comparison proportion and mixing approach. Finally, another future work recommendation would be to compare tri-fuel emulsions and blending microstructure subsequent to stream under common rail injection mechanism.

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